# Managing urban water resources in Sydney — integrating science with the role of local government policy, planning and implementation


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This thesis is presented for the degree of
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(Environmental Science)

Cover photo:

Bioretention system at Comenarra Oval, South Turramurra immediately upstream of a stormwater harvesting scheme.

# Declarations

I certify that this thesis has not been submitted to any other university or institution for a higher degree. Nor does it contain, to the best of my knowledge, any material published or written by another person. Except where acknowledged, this thesis is comprised solely of my own work.

Peter Davies

26 March 2011

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# Summary

This thesis examines the management of urban water resources in Sydney from a local government perspective. It describes and evaluates the assumptions and practices underpinning various aspects of urban water policy, planning, engineering and environmental management from an applied, practical perspective. The research and case studies comprising this thesis centre on the Ku-ring-gai local government area in northern Sydney, Australia, where I have been the sustainability and planning manager for almost 10 years. These case studies detail projects I have initiated and led, and showcase the multidisciplinary approach advocated for in this thesis.

This thesis is structured around published papers and peer and non-peer reviewed conference proceedings papers, each of which examines a different issue or perspective. The central theme of this work is how theory and practice must be integrated to achieve effective urban water management, both from the perspective of water as a commodity for use by cities, and water and as an urban environmental resource.

Management of urban water resources across Sydney extends over a wide geographic area, involves many government and administrative systems and agencies, and crosses multiple disciplines, as described in Chapters 1 and 2. Following these introductory and overview chapters, this thesis focuses on three main areas that fall predominantly within the domain of local government.

1. Land use planning and development control, with a particular emphasis on riparian systems (Chapters 2 and 3)

2. Environmental protection and management, examining pressures on natural waterways (Chapters 4 and 5)

3. Water demand and supply, through case studies of stormwater harvesting and water recycling (Chapters 6 and 7).

Key findings and recommendations (detailed more fully in the Conclusion to this thesis) are:

- Concrete drainage systems have a significant impact on the water chemistry of urban creeks. This impact should be recognised by water sensitive urban design practitioners and incorporated within water sensitive urban design guidelines.

- Effective management and protection of urban riparian environments in Sydney is hampered by ineffective legal and policy frameworks that do not respond to the cumulative impacts of past development nor adequately reflect the diversity of aquatic environments.

- To achieve the Federal Government's stated aim of creating water sensitive cities, urban water managers must take a multidisciplinary, adaptive management approach to recognise and respond to existing land uses and past engineering practices.

Policies, frameworks and guidelines aimed at improving urban water systems need to be consistent in their direction, flexible in their application and iterative in their revision. Urban water managers must learn from the past if we are to transition to a more sustainable future.

# List of Tables*



# List of Figures*



* Note: Tables and Figures included in the 23 papers that comprise this thesis are not listed here. The numbering for Table and Figures is aligned with chapter numbers.

# Acronyms, abbreviations and symbols

ABS – Australian Bureau of Statistics

ACI – American Concrete Industry

ANOVA – Analysis of variance

ANOSIM – Analysis of similarity

ANZECC – Australian and New Zealand Environmental Conservation Council

ARMCAZ – Agriculture and Resource Management Council of Australia and New Zealand

AS – Australian Standards

AVRC - Average volumetric runoff coefficient

AWA – Australian Water Association

BACI – Before versus After, Control versus Impact

BASIX – Building and Sustainability Index

BoM – Bureau of Meteorology (Australia)

CBD – Central business district

CMA – Catchment Management Authority

CMB – Catchment Management Board

CMC – Catchment Management Committee

CRCCH – Cooperative Research Centre for Catchment Hydrology

CSH – Calcium silicate hydroxide

CSIRO – Commonwealth Scientific Industry and Research Organisation

CUA – Clean up Australia

DCP – Development control plan

DEC – Department of Environment and Conservation (DEC)

DECC – Department of Environment and Climate Change (NSW)

DECCW – Department of Environment, Climate Change and Water (NSW)

DEST – Department of Environment, Sustainability and Technology (Cth)

DEUS – Department of Energy, Utilities and Sustainability (NSW)

DIPNR – Department of Infrastructure, Planning and Natural Resources (NSW)

DWE – Department of Water and Energy (NSW)

*E-coli* – Escherichia coli

EC – electrical conductivity

EoI – expression of interest

EPA – Environment Protection Authority (NSW)

EPA Act – *Environmental Planning and Assessment Act 1979* (NSW)

EPBC Act – *Environmental Planning and Biodiversity Conservation Act 1999* (Cth)

EPI – Environmental planning instruments

EPT – Ephemeroptera, Plecoptera and Trichoptera (macroinvertebrate families)

ESB – English- speaking background

ESD – Ecologically sustainable development

FAWB – Facility for advancing water biofiltration

GIS – Geographic information system

GPT – Gross pollutant trap

Ha – Hectares

HCCC – Hydraulic conductivity compaction curve

HRC – Healthy Rivers Commission

ICLEI – International Centre for Local Environmental Initiatives

IPART – Independent Pricing and Regulatory Tribunal (IPART NSW)

ISF – Institute for Sustainable Futures (University of New South Wales)

IUWCM – Integrated urban water cycle management

LEP – Local Environmental Plan

LID – Low impact development

LGA – Local government area

MUSIC – Model for urban stormwater improvement conceptualisation

NATA – National Association of Testing Authorities (Australian)

NESB – Non-English speaking background

NMDS – - On-metric multidimensional scaling

NorBE – Neutral or beneficial effect

NSCABD – National Strategy for the Conservation of Australia's Biodiversity

NSESD – National Strategy for Ecologically Sustainable Development

NSW – New South Wales

NSWLEC – New South Wales Land and Environment Court

PVC – Polyvinyl chloride

REP – Regional Environmental Plan

RRA – Rapid riparian assessment

SEPP – State Environmental Planning Policy

SIA – Stormwater Industry Association

SIGNAL – Stream invertebrate grade number average level

SPCC – State Pollution Control Commission (NSW)

SWC – Sydney Water Corporation

TSC Act – *Threatened Species Conservation Act 1995* (NSW)

UN – United Nations

UPRCMT – Upper Parramatta River Catchment Management Trust

USGA – United States Golf Association

USPCT – Urban Stormwater Pollution Control Taskforce

UV – Ultra violet

VRC – Volumetric runoff coefficient

WHO – World Health Organisation

WSUD – Water sensitive urban design

# Acknowledgements

There are many people who have assisted me in completing this thesis. Without them my ideas would have remained be just that. First, Mark Taylor, my primary supervisor, who had the confidence and belief that I could not only undertake such a project part-time but also complete it. Ian Wright, a valued colleague, collaborator and joint supervisor (in that order and often all at once). Second, Jay (Olof) Jonasson and Sophia Findlay, my colleagues, co-authors and friends at Ku-ring-gai Council. Their commitment to the urban water sector is second to none. Third, my other collaborators and co-authors including Chris Ives, Rebekah Brown, Michael Muston, Melanie Schwecke, David Wilks, David Nipperess, Seb Ingilizian and Shelly Burgin.

There are many other who have provided valuable insights, comments and suggestions on various papers and to this thesis in general. In particular I would like to mention Tim Fletcher, Stuart Kahn, Chris Walsh and David Dekel, each of whom in their own way have shaped the direction of my research.

Within Ku-ring-gai Council there are many that I would like to acknowledge. My past and current directors: Steven Head, for his initial support for the development of an environmental management program that had a significant focus on water reuse; Andrew Watson who recognised and enabled this program to continue; and Craig Roberts who helped build many of the projects.

I extend my thanks and appreciation to the institution of Macquarie University and the many staff within. The university warmly accepted me as a part- time PhD student and continues to embrace applied and multi-disciplinary research. In particular thanks go to the following staff: Wendy Southwell for her patience and administrative support; Paul Beggs who stepped in as honorary supervisor for 12 months; and Damian Gore for his ongoing encouragement. I would also like to acknowledge the generosity of the Postgraduate Research Fund which enabled me to travel to France in 2010 to present at a conference that helped ground my research and provide greater focus for completing my work.

Finally, and most importantly, I acknowledge my family: Linda, my wife, and editor, and my two daughters Emma and Alicia. Your support and patience has been remarkable. I hope I was able to find some semblance of balance between family life, my thoughts and the many hours in my office. I leave you with a poem written by Emma in 2009 that I have carried around with me since:

***Dad***
*I like him because he plays with me!*
*I don't like him because he's doing his PDHP [sic PhD]!*
*I like him because he takes me on rides!*
*I dislike him because he takes me on drives.*

*Love Delemma (aged 9*)

## A note for the reader

This thesis draws together my professional practice, research, experience, observations and reflections on urban water management in Sydney from a local government perspective. Many of the case studies are centred within and around the Ku-ring-gai local government area some 14 kilometres to the north of Sydney. Over the past nine years I have managed environmental programs at Ku-ring-gai Council relating to policy, planning, capital works, monitoring and evaluation. The focus of my work at Council has been to protect, enhance and manage riparian and bushland environments as well as to implement water conservation and reuse projects. Previous to my appointment at Ku-ring-gai Council I managed a major NSW Government urban runoff control program in the Blue Mountains, on the western fringe of Sydney. This role provided insight into the workings of various government agencies involved in the water sector. From 1995 to 2000 I was employed as the Environmental Manager for Waverly Council. This role involved part responsibility for improving the quality of Bondi Beach, a defining icon of Sydney. These experiences have shaped my thinking as well as my practical and philosophical approach to the management of the environment, and water resources specifically in an urban context.

Based on these experiences, this thesis addresses the burning question that drives so much of my work: how to better manage the urban water resources of Sydney from a local government perspective. Using a multi-disciplinary approach I have established and led many science, policy and engineering collaborative teams. This has enabled me to better understand key areas of urban water management that were under-researched and inadequately reported in the literature.

This thesis contains five published journal articles, one in press and one in final review, for four of which I was lead author or equal shared lead author. Supporting these papers a re 16 conference papers (five of which were peer reviewed) that document a specific contribution to improving understanding in this area of study. My contribution to each paper (as an approximate percentage) is noted in the chapter overview section below.

Researchers and practitioners typically approach issues of urban water management from a state government central water utility perspective (ie Sydney Water

Corporation and its predecessors). This is but one part of the story. Having worked for and within many councils in the Sydney metropolitan area, and also with relevant State government agencies it has been my experience that there is a tendency for inward and sector-focused reflection. The urban water management discourse suffers from a lack of balanced input across relevant disciplines and levels of government. This may be due to a range of reasons, including professional conservatism, past work practices and organisational cultures, management structures or the fact that existing assets and a singular engineering or project focus can inhibit innovation and change. This thesis does not seek to explore or explain these governance or organisational traits. However, the research discussions and learnings from this thesis highlight the need for reform in these areas. Based on the research findings in this thesis I have made recommendations for changes to policy, legislation and practice across all sectors involved in the management of this critical resource.

This thesis focuses on areas within the sphere of influence of local government. The level of participation of local government at the planning table is far from ideal. This is particularly relevant given that responsibility for delivering urban water outcomes is increasingly devolved to local government, but without a robust framework, clear coordination, funding or technical support – all of which are clearly needed.

Key areas of research covered in this thesis are:
- Historical review of urban water management in Sydney (Chapter 2)
- Riparian management and land use policy. Local government plays a major role in local urban planning and development control and in environmental monitoring, maintenance and protection, all of which impact on riparian systems (Chapters 3 and 4)
- Contribution of the stormwater system to in-transport effects of urban water chemistry(Chapter 5)
- Stormwater harvesting and water recycling schemes and other water sensitive urban design techniques (Chapter 6)
- Community engagement in the urban water cycle (Chapter 7).

Chapters 2 to 7 comprise 23 papers. Each paper is self-contained with its own background, research methods, results and findings. For this reason, this thesis does not contain a separate literature review, methods or results section. Similarly, a consolidated reference list is not given as references are provided within the published and conference papers and, where relevant, at the end of each chapter.

# Chapter overview

## Chapter 1 – Introduction

This chapter sets the scene and provides an overview of the thesis. It introduces the broader thesis research question, structure and themes that are presented in subsequent chapters.

## Chapter 2 – A brief history of urban water management in Sydney

This chapter presents an historical review of water management for Sydney, discussing the emergence development of water resource and catchment management since the time of European settlement and discusses changes in priorities around urban water planning and infrastructure. It makes recommendations for the future direction of this sector.

Understanding the social and engineering history of urban water management in Sydney enables a clearer understanding as to how and why the current regulatory, planning and administrative systems exist. Previous reviews have tended to take a narrow perspective, focusing on the emergence of the centralised water authority and its contribution to civil engineering (Aird (1961)), policy and infrastructure directions regarding the deepwater ocean outfalls (Beder (1989a,b)) or the role of local government in stormwater management (O'Loughlin et al (1999). The themes in this chapter draw from the opinions presented by Brown (2005) and her research as part of the National Urban Water Governance Program. Chapter 2 also highlights the importance of urban planning and the legislative recognition of urban waterways in this process. While not yet submitted for publication, this chapter has been a long-standing area of discussion with one of my adjunct supervisors and collaborators, Dr Ian Wright.

## Chapter 3 – Policy and legislative frameworks for the management of urban riparian environments

This chapter discusses a range of contemporary policy and legislative frameworks affecting the management of urban riparian systems and biodiversity. It describes the introduction of a riparian policy by Ku-ring-gai Council (Ku-ring-gai Council (2004)); development of a riparian mapping protocol tool (Findlay et al (2009)); the adoption of an integrated urban water management policy and strategy (Ku-ring-gai Council (2008a and b)); and incorporation of these policies and protocols in the recently adopted Ku-ring-gai Council Town Centres Local Environment Plan (NSW Department of Planning (2010)) and supporting Development Control Plan (Ku-ring-gai Council (2010)).

This chapter draws on the work of Ku-ring-gai Council as a case study to demonstrate how evidenced-based science can inform and underpin policy and planning. It recognises and quantifies the significant impacts arising from development on and affecting urban waterways and presents a tool developed to evaluate the condition of urban riparian systems. The chapter describes how this information has been incorporated into Ku-ring-gai Council's land use planning, policy and strategies. It also identifies areas for further policy and legal reform that are beyond the control of local government.

A key contention of the chapter is that inadequate planning and development decisions lead to small but cumulative impacts on the health of waterways and the adjoining riparian systems.

The papers comprising Chapter 3 are:

paper one (in press for publication in the *Environmental and Planning Law Journal*) ***Environmental planning frameworks for the protection of urban riparian corridors*** **Davies P J** (75%), Ives C (15%), Taylor M P (5%), and Findlay S J (5%) (in preparation for publication in NSW *Environmental and Planning Law Journal*).

The work described and analysed in this paper was developed in response to an identified need when, in 2004, Ku-ring-gai Council adopted a riparian policy to manage its watercourses and riparian areas. The initial concept for the paper arose from discussions between myself and Taylor. We both recognised the shortcomings of the existing legal framework to support such a policy at a local government level. I prepared the first draft of this paper drawing on Taylor's work on the legal definition of rivers, and applied this to an urban setting. Ives built on this draft as part of his research into urban biodiversity (see Paper 3 below). Findlay's contribution reflects her work on the development of a rapid riparian assessment tool and, from a practical perspective, reviewing development applications within riparian areas (Paper 2 below). This paper is in review by the NSW *Environmental Planning and Law Journal*.

paper two (published in *Water and Environment Journal*)

***Development and application of a rapid assessment tool for urban stream networks***

Findlay S J (55%), Taylor M P (20%), **Davies P J** (20%) and Fletcher A (5%) (2011) *Water and Environment Journal* 25:2-12.

The catalyst for the work that forms the basis of this paper was the development of a riparian policy for Ku-ring-gai Council, which I initiated and led in my capacity as manager of sustainability and planning at Ku-ring-gai Council. Research and analysis undertaken while developing the policy led to the formation of a research question around a riparian assessment tool, which in turn formed the basis of a Masters of Science (Hons) degree by Findlay, with Taylor and myself as supervisors. Findlay and Fletcher undertook the initial fieldwork. These concepts were further developed, by Findlay, Taylor and myself, into an applied river and riparian assessment tool for local government. In addition to developing the concept for the assessment tool, my contribution included the development of the initial ideas, ongoing review and discussion of the method over a period of two years. The technical aspects of my contribution were to validate the relevance the tool for local government and ensure it had a practical focus across the areas of policy, planning and capital works.

paper three (published in *Environmental and Planning Law Journal*)

***New directions in urban biodiversity conservation: the role of science and its interaction with local environmental policy***

Ives C D (60%), Taylor M P (15%), Nipperess D A (15%) and **Davies P J** (10%) (2010) Environmental and Planning Law Journal (2011) 27(4) 25:2-12.

The concept for this paper came from Chris Ives and emanated from previous research on urban biodiversity initiated as a summer research project under my joint supervision at Ku-ring-gai Council with Taylor. My involvement was focused around the need to prepare a new local environment plan and development control plan for the Ku-ring-gai local government area to fit a constrictive template as provided by the NSW Department of Planning. The paper also sought to provided sound policy rationale based on evidence and science. During the development of the ideas and paper I reviewed and edited numerous drafts to ensure its focus reflected the realities faced by local government in its capacity as an urban planner, in development control and as a land manager responsible for maintaining urban biodiversity across the landscape.

## Chapter 4 – Condition and health of urban waterways in northern Sydney

This chapter presents the results of a long-term macroinvertebrate and water quality-sampling program across the Ku-ring-gai local government area and nearby reference streams. The two research papers presented in this chapter drew on previous monitoring undertaken by Ku-ring-gai Council between 1998 and 2004. Macroinvertebrate sampling is a common monitoring tool used by local councils across Sydney. However this data is rarely interrogated to identify underlying trends that may respond to changes in the catchment. As a result there remains a significant gap when using science to inform policy frameworks at the local scale.

The key research questions explored include:

- Whether the data for urban and reference sites for northern Sydney are consistent with similar comparative studies, such as those by Walsh (2006) relating to Melbourne's streams.
- If there are significant differences in macroinvertebrate assemblages within riffle, edge and pool habitats within an urban and reference context as reported by Chessman (1995), Chessman et al (2007) and as found in non-urban streams (Parsons and Norris (1996)).
- Whether there are certain guilds that are sensitive to urban streams or demonstrate some comparative advantage.
- If there are any notable differences in water quality between urban and reference streams that may be causative to the composition of macroinvertebrate assemblages.

The results from the Ku-ring-gai Council macroinvertebrate sampling program are consistent with other similar urban / reference waterway studies, that is:

- there is a decrease in family richness as imperviousness (as a measure of urbanisation) increases;
- certain guilds seem to have some competitive advantage in particular environments; and
- biotic indices such as SIGNAL (Chessman (1995)) and EPT (Cairns and Pratt (1993)) differ between habitats, suggesting caution should be applied when attempting to use these indices more widely.

The findings clearly demonstrate that the urban creeks in the northern suburbs of Sydney are experiencing environmental pressure and are exhibiting the characteristics of what Paul and Myer (2001) refer to as the 'urban stream syndrome.' In the context of managing Sydney's water resources, the data suggests clearly that there is no single causative agent and changes are required to minimise the impacts of urban development, specifically the drainage network. These points are investigated and discussed further in Chapters 5 and 6.

Papers comprising this chapter are:

paper four (published in *Aquatic Ecology*)

***Impact of urban development on aquatic macroinvertebrates in south eastern Australia: degradation of in-stream habitats and comparison with non-urban streams***
**Davies P J** (42%), Wright I A (42%), Findlay S J (10%), Jonasson O J (5%) and Burgin S (1%) *Aquatic Ecology* (2010) 44:685-700 DOI: 10.1007/s10452-009-9307-y.

I was joint lead author with Wright on this paper, which involved the development of ideas and writing. Jonasson provided the analysis of catchment imperviousness, Findlay provided the figures and assisted with the tables and review and Burgin proofed the final manuscript. This paper followed from the results presented in Paper 5 (below) in which the lead authors examined:

- if the relationships of catchment imperviousness to stream health were similar to the results reported by Walsh's research in 2006 based in Melbourne given differences in physical environment and land use
- whether macroinvertebrate sampling could be simplified by examining certain guilds or habitats, and
- whether water quality and water chemistry data collected as part of routine macroinvertebrate sampling were able to shed light on key differences between urban and reference environments.

paper five (peer reviewed conference paper)

***Aquatic macroinvertebrates in urban waterways: comparing ecosystem health in natural reference and urban streams***
Wright I A (50%), **Davies P J** (35%), Wilks D (5%), Findlay S J (5%) and Taylor M P (5%) (2007) in Wilson A L, Dehaan R L, Watts R J, Page K J, Bowmer K H and Curtis A, (eds) *Proceedings of the 5th Australian Stream Management Conference. Australian rivers: making a difference,* Charles Sturt University, Thurgoona, New South Wales, 2007

This was a peer reviewed conference paper that presented a preliminary analysis of macroinvertebrate and water quality data against catchment imperviousness. As with Paper 4, I was joint lead author with Wright (Wright presented at the conference). Wilks and Findlay assisted with the data analysis and Taylor assisted with the review.

## Chapter 5 – Chemistry of urban streams – the impact of the urban drainage network

This chapter investigates one of the major causative factors that influence the chemistry of urban waterways –- the concrete drainage network. This research direction arose, somewhat by chance, from the analysis of water quality data comparing reference and urban streams across the northern suburbs of Sydney (Chapter 4). The research found reference streams were mildly acidic with low bicarbonate concentrations while urban streams were mildly alkaline with bicarbonate levels more than an order of magnitude higher. Given the similar geology and soils between the urban and reference environments it became apparent this discrepancy required further investigation. Experimental research was undertaken to ascertain if the materials comprising the urban drainage system were a significant contributor to the pollution of waterways. This raised a number of important questions for urban water management:

- Is the stormwater drainage system contributing to the pollution of urban streams?
- To what extent does the chemical pollution from the dissolution of cement products affect the ecology of waterways?
- Should the in-transport process (ie gutter and pipe network) be included as a factor to consider as part of water sensitive urban design projects?

This area of inquiry was not envisaged at the outset of the thesis and had previously been overlooked by other research projects investigating urban water pollution. In this sense the research is both novel and innovative. Through a series of experiments it became apparent concrete drainage systems (urban geology) have a significant affect on water chemistry. The findings point strongly towards the need to consider the material composition of stormwater drainage systems and their consequent impact on the pollution on sensitive biota found in waterways.

The papers comprising this chapter represent the progression of research on this topic. The initial investigation was undertaken to explore if there was a link between the water chemistry in urban streams and the materials comprising the urban drainage system (Papers 6 and 7). Following on from these results, a further study was undertaken to assess if the changes could be attributed to the dissolution of concrete pipes of various types and ages (Paper 8). This research was then applied to concrete gutters (Paper 9). Paper 10 examines the data from a limnology perspective and concludes that the artificial urban geology is responsible for a significant change in the chemical characteristic of freshwater streams.

I initiated the original ideas, research methods, the majority of the literature reviews, discussion sections, review of final papers and led the project team in this research for Papers 6 to 9. Fieldwork for the research was a collaborative effort by all authors. Wright and Findlay undertook most of the data review and statistical analysis as reported in the results section of the papers. Jonasson provided technical and engineering experience as part of the set up for the experimental design.

Papers comprising this chapter are:

paper six (published in *Urban Water Journal*)

***Impact of concrete and PVC pipes on urban water chemistry***

**Davies P J** (40%), Wright I A (25%), Jonasson O J (20%) and Findlay S J (15%) *Urban Water Journal* (2010) 7:4 233-41

Acknowledgement is given to the reviewers of the *Urban Water Journal*, particularly Tim Fletcher from Monash University who provided valuable editorial and technical comment, which assisted in improving the messages within the paper.

paper seven (peer reviewed conference paper)

***The effect of the in-transport process on urban water chemistry –- an examination of the contribution of concrete pipes and gutters on urban water quality***

**Davies P J** (40%), Wright I A (25%), Findlay S J (20%), and Jonasson O J (15%) *7th International Conference on sustainable techniques and strategies in urban water management, NOVATECH,* 28 June-1 July 2010, Lyon, France, June-July 2010

This was a peer reviewed conference paper. Acknowledgement is given to Tim Fletcher from Monash University who provided valuable editorial and technical comment in his capacity of reviewer and conference organiser.

paper eight (non- peer reviewed conference paper)

***Effects of concrete and PVC pipes on water chemistry***

**Davies P J** (50%), Wright I A (20%), Jonasson O J (15%) and Findlay S J (15%) (2009) *6th International Water Sensitive Urban Design Conference and Hydropolis No 3,* 5–8 May 2009, Perth, Australia

I presented the paper at the conference. Although the conference organisers had undertaken to have the papers peer reviewed, this did not eventuate.

paper nine (peer reviewed conference paper)

***Impact on stormwater runoff quality by the concrete drainage system***

**Davies P J** (60%), Wright I A (15%), Jonasson O J (10%) and Findlay S J (10%) (2010) *Stormwater 2010, 1st National Conference of the Stormwater Industry Association of Australia*, 8-12 November 2010, Sydney, Australia

This was a peer reviewed conference paper that built on the results of a summer research scholarship with undergraduate students from Macquarie University. The students who assisted with much of the fieldwork are acknowledged in the paper. All authors assisted in the design and supervision of the project while I wrote the paper and presented it at the conference.

paper ten (in final review for publication in *Marine and Freshwater Research*)

***A new type of water pollution: concrete drainage infrastructure and geochemical contamination of urban waters***

Wright I A (45%), **Davies P J** (35%), Findlay S J (15%) and Jonasson O J (5%).

The idea for this paper arose from the previous studies (Papers 6–9 above). As the leader of this research I recognised the need to examine how urban geology (runoff surfaces) influences the chemistry of urban streams. Wright and I developed the modified theoretical diagram reflecting the earlier work of Gibbs (1970) and Wright took the role of lead author and performed the data analysis.

## Chapter 6 – Case studies in stormwater harvesting, water recycling and water sensitive urban design

This chapter presents eleven case studies on stormwater harvesting, water recycling (sewer mining) and the application of water sensitive urban design (WSUD) practices across the Ku-ring-gai local government area. The papers were presented at various industry conferences. Key aspects explored include:

- How the planning and design of various WSUD systems respond to legislative, policy and best practice design guidelines
- How various WSUD systems perform against theoretical models and industry guidelines
- What insights can be gained by the urban water sector from these case studies.

The value of this research is that it provides much needed scientific evidence to ground the extent of design theory (ie research outside of the laboratory) by examining the performance and outcomes of real projects in relation to predetermined policies, guidelines and legislative requirements. While the methods and monitoring frameworks applied to analysis of the projects are less rigorous than would be possible in a controlled laboratory setting, these limitations need to be balanced by real value of applied research. The topics covered in this chapter include:

- design and performance of stormwater schemes
- hydraulic and conceptual modeling for WUSD systems
- design and performance of rain gardens and biofiltration systems, and
- planning and legislative frameworks around water recycling schemes (sewer mining).

The results underscore the importance and contribution of concurrent research for professional practice. Ku-ring-gai Council's WSUD and water conservation program responds to the policy framework and direction I developed as the manager responsible for this area.[1] Ku-ring-gai Council funded most of the monitoring through its regular monitoring and evaluation program. Minor funding was also provided by Macquarie University. The authorship of the papers (11 to 21) represents the combined efforts of my staff at Ku-ring-gai Council and demonstrates a truly collaborative and multi-disciplinary program. The lead author of each of the papers presented the research at the respective conferences, unless stated otherwise.

Papers comprising this chapter are:

paper eleven (non-peer reviewed conference paper)

***Water Sensitive Urban Design and Stormwater Harvesting – on the path to sustainable urban development: case studies from Sydney Australia***

Jonasson O J (60%) and **Davies P J** (40%) *Proceedings from the 6th International Conference on Technologies for Water and Wastewater Treatment, Energy from Waste Remediation of Contaminated Sites and Emissions Related to Climate,* Kalmar ECO-TECH and the Second Baltic Symposium on Environmental Chemistry, 26-28 November 2007, Kalmar, Sweden.

1. Many projects are still under construction or are in the early stage of commissioning and evaluation. These projects have not therefore been presented at conferences at this point in time. Should the reader of this thesis be interested in further work I would strongly encourage them to follow the progress of other projects through Council's web site (www.kmc.nsw.gov.au).

I initiated this paper to document, as a case study, the first project of Ku-ring-gai Council's stormwater harvesting program funded by Council's environmental levy. I completed the background text, which was subsequently incorporated into Council's integrated water cycle management strategy (Ku-ring-gai Council (2008(a) and (b)). Jonasson undertook the modelling and design for the projects. The paper was published in the conference proceedings but was not presented at the conference as it was not possible to secure funding to travel to Sweden.

paper twelve (non-peer reviewed conference paper)

***Stormwater harvesting – case study of Edenborough sportsfield, Lindfield, NSW***

Jonasson O J (70%) and **Davies P J** (30%) '*Stormwater 2008, Joint annual conference of the NSW and Queensland Stormwater Industry Associations,* 8-11 July 2008, Surfers Paradise, Australia

The Edenborough sportsfield stormwater harvesting project was the first system designed by Jonasson for Ku-ring-gai Council. The concept design process was a collaboration between Jonasson and myself. Jonasson in his role as Council's Environmental Engineer undertook the detailed design and modelling and supervised the construction. I played a major role in the review and editing of the manuscript.

paper thirteen (non-peer reviewed conference paper)

***Stormwater management –water balance modelling and impact on project costs: a case study from Ku-ring-gai Council NSW***

Jonasson O J (70%) and **Davies P J** (30%) *Ozwater 2007, Australian Water Association Conference, 4-8 March 2007, Sydney, Australia*

The idea for this paper was initially Jonasson's, following discussions within the water team at Ku-ring-gai Council as well as other colleagues in local government and consultancies involved in the design of similar structures. Jonasson undertook the design and modelling for the specific projects. My role was to review the ideas and concepts as well as the manuscripts.

paper fourteen (peer reviewed conference paper)

***Biofiltration design: a case study of biofiltration systems in residential areas using different filter media***

Jonasson O J (60%), Findlay S J (20%) and **Davies P J** (20%) *Stormwater 2010, 1st National Conference of the Stormwater Industry Association of Australia,* 8–12 November 2010, Sydney, Australia

As with Paper 13, Jonasson undertook the design and hydraulic modelling for the projects. Findlay assisted with the monitoring of data. I provided ongoing support and direction to the project including reviewing various the manuscripts.

paper fifteen (peer reviewed conference paper)

***Hydraulic conductivity and impact on retrofit stormwater biofiltration – case study of the design, assessment and function of retrofit raingardens using different filter media in Sydney***

Jonasson O J (55%), **Davies P J** (20%) and Findlay S J (25%) *Proceedings of the 7th International Conference on Sustainable Techniques and Strategies in Urban Water Management, NOVATECH,* 28 June–1 July 2010, Lyon, France.

The concept for this paper was based on observations made by Jonasson of infiltration rates across other raingardens. All authors undertook the monitoring of raingardens. Jonasson played a major role in the analysis of the results. I reviewed and commented on the various manuscripts through to acceptance of the paper at this international conference.

paper sixteen (non-peer reviewed conference paper)

***Stormwater management – Runoff generation in the Sydney region and impact on stormwater harvesting design***

Jonasson O J (60%) and **Davies P J** (40%) *6th International Water Sensitive Urban Design Conference and Hydropolis No 3,* 5–8 May 2009, Perth, Australia

The concept for this paper arose from discussions between Jonasson and myself questing the assumptions behind WSUD modeling tools such as MUSIC. We previously identified that each catchment behaves differently to the 'normal' (that is, default model configuration) parameters. Rain gauge and flow monitoring was undertaken by an external consultant and the data was compared against the modelling undertaken by Jonasson as part of the design for the various projects. I played an ongoing role in the development of the ideas and production of the final paper.

paper seventeen (non-peer reviewed conference paper)

***Stormwater reuse: can health risks be adequately managed without disinfection?***
Findlay S J (60%), Jonasson O J (25%) and **Davies P J** (15%) *6th International Water Sensitive Urban Design Conference and Hydropolis No 3,* 5-8 May 2009, Perth, Australia

I initiated the concept and developed the idea for the line of inquiry presented in Papers 17 and 18 based on the need to test the performance of a number of current stormwater harvesting schemes. These were designed prior to the NSW Government's guidelines on stormwater harvesting and reuse. Findlay undertook most of the monitoring. Findlay and Jonasson collectively undertook the data analysis. My role involved directing the project and reviewing the manuscripts and providing direction to the project.

paper eighteen (peer reviewed conference paper)

***What level of disinfection do we need for stormwater reuse and why?***
Findlay S J (50%), Jonasson O J (25%), **Davies P J** (15%) and Ingilizian S (10%) *Stormwater 2010, 1st National Conference of the Stormwater Industry Association of Australia,* 8-12 November 2010, Sydney, Australia

Similar to Paper 17, my role was in setting the research question and direction of the paper. Data collection was undertaken by Findlay, Ingilizian and Jonasson. Data analysis was mostly undertaken primarily by Findlay.

paper nineteen (non-peer reviewed conference paper)

***Comparison of filter media in rain-gardens – Ku-ring-gai Council case study***
Findlay S J (40%), **Davies P J** (30%), and Jonasson O J (30%) *Stormwater 2008, Joint annual conference of the NSW and Queensland Stormwater Industry Associations* 8-11 July 2008, Surfers Paradise, Australia
This paper represents the research preceding the hydraulic conductive research presented in Paper 15. Monitoring was undertaken by Findlay, Jonasson undertook the modelling and all authors were involved in the production of the manuscript. I reviewed and edited each of the drafts. The conference organisers had undertaken to have conference papers peer reviewed, however this did not eventuate.

paper twenty (non-peer reviewed conference paper)

***Water reuse for golf course irrigation – a case study within the Ku-ring-gai local government area***

**Davies P J** (65%) and Muston M H (35%) *Proceedings of REUSE07 Conference of Australian Water and Wastewater Association*, 16-18 July 2007, Sydney, Australia

I initiated this project to explore water recycling as a means of providing a regular supply of water to irrigate Council's two golf courses in response to the severe drought and subsequent water restrictions. At the time, there were no NSW guidelines, relevant legislation or government policy to direct or facilitate such projects in urban Sydney. This paper represented an initial review of emerging frameworks related to water recycling focusing on the proposed project at Gordon golf course. I drafted the first manuscript of this paper. Muston reviewed this and provided valuable insights from his experience in the water and local government sector as well as his role as an advisory consultant to the Gordon golf course project. I completed and submitted the manuscript and Muston presented the paper at the conference (unfortunately I had chickenpox at the time).

paper twenty one (non-peer reviewed conference paper)

***Implementing a water recycling scheme by local government in Sydney***

**Davies P J** (70%) and Muston M H (30%) *Proceedings of OzWater 2009 Conference, Australian Water and Wastewater Association,* 15-18 March 2009 Melbourne, Australia

Muston had the idea to write a follow up paper on the Gordon golf course project for the Australian Water and Wastewater Association conference the following year. As with Paper 20, I wrote the first draft paper and completed the manuscript following comment and input from Muston. Muston presented the paper at the conference.

## Chapter 7 – Community understanding of water reuse and recycling

This chapter presents the findings of two social research projects that explore the understanding and support of the Ku-ring-gai community for stormwater harvesting and recycling projects. This social research informed the communication strategies supporting the water reuse projects undertaken by Ku-ring-gai Council and provided insight into community preparedness for the acceptance of lower quality water for open space irrigation as part of the stormwater harvesting projects.

The significance of this type of research should not be underestimated or overlooked by the water sector. Given that expenditure by local councils comes under much closer scrutiny than other levels of government, it is vital to ascertain the level of community support for and understanding of the direction of new and innovative works programs such as water reuse and recycling. Further, the research supports the biophysical research undertaken in Chapter 6 by demonstrating a commitment to evaluation, review and improvement supported by community understanding, in turn informing environmental education on the value of the various water projects.

The surveys and consultations reported in these papers were reviewed and approved by the respective ethics committees of the University of New South Wales (Paper 22) and the University of Western Sydney (Paper 23). Paper 23 also formed part of a PhD research by Schwecke (submitted 2010).

paper twenty two (published in *Water Science and Technology*)

***Understanding community receptivity to water re-use: Ku-ring-gai Council case study***
Brown R R (50%) and **Davies P J** (50%) *Water Science and Technology* (2007) 55 (4): 283-290

This paper was a joint collaboration between Brown and myself. It followed a social research project led by Brown at the University of New South Wales and later Monash University as a consultancy under my supervision at Council. I had the initial idea for the project, Brown led the majority of the social research and we jointly authored the paper.

paper twenty three (non-peer reviewed conference paper)

***Community understanding of the use of alternative water sources for irrigation of golf courses: Ku-ring-gai Council case study***
Schwecke, M. (70%) and **Davies P J** (30%) *Proceedings of the 5th International Water Sensitive Urban Design Conference,* 12-23 August 2007, Sydney, Australia

I had the idea for this paper following the earlier study with Brown. This coincided with a PhD project by Schwecke investigating community understanding of water reuse and recycling schemes, of which the Gordon Golf Course project became a case study. I had a major role in the research design as well as ongoing review of the data and drafting of the report. Schwecke undertook the research and data analysis and presented this work at the WSUD conference.

## Chapter 8 – Discussion

This chapter draws together the totality of the research findings presented in the preceding chapters. The aim of the chapter is to build on these findings by reflecting on their impact and influence on the management of urban water resources as a whole, and more specifically in relation to the role of local government. It discusses the insights and findings across various scales and values assigned to urban water resources.

The discussion considers the theoretical arrangements and approaches adopted at a policy level (Chapters 2 and 3), relates this to the condition of and some of the pressures on urban water resources (Chapters 4 and 5), and draws on case studies to assess the contribution of various water sensitive urban design approaches to better improve water resources (Chapter 6) and the acceptance and understanding of urban water management by the Ku-ring-gai community through social research studies (Chapter 7).

The discussion focus on three themes: land use planning and development control; environmental protection and management; and water demand and supply. For each of these themes, new directions are proposed based on the cumulative evidence and need to move towards more sustainable management of urban land and water resources.

## Chapter 9 – Conclusion

This chapter provides a brief summary of the key findings.

# Chapter 1: Introduction

## 1.1 Overview

This thesis examines how water and catchments are managed across Sydney in a local government context. This perspective has been chosen because local government plays a major role in land use planning and management, development control and compliance, environmental monitoring and the delivery of stormwater services. For the most part the contribution of local government has been undervalued and as a sector of government has not been adequately engaged in broader decision making frameworks. In addition, local government's capacity to deliver complementary water supply and waste water treatment schemes is increasing as metropolitan water planners recognise the advantages of decentralised, flexible and locally adaptive solutions.

While this thesis focuses on the local government sector, the findings and recommendations are relevant across all levels of government and the water sector nationally and internationally. This thesis responds to many of Australia's national research priorities for an environmentally sustainable Australia, particularly the recognition that water is a critical resource (Department of Innovation, Industry, Science and Research (2010)). It contributes to the commitments of the National Water Initiative in relation to managing urban water demands and addresses one if its key funding areas, to build water sensitive cities (for example, Commonwealth Government (2004) and National Water Commission (2007)). This thesis provides insight about the delivery and review of the NSW Government's Metropolitan Water Plan, specifically around the themes of improving catchment and river health and increasing recycling (NSW Government (2006, 2010) and White et al (2006)). At a regional scale, decisions by local government about stormwater management, urban planning and general environmental management influence up and down-stream councils and communities through a vast array of policies and on-ground works.

This thesis draws together theory and practice across various spatial dimensions, and considers how water is valued by different sectors of society and government agencies. Spatially, it touches on the growth of Sydney's water supply footprint, focusing on management at a sub-catchment or local creek scale. It investigates how water and riparian systems within a city are used and valued as a commodity, with particular emphasis on water as an environmental resource. It draws on multiple disciplines including physical and social sciences, engineering, law, policy and government administration. This reflects the complexity of urban water management, which requires a multidisciplinary approach to link theoretical understanding and policy with practice. This approach and the structure for each of the major research chapters is depicted in Figure 1.1.

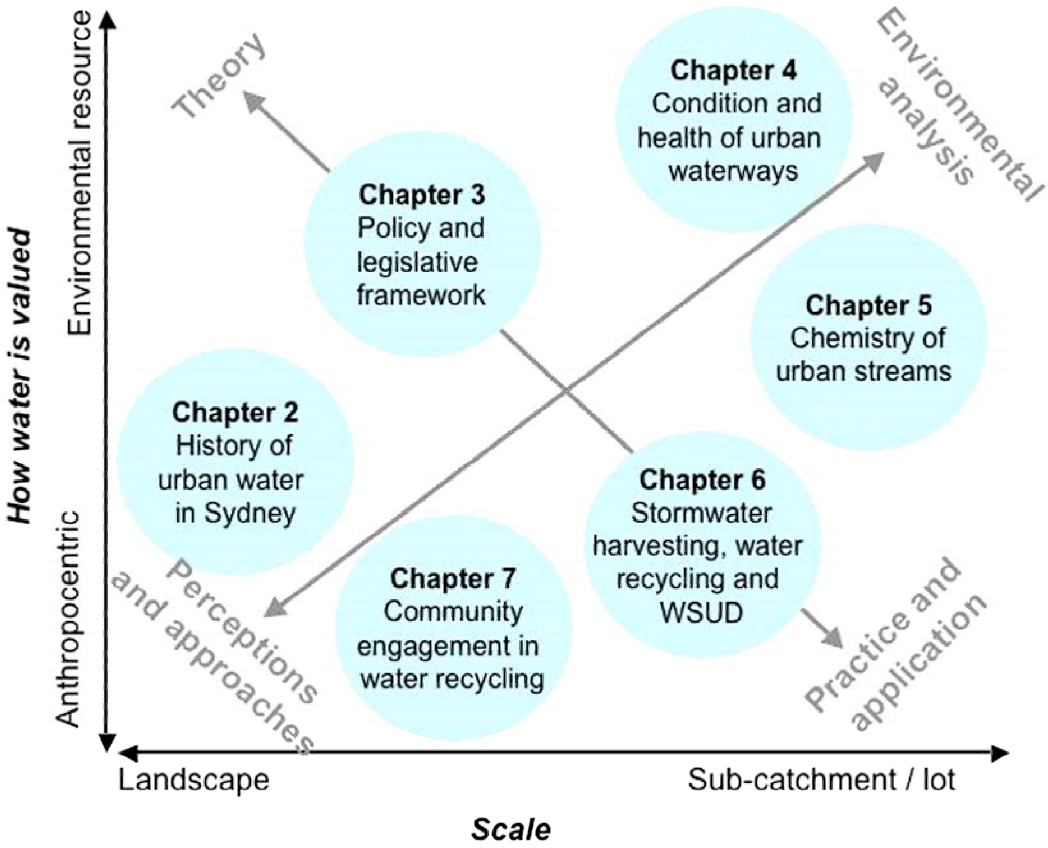


*Figure 1.1 Overview of thesis direction and chapters*

Six major research themes are presented in Chapters 2 to 7. Each chapter analyses a different aspect of urban water management and seeks new perspectives on current and emerging issues. Chapters 8 and 9 provide the discussion and conclusion to this thesis. This thesis aims to:

- Question the assumptions and outline the shortcomings of current management of urban water resources

- Support the evolution of urban water management discourse towards a more wholistic approach[1]
- Contextualise and evaluate how urban water policies and standards apply in practice through case studies
- Provide an evidenced-based approach to urban water management and policy (as advocated by the NSW Land and Environment Court[2])
- Report on key learnings that are relevant to the urban water sector and
- Assist in setting a vision and new direction for this sector.

Research for this thesis draws on policies and projects designed for the landscape within the Ku-ring-gai local government area (LGA) located some 14km north of Sydney (Figure 1.2). Some contextual background is therefore relevant to describe the environment within which these policies and projects area set. In 2004 Ku-ring-gai Council adopted a riparian policy recognising the need to protect and better manage the many watercourses throughout the LGA (Ku-ring-gai Council (2004)). This led to a review of the condition of the Council's riparian areas (Findlay et al (2005), Taylor et al (2005a) and Findlay et al (2006)). In 2006, the Council introduced a special rate (or local levy) to help protect and improve the condition of its urban waterways. To underpin this policy and provide direction to its capital works, monitoring and education programs, Ku-ring-gai Council also adopted an integrated water cycle management policy and strategy (Ku-ring-gai Council (2008a and 2008b)). Although much of the research presented in this thesis was designed to evaluate these programs, the conclusions are generally applicable to those involved in urban water management.

This thesis advocates strongly the need for a greater focus on urban planning and development control (Chapters 2 and 3). It details new research into the condition of urban waterways in northern Sydney (Chapters 4 and 5). It adds to the discussion of the management of stormwater from a quality, quantity and sustainability perspective (Brown (2003)) as evidenced through case studies presented in Chapters 6 and 7. Ultimately the thesis seeks to influence the future direction of urban water management in terms of policy, planning, guidelines and strategy (Chapters 8 and 9).

1 Many terms are used in the literature to describe this 'wholistic' approach including integrated urban water cycle management (IUWCM), water sensitive cities, low impact development (LID) and sustainable urban drainage system (SUDS).

2 McClellan CJ in *Stockland Development Pty Ltd v Manly Council* [2004] NSWLEC 472, revised 1 October 2004.

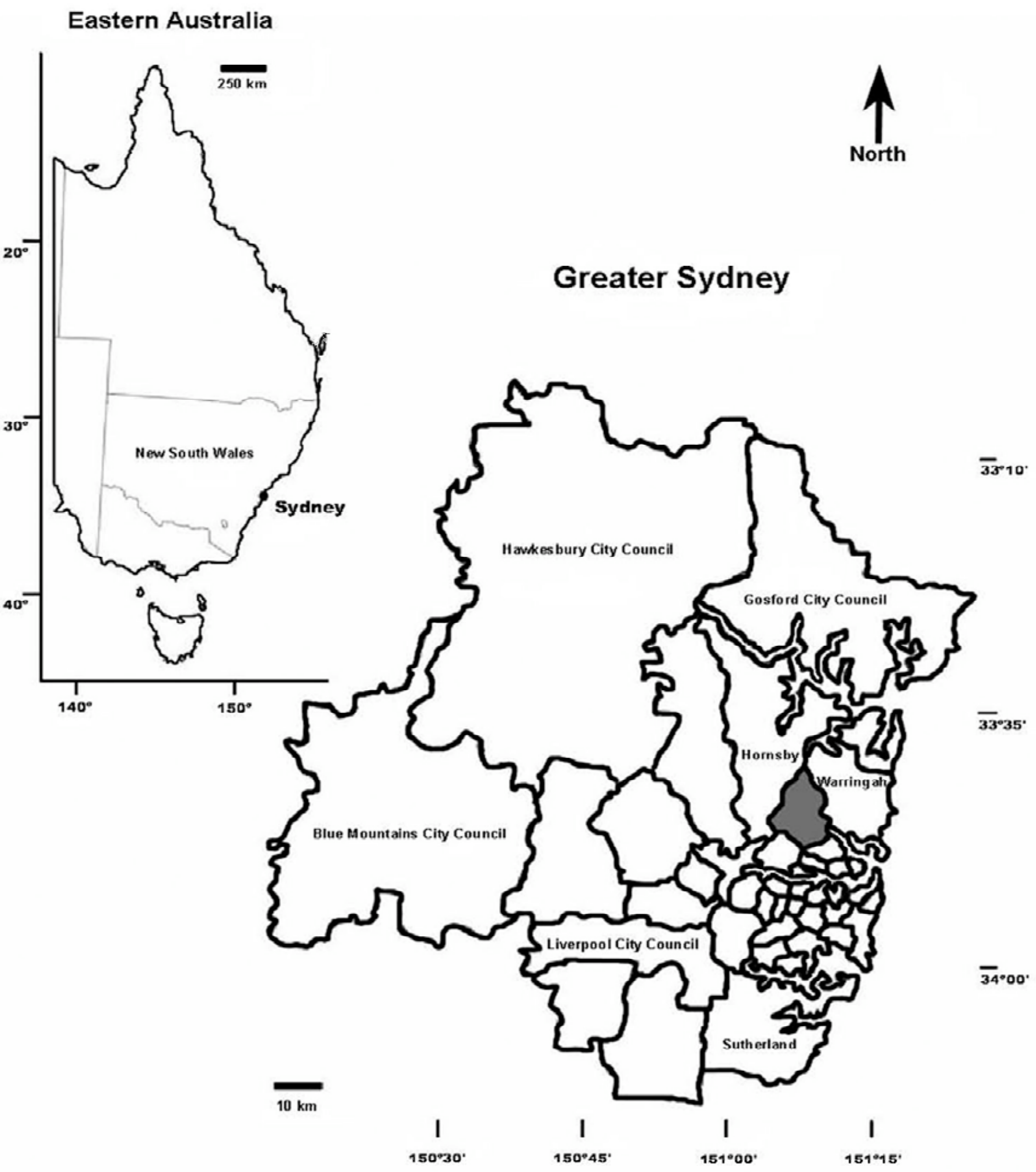


*Figure 1.2. Location of the Ku-ring-gai local government area*

The major research chapters (Chapters 2–7) comprise five published papers, one paper in press and one in final review and 16 conference papers. This approach differs from that of the traditional doctoral thesis. The approach adopted is designed to ensure that the research and findings of this thesis inform, rather than follow, contemporary discussion, policy and legislative change and the development of best practice guidelines. This is particularly relevant given the current rate of political, institutional and policy changes affecting the sector in response to the drought that affected Sydney (and much of Australia) from the mid–1990s to 2008.

## 1.2 Sydney's urban water management journey

Cities rely on their water systems. As populations grow, water supply and wastewater networks become increasingly large and complex to meet ever-increasing demand. For most cities this requires larger water catchments and the use of technology previously financially, politically, environmentally or socially unacceptable. Within the urban area, development also places pressures on the environment. For example, natural waterways are engineered to manage flood risk and nuisance stormwater runoff. However, only relatively recently has there been a move towards a more integrated approach to the management of urban water resources which considers wider environmental impacts (refer to Figure 1.3).

The urban water management discourse in Sydney has followed a similar pattern to many other major cities established prior to the emergence of the urban water engineer in the mid-1800s (Chapter 2). The demand for a reliable and clean supply of fresh drinking water led to successive water supply schemes radiating ever outwards from the city centre. The new colonists of Sydney came expecting permanent flowing streams (reflecting their experience from England). These expectations were challenged by periods of drought in the early years of settlement. The mid-to-late 1800s were also marked by successive waves of waterborne disease due to poor sanitation and waste water systems. As scientists were discovering the causes of disease, engineers were developing solutions in response to political and community demand (Aird (1961)). Globally this period represents the renaissance of urban supply and treatment for greater sanitation and can be described as the rise of the sanitarians.[3]

The engineering focus that brought Sydney a new generation of water and sewerage systems preceded an understanding of flood management and its relationship to urban planning. This may have been in part due to the enthusiasm of the early population to spread and grow, outpacing a more coordinated approach to stormwater infrastructure, which was left to the individual councils. As council engineers responded to the need to manage stormwater, streams were straightened, banks were concreted, pipes were laid and roads were curbed and guttered. This was undertaken with the objective of making urban areas hydraulically efficient so as to move stormwater away to the major receiving water bodies as quickly as possible (O'Loughlin (1994)).

3 Noting that many ancient civilisations, such as the Romans, had well developed water and waste-water systems (as discussed in Chapter 2).

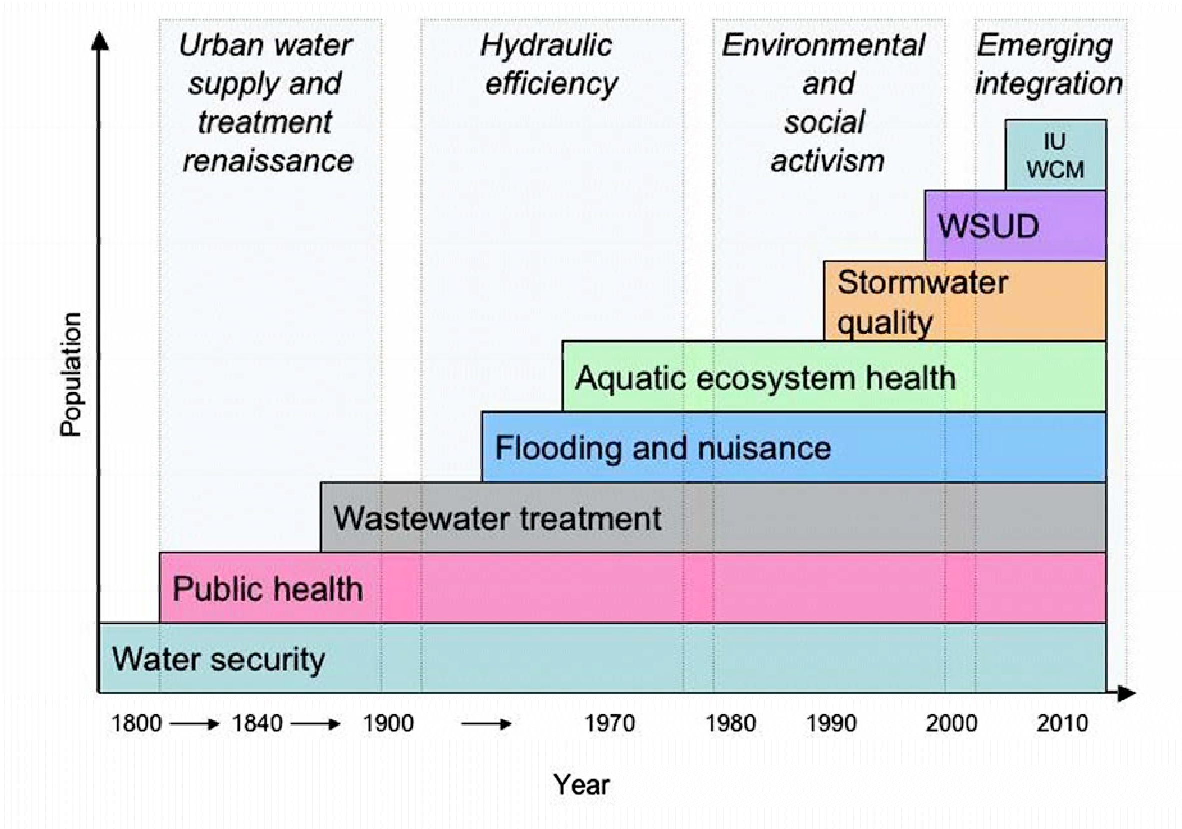


*Figure 1.3 Major urban water management discourses in Sydney since European settlement*

Increased scientific understanding of aquatic ecosystems coupled with legal reforms in the late 1960s and early 1970s saw the attempt to control (by licensing) point source pollution with the introduction of the *Clean Waters Act 1971* (NSW). For many urban streams this was a critical turning point – they could no longer be used as unregulated depositories for liquid waste. Throughout the 1980s public debate on urban water issues was reinvigorated, with a focus on sewage impacting many of Sydney's beaches and Sydney Harbour. The social activism of this era led to the next generation of improvements in the treatment and disposal of sewage discharging along with the emergence of stormwater quality as an important consideration for local and state government (Water Board (1994)).

Social values are a key driver of urban water policy and legislation. This is the subject of ongoing research by the Commonwealth Scientific Industry and Research Organisation (CSIRO) as part of its Water for a Healthy Country National Research flagship program (for example Po et al (2003 and 2006)) and the environment agency in NSW as part of its series of community surveys 'Who cares about the environment?' (refer to NSW Environment Protection Authority (1997, 2000, 2003 and 2006)). In each case, the management of urban water has emerged as one of the highest community priorities. On a more local level similar preferences were reported by residents within the Ku-ring-gai local government area, the focus area for this thesis, who are very supportive of water reuse and water recycling schemes (Brown and Davies (2007) (Paper 22) and Scheweck and Davies (2007) (Paper 23)).

Water planning for Sydney is becoming more integrated. The first water plan for Sydney was prepared and published by Sydney Water in 1997 (Sydney Water Corporation (1997)). This was more or less the capital works program for the water utility and served as the water infrastructure blueprint that supported the green Olympics that were to come to the city in 2000. In 2004, it was the Department of Infrastructure, Planning and Natural Resources that published the next incarnation of the plan, rather than Sydney Water (Department of Infrastructure Planning and Natural Resources (2004a)). This plan recognised the need for a more coordinated approach to urban water management beyond potable supply and wastewater treatment. The second plan, however, was very much supply and demand focused. By necessity, the plan responded to the drought conditions that existed at the time and the projected shortfall in the water storages.

The third water plan matured further and was presented as a whole of government document released in 2006 (NSW Government (2006)). It contained considerably more detail and placed greater emphasis on decentralising parts of the water system. It followed the contemplation and subsequent introduction of the *Water Industry Competition Act 2006* (NSW). The objectives of this Act are to encourage competition in the water industry and to foster innovative recycling projects and dynamic efficiency in the provision of water and wastewater services (section 21). The 2006 Metropolitan Water Plan, however, still focused largely on the activities and initiatives of Sydney Water. To its credit, this plan recognised catchment and river health, albeit within the context of water supply, and touched briefly on planning and development control as well as the role of local government. The 2010 Metropolitan Water Plan has further broadened its focus beyond delivery of water services, emphasising many initiatives of Sydney Water and the private sector to reduce demand and increase water reuse and recycling. Nevertheless the plan's integration with urban planning remains wanting, as does the recognition of urban creeks aside from the major waterways (NSW Government (2010)). The challenge for future plans and urban water management in general continues to be coordinating the many stakeholders involved in and responsible for the various and often overlapping elements of Sydney's urban water management systems.

While it can be easy to pass judgement on Sydney's water plans for not being as comprehensive and inclusive as they could be (White (2006)), such criticisms are not new. Since the 1800s a succession of reviews, committees and organisations have sought to improve the delivery of services by this sector. In 1854 the then City Council (the precursor to Sydney City Council) was dissolved by the NSW Government due to its financial and administrative incapacity and failure to deliver necessary services including water and sewerage infrastructure (Aird (1961)). The 1970 Senate inquiry into water pollution across Australia concluded '… water resources all over the country are being squandered by neglect or deliberate action or by lack of administrative coordination …' (Commonwealth Government (1970)). In 1998 the NSW Healthy Rivers Commission reported a lack of coordination between many government agencies implementing their respective studies and reports that was a substantial contributor to the decline of the Hawkesbury-Nepean River system (Healthy Rivers Commission (1998)). From a local government perspective, Brown and Ryan (2000) in their review of the NSW Stormwater Trust Program identified that organisational obstacles within councils prevented a trans-disciplinary and whole of council approach to the management and control of stormwater pollution.

In the early 1990s, Western Australia planners and engineers started working together to develop structural and non-structural solutions to better manage urban water resources (Evangelisti and Moritz (1994) and Moritz (1996)). This led to the birth of the Water Sensitive Urban Design (WSUD) movement in Australia and represented a significant step towards a more integrated water sector. In Sydney, however, these ideals remain at the fringe, a boutique industry. This is evidenced by their continued write up as case studies and trials as part of grant-funded programs by local government or industry and their continual inclusion within industry conferences as new and innovative ideas. In Sydney this is hampered by strategic documents seeking to encourage rather than mandate their implementation. For example, the NSW Government's Metropolitan Strategy for Sydney (NSW Government (2005)) contains an action to promote WSUD. This simply suggests it be considered as part of the development assessment process by way of reference to stormwater quality, in the same way that development control plans encourage such activities while not specifically included them in the overarching Local Environmental Plans.[4] In the most

4 Action E2.1.3 of the City of Cities: A Plan for Sydney's Future (NSW Government (2005) states: 'Promote water sensitive urban design and improve stormwater management by ensuring development is consistent with strategic stormwater management plans.' This is to be achieved via a simple process for checking development applications against strategic stormwater management planning that will be developed (but remains incomplete) (http://www.metrostrategy.nsw.gov.au/dev/uploads/paper/environment/index.html accessed 22 August 2010).

recent review of the Metropolitan Strategy, and in spite of the drought and ongoing development across new urban corridors where WSUD can have the greatest impact, the management of water resources is barely mentioned, let alone being fully integrated within the urban planning process (NSW Government (2010)).

A succession of NSW state governments has sought to determine the most effective structure to manage urban water resources. The centralist approach that more or less still applies today commenced with the creation of the Board of Water Supply and Sewerage in 1890 under the auspices of the *Metropolitan Water and Sewerage Act 1890* (NSW). The *Act* empowered the Board to control, regulate, operate, harvest water, distribute, treat and dispose of waste including stormwater. These tasks were removed from the City Council (now Sydney City Council). The modern day equivalent of this Board, now established as a government owned corporation, was formed under the *Sydney Water Act 1994* (NSW). The Sydney Catchment Authority (SCA) was established in 1998 in response to the *Cryptosporidium* 'outbreak'. This had the effect of splitting the bulk water and catchment management functions from Sydney Water Board (refer to Stein (2000)). The SCA has substantial legislative and regulatory powers over the activities in Sydney's drinking water catchments that has enabled it to be far more effective than the regional catchment authorities, particularly in an urban context.

More recently the NSW Government created the Office of Water as a separate division within the NSW Department of Environment, Climate Change and Water.[5] Politically the majority of the functions of this super department report to the Minister for the Environment, while the water functions report to the Minister for Water. The NSW Office of Water has assumed overarching responsibilities for water planning, science and evaluation, policy and regulation and legal advice on water matters to the NSW Government. One of its core roles is coordinating and developing the Metropolitan Water Plan. However its contribution to and influence on urban planning policy and relationship to the NSW Department of Planning is unclear.

A multitude of other agencies have shared, often overlapping, areas of responsibility for the management of Sydney's urban water resources. Table 1.1 seeks to illustrate this with a qualitative assessment, from the author's perspective, of the relative involvement and responsibilities of the agencies against various aspects of urban water management (the darker the shading the more significant the role). However, given the

5 Details of the NSW Office of Water can be found at http://www.water.nsw.gov.au/About-Us/default.aspx (accessed 23 August 2010)

ever-changing nature of government departments and priorities the real purpose of the table is to emphasise the potential opportunities for greater integration and coordination across the many sectors involved in managing this valuable resource.[6]

*Table 1.1 Summary of major government agencies involved in the urban water cycle in the Sydney metropolitan area circa 2010*

| **Aspect (1)**<br>**Organisation** | **Potable supply** | **Sewerage network** | **Sewage treatment** | **Storm-water** | **River mgt** | **Regulation** | **Research** | **Urban planning** |
|---|---|---|---|---|---|---|---|---|
| **Office of Water** | | | | | | | | |
| **NSW Cabinet Office** | | | | | | | | |
| **Sydney Water Corporation** | | | | | | | | |
| **Sydney Catchment Authority** | | | | | | | | |
| **Department of Environment, Climate Change and Water** | | | | | | | | |
| **Sydney Metropolitan Catchment Management Authority** | | | | | | | | |
| **Independent Pricing and Regulatory Tribunal** | | | | | | | | |
| **Department of Planning (including Joint Regional Planning bodies)** | | | | | | | | |
| **Department of Industries and Investment (incorporating NSW Fisheries)** | | | | | | | | |
| **Roads and Traffic Authority** | | | | | | | | |
| **Local government** | | | (2) | | | | | |
| **NSW Health** | | | | | | | | |
| **NSW Public Works** | | | | | | | | |

Notes:
(1) The darker the shading, the more significant the role (qualitative assessment by the author Davies P J)

(2) The role of local government in sewage treatment within the Sydney Metropolitan area extends to sewer mining projects (with minor exceptions for Hawkesbury City Council).

In addition to these departments and agencies, other statutory organisations have been established (and also disbanded) to provide direction to the management of urban water resources. In 1989 the Upper Parramatta River Catchment Management Trust

6 Note: the accuracy of this table is not assured given the frequent changes in NSW Government departments and responsibilities, with more changes sure to come following the upcoming State election in March 2011. For example an earlier version (circa 2008) was produced in the Ku-ring-gai Council Integrated Urban Water Management Strategy (2008) that varies from the one produced above (http://www.kmc.nsw.gov.au/resources/documents/Integrated_Water_Cycle_Management_Strategy_20081.pdf at page 7, accessed 23 August 2010)

(UPRCMT) was established under the *Water Supply Authorities Act 1987* (NSW) to manage flooding risks from upstream development on downstream councils across four local government areas. This responded to the findings of many flood studies throughout the catchment that dated from the 1970s. The success of the URPCMT was marked by the delivery of a number of important infrastructure works across the catchment, the development of leading stormwater policies for local government (for example UPRCMT (2005)) and as an example of cooperation between agencies and the local councils. The UPRCMT has since been subsumed within the Sydney Catchment Management Authority. Unfortunately it has lost its former revenue raising capabilities and consequent influence. The Hawkesbury-Nepean Catchment Management Trust (1993–2001) was one of the more influential organisations in terms of delivering a broad range of catchment programs and projects involving a variety of government agencies, local councils and landholders (Legislative Council of NSW (2002)). Less successful has been the succession of catchment management committees (1998–2000), catchment management boards (2000–2003) and now catchment management authorities (2003 to present). Each iteration of the catchment management bodies has seen a larger area of responsibility with only modest increments in policy, responsibility, budget (particularly for the Sydney Metropolitan area) and legislative influence.

The role of environmental science informing urban water management has been increasing since the pivotal work of Jolly and Chapman (1966)). Their investigations into the impacts of the local sewage treatment plant at Lithgow on downstream waterway health were the catalyst for many other studies around Australia. They provided the much-needed evidence for the then State Pollution Control Commission (SPCC) to set licensing standards for various industries that accompanied the introduction of the *Clean Waters Act 1971* (NSW). In more recent times environmental science has broadened its focus to the generation of pollution from stormwater runoff on local waterways (such as Dunne and Leopold (1978), Hall and Ellis (1985)), Chin (2006) and Chin and Gregory (2009) and the health of urban riparian systems (such as Arnold and Gibbons (1996), Walsh et al (2001), Chin and Gregory (2005), Davies et al 2010 (Paper 4) and Wright et al (2007) (Paper 5)). As if describing a medical condition, Meyer et al (2005) coined the term 'urban stream syndrome' to describe the complex web of interrelated causal factors and environmental symptoms in urban catchments. She identified six major factors contributing to the deterioration of urban streams: loss of sensitive aquatic biota; invasion of pest species; deterioration of water quality; modification of stream channels; disruption of natural flow regime; and a reduction in habitat values within the water and associated riparian zone. In Australia, Lawrence and Breen (2006) disaggregated this further to nine major factors: biology; geology; in-stream habitat;

hydrology; hydraulics; water quality; sediment quality; riparian habitat; and continuity and barriers. Figure 1.4 lists these factors and seeks to align areas of major similarity between the approaches. Whichever method is taken these models move beyond a simplistic cause and effect view of urban development and its impact on the environment.

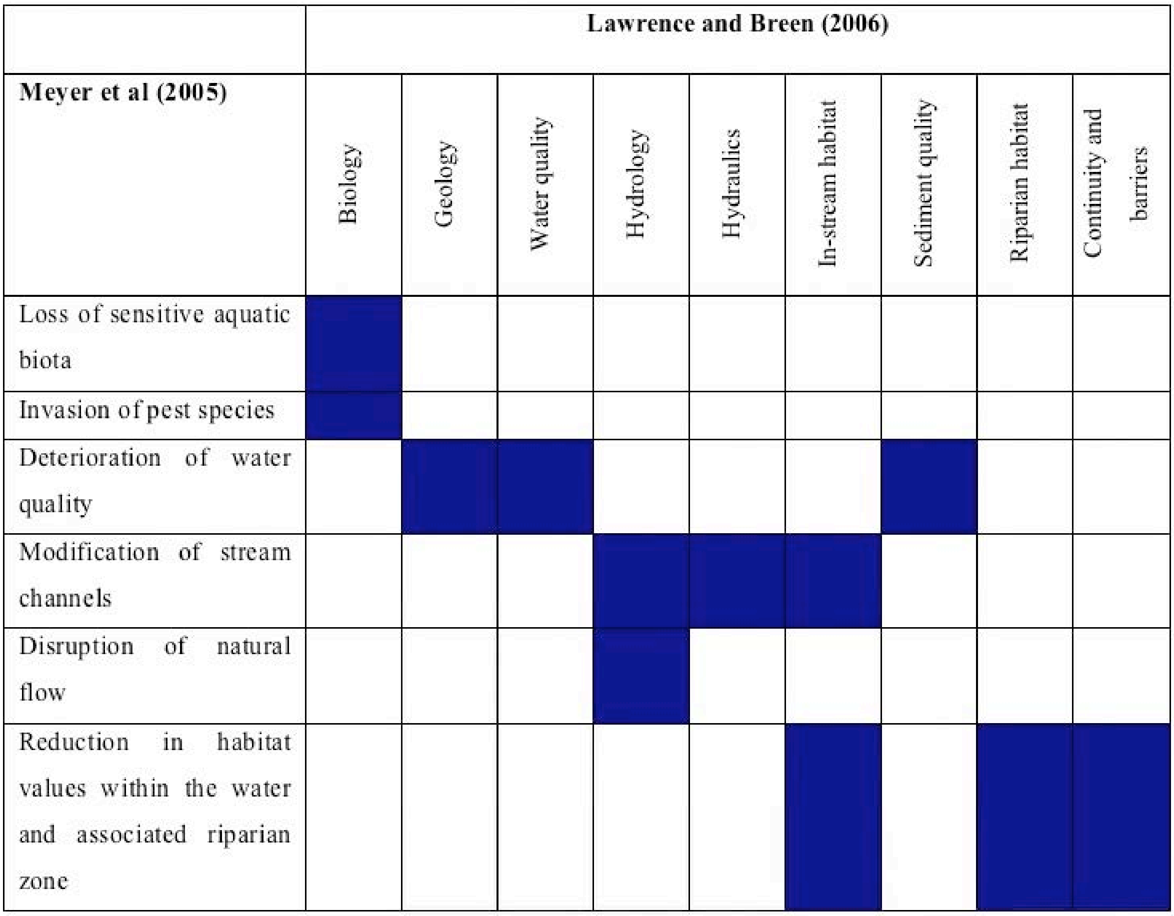


*Figure 1.4. Factors causing 'urban stream syndrome' and the interrelationships to biophysical processes (adapted from Meyer et al (2005) and Lawrence and Breen (2006))*

Policy and legislation is beginning to recognise the mounting evidence that there are many causative factors that influence urban water management, albeit at different rates of recognition and implementation across the country. NSW had the early lead in the late 1990s with its catchment-based stormwater management program targeting local government and a range of State agencies (Sharpin et al (1999)). However, the administrative, political and financial impetus of the State government funded program was insufficient to carry forward the initial momentum by local government. Remaining as a major policy legacy was the water reduction targets for new developments as part of the State Environmental Planning Policy—Building Sustainability Index (BASIX) 2004 (the BASIX SEPP) and water conservation plans required by the Department of Environment, Climate Change and Water that responded to the subsequent drought. Victoria, on the other hand, has shown much greater progress in recognising the importance of urban water management. Building on the shortcomings of the NSW experience, Victoria went further and changed its planning provisions, which now include legislative pollution reduction targets for runoff from new developments.[7] Accompanying this has been the mainstreaming of WSUD technical practices as part of new development and urban renewal projects (CSIRO (1999)). In Queensland, the health of aquatic ecosystems is becoming central to their urban water management planning and practices (Queensland Government (2009)). Land use not only considers individual allotments but contextualises this as part of catchment scale planning. In particular, the approach taken by the South-East Queensland Healthy Waterways Partnership requires not only minimum reductions in pollutant loads (i.e. following the Victorian model), but also limits post-development peak one-year average flood recurrence interval events and places controls on frequent flows to assist in stabilising waterways (Queensland Government (2009)). In particular this recognises and seeks to manage the often ignored problem of too much and too frequent flow in urban creeks.

The management of rivers in NSW, on the other hand, remains constrained by an inadequate and outdated Eurocentric definition of rivers that require permanent or intermittent flow (Taylor and Stokes (2005)). Across Sydney, the 'natural' watercourses that remain are generally in poor condition (eg Davies et al 2010 (Paper 4) and Wright et al (2007) (Paper 5)). By and large environmental protection of waterways is reliant on ad hoc planning policies such as development control policies (eg Ku-ring-gai Council (2004); Department of Infrastructure Planning and Natural Resources (2004b)), opportunistic planning agreements through related policies such as biobanking (DECC (2007)) or decisions by the NSW Land and Environment Court resulting in their protection from damaging development.

It is clear that urban water management is a complex web of social, environmental, practical, political and economic objectives and decisions. As such, it requires a multi-dimensional and multi-disciplinary approach. No single approach or solution can achieve sustainable urban water management. However, learning from the past, critiquing the present and setting a new direction for the future will help Sydney develop a trajectory towards being considered a water sensitive city.

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7 For example, refer to http://www.epa.vic.gov.au/water/stormwater/stormwater_clause56.asp (accessed 10 October 2010)

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# Chapter 2:
# A brief history of urban water management in Sydney: challenges and lessons from the last 200 years

## 2.1 Introduction

The management of water in Sydney is marked by tragedy, foresight, protectionism and social upheaval. The settlement of the first fleet colony at Sydney was determined by its water assets with its sheltered and deep harbour and access to reliable freshwater for the soon to be burgeoning town. During the first 100 years of European settlement, the management of Sydney's water resources was characterised by minimal planning and arguably contempt for any regulatory regime, culminating in a pandemic of water borne diseases and pollution. From a perilous beginning characterised by drought and disease, water management evolved over the next century to achieve world's best practice in sanitary engineering and laying the foundation for the water systems we have today. These achievements relied on a centralised approach, which solved water supply and sanitation issues but created a new set of environmental problems such as the discharge of diffuse water pollution into urban streams. As the city of Sydney moves into its third century, water management has moved back to centre stage. This has occurred through the convergence of a range of social, political, climatic and environmental factors, each with their own separate but interrelated and overlapping agendas. Sydney still defines its essential character in terms of its harbour, beaches and waterways. If urban water management is to be a central foundation for a sustainable future for Sydney, reforms are needed and necessary.

The history of water management in Sydney has followed a path common to many cities evolving from a small settlement to a major metropolis. The catalysts for change have been many and varied, perhaps best described as stochastic, turning on pivotal changes in community needs and expectations, engineering, scientific discovery and, occasionally, political foresight. This chapter presents a perspective on how Sydney has grappled with, and responded to, the many challenges facing water managers from early European settlement to the present. It concludes with an analysis and assessment of the NSW Government's *Metropolitan Water Plan* and other related plans and strategies designed to set future directions for urban water management.

## 2.2 Early days of settlement 1770–1800

The intended location for the settlement of the First Fleet was Botany Bay, as identified by Captain Cook following his brief stop over in 1770. However, after some seven and a half months at sea with 11 ships, Captain Arthur Phillip was less than enthusiastic about the site identified by Cook. Not only did it offer little protection to shipping, the 'fine meadows' referred to by Cook could not be found and fresh water, while ample for the crew of the *Endeavour*, was insufficient to meet the needs of the First Fleet, let alone those of a permanent settlement. Fortunately, a short sail north revealed what Captain Phillip described to Lord Sydney in his first dispatch as 'the finest harbour in the world' (Barnard (1980)). This optimism was not universally shared, as Daniel Southwell, a sailor on the *Sirrus* wrote, 'there are no rivers of water, we are indebted to the frequent rains that supply the little runs that furnish us' (Cathcart (2009)). So Sydney as we know it today was born.

The Tank Stream, the original water supply for the city (1788–1830), soon became unreliable, particularly during the times of drought that plagued the early years of settlement (refer to Figure 2.1). To overcome this, Captain Phillip ordered the construction of Australia's first water engineering project, consisting of three holes or tanks (thus its name) into the sandstone abutting the stream to act as reservoirs. Given the proximity of the city's residents to these reserves coupled with a lack of understanding of water borne disease, they soon become polluted with human and animal waste and gradually transformed into an open sewer.

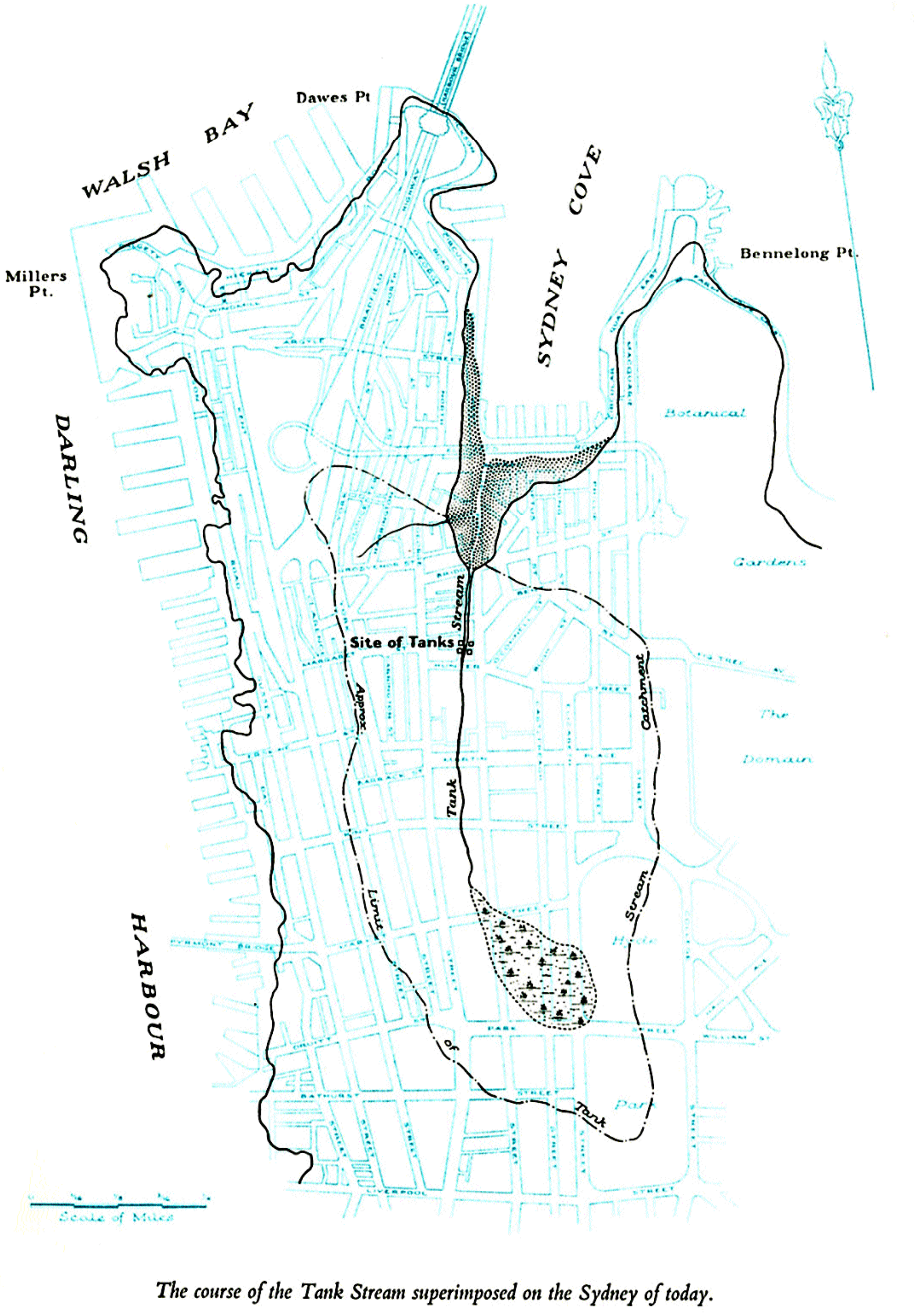


*Figure 2.1 The course of the Tank Stream superimposed on Sydney circa 1961 (Aird (1961) p 7)*

## 2.3 Disease and deterioration of the waterways 1800–1890

The 19th century in Sydney was a century of disease (Curson (1985)). The urban waterways linking the everyday activities of the early town contributed to the spread of waterborne infectious disease (Gilbert (1998)). By today's standards, Sydney in the 1800s had human health statistics that we would now associate with developing nations (World Health Organisation (2008)). For example, in 1855 infant mortality in Sydney claimed more than one-quarter of all live births (Curson (1985)). The growth of Sydney's population was hampered by wave after wave of infectious diseases, including whooping cough, scarlet fever, small pox, typhoid, and the plague (Curson (1985)). This was not dissimilar to other cities of the world at the time. London, for example, suffered many devastating cholera outbreaks in the 1850s (Smith (2002)). This reflected the reality that only a few of the larger European cities (for example Paris) had seriously turned their minds to water and sanitary engineering.

The management of water supply within and outside of cities was not a new problem. As far back as 3000 BC archaeological evidence from the Indus civilisation suggests they had engineered possibly the first sewerage system for a city (Webster (1962)). In addition, the Mesopotamian Empire developed its own water and wastewater system in 2500 BC (Jones (1967)). Better known to the modern world are the water engineering feats of the Romans (who borrowed best practice from other civilisations, in this case the Etruscans), who built aqueducts and wastewater systems to service many of their cities with great success (Kirby et al (1990)). Needless to say, the transfer of these practices to succeeding civilisations and centuries fell into a dark hole of history.

This is not to suggest early settlers were completely unaware of the issues of urban water management. In 1803, the *Sydney Gazette* (18 December) published what was most likely Australia's first government environmental order in relation to water pollution:

> *If any person whatever is detected in throwing any filth into the stream of fresh water, cleaning fish, washing, erecting pigsties near it or taking water out of the Tanks, on conviction before a Magistrate their house will be taken down and forfeit five pound for each offence to the Orphan Fund.*

Sadly this order did not achieve its intent, despite the severity of the penalty. In 1810 and regularly thereafter it was necessary to introduce further orders that sought to reduce ongoing pollution of the local waterways by residents and industry (Henry (1939), Aird (1961)).

In spite of the challenges of securing a clean and reliable water supply, Sydney's residents remained by and large on the southern side of the harbour. The gradual demise of the Tank Stream led the colony to look for water elsewhere. Those that could sink bores did so, not knowing that the contaminants that had infected the Tank Stream also permeated the porous sandstone into which their bores were sunk, polluting their supply. Wealthy residents were also able to buy water from the Lachlan Swamp wetlands (now Centennial Park) further afield (Figure 2.2). This ultimately led to the construction of Busby's bore in 1830 (Hirst (1983)). Industry was gradually forced to relocate south towards Botany Bay drawing on the more regular groundwater supply, but more importantly to minimise its polluting impact on the city's water supply. During this period, agriculture shifted to the more fertile soils up the Parramatta River and also to the Hawkesbury River.

In 1842, the management of water passed from the Imperial Colony to the new Sydney Corporation – the forerunner of Sydney City Council. A Water Committee was established with responsibility for the supply of water to the city and suburbs. The Committee also had responsibility for setting water rates and exemptions, licensing of plumbers, making water supply by-laws and other curious tasks such as maintaining Council's fire engines and erecting public fountains.

Politically, this period saw a transition from the dominant views of the powerful landed and wealthy gentry to an emerging democracy reflecting the egalitarian spirit of residents and the press. In 1856 those in power were forced to acquiesce to a new form of government independent of England and able to make its own decisions based on local needs and conditions, including the provision of water assets and services.

While Sydney was still a modestly sized town it had outgrown its rudimentary settlement origins. Little care was taken with disposal of waste and it was common for latrines to be dug in backyards beside drinking water wells (Clark (1978)). Infectious diseases created hysteria amongst the community and infant mortality rose sharply during the middle and second half of the 19th century (Smith (1990)). Through the lack of proper water management, Sydney had polluted and channelised the Tank Stream, drained the Lachlan Swamp wetlands and, by 1858, was up to its third water supply scheme, the Botany Swamps (refer to Figure 2.2).

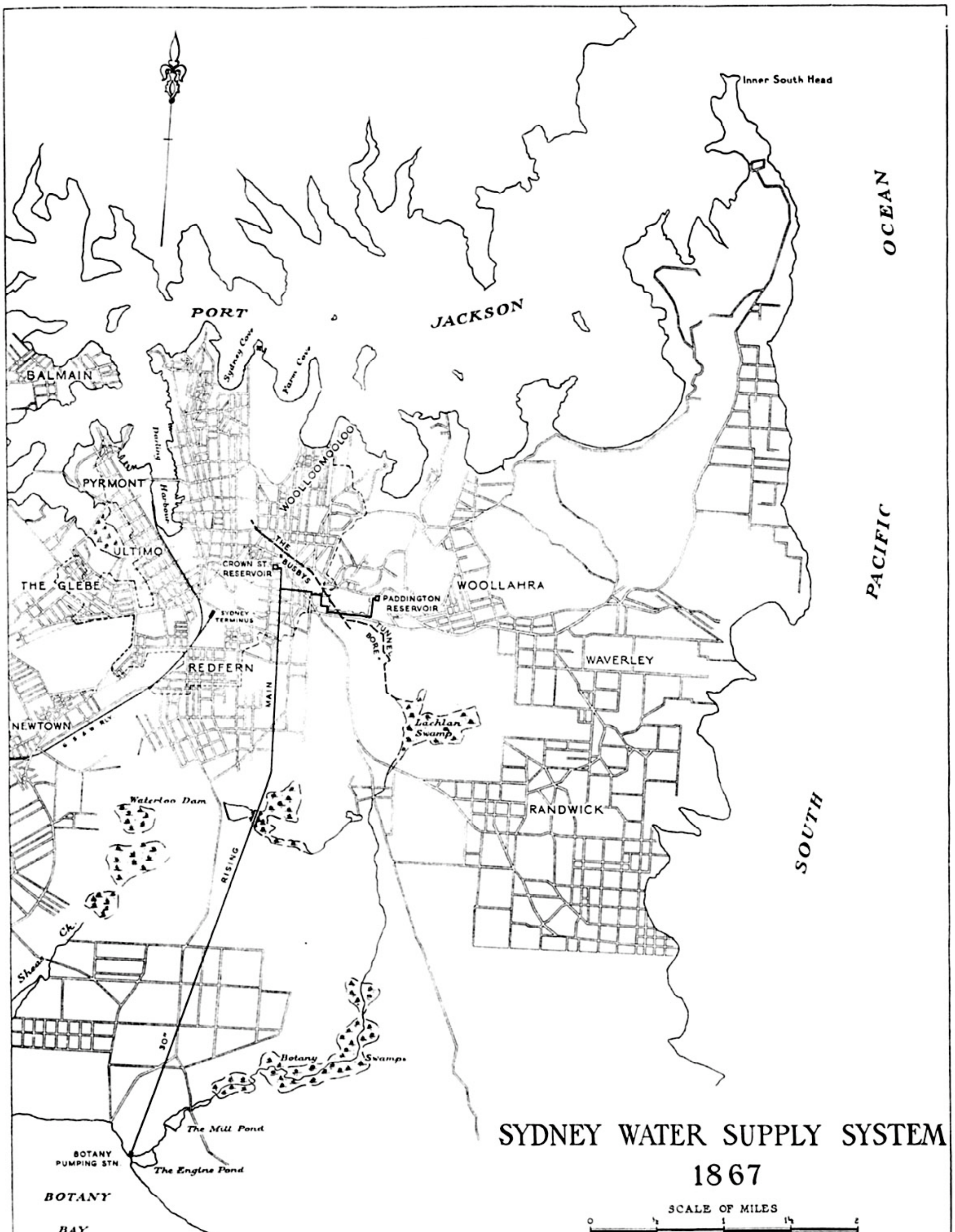


*Figure 2.2 Sydney's water supply scheme 1867 (Aird (1961) p 9)*

### *2.3.1 Emergence of visionary water planning*

A lack of public finances and possibly political will led the State Government to dissolve the City Council only 12 years after Sydney was incorporated as a city (Aird (1961)). Three Commissioners (nowadays referred to as administrators) were appointed to take charge from 1854 to 1857 (Act No 17 1853). During this period plans were drawn up and work commenced on the construction of minor sewers in almost every street linked to five designed sewer outfalls at Wattle Street (Blackwattle Bay), Hay Street (Darling Harbour), Tank Stream (Sydney Cove), Fort Macquarie (Bennelong Point) and Woolloomooloo (Woolloomooloo Bay) (Aird (1961)). These works were completed in 1859 under the direction of the newly formed Sydney City Council and a specific committee charged with responsibility for sewage, among other things.

The newly formed Council, however, did not capitalise fully on this momentum. Many aspects of the water supply, sewerage and stormwater systems still did not meet the community's, political, social or health expectations. In 1867 a Royal Commission into Sydney's water supply was instigated 'to make a diligent and full inquiry into the present provision for a supply of pure water to the city of Sydney and suburbs …' and in 1873 the Sewage and Health Board was established by the government to prepare a scheme for Sydney and its suburbs (Aird (1961) and *Sydney Morning Herald* 9 May 1885). In relation to water supply, the Commission recommended the construction of the Upper Nepean dam to replace the drought-affected Botany supply scheme (Aird (1961)). Once constructed, this scheme was able to supply sufficient water to assist in the flushing of the sewage system that had previously left many streams so polluted 'that eventually their dry weather flow consisted largely of fouled or slop water' (Aird (1961) p 128).

However it was not until 1890 that the Secretary for Public Works, the Hon Bruce Smith, provided reinvigorated focus to fund the upgrade of the sewage and stomwater systems. This incorporated the NSW Government's initiative to separate wastewater and stormwater, and to utilise extensive pipes and pumps (Tarr and McMichael (1977)). This direction to separate runoff (stormwater) and sewage ran contrary to the direction of the design of many other sanitary systems across the world at the time. London, Paris and New York were each building combined sewer stormwater systems (Tarr (1979) and Burian et al (1999)). While there was no doubt sound justification as to why these other cities went down this path, a major impediment of combined schemes was the need to have pipes to cope with wet weather flows of up to one hundred times the normal dry flow and also the need for larger pumps and treatment facilities, costly to build and operate (Burian et al 1999). Apart from the obvious health benefits, the separated scheme for Sydney was simply more cost effective and by 1889 nine major stormwater drains had been built by the government, into which the local councils had the responsibility of laying subsidiary drains from the streets.

While the Bondi and Botany sewage outfalls were completed in 1889, many of the older properties in the city, and in particular the inner western suburbs, continued to rely on the previous combined stormwater and sewer channels. For the newer residential areas, the condition of their local waterways mirrored that of the early days of Sydney. As Smith described:

> *… at present the watercourses which serve to carry off storm waters [in the new districts] a re almost entirely in their natural state, and are the receptacles of the sewage of the large populations which have settled in these suburbs, becoming in consequence a series of foetid pools which menace the health of the whole population. (Aird (1961) p 202).*

## 2.4 Foundations of Sydney's water engineering 1890–1960

In 1880, and still in the midst of a public health crisis caused by water borne disease, another recommendation of the 1867 Royal Commission was implemented. The Board of Water Supply and Sewerage was established under the *Metropolitan Water and Sewerage Act 1890* (NSW). The Board was empowered to control, regulate, operate, harvest water, distribute, treat and dispose of waste including stormwater, effectively taking over these tasks from Sydney City Council. The Board had two initial tasks: provide a reliable supply of water and reduce water borne disease. Unfortunately, before the Board could commission any significant projects, a particularly bad typhoid fever outbreak occurred in 1894, attributed to contaminated water and inadequate sanitation (Curson (1985)).

In 1880 the Board gazetted the boundaries of the water supply catchments to prevent any pollution to Sydney's water supply. These were subsequently amended in 1922 after they were found to be 'very faulty'. They included areas outside the water supply catchment and omitted other areas such as holiday parks that were inside the catchment areas (Henry (1939)). The catchments were selected on the basis that they had not attracted much development and produced water that did not require treatment or filtration. They also had to satisfy eight criteria, listed in true engineering style by Aird (1961): area; availability of suitable dam sites; estimated number of people to be supplied; rainfall; runoff; evaporation; extent of settlement location; and elevation in relation to centres of population to be served.

From the 1880s to early 1900s the Board's powers to protect the gazetted catchment areas were limited and relied on what would be described today as a whole of government approach to control land use to protect the catchments and water supply. This involved the Lands Department, Mines Department, Public Health Department and Forestry Department, with each controlling the issuing of various leases, tourism and the general day-to-day activities of landholders that had already developed. This cooperative approach was necessary up until 1924 when the Board's powers were expanded to include greater regulatory functions and, importantly, land use and development control (Henry (1939)).

In 1887 the Upper Nepean or Metropolitan Catchment Scheme was completed (and remains part of the water supply network to this day). In 1889 the Bondi Ocean Outfall and Botany Bay sewerage systems were finalised. This effectively put an end to most of the sewage discharge into the Sydney Harbour. The planning and scale of these schemes represented a quantum shift in the confidence and ability of water engineers to develop effective schemes and the determination of the government to provide the necessary public water infrastructure to benefit the health and wellbeing of its residents for generations to come. This was articulated by Dr Theo M Kendall, Sydney's public health officer in 1897, who stated (Aird (1961) p 203):

> ... *the value of the foul water and stormwater sewers may be well estimated by the decrease which has become apparent in the death-rate in their various localities.*

At the time (early 1900s), stormwater drainage was viewed as less important, and only necessary to reduce the nuisance factor of flooding, overland flow and to drain low-lying swampy areas that were regarded as harbouring contamination and disease (Aird (1961)). The urban sprawl of the day saw vast tracks of bushland cleared rapidly for new housing with little or no stormwater infrastructure.

The consequence of this lack of stormwater infrastructure and urban planning around the Cooks River provides a good example. In 1889, following a weekend downpour of 430 mm of rain in the Canterbury area, new housing estates, market gardens, roads and bridges were washed away. This led to a growing chorus of complaints about the state of the river and how it could be better engineered to offer new and safer opportunities. In a report to the Engineering Association of NSW in June 1896, an engineer by the name of Henson recommended a three point plan involving the removal of all dams and weirs to improve flow and flushing of what had become a silted river, the construction of a canal and tunnel from Parramatta River via Long Cove and Dulwich Hill into the Cooks River and also joining the Cooks River with Homebush Bay via a canal through Strathfield (Henson (1896)). This plan, while possibly inspired by the Suez and Panama Canal projects, was largely ignored, as was a subsequent plan in 1925. The limited work that was carried out, in part due to a lack of funding and the onset of the Great Depression, involved dredging of parts of the river and commencing concreting the banks as part of an unemployment relief project (Canterbury City Council (2009)). Sydney Water Corporation is now beginning to remove some of the concrete banks as part of the Cooks River bank naturalisation project (Sydney Water Corporation (2010)).

This engineering approach to stormwater management became government policy that helped shape the emergence of stormwater drainage as a core function for councils as reflected in the *Local Government Act 1919* and through specific legislation such as the *Cooks River Improvement Act 1946* and more generally (and mostly directed outside the urban area) *Rivers and Foreshores Improvement Act 1948* and *Water Act 1912*.

Sydney's harbour remained a defining and important feature for its residents. At the turn of the century, the rich and privileged expanded their hold on harbour foreshore properties, effectively limiting access for the rest of the population. The obsession with waterfront property (that continues still) resulted in the government of the day clawing back some land into public ownership. This included the declaration of the Upper Lane Cove River (now Lane Cove National Park) as parkland in 1925 and the reclamation of various harbour foreshores for parkland within the respective council areas.

In 1925 the Metropolitan Water, Sewerage and Drainage Board was established. For a new organisation, the timing could not have been worse. It emerged in the interwar period that saw the Great Depression (1929–32) and the lead up to World War II (1937–1945). The Board had to complete for resources, with most attention already given to the construction of the Warragamba water supply scheme Sydney experienced one of its worst droughts between 1934 and 1942 and, following the end of World War II, there was huge growth in housing, industry and infrastructure (Beasley (1988)).

Despite these initial obstacles, engineers designed and built major infrastructure projects, such as Warragamba Dam, that were financed by governments. Water infrastructure was a social and political priority, legislative reform provided a new focus on water management, and the community benefited from improvements in health and lower disease previously linked to inadequate water management. In terms of urban water reform, modern Sydney came of age.

## 2.5 Water pollution and the environment 1960s–1980s

During the 1960s concerns about water pollution were starting to emerge throughout Australia. A Commonwealth Senate enquiry into water pollution concluded (Commonwealth Government (1970)):

> *… the problem of pollution is so vast, the responsibility so diffuse, and the ignorance of causes and consequences so widespread, that only a concerted national effort can save many Australian water resources from becoming unusable.*

In arriving at this position the enquiry noted:

> *Water resources all over the country are being squandered by neglect or deliberate action, or by lack of administrative coordination; rivers, streams, coastlines and underground aquifers are being polluted in all States and Territories; and some waterways can no longer be used except as sewers… Pollution caused by the discharge of sewage effluent and the lack of adequate sewerage facilities is a major problem because it affects so many people and so many natural resources that are valuable simply because they are near the large concentrations of population.*

While the basic concerns of public health and water security had been addressed, at least in the major cities such as Sydney, a new chapter in urban water management had arisen.

### *2.5.1 Point source and diffuse pollution*

Prior to 1970, industry in NSW generally disposed of liquid waste directly to the local waterways. This was in spite of a range of legislative instruments designed to attempt to deal with this problem of water pollution. For example, the *Water Act 1912* (NSW) prohibited the discharge of a wide range of pollutants into rivers or lakes and gave the Board of Water Supply and Sewerage and its successors the power to deal with the problem (section 21A). The *Public Health Act 1902* (NSW) enabled the abatement of a nuisance (sections 64–66) and the *Local Government Act 1919* (NSW) allowed local councils to control various forms of pollution (sections 288, 289 and 510A).

The first Australian study into urban waterways occurred during this era. In 1966 Jolly and Chapman examined the condition of the water chemistry and biota living in waterways in and around Lithgow (Jolly and Chapman (1966)). This study found sewage effluent was polluting the local waterway, and was a catalyst for the emerging regulatory period under the State Pollution Control Commission (SPCC). Similar studies soon followed in Sydney (Cordery (1977)), Melbourne (Campbell (1978)) and Brisbane (Arthington et al (1982)) that started to explore the impact of diffuse source pollution on waterways health.

The introduction of the *Clean Waters Act 1971* (NSW) saw a revitalised focus on the regulation of water pollution from point source discharges. Regulation and control of water pollution relied on a 'command and control' approach. Licences were issued that permitted the holder to discharge liquid wastes of specified quality and quantity into waterways (Farrier and Stein (2006)). This was similar to the 'permit' approach to regulation of pollution pioneered in the United States under the Federal *Water Pollution Control Act 1948*, now commonly know as the Clean Water Act (Andreen, (2003)). The political reality was that the legislation sought to control, not eliminate, levels of pollution and in effect to transfer discharge of industrial wastes to sewer rather than the stormwater system. While there was a significant improvement in waterways health, for many industries this simply resulted in the transference of the pollution from the local stream to the Water Board's sewerage system. At a system scale the SPCC required the Water Board to have only rudimentary screening as its treatment system (Beder (1989a), (1989b)), effectively endorsing dilution as a major strategy to manage urban water pollution at the major outfalls (refer to Figure 2.3).

Unlike similar pollution laws at the time (such as the *Clean Air Act 1961* (NSW) and *Noise Control Act 1975* (NSW), the *Clean Waters Act 1971* (NSW) did not differentiate between scheduled premises (licensed by the SPCC) and non-scheduled premises. This effectively meant the SPCC was the sole authority for water pollution-related matters, with very few regulatory roles shared with local government and agencies. However, because the SPCC did not have the resources to deal with diffuse source pollution, it retained a policy to focus its attention only on point source pollution (NSW Water Management Audit (1984)). The unwillingness of the State Government to devolve power over water pollution (apart from minor offences) was repeated with the consolidation of pollution legislation under the *Protection of the Environment Operations Act 1997,* with some minor devolution of regulatory and enforcement powers to local councils (Bateman et al (1997)) (see later discussion in 2.6.1). The decision by the NSW Government to maintain control in a centralised yet under resourced agency versus a more decentralised framework where potentially variable standards that may be imposed by local councils or other government agencies (albeit within the constraints of the legislative framework and the oversight provided by the NSW Land and Environmental Court) remains a point of discussion. The *Clean Waters Act 1971* (NSW) and its Regulations also introduced the idea of classifying waterways according to their level of use and environmental sensitivity.

This built on the protections afforded to water supply catchments and also considered the value of the waterways for recreational, agricultural and environmental uses. By 1979, only the water supply catchment areas and the Georges River, Cooks River and Alexandra Canal were classified in Sydney, leaving arguably the most important systems (Parramatta River, Sydney Harbour and Botany Bay) unclassified. Ultimately the SPCC abandoned the classification system in favour of pollution licences, as it clearly did not meet its intended outcomes (Beder (1989a), (1989b)). Furthermore the classification system was not designed for or able to regulate diffuse pollution (such as stormwater pollution), which had now become the major source of pollutants contributing to the decline in urban waterways health.

## 2.5.2 Role of urban planning in water resource management

In 1951 the Country of Cumberland Planning Scheme, Sydney's first statutory land use plan, came into being. It contained a number of principles to manage post-war development (albeit late in the piece), and sought to consolidate public infrastructure, such as public transport and water services, into existing urban areas. In doing so it established a policy for a Green Belt area that ringed Sydney, described by Freestone (1992) as an 'antidote for promiscuous urbanisation' (p 72). This effectively protected many areas of farmland in the Sydney basin, particularly along the Hawkesbury-Nepean River and tributaries and conserved large tracts of remnant bushland and riparian systems. Needless to say, encroachment into these areas occurred and continues. This encroachment commenced even before the schemes gazettal as opportunistic developers and land speculators feared quarantining of the land. The Minister for Planning finally abandoned the policy in September 2005 in favour of a Green Web, substituting a metaphor based on the few remaining riparian corridors and bushland areas that weave their way across the metropolitan landscape (Sydney Regional Organisational of Councils (1999)).

The landmark *Environmental Planning and Assessment Act 1979* (NSW) became and remains the statute governing planning, establishing a regime to replace planning scheme ordinances through local environment plans (LEPs). The Act introduced a new mechanism to properly manage development, ensure suitable areas are conserved and promote coordination and provision of utilities and services (section 5(a)). The Act was described by Farrier (1988) as one that sought to balance the general goals or visions described for particular areas and set out a series of laws that explicitly state permissible and prohibited land uses.

The Act established a statutory requirement for sharing of responsibilities between the different levels of government, something that the urban water sector had needed for some time. Practically, this evolved into a process of concurrence between government departments and local government on matters requiring approval. One example was the requirement for approval to develop within 40 metres of a stream that falls within the definition of the *Rivers and Foreshores Improvement Act 1948* (NSW) (now *Water Management Act 2000* (NSW)). For private development, this usually relies on a determination by the State Government's land and water agency that would form part of a condition of approval issued by the relevant local council or other consent authority. In practical terms, however, the planning legislation and related Acts are not all-inclusive, cannot regulate for the cumulative impacts of development (often referred to as 'death by a thousand cuts') and do not recognise the mosaic of environments that are contained in urban areas. This is most obvious in the variations in how rivers are defined by legislation, and in turn, interpreted by various courts (Taylor and Stokes (2005)).

### 2.5.3 Stormwater and flood control

The 1960s and 1970s have been described as a period during which there was an immature understanding of the interconnections between upstream and downstream catchments (USPTF (1994)). Councils across Sydney, and the Water Board, continued their focus on providing economically efficient flood protection infrastructure, essentially to rapidly and safely convey stormwater to the closest waterway (O'Loughlin and Robinson (1999)). Meanwhile, urban development marched ever forward, progressively encroaching onto new and old floodplains and consolidating in already established areas.

This era also saw the introduction of many policies designed to better manage specific aspects of urban water. Most notable was the introduction of on-site stormwater detention that sought to detain or hold back large stormwater flows to reduce peak discharges into the drainage system. Ku-ring-gai Council was first to adopt such a policy in 1980 and by 1995 this was a standard approach for almost all councils in the Sydney region (O'Loughlin et al (1995)).

Examples of cooperation and a whole of government focus on water did occur, although they were infrequent (NSW Water Management Audit (1984)). The establishment of the Upper Parramatta River Catchment Management Trust (UPRCMT), established in 1989, signalled a shift from individual to collective as four councils that previously operated independently worked cooperatively to overcome localised flooding, particularly in downstream suburbs. The UPRCMT's emergence was not spontaneous, nor was it an immediate response to an identified problem. A major flood study in the 1970s made a number of recommendations to address current and emerging problems. This was followed by subsequent reports and studies in the 1980s. This activity resulted in the construction of only three flood-retarding basins. During the intervening period, properties that had never before flooded were inundated repeatedly as a result of increased runoff generated by the opening up of new urban areas. As a model for cooperation it was convoluted: the Trust was constituted under the *Water Supply Authorities Act 1987* (NSW), its revenue was collected by Sydney Water Corporation, it relied on the Department of Land and Water Conservation for administrative support and works were carried out by the respective councils. However, while administratively challenging, the UPRCMT provided a solid example of successful cross–government cooperation (UPRCMT (2002)), although it is now subsumed within the Sydney Catchment Management Authority.

## 2.6 Social awareness and political response 1980s–2000

The late 1980s and early 1990s was a time of community concern over the health of Sydney's waterways. 'Poo' marches were organised at Bondi and Manly beaches in protest against the low level of treatment of sewage that was perceived as an antiquated and inadequate solution impacting on public health and responsible for high levels of contamination in fish at the ocean outfalls (Beder (1989a), (1989b)). The *Sun-Herald* and other Sydney newspapers supported this movement and agitated for change. This included a call from 80 doctors led by Dr Peter MacDonald (subsequently elected as an independent member of State Parliament for the seat of Manly) to close 15 northern suburbs beaches until they could be proved safe (Beder (1989a) (1989b)) and the 'Turn Back the Tide' concert attended by 240,000 Sydneysiders. Riding on this interest, Ian Kiernan started his now internationally successful 'Clean Up' conglomerate with 40,000 participants turning up in 1998 as part of the inaugural Clean Up Sydney Harbour day.

The political response to the wave of community action and greater expectation of water quality was the introduction of a $488 million environmental program funded through water rates collected by the Water Board. The five year 'Clean Waterways' program (1989–1994) achieved substantial outcomes including: cleaning up Sydney's beaches via improvements to the sewage treatment process and construction of three deepwater ocean outfalls; reducing nutrient levels in the Hawkesbury-Nepean and various steams in the Blue Mountains; extending sewerage services to previously unconnected urban areas; and the regeneration of bushland and wetlands, most often within Sydney Water's control or otherwise influenced by sewer overflows from the surcharges by the gravity fed sewers (Sydney Water Board (1994)).

## 2.6.1 Government and intergovernmental action for improving waterways health

During the 1990s the Federal Government re-entered the debate on the future of Australia's water resources. The National Water Quality Management Strategy (1994) reflected changing community values and the need to place greater importance on the environment and improving access to open space and recreation facilities. Within this discussion it was acknowledged that the ongoing expansion of urban areas was approaching the economic limits of water supply and that alternative supply options would need to be found. In 1996 national guidelines were produced to advise state and local government on assessment of water quality and how to achieve integrated water management (ANZECC and ARMCAZ (1996)).

Consistent with these themes, the use of Regional Environmental Plans (REPs), instruments under the *Environmental Planning and Assessment Act 1979* (NSW), came of age in this era to bring a broader planning perspective to development. These changes sought to recognise the impacts of cumulative planning decisions on the environment, including waterways. Many of these instruments, however, had short lives. The Hawkesbury-Nepean River (REP 20) (1989–1993) was the first and was soon followed by instruments for Parramatta River (REP 22) (1990–1994) and Sydney and Middle Harbours (REP 23) (1990–1994). The State Environmental Planning Policy (SEPP) No 58 Protecting Sydney's Water Supply (SEPP 58) (1998–2007) was replaced with the Drinking Water Catchments Regional Environmental Plan (REP) No 1 in 2007 to address water quality issues in the drinking water catchment area.

Catchment-based organisations were also formed in this period under the *Catchment Management Act 1989* (NSW). The first was the Hawkesbury-Nepean Catchment Management Trust in 1983, established to oversee the multitude of institutional arrangements that plagued the management of the Hawkesbury-Nepean river system. This Trust existed through to 2001 when the Minister for Land and Water Conservation determined, without consultation, to abolish the Trust in spite of a number of successful programs and projects (NSW Legislative Council (2002)).

During this period the NSW Government established the Healthy Rivers Commission (1995–2004) under the *Natural Resources Commission Act 2003* (NSW) to provide independent public inquiries into selected NSW rivers and make recommendations to the government. Like many organisations preceding and following, it became the victim of numerous government restructures and was eventually replaced by the next government organisation established to provide independent advice to government, in this case the Natural Resources Commission.

During its time, the Healthy Rivers Commission undertook an inquiry into the Hawkesbury-Nepean River. It found, not surprisingly, that a lack of coordination between many government agencies in implementing their respective studies and reports and the discretionary nature of the planning parameters in the REPs all contributed to the decline in this health and condition of the river system (Healthy Rivers Commission (1998)).

A more successful, and still existing example is the *Statement of Joint Intent* between Hornsby Shire Council, Department of Urban Affairs and Planning, Environment Protection Authority, Hawkesbury-Nepean Catchment Management Trust and Sydney Water. Signed in 1994, its focus was to improve the environmental health of Berowra Creek and has since led to significant capital and operational changes to stormwater and wastewater management as well as integrated planning outcomes for the catchment (Hornsby Shire Council (2006) and Institute for Sustainable Futures (2005)). Interestingly, however, no similar agreements of this scale or involvement by numerous government agencies have followed. This may suggest that for some of the partners the collective outcomes have not been worth the initial and ongoing investment.

In 1997 the Environment Protection Authority (EPA) came into existence, signalling a shift in the direction of the pollution control from its predecessor the State Pollution Control Commission (SPCC). Accompanying this change was the introduction of the *Protection of the Environment Operations Act 1997* (NSW). This Act consolidated a range of pollution laws and created a much wider range of statutory notices, environmental audits and performance agreements for industries and polluters in general. For local government, it clarified and expanded its regulatory role and also enabled it to comment on licences for particular activities and premises in their local area (Bateman et al (1997)).

One of the first initiatives in 2007 of the new Authority was the creation of the NSW Urban Stormwater Trust. The genesis of the Trust and the program of grants it was to establish arose from a Stormwater Forum in 1993 attended by all three levels of government (Federal, State and local), business, industry, academics and the non-government sector. A central theme of discussion was the need for a total water cycle approach (Urban Stormwater Pollution Taskforce (USPTF) (1993)). The forum concluded there would be substantial benefits from having a single body to coordinate the management of stormwater and that such a body could address the need for integrated water cycle management (not dissimilar to the recommendations of the 1867 Royal Commission into Sydney's water supply). The EPA took charge and ordered all 53 Sydney metropolitan councils and a variety of State Government departments and agencies to prepare stormwater management plans (this action was later rolled out to all councils across NSW).

Development and implementation of the stormwater management plans, at least in part, was facilitated by an enabling grants scheme administered by the Trust. The program of grants focused on stormwater quality and education, recognising the impact of diffuse pollution on receiving waterways. The NSW Urban Stormwater Trust, in its evaluation of the program, highlighted the benefits including a reduction in pollution and increased community awareness, although pointed to a need to continue the program for a further period to 'allow a transition from the current structures to a more sustainable funding framework' (NSW Urban Stormwater Trust (2000) p 1). Brown (2005) perhaps better described this period as a 'brief unified approach' to stormwater planning. Not surprisingly, following the drying up of the fully funded projects by the Trust, local government retreated, although not entirely, back to its 'core' programs that typically focused on managing flood risk as their primary water concern. As a legacy, this initiative should not be understated. It moved stormwater management from simple flood control to consider water quality impacts and objectives. This subsequently set the groundwork for stormwater reuse initiatives embraced by numerous councils and the emergence of a total water cycle perspective.

Supporting the stormwater grants initiative was the establishment in 1998 of 43 new Catchment Management Committees constituted under the *Catchment Management Act 1989* (NSW). These were established to provide real local representation and perspectives on catchment issues and added to existing committees such as the Hawkesbury-Nepean Catchment Management Committee (CMC). This was seen at the time as a progressive move, however the initiative reflected the transitory nature of water management in this era. In 2000 the Catchment Management Committees were dissolved to form 18 Catchment Management Boards (under the *Catchment Management Act 1989* (NSW)) and in 2003 the Boards were abolished in favour of 13 Catchment Management Authorities (*Catchment Management Authorities Act 2003* (NSW)). The consistent theme of these 'reforms', at least for the Sydney metropolitan area, was a lack of real statutory power and revenue raising ability, which in turn has limited the political and institutional clout of these bodies.

In support of a centralised water authority, Sydney Water released its *Water Plan 21* in 1997. Its vision was to provide Sydney with clean beaches in which to swim and rivers to fish as well as improving its own water recycling efforts. *Water Plan 21* explored a number of options for managing water in Sydney, most notably in the area of water recycling. As water plans go it never pretended to be wholistic, but rather set the strategic direction for Sydney Water's own capital works and operational programs, in addition to outlining how it would deliver the sustainable water initiatives as part of the NSW Government's promise to deliver the Sydney 2000 'green' Olympic games.

One scenario discussed in *Water Plan 21* was an option to re-plumb every house in Sydney to a dual water system with recycled water for toilet flushing and outdoor water reuse. The plan concluded that it was unlikely that all of Sydney's treated wastewater could be recycled and estimated the cost at $5.5 billion or $5,000 per house (Sydney Water (1997)). This proposal can be compared (without indexed inflation) with the cost for the installation of a 5,000-litre domestic rainwater tank at $3,000 (Marsden (2007)) and the cost of the desalination plant at Kurnell at $1.9 billion (Sydney Water Corporation (2008)) that serves only a fraction of the Sydney water supply area.

This account would not be complete without the mentioning the introduction into the common vernacular of two water borne parasites, Giardia and Cryptosporidium (Stein (2000)), found in the reticulated water system and Warragamba Dam in 1998. Sydneysiders were advised to boil their water until sampling showed an all clear. What ultimately occurred was a decrease in trust and confidence in the water supply, serving as a catalyst for the community's obsession with bottled water. Administratively, the main outcome of this event was that the Sydney Catchment Authority was formed under the *Sydney Water Catchment Management Act 1998* (NSW), separating the bulk water supply functions from Sydney Water to ensure one agency focused on catchment management and bulk water collection, while the other would focus on treatment and distribution.

Overall, this era focused on three areas: cleaning up the beaches with a combined effort by Sydney Water and local government through the Stormwater Trust; reducing nutrient levels in the Hawkesbury-Nepean and other waterways; and providing some, although certainly not an overwhelming number, of examples of inter- and intra-government cooperation on urban water management.

## 2.7 Drought and changing community attitudes 2000 to the present

The widespread drought across south-eastern Australia has reshaped community perceptions about the value and levels of consumption of water. As a result, there has been renewed policy focus on water policy and management at all levels of government. The Commonwealth established the National Water Commission in 2004 under the *National Water Commission Act 2004* (Commonwealth). The NSW Government established the Office of Water in 2009 and there have been various efforts by local government such as their involvement in the Water Sensitive Urban Design in the Sydney Region program (established under a state government grant and now forming part of the Sydney Metropolitan Catchment Management Authority). Common to each is the clear recognition that the extraction and return of water to the environment has significant impacts, our current practices are unsustainable and a changing climate has caused a rethink in the planning and delivery of water services.

The imposition of water restrictions by Sydney Water in 2003 was the catalyst and justification for many reforms previously considered politically difficult or socially unacceptable. The use of domestic rainwater tanks in urban Sydney, previously discouraged by NSW Health and local government because of the concerns about water borne disease, is now acceptable, encouraged by rebates and almost mandatory under the BASIX State Environmental Planning Policy, albeit with some caution (NSW Health (2007)). Water reuse and recycling demonstration projects have transitioned to become part of the mainstream water supply such as the Western Sydney recycled water initiative, Camellia recycled water project and a host of stormwater reuse schemes by local government. The desalination scheme, initially intended as a back-up supply, came on-line in 2010 and now forms part of the regular water supply (unless dam supply levels exceed 80 per cent).

These initiatives have been assisted by the finalisation of recycled water guidelines related to water quality for non-drinking and other uses. Importantly the guidelines accept that not all water needs to be of drinking standard, but should meet guidelines according to the use for which it is intended (National Resource Management Ministerial Council et al (2006)).

### 2.7.1 Water plans

Accompanying the water shortages has been a marked change in language and direction in Sydney's water plans. In 1997 *Water Plan 21* spoke about 'exploring possibilities of supplying different qualities of water for different purposes' (Sydney Water Corporation (1997) p 17). The 2004 Metropolitan Water Plan (Department of Infrastructure Planning and Natural Resources (2004)), developed by a multi-agency team rather than the monopoly water agency (Sydney Water Corporation), included what could have been described as aspirational targets and plans for various infrastructure projects. The 2006 Metropolitan Water Plan (NSW Government (2006)) cited the progress against the earlier strategies and extended these to the next phase of planning. The 2010 Metropolitan Water Plan (NSW Government (2010)) continues to support water conservation and recycling, although remains inadequate in terms of integration with the urban planning process (refer to Figure 2.3).

The direction of the 2006 and 2010 plans were subject to more scrutiny and comment than previous plans, including the establishment of an independent review panel. This panel oversees reviews of the plans such as those by the Institute for Sustainable Futures (White et al (2006)), commissioned by the NSW Cabinet Office to review the 2004 plan, and reviews by other bodies, such as the review by the NSW Legislative Council (NSW Legislative Council (2006)). A major theme identified by these reviews, and being increasingly reflected in planning and on-ground activity, is the need for source diversification (reducing the reliance on dam water), introducing recycling initiatives and demand management and having a back-up source plan such as groundwater (recognised as a short term option) and desalination (an expensive yet reliable option). The review by White et al (2006) best describes this shift from planning for the worst-case drought to placing greater importance on adaptive strategies encompassing both supply and demand, importantly underlined by institutional reforms across the water sector. The review discussed how various strategies should be assessed from a financial, social and environmental perspective, and in turn, what should have the highest priority. Ultimately these have been and continue to be political decisions. This line of thinking is consistent with Kenneth Arrow's economic theory of the 1950s that suggests it is impossible to determine an optimal or best solution with multiple decision making bodies and options (Arrow (1950)).

One option raised by Sydney Water in its submission to the 2006 NSW Legislative Council review was the possible introduction of treated wastewater into the potable water supply. The submission stated that 'most people realise that indirect potable [is], while unpalatable, inevitable' (NSW Legislative Council (2006)). The Standing Committee conducting the review, most likely reflecting on the experiences of Toowoomba (Harding et al (2009)) rejected this as an option. It is possible that a large proportion of Sydney's population is not aware some the flow in their water supply catchment rivers (particularly the Warragamba catchment) contains treated sewage discharges.


Area covered by the *Metropolitan Water Plan*

*Figure 2.3 Area covered by the 2010 Metropolitan Water Plan (NSW Government (2010) p 12)*

## 2.7.2 Demand management and urban development

Demand management of the drinking water supply has been positioned and marketed with success. This has come about through voluntary schemes (such as rebates for rainwater tanks and appliances), education (via labelling and performance standards), coercion (through mandatory water efficiency programs for local government and high water using businesses) and regulation (with the introduction of the Building and Sustainability Index State Environmental Planning Policy (BASIX SEPP)). These measures have been successful. The previously profligate water use habits of Sydneysiders have reduced from a peak in 1980 at over 500 litres per person per day to around 300 litres per person per day in 2008 (Sydney Water Corporation (2008)). While this reduction is significant, consumption is still high in comparison with Melbournians at 277 litres per person per day (Melbourne Water (2009)), while the usage of residents of South East Queensland has reduced to as low as 140 litres per person per day (Queensland Water Commission (2009)), albeit under even tighter water restrictions.

The water conservation gains made as a result of the BASIX SEPP have not, however, been achieved without tension. BASIX specifies consent authorities are not able to impose additional requirements on developers in relation to potable water reductions or emissions of greenhouse gases. In effect this has created a legislative 'glass ceiling' for councils that may otherwise wish to impose higher environmental standards, reflecting community values. There is, however, provision to offer incentives for development proposals that may seek to go above the standards. Such incentives could be, for example, a reduction in the rate of development contributions (required under the *Environmental Planning and Assessment Act 1979* section 94), or other application-specific agreements. In reality, such provisions are of limited use for most development types approved by local councils in Sydney. This is because local government in Sydney (with a few exceptions) does not benefit from potable water savings or reductions in sewerage discharges as they are not water authorities nor is their performance tied to such outcomes. There is therefore no compliance-driven or financial incentive for developers or councils for that matter to go beyond BASIX requirements.

## 2.7.3 Role of local government in urban water management

Local government has come on-board with respect to water management, drawing on subsidies and grants available from Federal and State Government to develop programs directly targeting projects with a water conservation and general urban water management focus. Case studies and guidelines now support these programs (eg the long awaited release of the NSW Stormwater Trust documents (Department of Environment and Conservation (DEC) (2006b), and Sydney Water's sewer mining policy (Sydney Water Corporation (2006)). The use of water sensitive urban design as a framework for integrating potable water, wastewater and stormwater in the urban context has also begun to take hold, most notably with the release of *Australian Runoff Quality* by the Institute of Engineers (Wong (2006a)) and recent work by the Commonwealth Scientific and Industry Research Organisation (CSIRO) under the direction of the Joint Steering Committee for Water Sensitive Cities as part of the work by the National Water Commission (CSIRO (2009)).

Stormwater harvesting projects have experienced a slow uptake, reflecting the challenges of retrofitting water engineering into catchments as well as the conservative approach of local government engineers. While there are now guidelines to inform the planning and design process (DEC (2006)), the water quality standards are arguably too conservative. This has led to the design and construction of overly costly systems (such as for North Sydney Oval that has relied on various governments grants to enable the construction of the system) and the many non-conforming systems that do not use either ultra-violet (UV) or disinfection as means of compliance or have not been evaluated to determine if they indeed meet the standards. For many projects this brings into question the financial viability of stormwater harvesting at a small scale, as noted by the Managing Director of Sydney Water in her submission to the General Purpose Standing Committee's Review of a Sustainable Water Supply for Sydney (NSW Legislative Council (2006)). Regional scale stormwater harvesting has still not occurred in Sydney and, as reflected in the 2006 Metropolitan Water Plan (p 47), it is likely to remain in the 'too hard' basket for some time.

### *2.7.4 Environmental health of Sydney's urban rivers and receiving waters*

Environmental flows for urban rivers have been given greater consideration following various reports such as the Healthy Rivers Commission report (HRC (1998)) and the consideration of unregulated rivers covered by water sharing plans (NSW Office of Water (2010)). Releases from water storages such as Warragamba and Tallowa Dam are now part of licence conditions and are designed to improve aquatic and riparian ecology as well as to improve the suitability of some rivers for recreational use (eg swimming and boating). Although less publicised, discharges of treated effluent will also be part of these reforms, with 'highly' treated effluent planned to be discharged to the Nepean River, in place of potable water, as an environmental flow, often referred to as 'replacement flows' (NSW Government (2010) p 100). The extent of the environmental and social gains is still in question with limited experience nationally and internationally in this area. For example, Howell and Benson (2008) have sought to predict the impact on weedy riparian vegetation along the Hawkesbury River and have come to the conclusion that this will most likely depend on the season and level of water releases.

Politically, the institutional merry-go-round continues. For major river systems such as the Hawkesbury-Nepean, 2009 saw the introduction of the NSW Office for the Hawkesbury-Nepean. Its relationship and interaction with the Hawkesbury-Nepean Catchment Management Authority and various government departments such as the Sydney Catchment Authority, Department of Environment, Climate Change and Water and others is yet to be seen. A core part of its function may be related to providing oversight of the Commonwealth's Water for the Future Program as part of its investment in the $77 million recovery package for the river (Kelly (2009)). Such a decision seems to be a return to the past. The once successful Hawkesbury-Nepean Catchment Management Trust, abolished by the Minister for Land and Water Conservation without seeking advice from his own department or other government bodies (Legislative Council (2002)), may yet rise again.

The management of urban waterways outside the Hawkesbury-Nepean, and to a lesser extent Sydney Harbour, has fallen by and large on local government. This is a huge problem; councils have their own interests, policies, resources and priorities for addressing water management. Cooperation between local government exists, such as the Cooks River Foreshore Working Group, Botany Bay Coastal Catchment Initiative, Georges River Combined Council Committee and through the Sydney Coastal Councils Group. However, many of these groups rely on the goodwill and enthusiasm of members, political and administrative. In common with the failings of catchment management organisations, these collectives lack a statutory force, have limited funding and their initiatives are often tied to one-off projects funded by State or Federal Government grants.

Ecologically, Sydney's urban waterways have been reported by Chessman and Williams (1999) and others (Davies (2010) and Wright et al (2007)) to be degraded. The level of investment needed to address causative issues (that range from contaminants from road runoff to increased hydraulic impacts on local creeks from urban drainage systems) and current consequences is well beyond the resource capacity of local government, in spite of its ability to raise special rates or apply stormwater charges. The seemingly simple task of water quality monitoring is not without its problems either. Councils and other bodies monitor the ecological health or water quality of their streams, with little understanding of what the results mean and, importantly, how their specific catchment interventions are reflected in their scientific evaluation programs (eg Chessman (1995) and Wright et al (2007)). In this respect one can only wonder what objectives are attainable in the absence of a whole of government position that genuinely incorporates urban waterways health as a core focus.

The ecological health of urban waterways is not helped by regular discharges of sewage from leaks and designed overflow points adjacent to streams. These are attributed to generally ageing infrastructure, infiltration and exfiltration (engineer-speak for leaking pipes) from stormwater and sewerage systems and, importantly, the sewerage system exceeding its design capacity. This is not to say the problem has gone unnoticed. Sydney Water's Sewerfix program seeks to address wet and dry overflows by 2012 (or at least the prioritised systems) (Sydney Water Corporation (2007)).

For some areas of Sydney, such as Homebush Bay, unregulated chemical discharges from decades past have left an ongoing toxic liability (eg Birch and Taylor (2000)). Contamination of sediments has forced health authorities to ban commercial fishing in one of the world's most beautiful waterways, Sydney Harbour, due to human health concerns about high levels of dioxins and other contaminants (Food Standards Australia (2006)).

## 2.7.5 Regulation and oversight

From a regulatory perspective, the NSW Independent Pricing and Regulatory Tribunal has weighed into the area of urban water reform It has considered licensing and regulatory arrangements within the sector, water pricing, access to sewage/ wastewater and private water supply following the introduction of the *Water Industry Competition Act 2006*. The Tribunal's current focus is on the operating licence of Sydney Water. Further review has occurred with the Independent Review Panel appointed to monitor the progress of the Metropolitan Water Plan (released in 2010 (NSW Government (2010)). However it is yet to be seen if both reviews seek to recommend the alignment of parts of the activities of Sydney Water, and possibly others involved in water management, to higher standards reflecting best practice carried out by other water utilities, as identified by the review of the National Water Commission (Water Services Association of Australia (2008)).

## 2.8 Lessons from the past and future directions

Sydney is endowed with a rich and unique array of waterways from mountain streams and rivers in the west, a coastline of beaches in the east, and a network of rivers and estuaries in between. When considering the management of water across various geographic, political and institutional scales, there is cause to both celebrate and commiserate.

The National Water Commission in its biennial assessment against the National Water Initiative found ‘reasonable’ progress against the urban water reforms (Water Services Association of Australia (2008)). In contrast the Sydney Metropolitan Water Independent Review Panel expressed its confidence in the progress made in drought readiness strategies (NSW Government (2007)). These reflections have quite rightly have centred on water supply being the motivating issue due to drought and the emergence of a changing climate.

However, just as Aird (1961) described the vicissitudes of the City Council’s mismanagement of water in Sydney in the mid 1800s, coordination and participation by all levels of government around a single strategy is still required. The creation of a central water authority responded to this lack of direction with the creation of the Board of Water Supply and Sewerage in 1880. Its legacy and that of its successors established an engineering outcome that revolved around the single use of water at a uniformly high standard. Meanwhile opportunistic development from the level of individual households through to whole suburbs, even to the present, continues to leave its heavy footprint on the supposed valued yet degraded urban waterways.

The institutional arrangements and, all too common in recent years, continual rearrangements of state government agencies and their functions have done little to provide direction and leadership. There has been some central oversight, such as the establishment of the Sydney Metropolitan Water Independent Review Panel and the creation of the Office of Water (previously within the functions of the Department of Water and Energy and now with the Department of Environment, Climate Change and Water as of July 2009). However the continued reshuffling of agencies and their functions has resulted in confusion and a lessening in public confidence in the management of water, the results of which will take years to restore. One only needs to reflect on the Giardia and Cryptosporidium ‘outbreak’ in 1998, real or otherwise, to understand the fragility of public confidence in water supply.

The *Water Industry Competition Act 2006* (NSW) has broken, at least in theory, the monopoly of Sydney Water over various elements of the water supply and wastewater network. Whether a competitive water market can deliver sustainable outcomes is under debate and how new players will be allowed into this market (which still requires approval by Sydney Water) and in turn be regulated against a growing number of industry performance measures remains unknown.

For Sydney's multitude of unmapped urban creeks, many suffer from a lack of legislative and policy consideration and, in turn, protection due to their ephemeral nature (Taylor and Stokes (2005)). The observations first made by Southwell from the First Fleet that there are 'no rivers of water' in Sydney should be remembered. The *Water Management Act 2000* (NSW) continues the tradition of a Euro-centric view of what a river should look like, although this is gradually evolving to a more inclusive position. It is not surprising, then, that our urban waterways are degraded, when they are regulated by inappropriate legislation.

Despite these issues the future outlook is positive. The Metropolitan Water Plan process continues to be more inclusive and appreciative of the principles behind integrated water cycle management. There is action by all levels of government covering a multitude of projects from supply and demand management, through to water sensitive urban design and cooperative initiatives at a catchment scale. The community remains empowered and its expectations for potable water have evolved to accommodate fitness for purpose (eg Brown and Davies (2007)). What seems to be missing (which has remained to date a constant in this sector) is a coordinated reform of all institutions and responsibilities involved in urban water management, rather then the current mode of simply reorganising existing agencies and formation of new offices. Such reforms, coupled with a commitment to funding projects across scales and locations, would bode well for the future management of urban water across Sydney.

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# Chapter 3:
# Policy and legislative frameworks for the management of urban riparian environments

This chapter discusses the legal and policy frameworks that influence the management of urban riparian environments. While river systems and adjoining riparian areas play a significant role in defining the bushland character of Sydney, the quality of water is generally poor and the vegetation immediately adjacent to the riverbanks and downstream of stormwater outlets is usually dominated by exotic weeds. In spite of this, riparian systems provide corridors for the movement and conservation of biodiversity and will play an increasingly important role as development across Sydney spreads and intensifies.

The greater area of Sydney is characterised by Hawkesbury sandstone to the north, south and far west in the Blue Mountains. Large tracts of the land contain incised rivers and were regarded as too steep and rugged consequently these have not been developed and now provide the foundation for many of the city's national parks and central to these are their riparian areas and waterways.

The urban riparian environments of Sydney have great significance for biodiversity conservation. They play a major role in providing a web that extends across the city to enable movement of flora and fauna, offer many types of habit and often represent the last refuges of urban bushland. Ecologically they also provide a function in managing the quality of water that ultimately discharges into the iconic Sydney Harbour, the Hawkesbury-Nepean River and the coastal beaches. Existing legislative and policy frameworks to protect and manage riparian corridors and urban waterways are largely managed by local government and are inadequate, especially ephemeral channels. There is however, significant scope to draw on existing knowledge and improve current understanding about water and ecosystem quality in these systems and to address the many factors driving the urban stream syndrome.

The themes in each of the following three papers illustrate that Sydney's urban bushland, and more specifically its riparian systems, are integral to the urban fabric of the city, not just in their utility (eg for managing flood waters) but more importantly as a significant contributor to net environmental capital.

Achieving a shift in the legislative and policy arrangements will require a rethink by government about the environmental and planning legislation. Currently it adopts a narrow focus on bushland and specifically endangered, threatened or vulnerable communities as determined by the NSW Scientific Committee[1] (**Paper 3**) and draws on a Eurocentric view of waterways and riparian areas (**Paper 1**).

Urban riparian environments often fall through a legislative gap (in terms of protection, as argued in **Paper 1**) or policy gap (in relation to their identification and condition assessment, as suggested in **Paper 2**). The lack of consideration of the incremental loss of habitat manifests in progressively fewer environmental resources and less biodiversity (as argued in **Paper 3**).

The key insights provided by this chapter include:

1. There is a need to develop better environmental data systems to collect and interpret relevant information on the condition and pressures impacting on urban riparian environments
2. Local government policy frameworks must be supported by statutory instruments such as Local Environment Plans (LEP) and not rely on local controls via Development Control Plans (DCPs)
3. Local policies need to be informed by evidence-based science specific to the area, not assumptions
4. State Government must recognise the importance of riparian systems as an environmental resource and not simply a functional landscape element used for drainage
5. The NSW Land and Environment Court needs to support, perhaps by way of its 'planning principles', those councils that have developed an evidence-based approach to the management of their natural resources and inscribe this within their local policies and plans
6. As development continues to incrementally compromise the quality of urban streams and bushland environments, policy makers need to rethink how the existing 'death by a thousand cuts' paradigm can be reversed.

1 The NSW Scientific Committee is an independent committee established under the *Threatened Species Conservation Act 1995* (NSW) that decides, among other matters, which species, populations or ecological communities should be given statutory recognition under the Act. Refer to http://www.environment.nsw.gov.au/committee/AboutTheNSWScientificCommittee.htm (accessed 20 August 2010). Once determined, these are then listed in the *Threatened Species Conservation Act 1995* (NSW) which is referenced in the primary planning legislation, the *Environmental Planning and Assessment Act 1979* (NSW).

paper one (in press for publication in *Environmental and Planning Law Journal*)

***Urban rivers and riparian systems – directions and recommendations for legislators, policy makers, developers and community users***

**Davies P J**, Ives C D, Taylor M P, and Findlay S J

This paper explores the existing legal, planning and policy arrangements that determine how urban riparian systems are managed. While it is acknowledged that most urban stream and adjoining natural areas will not return to their predevelopment condition and function, this should not reduce the urgency for reform to incrementally improve the quality of riparian areas and protect existing conditions to maintain their current state.

paper two (published in *Water and Environment Journal*)

***Development and application of a rapid assessment tool for urban stream networks***

Findlay S J, Taylor M P, **Davies P J** and Fletcher A (2011) *Water and Environment Journal* 25:2-12

This paper describes why a new assessment tool was developed to determine the condition of urban streams and how it is being applied. The paper has been included in this chapter as it seeks to reinforce the need for applied field assessment approaches specific to urban environments using data that can inform environmental management investment decisions.

paper three (published in *Environmental and Planning Law Journal*)

***New directions in urban biodiversity conservation: the role of science and its interaction with local environmental policy***

Ives C D, Taylor M P, Nipperess D A and **Davies P J** (2010) *Environmental Planning and Law Journal* 27(4) 245-71

This paper brings together science and policy, advocating for evidenced-based research (in this case science) to inform legislation, policy and on-ground management. While this paper takes a broader view of urban biodiversity, *inter alia* urban rivers and riparian environments, it nevertheless establishes important themes that seek to link the largesse of urban conservation goals to meaningful actions supported by legal frameworks.

paper one

# Urban rivers and riparian systems – directions and recommendations for legislators, policy makers, developers and community users

Authors: Davies P J, Ives C D, Taylor M P, and Findlay S J

Publishing details: In press for publication in *Environmental and Planning Law Journal*

paper one

# Urban rivers and riparian systems – directions and recommendations for legislators, policy makers, developers and community users

Peter J Davies, Christopher D Ives, Sophia J Findlay and Mark P Taylor*

*This article examines the evolution of the current legal and planning system influencing urban rivers in New South Wales. A future direction for legislators and policy makers is presented as a means to improve the condition of urban waterways. Ensuring water management professionals appropriately value river systems is a key element. Waterways occupy a tenuous position in the urban landscape despite their ecological significance, often providing the last refuges for biodiversity. Smaller waterways are often piped to improve stormwater drainage, while larger systems are chemically, physically and biologically degraded as a result of development within the catchment. Legal, planning and policy arrangements have historically provided limited protection for urban waterways and riparian environments. This is due to four main factors: rivers are traditionally valued for their utility as conduits for stormwater to manage flooding; the biodiversity value of riparian areas is not widely understood and acknowledged; the cumulative impacts of development on river health are nor recognised; and an inadequate legal definition for "river" in legislation and at common law. The fate of many urban riparian environments is often determined due to "death by a thousand pipes".*

## Introduction

"Urban stream syndrome" is a phrase that has been used to describe the degradation of urban waterways.[1] It encapsulates changes to the physical, chemical and biological state of rivers as a result of land-use change associated with urbanisation. Implicit in this phrase is an acknowledgment that urban rivers have a function beyond being an engineered pipe or culvert. Smaller streams are often piped and major rivers have been straightened and channelled, compromising their natural form and function. Just as the incremental clearing of native

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1 Meyer JL, Paul MJ and Taulbee WK, "Stream Ecosystem Function in Urbanizing Landscapes" (2005) 24 J N Am Benthol Soc 602.

vegetation for development is often described as "death by a thousand cuts",[2] the cumulative impact of development on urban rivers can be described as "death by a thousand pipes".

In Australia, population pressures in urban areas continue to grow, resulting in further and more significant impacts on the health of urban waterways. For example, by 2050 it is estimated that 42% of the eastern Australian coastline between Nowra and Noosa will be urbanised.[3] For those that live in cities, population growth will be greatest in the inner city, characterised by high-rise development. On the city fringes new subdivisions will emerge from existing farmland or bushland.[4] This ongoing increase in the urban footprint will have substantial impacts on the physical, chemical and biological condition of urban waterways.[5] Changes may include:

- modified hydrologic conditions;[6]
- alterations to stream channel morphology and function (most notably through piping and associated catchment imperviousness);[7]
- increased water temperature and light (as riparian vegetation is cleared);[8]
- increased barriers affecting the movement of aquatic and other riparian organisms;[9]
- increased toxicants (derived from urban surfaces);
- changes to dissolved oxygen and pH, and increased ionic concentrations;[10] and
- increased available nutrients.[11]

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2 Bradsen J, "Biodiversity Legislation: Species, Vegetation, Habitats" (1992) 9 EPLJ 175 at 179.

3 Beeton RJS (Bob), Buckley KI, Jones GJ, Morgan D, Reichelt RE and Trewin D (2006 Australian State of the Environment Committee), *Australia State of the Environment 2006* (independent report to the Australian Government Minister for the Environment and Heritage, Department of the Environment and Heritage, 2006) p 50.

4 Australian Bureau of Statistics, *Regional Population Growth for Australia 2008-09*, http://www.abs.gov.au/ausstats/abs@.nsf/Products/3218.0~2008-09~Main+Features~Main+Features?OpenDocument#PARALINK11 viewed 13 May 2011.

5 Walsh CJ, Roy AH, Feminella JW, Cottingham PD, Groffman PM and Morgan RP, "The Urban Stream Syndrome: Current Knowledge and the Search for a Cure" (2005) 24 J N Am Benthol Soc 706; Dunne T and Leopold LB, *Water in Environmental Planning* (WH Freeman and Company, 1978).

6 Booth DB and Jackson CR, "Urbanisation of Aquatic Systems: Degradation Thresholds, Stormwater Detection, and the Limits of Mitigation" (1997) 33(5) *Journal of the American Water Resources* 1077.

7 Klein RD, "Urbanization and Stream Quality Impairment" (1979) 15 J Am Water Resour As 948.

8 Bunn SE, Davies PM and Mosisch TD, "Ecosystem Measures of River Health and their Response to Riparian and Catchment Degradation" (1999) 41 Freshwater Biol 333.

9 Harding JS, Benfield EF, Bolstad PV, Helfman GS and Jones EBD, "Stream Biodiversity: The Ghost of Land Use Past" (1998) 95 Proc Natl Acad Sci USA 14843; Walsh CJ, "Biological Indicators of Stream Health Using Macroinvertebrate Assemblage Composition: A Comparison of Sensitivity to an Urban Gradient" (2006) 57 Mar Freshw Res 37; Davies PJ, Wright IA, Findlay, SJ, Jonasson OJ and Burgin S, "Impact of Urban Development on Aquatic Macroinvertebrates in South Eastern Australia: Degradation of In-stream Habitats and Comparison with Non-urban Streams" (2010) 44 Aquat Ecol 685.

10 Davies PJ, Wright IA, Jonasson OJ and Findlay SJ, "Impact of Concrete and PVC Pipes on Urban Water Chemistry" (2010) 7 *Urban Water Journal* 233.

11 Birch GF, Cruickshank B and Davies B, "Modelling Nutrient Loads to Sydney Estuary (Australia)" (2010) 167 Environ Monit Assess 333.

In addition to altering catchment hydraulics and hydrology, urbanisation also has inevitable secondary impacts on the availability of long-term potable water supply. Increased demand for potable urban water has resulted in Sydney being connected with drinking water catchments as far away as the Shoalhaven River and drawing on ocean water resources via desalination.[12] Increases in population also contribute to an increase in wastewater volumes. Treatment systems are becoming increasingly more effective at delivering cleaner water to receiving waters, and water reuse schemes enable secondary use of water in the catchment prior to their eventual discharge. However past and present activities continue to impact the condition of major urban waterways such as the Hawkesbury-Nepean river,[13] Sydney Harbour[14] and the areas around the deepwater ocean outfalls.[15]

In Sydney, sewerage systems are designed to have overflows directed into natural waterways. These overflows continue to contribute high levels of nutrients to urban streams during heavy rainfall or blockages (as directed by relevant environmental protection licences under the *Protection of the Environment Operations Act 1997* (NSW)).[16] This affects both river and human health as sewerage pipes deteriorate and carry increasing volumes of sewage and infiltrated stormwater flows.[17] As new suburbs emerge at the city fringe, existing natural waterways (particularly headwater streams) will be impacted by the engineering of waterways and their catchments, despite efforts to keep them natural (eg by re-enforcing beds and banks to accommodate increased storm flows, using water sensitive urban design treatments to remove nutrients and sediment). Examples of these impacts include bridges, piping, and flow structures necessary to enable urban transportation.[18]

12 New South Wales Government, *2010 Metropolitan Plan – Water for People and the Environment* (The NSW Office of Water, 2010), http://www.waterforlife.nsw.gov.au/mwp viewed 13 May 2011.

13 Simmons B and Scott J, "The River has Recorded the Story, Living with the Hawkesbury River, Sydney, NSW, Australia" in Tvedt T and Jakobsson EJ (eds), *A History of Water Volume 1: Water Control and River Biographies* (IB Tauris Publishers, 2005) pp 253-276.

14 Birch G and Taylor S, "Source of Heavy Metals in Sediments of the Port Jackson Estuary, Australia" (1999) 227(2-3) The Sci Total Environ 123.

15 Beder S, *Toxic Fish and Sewer Surfing – How Deceit and Collusion are Destroying our Great Beaches* (Allen and Unwin, 1989).

16 Sydney Water, *Annual Report 2010* (2010), http://www.sydneywater.com.au/Publications/Reports/AnnualReport/2010/performance/sustainability/clean_waterways_si2.html viewed 13 May 2011.

17 Sydney Water's SewerFix program is an example of the large amount of investment and work that goes into repairing and augmenting infrastructure to prevent excessive sewer overflows. For details of this program, see http://www.sydneywater.com.au/MajorProjects/Wastewater/SewerFix/index.cfm viewed 13 May 2011. A more detailed discussion of the impacts of nutrient enrichment on urban stream ecosystems is also found in Walsh et al, n 5.

18 Walsh CJ, Fletcher TD and Ladson AR, "Stream Restoration in Urban Catchment through Redesigning Stormwater Systems: Looking to the Catchment to Save the Stream" (2005) 24 J N Am Benthol Soc 690.

The extent of physical changes to river systems from urbanisation and their cumulative and synergistic effects on water health are not yet sufficiently understood. Significant contemporary scientific research and reflection in this area is ongoing.[19] The law, engineering practice and land-use planning in New South Wales are slow to reflect and adopt the emerging scientific evidence supporting adoption of the precautionary principle to manage urban waterways.[20] Australia's biophysical environment is significantly different to England, from which our common law definitions and statutory principles are derived. For example, the legal definition of a river in Australia reflects English traditions and common law roots dating back to 1854.[21] The English common law sees a river as having a definable bed, bank and flows that occur most of the time. This approach, although ill-suited to the Australian environment, has been used since colonial settlement to determine numerous legal cases.[22] Only recently have legislators and courts begun to broaden their views that reflect a more contemporary and Australian context. This new approach is discussed below.

Interwoven with the legal framework are the values that communities and professions place on waterways. As with legislation and policy, these change over time. Nevertheless, the present understanding of the form, function, condition and treatment of urban waterways still largely reflect historical approaches to waterways management. This understanding has, to a large extent, been responsible for the urban stream syndrome.[23]

This article examines how the current legal and planning system for urban river management has evolved. It draws on social and professional values, and uses Sydney and the laws of New South Wales as a case study. The article also presents a way forward for legislators and policy makers that may lead to improvements in the condition of these waterways.

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19 Wenger SJ, Roy AH, Jackson CR, Bernhardt ES, Carter TL, Filoso S, Gibson CA, Grimm NB, Hession WC, Kaushal SS, Martí E, Meyer JL, Palmer MA, Paul MJ, Purcell AH, Ramirez A, Rosemond AD, Schofield KA, Schueler TR, Sudduth E and Walsh CJ, "Twenty-six Key Research Questions in Urban Stream Ecology: An Assessment of the State of the Science" (2009) 28 J N Am Benthol Soc 1080.

20 Underwood AJ, "Precautionary Principles Require Changes in Thinking about Planning Environmental Sampling" in Harding R and Fisher E (eds), *Perspecitves on the Precautionary Principle* (Federation Press, 1999) pp 254-266.

21 Angell JK, *A Treatise on the Common Law, In relation to Watercourses: Intended more particularly as an Illustration of the Rights and Duties of the Owners and Occupants of Water Privileges* (5th ed, Wells and Lilly, 1854).

22 See Taylor MP and Stokes R, "Up the Creek: What is Wrong with the Definition of a River in New South Wales?" (2005) 22 EPLJ 193.

23 See Walsh et al, n 5; Meyer et al, n 1

## Who values urban streams?

How riparian environments are managed into the future depends on the perspective and values of those drafting and implementing legislation, policy and industry guidelines.[24]

The engineering profession has long dominated the management of urban waterways and water resources.[25] Its focus has been on securing reliable water supply, ensuring safe wastewater systems and protecting private and public property from heavy rain and flooding. This anthropocentric and utilitarian view focuses on controlling rivers and water resources. Methods used include damming rivers to provide potable water, using rivers as extensions to the stormwater drainage network, and designing sewer overflows to discharge directly to river systems. Indeed, the name and intent (ie improvement of rivers) of the now repealed *Rivers and Foreshores Improvement Act 1948* (NSW) (RFI Act) reflects the modern historical view of how human society should approach and interact with natural water systems; namely, that humanity can improve upon nature. Biomimicry is one aspect of industrial design that has proven to be successful in the development of more sustainable and effective human technologies, but demonstrable improvements on nature are much more arbitrary.[26]

Within urban areas, rivers have long been piped, channelled or straightened in order to improve (sensu RFI Act) their hydraulic efficiency to minimise the risk of flooding. The first industry guideline for the engineering profession on stormwater drainage was published in 1958 by the Institution of Engineers Australia.[27] The guideline sought to ensure that the stormwater drainage system had sufficient capacity to control stormwater runoff. This was particularly relevant because, as land was cleared and subsequently developed, the frequency, duration and intensity of runoff changed. While this guideline has been updated a number of times, it wasn't until 2006 that the engineering profession published its first significant document on stormwater drainage incorporating stormwater quality and urban stream health – *Australian Runoff Quality* (ARQ).[28] Uptake and application by civil and

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24 Findlay SJ and Taylor MP, "Why Rehabilitate Urban River Systems?" (2006) 38 *Area* 312.

25 Brown RR, "Impediments to Integrated Urban Stormwater Management: The Need for Institutional Reform" (2005) 36 *Environmental Management* 455; O'Laughlin G and Robinson DK, "The Coming of Quality: The Recognition of Urban Stormwater Pollution in Australia" in Jollife IB and Ball JE (eds), *Proceedings of the 8th International Conference on Urban Storm Drainage* (Vol 1, Institution of Engineers Australia, 30 August-3 September 1999) pp 315-323.

26 Benyus JM, *Biomimicry: Innovation Inspired by Nature* (Perennial, 2002).

27 Institution of Engineers Australia, *Australian Rainfall and Runoff* (first report of the Stormwater Standards Committee, Institution of Engineers Australia, 1958).

28 Wong THF (ed), *Australian Runoff Quality* (Australian Institute of Engineers, 2006).

hydraulic engineers of ARQ and associated best practice implementation is still in its infancy, although appreciation of water sensitive urban design is steadily growing, despite its many hurdles.[29] These hurdles remain evident in New South Wales; the standards recommended by ARQ for the protection of urban waterways, for example, have remained by and large in the domain of guidelines and non-enforceable policy.[30]

Urban planners have long recognised the value of green corridors across the landscape.[31] Their location has often been determined by topography, such as waterways or ridge-tops, or historical land-use. Within Sydney, the value of these corridors was first recognised in 1925 when parts of the Lane Cove River (to the north of Sydney Harbour) was set aside as parkland and later declared a national park. This decision is supported by current evidence that urban green spaces, such as riparian corridors, contribute greatly to psychological health and human wellbeing,[32] as well as providing recreational opportunities including walking and cycling and enhanced economic value, reflecting society's desire to live near aquatic environments.[33]

Riparian areas are significant and unique environmental systems due to their position at the interface between the aquatic (river) and terrestrial (riparian) environments.[34] The interaction between these contrasting environments results in high levels of habitat heterogeneity,[35] species richness[36] and biological productivity.[37] From a conservation perspective, riparian corridors are

29 Brown RR and Farrelly MA, "Delivering Sustainable Urban Water Management: A Review of the Hurdles We Face" (2009) 59 Water Sci Technol 839.

30 New South Wales Government, *City of Cities: A Plan for Sydney's Future, Metropolitan Strategy* (Department of Planning, 2005); BMT WBM, *Draft NSW MUSIC Modelling Guidelines* (Sydney Metropolitan Catchment Management Authority, 2010).

31 Amati M (ed), *Urban Green Belts in the Twenty-First Century* (Ashgate, 2008).

32 Kuo FE, "Coping with Poverty: Impacts of Environment and Attention in the Inner City" (2001) 33 Environ Behav 5; Miller JR, "Biodiversity Conservation and the Extinction of Experience" (2005) 20 Trends Ecol Evol 430; Fuller RA, Irvine KN, Devine-Wright P, Warren PH and Gaston KJ, "Psychological Benefits of Greenspace Increase with Biodiversity" (2007) 3 Biol Lett 390.

33 Torre A and Hardcastle K, "River Rehabilitation in South-West Western Australia" in Rutherfurd ID, Wiszniewski I, Askey-Doran MA and Glazik R (eds), *Proceedings of the 4th Australian Stream Management Conference: Linking Rivers to Landscapes* (Department of Primary Industries, Water and Environment, Tasmanian Government, 2005) pp 609-617.

34 Riparian zones are known in ecological terms as "ecotones" because of their position between two contrasting habitat types. For a good overview of riparian structure and ecological function, see Gregory SV, Swanson FJ, McKee WA and Cummins KW, "An Ecosystem Perspective of Riparian Zones" (1991) 41 *BioScience* 540.

35 Ward JV, Tockner K and Schiemer F, "Biodiversity of Floodplain Ecosystems: Ecotones and Connectivity" (1999) 15 Regul Rivers Res Manage 125.

36 Naiman RJ and Decamps H, "The Ecology of Interfaces – Riparian Zones" (1997) 28 Annu Rev Ecol Syst 621.

37 Ward et al, n 35.

38 Naiman RJ, Decamps H and Pollock M, "The Role of Riparian Corridors in Maintaining Regional Biodiversity" (1993) 3 Ecol Appl 209.

often the last remnant natural areas within urban landscapes and as such are instrumental in helping to protect and promote biological conservation at a local and regional scale.[38] Their connectivity throughout the landscape can be critically important for facilitating the movement of flora and fauna. As a result, riparian corridors may enable larger populations of many species to exist because they provide access to better foraging areas or unique habitats. In addition, they are also known to increase the long-term viability of populations as a function of increasing genetic flow due to the connectedness of suitable environments and habitat.[39] Furthermore, this regular movement of organisms throughout landscapes generally results in higher levels of species richness as it increases the rate of species immigration into any given patch, thereby effectively increasing the area of the habitat "island" within an inhospitable "matrix".[40] For these reasons, riparian zones often play a critical function in conservation planning for a wide range of human-altered landscapes including urban areas.[41]

Despite their often-degraded state, urban rivers and their riparian zones have been historically undervalued or even ignored by scientists because these professions have focussed more on aquatic systems in good environmental condition. Urban systems have often been disregarded because of their known aquatic ecological degradation and weed-infested riparian zones. However, over the past 40 years, there has been increasing attention on the pressures of urbanisation and alterations to the natural hydrological cycle within cities.[42] In the late 1960s and 1970s, research focused on the impacts of point-source pollution on waterways in response to the contamination of waterways by industry using them as a convenient and inexpensive way to dispose of liquid waste.[43] This growth in

39 Compare Mech SG and Hallett JG, "Evaluating the Effectiveness of Corridors: A Genetic Approach" (2001) 15 Cons Biol 467.

40 Damschen EI, Haddad NM, Orrock JL, Levey DJ and Tewksbury JJ, "Corridors Increase Plant Species Richness at Large Scales" (2006) 313 *Science* 1284; Forman RTT, *Land Mosaics: The Ecology of Landscapes and Regions* (Cambridge University Press, 1995).

41 Bennett A, *Linkages in the Landscape: The Role of Corridors and Connectivity in Wildlife Conservation* (International Union for the Conservation of Nature, 1999); Parker K, Head L, Chisholm LA and Feneley N, "A Conceptual Model of Ecological Connectivity in the Shellharbour Local Government Area, New South Wales, Australia" (2008) 86 Landsc Urban Plan 47.

42 See eg Cordery I, *Evaluation and Improvement of Quality Characteristics of Urban Stormwater* (Report No 147, Water Research Laboratory, University of New South Wales, 1976); Lees SJ and Lynch SJ, "Development of a Catchment On-site Stormwater Detention Policy" in *International Symposium on Urban Stormwater Management* (Institution of Engineers Australia, 1992), http://search.informit.com.au/documentSummary;dn=697375622493817;res=IELENG viewed 16 May 2011; O'Loughlin G, "Pollution Prevention and Politics – The Recent Experience in Sydney" (1994) 30 Water Sci Technol 13.

43 Birch GF, Evenden D and Teutsch ME, "Dominance of Point Source in Heavy Metal Distributions in Sediments of a Major Sydney Estuary (Australia)" (1996) 28 Environ Geol 169; Birch G and Taylor S, "Source of Heavy Metals in Sediments of the Port Jackson Estuary, Australia" (1999) 227 Sci Total Environ 123.

44 Eg *Environmental Planning and Assessment Act 1979* (NSW); *Environmentally Hazardous Chemicals Act 1985* (NSW).

knowledge of environmental impacts eventually led to the licensing of pollution discharges through the introduction of the *Clean Waters Act 1971* (NSW) inter alia related laws.[44]

It is only over the last couple of decades, however, that the poor geomorphic (physical) and ecological condition of many urban riparian systems has become a relevant and significant area of research.[45] This has led to an enhanced understanding of the role and function of urban waterways from a landscape and ecological perspective, particularly how these systems respond to developments in their catchment.[46] Arising from this growth in knowledge, in the late 1990s urban planners, engineers and scientists came together to promote a more integrated way to manage urban waterways and water resources. In Western Australia, this emerged as water sensitive urban design, also referred to as low impact development (LID) or sustainable urban drainage systems (SUDS).[47]

New South Wales took a more regulatory approach to urban water management. In 1997, the Environment Protection Authority ordered local government to develop formal plans focused on stormwater.[48] While this was a top down approach, it represented the beginning of a new paradigm in the management of urban water systems, broadening the focus of stormwater management beyond basic flood control to incorporate water quality and waterway health requirements. Arising from multiple cross-disciplinary research studies, new best practice guidelines have been promulgated for greenfield developments and, to a lesser extent, urban infill developments.[49]

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45 Eg Spink A, Fryirs K, Brierley G and Lloyd K, "An Interdisciplinary Perspective of Riverwork Projects in the Upper Hunter Catchment, NSW: Has River Rehabilitation Begun?" in Wilson AL, Dehaan RL, Watts RJ, Page KJ, Bowmer KH and Curtis A (eds), *Proceedings of the 5th Australian Stream Management Conference. Australian Rivers: Making a Difference* (Charles Sturt University, 2007); Walsh et al, n 5; Walsh CJ, "Biological Indicators of Stream Health Using Macroinvertebrate Assemblage Composition: A Comparison of Sensitivity to an Urban Gradient" (2006) 57 Mar Freshw Res 37.

46 For example, the Cooperative Research Centre (CRC) for Catchment Hydrology existed between 1992 and 2005 and facilitated many research studies with an urban water focus. Much of their work has been incorporated into the research program by the eWater CRC (see http://www.ewater.com.au/ viewed 16 May 2011). Key publications arising from the CRC include Walsh CJ, Leonard AW, Ladson AR and Fletcher TD, *Urban Stormwater and the Ecology of Streams* (Cooperative Research Centre for Freshwater Ecology and Cooperative Research Centre for Catchment Hydrology, 2004); Walsh et al, n 18.

47 Moritz M, *Sustainable Urban Water Systems: Policy and Professional Praxis* (PhD Thesis, Murdoch University, 1996); Evangelisti M and Moritz M, *Water Sensitive Urban Design Seminar, How Do You Do It?* (Proceedings of the Water Sensitive Urban Design Seminar, Institution of Engineers Australia, West Perth, 12 September 1994), http://search.informit.com.au/documentSummary;dn=440985937980985;res=IELENG viewed 16 May 2011.

48 NSW Urban Stormwater Trust, *Evaluation of the Stormwater Management Planning Process* (Environmental Protection Authority, 2001), http://www.environment.nsw.gov.au/resources/stormwater/usp/usped.pdf viewed 16 May 2011.

49 CSIRO, *Urban Stormwater – Best Practice Environmental Management Guidelines* (CSIRO Publishing, 1999); Wong, n 28.

## Legislative, planning and management frameworks

The legal framework protecting urban rivers and riparian systems is yet to respond to contemporary knowledge and understanding. This section looks at two major areas that have the potential to substantially influence the management of urban riparian systems: the definition of a river and a riparian area; and the role of urban planning instruments and policies. Using New South Wales as an example, the discussion focuses on the two most influential laws – the *Water Management Act 2000* (NSW) (WM Act) and the *Environmental Planning and Assessment Act 1979* (NSW) (EPA Act). The authors examine how each of these Acts could be better used or improved on by the State government, specifically the Department of Planning, the Department of Environment Climate Change and Water, and collectively by the many councils within the greater Sydney metropolitan area.

## Legal definitions

### *Current situation*

The definition of a river has been evolving in recent times. The WM Act defines a river as:

> (a) any watercourse, whether perennial or intermittent and whether comprising a natural channel or a natural channel artificially improved, and
>
> (b) any tributary, branch or other watercourse into or from which a watercourse referred to in paragraph (a) flows, and
>
> (c) anything declared by the regulations to be a river, whether or not it also forms part of a lake or estuary, but does not include anything declared by the regulations not to be a river.[50]

A key driver for the reform of this Act, and as contained in the objects, is to provide for the sustainable and integrated management of water sources for present and future populations. This builds on the RFI Act (repealed) and places greater emphasis on the environmental value of waterways. Specifically, the WM Act includes clear directions aimed at protecting, enhancing and restoring water sources and their associated ecosystems, ecological processes and biological diversity and their water quality (s 3(b)), and integrates the management of water sources with the management of other aspects of the environment including the land, its soil, native vegetation and native fauna (s 3(f)). Further, the WM Act enables a river to be declared a river through the supporting *Water Management (General) Regulation 2004* (NSW). However, as noted by Taylor and Stokes, this definition, prima facie, still fails to encompass all river systems, types and flow behaviours that occur across

50 *Water Management Act 2000* (NSW), Dictionary.

New South Wales.[51] From an urban perspective, it recognises artificially-modified channels; however, uncertainty remains around how it may encompass a piped watercourse, first order stream,[52] ephemeral flows within a watercourse experiencing an altered hydrological regime resulting from stormwater infrastructure, or the contributions of long-term leaks from a water main or sewer pipe.

The New South Wales Land and Environment Court (LEC) has consistently struggled with the definition of a river. Its reliance on historical perspectives arcing back to English common law is gradually changing. Bannon J in *Narambulla Action Group Inc v Mulwarree Council* [1996] NSWLEC 199 noted awareness of the dichotomy between common law definitions of a river and the environmental realities that exist across the spectrum of Australian watercourses. This was a notable departure from the approach that relied on the rather narrow definition used by Barwick CJ in *Knezovic v Swan-Guildford* (1968) 118 CLR 468; 18 LGRA 365. Pearlman J in *Zouki v Water Administration Ministerial Corporation* (2001) 118 LGERA 229 at 233, commented that there is a need to consider both the legal definition of a river, waterbody or watercourse under common law as well as “any other definition derived by reference to the ordinary meaning of the word”. In effect, this further opened the door to enable consideration of other definitions, including those from the scientific community as well as common parlance, outside of the statutes. More recently, Lloyd J in *O’Keefe v Water Administration Ministerial Corporation* [2010] NSWLEC 9 at [53], accepted that “in the science of the fluvial geomorphology the words intermittent and ephemeral are regarded as being synonymous”. This determination would seem to have (finally) expanded the definition of a river in the WM Act to encapsulate the flow characteristics of all rivers including perennial, intermittent or ephemeral and bodes well for a statutory revision.

While the authors believe Lloyd J arrived at the right conclusion with respect to the need to consider both intermittent and ephemeral streams as part of the environmental assessment for the matter in *O’Keefe*, it is contended that the evidence provided in the case was incomplete.

The *Land and Environment Court Act 1979* (NSW), s 38(2) – Procedure, allows judges and commissioners in relation to matters in Classes 1-3 to inform themselves in such a manner as is appropriate:

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51 Taylor and Stokes, n 22.

52 First order streams are the smallest streams that make up a drainage network as proposed in Strahler AN, “Hypsometric (Area-Altitude) Analysis of Erosion Topography” (1952) 63 Bull Geol Soc Am 1117. For a good discussion of the unique geomorphic and ecological features of headwater streams, see John PR, Gooderham JPR, Barmuta LA and Davies PE, “Upstream Heterogeneous Zones: Small Stream Systems Structured by a Lack of Competence?” (2007) 26 J N Am Benthol Soc 365.

(2) In proceedings in Class 1, 2 or 3 of the Court's jurisdiction, the Court is not bound by the rules of evidence but may inform itself on any matter in such manner as it thinks appropriate and as the proper consideration of the matters before the Court permits.

However, in practice, this happens rarely and usually only in situations where the knowledge of the adjudicating officer intersects with the matter before the court. Consequently, the decision-makers usually rely on the expert evidence provided to the court. This is why it is imperative that experts are active in both research and practice in their fields, so that any evidence presented to the court is contemporary and fully informed.

### *Proposed new definitions for "river" and "riparian zone"*

It is clear from the *O'Keefe* judgment that Lloyd J had to rely on insufficient evidence with respect to the commonly accepted scientific understanding of stream flow regime characteristics. The judgment reported that the experts said that the terms "intermittent" and "ephemeral" were synonymous, or they had used them in an interchangeable manner in the evidence provided to the court (at [26]-[32]). While it may be common parlance for some to not discriminate between an intermittent and ephemeral flow, these differences are understood and used by environmental scientists and geomorphologists to discriminate between river systems and their function. Thomas and Goudie[53] identify three types of river and stream flow regime: perennial, intermittent and ephemeral:

> Perennial stream: A stream that flows all year. A dynamic drainage network also includes intermittent streams and ephemeral streams but there should always be flow in a perennial stream channel. For much of the time this flow may be in the form of base flow or delayed flow except when quick flow occurs after rainstorms.
>
> Intermittent stream: A stream is classified as intermittent if flow occurs only seasonally when the water table is at maximum level. The drainage network is composed of ephemeral, intermittent and perennial streams and the network expands during rainstorms and extends to limits affected by antecedent conditions especially antecedent moisture. Flow may occur along intermittent streams for several months each year but will seldom occur when the water table is lowered during the dry season.
>
> Ephemeral stream: A stream which is often one of the outer links of the drainage network and which contains flowing water only during and immediately after a rainstorm which may be fairly intense. As the water flows along the ephemeral channel it may infiltrate into the channel bed as a transmission loss by influent seepage and therefore the peak discharge may decrease downstream along the ephemeral channel by as much as 5 per cent per km of channel. In arid and semi-arid areas of the world ephemeral streams are very extensive and represent the major channel type.

53 Thomas DSG and Goudie AS (eds), *The Dictionary of Physical Geography* (Blackwell, 2000).

The legal intersection of the definition of a river within the urban setting was examined by Taylor C in *Silva v Ku-ring-gai Council* [2009] NSWLEC 1060 at [17]. It was contested by the applicant that as the watercourse was not defined in the WM Act, it could not be applied in this case. Further it was proposed by the applicant, though dismissed in the judgment, that the definitions of a watercourse in the *Local Government (General) Regulation 2005* (NSW), cl 100 and State Environmental Planning Policy (Sydney Regional Growth Centres) 2006, Dictionary, had an emphasis on natural systems, as distinct from a modified system, and therefore would not apply to their application. Taylor C noted (at [67]) that as watercourses in the Ku-ring-gai local government area drain predominantly into larger receiving water sources such as national parks it is "good management practice to protect, restore, maintain these systems while simultaneously mitigating any further negative impacts on watercourses and their riparian habitats". Such management objectives are synonymous with ecological sustainable development and the Objects and Principles of the WM Act that are to:

> provide for the sustainable and integrated management of the water sources of the State for the benefit of both present and future generations and, in particular:
>
> (a) to apply the principles of ecologically sustainable development, and
>
> (b) to protect, enhance and restore water sources, their associated ecosystems, ecological processes and biological diversity and their water quality, and
>
> (c) to recognise and foster the significant social and economic benefits to the State that result from the sustainable and efficient use of water, including:
>
> (i) benefits to the environment, and
>
> (ii) benefits to urban communities, agriculture, fisheries, industry and recreation, and
>
> (iii) benefits to culture and heritage, and
>
> (iv) benefits to the Aboriginal people in relation to their spiritual, social, customary and economic use of land and water,
>
> (d) to recognise the role of the community, as a partner with government, in resolving issues relating to the management of water sources,
>
> (e) to provide for the orderly, efficient and equitable sharing of water from water sources,
>
> (f) to integrate the management of water sources with the management of other aspects of the environment, including the land, its soil, its native vegetation and its native fauna,
>
> (g) to encourage the sharing of responsibility for the sustainable and efficient use of water between the Government and water users,
>
> (h) to encourage best practice in the management and use of water.

The implications of the decision of Taylor C and Lloyd J is that even minor, degraded, modified and ephemeral flowing watercourses in rural and urban environments that connect to an important waterbody (as all rivers of metropolitan Sydney do) should be legally recognised as a river and protected accordingly. Drawing on these revised ideas and perspectives, it is suggested that a river be redefined as follows:

> Any stream of water, whether perennial, intermittent or ephemeral, flowing in a natural or artificially improved channel or in an artificial channel that has changed in the course of the stream of water, and any other stream of water into or from which the stream of water flows.[54]

Unlike rivers, riparian areas have no statutory definition in New South Wales. This is a remarkable omission given that it is well known that these areas of the landscape have significant biodiversity, recreation and flood protection values. Broadly, riparian lands form the transition between terrestrial and aquatic environments,[55] although – as noted in the New South Wales Department of Infrastructure, Planning and Natural Resources study – there are many definitions of riparian lands depending on perspective of the discipline. From an environmental perspective, Illhardt et al seek to incorporate multidimensional interactions, including terrestrial and aquatic ecosystems, groundwater, canopy vegetation and floodplains,[56] while Trueman and Price, coming from a geomorphology background, are more specific in terms of the physical representation of river and associated systems on the landscape.[57]

Building on these perspectives, geomorphologists are likely to consider the riparian area that is related directly to the area of land between the banks of a river with the top of bank being the extent capable of containing the bank full flow.[58] However, what defines the bank full flow is also subject to conjecture even within this profession. There is some agreement that this can be characterised as the recurrence interval flow of approximately one to two years,[59] although this recurrence interval flow in urban areas would typically occur much more frequently as a result of the increase in imperviousness and, in turn, runoff.[60] The location of the top of bank is also an area of professional difference – which could benefit from further

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54 Adapted from the definition of a watercourse under the *Local Government Act 1993* (NSW), s 36(5).

55 New South Wales Government, *Riparian Corridor Management Study Covering all of the Wollongong Local Government Area and Calderwood Valley in the Shellharbour Local Government Area* (Department of Infrastructure, Planning and Natural Resources, 2004) p 7.

56 Ilhardt BL, Verry ES and Palik BJ, "Defining Riparian Areas" in Verry ES, Hornbeck JW and Dolloff CA (eds), *Riparian Management in Forests of the Continental Eastern United States* (Lewis Publishers, 2000) pp 23-42.

57 Tubman W and Price P, "The Significance and Status of Riparian Land" in Lovett S and Price P, *Riparian Land Management Technical Guidelines, Volume 1: Principles of Sound Management* (Land and Water Resources Research and Development Corporation, 1999) pp 1-8.

58 Hupp CR and Osterkamp WR, "Riparian Vegetation and Fluvial Geomorphic Processes" (1996) 14 *Geomorphology* 277.

59 Knighton AD, *Fluvial Forms and Processes: A New Perspective* (Arnold, 1988).

60 Christopher JW, Leonard AW, Ladson AR and Fletcher TD, *Urban Stormwater and the Ecology of Streams* (Cooperative Research Centre for Freshwater Ecology and Cooperative Research Centre for Catchment Hydrology, 2004).

clarification. As with bank full flow, the precise top of bank depends on the rainfall-runoff relationship and also the geomorphic form of a channel (that is known to differ significantly throughout Australia).[61]

Ecologists on the other hand are more likely to adopt a broader view of a riparian area to include any part of the terrestrial landscape that is ecologically influenced by fluvial processes.[62] A variety of approaches have been used to identify the extent of riparian zones, such as amphibian presence[63] and examination of forest structure and functional characteristics.[64] Specific examples of definitions include: "the area of land that forms the banks of a water-body and the adjacent land it directly affects, including the vegetation";[65] or more simply "ecosystems adjacent to the river".[66] This more inclusive approach has merit because it has the capacity to include many ephemeral streams that often dominate the type of runoff present in the upper reaches of a catchment. Furthermore, such systems may comprise not only a greater proportion of the total area that drains to a major river, but may also encompass more diversity in terms of their form and ecological function even over a very short time.[67]

As evident from the discussion above, the lack of an agreed definition of a riparian area and the uncertainty this creates, leads to uncertainty and interpretation. The Urban Development Industry Association (UDIA) of New South Wales has noted this in their submission on riparian reforms affecting development contributions. The UDIA's submission was also critical of the inconsistent approach by officers within State government when dealing with riparian areas,[68] which in part reflects a lack of policy and guidelines. A similar criticism can also be made in relation to the definition of a river for determining the geomorphic order of

61 Lamaro E, Stokes R and Taylor MP, "Riverbanks and the Law: The Arbitrary Nature of River Boundaries in New South Wales, Australia" (2007) 27 *The Environmentalist* 131; Erskine WD and Livingstone EA, "In-channel Benches: The Role of Floods in their Formation and Destruction on Bedrock-confined Rivers" in Miller AJ and Gupta A (eds), *Varieties of Fluvial Form* (John Wiley & Sons Ltd, 1999) pp 445-475.

62 Naiman et al, n 38.

63 Perkins DW and Hunter ML, "Use of Amphibians to Define Riparian Zones of Headwater Streams" (2006) 36 Can J For Res 2124.

64 Clinton BD, Vose JM, Knoepp JD, Elliott KJ, Reynolds BC and Zarnoch SJ, "Can Structural and Functional Characteristics be used to Identify Riparian Zone Width in Southern Appalachian Headwater Catchments?" (2010) 40 Can J For Res 235.

65 Ku-ring-gai Council, *Riparian Policy* (2004), http://www.kmc.nsw.gov.au/resources/documents/Riparian_Policy_December_2004[1].pdf viewed 16 May 2011.

66 Malanson GP, *Riparian Landscapes* (Cambridge University Press, 1993).

67 Doyle MW and Bernhardt ES, "What is a Stream?" (2011) 45 Environ Sci Technol 354.

68 Urban Development Institute of Australia (UDIA) NSW, *The Water Management Act 2000 – Riparian Corridors* (submission to the Department of Environment, Climate Change and Water and the Department of Planning, 2009) p 8, http://www.udia-nsw.com.au/resource/Riparian%20Corridors%20submission%202009.pdf viewed 16 May 2011.

a stream because of the absence of statutory guidelines to guide field assessment, as noted by Taylor and Stokes.[69]

In relation to a definition of an urban riparian area, the authors contest that the extent of the riparian zone will be dependent on many factors, not least its position in the catchment (top or bottom), proximity to development, nature of the vegetation between the development and the river (natural or modified) and how the river is connected to urban drainage system (eg pipe to natural watercourse). For this reason, it is recommended that the definition of a riparian zone be directly related to the observed influence of the river on the biota within and adjacent to the river. The authors contend that riparian land or zone would more effectively be defined as:

> The area of land adjacent to a water body showing visible signs of inundation, geomorphic reworking by fluvial processes; or, occupied by organisms that require environmental conditions provided by a river processes for all or part of their life cycle.

## Urban planning instruments and policies

In support of a revision of the definitions of a river and the inclusion of a definition of riparian zones within the WM Act and EPA Act (inter alia other relevant legislation, eg *Crown Lands Act 1989* (NSW) and *Water Act 1912* (NSW)), there is a need to consider how land-use plans and policies can support the protection and management of urban water resources. This section examines how local planning provisions can, and should be, integrated into the planning process. This reflects the need for consistency with the strategies, policies and legislation of national and State governments along with the principles of good management practice as suggested in recent LEC decisions.

### *Hierarchy of planning objectives*

It is important that there is a consistent direction at all levels of government, agencies and courts in relation to urban water resources and how these can be managed appropriately within their natural renewable limits.

The National Water Initiative has devised a program to further contribute to water sensitive cities activities. These support water sensitive urban developments and help to stimulate innovation by providing guidance on incentives to drive integrated water cycle

69 Taylor and Stokes, n 22; Taylor MP and Stokes R, "When is a River Not a River? Considerations of the Legal Definition of a River for Geomorphologists Practicing in New South Wales, Australia" (2005) 36 Aust Geogr 183.

management.[70] Within this program, the water sensitive cities project sets objectives to meet and manage urban water demands and to build water sensitive cities (eg Commonwealth Government 2004 and National Water Commission 2007). Consistent with many aspects of the National Water Initiative are the aims of the 2005 Metropolitan Strategy for Sydney.[71] This statutory document set the vision for Sydney in terms of its growth over the next 25 years and provides objectives as to how urban waterways in Sydney are to be considered in the planning process and consequently managed. It charges various State government agencies and local government with actions to help inform natural area management against the various objectives in the strategy, such as "improving the health of waterways, coasts and estuaries".[72]

Subordinate planning documents, such as regional plans, are currently used to provide greater levels of technical guidance for land-use planning affecting urban waterways. In Sydney, examples include the Catchment Action Plans for Sydney[73] and the Hawkesbury Nepean River,[74] and the Georges River Catchment Regional Environment Plan.[75] When these plans are coupled with more specific catchment condition assessment such as riparian mapping (as discussed below), they provide a constructive basis to inform decisions as to whether certain waterways and riparian areas should be protected by particular catchment-based land-use zoning. For example, protection of specific areas could be achieved by permitting modification to the *Standard Instrument (Local Environment Plans) Order 2006 (Environmental Planning and Assessment Act 1979* (NSW)).

Absent from most government policy documents is a clear explanation as to how each relates vertically (from a government and agency perspective), spatially (in terms of the geographic spread of their influence) and technically (as to how the various plans, programs

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70 *Intergovernmental Agreement on a National Water Initiative between the Commonwealth of Australia and the Governments of New South Wales, Victoria, Queensland, South Australia, the Australian Capital Territory and the Northern Territory* (2004) at [92(iii)], [92(v)], http://www.nwc.gov.au/resources/documents/Intergovernmental-Agreement-on-a-national-water-initiative.pdf viewed 16 May 2011.

71 The National Water Initiative forms Australia's blueprint for water reform (see http://www.nwc.gov.au/www/html/117-national-water-initiative.asp viewed 16 May 2011) and has as a core area of research and funding its urban water program of which the water sensitive cities is a major theme: see Australian Government, *Integrated Urban Planning* (National Water Commission, 2011), http://www.nwc.gov.au/www/html/214-integrated-uban-planning.asp viewed 16 May 2011.

72 New South Wales Government, *City of Cities – A Plan for Sydney's Future* (Department of Planning, 2005).

73 NSW Government, n 72, Action E.2.1.

74 Catchment Action Plans are developed under the *Catchment Management Authorities Act 2003* (NSW), s 23.

75 New South Wales Government, *Catchment Action Plan* (Sydney Metropolitan Catchment Management Authority, 2010), http://www.sydney.cma.nsw.gov.au/index.php?option=com_remository&Itemid=157&func=startdown&id=441 viewed 16 May 2011.

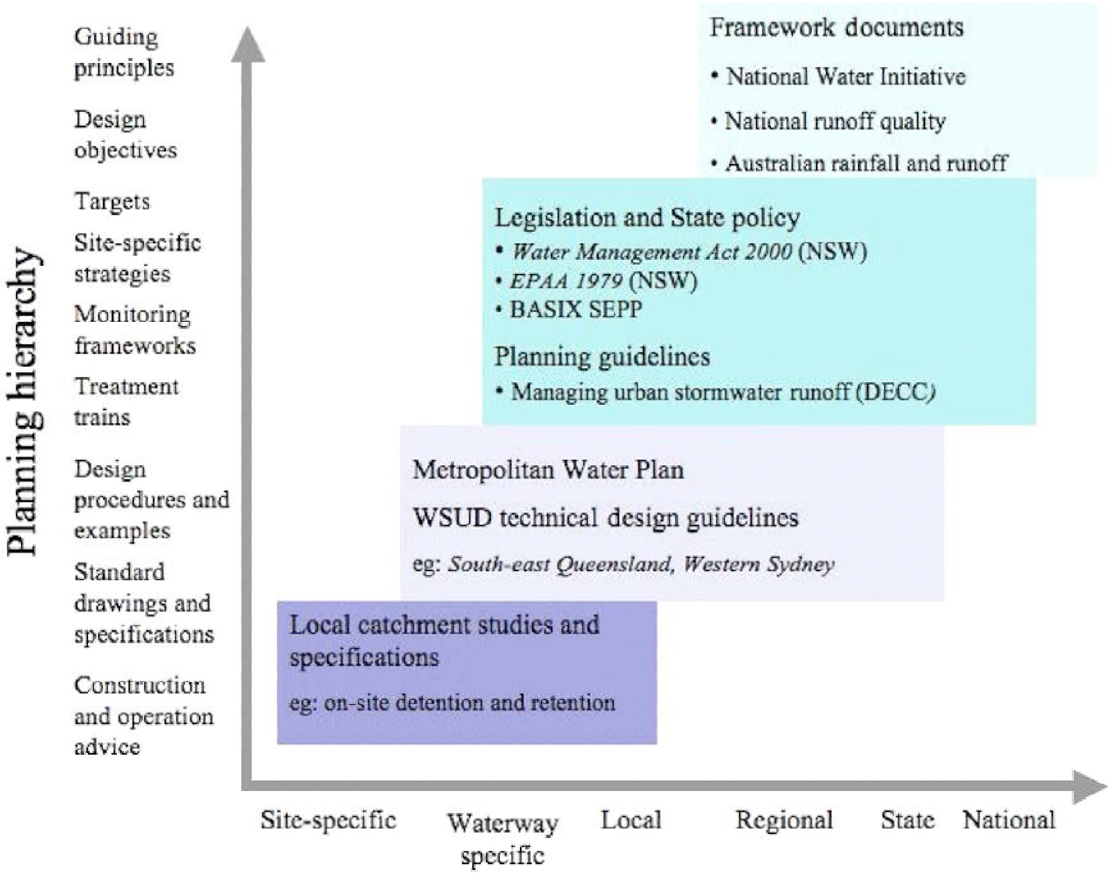


*Figure 1 Hierarchy of planning and spatial documents to support integrated urban water management*

and land-use controls relate within an apparently nested set of objectives). The authors propose developing a consistent set of urban water planning objectives and principles as illustrated in Fig 1.[76] Objectives should cascade from the National Water Initiative through to local and site controls (scale). The planning hierarchy (y-axis) should be informed by iterative review and evaluation of regulatory and land-use policies and plans relevant at various geographic scales (x-axis).

The courts too have considered the need to apply decisions consistent with broader sustainability principles and underpinned by credible science[77] and planning precedents.

76 New South Wales Government, *Hawkesbury Nepean Catchment Action Plan* (Hawkesbury Nepean Catchment Management Authority, 2007), http://www.hn.cma.nsw.gov.au/multiattachments/3776.html viewed 16 May 2011.

77 New South Wales Government, *Georges River Catchment Regional Environmental Plan* (Department of Urban Affairs and Planning, 1999), http://www.planning.nsw.gov.au/plansforaction/pdf/rep_grc.pdf viewed 16 May 2011.

The LEC has adopted this approach for planning matters under its jurisdiction that draws on a body of case law, although none exist for waterways or riparian areas.[78]

### *Role of the Local Environment Plan*

In New South Wales, the Department of Planning is presently requiring all councils to prepare new Local Environment Plans (LEPs) in accordance with a new standard instrument that applies across the State.[79] In relation to waterways, this standard LEP instrument allows for three land-use zones: natural waterways; recreational waterways; and working waterways.[80] Each land-use zone contains supporting provisions that seek to protect the ecological and scenic values of the waterways. These provisions occur on a spectrum from high priority for natural waterways to working waterways that have economic importance as the major value.

There are opportunities to provide greater detail and local context in the provisions. For example, local councils are able to include additional provisions (commonly referred to as "local provisions" or "model local clauses"), which can be used to recognise locally-relevant features or attributes of their areas. Currently, these are limited to new urban release areas and can provide for:

> (c) an overall landscaping strategy for the protection and enhancement of riparian areas and remnant vegetation, including visually prominent locations, and detailed landscaping requirements for both the public and private domain,
>
> …
>
> (e) stormwater and water quality management controls,
>
> (f) amelioration of natural and environmental hazards, including bushfire, flooding and site

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78 For example, the New South Wales Government, *North Sub-Region Draft Sub-Regional Strategy* (Department of Planning, 2007) Action E2.1.2, p 80, tasks the Sydney Metropolitan and Hawkesbury-Nepean Catchment Management Authorities to coordinate a regional approach to river values, including identifying priority areas for management.

79 Adapted from Northern Territory Government, *Water Sensitive Urban Design – Implementation Framework for Darwin* (discussion paper, Department of Planning and Infrastructure, May 2009), http://www.nt.gov.au/lands/planning/wsud/publications/documents/8005_Darwin%20WSUD%20Planning%20Guide%20FINAL%20_May09_.pdf viewed 16 May 2011.

80 For example, in *David Kettle Consulting Pty Ltd v Gosford City Council* [2008] NSWLEC 1385, the commissioners utilised the broad principles of ecological sustainable development when Coca Cola Amatil Pty Ltd sought a licence to extract water from the Peats Ridge area in New South Wales. The court heard compelling evidence from a groundwater expert in regard to the effects of water extraction on the water table. However, the evidence was significantly contradictory (at [30]-[33]) to warrant concern in regard to the true sustainability of a perpetual extraction licence, such that the commissioners refused the request.

> contamination and, in relation to natural hazards, the safe occupation of, and the evacuation from, any land so affected.[81]

However, how various locations are to be identified for inclusion in these model provisions is somewhat ambiguous. This is a matter requiring attention to eliminate the same type of uncertainty that plagues the definition of small creeks and watercourses. Furthermore, there remain ongoing pressures to pipe waterways within middle-ring suburbs (that fall outside the intense infill development of the inner city and greenfield or new urban release areas) that are presently excluded, which was one of the focus points in *Silva v Ku-ring-gai Council* [2009] NSWLEC 1060. Therefore, it is contended that, in line with the Objects (s 3) and Principles (s 5) of the WM Act, the application of these provisions should be broadened as soon as possible.

### *Local Environment Plans and Development Control Plans*

The ways in which local controls (as discussed above) are supported by the Department of Planning through their approval of LEPs and subsequent incorporation into Development Control Plans (DCPs), is likely to be of significant interest to the courts. In particular, the extent of departmental support for the vertical integration of provisions and local controls in legislative instruments (such as LEPs) and policies (such as metropolitan plans and strategies) is likely to influence significantly the court’s perspective on proposals affecting rivers and riparian areas. For example, in the Court of Appeal’s decision in *Zhang v Canterbury City Council* (2001) 51 NSWLR 589; 115 LGERA 373 at [75], Siegelman CJ found that the DCP must be central to any decision:

> The consent authority has a wide ranging discretion - one of the matters required to be taken into account is `the public interest’ - but the discretion is not at large and is not unfettered. DCP 23 had to be considered as a “fundamental element” in or a “focal point” of the decision making process. A provision so directly pertinent to the application for consent before the Council as was cl 4.0 of DCP 23 was entitled to significant weight in the decision making process but was not, of course, determinative.

This point was also highlighted by the former Chief Justice of the LEC, McClellan CJ, in *Stockland Development Pty Ltd v Manly Council* (2004) 136 LGERA 254. In this decision, McClellan CJ raised a number of principles that are relevant to the development and implementation of local provisions relating to the protection and management of urban riparian systems. Most notably these included:

81 See NSW Land and Environment Court, *Planning Principles* (2010), http://www.lawlink.nsw.gov.au/lawlink/lec/ll_lec.nsf/pages/LEC_planningprinciples viewed 16 May 2011.

*1. Consistency in the planning process*

This is particularly relevant to the need for a nested set of planning hierarchies across all levels of government as discussed above.

*2. Consistency in application as part of the development approval process*

Across metropolitan Sydney development provisions are often applied inconsistently. This is largely a result of varying standards of information and knowledge held by State and local government on the location, condition and buffer widths for riparian areas.[82] Consequently, it is recommended that the interpretation of urban planning controls could be improved greatly by the introduction of a specific riparian policy at the State or regional scale or related to specific environments. Presently, a number of councils have such policies that are used to assist development decisions made by local approval authorities and the courts. However, these need to be expanded across other jurisdictions if riparian systems are to be consistently and meaningfully protected and improved.[83] An example of a standard approach to the implementation of a policy is Sydney Catchment Authority's published guideline on how it determines development applications that are subject to the Drinking Waters Regional Environmental Plan (REP) No 1.[84]

*3. Consultation and notification of a new policy*

Section 55(2)(e) of the EPA Act requires that councils inform the Director General of the Department of Planning as part of the consultation required to prepare a LEP. While notification to the Director General is not required for DCPs, s 74E(1)(b) of the EPA Act and cl 18 of the *Environmental Planning and Assessment Regulations 2000* (NSW) require public exhibition of a draft DCP. While the regulations state that the public notice of the plan is to be in the local newspaper (cl 18(1)(a)), the regulation does not require all affected parties to be notified explicitly. Given that all catchment activities will have some impact on riparian or river health, it is suggested here that it would be best practice if all properties be

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82 Local Environment Plans are created under the *Environmental Planning and Assessment Act 1979* (NSW). Further information about the implementation of the new standard instrument can be found in New South Wales Government, *Implementing the Standard Instrument LEP Program – Questions and Answers* (Department of Planning), http://www.planning.nsw.gov.au/LinkClick.aspx?fileticket=T32N5aDk4aQ%3d&tabid=247 viewed 16 May 2011.

83 New South Wales Government, *Standard Instrument for LEPs* (Department of Planning, 2011), http://www.planning.nsw.gov.au/LocalEnvironmentalPlans/StandardInstrument/tabid/247/language/en-US/Default.aspx viewed 16 May 2011.

84 New South Wales Government, *Model Local Clauses for Standard Instrument Local Environment Plans Part 6.3* (Department of Planning, 2009), http://www.planning.nsw.gov.au/lep/pdf/Part_6_Urban_release_areas_6.3.pdf viewed 16 May 2011.

notified or otherwise made aware of the potential impacts of any such policy. This should also include relevant State agencies, particularly given the increasing role of regional planning panels and referrals of development applications to State agencies, such as the New South Wales Office of Water and the New South Wales Rural Fire Service. In practice, however, broad-reaching notification is a time-intensive and expensive process. A more efficient mechanism may be for a council to rely on community support for the protection of its environmental assets through its strategic planning process and associated consultation. This is most relevant in the development of a council's community strategic plan as required by the *Local Government Amendment (Planning and Reporting) Act 2009* (NSW), s 402.[85]

*4. Whether the policy contains significant flaws*

Councils should acknowledge any supporting research as well as assumptions or gaps in the scientific and policy process that have led to the development of controls and assessment protocols. A great deal of research is still required in order to understand how the design, spatial organisation and management of urban green spaces such as riparian corridors contribute to the ecological functioning of urban systems and the ecological services they provide.[86] At present there is a paucity of data on the ecological responses of riparian systems to planning policies such as the setting of minimum riparian corridor widths or the responses of stream ecosystems to integrated water management at the catchment scale. However, in the absence of local empirical evidence, local-based catchment understanding and research undertaken in other localities can be used to support and prioritise the major objectives considered to be important when restoring the health of urban streams. Further, such knowledge can help translate these objectives into planning and development controls, and inform engineering design and retrofitting works. The translocation of knowledge from wider geographic areas has been used previously to inform court decisions to support decision-making in relation to bushland reserves, riparian setbacks and rivers and its application is supported in the absence of local datasets.[87]

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85 UDIA, n 68.

86 For example, Ku-ring-gai Council's Riparian Policy (n 65) and subsequent inclusion into DCP 47 was cited in *Murlan Consulting Pty Ltd v Ku-ring-gai Council and John Williams Neighbourhood Group Inc* [2007] NSWLEC 374.

87 New South Wales Government, *Sustaining the Catchments – the Regional Plan for the Drinking Water Catchment of Sydney and Adjacent Regional Centres, Neutral or Beneficial Effect on Water Quality Assessment Guidelines* (Sydney Catchment Authority, 2006).

## *Identification of important urban riparian areas*

The management of urban streams and riparian zones at the local scale is ordinarily delegated to local government under s 36M of the *Local Government Act 1993* (NSW). This should typically be informed by broader catchment mapping undertaken by regional bodies, such as catchment management authorities.[88] However, in order to achieve effective and targeted management outcomes, it would be helpful if the following were to take place:

(i) provide a consistent approach and method to identify specific areas of concern;

(ii) establish how the management of riparian systems relates to the overriding planning controls, such as LEPs; and

(iii) develop a consistent biophysical method for the assessment of condition of urban streams and their change over time.

Examples of such an approach could follow the method used by Wollongong City Council[89] and Ku-ring-gai Council[90] in the development of riparian policies to inform land-use controls within relevant development control policies. Such an approach would be strengthened if they were given concurrent approval and support by the two most immediately relevant government authorities: the New South Wales Office of Water, and the relevant catchment management authorities. An agreed method would allow consent authorities (including councils) to map and document the location of river, watercourse and the extent of the protected riparian zone. This would have the benefit of reducing or eliminating unnecessary and costly challenges as to the validity of the presence of a river and its associated riparian setbacks.

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88 A detailed outline of the purpose, elements and implementation of the community strategic plan can be found in New South Wales Government, *Planning and Reporting Guidelines for Local Government in NSW* (Division of Local Government, Department of Premier and Cabinet, 2010). Also refer to the New South Wales Government, *Guidelines on Integrated Planning and Reporting* (Division of Local Government, Department of Premier and Cabinet, 2010), http://www.dlg.nsw.gov.au/dlg/dlghome/Documents/Information/IPRGuidelines January2010.pdf viewed 16 May 2011.

89 James P, Tzoulas K, Adams MD, Barber A, Box J, Breuste J, Elmqvist T, Frith M, Gordon C, Greening KL, Handley J, Haworth S, Kazmierczak E, Johnston M, Korpela K, Moretti M, Niemelä J, Pauleit S, Roe MH, Sadler JP and Ward Thompson C, "Towards an Integrated Understanding of Green Space in the European Built Environment" (2009) 8 *Urban Forestry and Urban Greening* 65.

90 See *Gerroa Environment Protection Society Inc v Minister for Planning and Cleary Bros (Bombo) Pty Ltd* [2008] NSWLEC 173; *O'Keefe v Water Administration Ministerial Corporation* [2010] NSWLEC 9; *Murlan Consulting Pty Ltd v Ku-ring-gai Council and John Williams Neighbourhood Group Inc* [2007] NSWLEC 374.

### *Planning controls*

In developing long-term sustainable management of urban rivers and riparian zones, policy objectives need to respond to immediate and cumulative impacts of land-use. There is a need to draw on contemporary knowledge and understanding of the causative factors influencing urban stream syndrome.[91] Controls that set quantifiable standards, such as a percentage reduction in nutrients or the maximum rate of stormwater discharged from a property, should reflect the proposed land-use and the present condition and future assimilative capacity of the receiving environments. This has been introduced, albeit tentatively, in Victoria and South East Queensland. In 2006, the Victorian planning system was amended to require certain types of development to achieve minimum pollution reduction standards that respond to the current condition and desired outcomes for Port Phillip Bay. South East Queensland has gone even further by requiring developments to achieve similar pollution reduction standards in addition to managing impacts on the geomorphology and hydrology of local waterways across various design storms.[92] This approach has been further supported by the Queensland government through amendment of the *Sustainable Planning Act 2009* (Qld). This Act requires certain types of development to comply with State Planning Policy 4/10 Healthy Waters,[93] which is designed to protect environmental values as prescribed in the Environmental Protection (Water) Policy 2009.[94] Presently neither of these approaches (Victorian or Queensland) relates to all development types. Consequently the majority of development applications that relate to alternations and additions and single dwellings are not subject to these new standards.

In order to help achieve the objectives of ecologically sustainable development as well meeting the Objects (s 3) and Principles (s 5) of the WM Act, quantifiable controls should be recommended to be legislated as part of the land-use planning and development approval process. A holistic and integrated set of controls should include the following as a minimum:

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91 One example of this is Australian Government, *Guide to Riparian Management* (Hunter Central Rivers Catchment Management Authority, 2009), http://www.hcr.cma.nsw.gov.au/uploads/res/WLMW_CentralCoast.pdf viewed 16 May 2011.

92 New South Wales Government, *Riparian Corridor Management Study Covering all of the Wollongong Local Government Area and Calderwood Valley in the Shell Harbour Local Government Area* (report prepared for Wollongong City Council by the Department of Infrastructure, Planning and Natural Resources, 2004).

93 Ku-ring-gai Council, n 65; Ku-ring-gai Council, *Ku-ring-gai Development Control Plan (Town Centres)* (2010). http://www.kmc.nsw.gov.au/www/html/3831-ku-ring-gai-development-control-plan-town-centres-2010.asp?intSiteID=1 viewed 16 May 2011.

94 Meyer et al, n 1; Lawrence I and Breen PF, "Stormwater Pollutant Processes and Pathways" in Wong, n 28; Davies et al, n 9.

*1. Biology and riparian habitat*

Landscaping (type and density of vegetation) and setback controls (from a stream) could be applied to improve biological health and reduce the gradient of impact from developments immediately adjacent or near to riparian areas. The extent of the buffer width would be dependent on the river, current and future land-use and refer to the definition of riparian areas as discussed above.

*2. Hydrology and hydraulics*

The extent and application of urban water management controls should be informed by the hydrology and hydraulics of the receiving waterway. This would include spatial concerns such as the catchment area, cumulative impacts and the magnitude and frequency of rainfall-runoff relationships. As drainage networks and impervious areas increase, hydrologic and other impacts will result in greater deterioration of riparian systems. In this context, controls should be applied to the following: bed and bank stability; attenuating the energy from stormwater outlets; and managing the frequency and duration of bank-full conditions (through the use of onsite stormwater retention and detention).

*3. Water quality*

Standards associated with water quality have traditionally focused on nutrients (total phosphorus, total nitrogen), suspended sediments (turbidity), microbial composition (faecal coliforms, enterococcuss) and heavy metals (copper, lead and zinc).[95] This has led to standards that specifiy maximum concentrations or loads[96] or relate to a percentage reduction in site discharges.[97] These standards should continue to be applied and form part of the successful approach to the management of water pollution by licensed activities. However, other water quality parameters need to be introduced into this framework particularly for waterways that are sensitive to certain changes in water chemistry or may have a significant impact on riparian conditions (see above). Other sources of pollutants that lead to significant and deleterious changes to water chemistry that impact biological health should also be included. For example, recent research in the northern suburbs of Sydney

95 For example, the Victorian Environment Protection Policy (Waters of Victoria) was amended to include a requirement that that runoff from urban and rural areas must not compromise the identified beneficial uses of the receiving waters. Importantly, cl 56 of the Victorian Planning Provisions was amended in 2006 to incorporate integrated water management and urban runoff-management to require subdivision applications to describe how the site will be managed to minimise the environmental impacts, sets quantifiable targets and refers to a best practice guideline to achieve this outcome.

has demonstrated that concrete drainage systems (gutters and pipes) cause significant changes to pH and various anions and cations.[98] This is particularly relevant to streams that are naturally minerally poor or acidic.

*4. Continuity and removal of barriers*

Returning the continuity of a river by removing barriers and structures will assist in the movement of aquatic fauna and also reduce the subsequent impacts of erosion and deposition. Policy reform could consider a requirement for the restoration of targeted reaches of waterways, day lighting of pipes (where they present a barrier for fauna and flora) and replacement of traditional concrete channels with more environmentally-appropriate solutions. Where further piping of watercourses is sought, a review could be undertaken by an external authority such as the New South Wales Office of Water to provide an independent assessment and also offer alternative solutions. Exceptional circumstances would need to be incorporated within such a policy to ensure the safety of life and property.

***Development contributions***

Changes made by the New South Wales Department of Planning to the development contributions provisions[99] in 2009 mean that councils and other authorities are no longer able to require financial contributions for the public acquisition of riparian corridors where these acquisitions serve only an environmental function. This decision appears to have been made on economic rather than environmental grounds and conflicts with the objectives and principles laid down in numerous State and local government environmental legislative[100]

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96 Queensland Government, *South East Queensland Regional Plan 2009-2031 Implementation Guideline No 7 Water Sensitive Urban Design: Design Objectives for Urban Stormwater Management* (Department of Infrastructure and Planning, 2009), http://www.dip.qld.gov.au/resources/guideline/final-wsud-guideline-pdf-11-11-09.pdf viewed 16 May 2011.

97 Queensland Government, *State Planning Policy 4/10 Health Waters* (Department of Environment and Resource Management, 2010), http://www.derm.qld.gov.au/environmental_management/water/environmental_values_environmental_protection_water_policy/pdf/spp-healthy-waters.pdf viewed 16 May 2011.

98 Queensland Government, *Environmental Protection (Waters) Policy 2009* (amended 16 July 2010), http://www.legislation.qld.gov.au/LEGISLTN/CURRENT/E/EnvProWateP09.pdf viewed 16 May 2011. Eg Australian and New Zealand Environmental and Conservation Council and Agricultural and Resource Management Council of Australia and New Zealand (ANZECC), *National Water Quality Management Strategy: The Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (Department of the Environment and Heritage, Australian Government, 2000) Paper No 4, Vol 1, Chs 3, 4.

100 For example, the control of erosion and sediment control is incorporated as part of the development and construction guidelines in Landcom, *The Blue Book – Managing Urban Stormwater: Soils and Construction* (Landcom, 2010). Eg Ku-ring-gai Council, n 93, Pt 5, s 5F.

and policy documents.[101] The Department of Planning argued that the consequence of leveraging contributions for riparian lands has been to "drastically increase the costs of contributions and to artificially inflate the value of these lands even though they have little development potential".[102] This change excludes riparian lands from being recognised as key community infrastructure,[103] creating an arbitrary and detrimental differentiation between riparian corridors on the one hand and open-space lands used for stormwater drainage infrastructure on the other.[104]

The Department of Planning *Draft Development Contributions Guidelines* are relevant to the discussion on how and why riparian areas need to be protected. The guidelines define a riparian corridor for the purpose of development contributions as "a corridor that includes a buffer to protect the existing bed and banks of a water course without any engineering (overt or otherwise) to manage water flows or environmental quality".[105] The guidelines (at s 2.3.4) assume that other planning tools such as biobanking may be used to protect and enhance such land. This assumption is based on a further assumption that riparian zones have sufficient environmental and/or ecological significance for the biobanking[106] provisions to apply. Currently, the biobanking provisions are restricted to areas containing endangered plants, animals and ecosystems; they do not specifically include urban riparian areas. This effectively removes the ability for councils to acquire riparian lands for strategic environmental purposes as part of the planning and development process. The authors believe that balancing the impacts of development on urban waterways by protecting riparian zones is a valid and effective environmental planning and management mechanism. Restricting access to s 94 financial contributions breaks the nexus between the impacts of development and environmental sustainability. By implication, the Department of Planning guidelines suggest the biobanking legislation is the appropriate mechanism to protect ecologically-valuable riparian areas. As described above, most urban riparian areas would not qualify for protection under this framework. The Department's approach, therefore, fails

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101 Davies PJ, Wright IA, Findlay SJ and Jonasson OJ, *The Effect of the In-Transport Process on Urban Water Chemistry – an Examination of the Contribution of Concrete Pipes and Gutters on Urban Water Quality* (7th International Conference on Sustainable Techniques and Strategies in Urban Water Management, Lyon, France, 28 July-1 June 2010).

102 *Environmental Planning and Assessment Act 1979* (NSW), s 94.

103 Eg *Local Government Act 1993* (NSW), s 8.

104 New South Wales Government, *The State Plan* (2010) Ch 5 "Green State", http://nsw.gov.au/sites/default/files/pdfs/chapters/5.%20Green%20State_WEB.pdf viewed 16 May 2011.

105 New South Wales Government, *Draft Development Contributions Guidelines: Preparation and Administration of Development Contributions Plans* (Department of Planning, 2009) p 18, http://www.planning.nsw.gov.au/LinkClick.aspx?fileticket=5OjXuNg3DlQ%3d&tabid=386 viewed 9 March 2011.

106 *Environmental Planning and Assessment Regulation 2000* (NSW), cl 31A(1)(g)

to recognise the multitude of environmental benefits that “degraded” urban riparian areas provide.[107] It also ignores the social amenity such areas provide for their local communities.

The Department of Planning’s decision to exclude development contributions for the purchase of riparian areas has been criticised by both developers and local government (Urban Development Industry of Australia and Local Government and Shires Association).[108] Both these groups support public ownership and management of riparian lands, recognising their important environmental functions and acknowledging the need for better management and coordination.

## Conclusions

This article contends there is a pressing need to revise the legislative definition of rivers as well as to provide statutory guidance on how to establish their bona fide existence, particularly in the upper reaches of a system and where channel development is poor. There is also a need to establish a clear and consistent definition for what is a riparian zone within relevant New South Wales legislation and policy. These definitions need to reflect contemporary decisions of the LEC as well as current scientific understanding and knowledge of environmental process. This is particularly relevant to urban environments that are the focus of significant development pressure, which place major stress on the few remaining natural remnant riparian systems. The authors propose that a river be redefined as:

> Any stream of water, whether perennial, intermittent or ephemeral, flowing in a natural or artificially improved channel or in an artificial channel that has changed in the course of the stream of water, and any other stream of water into or from which the stream of water flows.

This new definition would recognise the many streams that have ephemeral flow (currently excluded) and the innumerable other smaller streams and watercourses modified or natural, whose flow, irrespective of permanency, contributes to a downstream waterbody.

The recommendation is for a riparian area to be defined as:

> The area of land adjacent to a water body showing visible signs of inundation, geomorphic reworking by fluvial processes; or, occupied by organisms that require environmental conditions provided by a river processes for all or part of their life cycle.

107 New South Wales Government, n 106, s 2.2.3.
108 New South Wales Government, n 106, s 2.3.4.

This definition turns on the definition of a river, as above, and recognises – from an urban perspective – the lateral and longitudinal extent of a river by virtue of its physical, chemical and biological contribution to riparian biodiversity.

While such amendments would be a valuable improvement to the current legislative framework, significant concurrent reform to the policy frameworks that support sound riparian management is also recommended. Included in any such reform should be a review of the relevant planning and policy objectives across all levels of government to ensure consistency, compatibility and recognition of the geographic scale of influence of river systems and their riparian environment (national to local level). In order to achieve maximum effect, LEPs should be able to incorporate riparian areas across the whole urban landscape and not just within new development areas. In providing details to LEPs, DCPs and supporting controls should be formulated and applied using a consistent framework and method that reflect legislative objectives for waterway and catchment management. In revising the approach to river and riparian systems, it is imperative to build in opportunities for flexibility and revisions to the controls (ie adaptive legislation) if and when there is new scientific evidence supporting a shift in approach. Finally, local government should be able to access s 94 development contributions for the public acquisition of riparian corridors, especially in cases where they provide identifiable environmental assets beyond a simple function as a drainage corridor.

The current ad hoc, out-dated and non-evidenced-based approach towards our urban and riparian environments is not aligned with the objects and principles of several statutory environmental instruments. Nor do the current approaches support the current thinking and drive toward water sensitive cities. Maintaining the status quo will only perpetuate the demise of river environments via “death by a thousand pipes” and stymie the development of appropriate legal responses and best practice policy informed by contemporary science.

paper two

# Development and application of a rapid assessment tool for urban stream networks

Authors: Findlay S J, Taylor M P, Davies P J and Fletcher A

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**Pages 126-135 of this thesis have been removed as they contain published material under copyright. Removed contents published as:**

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# New directions in urban biodiversity conservation: the role of science and its interaction with local environmental policy

Authors: Ives C D, Taylor M P, Nipperess D A and Davies P J

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paper three

# New directions in urban biodiversity conservation: The role of science and its interaction with local environmental policy

**Christopher D Ives, Mark Patrick Taylor, David A Nipperess and Peter Davies***

*The conservation of biodiversity is a well-established principle of ecologically sustainable development and is an integral part of environmental policy and legislation in Australia. How the concept of biodiversity as understood by scientists and policy makers is reflected in environmental planning instruments and law and managed at various scales is another matter entirely. This article contends that if strategies are to be effective in reducing the dramatic decline in biological diversity, they must be founded upon clear, holistic and workable concepts of biodiversity that are grounded in science and positioned within a spatial hierarchy. For urban areas that rely greatly on local government policy, practice and regulation to manage natural assets, more effective utilisation of scientific knowledge about a range of biodiversity attributes at local and regional scales is needed. This will enable local government authorities to plan strategically for biodiversity across all land uses and multiple scales, thus minimising the loss of bushland and mitigating against ecological impacts resulting from increased development pressure. However, this article argues that this will only be realised through the establishment of planning policies and management strategies with meaningful and achievable conservation goals, integration of regional conservation priorities, and consideration of community values and economic and socio-political connections.*

## INTRODUCTION

Biodiversity has become a key theme of environmental policy in Australia, attributable largely to the adoption of ecologically sustainable development (ESD) principles across all levels of government. However, the diversity and long-term viability of species, communities and ecosystems continues to be in serious decline across many parts of Australia.[1] Urbanisation is one of the major drivers of biodiversity loss worldwide, precipitating the loss and modification of vegetation, invasion of exotic species, and the disruption of ecological processes and cycles.[2] Anticipated global population growth in urban areas of 3.1 billion by 2050[3] will exacerbate the ecological impacts both within and outside

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[1] Beeton RJS (Bob), Buckley KI, Jones GJ, Morgan D, Reichelt RE and Trewin D (2006 Australian State of the Environment Committee), *Australia State of the Environment 2006* (independent report to the Minister for the Environment and Heritage, Australian Government, 2006), http://www.environment.gov.au/soe/2006/publications/report/index.html viewed 31 May 2010.

[2] Niemela J, "Ecology and Urban Planning" (1999) 8 *Biodiversity and Conservation* 119; McKinney ML, "Urbanization, Biodiversity and Conservation" (2002) 52 *Bioscience* 883; McKinney ML, "Urbanization as a Major Cause of Biotic Homogenisation" (2006) 127 *Biological Conservation* 247.

[3] United Nations, *World Urbanization Prospects: The 2007 Revision* (United Nations Department of Economic and Social Affairs – Population Division, 2008), http://www.un.org/esa/population/publications/wup2007/2007WUP_Highlights_web.pdf viewed 31 May 2010.

of the urban core via lower density suburban sprawl.[4] Additionally, urban population growth will enlarge the ecological footprint of cities, increasing the demands placed on remote ecological systems to provide the food, energy and resources to support urban populations.[5] Urbanisation can therefore be considered as one of the most pressing threats to biodiversity.[6]

Australia's biodiversity is especially threatened by urbanisation due to the nation's recent colonisation and highly-urbanised population.[7] Urban development has been most intense along the biologically-rich coastline, with almost one quarter of original native forests and woodland lost and the remainder under increasing threat.[8] If current trends continue, it is estimated that 42.3% of the coastline between Nowra and Noosa will be urbanised by 2050.[9] Habitat loss and transformation associated with urbanisation has contributed to the recorded extinction of 116 native plants and animals since European settlement,[10] due in part to Australia's high species endemism (˜80%) and localised species distributions. Indeed, urban and residential development threatens over half of the 88 endangered ecological communities listed in New South Wales.

Science, in principle, generates knowledge that is objective, evidence-based and internally validated, and as such has a pivotal role in informing environmental policies that seek to curb the impacts of urbanisation on biodiversity. Unfortunately, a disconnection between the scientific study of biodiversity and environmental planning policy has left decision-makers without appropriate knowledge or tools to manage and protect urban biodiversity effectively. This often results in poorly-informed and unsubstantiated strategies.[11] The dynamic integration of appropriate scientific knowledge into policies that achieve both ecological sustainability and effective urban planning outcomes remains a central challenge for local governments in Australia today.

In Australia, local governments are in a strong position to combat biodiversity loss in urban areas because they can assess and respond to pressures at the local scale.[12] They are often the consent authority for development applications and can set policy within their planning instruments. However, direction in how to translate large-scale conservation goals into policies at the local scale is often lacking. It is imperative therefore that the goals set, assessments performed and the management strategies enacted by councils reflect locally-significant biodiversity values in the context of wider conservation priorities. These should be grounded within a solid and comprehensive scientific understanding of the concept of biodiversity that encompasses the breadth and complexity of biological components and how they are arranged and interact across multiple spatial scales.[13]

This article explores the interactions within and between the scientific understanding of biodiversity and conservation as a policy response. While focusing on New South Wales, the issues

[4] Marzluff JM, "Fringe Conservation: A Call to Action" (2002) 16(5) *Conservation Biology* 1175.

[5] McGranahan G and Marcotullio P (coordinating lead authors), "Urban Systems" in *The Millennium Ecosystem Assessment* (2005), http://www.millenniumassessment.org/documents/document.296.aspx.pdf viewed 31 May 2010.

[6] McKinney, n 2; Beatley T, "Preserving Biodiversity: Challenges for Planners" (2000) 66 *Journal of the American Planning Association* 5.

[7] 88% of Australians are known to be residing in cities or urban landscapes: United Nations, *Urban Population, Development and the Environment 2007* (United Nations Department of Economic and Social Affairs – Population Division, 2008), http://www.un.org/esa/population/publications/2007_PopDevt/Urban_2007.pdf viewed 31 May 2010.

[8] Beeton et al, n 1.

[9] Beeton et al, n 1.

[10] Beeton et al, n 1.

[11] For a good overview of the role of science in formulating effective environmental policy, see McNie EC, "Reconciling the Supply of Scientific Information with User Demands: An Analysis of the Problem and Review of the Literature" (2007) 10 *Environmental Science and Policy* 17.

[12] Beatley, n 6; Theobald DM, Hobbs NT, Bearly T, Zack JA, Shenk T and Riebsame WE, "Incorporating Biological Information in Local Land-use Decision Making: Designing a System for Conservation Planning" (2000) 15 *Landscape Ecology* 35; Marzluff, n 4; Miller JR, Groom M, Hess GR, Stokes DL, Steelman TA, Thomson J, Bowman T, Fricke L, King B and Marquadt R, "Biodiversity Conservation in Local Planning" (2009) 23 *Conservation Biology* 53.

[13] Compare Savard JL, Clergeau P and Mennechez G, "Biodiversity Concepts and Urban Ecosystems" (2000) 48 *Landscape and Urban Planning* 131.

explored are to a large degree generic and as a result will have wider application to other jurisdictions. First, the term "biodiversity" as presented in the scientific literature is reviewed and placed into a holistic and integrated framework for understanding biodiversity and its measurement. Secondly, the extent to which the scientific understanding of biodiversity is represented within current environmental policy at all three levels of government in Australia is considered. Thirdly, the roles and interactions between scientific theory, scientific data and community values within the dynamics of local environmental policy are examined. These are discussed in relation to how a comprehensive understanding of biodiversity can help establish a more enlightened approach to urban biodiversity management, resulting in enhanced biodiversity outcomes. Finally, drawing from local and international examples, recommendations are made as to how a revised understanding of biodiversity can be applied to Australian local environmental planning policy and management to achieve improved biodiversity outcomes.

## THE SCIENCE OF BIODIVERSITY

The term "biodiversity" emerged over two decades ago, coined by Lovejoy in 1980.[14] The term is linked to the discipline of conservation biology, which arose from a recognition of anthropogenic environmental impacts and the desire of ecologists to make their knowledge more relevant to the legal and political arena.[15] Since this time "biodiversity" has become somewhat of a buzzword in both scientific literature and general society.[16]

Biodiversity is a broad, holistic concept.[17] In its literal sense it encompasses the variety of all forms of life, and is often associated with concepts such as "nature" and "wilderness".[18] The term therefore requires clear definition if it is to be applied meaningfully to policies and legislative instruments, particularly those relating to highly-modified urban environments.

### Defining biodiversity

A commonly-cited working definition of biological diversity is found in the *United Nations Convention on Biological Diversity* (UN Convention):

> [T]he variability among living organisms from all sources…and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems.[19]

There have been numerous scientific definitions of biodiversity, the majority of which seek to divide the term into discrete components according to hierarchy and scale concepts.[20] A useful framework for understanding relationships between the different scales at which biological diversity exists was

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[14] Lovejoy TE, "Changes in Biological Diversity" in Barney GO (ed), *The Global 2000 Report to the President* (vol 2 – "The Technical Report", 1980) pp 327-332.

[15] Soulé M, "Conservation Biology and the Real World" in Soulé M (ed), *Conservation Biology: The Science of Scarcity and Diversity* (Sinauer Associates, 1986) pp 1-12; McCoy ED, "Advocacy as Part of Conservation Biology" (1996) 10 *Conservation Biology* 919; Dawson F, "Analysing the Goals of Biodiversity Conservation: Scientific, Policy and Legal Perspectives" (2004) 21 EPLJ 6.

[16] Wilson EO, "The Current State of Biological Diversity" in Wilson EO and Peter FM (eds), *Biodiversity* (National Academy Press, 1988) pp 3-18; Beattie A (ed), *Australia's Biodiversity: Living Wealth* (Reed Books, 1995); Perlman DL and Adelson G, *Biodiversity* (Blackwell Publishing, 1997); Healey J (ed), *Australia's Biodiversity* (Spinney Press, 2007).

[17] Adam P, "Biodiversity – The Biggest of Big Pictures" in Lunney D, Dawson T and Dickman CR (eds), *Is the Biodiversity Tail Wagging the Zoological Dog?* (The Royal Zoological Society of New South Wales, 1998).

[18] Dawson, n 15 at 7.

[19] United Nations, *Convention on Biological Diversity*, concluded at Rio de Janeiro on 5 June 1992 (United Nations Environment Programme, 1992) p 146, http://www.cbd.int/doc/legal/cbd-un-en.pdf viewed 31 May 2010.

[20] For example, Soulé M, "Conservation Tactics for a Constant Crisis" (1991) 253(5021) *Science* 744; Harper JL and Hawksworth DL, "Preface" in Hawksworth DL (ed), *Biodiversity: Measurement and Estimation* (Chapman & Hall, 1995) pp 5-12; di Castri F and Younes T, "Introduction: Biodiversity, the Emergence of a New Scientific Field – Its Perspectives and Constraints" in di Castri F and Younes T (eds), *Biodiversity, Science and Development, Towards a New Partnership* (CAB International, 1996) p 1; Gering JC, Crist TO and Veech JA, "Additive Partitioning of Species Diversity across Multiple Spatial Scales: Implications for Regional Conservation of Biodiversity" (2003) 17 *Conservation Biology* 488.

introduced by Whittaker.[21] Whittaker categorised species diversity into inventory diversity (the diversity of a set geographical area) and differentiation diversity (the compositional change between areas). Each of these concepts can be assessed at different scales with corresponding terms for each category. Inventory diversity consists of:

(i) *point diversity*: the diversity of a single sample;
(ii) *alpha (α) diversity*: the diversity of a defined habitat;[22]
(iii) *gamma (γ) diversity*: the diversity of a landscape; and
(iv) *epsilon (ε) diversity*: the diversity of an ecoregion.

Corresponding categories exist for differentiation diversity such as *pattern diversity* (the variation between samples within a habitat) and *beta (β) diversity* (the variation between habitats). While these terms are found commonly in the scientific literature, they imply no specific spatial boundaries since these may vary significantly between taxa[23] and also between habitat settings. Indeed, the terms "alpha" and "beta" diversity often refer to inventory and differentiation diversity at any scale.[24]

Noss[25] added a further dimension to the biodiversity concept, characterising it according to three primary attributes: composition, structure and function. These can be assessed within each level of organisation as previously mentioned and are defined as follows:

> Composition has to do with the identity and variety of elements in a collection, and includes species lists and measures of species diversity and genetic diversity.
>
> Structure is the physical organization or pattern of a system, from habitat complexity as measured within communities to the pattern of patches and other elements at a landscape.
>
> Function involves ecological and evolutionary processes, including gene flow, disturbances, and nutrient cycling.[26]

Notwithstanding the compartmentalisation of biodiversity discussed above, the authors acknowledge that this is a purely conceptual exercise, and each component of biodiversity should not be considered in isolation since all aspects are interconnected and influential parts of a dynamic complex.

## Biodiversity measurement and assessment

For biodiversity to have meaning within a policy setting, there needs to be agreement as to its scope and extent within a scientific construct. That is, what can be measured and monitored, and how this information can be analysed and then presented to inform decision-makers. This process of biodiversity measurement and assessment must address issues of scale: spatially, in terms of identifying appropriate attributes of biodiversity; and temporally, in terms of providing feedback within an adaptive management approach.[27] Conceptually, the large and multidimensional nature of biodiversity cannot be assessed readily by a single technique or model. A measure of some part of biodiversity (eg species richness of vascular plants) should be presented as such, and cannot constitute a complete assessment of the biodiversity of an area.[28] To obtain a comprehensive description of the biodiversity of an area of interest, a range of compositional, structural and functional components

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[21] Whittaker RH, "Vegetation of the Siskiyou Mountains, Oregon and California" (1960) 30 *Ecological Monographs* 279; Whittaker RH, "Evolution and Measurement of Species Diversity" (1972) 21 *Taxon* 213.

[22] Compare Magurran AE, *Measuring Biological Diversity* (Blackwell, 2004).

[23] Whittaker RH, "Scale and Species Richness: Towards a General, Hierarchical Theory of Species Diversity" (2001) 28 *Journal of Biogeography* 453.

[24] An applied example of this can be found in Gering et al, n 20, in which the terms "alpha" and "beta" diversity were applied to biodiversity patterns across local and regional scales.

[25] Noss R, "Indicators for Monitoring Biodiversity: A Hierarchical Approach" (1990) 4 *Conservation Biology* 355.

[26] Noss, n 25 at 356-357.

[27] Walters CJ and Holling CS, "Large-scale Management Experiments and Learning by Doing" (1990) 71 *Ecology* 2060; Lee KN, "Appraising Adaptive Management" (1999) 3 *Conservation Ecology* (online), http://www.consecol.org/vol3/iss2/art3 viewed 31 May 2010.

[28] Adam P, "Ecological Communities – The Context for Biodiversity Conservation or a Source of Confusion?" (2009) 13 *Australasian Journal of Natural Resources Law and Policy* 7.

should be assessed across a range of scales.[29] A summary of the different facets of biodiversity and the practical methods of their assessment is provided in Table 1.

**TABLE 1 A framework for conceptualising biodiversity across multiple spatial scales and components**

For each component (ie composition, structure or function) operating at a particular scale, examples of scientific concepts (properties) and possible assessment techniques are listed. For further information about listed concepts or techniques, please refer to the references cited.

| SCALE | COMPOSITION | | STRUCTURE | | FUNCTION | |
|---|---|---|---|---|---|---|
| | **Property** | **Techniques** | **Property** | **Techniques** | **Property** | **Techniques** |
| **Sample** | • Point richness | • Species richness (S)<br>• Sampling curves[a] | • Evenness | • Numerical indices[b]<br>• Species Abundance Models[c] | • Functional diversity[d] | • Number of guilds[e] |
| **Habitat** | • Habitat richness (α diversity) | • Species richness (S)<br>• Sampling curves<br>• Richness estimators[f] | • Biotic hetero-geneity of habitat (pattern diversity) | • β diversity indices[g]<br>• Resemblance indices[h]<br>• Ordination[i] | • Ecological resilience<br>• Functional diversity | • Monitoring of populations<br>• Time series analysis[j] |
| **Landscape** | • Landscape richness (γ diversity) | • Species richness (S)<br>• Ecological community richness | • Complementarity/ Irreplaceability (β diversity) | • Ordination of habitats<br>• Conservation planning techniques and algorithms[k]<br>• Generalised Dissimilarity Models (GDMs)[l] | • Connectivity<br>• Permeability<br>• Functional diversity | • Source/Sink population analysis |

[a] Gotelli NJ and Colwell RK, "Quantifying Biodiversity: Procedures and Pitfalls in the Measurement and Comparison of Species Richness" (2001) 4 *Ecology Letters* 379. For sample scale, use rarefaction by individuals rather than samples.

[b] For example, Shannon evenness (J'): Pielou EC, *Ecological Diversity* (Wiley, 1975).

[c] Magurran, n 22, Ch 2

[d] Petchey OL and Gaston KJ, "Functional Diversity: Back to Basics and Looking Forward" (2006) 9 *Ecology Letters* 741.

[e] For example, for ant functional groups, see Andersen AN, "A Classification of Australian Ant Communities, Based on Functional Groups which Parallel Plant Life-forms in Relation to Stress and Disturbance" (1995) 22(1) *Journal of Biogeography* 15; and for avian and mammalian guilds, see Croonquist MJ and Brooks RP, "Use of Avian and Mammalian Guilds as Indicators of Cumulative Impacts in Riparian-wetland Areas" (1991) 15(5) *Environmental Management* 701.

[f] EstimateS free software: Colwell RK (Department of Ecology and Evolutionary Biology, University of Connecticut, 2009), http://viceroy.eeb.uconn.edu/estimates viewed 31 May 2010.

[g] See Magurran, n 22, Ch 6.

[h] Magurran, n 22, Ch 6.

[i] A good practical summary of these techniques can be found in Clarke KR and Warwick RM, *Change in Marine Communities: An Approach to Statistical Analysis and Interpretation* (2nd ed, Plymouth Marine Laboratory, 2001).

[j] See Bjørnstad ON and Grenfell BT, "Noisy Clockwork: Time Series Analysis of Population Fluctuations in Animals" (2001) 293(5530) *Science* 638.

[k] Margules CR and Pressey RL, "Systematic Conservation Planning" (2000) 405 *Nature* 243.

[l] Ferrier S, Manion G, Elith J and Richardson K, "Using Generalized Dissimilarity Modelling to Analyse and Predict Patterns of Beta Diversity in Regional Biodiversity Assessment" (2007) 13 *Diversity and Distributions* 252.

[m] Hanski I, "Metapopulation Dynamics" (1998) 396 *Nature* 41.

[29] Noss, n 25; Purvis A and Hector A, "Getting the Measure of Biodiversity" (2000) 405 *Nature* 212; Linke S and Norris R, "Biodiversity: Bridging the Gap between Condition and Conservation" (2003) 500 *Hydrobiologia* 203-211.

## BIODIVERSITY CONSERVATION APPROACHES IN AUSTRALIA

### Ecologically sustainable development

Conservation and development in Australia is guided by the overarching philosophy of ecologically sustainable development. ESD was introduced as Australia's response to Agenda 21,[30] the international plan of action for sustainable development, which was revealed at the 1992 Rio de Janeiro United Nations Earth Summit. ESD was adopted officially in Australia in 1992 with the release of the *National Strategy for Ecologically Sustainable Development* (NSESD).[31] Australia has positioned its definition of sustainability distinctly with a natural environment focus. Indeed, one of the three core objectives of the NSESD is "to protect biological diversity and maintain essential ecological processes and life-support systems".[32] In 1996, the Australian and New Zealand Environment and Conservation Council (ANZECC) released the *National Strategy for the Conservation of Australia's Biological Diversity* (NSCABD)[33] to outline how this objective could be achieved in line with Australia's ratification of the UN Convention. Article 7 of the UN Convention states that "each contracting party shall: identify components of biological diversity important for its conservation and sustainable use". Within the NSCABD, Australia has identified biological diversity as occurring at three levels:

(i) *Genetic diversity* – the variety of genetic information contained in all of the individual plants, animals and microorganisms that inhabit the earth. Genetic diversity occurs within and between the populations of organisms that comprise individual species as well as among species.
(ii) *Species diversity* – the variety of species on the earth.
(iii) *Ecosystem diversity* – the variety of habitats, biotic communities and ecological processes.

It is clear from the goals of ESD and the associated biodiversity strategies that Australia is committed to conserving biodiversity in a holistic sense, comparable with how the term is understood by the scientific community. The translation of this into environmental policy and legislation is explored below.

### Australian national and New South Wales State conservation approaches

The degree to which ESD is pursued in Australia depends upon policies developed at federal, State and local levels of government. At the federal level, the primary legislative instrument concerned with the conservation of biological diversity is the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act). The Act defines biological diversity in a similar manner to the UN Convention. It lists components of biodiversity as including "species, habitats, ecological communities, genes, ecosystems and ecological processes" (s 171(c)). In New South Wales, the primary piece of legislation designed to address issues of biodiversity conservation is the *Threatened Species Conservation Act 1995* (NSW) (TSC Act), although protection for certain aquatic organisms may also fall under the *Fisheries Management Act 1994* (NSW). The TSC Act identifies three components that comprise biodiversity: genetic diversity, species diversity and ecosystem diversity (s 4(1)). Although both Acts seek to conserve biodiversity in a broad sense, in practice they adopt a much narrower focus, primarily protecting threatened species, populations and ecological communities.[34] While this approach is not without merit, threatened species, populations or ecological

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[30] United Nations, *Agenda 21: Earth Summit – The United Nations Programme of Action from Rio* (United Nations Division for Sustainable Development, 1992), http://www.un.org/esa/sustdev/documents/agenda21/english/agenda21toc.htm viewed 31 May 2010.

[31] Ecologically Sustainable Development Steering Committee, *National Strategy for Ecologically Sustainable Development* (Department of the Environment, Sport and Territories, Australian Government, 1992), http://www.environment.gov.au/esd/national/nsesd/strategy/intro.html viewed 31 May 2010 (NSESD).

[32] NSESD, n 31, Pt 1.

[33] Australian and New Zealand Environment and Conservation Council (ANZECC), *National Strategy for the Conservation of Australia's Biological Diversity* (Department of the Environment, Water, Heritage and the Arts, Australian Government, 1996), http://www.environment.gov.au/biodiversity/publications/strategy/index.html viewed 31 May 2010.

[34] Adam, n 28; Riddell G, "A Crumbling Wall: The Threatened Species Conservation Act 10 Years On" (2005) 22 EPLJ 446.

communities do not encompass all of "the variability among living organisms from all sources" as expressed in the UN Convention. The fact that these entities are only afforded protection after their long-term persistence has reached critical/endangered status indicates a reactionary approach to conservation, which does little to keep species *off* threatened species lists.[35] This is fundamentally in conflict with the precautionary principle listed as a core element of ESD in the NSESD.[36]

The New South Wales principal piece of planning legislation – the *Environmental Planning and Assessment Act 1979* (NSW) (EPA Act) – reflects the crisis management approach of the EPBC Act and the TSC Act. The Act requires that a seven-part test be undertaken to determine whether a proposed development action will impact adversely upon the population or habitat of any species at risk of extinction (EPA Act, s 5A). Of even greater concern for biodiversity are the recent amendments to Pt 3A of the EPA Act, which have enabled the Minister for Planning to override this requirement in cases deemed to be of State significance.[37]

Conservation approaches focusing on endangered species have been favoured traditionally because species loss is relatively easy to observe, evokes emotional responses in people and allows management actions to be easily monitored and evaluated for effectiveness.[38] Nevertheless, despite hundreds of species being afforded enforceable legal protection in Australia, the number of species and ecological communities on threatened species lists continues to rise.[39] The species approach to conservation such as that embedded within the EPBC Act and the New South Wales TSC Act has therefore been criticised as a reactive "emergency-room" strategy that is unable to keep up with the escalating biodiversity crisis.[40] This is because conservation dollars are directed toward species that are in most danger of extinction (perhaps irreversibly so), rather than focusing on habitats where the greatest ecological outcomes can be achieved.[41] Furthermore, endangered species are of limited use as biodiversity surrogates[42] and a single-species focus can bias conservation action towards well-studied, charismatic species while neglecting cryptic species or indeed the entire ecosystems they comprise.[43] This is of particular concern considering many species (especially invertebrates) are unknown to science[44] and therefore have not had their conservation status assessed.

Conservation approaches that encompass biodiversity values broader than the traditional species inventory approaches have begun to infiltrate legislation at the State level in New South Wales. For example, in addition to protecting individual species, the TSC Act seeks to protect endangered

[35] Riddell, n 34.

[36] Riddell, n 34; Kelly AH, "Biodiversity, the Planning System and Local Government: A Happy Trio?" in Lunney et al, n 17.

[37] Ratcliff I, Wood J and Higginson S, *Technocratic Decision-Making and the Loss of Community Participation Rights: Part 3A of the Environmental Planning and Assessment Act 1979* (Environmental Defenders Office (NSW), 2007), http://www.edo.org.au/edonsw/site/part3a_article.php viewed 31 May 2010.

[38] Tracy CR and Brussard PF, "Preserving Biodiversity: Species in Landscapes" (1994) 4 *Ecological Applications* 205; Toussaint Y, "Debating Biodiversity: Threatened Species Conservation and Scientific Values" (2005) 16 *The Australian Journal of Anthropology* 382; Simberloff D, "Flagships, Umbrellas, and Keystones: Is Single-species Management Passé in the Landscape Era?" (1998) 83 *Biological Conservation* 247.

[39] Department of the Environment, Water, Heritage and the Arts, *Indicator: BD-02 Conservation Status of Nationally Significant Species and Ecological Communities, Compared with Previous Years* (supplementary publication for State of the Environment 2006 Report, Australian Government, 2006), http://www.environment.gov.au/soe/2006/publications/drs/indicator/93/index.html viewed 31 May 2010.

[40] Franklin JF, "Preserving Biodiversity: Species, Ecosystems, or Landscapes?" (1993) 3 *Ecological Applications* 202; Sergio F, Pedrini P and Marchesi L, "Reconciling the Dichotomy between Single Species and Ecosystem Conservation: Black Kites (Milvus migrans) and Eutrophication in Pre-Alpine Lakes" (2003) 110 *Biological Conservation* 101; Beatley, n 6; Riddell, n 34.

[41] Possingham HP, "Ecological Triage" (2002) 27(5) *Nature Australia* 84.

[42] Possingham HP, Andelman SJ, Burgman MA, Medellín RA, Master LL and Keith DA, "Limits to the Use of Threatened Species Lists" (2002) 17 *Trends in Ecology and Evolution* 503.

[43] Riddell, n 34.

[44] Pimm SL, Russell GJ, Gittleman JL and Brooks TM, "The Future of Biodiversity" (1995) 269(5222) *Science* 347.

ecological communities against further fragmentation and degradation. However, identification of ecological communities and how they are dealt with in judicial proceedings has been plagued with uncertainty and complication.[45]

The *Native Vegetation Act 2003* (NSW), *Threatened Species Conservation Amendment (Biodiversity Banking) Act 2006* (NSW), and Biodiversity Certification (Biocertification) of Environmental Planning Instruments (EPIs) (TSC Act, s 126G(1)), such as Local Environment Plans (LEPs), State Environmental Planning Policies (SEPPs) and Regional Conservation Plans (RCPs), are the most comprehensive of all New South Wales biodiversity policies in terms of how biodiversity is understood and framed. These instruments generally seek to ensure biodiversity values are "maintained or improved" with respect to development or land clearing.[46] Biodiversity Banking and Biocertification exemplify a unique approach to this end, whereby the impacts of development on remnant vegetation are offset by securing for conservation bushland occurring offsite. The authors agree with Connolly and Fallding[47] that Biobanking and Biocertification have potential to protect biodiversity more effectively than species-based models as they consider ecological structure and function and can take a landscape approach to conservation. However, two fundamental issues in regard to offset schemes in addition to the logistical complications outlined by Connolly and Fallding have been identified.[48] First, because biodiversity in scientific terms is intrinsically complex, any attempt to quantify it in the same manner as carbon emissions or water resources for example will result in gross oversimplification and a loss of information. In reality, biodiversity is not a single entity, but a system of interconnected parts that can be understood from different angles and different scales, thus a "like for like" exchange can *never* be made. Ascribing to biodiversity a value is a subjective exercise and will always reflect a set of preferences at a point in time. If these schemes are to achieve demonstrable biodiversity outcomes, it is critical that the particular facets of biodiversity being transferred or exchanged are identified, and scientifically-robust assessment methods are used. Secondly, a key component of biodiversity is its spatial arrangement (ie structure), not simply its composition. Therefore, it is conceptually erroneous to reason that an improvement in biodiversity value in one location can compensate for loss in another. Any value attributable to biodiversity, either in anthropocentric or scientific terms, is fundamentally associated with its location. Instead of claiming that offsetting will result in no net loss of biodiversity, it may be more constructive to focus on reaching pragmatic outcomes that enhance biodiversity as much as possible amidst new development. Separating biodiversity both physically and ideologically from human society is inconsistent with the principles and objectives of ESD.

## Local government in Australia

Councils are required to act in accordance with conservation legislation at the State and federal levels, yet they possess the freedom to manage biodiversity in a manner appropriate for their local jurisdiction. Therefore, local government has the potential to adopt a more holistic approach to biodiversity conservation than is available via the EPBC and TSC Acts. For this reason, the focus of

[45] Larkin PW, "Bright Lines on Fuzzy Boundaries? How the Law of New South Wales Deals with the Existence and Extent of Endangered Ecological Communities" (2009) 10(S1) *Ecological Management and Restoration* 35.

[46] For thorough reviews on these pieces of legislation, including appraisals of their scientific strength and legal efficacy, see Curnow P and Fitz-Gerald L, "Biobanking in New South Wales: Legal Issues in the Design and Implementation of a Biodiversity Offsets and Banking Scheme" (2006) 23 EPLJ 298; Farrier D, Kelly A and Langdon A, "Biodiversity Offsets and Native Vegetation Clearance in New South Wales: The Rural/Urban Divide in the Pursuit of Ecologically Sustainable Development" (2007) 24 EPLJ 427; Lyster R and Stephens T, "The Rise and Rise of Environmental Markets in Australia: Biodiversity Banking in New South Wales" (2007) 10 *Asia Pacific Journal of Environmental Law* 1; Urban Development Institute of Australia, *Draft Threatened Species Conservation (Biodiversity Banking) Regulation 2007*, Submission of the Urban Development Institute of Australia NSW to the New South Wales Department of Environment and Climate Change (Urban Development Institute of Australia NSW, February 2008), http://www.udia-nsw.com.au/resource/BioBanking%20Submission_Feb08.pdf viewed 31 May 2010; Connolly I and Fallding M, "Biocertification of Local Environmental Plans – Promise and Reality" (2009) 26 EPLJ 128.

[47] Connolly and Fallding, n 46.

[48] Connolly and Fallding, n 46.

this article is on local-scale approaches to biodiversity conservation. However, it is appropriate to first review the role of local councils and the legislative context of biodiversity conservation within local government in Australia.

### *The many hats worn by local councils*

A key role of local government is to act as a consent authority for development applications. Although the process is complex, councils have a limited range of outcomes from which they can choose to respond to an application, analogous to a set of traffic lights. A development application can be refused (red light), permitted (green light), or permitted contingent upon a certain set of conditions (amber light). Biodiversity conservation is, however, only one component of ESD, and local councils regularly face the challenge of examining a development application to determine whether both "conservation and development can be compatibly combined or one or other should prevail".[49] The role of local councils in pursuing ESD is complicated further considering that they can be required to act as the proponent *and* consent authority for an activity, along with functioning as a management authority for publicly-owned conservation areas. Additionally, local government personnel are required frequently to gather and/or interpret and apply data on the environmental condition of their Local Government Area (LGA). Given that these tasks usually require a high degree of scientific literacy or specialist knowledge, the ability of a local government to design effective and appropriate policy is dependent upon the skills available within the organisation. If local environmental policies are to uphold conservation values effectively, they must contain clear goals and management strategies, and be grounded in pertinent, well-established scientific principles and high-quality data.

### *Guiding principles for local government practice*

A number of generic guidelines exist to support the formulation of biodiversity plans, policies and strategies by local governments in Australia. Examples include the Perth Metropolitan Region Local Government Biodiversity Planning Guidelines,[50] the New South Wales Biodiversity Planning Guide for Local Government,[51] and the Local Government and Shires Associations of New South Wales capacity building exercise for local governments.[52] The degree to which Australian local government legislation requires councils to promote principles of ESD varies from State to State. For example, the *Local Government Act 1993* (NSW) (LG Act) requires "councils, councillors and council employees to have regard to the principles of ecologically sustainable development in carrying out their responsibilities" (LG Act, s 7(e)), while the *Local Government Act 1993* (Qld) and the *Local Government Act 1989* (Vic) merely imply consideration of ESD through use of phrases like "social, economic and environmental viability" (*Local Government Act 1989* (Vic), s 3C(2A)) and terms such as "sustainability" (*Local Government Act 1993* (Qld), Ch 10, Pt 1, s 769). Although these Acts differ in their degree of emphasis on ecological sustainability, the implementation of ESD is collectively supported by local government within the national *Local Agenda 21* program.[53] Further, the *National Local Government Biodiversity Strategy*[54] was drafted to provide a framework for local implementation of ESD. Since this time, biodiversity conservation targets have become more

[49] McDonald T, "Is New Language – or a New Attitude – Needed for Innovations that Integrate Conservation and Development?" (2008) 9 *Ecological Management and Restoration* 85.

[50] Western Australian Local Government Association, *Local Government Biodiversity Planning Guidelines* (2004), http://www.walga.asn.au/about/policy/pbp/publications/lg_bio_planning_guide viewed 7 June 2010.

[51] Fallding M, Kelly AH, Bateson P and Donovan I, *Biodiversity Planning Guide for Local Government* (NSW National Parks and Wildlife Service, 2001), http://www.environment.gov.au/archive/biodiversity/toolbox/templates/nsw-bio-plan-guide.html viewed 31 May 2010.

[52] Local Government and Shires Associations of NSW, *Capacity Building for Local Government in Biodiversity Management* (prepared for Sydney Metropolitan CMA, November 2006), http://www.lgsa.org.au/resources/documents/biodiversity_final_report_301106.pdf viewed 31 May 2010.

[53] Cotter B and Hannan K, *Our Community Our Future: A Guide to Local Agenda 21* (prepared by Environs Australia, Australian Government, 1999).

[54] Australian Local Government Association and Biological Diversity Advisory Council, *National Local Government Biodiversity Strategy* (Australian Government, 1999).

prominent in many EPIs, and there have been a number of commendable attempts to provide guidelines for local-scale biodiversity planning within the current legal framework.[55] Nevertheless, biodiversity remains a largely separate and secondary consideration within the current New South Wales land-use planning system. A good example of this is the *NSW Environmental Planning Policy (Exempt and Complying Development Codes) 2008* that permits development with 900 mm setbacks from side boundaries, thus removing the opportunity for planting large shade and habitat providing trees (reg 3.16).

### *Land-use planning*

Land-use zoning has been the traditional method of regulating local land-use activities in Australia by both State and local governments. The partitioning of land by local councils into land-use zones can be an important tool for managing biodiversity; however, it was not designed specifically for this purpose and can reflect outdated planning priorities.[56] Inconsistencies with modern biodiversity management objectives can result therefore in undesirable biodiversity outcomes when land-use zoning is adopted as the primary conservation tool for an area. Indeed, consent authorities can permit a development if they are satisfied that it is not fundamentally inconsistent with zoning objectives,[57] regardless of the consequential biodiversity impacts. McClellan CJ made the following observations in *BGP Properties Pty Ltd v Lake Macquarie City Council* (2004) 138 LGERA 237 at [118]-[119]:

> In most cases it can be expected that the Court will approve an application to use a site for a purpose for which it is zoned, provided of course the design of the project results in acceptable environmental impacts.
>
> However, there will be cases where, because of the history of the zoning of a site, which may have been imposed many years ago, and the need to evaluate its prospective development having regard to contemporary standards, it may be difficult to develop the site in an environmentally acceptable manner and also provide a commercially viable project.

Furthermore, traditional land-use zoning, coupled with the application of threatened species legislation, may result in an *acceleration* of development, since landholders fear that they will be prevented from developing their land in the future if they retain bushland on their property in the immediate term.[58]

In New South Wales, the primary EPIs that regulate land use at the local scale are LEPs. Development Control Plans (DCPs) are also prepared by councils to provide detail for matters addressed in individual LEPs. In 2006, the New South Wales government introduced a compulsory standard template for all LEPs in an attempt to provide consistency across all LGAs.[59] The *Standard Instrument (Local Environment Plans) Order 2006* under the EPA Act provides 34 specific land-use zones (eg Medium Density Residential, Public Recreation or Heavy Industrial) with associated objectives and permissible and prohibited land uses.[60] Councils are required to select zonings from this list to cover their LGA. Kelly and Angel[61] argue that while the standardisation of LEPs may improve the quality of environmental planning across many LGAs, it reduces the ability of councils to adopt locally-tailored approaches to biodiversity conservation as only a small range of conservation

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[55] For example, Fallding et al, n 51.

[56] Kelly, n 36; Kelly AH and Smith C, "The Capriciousness of Australian Planning Law: Zoning Objectives in NSW as a Case Study" (2008) 26 *Urban Policy and Research* 83.

[57] Kelly, n 36.

[58] Kelly, n 36.

[59] These changes are discussed in detail in Kelly F and Angel J, *Submission to: Standard Instrument (Local Environmental Plans) Order 2005* (report from Total Environment Centre Inc, 2005); Kelly and Smith, n 56.

[60] See Department of Planning, *Planning Circular: Planning System – Local Planning, Circular PS 06-008, Local Instrument (Local Environmental Plans) Order 2006* (2006), http://www.planning.nsw.gov.au/planningsystem/pdf/circulars/ps06_008_standardlep.pdf viewed 31 May 2010.

[61] Kelly and Angel, n 59.

zones are available.[62] For biodiversity to be promoted in its broadest sense, biodiversity outcomes should be promoted on all land-use types, not only those designated for "conservation".[63]

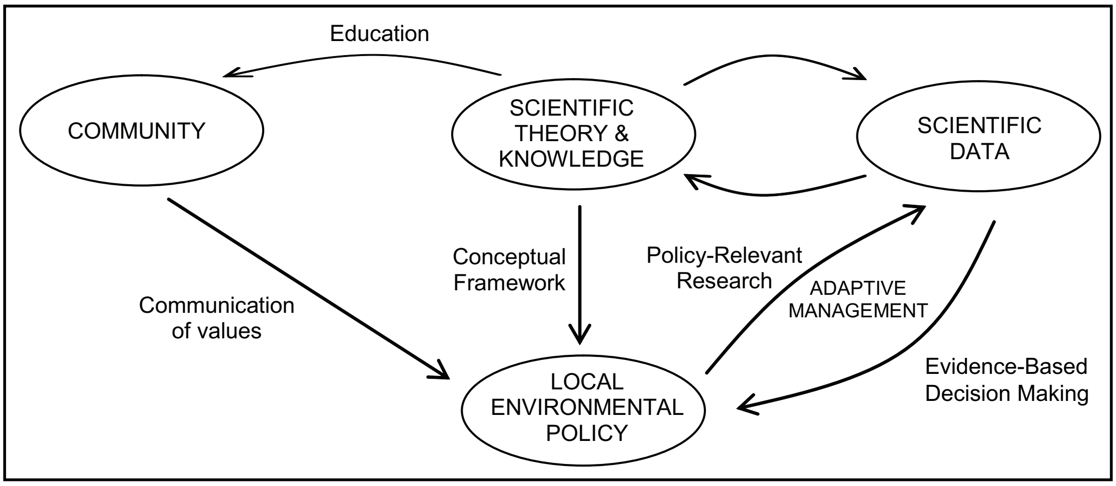
### *Biodiversity assessment*

Since the introduction of the LG Act in 1993, councils in New South Wales are required to provide regular assessments of the environmental condition of their LGA, detailed in the form of State of the Environment (SoE) reports. In 1997, it became obligatory for local governments to explicitly address biodiversity as a key component within the report. The collation of data on the condition of biological resources is an important part of achieving ESD, yet it is essential that the particular facets of biodiversity assessed are carefully chosen and meaningful, and monitored consistently over time.

## THE DYNAMICS OF EFFECTIVE LOCAL ENVIRONMENTAL POLICY

There is an inherent tension between biodiversity conservation and development. Economic pressures in favour of urban development contribute to gradual and incremental destruction of bushland habitat, cumulatively resulting in irreversible biodiversity loss. At present, the remaining undeveloped land in cities falls commonly into one of three categories. It may be land for which development is undesirable or unfeasible such as "moderate to steep land bordering creeks, rivers and bays",[64] land on the urban periphery where growth pressure is yet to increase, or land that contains habitat critical to the survival of legally-protected endangered species or ecological communities. A paradigm shift is required therefore if native biodiversity is to be retained in urban landscapes outside of these undesirable or restricted locations. Local government is in an important position to adopt such a change, for it is at the local scale that the breadth of the biodiversity concept discussed above can most practically be appreciated and acted upon within a legal framework. Figure 1 outlines the essential pathways of knowledge and the various relationships between community, environmental data, science and policy that are necessary to bring about a more holistic approach to biodiversity conservation.

**FIGURE 1 A schematic representation of the interaction between key areas of consideration when formulating effective environmental policy**




[62] Compare Connolly and Fallding, n 46.

[63] Miller JR and Hobbs RJ, "Conservation Where People Live and Work" (2002) 16 *Conservation Biology* 330; Smith GS, Phillips E and Doret G, *The Contribution of Biodiversity Conservation on Private Land to Australian Cityscapes* (42nd ISoCaRP Congress, 2006), http://www.isocarp.net/Data/case_studies/828.pdf viewed 31 May 2010.

[64] Schoer G, "The Biological 'Pros and Cons' of Urban Bushland" (1983) 27(6) *National Parks Journal* 12.

Environmental policy provides a nexus between scientific understanding and socio-economic systems, values, needs and wants. In seeking to regulate the actions of individuals and organisations such that natural ecological systems are maintained,[65] local policy must interact closely with the spheres of science and society. This was expressed by McClellan CJ who considered one of the key matters when determining the weight to be given to a planning policy to be "the extent, if any, of research and public consultation undertaken when creating the policy" (*Stockland Development Pty Ltd v Manly Council* (2004) 136 LGERA 254 at [92]).

## Setting clear goals

A scientifically-based and holistic conceptual framework such as that presented in Table 1 can provide context to biodiversity and should aid decision-makers in translating the somewhat overwhelming ESD goal – "to protect biological diversity and maintain ecological processes and systems"[66] – into goals for local biodiversity policy. This framework enables the collection and interpretation of biodiversity data at scales appropriate to the needs of explicit policy goals and management actions.[67] For example, if a local council seeks to understand the impact of habitat fragmentation on the biodiversity of a reserve, one researcher may evaluate changes in native plant species richness. In contrast, another might monitor the population of an endangered mammal, while a third may document structural changes in habitat patches within the reserve. All these approaches are valid measures of biodiversity. However, each is limited in focus when seeking to express the broader spectrum of biodiversity outlined within NSESD. While narrowing data collection and analysis is often necessary and practical, the limitations and assumptions should be clearly stated to avoid misleading or unnecessarily narrow outcomes.

Environmental goal setting is complicated further by the fact that biodiversity conservation will typically be one of multiple environmental concerns within a local policy, which may or may not be compatible.[68] An example of this is riparian management in which policies are expected to achieve objectives such as channel geomorphic integrity, terrestrial biodiversity conservation, vegetation condition enhancement, water quality improvement and wildlife corridor provision (eg Ku-ring-gai Council Riparian Policy[69]). While many of these can be achieved through similar management approaches, composite goals will often necessitate compromise, and prioritisation of specific goals is required. This issue was exposed in the case of *Silverwater Estate Pty Ltd v Auburn Council* [2001] NSWLEC 60. In this case, attempts to achieve multiple outcomes, such as the protection of a vulnerable plant and wetland ecosystem, and mitigating stream pollution using a 30 m riparian buffer, were the cause of much conflict. *Silverwater* highlights not only the challenges faced in riparian management but also the limitation of any biodiversity strategy seeking to simplify ecological complexity and assume an action will lead to universally-positive biodiversity outcomes.

## Local versus regional goals

Since biodiversity is present across all spatial scales, local environmental policy should look to enhance both local, regional, catchment, State and national conservation values. Local policies must consider regional conservation goals (such as preventing species extinction), since their success will

[65] Kraft ME, *Environmental Policy and Politics* (Pearson Education, 2004) Ch 1.

[66] NSESD, n 31, Pt 3, Ch 9

[67] Linder HP, "Setting Conservation Priorities: The Importance of Endemism and Phylogeny in the Southern African Orchid Genus Herschelia" (1995) 9 *Conservation Biology* 585; Possingham HP, "The Business of Biodiversity: Applying Decision Theory Principles to Nature Conservation" (2001) 9 *Tela* 1 (Australian Conservation Foundation).

[68] Compare Kelly AH, "Securing Urban Amenity: Does it Coincide with Biodiversity Conservation at the Local Government Level?" (2006) 13 *Australasian Journal of Environmental Management* 243.

[69] Ku-ring-gai Council, *Riparian Policy: Managing Watercourses and Riparian Zones in the Ku-ring-gai Local Government Area* (Ku-ring-gai Council, New South Wales, 2004), http://www.kmc.nsw.gov.au/resources/documents/Riparian_Policy_December_2004[1].pdf viewed 31 May 2010.

depend greatly upon their translation into the multitude of land-use planning decisions that are made at the lot and municipality scale.[70] The value of local policy in tackling broad environmental issues is clearly outlined in the UN Agenda 21:

> Because so many of the problems and solutions being addressed by Agenda 21 have their roots in local activities, the participation and cooperation of local authorities will be a determining factor in fulfilling its objectives. Local authorities…play a vital role in educating, mobilizing and responding to the public to promote sustainable development.[71]

However, biodiversity goals devised at larger scales (particularly those pertaining to threatened species or ecological communities) may not always be relevant when developing biodiversity strategies at local scales where certain species or habitats may not exist. Therefore, councils should also set goals that give weight to *locally*-significant biodiversity values. Disturbed bushland, which may be considered of little conservation value, can function as habitat for keystone species, a source of local provenance propagules or stepping stones and corridors for the movement of species throughout the landscape.[72] The protection of locally rare but regionally common species can also have many benefits to ecological function, while also promoting a conservation ethic within society.[73]

## Bridging policy, theory and empirical data

Integration of a broader suite of biodiversity values into local policy will require the application of reliable empirical data. Disconnection between science and decision-making can often result in a failure to apply ecological knowledge to local policies[74] resulting in a "close your eyes and hope for the best" approach to conservation.[75] There are two principal reasons for this disconnection, either:

(i) poor communication between those with the information (ie scientists) and those who make decisions; and/or

(ii) a lack of understanding on both sides of how to apply scientific knowledge to the planning process.[76]

This disconnection will only be overcome through greater appreciation by both scientists and policy makers of each other's role, and an understanding of the challenges of effective environmental policy formulation.[77] Thus, there are two essential components of effective biodiversity policy formulation: *policy-relevant research*, and *evidence-based decision-making*.

There is a paucity of reliable scientific data that can be directly applied to urban biodiversity management. For example, Collins et al[78] found that only 0.4% of articles published in leading ecological journals between 1995 and 2000 dealt with urban species or environments. Research scientists often strive for successful, positive experimental outcomes, forgetting that policy is enhanced more greatly from "approximate answers to the right questions, not precise answers to the

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[70] Marzluff, n 4; Beatley, n 6; Wild River S, *The Role of Local Government in Environmental and Heritage Management*, (article prepared for the 2006 Australia State of the Environment Committee, Department of Environment and Heritage, 2006), http://www.environment.gov.au/soe/2006/publications/integrative/local-government/pubs/local-government.pdf viewed 31 May 2010.

[71] United Nations, n 30, s 28.1

[72] Adam, n 28.

[73] Hunter ML and Hutchinson A, "The Virtues and Shortcomings of Parochialism: Conserving Species that are Locally Rare, but Globally Common" (1994) 8 *Conservation Biology* 1163.

[74] Lindenmayer D, Hobbs RJ, Montague-Drake R et al, "A Checklist for Ecological Management of Landscapes for Conservation" (2008) 11 *Ecology Letters* 78-91; McNie, n 11.

[75] Babbitt B, "Noah's Mandate and the Birth of Urban Bioplanning" (1999) 13 *Conservation Biology* 677 at 677.

[76] Cort CA, "A Survey of the Use of Natural Heritage Data in Local Land-use Planning" (1996) 10 *Conservation Biology* 63; Meredith T, "Linking Science and Citizens: Exploring the Use of Geographic Information and Analysis in Community-based Biodiversity Conservation Initiatives" (1996) 3 *Human Ecology Review* 231; Babbitt, n 75.

[77] Rockwood P, "Landscape Planning for Biodiversity" (1995) 31 *Landscape and Urban Planning* 379; Broberg L, "Conserving Ecosystems Locally: A Role for Ecologists in Land-use Planning" (2003) 53 *Bioscience* 670.

[78] Collins JP, Kinzig A, Grimm NB, Fagan WF, Hope D, Wu J and Borer ET, "A New Urban Ecology" (2000) 88 *American Scientist* 416.

wrong questions".[79] However, even where appropriate scientific information is available, it can remain unknown to managers, with only around 20% of jurisdictions acquiring information for conservation efforts from scientific journals.[80]

The lack of policy-relevant research for local government can be attributed to a number of issues:

(a) funding available to local and indeed all levels of government for research is often inadequate to obtain data of necessary quality,[81] and investment into research with inherently uncertain outcomes can be unpopular in the context of outcome-driven local government;
(b) there is limited ongoing commitment to research and monitoring projects, preventing effective adaptive management;
(c) review and interpretation of existing data is often elementary and inadequately describes complex ecological systems;
(d) personnel often lack the advanced scientific skills necessary for data collection, interpretation and application;
(e) collaboration with research institutions is limited; and
(f) there are often insufficient partnerships with other local government agencies that manage similar environments.[82]

This results in data replication, lack of peer review as well as catchment/bioregional environmental assessment programs based upon shared or easily obtained data that may not be appropriate to biodiversity outcomes. For example, the New South Wales SoE reporting system provides a framework to acquire and distribute local environmental data, yet the reports often lack scientific rigour[83] and do not always influence biodiversity planning or local government policy.[84]

## Community engagement

Public participation as part of a collaborative approach to environmental management can help to represent varied community values and opinions in environmental policy.[85] The selection of species or attributes of biodiversity that are to be the focus of local conservation efforts rests not with science (which provides information on ecological *function*), but with local communities.[86] Therefore, educating people about the value of ecosystem services or "green infrastructure"[87] and engaging communities in discussion of environmental issues will go a long way to increasing environmental care and awareness, because citizens "*will not support what they do not understand and cannot understand that in which they are not involved*".[88]

Members of the community often possess an intimate knowledge of their local environment and can assist environmental managers in understanding the condition and functioning of an ecosystem. However, community members will not always understand fully the intricacies of biodiversity assessment, management and development controls and restrictions. In cases where biodiversity

[79] Holling CS, "The Inaugural Issue of Conservation Ecology" (1997) 1 *Conservation Ecology* 1, http://www.consecol.org/vol1/iss1/art1 viewed 31 May 2010.

[80] Miller et al, n 12.

[81] Kelly, n 36.

[82] Kelly, n 36.

[83] Lloyd B, "State of Environment Reporting in Australia: A Review" (1996) 3 *Australian Journal of Environmental Management* 151.

[84] Brown VA, Batros B, Williams R and Powell J, *Pitfalls and Promises of Local State of the Environment Reporting* (Hawkesbury Nepean Catchment Management Trust, 1998).

[85] Koontz TM, Steelman TA, Carmin J, Smith Korfmacher K, Moseley C and Thomas CW, *Collaborative Environmental Management* (Resources for the Future, 2004).

[86] Barry D and Oelschlaeger M, "A Science for Survival: Values, and Conservation Biology" (1996) 10 *Conservation Biology* 905; Possingham, n 67; Toussaint, n 38; Adam, n 28.

[87] Beatley, n 6.

[88] FEMAT 1993, II-80 in Theobald et al, n 12 at 43.

values held by the community are broad and non-specific (eg maintaining "healthy bushland"), it is the role of policy makers in combination with scientists to determine how such a goal should be achieved, articulated and disseminated within the local context. Effective communication is therefore essential to enable the flow of information between local councils and their constituents, engage local residents in the management of their environment, and ultimately achieve biodiversity outcomes. Local government community advisory boards and community forums can encourage discussion and provide a platform from which collaborative partnerships between councils and other stakeholders can be built.

### A way forward

Local environmental policy can provide a means for strategically negotiating the often-competing conservation and development requirements of ESD within an urban context. Under current legislation, threatened species and communities are singled out for protection, often to the detriment of small but collectively large sections of bushland existing within an urban matrix. This approach is reinforced further through the recently adopted Biobanking instrument – the *Threatened Species Conservation Amendment (Biodiversity Banking) Act 2006* (NSW) – which permits the loss of native vegetation in exchange for improved management of bushland offsite.[89] However, how this policy relates to LEPs, particularly within an urban context, remains to be fully tested. Combating incremental habitat loss according to the presence of endangered species or the long-term viability of ecological communities has often proven to be ineffective (eg *BTG Planning v Blacktown City Council* [2008] NSWLEC 1500), since this approach fails to address the underlying processes that drive populations to crisis points.

If biodiversity is to be conserved and appreciated in our cities now and into the future, councils require a fundamentally new approach to conservation and land-use planning policy. Policies should adopt a broad range of biodiversity values relevant at local scales in the context of regional priorities.[90] The framework for conceptualising biodiversity summarised in Table 1 can assist in identifying biodiversity values in line with Australia's commitment to biodiversity conservation under the NSESD. These policies can be used to complement threatened species legislation that typically informs "red light" development refusals, determine strategically where development may be permitted (ie the "green light" areas) and inform how the pragmatic "amber light" outcome (development with conditions) should be applied.

## A new approach to biodiversity conservation: Multi-scale land-use planning

A renewed approach to urban biodiversity conservation is required across many aspects of the land-use decision-making process. This approach must respond to the breadth and complexity of the biodiversity concept, the continuing observable destruction of biodiversity in cities, and the failure of piecemeal approaches to conservation policy to secure biodiversity resources. However, optimal biodiversity outcomes will hinge upon the following three primary factors. First, land-use planning must be strategic and nested in the context of wider conservation objectives; secondly, planning must be supported by robust regulation; and thirdly, councils must collaborate with private landholders and other relevant governing agencies to achieve tangible outcomes to planning strategies.

### Land-use planning

#### *Adoption of conservation planning principles*

Contrary to reactionary land-use decision-making, which is often triggered by development proposals, long-term biodiversity planning can ensure that regulatory authorities take a leading role in determining biodiversity outcomes and can more easily adopt a broad perspective of biodiversity.

[89] Robinson D, "Strategic Planning for Biodiversity in New South Wales" (2009) 26 EPLJ 213.

[90] Karr JR, "Biological Integrity and the Goal of Environmental Legislation: Lessons for Conservation Biology" (1990) 4 *Conservation Biology* 244; Gaston KJ, Pressey RL and Margules CR, "Persistence and Vulnerability: Retaining Biodiversity in the Landscape and in Protected Areas" (2002) 27 *Journal of Biosciences* 361.

While strategic planning must take place at all spatial scales, councils should specifically position their EPIs to address locally-significant biodiversity values. These values may include the irreplaceability of habitats,[91] the permeability of suburban landscapes to wildlife,[92] or even the invertebrate species richness and ecological integrity of a reserve.[93]

Systematic conservation planning[94] provides transparent and logical solutions to reserve selection queries based upon the distribution and value/scarcity of natural resources and the relative costs incurred by setting aside that land. Although these techniques have been applied predominantly to reserve selection at regional or landscape scales, they are applicable to urban land-use planning applications because of their ability to balance competing priorities of conservation and anthropogenic land use according to a set of predefined parameters. The efficacy of such approaches, however, is related directly to the quality and quantity of data utilised and the accuracy to which we can predict the responses of ecological systems and biological communities and populations.

### *Foundational research*

Biodiversity planning is essentially dependent upon policy-relevant research to determine the presence and location of biodiversity "assets" and predict ecological responses to land-use change. Research into urban ecological patterns and processes is beginning to highlight the need for biodiversity to be understood and managed at multiple spatial scales[95] in line with the framework proposed in Table 1. The response of biodiversity to reserve size, habitat fragmentation and to ecological connectivity have been topics of intense research. The findings of such studies have varied, however, depending on the taxa of interest, attribute of biodiversity and location of the research. Drinnan et al[96] in their study south of Sydney identified a reserve area threshold of 4 ha for birds and frogs, below which species richness declined rapidly. Likewise, a threshold of 2 ha was found for plants and fungi. Results of a similar magnitude have been identified for bird populations elsewhere across the globe.[97] Analysis of species composition, however, has revealed substantially different habitat area requirements. For example, Drinnan et al[98] found that a reserve area of 50 ha was required for forest interior species of birds and frogs to dominate. Indeed, although no difference in arthropod species richness was observed between large (< 80 km$^2$) and (small (< 4 km$^2$) bushland fragments in Sydney,[99] Gibb and Hochuli[100] found that they did support significantly different assemblages. However, this pattern does not appear to be consistent across all localities or regions, with Angold et al[101] finding that habitat quality was more important for determining species occurrences of invertebrates and plants in Birmingham, United Kingdom than reserve size or connectivity. In Brazil, parkland was found to be of greatest ecological value, as indicated by ant communities, compared to other urban green spaces.[102]

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[91] Margules and Pressey, n k in Table 1.

[92] Compare Gobeil JF and Villard MA, "Permeability of Three Boreal Forest Landscape Types of Bird Movements as Determined from Experimental Translocations" (2002) 90(3) *Oikos* 447.

[93] Refer to concepts and methods at the "habitat" scale in Table 1.

[94] Margules and Pressey, n k in Table 1.

[95] See Clergeau P, Jokimäki J and Snep R, "Using Hierarchical Levels for Urban Ecology" (2006) 21 *Trends in Ecology and Evolution* 660.

[96] Drinnan IN, "The Search for Fragmentation Thresholds in a Southern Sydney Suburb" (2005) 124 *Biological Conservation* 339.

[97] Evans KL, Newson SE and Gaston KJ, "Habitat Influences on Urban Avian Assemblages" (2009) 151 *Ibis* 19.

[98] Drinnan, n 96.

[99] Drinnan, n 96.

[100] Gibb H and Hochuli DF, "Habitat Fragmentation in an Urban Environment: Large and Small Fragments Support Different Arthropod Assemblages" (2002) 106 *Biological Conservation* 91.

[101] Angold PG, Sadler JP and Hill MO, "Biodiversity in Urban Habitat Patches" (2006) 360 *Science of the Total Environment* 196

[102] Pacheco R and Vasconcelos, "Invertebrate Conservation in Urban Areas: Ants in the Brazilian Cerrado" (2007) 81 *Landscape and Urban Planning* 193.

At smaller scales, habitat characteristics have proven to be critical to biodiversity. For example, the structure of vegetation in residential gardens in the United Kingdom has been found to influence bird and invertebrate abundance and species richness.[103] Studies in the United States and Australia have also demonstrated how planting native vegetation in gardens can influence bird and invertebrate diversity.[104] Research such as this can greatly aid our understanding of how to design urban spaces at various scales that will support and promote biodiversity. Overall, the varied observed ecological responses to urbanisation demonstrate the need for *local* empirical evidence and clarity regarding spatial scale when seeking to apply ecological observations to conservation and urban land-use planning. However, biodiversity planners should look not only to research on the ecological responses to human environments, but also to human responses to natural ecologies. Indeed, research that investigates the utility or anthropocentric values of biodiversity may inadvertently support actions that will result in positive outcomes for both biodiversity and human society. Examples of this include the psychological benefits of urban greenspace[105] or the thermal comfort services offered by mature trees in residential areas.[106]

### An outline of biodiversity planning at multiple scales

The process of land-use planning at multiple scales is illustrated visually in Figure 2. At each spatial scale, the landscape is to be viewed through a biodiversity "filter" (ie Table 1). Perceiving the landscape in this way enables the compositional, structural and functional attributes of the biological resources to be assessed, and provides a framework for contextually-appropriate biodiversity targets to be selected. Although biodiversity planning approaches are employed commonly at landscape scales as part of reserve selection procedures, these techniques and concepts have largely been neglected at fine-scales. For ESD to be promoted in its true sense, biodiversity must be considered at all scales of land-use planning, zoning and urban design. Indeed, planning for biodiversity in cities should be a practical response to an emerging realisation that biodiversity exists not only "out there" within the confines of national parks and reserves, but also in and around the places people live and work. In this way, just as incremental habitat loss and degradation has led to a broad scale decline in urban biodiversity, incremental habitat improvement also has the potential to transform the ecological character of entire suburbs and cities.

[103] Daniels GD and Kirkpatrick JB, "Does Variation in Garden Characteristics Influence the Conservation of Birds in Suburbia?" (2006) 133 *Biological Conservation* 326; Smith RM, Gaston KJ, Warren PH and Thompson K, "Urban Domestic Gardens (VIII): Environmental Correlates of Invertebrate Abundance" (2006) 15 *Biodiversity and Conservation* 2515; Smith RM, Warren PH, Thompson K and Gaston KJ, "Urban Domestic Gardens (VI): Environmental Correlates of Invertebrate Species Richness" (2006) 15 *Biodiversity and Conservation* 2415.

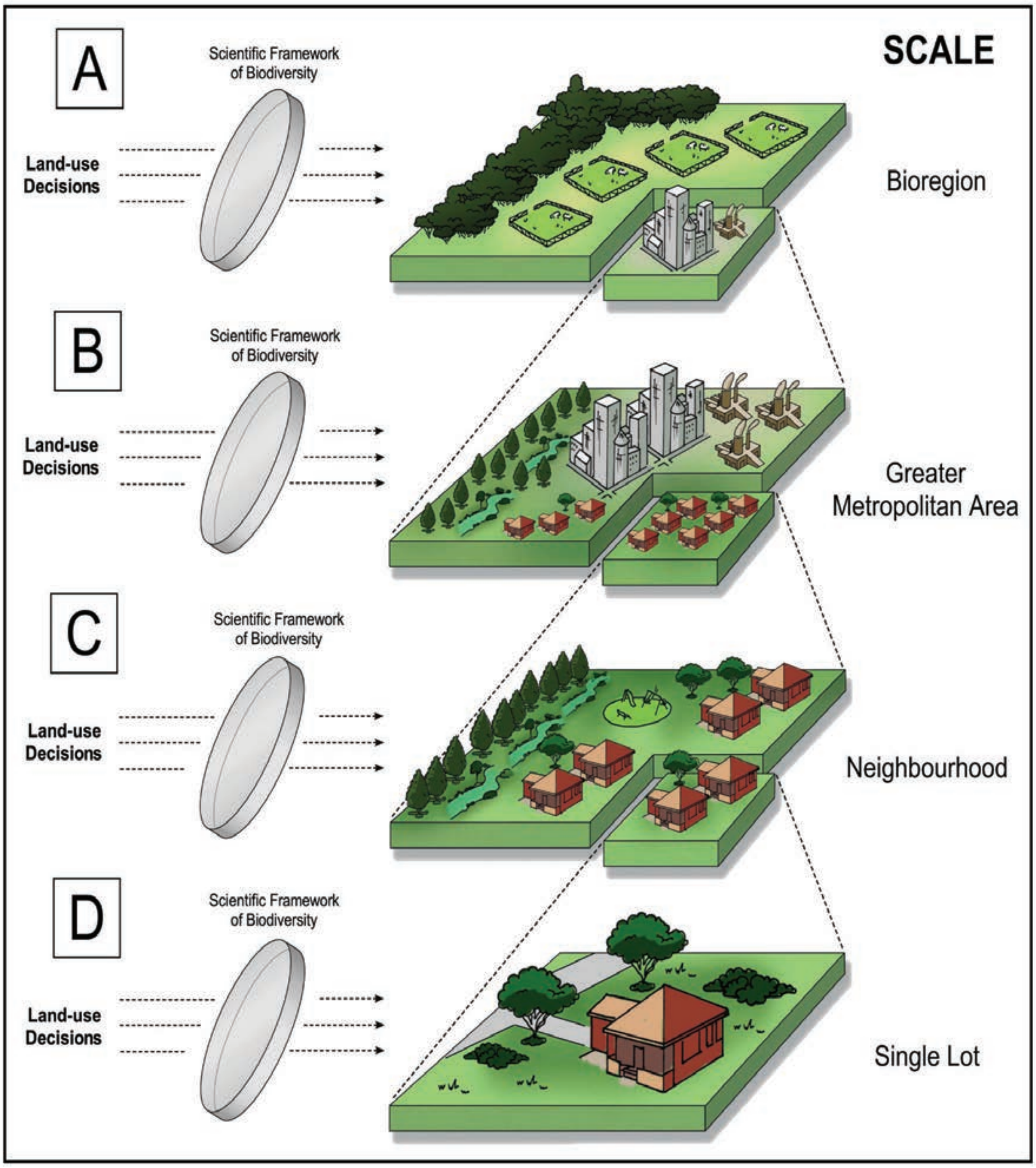
[104] Burghardt KT, Tallamy DW and Shriver WG, "Impact of Native Plants on Bird and Butterfly Diversity in Suburban Landscapes" (2009) 23 *Conservation Biology* 219; Daniels and Kirkpatrick, n 103.

[105] Fuller RA, Irvine KN, Devine-Wright P, Warren PH and Gaston KJ, "Psychological Benefits of Greenspace Increase with Biodiversity" (2007) 3 *Biology Letters* 390.

[106] Parkinson T, *The Effects of Vegetation Shading on Residential Energy Use and Comfort* (Honours thesis, Macquarie University, 2009).

**FIGURE 2 Schematic diagram of the application of biodiversity planning principles at multiple spatial scales**

Land-use decisions are made at each level of spatial organisation, as represented by panels A to D, which focus on progressively smaller portions of a landscape. The lens represents a holistic and scientifically-grounded understanding of biodiversity (eg the conceptual framework in Table 1), through which decision-makers should view a landscape. This will enable biodiversity to be planned for and promoted in a meaningful and spatially-appropriate manner.




The upper panel (A) of Figure 2 represents a landscape at the $10^2$ to $10^3$ km scale, comparable to an entire State or the Sydney Basin Bioregion. At this scale, land-use decisions include the positioning of cities, agricultural areas and national parks. These decisions fall under State or federal governance, yet the actual location of such regions is usually the result of historical responses to environmental conditions. Australian cities, for example, have most commonly been determined by transport access (ie bays suitable for shipping ports) and water supply, with virtually no consideration of biodiversity impacts. Nevertheless, biodiversity planning at this scale is crucial to the design of reserve networks that incorporate ecological communities from different bioregions and maintaining landscape ecological connectivity.[107] A current example of planning at this scale is the Gondwana Link project in south-western Australia, in which ecological connectivity is being promoted through the protection of interconnected reserves from Karri forests in the south-west to Mallee forests bordering the Nullarbor Plain.

Panel B can be likened to a region such as the highly-populated Sydney Metropolitan area. Land-use planning at this scale determines the broad distribution of specific functional areas such as business districts, industrial zones, residential areas and conservation reserves. It is also at this scale that regional biodiversity planning takes place under the authority of State governments and expressed in SEPPs, RCPs, or similar EPIs. Current New South Wales examples of such planning policies include the Far North Coast Regional Conservation Plan[108] and the Sydney Metropolitan Strategy.[109] Biodiversity objectives that are most appropriate at this scale may include the adequate protection of ecological communities and vegetation types that occur within a region.

Panel C represents a catchment or neighbourhood scale perspective of land-use planning. This deals with the location of specific developments and natural habitats, and is arguably best managed by local government, typically in New South Wales through LEPs. Common planning decisions include the design of road networks, the position, style and scale of residential or commercial development, and the provision of recreation and conservation areas. It is at this scale that planning decisions are likely to have the greatest impact upon the landscapes that people interact with on a daily basis. Biodiversity objectives that are most appropriately targeted at this scale include the protection of ecologically-sensitive habitats such as riparian zones, and ensuring the protection of bushland reserves and maintenance of their ecological integrity.

Finally, Panel D represents land-use planning at the lot or single development scale. Although regulated by relevant DCPs, decisions and designs are made by landscape architects, builders, and landholders. The biodiversity outcomes at this scale may include maintaining significant trees on a lot,[110] planting of native vegetation, and designing gardens as habitat for urban wildlife. Although actions such as these may seem insignificant in isolation, the combined ecological benefits gained when repeated across entire regions can be great. This was recognised in the judgment for *Murlan Consulting Pty Ltd v Ku-ring-gai Council and John Williams Neighbourhood Group Inc* [2007] NSWLEC 374, which stated that the removal of isolated trees was inappropriate because of their cumulative ecological significance. Specifically, a key piece of evidence to this end was research demonstrating that isolated trees can be highly significant as stopover bird habitat and a source of genetic material for surrounding populations (at [88]).

Some positive examples of how conservation planning principles can be applied in an urban context are beginning to emerge both in Australia and internationally. A recent study by Gordon et

[107] In 2008, the New South Wales government released a plan for the growth of reserve networks. The *New South Wales National Parks Establishment Plan* is an encouraging example of reserve selection methodology based upon comprehensive, adequate and representative conservation of bioregions within the State: http://www.environment.nsw.gov.au/protectedareas/npestabplan.htm viewed 31 May 2010.

[108] Department of Environment and Climate Change, *Draft Far North Coast Regional Conservation Plan* (New South Wales Government, 2009), http://www.environment.nsw.gov.au/resources/biodiversity/09241farnorcoastrcp.pdf viewed 31 May 2010.

[109] *Sydney Metropolitan Strategy* (New South Wales Department of Planning), http://www.metrostrategy.nsw.gov.au viewed 31 May 2010.

[110] For example, objectives in the *Mosman Residential Development Control Plan*, s 4.4 are as follows: (1) "To have the existing canopies and vegetated landscape character of Mosman townscape areas protected and enhanced"; and (2) "To have Mature Trees protected".

al[111] in Melbourne's urban fringe demonstrates how transparent conservation decisions can be made in a complex land-use matrix. Data on the location of known habitat for 30 threatened fauna species was used to inform where existing reserves should be expanded to quantify the expected biodiversity impacts associated with different land-use planning scenarios. This study showed that by considering landscape scale processes such as connectivity between populations, the impacts of individual developments on larger population dynamics were appreciated more accurately. The approach outlined by Gordon et al was progressed further by Bekessy et al.[112] In this study, conservation planning principles were again applied, yet rather than identifying areas of conservation significance for protection, they were used to prioritise parcels of land for development that would impact least upon biodiversity. Furthermore, economic and social values were integrated into the decision process, such that high-value land (eg close to railway lines) was given greater weight for development in land-use plans. The techniques applied in these research studies are positive examples of how new decision-making technologies can be utilised to help achieve improved biodiversity outcomes while balancing development priorities. Approaches such as these are key therefore to the advancement of ESD and achieving the NSESD objectives.

Similar biodiversity planning techniques to those outlined above have been adopted officially by the City of Cape Town, South Africa. There, large areas of internationally-significant vegetation have been lost in the past due to fragmented conservation management, poorly-regulated development and rapid urban sprawl. This has particularly been the case in the flat, lowland areas that are more conducive to urban development. Cape Town is situated within the Cape Floristic Region, which is considered a biodiversity hotspot because of the richness of locally endemic flora. Eleven of the 21 critically-endangered vegetation types in South Africa are present within the city, three of them exclusively. The city has addressed the significant challenge of conserving these communities for future generations by producing a fine-scale conservation plan known as the Biodiversity Network.[113] The plan was produced using conservation planning techniques based upon high-quality vegetation mapping and is now applied formally by Cape Town Council. It has been used to identify significant terrestrial and freshwater sites, important corridor linkages, and prioritise sites for conservation at scales at which land-use decisions are made. This approach represents an encouraging step forward in how urban biodiversity is managed, and moves away from the more traditional reactionary and ad hoc approaches. Further, the methods applied are highly transferrable and could be adopted by other large cities that have significant remnant ecological communities that require careful planning and protection.

## Regulation

Fine-scale biodiversity planning approaches would be an effective means of local governments fulfilling their biodiversity conservation mandate under Local Agenda 21.[114] However, the success of strategic planning approaches will depend upon their regulation and the management of biodiversity resources over time. The ways in which the multi-scale biodiversity planning concept proposed above would likely interact with existing frameworks for local biodiversity conservation in New South Wales are explored below.

The most natural context for local biodiversity planning to be afforded necessary statutory recognition is within LEPs. LEPs in New South Wales could be revised such that in addition to identifying and protecting areas of significant biodiversity value, enhancing biodiversity is obligatory across all land uses. For example, a rural/residential zoning may require a certain degree of

[111] Gordon A, Simondson D, White M, Moilanen A and Bekessy SA, "Integrating Conservation Planning and Land-use Planning in Urban Landscapes" (2009) 91 *Landscape and Urban Planning* 183.

[112] Bekessy SA, White M, Gordon A, Moilanen A, McCarthy MA and Wintle BA, "Transparent Biodiversity Planning in the Urban Fringe" (2010) *Landscape and Urban Planning* (in review).

[113] Holmes P, Wood J and Dorse C, *City of Cape Town Biodiversity Report, 2008* (City of Cape Town, Biodiversity Management Branch, 2008).

[114] United Nations, n 30.

connectivity between remnant vegetation, while medium-density residential may contain a minimum percentage of greenspace with indigenous flora present. This would go some way towards dismantling the current perverse incentive for developers to disregard biodiversity in areas already biocertified.[115] Nevertheless, certain elements of the recently reformed New South Wales planning system, although significantly flawed for reasons outlined previously, may be helpful in demonstrating how a broad view of biodiversity can be applied within a legislative framework. For example, the assessment component of the biodiversity offset approach could be modified to provide rigorous, accurate, and comprehensive inventories of biodiversity within a mosaic of land uses. Indeed, even offsetting may be a useful tool to ensure biodiversity is conserved amidst increasing development, provided that biodiversity values are "maintained or improved" through better management and protection of remaining remnants *within the same general area*.

Even at the scale of an individual lot, biodiversity should be a key consideration in the planning and design phase of a development. Enforcement of "green standards", whereby development must conform to a standard of ecological responsibility, has potential to significantly enhance biodiversity conservation within cities through cumulative small-scale improvements. "Green standards" are already in place in Toronto, Canada[116] as a means of promoting sustainable development. These standards pertain to all new building and site developments in the city, and contain requirements under categories of air quality, greenhouse gas emissions/energy efficiency, water quality, quantity and efficiency, ecology, and solid waste. Adoption of similar "green standards" by Australian councils would be an effective way of promoting ESD. Indeed, modification of these standards to include more detailed biodiversity guidelines applicable to the local context could significantly help curb the loss of biodiversity through the protection of urban trees and remnant vegetation, and could promote the creation of habitat for wildlife within all forms of land use.[117]

## Collaboration

Local councils cannot achieve the goals of the NSESD alone: they must collaborate with a range of natural resource management bodies across different levels of government, other local governments both locally and internationally, and landholders within their constituency. Furthermore, regional biodiversity targets, although formulated at higher levels of government, necessitate collaboration between local councils and State and federal government departments to reach their objectives, such that councils draw upon regional goals to inform local biodiversity plans, strategies and actions.

Commonly, jurisdictional boundaries do not follow the arrangement of natural resources such as watersheds or vegetation communities. Structures such as Catchment Management Authorities (CMAs) or Regional Organisations of Councils may provide a platform for local governments to share the professional skills and knowledge needed to effectively formulate and implement biodiversity plans that take into account regional cumulative impacts of fine-scale planning decisions. A current example of this type of collaboration is the production of combined State of the Environment Reports by the Northern Sydney Regional Organisation of Councils to replace multiple individual reports prepared by adjacent municipalities. Another pertinent example is the fine-scale vegetation mapping project recently completed by the Sydney Metropolitan CMA, which identifies the distribution of vegetation types across the Sydney Basin.[118] This information is readily accessible to councils and will assist greatly in the management of remnant vegetation within individual LGAs, as well as setting appropriate biodiversity targets in accordance with the distribution of vegetation in surrounding areas.

[115] Robinson, n 89.

[116] City of Toronto, *Toronto Green Standard* (2010), http://www.toronto.ca/planning/environment/greendevelopment.htm viewed 31 May 2010.

[117] See Goddard MA, Dougill AJ and Benton TG, "Scaling Up from Gardens: Biodiversity Conservation in Urban Environments" (2010) 25 *Trends in Ecology and Evolution* 90, for a thorough discussion of how private gardens can be used to promote biodiversity.

[118] This map product is currently in draft form and is being revised following a six-month review period. The final version should be available sometime after February 2010. For more information, visit http://www.sydney.cma.nsw.gov.au/our-projects/vegetation-mapping.html viewed 31 May 2010.

Finally, international collaboration between local governments through organisations such as the ICLEI group of Local Governments for Sustainability[119] is key to adopting the best possible management approaches through the sharing of ideas, successes and failures across a range of global contexts.

Arguably, the most important collaborative partnerships are between councils and private landholders. Seventy per cent of land in Australia is privately owned[120] and, globally, habitat conversion is outpacing habitat protection by up to 10 times.[121] This is particularly observable in areas with high potential for future urban development. For example, in Sydney's west, less than 6% of the original extent of Cumberland Plain Woodland remains,[122] and 76% of this is under private ownership.[123] Consideration of biodiversity management and planning on private land is therefore an essential component of any conservation agenda. Indeed, a recent study of land use in South Africa found that by including privately-owned conservation areas in conservation plans, the achievement of biodiversity targets nearly tripled because they contained significant areas of ecological communities that were under-represented within the existing statutory reserve system.[124] Because the scale of management (ie residential lots and gardens) are frequently smaller than the scale of ecological outcomes (ie ecological processes and population dynamics),[125] councils should look at ways in which landholder efforts to conserve biodiversity can be coordinated within a landscape. Goddard et al[126] in their review of the importance of urban gardens in biodiversity conservation identify a number of mechanisms by which this "scale dependent tension" can be overcome and positive biodiversity outcomes can be achieved. These include planning for interconnected networks of gardens that are sympathetically managed as "habitat zones", or targeting gardens located adjacent to existing natural vegetation to be more favourable to wildlife.[127]

To sustain conservation outcomes on private lands, a fundamental shift in landholder attitudes is required. Instead of focusing on landholder rights, it is necessary that landholders also consider the significant responsibilities that come with owning property, including protecting biodiversity. Local councils are strategically positioned to be able to influence directly landholder actions and interpret and translate regional plans and policies to the public. A range of models exist to facilitate effective private landholder management of biodiversity, and have been reviewed extensively in the literature.[128] Some "top down" strategies include conservation covenants, tax incentives, educational

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[119] ICLEI Local Governments for Sustainability, http://www.iclei.org/index.php?id=3896 viewed 31 May 2010.

[120] Hatfield-Dodds S and Proctor W, *Delivering on the Promise of Stewardship: Issues in Realising the Full Potential of Environmental Stewardship Payments for Landholders and the Land* (a discussion paper prepared for the Australian Conservation Foundation, CSIRO Sustainable Ecosystems, 2008) p 3.

[121] Hoekstra JM, Boucher TM, Ricketts TH and Riberts C, "Confronting a Biome Crisis: Global Disparities of Habitat Loss and Protection" (2005) 8 *Ecology Letters* 23.

[122] Department of the Environment, Water, Heritage and the Arts, *Woodlands Vanishing from Sydney's Outskirts* (Australian Government, 2007), http://www.environment.gov.au/biodiversity/threatened/publications/cumberland.html viewed 31 May 2010.

[123] Department of the Environment, Water, Heritage and the Arts, *The Cumberland Plain and its Vegetation* (Australian Government), http://www.environment.nsw.gov.au/resources/nature/RecoveringCumberlandPlainCh1-2.pdf viewed 31 May 2010.

[124] Gallo JA, Pasquini L, Reyers B and Cowling RM, "The Role of Private Conservation Areas in Biodiversity Representation and Target Achievement within the Little Karoo Region, South Africa" (2009) 142 *Biological Conservation* 46.

[125] Goddard et al, n 117.

[126] Goddard et al, n 117.

[127] Parker et al recommend the planting of native vegetation in private gardens adjacent to riparian corridors to effectively "widen" the corridor for biodiversity purposes: Parker K, Head L, Chisholm LA and Feneley N, "A Conceptual Model of Ecological Connectivity in the Shelharbour Local Government Area, New South Wales, Australia" (2008) 86 *Landscape and Urban Planning* 47.

[128] For example, Doremus H, "A Policy Portfolio Approach to Biodiversity Protection on Private Lands" (2003) 6 *Environmental Science and Policy* 217; Hatfield-Dodds and Proctor, n 120; Municipal Association of Victoria, *Financial Incentive Schemes for Natural Resource Management in Local Government* (2007).

programs, and conservation contract auctions whereby landholders compete for funding to achieve biodiversity outcomes. Research has found that economic incentives are very important to rural landholders[129] and also have unexplored potential for success in an urban context, provided that biodiversity targets are communicated clearly and professional support is available where needed. More thorough investigation of how these positive incentives for landholder biodiversity stewardship can be incorporated into a complex urban context is therefore warranted. However, in providing balance to such positive incentive schemes, it may be necessary to ensure good landholder stewardship of biodiversity by introducing greater penalties for the destruction, negligence or mismanagement of remnant bushland in their care.[130] In trying to deliver these aims, councils could look to expand tree preservation orders to include other aspects of biodiversity such as weed management. With any penal reforms, however, the authors anticipate that the best biodiversity outcomes are more likely to be achieved when regulatory authorities are slow to discipline and quick to encourage positive incentives for compliance.

Although "top-down" approaches can be effective in influencing real biodiversity outcomes, "bottom-up" community-led initiatives can help change the underlying ideas and values held by landholders, which largely determine the ecological character of urban landscapes via garden management.[131] Local governments should encourage good community stewardship through assisting with ecologically-sensitive landscaping works, providing native seedlings and wildlife boxes, or helping to set up bushcare and community environment groups. Promoting a strong environmental ethic within a community can lead to increased appreciation of natural environments, physical and psychological health benefits, and a promotion of biodiversity values into the future.

## CONCLUSION

Management of urban biodiversity is an increasingly important issue for the future of Australia's biological resources and the interactions people will have with the natural environment. The extent to which the goals of ESD are realised will depend largely on how local government and regional bodies implement environmental policies specific to the needs and opportunities present within their jurisdictional areas and across a range of spatial scales. In urban areas, incremental habitat loss will only be curbed through policies that are grounded in a comprehensive scientific understanding of the concept of "biodiversity". This understanding must be translated into clear, specific and measurable goals and policies that are formulated through ongoing and dynamic communication between local governments and communities. Fine-scale conservation planning is a means by which many of these goals can be translated into tangible outcomes and biodiversity can be recognised as an important and highly-valuable component of urban landscapes. These changes would replace current ad hoc and opportunistic land-use planning and assessment processes with a strategic and proactive approach that will maximise biodiversity outcomes consistent with ESD principles.

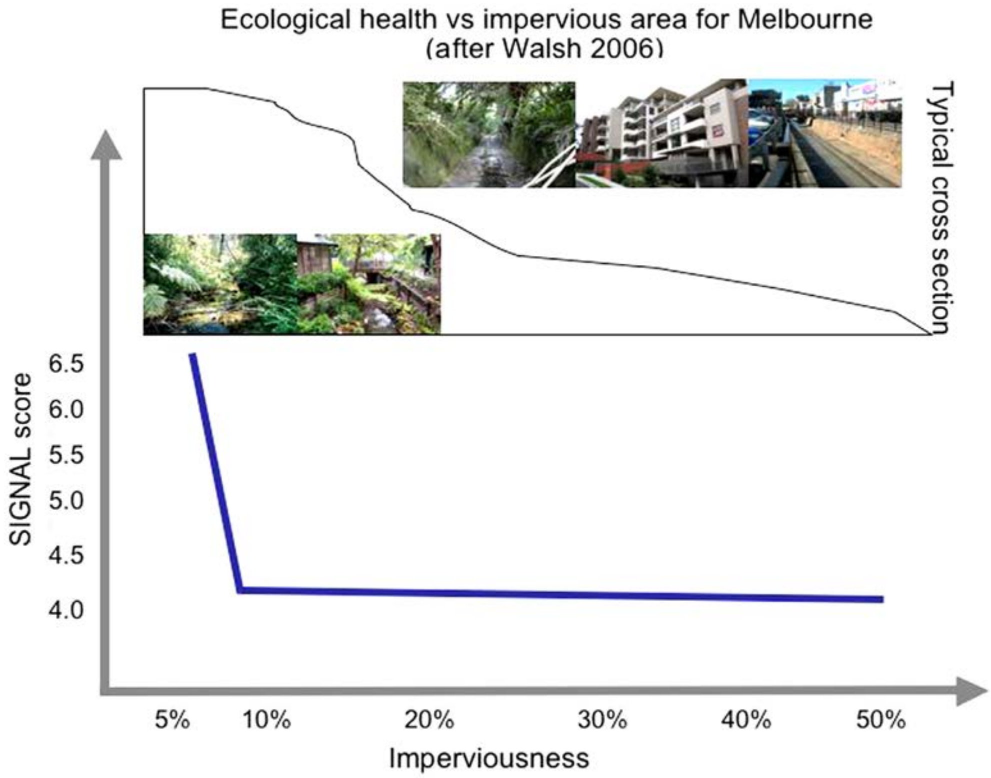
# Chapter 4:
# Condition and health of urban waterways in northern Sydney

The condition and health of urban waterways has been measured using macroinvertebrate indices for many years. In Australia this has largely followed the SIGNAL (Chessman (1995) method that seeks to standardise monitoring, reporting and interpretation between studies.

Most urban creeks are highly degraded. This is influenced by many factors and is reflected in physical monitoring studies such as SIGNAL or chemical monitoring through various water quality attributes. This is the case for most urban waterways within the Ku-ring-gai local government area when compared with nearby reference waterways (**Paper 4** Wright et al 2007).

Since 1978 it has been known that catchment imperviousness is a major factor influencing catchment hydrology contributing to the degradation of urban streams (Dunne and Leopold (1978). The extent of this impact has more recently been established in Melbourne (Walsh (2006)) where a 10 per cent imperviousness threshold was proposed as the upper limit beyond which effects on macroinvertebrate increase and the health of waterways significantly declines. However, it was unknown if the results of the Walsh study would transpose to different physical and geographic environments. This is particularly the case for northern Sydney where high rise development occurs at the top of catchments, transitioning to low density housing mid catchment and forested lower reaches to the waterways. This is opposite to most other urban areas where the density of development occurs on and adjacent to rivers and waterways and decreases up slope to typically forested upper catchments.

The findings detailed in **Paper 4** by Wright et al (2007) and **Paper 5** by Davies et al (2010) for northern Sydney are consistent with the trends observed by Walsh (2006) in Melbourne in terms of the correlation of physical decline in waterway health with higher levels of imperviousness, although this was largely confined to a comparison of reference versus distinctly urbanised waterways. What remains untested by this thesis is whether the 10 per cent threshold proposed by Walsh holds true for catchments that are developed in their upper reaches and have large areas of bushland in the lower reaches. Figure 4.1 is used to illustrate this research question (note the change in x-axis scale).



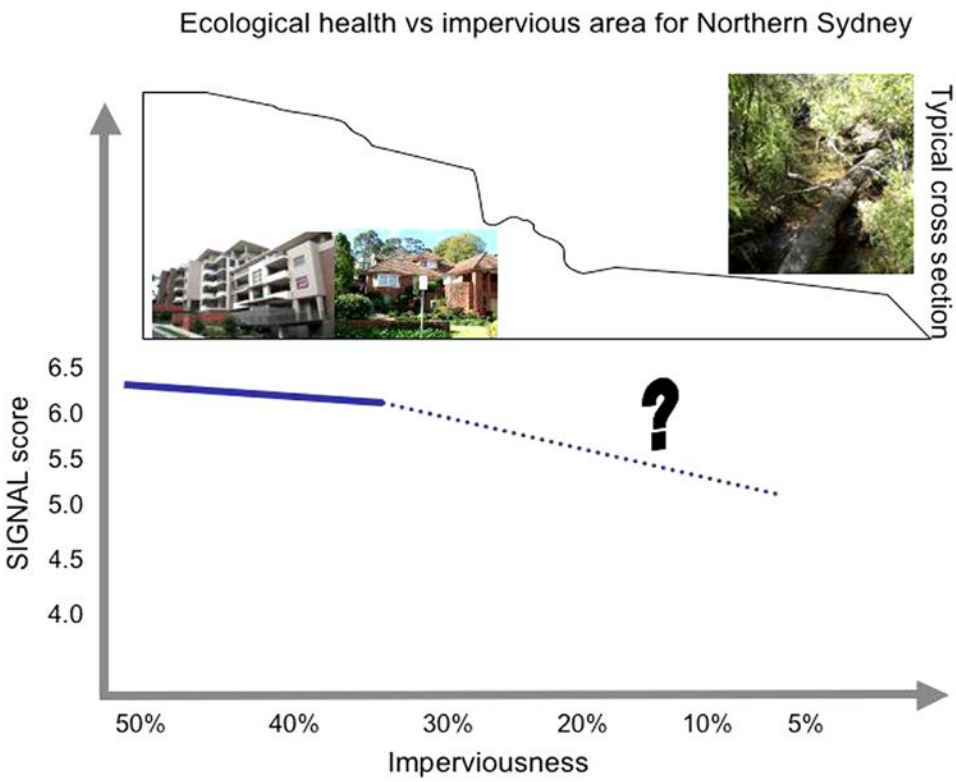




*Figure 4.1 Comparison of cross-section, imperviousness and SIGNAL scores for Melbourne (after Walsh et al (2005)) and northern Sydney (Davies et al (2010))*

The data from the two studies (**Papers 4** and **5**) in this thesis also points towards the ecological value of maintaining large areas of bushland as part of the urban catchment given the nature of development in northern Sydney. In the Ku-ring-gai Council based studies this contributed to diverse macroinvertebrate assemblages in the rivers downstream of development.

The research presented in this chapter also finds variation in macroinvertebrate assemblages within the pool, edge and riffle environments across both urban and reference waterways. Edges were found to be taxonomically richer that the other habitats. This research may be useful for urban sampling regimes where sedimentation of creeks fills many rock pools, creating a more homogeneous creek environment.

Other notable observations, consistent with other studies, relate to the dominance of two gastropod (snail) families, *Hydrobiidae* and *Physidae,* in urban creeks and absent from reference waterways. These gastropods are invasive pests and like all snails require significant amounts of calcium and other minerals in water to form their exoskeleton. A hypothesis raised, although not tested in this thesis, was that the chemistry of urban water provided an ecological advantage to these guilds. In reference streams in northern Sydney, the conductivity and pH was significantly lower than for urban streams. The limited water quality sampling undertaken as part of the studies in Papers 4 and 5 led to an exploration of the difference in water chemistry between urban and reference waterways (Chapter 5) that may be one of the causative factors for the prevalence of aquatic snails in urban waterways in Sydney, in particular the bicarbonate derived from concrete.

paper four (published in *Aquatic Ecology*)

***Impact of urban development on aquatic macroinvertebrates in south eastern Australia: degradation of in-stream habitats and comparison with non-urban streams***

**Davies P J,** Wright I A, Findlay S J, Jonasson O J and Burgin S (2010) *Aquatic Ecology* 44:685-700 DOI: 10.1007/s10452-009-9307-y

This paper reports the results of a 30-month family level macroinvertebrate study that compared the results of the three habitats (riffle, edge and pool) across urban and reference streams. The data was also compared against imperviousness and other catchment characteristics and the associated water quality sampling data.

paper five (peer reviewed conference paper)

***Aquatic macroinvertebrates in urban waterways: comparing ecosystem health in natural reference and urban streams***

Wright I A, **Davies P J,** Wilks D, Findlay S J and Taylor MP (2007) in Wilson A L, Dehaan R L, Watts R J, Page K J, Bowmer K H, and Curtis A (eds) *Proceedings of the 5th Australian Stream Management Conference. Australian rivers: making a difference* Charles Stuart University, Thurgoona, Australia

This research was submitted as a peer reviewed conference paper and offered the preliminary results of the 30-month macroinvertebrate sampling program with a particular focus on differences between urban and reference waterways when compared against the EPT taxa (Ephemeroptera, Plecoptera and Trichoptera as per Cairns and Pratt 1993) and the SIGNAL score (Chessman 1995).

paper four

# Impact of urban development on aquatic macroinvertebrates in south eastern Australia: degradation of in-stream habitats and comparison with non-urban streams

Authors: Davies P J, Wright I A, Findlay, S J, Jonasson O J and Burgin S

Publishing details: *Aquatic Ecology* (2010) 44:685-700 DOI: 10.1007/s10452-009-9307-y

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paper five

# Aquatic macroinvertebrates in urban waterways: comparing ecosystem health in natural reference and urban streams

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## Abstract

A macroinvertebrate survey and water chemistry study of small coastal upland streams was conducted in the Ku-ring-gai Council area in the northern suburbs of Sydney. The purpose of this six year investigation was to provide information on the ecological condition of its waterways. The study revealed that all streams draining urbanised catchments exhibited clear signs of ecological impairment, in contrast to local reference sites. The macroinvertebrate survey reported lower SIGNAL scores and fewer pollution sensitive Ephemeroptera, Plecoptera and Trichoptera in the urban streams when compared against naturally vegetated non-urban streams. Further, the urban waterways revealed different water chemistry than the reference sites that were soft, dilute and acidic.

## Keywords

EPT taxa, SIGNAL index, urban stream syndrome

## Introduction

Macroinvertebrates are widely regarded as one of the best biological indicators for assessing the effects of water pollution on rivers and streams (Hellawell, 1986; Rosenberg & Resh, 1993; Turak & Waddell, 2001). Several Australian studies have used them to assess the impact of urban landuse on waterways (Campbell, 1978; Arthington *et al.*, 1982; Chessman & Williams, 1999; Walsh *et al.*, 2001). The degradation of urban waterways involves symptoms such as the loss of sensitive macroinvertebrates, invasion of pest species, deterioration of water quality, modification of flow regimes and reduction in habitat values. This has been referred to as 'the Urban Stream Syndrome' by Meyer *et al.* (2005).

Ku-ring-gai Council (Council) is responsible for managing the urban waterways within its local government area (LGA). It embarked on the macroinvertebrate monitoring program in 1998 to assess the relative level of ecosystem health and determine if the waterways health is changing. This research has since been used to inform other scientific studies commissioned by Council to map the condition of its urban streams (Findlay *et al.*, 2005; Taylor *et al.,* 2005), develop specific development control policies (Ku-ring-gai Council, 2004) and more recently an investigation into the use of terrestrial macroinvertebrates to assess broader ecosystem health (Ives, 2005).

This paper investigates the findings of a survey of freshwater macroinvertebrates and water chemistry attributes in urban waterways compared to local reference streams. The aim is to report a baseline data set for reference streams for the northern suburbs of Sydney and compare this against streams impacted by urban development.

## Methods

Conducting waterway impact studies within the Ku-ring-gai local government area (LGA) is very difficult as the impacts of human activity have been gradually intensifying over nearly 200 years. It is practically impossible to conduct before/after control/impact (BACI) studies (e.g. Underwood, 1991) that would enable the progressive assessment of a natural catchment before, during and after it is subject to urban development. Comparison with multiple reference sites (Fairweather, 1990) is one of the few practical alternatives available to detect ecological effects of urban landuses on waterways and was chosen for this study.

Macroinvertebrate and water samples were collected in the northern suburbs of the Sydney metropolitan area of NSW from 1998 to 2004. The study area was predominantly located in the Ku-ring-gai LGA. The urban waterway sites are located within either the Middle Harbour (Moores Creek, Gordon Creek and Rocky Creek) or Lane Cove River (Coups Creek, Avondale Creek, Quarry Creek, Blackbutt Creek and Little Blue Gum Creek) catchments. Only one reference sites was located in the Ku-ring-gai LGA, an unnamed tributary of Kierans Creek, with the others located within nearby National Parks to the east (Deep Creek and McCarrs Creek) and north-west (Little Cattai Creek).

All sites are located on coastal incised sandstone streams, under 200 m Australian Height Datum (AHD), and resemble small montane upland streams with frequent pool and riffle sections. Channels are rocky bottomed, sometimes bedrock, frequently combined with boulders and cobbles. Sand, silt and gravel was present in most habitats, particularly the urban waterways, which often had 'sediment slugs' dominating many stream habitats. All streams are small (1-3 m wide) and shallow (0.1-2 m deep) and generally have permanent flow, except during prolonged periods of drought. The majority of waterways have natural channels with well vegetated riparian zones, although weed invasion of the urban riparian zones has become a major environmental problem in the LGA (Lake & Leishman, 2004).

Macroinvertebrate samples were collected in accordance with the National River Health Program protocols (Anon. 1994) and NSW AUSRIVAS (Australian River Assessment) protocols (Turak & Waddell, 2001). Sampling was done using a 'kick' net, with 250-micron mesh, a square 30 x 30 cm net frame (Chessman, 1995; Turak & Waddell, 2001). Samples in 1998 and 2000 were collected from riffle, pool edge and pool rocks habitats and in later years (2001-2004) were collected only from pool edge habitats. Pool edge was selected as it was the only habitat present at every site (Williams & Silva, 1998). Electrical conductivity (EC), pH and alkalinity (ALK) were collected in conjunction with the macroinvertebrate sampling, following the AUSRIVAS protocols (Turak & Waddell, 2001). All sampling was conducted in dry weather conditions at least a week after significant rainfall events.

Richness of Ephemeroptera, Plecoptera and Trichoptera (EPT) families were calculated per site per sampling occasion. Measurement of EPT taxa has been found to be a useful method for detecting impacts from pollution as these three orders are often the most pollution-sensitive macroinvertebrate guilds (Lydy *et al.*, 2000; Camargo *et al.*, 2004). The macroinvertebrate results were also expressed as values of the SIGNAL biotic index (Chessman, 1995; Chessman *et al.*, 1997). Student's *t*-test was used to determine if mean macroinvertebrate (SIGNAL biotic index scores and EPT richness) or water chemistry results (pH, EC, ALK) varied significantly according to the site classification as reference site (pooled) or urban site (pooled). SIGNAL data is also compared to the Catchment Imperviousness (CI) determined for each sample site. This comparison has been completed as the importance of CI to stress of aquatic ecosystems has been established by several authors (see Walsh *et al.,* 2004). The CI data for each catchment was determined by applying representative values for land use imperviousness to council land use information (Findlay, 2006). The CI was only calculated for sites within Ku-ring-gai Council, and as such only one reference site (tributary of Kierans Creek) is represented. The CI for each site is shown in Table 1.

**Table 1. Figures for catchment imperviousness within the Ku-ring-gai LGA (from Findlay, 2006).**

| SITE | CATCHMENT IMPERVIOUSNESS % |
|---|---|
| Trib. of Kierans Creek | 6.12 |
| Coups Creek | 35.92 |
| Quarry Creek | 44.46 |
| Gordon Creek | 42.84 |
| Moores Creek | 35.82 |
| Rocky Creek | 44.17 |
| Little Blue Gum Creek | 42.51 |
| Avondale Creek | 43.58 |
| Blackbutt Creek | 42.75 |

**Macroinvertebrate results**

A total of 16 EPT taxa were recorded of which 14 were recorded at three or more sites. Macroinvertebrate EPT richness (Figure 1a) varied highly significantly between reference and urban sites (df = 99, t = 19, P <0.0001). The average number of EPT taxa at reference sites ranged from 3 to 6 taxa and an average of 0 to 2 were recorded from the urban sites (Figure 1a). Macroinvertebrate SIGNAL scores (Figure 1b) varied highly significantly between reference and urban sites (df = 64, t = -95, P <0.0001). The SIGNAL score recorded at reference sites ranged from 6 to 7 and from 4 to 5 at the urban sites (Figure 1b). Comparison of SIGNAL score and CI demonstrated a strong relationship (n = 9; r2 = 0.9677), despite the small number of sites analysed. As shown by Figure 1c, there is an absence of sites characterised by 7-35% CI. However, it does demonstrate the disparity in condition according to catchment imperviousness.

**Water chemistry results**

Water chemistry results indicated that reference sites exhibited distinctly different chemical properties compared to the urban sites. Although pH varied highly significantly between reference and urban sites (df = 45, t = -9.6, P <0.0001), the reference sites were all acidic (mean pH 5.3 – 6.1) and the urban sites were mildly acidic to mildly alkaline (mean pH 6.6 – 7.7, Figure 1c). Electrical conductivity and alkalinity both varied significantly between reference and urban sites (EC: df = 37, t = -5.9 P <0.0001; ALK: df = 31, t = -6.5, P <0.0001) and both were lower at reference sites (Figure 1d and 1e). The properties of urban sites varied. Quarry Creek is labelled as it had extreme levels of electrical conductivity and alkalinity, possibly reflecting former catchment landuses including an incinerator and a small landfill.

**Discussion**

The results of the macroinvertebrate sampling from 1998 to 2004 assert that urban waterways in the Council LGA have poor ecosystem health as reflected by low numbers of sensitive taxonomic groups (EPT taxa, Figure 1a) and low SIGNAL scores (Figure 1b) in comparison to local, forested reference streams. The results reported in this study are similar to other Australian (Campbell, 1978; Arthington *et al.*, 1982; Chessman & Williams, 1999; Walsh *et al*., 2001) and worldwide studies (Roy *et al.,* 2003) that have associated urbanisation with degraded waterway ecosystem health, particularly through representation by aquatic macroinvertebrates. As many other authors have noted (e.g. Walsh *et al.*, 2001), the loss of ecosystem health due to urbanisation is caused by complex linked changes referred to by Meyer *et al.* (2005) as the 'urban stream syndrome'. Our results suggest that this syndrome is affecting the urban creeks within the Ku-ring-gai LGA as a result of changes to hydrology, hydraulics, water quality, habitat, pest species, geomorphology, erosion and sedimentation (see Walsh *et al.,* 2004, Breen & Lawrence, 2003).

The water chemistry of the urban waterways was more variable and reported much higher pH, electrical conductivity and alkalinity than the reference streams (Figures 1 d-f). Non-urban reference streams were dilute, acid and were poorly buffered (low alkalinity) in contrast to the urban streams which had higher EC, were circumneutral to mildly alkaline and were much more buffered (medium to high alkalinity). Alkalinity was particularly different between the two groups of sites, ranging from 5-10 mg/L at reference sites and was 30-125 mg/L at urban sites. This has been noted in other studies of urban waterways (Walsh, 2006). The water chemistry results presented provide some clues as to the possible factors associated with urbanisation that may contribute to this ecological degradation of urban waterways, such as materials that affect pH and alkalinity. For example, Quarry Creek had much higher EC and alkalinity than the other urban sites which we speculate may be due to previous activities within the catchment such as the operation of a municipal waste incinerator, quarry and small landfill for vegetation and building waste.

Water chemistry was only measured in dry weather conditions, avoiding the high flow events that probably suffer the poorest water quality episodes. In this respect changes in water chemistry did not distinguish the impacts of sewerage overflows that are known to occur in the LGA.

In reference to general stream health, the assessment of the condition of riparian systems as undertaken by Findlay *et al.* (2005) reported that the physical condition of the 230 km of streams in the LGA was better than was expected, with 61 % being classified as being excellent and good. This was attributed to a large extent the comprehensive system of natural riparian corridors that have been retained within the LGA. This is in contrast to many other urban areas that have engineered their waterway through pipes and channels and straightening and de-snagged channels to achieve hydraulic efficiency. Recognising the broader ecological functions of waterways, Ku-ring-gai Council developed a 'riparian policy' to ensure protection of this sensitive environment whilst seeking to balance the risk of flooding and property protection (Ku-ring-gai Council, 2004). The long term effectiveness of this policy, in combination with other development control instruments that seek to promote water sensitive urban design are yet to be demonstrated.

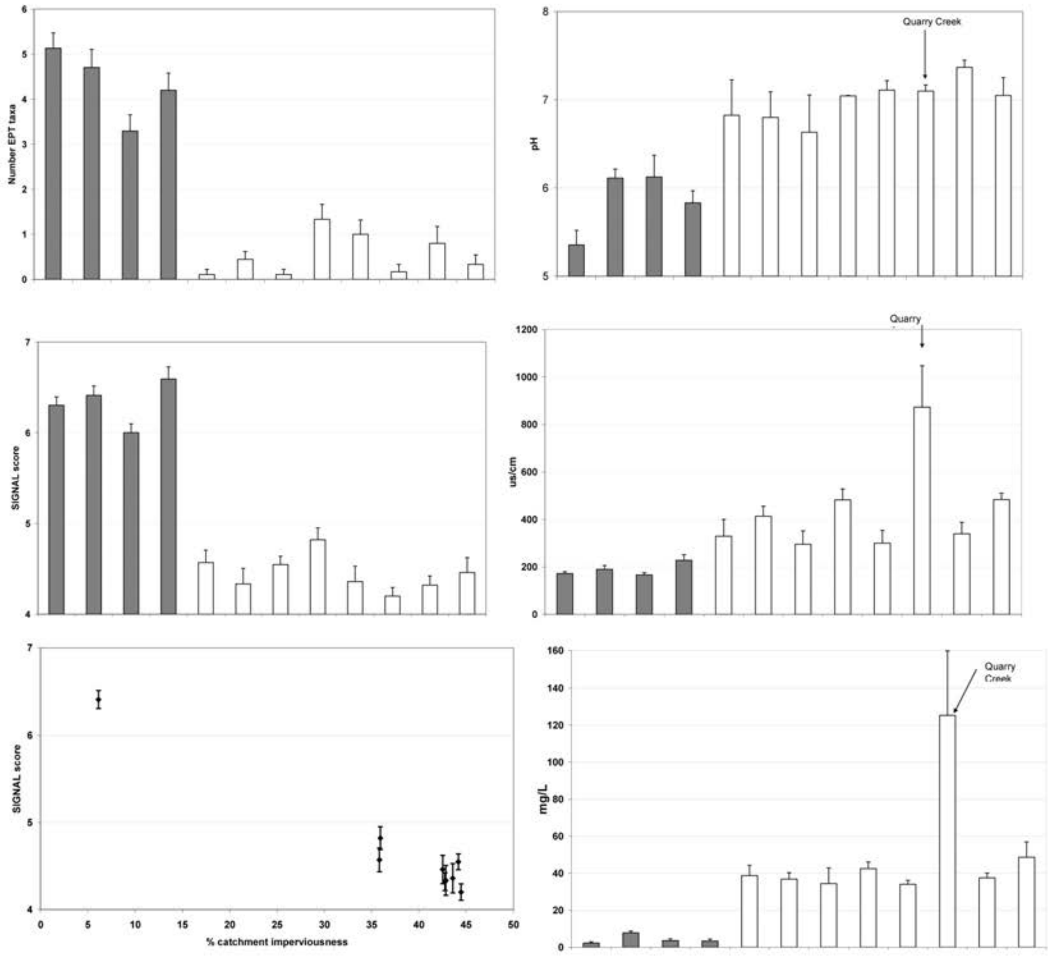


**Figure 1. Macroinvertebrate (left) and water quality (right) results.**
**a) (Top Left) EPT richness (plus std. error) at reference (grey) and urban sites.**
**b) (Mid Left) Mean SIGNAL score (plus std. error) at reference (grey) and urban sites.**
**c) (Bottom Left) Mean SIGNAL score (plus std. error) compared to catchment imperviousness for sites within the Ku-ring-gai LGA (n=9, $r^2$ = 0.9677).**
**d) (Top Right) Mean pH (plus std. error) at reference (grey) and urban sites.**
**e) (Mid Right) Mean EC (plus std. error) at reference (grey) and urban sites.**
**f) (Bottom Right) Mean alkalinity (plus std. error) at reference (grey) and urban sites.**

The influence of CI on altered flow conditions and transport of pollutants in urban streams has frequently been identified as a highly influential cause of degradation to urban waterway ecosystems with researchers suggesting a reverse in impervious areas could improve stream health (Walsh *et al.*, 2005 and Ladson *et al.*, 2006). Figure 1c provides an indication that such an assumption is valid; however additional data is required to fill the gap between 7-35% in order to determine the target CI for the Ku-ring-gai landscape.
A key result of this study was characterising four local reference sites and for comparison with urban waterways. The reference sites all benefit from a large proportion of their watershed being protected through

National Park estate lands. Reference waterways are becoming increasingly rare within urban environments. Within the Ku-ring-gai LGA only tributary of Kierans Creek can serve as an example of how the natural waterway would have existed pre development. Given the marked difference in aquatic macroinvertebrates and water chemistry, as investigated in this study, such locations deserve greater legislative protection due to their scarcity and conservation value. Legislative instruments could include protection of the catchment of each reference waterway under the *Threatened Species Conservation Act 1995* NSW as an endangered ecological community. This would complement current controls via part 3A approvals pursuant to the *Rivers and Foreshores Improvement Act 1948* NSW that is soon be repealed by the *Water Management Act 2000* NSW.

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# Chapter 5
# Chemistry of urban streams – impact of the urban drainage network on stream health

This chapter introduces a new area of investigation to the urban water literature. It identifies the concrete drainage network as a significant contributor to the pollution of urban streams. It draws on the research presented in Chapter 4 that identified significant differences in pH and conductivity between urban and reference waterways. This was identified by the water quality monitoring data associated with macroinvertebrate sampling (**Papers 4** and **5**).

Traditionally urban water quality analysis has focused on a narrow range of parameters such as nutrients, faecal contaminants, sediments, dissolved oxygen and other toxicants with a focus on individual streams and water bodies. The analysis of anions and cations on stream chemistry has been left to the geochemist as part of landscape scale analysis that has sought to understand the relationships between geology, atmospheric precipitation and evaporation (eg Gibbs (1970)). This is in spite of a long-standing understanding that waterways have distinct chemical signatures influenced by particularly pH, salinity and other environmental factors. However, the notion that urbanisation, and specifically the use of new concrete that is used extensively within urban areas, can influence urban stream water chemistry has been largely overlooked.

The notion that the conveyance of stormwater through the concrete drainage network adds to the decline in urban water quality is a new area of discovery in this thesis. Although the significance is yet to be fully explored the initial findings presented in this chapter suggest that best practice management guidelines for stormwater quality improvement and water sensitive urban design (for example Australian Runoff Quality, Institute of Engineers Australia (Wong (2006)) should acknowledge and suggest solutions for urban drainage systems discharging into sensitive waterways, particularly where they may be naturally acidic and have low levels of major anions and cations (as has been the case with this research in the northern suburbs of Sydney).

The results add a new body of knowledge that recommends wider consideration of in-transport processes from the concrete drainage system. The urban drainage system is usually associated with the decline in the natural hydraulic and hydrological function of urban waterways. From a water quality perspective, the drainage network has been simply considered as a conveyance system, taking polluted runoff to the receiving water body. This thesis presents data that challenges the benign role of concrete drainage networks.

**Papers 6 to 10** follow an iterative process to answer the following research questions:

1. Does rainwater running through concrete pipes have a significant effect on water chemistry? (**Paper 6**)
2. How does water chemistry change when passing urban creek water (that is presumably influenced by concrete and other contaminants), natural creek water (from a reference or natural condition) and rainwater through two types of concrete pipes? (**Papers 6** and **7**)
3. Does the condition (or age) of the concrete pipe influence the water chemistry (ie will it change over time as the pipe degrades?) (**Papers 7** and **8**)
4. Is there a similar result when applied to concrete gutters of various ages? (**Paper 9**)
5. What does this mean in term of limnology where urbanisation replaces the natural geology with artificial surfaces? (**Paper 10**)

paper six

# Impact of concrete and PVC pipes on urban water chemistry

Authors: Davies P J, Wright I A, Jonasson O J, and Findlay S J

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paper six

RESEARCH ARTICLE

# Impact of concrete and PVC pipes on urban water chemistry

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Waterways contain a chemical signature of catchment land use, climate and geology. This is increasingly being influenced by the urban landscape and particularly the composition of materials and activities that occur on impervious surfaces. This paper examines the degree and extent of two types of drainage materials, concrete and PVC, on urban water chemistry. This study found that water collected from a zinc and slate/tile roof and stored in a plastic rain tank (roof water) was acidic (pH 4.79) and had low bicarbonate concentrations (0.5 mg/l), water from an undeveloped catchment (reference creek) was mildly acidic (pH 5.5) with bicarbonate concentrations of 1.7 mg/l while water from a stream draining a residential catchment (urban creek) was mildly alkaline (pH 7.35) with bicarbonate concentrations of 36.3mg/l. The three types of water were then circulated through a concrete pipe or PVC pipe for 100 min and measured for a range of water chemical attributes. Roof water and water from the reference creek reported a significant increase across a range of analytes, most notably bicarbonate and calcium levels when passed through the concrete pipe, while water from the urban creek changed a lesser amount. When passed through the PVC pipe the changes in water chemistry were significantly less for roof water and urban creek water. The data suggests that in-transport processes from concrete drainage systems are having a significant influence on water chemistry, particularly where inflow is acidic. The major factor identified in this study could be attributed to the dissolution of calcium, bicarbonate and potassium ions from the concrete pipe. This could impact on receiving environments that are naturally acidic and low in bicarbonate, such as those in northern Sydney. The implications of this study point towards a need to consider the type of materials used in urban drainage networks if water chemistry and stream ecosystem health is to be protected.

**Keywords:** diffuse pollution; hydrogeology; integrated urban water management; stormwater quality; sustainable urban water management; water sensitive urban design

## Introduction

The use of pipes and culverts to convey urban runoff has become a ubiquitous treatment used by drainage engineers around the world. This has come from the necessity to mitigate and manage the risk of flooding. More recently, water sensitive urban design (WSUD) or low impact development (LID) has entered the domain of the engineering, physical scientists and landscape architects such that urban runoff is no longer confined to the management of flood or overland flow prevention rather now takes a broader view of water within its catchment (Meyer *et al*. 2005).

As most of the world's population live in cities (Grimm *et al*. 2008), there is a growing concern about the degradation of urban waterways by urban and human activity (Aplin 2002). There have been numerous studies describing the generally poor quality of runoff from various urban surfaces such as roofs (Bridgman 1992, Garnaud *et al*. 1999), roads and other transport related surfaces (Sartor and Boyd 1972, Schuler 1987, Ball *et al*. 1998, Drapper *et al*. 2000, Shinya *et al*. 2000) and impervious surfaces generally (Ladson *et al*. 2006, Conway 2007). Many studies have sought to quantify the degree to which urban stormwater adversely influences waterway health (Dunne and Leopold 1978, Klein 1979, Hall and Ellis 1985, Walsh *et al*. 2001, Hatt *et al*. 2004, Walsh 2006).

Scientific studies, and waterway managers, have often focused their attention on diffuse pollutants in urban waterway including nutrients, hydrocarbons, metals, particulates, oxygen demanding substances and micro organisms (such as pathogens and indicator bacteria). This work has influenced regulatory standards or similar guidelines (e.g., McKay and Moeller

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2002) as issued by government for urban runoff (Austroads 2003) and other water sources (ANZECC and ARMCANZ 2000).

The challenge for those within the urban water profession is to protect both water quality and the ecological health of urban waterways (Aplin 2002). A number of researchers (e.g., Meyer *et al.* 2005, Lawrence and Breen 2003) have sought to encapsulate both perspectives and have identified a number of interrelated factors that influence waterway health. This has been aptly described by Meyer *et al.* (2005) as the "urban stream syndrome". This considers not only the quality of water but also factors such as stream hydrology and the degree of connection of the urban drainage network directly into waterways.

When describing the role of urban land use and its impact on urban water pollution, the processes that lead to changes in pollution loads have generally focused on build-up and subsequent wash off of contaminants (Lawrence and Breen 2003). Build-up is a combination of wet and dry deposition, point source and diffuse pollution, while the transportation process, such as wash off, has focused on surface flow processes or in-stream erosion.

Missing in the discussion to date is the role of the drainage network itself with respect to contributing to the in-transport pollution load and also the natural ionic balance and how this may impact on ecological health.

While focusing on the hydrogeochemistry in Hong Kong, Leung and Jiao (2006), investigated the quality of water that came in contact with the basements and foundations of high-rise buildings that are periodically or permanently below the water table. Leung and Jiao (2006) concluded that the dissolution of concrete from the foundations was most likely to be responsible for the chemical signature reporting a high pH and high levels of bicarbonate, calcium and other ions associated with concrete. Whilst this could be seen as another source of diffuse pollution within the urban landscape it identifies a new area for investigation. Conway (2007) investigated changes in pH as related to catchment imperviousness, and while that study noted an increase in pH coupled with an increase in impervious surfaces, it did not identify the materials that comprise the drainage system as a possible causal factor.

Hart and McKelvie (1986) reviewed the chemical nature of Australian inland waters that focussed on the importance of the natural ionic balance of waterways. They discussed the importance of the composition and relative proportion of the major ions (Na, Ca, Mg, K, $HCO_3$, Cl, $SO_4$) which responded to the chemical nature of each waterway depending on atmospheric and/or catchment geological sources of ions.

Within the northern suburbs of Sydney, urban waterways have previously been found to have significantly different chemistry and ecology to that found in nearby non-urban waterways (Wright *et al.* 2007). Dry weather water quality was highly dissimilar with higher levels of alkalinity and electrical conductivity at urban streams. Urban waterways were generally circumneutral to slightly alkaline while undeveloped (natural) streams were acidic (Wright *et al.* 2007). As a result of these observations, this current study was developed with an objective to explore the existence of any causal link between the water chemistry in urban streams and the materials comprising the urban drainage system.

## Methods

### *Study area*

Research was undertaken within the Ku-ring-gai local government area (LGA), situated north of Sydney City at 33°45′20"S and 151°9′0"E. Development across the Ku-ring-gai LGA, is dominated by low density residential housing on block sizes around 940 $m^2$ with little commercial and no industrial development. The LGA is 84 $km^2$ with one-third bushland and has a population of 101,000 (ABS 2007).

The geology is characterised as Wianamatta Shale overlying Hawkesbury Sandstone on ridges with the deeply incised valleys and streambeds dominated by exposed Hawkesbury sandstone (NSW Department Mineral Resources 1983). The soil type is closely related to the underlying geology and is generally described as poor in both structure and geochemistry (Herbert and Helby 1980). A notable characteristic of the northern suburbs of Sydney is that development has occurred on the upper and flatter sections of the catchment while the steeper incised valleys contain remnant bushland and modified streams. The intermittent and ephemeral streams that would have existed in the upper reaches of the catchment have largely been replaced by concrete pipes that discharge to either the permanent or intermittent streams within the steeper sections of the landscape and narrow valley floors.

### *Study design*

Three types of water were used in this study: roof water, urban stream water and non-urban reference stream water. Each type of water involved collection and mixing from two different sources within each category to help ensure that the sample used in the experiment was representative of water quality of that type in the study area. Rainwater was collected from two sources within the LGA: a 100% zincalume roof and the other had an 80% slate and 20% ceramic tile roof. Both rainwater samples were stored for approximately two weeks in an on-site plastic rainwater tank prior to sampling. Urban stream water was collected from two creeks within the Ku-ring-gai local government area (Falls Creek and Quarry Creek, Table 1). In each case samples were taken immediately downstream from the urban/bushland interface. Reference creek water was taken from two creeks draining predominantly naturally vegetated, non-urban catchments, within the Ku-ring-gai Chase National Park, Salvation Creek and McCarrs Creek (Table 1).

Water samples were collected from the rainwater tanks (roof water) and from the urban and non-urban creeks on the same day as the experiment. Samples were collected in clean 20 litre plastic jerry cans, and were stored in the shade prior to their use. The weather was overcast and dry and the flow in all waterways was typical of dry weather (low flow) conditions.

A polyvinylchloride (PVC) and steel-reinforced concrete pipe was fixed to a frame with a 6.5% and 7.5% grade respectively, the higher grade for concrete chosen to counteract the higher roughness of the pipe. Each pipe was previously unused and was 1.4 m in length. Equal portions of the same water type were mixed to make a composite sample. These were divided into two batches, each with a volume of 20 l. Each water type was manually circulated using buckets, with the water delivered to the pipes through an anti-scouring device at a rate of approximately 0.2 l/s for 100 min. Prior to the commencement of sampling, each pipe was flushed with surplus sample water of the type to be used in order to remove any residue chemical or particulate matter.

Water samples were collected at five instances over the 100-min period. The first were prior to commencement of flow through the water pipes, and then every 25 min. Three replicates were collected on each occasion. These samples were analysed at a commercial quality-assured laboratory for total alkalinity (bicarbonate, hydroxide and carbonate) and other major dissolved major anions and cations (calcium, sodium, magnesium, potassium, chloride and sulfate) and all were reported with a lower detection limit of 1 mg/l. Ionic balance (total anions and total cations) was reported to a lower detection limit 0.01 meq/l. In addition to the laboratory analyses, electrical conductivity (EC), pH and temperature readings were collected every 5 min (starting prior to experiment commencement and concluding at 100 min) using a hand-held water chemistry meter (TPS Model Aqua CP, TPS Pty. Ltd. Springwood, Queensland). On each occasion three replicate readings were obtained.

Results were compared by analysis of variance (ANOVA) to determine if any varied temporarily. Results below detection limits were set at half the detection limit to enable parametric data analysis (Clarke 1998).

## Results

### *Initial water chemistry*

Major differences were reported between the water chemistry of the three water types (Table 2). Roof water was strongly acidic (pH 4.8) and had a low concentration of dissolved salts (EC 26 $\mu$S/cm). The concentrations of chloride (5.9 mg/l) and sodium (2.0 mg/l) was elevated, reflecting the high levels of atmospheric salt fall-out being 16–19 km from the coast (e.g., Hart and McKelvie 1986). Reference creek water was similarly mildly acidic (pH 5.2). Conductivity of non-urban reference creeks was higher than roof water (152.6 $\mu$S/cm) and levels of dissolved minerals were generally low. Sodium and chloride concentrations of reference creeks (17.7 and 42.1 mg/l) similarly reflected their coastal proximity (16–18 km from the ocean). Water from the urban creeks was mildly alkaline (pH 7.4) with a conductivity of 355.7 $\mu$S/cm.

The alkalinity (bicarbonate) concentrations varied significantly according to type of water ($F_{2,6} = 844.7$, $P < 0.001$). Urban creek water was 2135% higher than reference creek water and 7260% higher than roof water (Table 2). Similarly concentrations of dissolved calcium were also significantly higher, 533 and 3200%, respectively ($F_{2,6} = 65535$, $P < 0.0001$).

Table 1. Catchment characteristics for urban and reference streams sampled this study.

| | Urban creeks | | Reference creeks | |
|---|---|---|---|---|
| | Falls Ck | Quarry Ck | Salvation Ck | McCarrs Ck |
| Catchment area (ha) | 90.8 | 87.4 | 71.1 | 458.7 |
| Roofs and hardstand (%) | 19.7 | 20.2 | 0.0 | 0.7 |
| Roads (%) | 6.1 | 9.5 | 0.7 | 0.7 |
| Other hard surfaces (%) (eg carparks, office buildings) | 4.0 | 4.3 | 0.0 | 0.4 |
| Connected impervious area (%) | 29.8 | 34.1 | 0.0 | 0.0 |
| Total impervious (%) | 29.8 | 34.1 | 0.7 | 1.8 |

Table 2. Mean concentration of water chemistry attributes before and after 100 min of recirculation through either a PVC or concrete pipe. The resulting level is bolded where a statistical increase was detected after the 100-min test.

| | Roof water | | | Reference creek | | | Urban creek | | |
|---|---|---|---|---|---|---|---|---|---|
| | | After 100 min. | | | After 100 min. | | | After 100 min. | |
| Units | Before | PVC pipe | Con. pipe | Before | PVC pipe | Con. pipe | Before | PVC pipe | Con. pipe |
| K (mg/l) | 0.5 | 0.5 | **4.0**[3] | 1.3 | 1.0 ns | **4.0**[3] | 3.0 | 3.0 | **6.0**[3] |
| Total alkalinity (bicarbonate) (mg/l) | 0.5 | **4.0**[1] | **17.3**[3] | 1.7 | 3.0 ns | **14.3**[3] | 36.3 | **40.0**[3] | **41.7**[3] |
| Ca (mg/l) | 0.5 | **1.0**[2] | **3.7**[3] | 3.0 | 3.0 | **6.0**[3] | 16.0 | **17.7**[2] | **18.3**[2] |
| Na (mg/l) | 2.0 | 2.0 | **4.0**[3] | 17.7 | 18.7 ns | **19.0**[1] | 36.3 | **38.0**[1] | 37.0 ns |
| EC ($\mu$S/cm) | 26.0 | **27.1**[3] | **56.2**[3] | 152.6 | 151.7 | **177.0**[3] | 355.7 | **358.0**[3] | **353.0**[3] |
| pH (pH units) | 4.8 | **6.4**[3] | **7.9**[3] | 5.2 | **7.1**[3] | **7.7**[3] | 7.4 | **7.9**[3] | **8.0**[3] |
| Cl (mg/l) | 5.9 | 6.6 ns | 7.4 ns | 42.1 | 43.3 ns | 42.8 ns | 74.0 | 75.7 ns | **76.3**[1] |
| $SO_4$ (mg/l) | 1.0 | 1.7 ns | **2.0**[3] | 8.0 | 8.0 | 8.0 | 19.7 | 20.0 ns | **21.0**[3] |
| Mg (mg/l) | 0.5 | 0.5 | 0.5 | 3.0 | 2.7 | 2.0 | 6.0 | 6 | 6 |
| Total anions (meq/l) | 0.2 | 0.3[2] | 0.6[3] | 1.4 | 1.4 | 1.6[3] | 3.2 | 3.4[3] | 3.4[3] |
| Total cations (meq/l) | 0.1 | 0.2[3] | 0.5[3] | 1.2 | 1.2 | 1.4[3] | 2.9 | 3.1[3] | 3.1[3] |

ANOVA results: df = 10 (EC and pH; df = 42), ns, $P > 0.05$; [1]$0.01 < P < 0.05$; [2]$0.001 < P < 0.01$; [3]$P < 0.001$.

The ionic proportions of roof water were very similar to that found in non-urban reference creek water. Urban water was dominated by sodium and chloride ions, but calcium and bicarbonate were the sub-dominant anion and cation. Reference creek water, when exposed to concrete pipe in the experiment for 100 min, had similar ionic proportions to urban water with sub-dominance of calcium and bicarbonate ions.

### *Impact of the pipes*

During the experiment, the pH in all water types and both pipe materials increased highly significantly over the 100-min period (Table 2, Figure 1). This rise in pH was largest for roof water and reference creek water.

The concrete pipe was associated with the largest changes in pH (Figure 1). It was greatest for the samples of rainwater and reference creek water. Although the pH of each water-type was different at the outset of the experiment (4.8–7.4), it was similar after 100 min circulation through the concrete pipe (7.7–8.0).

Total alkalinity (bicarbonate) levels also increased after the experiment with the concrete pipe: roof water (3360% increase), reference creek (741% increase) and urban water (14% increase) (Figure 2). Calcium concentrations also displayed large and highly significant increases for all water types exposed to concrete: roof water (640% increase), reference creek (100% increase) samples and urban (15% increase) (Table 2, Figure 3). The increase in potassium concentrations was also highly significant, increasing between 100 and 700%, in all water types exposed to the concrete pipe (Figure 4). PVC pipes did not result in an increase in potassium (Table 2).

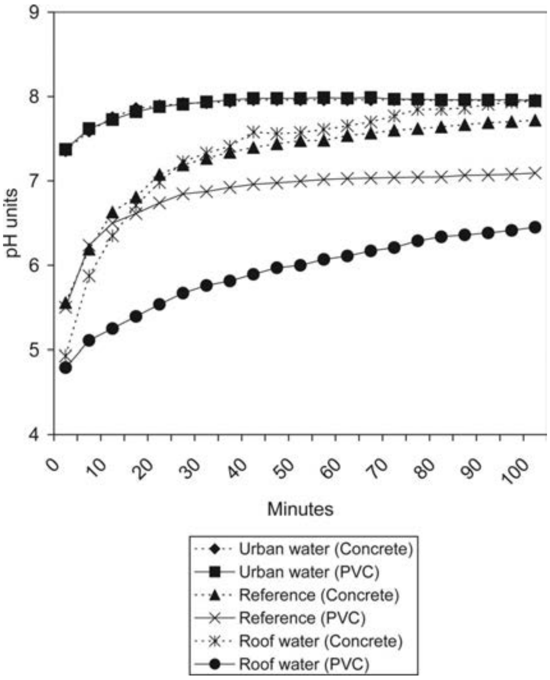


Figure 1. Mean pH levels of water samples measured every 5 min over 100 min.

The total anion and cation levels in all three water types increased after each 100-min experiment in PVC and concrete pipes (Table 2). Urban water resulted in the lowest increases (anions: 4.3% PVC and 6.2% concrete; cations: 5.4% PVC and 6.5% concrete). Reference creek water had moderate increases (anions: 5.1% PVC and 11.5% concrete; cations: 5% PVC and

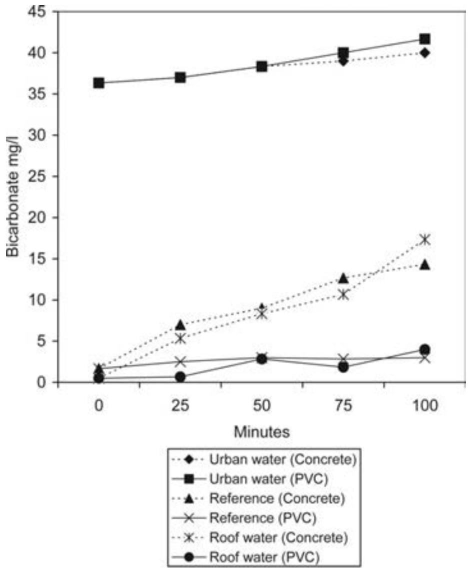


Figure 2. Mean total alkalinity (bicarbonate) levels of water samples measured every 25 min over 100 min.

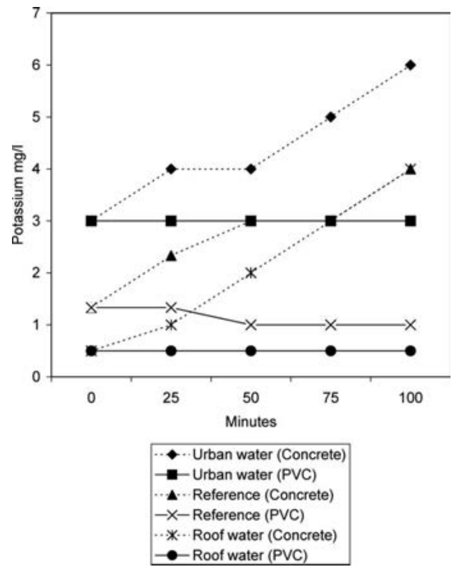


Figure 3. Mean potassium levels of water samples measured every 25 min over 100 min.

15.2% concrete). The largest increases were recorded in roof water (anions: 158% PVC and 337% concrete; cations 170% PVC and concrete 460%).

**Discussion**

Results from the current study provide support for the idea that concrete drainage materials and their

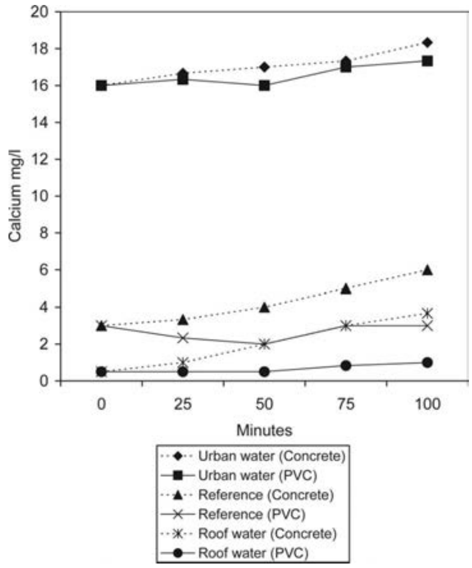


Figure 4. Mean calcium levels of water samples measured every 25 min over 100 min.

widespread use as construction materials, has an influence on the water chemistry of urban streams. The largest rises in pH, EC and several major anions and cation concentrations was recorded when acidic and mineral-poor water was circulated through a concrete pipe. The increase was greatest for rainwater, lowest for urban creek water and was intermediate for reference creek water.

As the water was circulating through the pipe gasses would have been expelled from the water influencing the chemistry. This was notable in the PVC pipe as reflected by an increase in pH, most likely attributed to a release of carbon dioxide. Such change would have also occurred in the concrete pipe, however the impact of the dissolution of concrete would seem to have had a greater influence.

***Material degradation***

The process of carbonation is a major factor in the degradation of concrete. It is the result of chemical reactions between carbon dioxide and concrete hydrates, such as calcium hydroxide ($Ca(OH)_2$ or portlandite) and calcium silicate hydrates (CSH) producing calcium carbonate ($CaCO_3$) and water. The mechanism is well described and understood in material science literature (Clifton 1993). A number of factors have been classified affecting the chemical attack of concrete including: acidic attack, alkaline attack, carbonation, chloride attach, leaching and sulphate attack (ACI 1982). In urban areas and where cementatious pipes are used to convey stormwater, it is likely that the acidic attack associated with the lower pH of rainfall is reacting with the alkaline hydration products of cement resulting in calcium salts (Zivica and Bajza 2001) as well as other changes to water chemistry. This process is evident in this experiment as demonstrated by the rise in pH and the elevation of alkalinity (bicarbonate), calcium and potassium concentrations (Figure 4).

### *In transport processes*

A change in water chemistry can in part be attributed to the circulation of water resulting in aeration and a slight increase in temperature. This processes results in the release of $CO_2$ from solution in the water in turn shifting the pH towards neutral (pH 7). Figure 1 shows the pH increases for all samples, for both the PVC and concrete pipes. Roof water recirculating through the PVC pipe was the only treatment not to reach pH 7. When these water types were exposed through the concrete pipe, the pH continues to increase towards 8. This additional change is most likely attributed to a high amount of dissolved calcium and bicarbonate ions in the sample as it previously was subject to the chemical changes from the urban drainage system and environs. Changes in water chemistry from the urban water sample through the concrete pipes were minimal. It is suggested that the water has already been modified by contact with concrete materials that are typically from the pipe drainage network as well as from urban concrete surface materials such as kerb and gutters, driveways and carparks.

The experimental exposure of roof water and reference creek water to the concrete pipe led to a change in water chemistry that exceeded the pH and potassium levels recorded in urban creeks (prior to pipe exposure) (Table 2). The ionic proportions of reference creek water, after 100 min exposure to concrete, were similar to those found in urban water samples. The reference creek samples (following concrete exposure) had higher relative concentrations of Ca and $HCO_3$ ions than were found in roof water or reference creek samples.

### *Base line water chemistry*

Ku-ring-gai's urban waterways are known to be of average to poor ecosystem health with degraded macroinvertebrate communities and elevated pH, alkalinity and EC levels (Wright *et al.* 2007, Davies *et al.* 2010). The current study also observed that pH, EC and major ionic constituents (major anions and cations) were clearly different at urban streams compared to non-urban reference streams. Within the study area natural or reference streams were mildly to strongly acidic while urban sites ranged from mildly acidic to slightly alkaline. The reference streams had a much lower level of dissolved salts and minerals, with much lower EC (mean 180–230 $\mu$S/cm) and lower levels of many major anions and cations, such as total alkalinity (bicarbonate) levels of 1–8 mg/l in reference streams compared to 30 –125 in urban streams (Table 2 and Figure 1). The major ionic proportions of roof water and reference creek water were relatively impoverished in calcium and bicarbonate compared to urban creeks. After roof and reference creek water were exposure to a concrete pipe, the relative proportions of calcium and bicarbonate rose, and became similar to that found in urban streams.

### *Implications*

At a catchment scale the results suggest that concrete pipes, as a conduit for stormwater, have a greater effect on water chemistry than PVC pipes for certain chemical attributes. The concrete pipe that was used in the experiment was new and therefore had a greater exposure to concrete when compared to an older pipe where the aggregates are visible. This suggests that as the pipe is degraded over time the extent of change may be less.

A relationship was also evident between time of contact and changes to water chemistry for some attributes, particularly for the rainwater sample. This points towards differing rates of change as a function of the chemistry of water either through its contact with the pipe and or the concentration of dissolved gases.

The sampling design used in this study (20 l of water at 0.2 l/s over 1.4 m of pipe for 100 min) represents flow lengths of approximately 84 m. This is 17% of the average flow length within a typical catchment in the Ku-ring-gai Council LGA. As such, the study results may be viewed as conservative. As water from the urban creeks had been conveyed through concrete pipes and gutters prior to collection, it is of little surprise that the chemistry of this water did not change a lot during the pipe experiments as it had previously been subject to the influence of concrete and associated dissolution of calcium ions.

From a catchment perspective, the causal factors contributing to degradation in urban stream health are complex and have tended to focus on land use, with catchment imperviousness identified as one of the most influential factors affecting the degradation of urban streams and their biota (e.g., Arnold and Gibbons

1996). While other researchers, such as Ladson *et al.* (2006), have identified major factors that contribute to urban waterway health (including: biology; geology; in-stream habitat; hydrology; hydraulics; water quality; sediment quality; riparian habitat; and continuity and barriers), this work suggests that materials used as part of the drainage conveyance system should be given further consideration. In this context, it is necessary to not only consider build-up and subsequent wash-off pollutants within an urban setting but also to examine the impact of the deterioration of materials within the urban fabric. This incorporates the drainage network, roads, driveways, buildings and other structure. Such consideration would follow in the same way that geology and soil chemistry influence physical and chemical changes within the environment.

From a water quality perspective, the results clearly identify significant changes in aquatic chemistry. Hydraulically, stormwater pipes usually play the major role in urban areas for stormwater conveyance. The results of this study also point towards the use of concrete stormwater and drainage materials as a potentially important human modification of urban catchment geology and water chemistry. Concrete drainage materials provide an unnatural source of ionic compounds (particularly calcium and bicarbonate) that leach into urban waters. The ionic proportions of both non-urban reference creeks and rainfall (from roof water samples) in this study were ionically very similar and both reflect the importance of atmospheric derived ions, with sodium and chloride being the dominant ions. Both the roof water and reference creeks had very low relative concentrations of calcium and bicarbonate. Urban waters had a different ionic composition and although sodium and chloride were still the dominant anion and cation, calcium and bicarbonate were the next most dominant anions and cations. According to the review of Australian inland waters, the concrete drainage material has created an unnatural "urban geological" signature or source of ions (Hart and McKelvie 1986).

Such modification of water ionic proportions has major implications for the ecology of urban waterways. For example, an extensive continental-scale study of benthic diatoms of US rivers (Patapova and Charles 2003) revealed the importance of the chemical ionic proportions to freshwater diatom communities. Patapova and Charles identified that calcium and bicarbonate were the two of the most influential ions to species assemblages in diatom communities. Other literature also supports that pH, EC and major anions and cation levels can have a strong influence on the base levels of aquatic ecosystem food chains. For example, algal diatoms are a major source of food and energy in flowing waters and have been found to be strongly influenced by pH, salinity and other environmental factors (e.g., Lowe 1974, Hirst *et al.* 2004, Chessman *et al.* 2007). Changes in water chemistry that recorded in this study are likely to influence algal diatoms communities in urban streams, with flow-on effects to other elements of the aquatic ecosystem (such as; bacteria, fungi, invertebrates, zooplankton and fish).

While this study was based within the Ku-ring-gai LGA and its immediate surrounds, the results have broader implications. From the data it can be argued that in locations where the receiving environments are naturally acidic, they are more likely to experience significant changes to water chemistry if concrete materials are used conveyance of rainfall and runoff.

If protecting the environmental condition of waterways is a primary objective of an urban design or drainage program, greater consideration should be given to materials used in construction and operation of hydraulic systems and generally within the catchment. While this study has not sought to understand the implications of the ionic and chemistry difference that may arise from the use of concrete or PVC pipes, it is foreseeable that it would impact biota within an otherwise calcium and bicarbonate limited and acidic environment.

## Conclusion

The results indicate that concrete pipes have a significant impact on water chemistry on rain water and water taken from a natural stream. This was most notable in terms of pH, EC, bicarbonate levels and concentrations of potassium and calcium. Aeration of water was also a factor that leads to a change in water chemistry. This was notable in the change to the water circulating through the PVC pipes and would have also been present in the concrete pipe though was overshadowed by other chemical changes from the concrete. Water from urban creeks reported the least change, though noting their cation, anion and pH levels were elevated from the outset from previous exposure. The research suggests that where creeks are naturally acidic and with naturally low calcium and bicarbonate levels, the use of concrete as part of the urban drainage system will impact on water chemistry. This points to yet another dimension for engineers and ecologists to consider when implementing water sensitive urban design or low impact developments.

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paper seven

# The effect of the in-transport process on urban water chemistry – an examination of the contribution of concrete pipes and gutters on urban water quality

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# The effect of the in-transport process on urban water chemistry – an examination of the contribution of concrete pipes and gutters on urban water quality

## Impact du processus de transport en réseaux sur la chimie des eaux urbaines : étude de la contribution des canalisations et caniveaux en béton sur la qualité des eaux urbaines

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## RÉSUMÉ

L'objectif de cette étude était d'évaluer l'impact des canalisations en béton sur les caractéristiques chimiques de l'eau et sur la qualité des cours d'eau urbains. Alors que la gestion des eaux urbaines permet aujourd'hui de mieux comprendre les impacts environnementaux du développement, peu de recherches portent sur les processus pendant le transport des eaux de pluie dans les réseaux d'assainissement. Les systèmes conçus pour les eaux pluviales sont essentiellement destinés à gérer l'impact des inondations et des écoulements de surface. Pour ce faire, ils font surtout appel à des matériaux robustes et à haute efficience hydraulique tels que les canalisations en béton. Lors des études sur la qualité de l'eau dans les banlieues nord de Sydney, des niveaux de pH et de bicarbonates statistiquement plus élevés ont été observés dans les bassins versants des zones d'aménagement par rapport à ceux notés dans les bassins versants de zones non aménagées ou de friches. Ceci a conduit les chercheurs à étudier le rôle éventuel du béton, matériau dominant dans les systèmes d'assainissement, dans cette différence. On a fait circuler de l'eau de pluie dans des canalisations en béton pendant 120 minutes, puis on a mesuré différents composants chimiques. Les résultats indiquent qu'indépendamment de l'ancienneté de la conduite en béton, les caractéristiques chimiques de l'eau changent significativement en comparaison avec l'eau circulée dans des canalisations en plastique (utilisées comme contrôle), avec le plus fort changement constaté sur les nouvelles conduites. La dissolution dans l'eau des produits de ciment en est la principale cause. Ces observations sont particulièrement pertinentes si les eaux réceptrices et leurs écosystèmes sont naturellement acides et sensibles aux changements des niveaux d'alcalinité et de bicarbonate.

## ABSTRACT

The objective of this study was to test the impact of concrete pipes on the chemistry of water and how this may be a factor that influences water quality in urban streams. While contemporary urban water management is increasing its understanding of the impacts of urban catchment development on the environment, little research has been undertaken on in-transport processes associated with the stormwater drainage network. Stormwater systems are designed primarily to manage the impacts of flooding and overland flow. Robust and hydraulically efficient materials, such as concrete pipes, have been the favoured to achieve these outcomes. An investigation of water quality in the northern suburbs of Sydney showed pH and bicarbonate levels were statistically higher in the developed catchments compared to the undeveloped or bushland catchments. This prompted the researchers to investigate if concrete, being the dominate material of the stormwater drainage system, may be contributing to this difference. Rainwater collected from the catchment was passed through various concrete pipes over a period of 120 minutes and measured for a range of analytes. The results reported that irrespective of the age of the concrete pipe there was a significant change in water chemistry when compared with the flows through a plastic stormwater pipe (used as a control). Newer pipes reported the greatest degree of change. The principal cause was the dissolution of cement products into the water. These findings are particularly relevant where the buffering of naturally acidic rain, primarily achieved through the dissolution of calcium from concrete drainage structures, alters the chemistry of natural water bodies. These ecosystems are naturally acidic and sensitive to changes in alkalinity and bicarbonate levels.

## KEYWORDS

Concrete pipes, urban water drainage, water chemistry, water sensitive urban design

# 1 INTRODUCTION

Urban drainage systems are dominated by a series of connected concrete pipes and culverts to convey stormwater runoff away from developed areas. The design philosophy behind this engineering has been to mitigate the impacts of local flooding and overland flow. In Australia, this has led to numerous design guidelines such as '*Australian Rainfall and Runoff*', by the Institute of Engineers Australia (O'Loughlin and Robinson 2001) and '*Flood Plain Development Manual*' (DIPNR 2005) that have informed hydrology, civil design and urban planning.

More recently the management of urban water drainage has broadened its focus from hydrology and hydraulics to encapsulate considerations of the broader water cycle such as water quality, riparian systems, potable water supply, wastewater disposal and stormwater drainage. The terms integrated water cycle management, water sensitive urban design (WSUD) (Wong 2006) and low impact development (LID) (Coffman 2002) are often used to describe this shift in philosophy, which has been encapsulated in broader urban water planning and local government policy (e.g. Ku-ring-gai Council 2008). These contemporary engineering and urban planning themes are consistent with the work of environmental scientists such as Dunne and Leopold (1978) Klein (1979), Hall and Ellis (1985) and Walsh et al (2001) that identified various impacts subsequently described by Meyer et al (2005) as the 'urban stream syndrome'.

In Australia, regulation of the pollution of waterways has traditionally been the domain of state governments through their environmental protection agencies. The point source regulatory regime introduced in the 1970s has evolved to the present day approach where diffuse pollution from stormwater runoff is also considered, although largely within a broader policy framework. The challenge for regulators, urban planners, environmental scientists and engineers is to identify the most influential factors and also interrelationships that impact on the health of the environment. For example, Breen and Lawrence (2006) identified nine major factors that contribute to waterway health (including: biology; geology; in-stream habitat; hydrology; hydraulics; water quality; sediment quality; riparian habitat; and continuity and barriers), although these are rarely considered in totality in the design and maintenance of urban drainage networks particularly in infill or already developed areas. Added to these considerations are other factors such as acidic deposition and pollution from urban building materials.

In seeking to understand the contribution of non-point source pollution, researchers have brought together water quality findings from various land uses (eg residential or industrial) or urban materials (eg roads and roofs) to estimate pollution generation across urban catchments (eg: Novotny et al 1985 and Wong 2006). Common to many of these studies has been the attempt to describe the accumulation of pollutants to help inform pollution generation models such as MUSIC (Fletcher et al 2001). For example Sartor and Boyd (1972) concluded most pollutants could be found within 1 metre of the kerb thus supporting a conclusion of pollutant load as an expression of the total length of kerb. Ladson et al (2006) and Conway (2007) suggested catchment imperviousness or connected imperviousness (generally be defined by the area linked by urban drainage systems) as a proportion of the catchment areas to be a surrogate indicator of total pollution generation and in turn waterway health. Most attempts to determine the sources and contribution of non-point source pollution in urban areas is recognition of the importance of the urban drainage network, be it length or proportion linking the impervious areas of the catchment. Research to date in this field has largely ignored the contribtion of in-transport processes of the urban drainage network to water quality, water chemistry and subsequent ecological implications, particularly given the widespread use of concrete (eg Clark et al 2005).

Leung and Jiao (2006) touched on this area where they reported groundwater downstream of concrete basements had a high pH and high levels of bicarbonate, calcium and other ions when compared to groundwater in the undeveloped catchment upslope. However they did not draw any strong conclusions as to the environmental impact. Conway (2007) reported a positive correlation between pH and catchment imperviousness, though did not suggest drainage materials to be causal factor.

Novotny and Kincaid (1981) considered the effect of in transport process as part of their investigations into the buffering capacity of pavements to neutralised acid rain. Their conclusions supported materials such as concrete due to their effectiveness in buffering very low pH levels associated with acid rain in Milwaukee.

Low pH, salinity and buffering values are natural characteristics for the coastal, sandstone dominated water bodies in the Sydney region, as identified by Hayes and Buckney (1995). Thus, the benefit of highly buffered run-off (pH 7+) containing elevated levels of bicarbonate and calcium ions in an environment usually devoid of such elements is questioned.

This paper seeks to provide supportive evidence of the impact of concrete (the most commonly used stormwater drainage material) on in-stream water quality and suggests that its effect should be considered as a significant contributor to changes in urban water chemistry that can affect urban waterway health.

## 1.1 Water chemistry and the urban environment

Gibbs (1970) identified three major mechanisms controlling world surface water chemistry: atmospheric precipitation, that is often but not always related to the proximity to the coast; rock dominance, where waters are often in equilibrium with the geology of their area; and the evaporation-crystallisation process that dominate in hot arid regions. He also concluded that second order factors such as composition of materials had a minor influence at a catchment scale. Building on this work, Hart and McKelvie (1986) looked at the natural ionic balance of waterways of inland Australian waters and similarly concluded the composition and relative proportion of the major ions (Na, Ca, Mg, K, $HCO_3$, Cl, $SO_4$) responded to the atmospheric and catchment geological sources of ions.

On a smaller scale, such as an urban catchment, the secondary impacts as described by Gibbs (1970) would seem to have greater dominance over water chemistry. As naturally acidic precipitation, pH 5.6 (AEC 1989), passes through the atmosphere and over the ground, buffering mechanisms neutralise the acids through a variety of cation exchanges, expressed broadly in terms of alkalinity (primarily carbonate and bi-carbonate levels).The composition of catchment surfaces is altered by urbanisation through the introduction of built structures and the extent of this buffering process is largely dependant upon catchment materials.

Past studies on the waterways in the northern suburbs of Sydney have identified major differences in base flow water chemistry between urban and non-urban 'reference' waterways (Wright et al 2007). These studies found dry weather sampling indicated a significantly different chemical signature across the major anions and cations with urban streams varying between mildly acidic to slightly alkaline while reference streams were about 1 pH unit more acidic, suggesting a different level of buffering. In addition, the urban waterways had a 20-fold higher alkalinity and twice the electrical conductivity of reference waterways.

As a result of these observations, an initial investigation was undertaken to explore if there was a link between the water chemistry in urban streams and the materials comprising the urban drainage system (Davies et al 2009). This research examined the changes in three water types (rain, urban stream and reference stream) when exposed to two commonly used drainage materials, concrete and PVC. Rainwater collected from rainwater tanks in the study area was acidic (pH 4.79) and had low bicarbonate concentrations (0.5mg/L). A composite water sample from two urban streams was mildly alkaline (pH 7.35) with bicarbonate concentrations of 36.3 mg/L. A composite water sample from two reference streams in close proximity to the urban area and with similar geology was mildly acidic (pH 5.5) with bicarbonate concentrations of 1.7 mg/L.

A 20 L sample from each of three water types (rain, urban stream and reference stream) was then circulated through a new concrete pipe and a new PVC pipe for 100 minutes. Roof water and stream water from the non-urban undeveloped catchment reported a significant increase across a range of analytes. Bicarbonate levels increased steeply when passed through the concrete pipe, while water from the urban creek changed a lesser amount. When passed through the PVC pipe the changes in water chemistry were significantly less for all water types (Davies et al 2009).

This study concluded, similar to Novotny and Kincaid (1981), that the elevated calcium ions are attributed to concrete and that in spite of the low pH of the rain, runoff from urban areas was always well above neutral indicating a high buffering capacity of the urban overland flow process.

## 1.2 Impact and degradation of concrete

The process of carbonation is a major factor in the degradation of concrete. It is the result of chemical reactions between carbon dioxide and concrete hydrates, such as calcium hydroxide ($Ca(OH)_2$) or portlanidite and calcium silicate hydrates (CSH) producing calcium carbonate ($CaCO_3$) and water. The mechanism is well described and understood in material science literature (eg: Clifton 1993). A number of factors have been classified as affecting the chemical attack of concrete including: acidic attack, alkaline attack, carbonation, chloride attach, leaching and sulphate attack (ACI 1982).

In urban areas and where cement pipes are used to convey stormwater, the acidic attack associated with the lower pH of the acidic rain reacts with the alkaline hydration products of cement as part of the buffering process. This results in calcium salts as well as other changes to water chemistry (Zivica and Bajza 2001). This process is evident in past research by the authors (Davies et al 2009) and other such as Novotny and Kincaid (1981) and Leung and Jiao (2006) that reported a higher concentration in alkalinity-bicarbonate, calcium concentrations and potassium in runoff or ground water flow that has had a prolonged contact with concrete surfaces

As the reinforced concrete pipe used in the earlier study by the authors was new, there was a need to explore if the age or degradation of the pipe resulted in any difference to the water chemistry as urban catchment typically contain drainage systems of a variety of ages reflecting their development pattern. The surface of new pipes can be described as smooth with no visible aggregate and can often have a fine film of dry cement material that is removed once flushed. These characteristics suggests a higher concentration of finer cement (concrete hydrates) at the surface than would be representative if the pipe has been in use and this "skin" or surface material had eroded or dissolved, consequently having a greater impact on water chemistry. It would therefore be expected that as pipes and other concrete drainage structures (such as gutters and culverts) degrade, their impact on water chemistry should lessen. This research was initiated to test this hypothesis.

## 2 METHODS

Two new (without the fine film described above) and two old pipes were used for this study in conjunction with a PVC pipe to provide a control. The two new pipes were selected as representative of the drainage materials used by local government: a steel reinforced concrete pipe and a fibre reinforced concrete pipe. Each was 1600mm in length and 375mm diameter. The two old pipes were sourced from a material stockpile having been retired from the drainage network and were visibly pitted with aggregate showing and contained hairline fractures visible once water had been passed through them. The first was a steel reinforced pipe 1800mm in length and 300mm in diameter; the second was a steel reinforced half pipe 800mm in length and approximately 225 mm in diameter. The concrete pipes and PVC pipe (as a control) were set at a grade of approximately 7.5%.

Rainwater was collected from two roof rainwater tanks within the Ku-ring-gai local government area, situated 14 km north of Sydney City at 33°45'20"S and 151°9'0"E. The first drained from a zincalume roof located in South Turramurra and the other from a slate (75%) and vitrified clay tile (25%) roof in Wahroonga. Both water samples were stored in a plastic rainwater tank for approximately two weeks prior to sampling. Equal portions of the rainwater were mixed to make a composite sample. These were divided into five batches, each with a volume of 20 litres.

A Rule 800GPH bilge pump operating off a 12 volt 5 amp fuse was used to pump the rainwater at a rate of approximately 0.5 L/s for 120 minutes. Prior to the commencement of sampling, each pipe was swept then flushed with surplus rainwater to remove any residual particulate or chemical matter. Samples were collected at time zero then at 5, 10, 20, 30, 40, 60, 90 and 120 minutes. The samples were analysed at a commercial NATA (National Association of Testing Authorities) accredited laboratory for Potassium, Bicarbonate Alkalinity, Carbonate, Hydroxide, Calcium, Sodium, Chloride, Sulphate, Magnesium, Total Anions and Total Cations. Bicarbonate Alkalinity (Alkalinity PC Titrator), dissolved major cations (Calcium, Sodium, Magnesium, Potassium) Chloride (Chloride discrete analyser) and Sulfate as SO4 (Turbidimetric) are all reported to a limit of 1 mg/L. Ionic balance (Total Anions and Total Cations) are reported to a level of 0.01 meq/L.

In addition to the laboratory analyses of conductivity, pH and temperature readings were collected every minute for the first 10 minutes then at five minute intervals using a hand held water chemistry meter (Yeo-Kal 615 Water Quality Analyser, Yeo-Kal Pty Ltd, Brookvale NSW).

## 3 RESULTS

The rainwater collected from the roofs in the urban catchment was acidic (pH 4.74-5.2) with an electrical conductivity of 12-25 µS/cm (Table 1). The low acidity of rainwater collected is likely to be caused by a combination of proximity to the coast and urban atmospheric pollutants (acid rain). The potential for acid rain has not been fully investigated in this study, however Chapman et al (2006) found that although Sydney's tank rainwater is slightly acidic it wasn't regarded as acid rain. The rainwater also had much lower levels of major anions and cations than had been previously recorded in urban streams in the northern Sydney area (Davies et al 2009).

Results from the field measurement and laboratory analysis are summarised in Table 1. Figure 1 shows the change in pH and conductivity for each of the different material type. Figure 2 shows the results of the laboratory analysis for Total Hardness; Bicarbonate alkalinity (as $CaCO_3$); Total Anions; Total Cations and Dissolved Major Cations – Calcium.

The rise in pH and conductivity over the experimental exposure period was greatest for the water conveyed in the new (steel-reinforced and fibre reinforced) concrete pipes, which had an average increase of 2.46 pH units and salinity increased by 43.5 µS/cm (Table 1). Water conveyed within the two older concrete pipes had lesser increases (average rise of 1.56 pH units and 9.5 µS/cm) (Table 1).

Bicarbonate and calcium levels both increased steeply after recirculation in both types of new concrete pipe, compared to old concrete pipes (Table 1). In comparison, bicarbonate levels also increased to a lesser magnitude in the PVC pipe, but calcium levels were unchanged (Table 1).

The PVC pipe recorded a negligible change in most water attributes over the same period (Table 1). The only notable increase was pH (average rise of 1.17 pH units) and bicarbonate (rise of 1.5 mg/L). (Table 1 and Figures 1 and 2).

| | New Steel Reinforced Pipe | | | New Fibre Reinforced Pipe | | | Old Steel Reinforced Pipe | | | Old Steel Reinforced Half-Pipe | | | PVC Pipe | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | S | F | D | S | F | D | S | F | D | S | F | D | S | F | D |
| pH | 4.9 | 7.59 | 2.69 | 5 | 7.22 | 2.22 | 5.07 | 6.32 | 1.25 | 4.74 | 6.61 | 1.87 | 5.2 | 6.37 | 1.17 |
| Conductivity µS/cm | 16 | 59 | 43 | 19 | 63 | 44 | 17 | 23 | 6 | 25 | 38 | 13 | 12 | 12 | 0 |
| Bicarbonate alkalinity (mg/L) | 0.5 | 22 | 21.5 | 0.5 | 16 | 15.5 | 0.5 | 3 | 2.5 | 0.5 | 5.3 | 4.8 | 0.5 | 2 | 1.5 |
| Total hardness (mg/L) | 0.5 | 17.7 | 17.2 | 0.5 | 17.0 | 16.5 | 0.5 | 4.7 | 4.2 | 0.5 | 6.0 | 5.5 | 0.5 | 0.5 | 0 |
| Total Calcium (mg/L) | 0.5 | 7.0 | 6.5 | 0.5 | 7 | 6.5 | 0.5 | 2 | 1.5 | 0.5 | 2.0 | 1.5 | 0.5 | 0.5 | 0 |
| Total anions (meq/L) | 0.18 | 0.71 | 0.53 | 0.18 | 0.53 | 0.35 | 0.2 | 0.3 | 0.1 | 0.20 | 0.26 | 0.06 | 0.20 | 0.19 | -0.01 |
| Total cations (meq/L) | 0.13 | 0.6 | 0.47 | 0.13 | 0.49 | 0.36 | 0.13 | 0.24 | 0.11 | 0.13 | 0.25 | 0.12 | 0.13 | 0.14 | 0.01 |

Table 1. Concentration of water chemistry attributes before (S – Start) and after (F – Finish) 120 minutes of recirculation through the pipes. The difference between the start and finish is represented by the values listed in column "D".

## 4 DISCUSSION

The results from this study confirm the previous research (Davies et al 2009 and Novotny and Kincaid 1981) that supports the hypothesis that concrete drainage materials influence the chemistry of water during conveyance or overland flow. We suggest that buffering rainwater will primarily occur when exposed to concrete hydrates. The degree of this impact lessens as the concrete pipes degrade.

As previously reported (Davies et al 2009), the change in pH in all pipes, including PVC, can in part be attributed to the circulation of water resulting in aeration. This causes carbon dioxide gas to be released from the water, which is part of the normal buffering process. The results for the PVC pipe also show that as pH increases, the level of bicarbonate ions also rise, due to the disassociation of carbonic acid (e.g. Boulton and Brock, 1999), with bicarbonate levels increasing four-fold after recirculation within the PVC pipe . The level of bicarbonate increase was considerably higher for all concrete pipes, with a 6 to 44 fold increase (Table 1).

Levels of pH appear to asymptote at different units as time of contact increases for the various pipes. This would suggest the buffering is nearing equilibrium. While the study circulated the water for only 120 minutes the flattening of the curves suggest a probable maximum pH change as reflected by the

Langeiler saturation pH value (Langelier 1936). This needs to be explored further and would be expected to be directly related to the molar concentration of calcium (as reflected by the composition of the pipe) and total alkalinity of the solution.

While pH can be used as an approximate measure of the level of influence the bicarbonate alkalinity, hardness and major cations provide the best indication as to the degree and extent of the dissolution of cement products into the water.

The circulation time of 120 minutes is roughly representative of the average time a given volume of base-flow interacts with the piped drainage network in Ku-ring-gai local government area. It should be noted that the impact on water chemistry as a result of contact with a concrete pipe would be more profound in low flows (base flow) than during storm flows, due to the relative ratio between wetted perimeter and flow during low flows. For the receiving waterways, low flows make up most of the volume of water found in permanent pools that occur between rain events and comprise the major habitat (by time) for aquatic plants and animals. Storm flows will typically pass through ephemeral and intermittent waterways as hydraulic peaks. For aquatic ecosystem health the water chemistry of base flow is therefore considered to be of high importance in urban creeks.

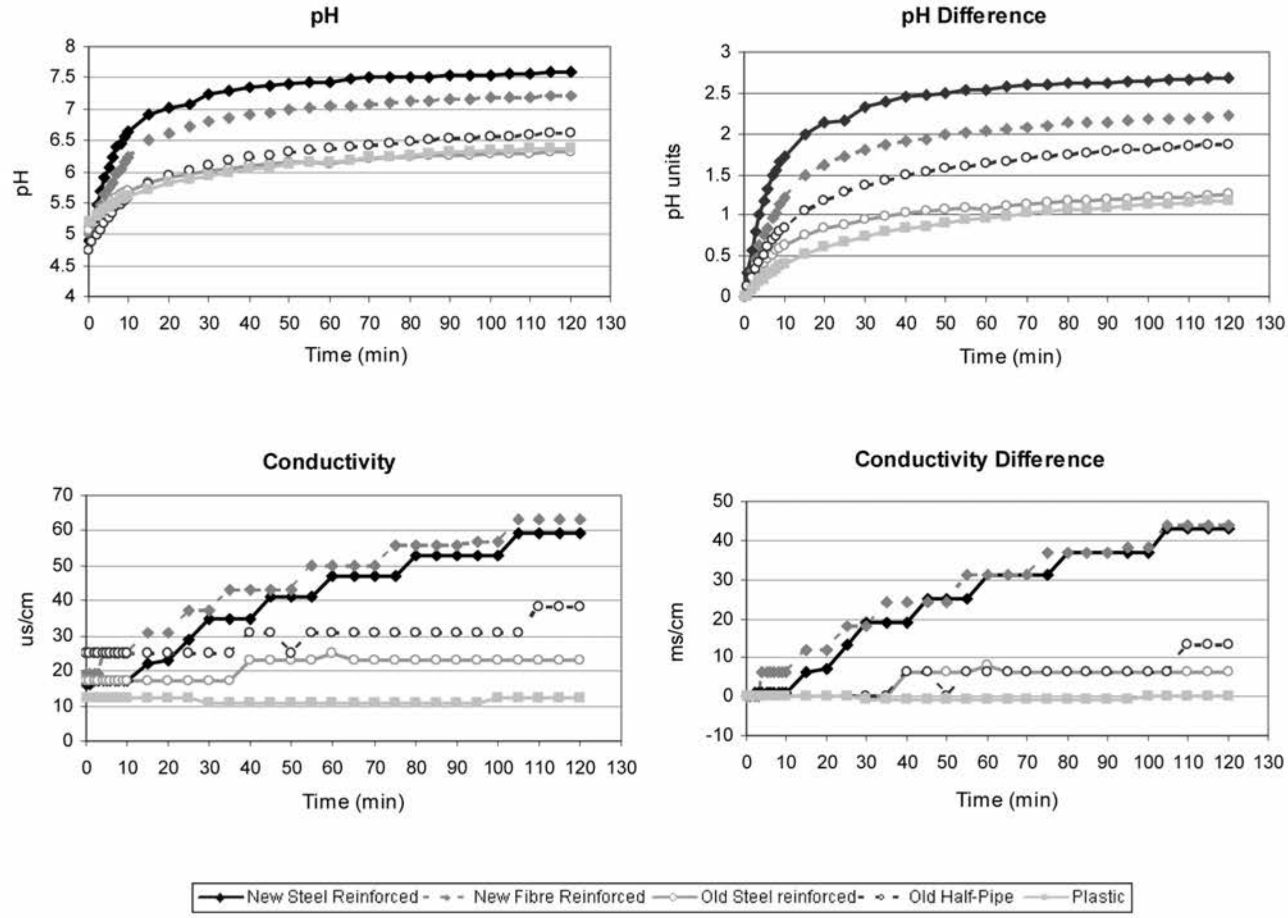


Figure 1. Field collected data graphs for pH and conductivity. Both the actual records and the difference from the start of circulation for each pipe are shown here. The different start points for the samples are due to a slight discrepancy in the meters (despite rigorous attempts to calibrate together) and the different batches of water.

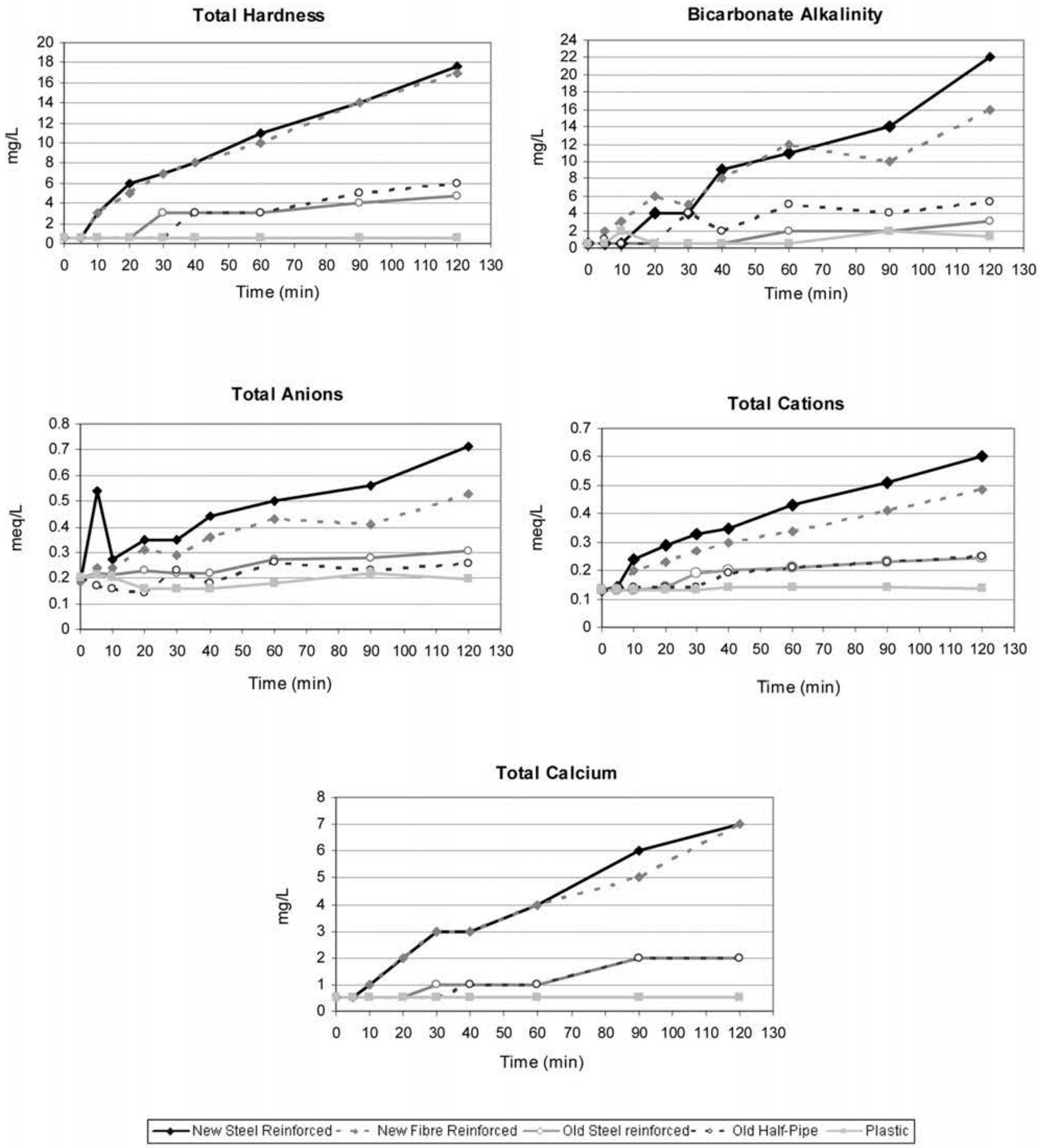


Figure 2. Graphs for Total Hardness; Bicarbonate Alkalinity; Total Anions; Total Cations and Total Calcium

## 4.1 Type, age and condition of concrete pipes and water chemistry effects

As reported in Table 1, this study found clear differences in the chemistry in water conveyed through new and old concrete pipes, when compared to the control. Figure 2 indicates that as circulation time increases so does the concentration of the respective anions and cations. Bicarbonate and calcium levels showed the greatest increase. We conclude that this is a result of the dissolution of the concrete. New pipes reported an increase in the concentration by over 35 times while the older pipes reported more than a four fold increase.

The most sudden increase was recorded for pH which displayed a rise of two (2) pH units within the first 20 minutes of exposure to new (steel and fibre reinforced) concrete pipe. Electrical conductivity did not start to increase for ten minutes, and for new concrete pipes, rose at a steady gradient for the entire experiment. Similar trends were also evident for hardness, bicarbonate and calcium analytes when recirculated within new concrete pipes. The stepped nature of this change is likely due to the sensitivity of the hand held water chemistry meter.

The water chemistry response in the two older concrete pipes was different. It increased over the 120 minutes, but to a lesser extent than was recorded for the new concrete pipes. Electrical conductivity and pH both changed to a much lesser degree. The change in pH was similar for water recirculated within the old steel-reinforced concrete pipe to the PVC pipe than the new concrete pipes (Figure 1). The old pipes did record substantial increases in ionic levels (calcium, bicarbonate, hardness, total anions, total cations) through the experiment, but these were generally about 40 to 60% lower than the increases recorded in the new pipes.

## 4.2 Implications and directions

From a water chemistry perspective, this study suggests that the second order factors such as composition of materials as described by Gibbs (1970) may have a greater level of influence on naturally acidic waterways within cities and other urban catchments. Precipitation across many cities is influenced by pollutants, particularly sulphate, sulphites and nitrates that contribute to a lowering of rainfall pH below the standard benchmark of pH 5 (AEC 1989). The impact of acidic rain on terrestrial and waterway health as well as built structures is well described in the literature (eg AEC 1989) and buffering by concrete during urban overland flow has been identified as an effective control against these negative effects (Novotny and Kincaid, 1981). However, buffering by concrete drainage systems not only elevates pH levels but also increases by many fold the concentrations of numerous cations, particularly calcium, that is not naturally prominent in all types of ecosystems.

If WSUD or low impact development is accepted as a contemporary management approach for urban development that seeks to improve the quality of the natural waterways, then recognising the impact of acidic rain and its relationship to urban building materials requires inclusion into design and maintenance considerations. These conclusions build on a long history of the impact of weathering of specific building materials such as limestone, marble and concrete (Schaffer 1932) and more recently the acceleration of this process through acid rain. Acknowledgement of this in part has been provided by the European Commission's mandate M/366 (EC, 2005) that has sought an assessment of the release of dangerous substances from construction products such that they will not be a threat to the hygiene or health of the inhabitants or neighbours not to the environment (EC, 1989). However, research undertaken by Schiopu et al (2009) to develop a model to estimate the leaching behaviours of concrete type construction materials recognised only Cr, Cu, Zn and $SO_4^{2-}$ as pollutants. Her research has however sought to include measure and model precipitation/dissolution reactions that could be used to quantify the effect of increasing various cations to waterways.

From a water quality perspective, variations in pH and salinity have been shown to have a strong influence on base levels of the aquatic ecosystem such as algal diatoms (Steinberg and Putz, 1991; Tibby et al. 2007). We suggest that some waterways are more susceptible to degradation from concrete-related contamination and this should be given the same level of consideration as the traditional pollutant suite such as nutrients and metals. This is particularly relevant for high conservation value waterways that are naturally acidic and have low levels of calcium and carbonate/bicarbonate.

At a practical level, the ubiquitous use of concrete as a drainage material will mean any change will be met with resistance and indeed the use of a substitute material must also undergo a similar level of investigation to determine its effect on receiving water bodies. While the rate of reactivity of calcite from acid attack has been shown to reduce with applying chemical and physical treatments (Wilkins et al 2001 and Alessandrini et al 2000), a similar approach may be possible, although there is a need to be cognisant of the abrasive forces of water and other debris that scour drainage systems during high flow. Given that the renewal of a concrete drainage system is one that is measured in decades (the useful life of drains has been estimated at 100 years and kerb and guttering at 70 years: NSW Department of Local Government 1995) and during this time the dissolution declines, the turnover of this asset to a more environmentally appropriate alternative will take time. Attention then may be best focused towards new development areas particularly at the urban fringe where discharges occur to waterways previously unaffected by concrete products particularly used in driveways, curbs and pipes.

# 5 CONCLUSIONS

This study has identified that rainwater collected from a major city and recirculated through different types and ages of concrete pipes can result in changes to water chemistry. This is reflected by increased levels of major anions and cations, particularity calcium, carbonates and bicarbonates. The extent of the change is greater for new pipes than old. New pipes also reported a greater level of change in pH and conductivity than old pipes and also with respect to PVC pipes that were used as a control. These findings support previous research into concrete degradation in urban areas. This research contributes to our understanding of our urban environment in that it points to a need to consider the impacts of in-transport processes from concrete structures such as drains on receiving water bodies. It also suggests that all materials across our urban landscape should be assessed for their contribution and impact on natural ecosystems. Furthermore there is a need to consider synergistic effects such as changes in pH on bioavailability of contaminants. While it is important to identify the individual contribution of pollutants in our waterways, the results of this study point to the need to look more closely at the drainage systems and their contribution beyond hydraulics and hydrology to the degradation of our aquatic ecosystems.

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paper eight

# Effects of concrete and PVC pipes on water chemistry

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# Effects of Concrete and PVC Pipes on Water Chemistry

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## Introduction

Australia has one of the world's most urbanised populations with approximately 75 per cent of its 21 million inhabitants living in urban areas (Australian Bureau of Statistics, 2004). This preference for urban living has resulted in extensive infrastructure to manage flood liable land, overland flow and general stormwater runoff. The vast majority of this drainage infrastructure is constructed from concrete based materials.

The objective of this study was to explore a possible link between the water chemistry of urban and reference streams to the composition of the stormwater conveyance system. The motivation behind this investigation follows the results from recent studies in the region that identified urban waterways as having different base flow chemistry to that found in nearby reference waterways (Wright *et al* 2007 Davies *et al* in press). Leung and Jiao (2006) also reported that one of the major factors controlling hydrogeochemistry of the developed slopes in Hong Kong is the dissolution of concrete, most likely attributed from concrete basements and deep foundations of high-rise buildings that are periodically or permanently beneath the water table.

The research was undertaken within the Ku-ring-gai local government area (LGA). The LGA covers 84 km$^2$ and is situated north of Sydney City at 33° 45′ 2 0″S and 151° 9′ 0″ E. Wianamatta Shale overlying Hawkesbury Sandstone characterises the interfluve areas with the deeply incised valleys and streambeds dominated by exposed Hawkesbury sandstone. The soil type is closely related to the underlying geology and is generally described as poor in both structure and geochemistry (Herbert and Helby 1980). Water quality between urban and reference creeks is significantly different across the major anions and cations and urban streams vary between mildly acidic to slightly alkaline while reference streams are acidic. Such differences are particularly apparent in dry weather conditions

A notable characteristic of the northern suburbs of Sydney is that development has occurred on the upper and flatter sections of the catchment. Remnant bushland remains on the steeper incised valleys. The developed area is dominated by low-density residential housing and there is no industry.

## Method

This study investigated the impact of a reinforced concrete pipe and a PVC pipe in changing the chemistry of three types of water including rainwater, urban stream water and reference stream water.

Rainwater was collected from two sources within the LGA. The first drained from a zincalume roof located in South Turramurra and the other a slate roof in Wahroonga. Both water samples were stored in a plastic rainwater tank prior to sampling. Urban stream water was collected from two creeks within the Ku-ring-gai local government area (Falls Creek, Gordon and Quarry Creek, West Pymble (refer to Table 1). In each case samples were taken immediately downstream from the urban interface. Reference creek water was taken from two creeks within the Ku-ring-gai Chase National Park, Salvation Creek and McCarrs Creek (Table 1).

A PVC and reinforced concrete pipe was fixed to a frame with a 6.5% and 7.5% grade respectively, the higher grade for concrete chosen to counteract the higher roughness of the pipe. Each pipe was 1.4 metres in length. Equal portions of the same water type were mixed to make a composite sample. These were divided into two batches, each with a volume of 20 litres. Each water type was manually circulated using buckets, with the water delivered to the pipes through an anti scouring device at a rate of approximately 0.2 l/s for 100 minutes. Prior to the commencement of sampling, each pipe was flushed with surplus sample water of the type to be used in order to remove any residue chemical or particulate matter.

Five samples were collected over the 100-minute period—the first prior to commencement and then every 25 minutes. These samples were analysed at a NATA accredited laboratory for Potassium, Bicarbonate Alkalinity, Calcium, Sodium, Electrical conductivity, pH, Chloride, Sulphate, Magnesium, Total Anions and Total Cations.

Bicarbonate Alkalinity (Alkalinity PC Titrator), dissolved major cations (Calcium, Sodium, Magnesium, Potassium) Chloride (Chloride discrete analyser) and Sulfate as SO4 (Turbidimetric) are all reported to a limit of 1 mg/L. Ionic balance (Total Anions and Total Cations) are reported to a level of 0.01 meq/L.

In addition to the laboratory analyses conductivity, pH and temperature readings were collected every five minutes (starting prior to experiment commencement and concluding at 100 minutes) using a hand held water chemistry meter (TPS Model Aqua CP, TPS Pty. Ltd. Springwood, Queensland).

Results were compared by ANOVA to determine if any varied temporarily. Results below detection limits were set at half the detection limit to enable parametric data analysis (Clarke 1998).

**Table 1. Catchment characteristics for urban and reference streams sampled for this study**

| | Urban | | Reference | |
|---|---|---|---|---|
| | Falls Ck | Quarry Ck | Salvation Ck | McCarrs Ck |
| Catchment area (ha) | 90.8 | 87.4 | 71.1 | 458.7 |
| Percentage Roofs and hardstand | 19.7% | 20.2% | 0.0% | 0.7% |
| Percentage Roads | 6.1% | 9.5% | 0.7% | 0.7% |
| Percentage Other hard surfaces (eg carparks, office buildings etc.) | 4.0% | 4.3% | 0.0% | 0.4% |
| Percentage connected impervious area | 29.8% | 34.1% | 0.0% | 0.0% |
| Total impervious percentage | 29.8% | 34.1% | 0.7% | 1.8% |

## Results

### Initial water chemistry

There were significant differences between the water chemistry of the three water types (Table 2). Roof water was strongly acidic (pH 4.7) with a low concentration of dissolved salts (EC 26 µS/cm). Chloride concentration was 5.9 mg/l that may reflect proximity to the coast and high levels of atmospheric salt fall-out with sample locations approximately 16–19 km from the coast. Reference creek water was similarly mildly acidic (pH 5.2). Conductivity was 152.6 µS/cm and levels of dissolved minerals generally low reflecting the geology, with sodium and chloride concentrations of 17.7 mg/L and 42.1 mg/L reflecting their coastal proximity, 16–18 km from the ocean. Water from the urban creeks was mildly alkaline (pH 7.4) with a conductivity of 355.7 µS/cm.

The bicarbonate alkalinity level varied significantly according to type of water ($F2,6 = 844.7$, $p < 0.0001$). It was 21.4 times higher in the urban creek sample compared to the reference creek and was 72.6 times higher in the urban creek than roof water. Similarly concentrations of dissolved calcium were also significantly higher, 5.3 and 32 times respectively ($F(2,6) = 65535$, $p < 0.0001$).

### Impact of the pipes

During the experiment, the pH in all water types and both pipe materials increased highly significantly over the 100-minute period (Table 2). This rise in pH was largest for roof water and reference creek water.

The concrete pipe had a significant influence on the change in pH. It was greatest for the roof water and reference creek water. Although the pH of each water-type was different at the outset of the experiment (4.7–7.4), it was similar after 100 minutes circulation through the concrete pipe (7.7–8.0).

The increase in Potassium concentrations was highly significant, between two and eight times, in all water types exposed to the concrete pipe. PVC did not report an increase (Table 2). Calcium concentrations also displayed a highly significant increase for all water types exposed to concrete: roof water (7 fold increase), reference creek (2 fold increase) samples and urban (15% increase) (Table 2). Total alkalinity/bicarbonate levels also increased after the experiment with the concrete pipe: roof water (35 fold increase), reference creek (8 fold increase) and urban water (14% increase).

The total anion and cation level in all three water types increased after each 100-minute experiment in PVC and concrete pipes. Urban water resulted in the lowest increases (anions: 4.3 % PVC and 6.2 % concrete; cations: 5.4 % PVC and 6.5 % concrete). Reference creek water had moderate increases (anions: 5.1 % PVC and 11.5 % concrete; cations: 5 % PVC and 15.2 % concrete). The largest increases were recorded in roof water (anions: 158 % PVC and 337 % concrete; cations 170 % PVC and concrete 460 %).

**Table 2. Concentration of analytes before and after 100 minutes passing through a PVC or concrete pipe (ANOVA results testing from testing for temporal differences: df=10 (EC and pH; df=42), ns, p>0.05; *, 0.01<p<0.05; **, 0.001<p<0.01; ***, p<0.001).**

| | Roof water | | | Reference creek | | | Urban creek | | |
|---|---|---|---|---|---|---|---|---|---|
| UNITS | Before | PVC pipe | Con. pipe | Before | PVC pipe | Con. pipe | Before | PVC pipe | Con. pipe |
| K (mg/l) | 0.5 | **0.5** * | **4.0*** *** | 1.3 | 1.0 ns | **4.0*** *** | 3.0 | 3.0 ns | **6.0*** *** |
| Total Alk-Bicarb (mg/l) | 0.5 | **4.0*** * | **17.3*** *** | 1.7 | 3.0 ns | **14.3*** *** | 36.3 | **40.0*** *** | **41.3*** *** |
| Ca (mg/l) | 0.5 | **1.0*** ** | **3.7*** *** | 3.0 | **3.0*** * | **6.0*** *** | 16.0 | **17.7*** *** | **18.3*** *** |
| Na (mg/l) | 2.0 | **2.0*** ** | **4.0*** *** | 17.7 | 18.7 ns | **19.7*** * | 36.3 | **38.0*** * | 37.0 ns |
| EC (µS/cm) | 26.0 | **27.1*** *** | **56.2*** *** | 152.6 | **151.7*** *** | **177.0*** *** | 355.7 | **358.0*** *** | **353.0*** *** |
| pH (pH units) | 4.7 | **6.4*** *** | **7.9*** *** | 5.2 | **7.1*** *** | **7.7*** *** | 7.4 | **7.9*** *** | **8.0*** *** |
| Cl (mg/l) | 5.9 | 6.6 ns | 7.4 ns | 42.1 | 43.3 ns | 42.8 ns | 74.0 | 75.7 ns | **76.3*** * |
| SO4 (mg/l) | 1.0 | 1.7 ns | **2.0** *** | 8.0 | 8.0 ns | 8.0 ns | 19.7 | 20.0 ns | **21.0*** ** |
| Mg (mg/l) | 0.5 | 0.5 ns | 0.5 ns | 3.0 | 2.7 ns | 2.0 ns | 6.0 | 6 ns | 6 ns |
| **Total anions (meq/L)** | 0.2 | 0.3* | 0.6*** | 1.4 | 1.4ns | 1.6*** | 3.2 | 3.4*** | 3.4*** |
| **Total cations (meq/L)** | 0.1 | 0.2*** | 0.5*** | 1.2 | 1.2* | 1.4*** | 2.9 | 3.1*** | 3.1*** |

## Discussion

Results from the current study provide support for our idea that concrete drainage materials and the widespread use of this as a construction material has an influence on the water chemistry of urban streams. We recorded the largest rises in pH, EC and several major anions and cations levels when water was circulated through a concrete pipe. The increase was greatest for roof-water, lowest for urban creek water and was intermediate for reference creek water. Several chemical attributes also increased in the circulation through a PVC pipe, possibly due to the experiment affecting the level of dissolved gases in the water.

### Material degradation

The process of carbonation is a major factor in the degradation of concrete. It is the result of chemical reactions between carbon dioxide and concrete hydrates, such as calcium hydroxide (Ca(OH)2) or portlanidite and calcium silicate hydrates (CSH) producing calcium carbonate (CaCO3) and water. The mechanism is well described and understood in material science literature. A number of factors have been classified affecting the chemical attack of concrete including: acidic attack, alkaline attack, carbonation, chloride attach, leaching and sulphate attack (ACI 1982). In urban areas and where cementatious pipes are used to convey stormwater it is likely that the acidic attack associated with the lower pH of rainfall is reacting with the alkaline hydration products of cement resulting in calcium salts (Zivica and Bajza 2001) as well as other changes to water chemistry. This process is evident in this experiment as suggestive of the higher concentration in alkalinity-bicarbonate levels (Figure 2), calcium concentrations (Figure 3) and potassium concentrations (Figure 4).

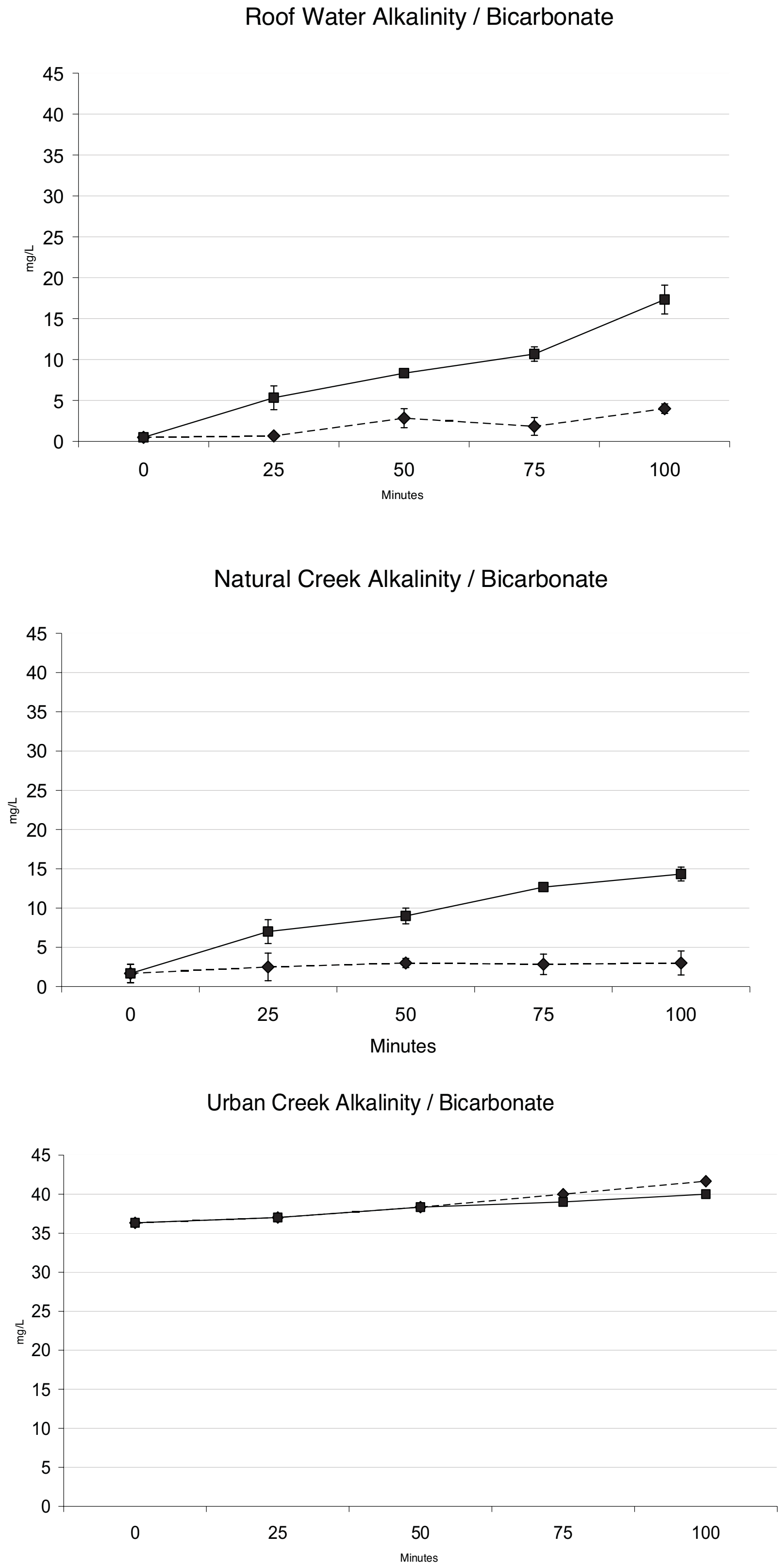


Figure 2. Alkalinity-bicarbonate concentrations in concrete and PVC pipes over 100 minutes

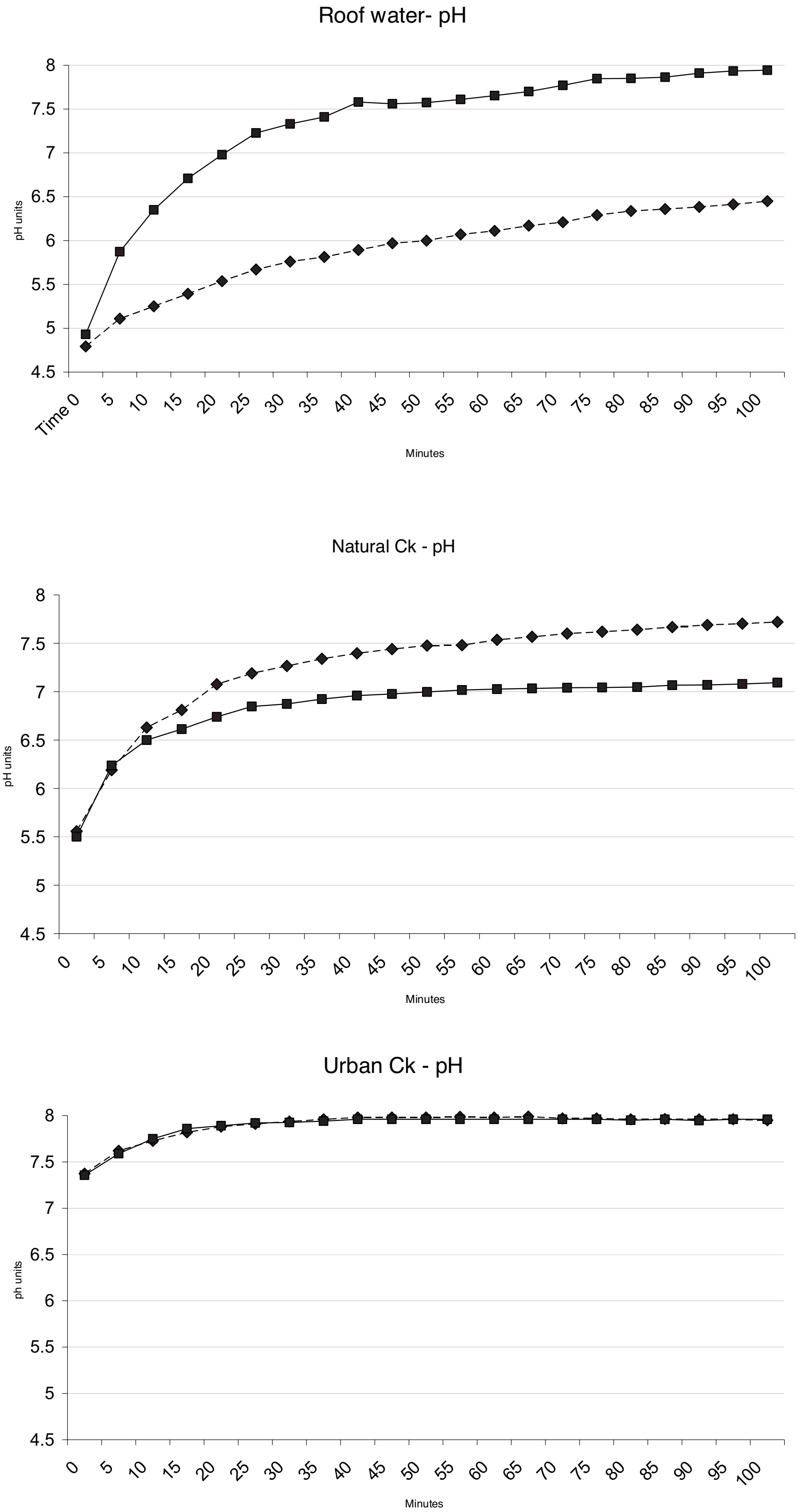


**Figure 3. pH levels in concrete and PVC pipes over 100 minutes**

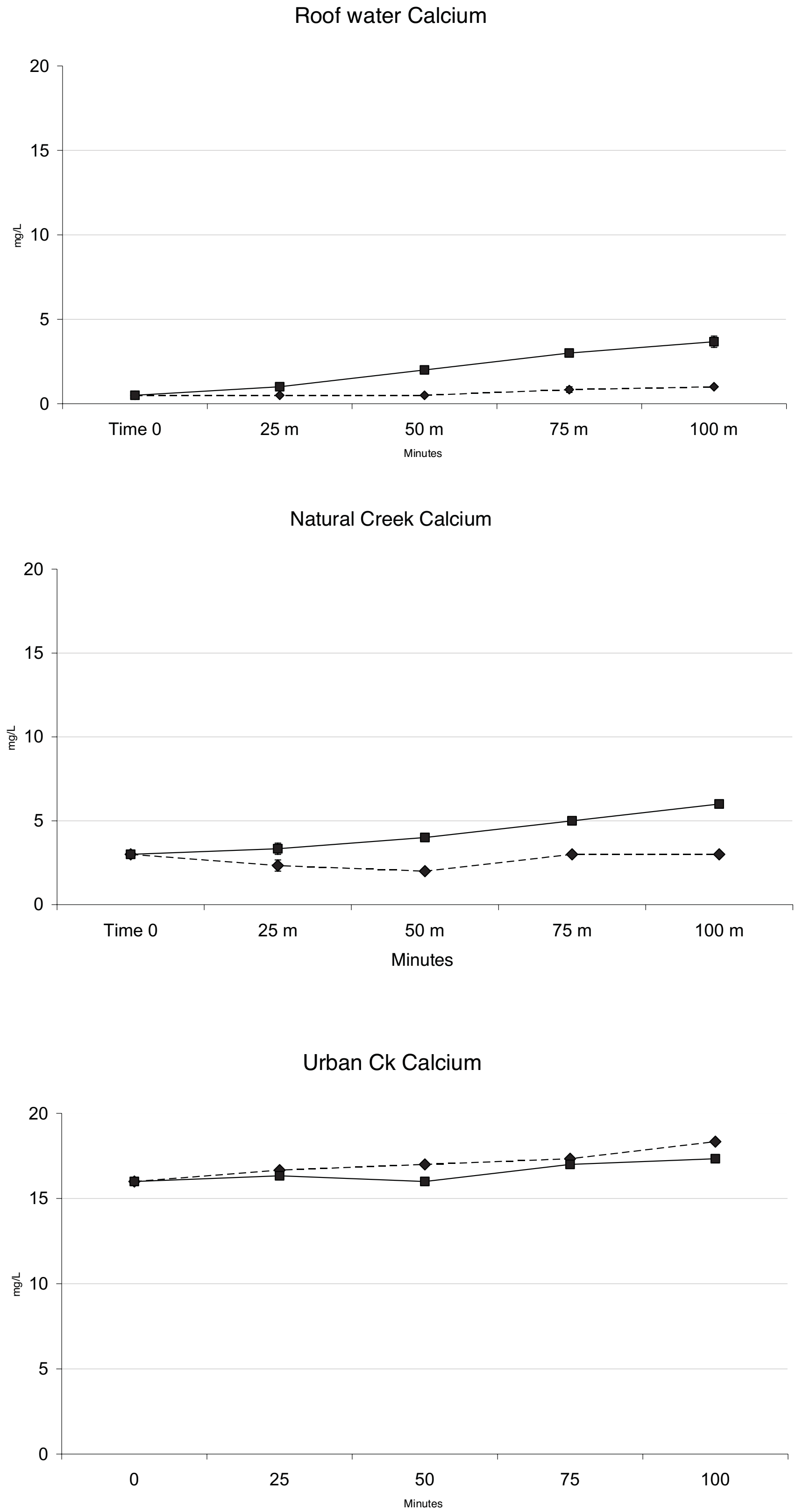


Figure 4. Calcium concentrations in concrete and PVC pipes over 100 minutes

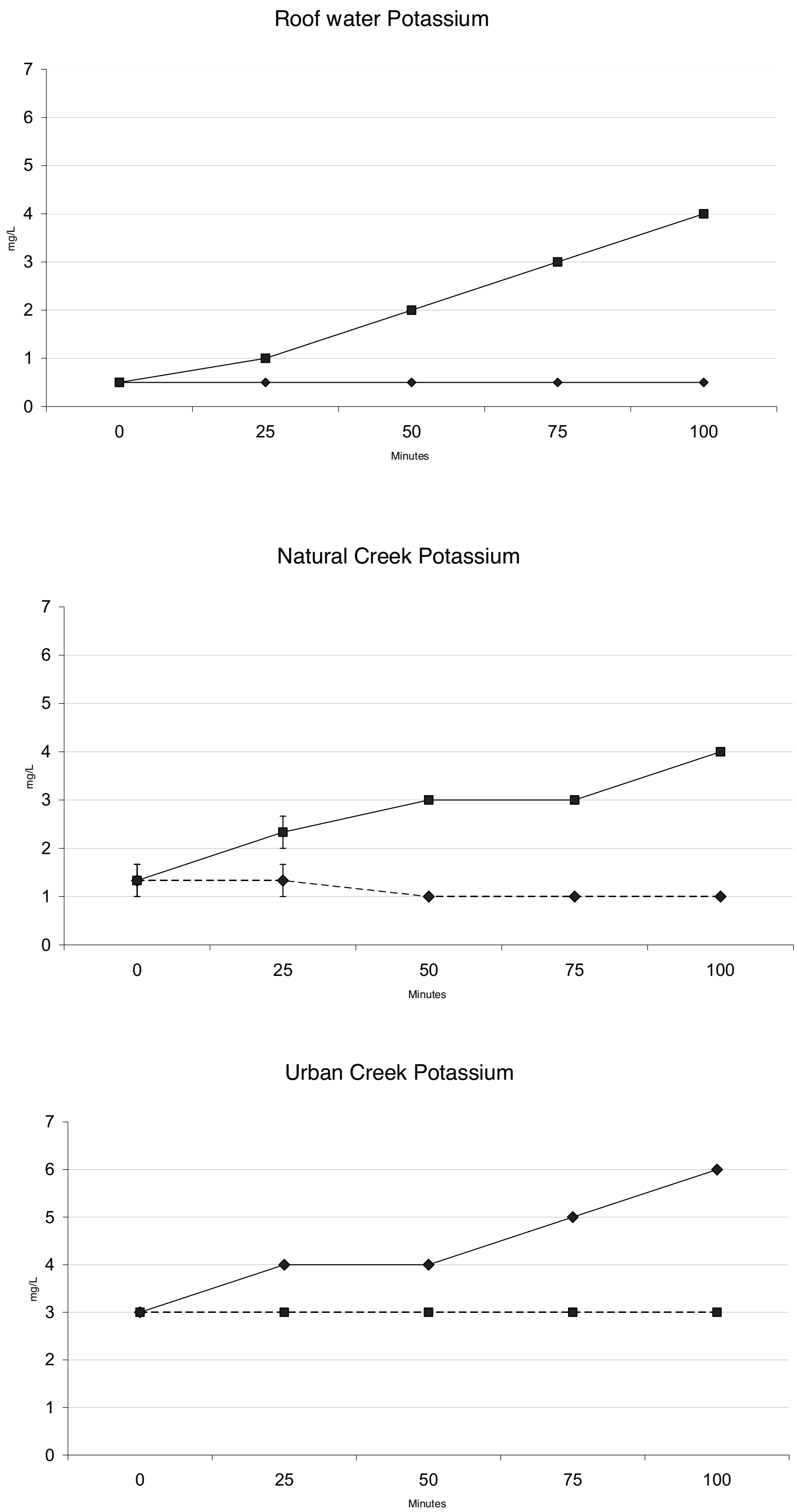


**Figure 5. Potassium concentrations in concrete and PVC pipes over 100 minutes**

### In transport processes

A change in water chemistry can in part be attributed to the circulation of water resulting in aeration and a slight increase in temperature. This processes results in the release of CO2 from solution in the water in turn shifting the pH towards neutral (pH7). Figure 3 shows the pH increases for all samples for both the PVC and concrete pipes. Roof water passed through the plastic pipe does not go above pH7 and creek water appears to steady at pH7. Where these water types are passed through the concrete pipe the pH continues to increase towards 8. This additional change is most likely attributed to a high amount of CaCO3 in the sample as it previously was subject to the chemical changes from the urban drainage system and environs.

### Base line water chemistry

Ku-ring-gai's urban waterways are known to be of average to poor ecosystem health and are suspected to be suffering from poor water quality, symptoms of which include high nutrient levels, high turbidity and sediment loads. This is consistent with many urban water studies that have demonstrated that such pollutants rise and fall under the influence of catchment rainfall and urban runoff. The pH, EC and major ionic constituents (major anions and cations) are clearly different at urban when compared to non-urban reference streams and are particularly apparent in dry weather conditions (Wright *et al* 2007). Within the study area natural or reference streams were mildly to strongly acidic while urban sites varied between mildly acidic to slightly alkaline. The reference streams had a mush lower level of dissolved salts and minerals, with much lower EC (mean 180–230 µS/cm) and lower levels of many major anions and cations, such as Total Alkalinity levels of 1–8 mg/l in reference streams compared to 30–125 in urban streams (refer to Table 2 and Figure 1).

### So what does this mean?

At a catchment scale the data suggests that concrete pipes as a conduit for stormwater have a greater effect on water chemistry than PVC pipes. There is also a strong correlation between time of contact and changes to water chemistry for some water types. We note, as do others, that urban creeks are degraded and simply from a water quality and water chemistry perspective this is evidenced in the concentrations between the urban and reference creeks in this study.

The sampling design used in this study (20 L of water at 0.2 L/s over 1.4 m of pipe for 100minutes) this represents flow lengths of approximately 84 m. This is 17% of the average flow length within a typical catchment in the Ku-ring-gai Council LGA and the study results may therefore be viewed as conservative. Furthermore, given that the water from the urban creeks had been conveyed through concrete pipes and gutters prior to collection, it is of little surprise that the chemistry of this water changed little during the pipe experiments as it had previously been subject to the influence of concrete and associated dissolution of calcium ions.

From a catchment perspective, the causal factors contributing to degradation in urban stream health are many and have tended to focus on land use, with catchment imperviousness identified as one of the most influential factors affecting the degradation of urban streams and their biota (Arnold & Gibbons, 1996 amongst others). Other authors such as Breen and Lawrence (2006) have identified major factors that contribute to waterway including: biology; geology; in-stream habitat; hydrology; hydraulics; water quality; sediment quality; riparian habitat; and continuity and barriers. We argue that the material type of the conveyance system should either be added to this list as a factor in its own right or at least be acknowledged as a significant contributor influencing many of the identified factors.

From a water quality perspective, the results clearly identify significant changes in aquatic chemistry. Hydraulically, stormwater pipes play the major role in urban areas for stormwater conveyance. Literature supports that pH, EC and major anions and cation levels can have a strong influence on the base levels of aquatic ecosystem food chains influencing the biology, sediment quality, hydrology and water quality. For example, algal diatoms are a major source of food and energy in flowing waters and have been found to be strongly influenced by pH, salinity and other environmental factors (Lowe, 1974). Changes in water chemistry that we recorded could strongly influence algal diatoms communities in urban streams, with flow-on effects to other elements of the aquatic ecosystem (bacteria, fungi, invertebrates, zooplankton, fish etc).

While this study was based within the Ku-ring-gai LGA and surrounds, the results have broader implications. From the data presented it can be argued that locations subject to greater levels of acidic deposition and where the receiving environments are naturally acidic, they are more likely to experience significant changes to water chemistry if concrete materials are used conveyance of rainfall or are otherwise in contact with surface and groundwater flows. If protecting sensitive waterways is a primary objective of a urban design or drainage program, greater consideration should be given to materials used in construction and operation of hydraulic systems and generally within the catchment. While this study has not sought to understand the implications of the ionic and chemistry difference that may arise from the use of concrete or PVC pipes, it is foreseeable that it would impact biota within an otherwise mineral limited and acidic environment.

## Conclusion

The results indicate that concrete pipes have a significant impact on water chemistry on rain water and water taken from a natural stream. This was most notable in terms of bicarbonate levels and concentrations of potassium and calcium. PVC pipes also reported a change though significantly less than their concrete equivalent. Water from urban creeks reported the least change, though noting their cation and anion levels were elevated from the outset. The research suggests that where creeks are naturally acidic, the use of concrete as part of the urban drainage system will impact on water chemistry. This points to yet another dimension for engineers and ecologists to consider within water sensitive urban design.

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# Impact on runoff quality by the concrete drainage system

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# IMPACT ON STORMWATER RUNOFF QUALITY BY THE CONCRETE DRAINAGE SYSTEM

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## Abstract

A major source of pollution of urban waterways is from urban runoff. Research over the past 20 years has lead to a greater understanding of the source and how to control many pollutants. However, recent investigations by the authors has identified that concrete, being the dominant material for public drainage systems including gutters and pipes, has a significant impact on the chemistry of urban water runoff. This in turn is influencing the water quality within urban creeks. Across the Northern suburbs of Sydney, reference or undisturbed natural creeks are acidic and characterised by their low alkalinity and electrical conductivity. Urban creeks, located with similar geology and soil, are mildly acidic to mildly alkaline with much higher alkalinity and electrical conductivity. To ascertain what may be a causal factor for this difference in water chemistry, rainwater collected within the catchment was pumped through various concrete pipes and along gutters. The results identify that the dissolution of cement products changes a range of analytes particularly calcium, bicarbonate, potassium and pH. There are significant changes to urban water quality as a result of the in-transport processes associated with the concrete drainage system. This should be factored into the design of urban drainage schemes particularly if they discharge into naturally acidic or minerally poor waterways.

## Introduction

Urbanisation has lead to many changes to the natural environment. Research into the impacts on waterway health from urban development commenced in Australia with a review of the water quality and biota up and downstream of a sewerage treatment plant in Lithgow by Jolly and Chapman (1966). This and other work focused on point source pollution that informed the development and introduction of a pollution licencing and regulatory system with the Clean Waters Act (NSW) 1971.

Non-point source or diffuse pollution is the other major contributor to the decline in urban water quality. From a regulatory perspective this is much harder to address and in part was identified in NSW through the stormwater management planning process in the 1990's. However as Meyer et al (2005), Breen and Lawrence (2003) and others have noted the causal factors for the decline in urban stream health is multi facetted and interrelated. Consequently the policy and regulatory response is much more challenging.

In undeveloped catchments the geology and soils play a major role in determining the chemistry of the water in streams. For urban catchments runoff is significantly influenced by new materials imported into the catchment, which effectively recalibrate the natural geochemistry. For example Bridgman (1992) and Garnaud et al (1999) investigated the changes in rainwater passing over various roof materials and Sartor and Boyd 1972, Ball et al. 1998, Shinya et al. 2000 and others have reported the effects of rainwater passing over concrete footpaths, bitumen roads and related transport surfaces. Others, such as Prowse (1978), Hayes and Buckney (1995) and Rose (2007), have looked at the changes in stream hydrochemistry (primarily baseflow) due to urbanisation. These investigations discuss the role of non point source urban pollutants such as leaking sewers, construction activity, impervious surface build-up, road and highway runoff, industrial pollution fertilisers and building materials amongst other anthropogenic impacts. More recently, Setunge et al (2009) reported that the pH of water changes significantly when in contact with freshly poured cement particularly within the first few days.

Looking at other factors influencing urban water chemistry, Novotny and Kincaid (1981) considered the effect of in transport process as part of their investigations into the buffering capacity of pavements to neutralised acid rain. Their conclusions supported the use of materials such as concrete due to their effectiveness in buffering the acid rain experienced in Milwaukee.

An interesting omission from the research to date has been an detailed analysis of the impact that the materials that make up the drainage system have on urban water quality. This is what we refer to as the in-transport drainage process.

This paper draws from the findings of previous studies by the authors and reports the most recent study on the impact of concrete gutters on urban water chemistry.

**Previous research**

Past studies on the waterways in the northern suburbs of Sydney identified major differences in base flow water chemistry between urban and naturally vegetated non-urban 'reference' waterways (Wright et al 2007). Dry weather sampling of the urban streams reported mildly acidic to slightly alkaline water while reference streams were about 1 pH unit more acidic. Urban waterways had an approximate 10-fold higher alkalinity and twice the electrical conductivity of reference waterways (Wright et al. 2007).

As a result of these observations, an initial investigation was undertaken to explore if there was a link between the water chemistry in urban streams and the materials comprising the urban drainage system (Davies et al 2009 and Davies et al 2010b).

This research project examined the changes in three water types (rain, urban stream and reference stream) when exposed to two commonly used drainage materials, concrete and PVC. This study found roof water and water from the undeveloped catchment reported a significant increase across a range of analytes: bicarbonate levels increased steeply when passed through the concrete pipe, while water from the urban creek (that had been exposed to concrete influence runoff) changed a lesser amount.

Following from these results, a further study was undertaken to assess if the changes could be attributed the dissolution of concrete products across pipes of various types and ages (Davies et al 2010a). In this study, rainwater was circulated through two new pipes (a steel reinforced concrete pipe and a fibre reinforced concrete pipe) and two old pipes (steel reinforced with visible pitting and hairline fractures). This study reported clear differences in water chemistry conveyed through new and old concrete pipes (when compared to a PVC pipe as a control), particularly for bicarbonate and calcium levels. The most sudden increase was recorded for pH which displayed a rise of two (2) pH units within the first 20 minutes of exposure to new (steel and fibre reinforced) concrete pipe. Electrical conductivity did not start to increase for ten minutes, and for new concrete pipes, rose at a steady gradient for the entire experiment. Similar trends were also evident for hardness, bicarbonate and calcium for the newer concrete pipes. The changes in water chemistry in the two older concrete pipes was generally around 40% to 60% lower than that recorded in the new pipes, though there were substantial increases in ionic levels (calcium, bicarbonate, hardness, total anions, total cations) through the experiment.

The other major part of the urban drainage system is gutter network. This study, and the subject of this paper, extended on the controlled experiments to investigate if rainwater passing over concrete gutters of varying lengths, age and condition produced similar changes in water chemistry.

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## Methods

### Study area

Research was conducted primarily in the Ku-ring-gai Local Government Area (LGA) in Sydney's northern suburbs (at 33°45'20"S and 151°9'0"E) with some urban sites located in the adjacent Ryde LGA.

The natural geology is characterised as Wianamatta Shale overlying Hawkesbury Sandstone on ridges with the deeply incised valleys and streambeds dominated by exposed Hawkesbury sandstone (NSW Department Mineral Resources 1983). The soil type is generally described as poor in both structure and geochemistry and is closely related to the underlying shale/sandstone geology (Herbert and Helby 1980).

Development across the Ku-ring-gai LGA, is dominated by low density residential housing on block sizes around 940 $m^2$ with little commercial and no industrial development. The majority of the development occurred between the 1940's to 1970's and for the last 30 years the population has been relatively stable at approximately 100,000.

A notable characteristic of the northern suburbs of Sydney is that development has occurred on the upper and flatter sections of the catchment while the steeper incised valleys contain remnant bushland and modified streams (this is generally inverse to traditional development patterns were the upper catchment remains forested or less developed while the lower flatter slopes contain the development). Within the urban area, approximately 40% of the local roads are constructed with concrete curb and guttering. The average total surface imperviousness is between 20-40% (Ku-ring-gai Council 2004) while the connected impervious area is approximately 29% (Davies et al 2010a).

### Study design

<u>Methods</u>

Rainwater was collected from a zincalume roof in South Turramurra into a 3000 litre plastic rainwater tank. The water was then transferred into 20 litre plastic jerry cans for the experiment. The water from the rainwater tank had been stored for up to two weeks and the water in the jerry cans was used on the day of sampling.

Twenty-three (23) sections of gutter across 12 different streets chosen for this study comprising 17 sites in the Lane Cove River catchment and 6 sites in Cowan Creek catchment (refer to Table 1). This included 6 gutters less than 10 years old, 8 gutters between 20 and 35 years old and 4 gutters that were 45 years old. The older gutters had a greater the amount of exposed aggregate, while the newer gutters still retained the finer cement covering (refer to Figure 1).

**Figure 1. Photo of the concrete surfaces at St Columbans Green constructed in 2008 (left) and Currong Place constructed in 1981 (right).**

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A leaf blower was used to remove the visible debris and the gutter was then flushed with rainwater prior sampling at a rate of approximately 10 litres for gutters of 15 to 25 meters and 20 litres for gutters between 50 and 100 metres.

Rainwater from the jerry cans was pumped at a rate of approximately 0.26 l/s using a 3060 LPH Bilge pump. Three (3) consecutive samples were collected at 5-10s intervals 10 seconds after the initial flush of water had passed the sample point. The sampling was repeated 3 times at each site with an interval of approximately 10 minutes between each run. Water used for the preparation flush was also sampled on random occasions.

Conductivity, pH and temperature were recorded for each batch of initial rainwater and every sample using a hand held water chemistry meter (Model 611 – Intelligent Water Quality Analyser - Yeo-Kal Electronics Pty. Ltd. Australia). Random samples from 1 of the 3 repeat runs at random sites were analysed at a NATA accredited laboratory for Potassium, Calcium, Sodium, Magnesium, Bicarbonate Alkalinity, Chloride, Sulphate, Total Anions and Total Cations. Results are all reported to a limit of 1 mg/L and ionic balance (Total Anions and Total Cations) are reported to a level of 0.01 meq/L.

**Results**

The chemistry from water sourced from the rainwater tank prior to its release into the concrete gutters was strongly acidic (mean pH 4.8) with a very low concentration of dissolved salts (EC 24 $\mu$S/cm) (Table 2). The major mineral constituents of (alkalinity) bicarbonate, calcium and potassium were also very low (2.0, 0.5 and 0.5 mg/L respectively).

There was a highly significant relationship (ANOVA: $F_{8,955} = 1297.5$, $p<0.0001$) between pH levels and the exposure of tankwater samples to different length of concrete road gutter (15 to 200m) (Table 3). The mean pH level rose (from mean 4.8) with progressive lengths of exposure to the concrete gutters. This was measured over relatively short distances rising from 5.3 at 15 m, 5.9 at 25 m and 6.7 at 50 m (Figure 2). Mean pH levels were elevated within a band of 6.9 to 7.6 at distances varying from 75 to 200 m of gutter.

The concentration of anions in water samples increased highly significantly (ANOVA: $F_{5,22} = 14.5$, $p<0.0001$) according to the length of gutter, rising from 0.11 (meq/L) to a mean of 0.54 (meq/L) after 200 metres of travel in the concrete gutter (Table 2 and 3). A similar relationship was observed for cations which also increased highly significantly (ANOVA: $F_{5,22} = 10.4$, $p<0.0001$), rising from 0.08 to a mean of 0.47 (meq/L) after 200 metres (Table 2 and 3). There was a highly significant relationship for changes to bicarbonate (ANOVA: $F_{5,22} = 17.35$, $p<0.0001$) and potassium (ANOVA: $F_{5,22} = 9.33$, $p<0.0001$) levels with exposure of tankwater samples to different lengths of concrete road gutter (50 to 200m) (Table 2 and Table 3). Calcium levels also had a significant relationship (ANOVA: $F_{5,22} = 4.99$, $p=0.003$) with exposure to concrete gutters (Table 2 and 3). Mean mineral levels rose steeply over progressive exposure of lengths of gutter (50 to 200m) (Figure 3-5). The mean levels of bicarbonate, calcium and potassium had all doubled at the 50 m length. The largest increase was observed for bicarbonate rising more than eight times, from 2 mg/L at the start to 16.3 mg/L at 200m (Figure 3). Mean potassium levels also increased more than eight fold, from 0.5 mg/L at the outset to a mean of 4.3 mg/L at 100 m (Figure 4). A similar trend was also observed for calcium, rising from 0.5 mg/L to a mean of 2.7 mg/L at 200 m (Figure 5).

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**Table 1. Sample site locations**

| Suburb | Street Name | Distance (m) | Date constructed |
|---|---|---|---|
| South Turramurra | Ashburton Ave | 150 | ~1981 |
| South Turramurra | Ashburton Ave ( near cul-de-sac) | 15 | ~1981 |
| South Turramurra | Ashburton Ave ( near cul-de-sac) | 25 | ~1981 |
| South Turramurra | Currong Place | 15 & 50 | 1981 |
| South Turramurra | Currong Place | 25 & 50 | 1981 |
| South Turramurra | Eden Avenue | 200 | 1965 |
| South Turramurra | Maxwell Street | 100 | 1977 |
| South Turramurra | Benning Avenue | 75 | 1965 |
| South Turramurra | Robin Avenue | 25 | 1965 |
| South Turramurra | Robin Avenue | 50 | 1965 |
| South Turramurra | Holmes Street | 50 | 1978 |
| North Turramurra | St Columbans Green | 25 & 50 | 2008 |
| North Turramurra | St Columbans Green | 15 | 2008 |
| North Turramurra | Sir Frederick Scherger Drive | 75 | 2003/2004 |
| North Turramurra | Beaufort Close | 75 | 2003/2004 |
| North Turramurra | Du Faur Street | 100 | ~1990 |
| North Ryde | Long Road, Macquarie University | 150 | 1999 |
| North Ryde | Long Road, Macquarie University | 15 & 100 | 1999 |

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**Table 2 Summary of gutter sampling results**

| Site | Kerb side | Distance (m) | K (mg/L) | Total Alk-Bicarb (mg/L) | Ca (mg/L) | Na (mg/L) | Cl (mg/L) | Total Anions (meq/L) | Total Cations (meq/L) |
|---|---|---|---|---|---|---|---|---|---|
| Initial Rainwater | N/A | 0 | 0.5 | 2 | 0.5 | 2 | 3 | 0.11 | 0.08 |
| Currong Place | Left | 50 | 1 | 7 | 2 | 3 | 4 | 0.29 | 0.25 |
| Currong Place | Left | 50 | 1 | 5 | 1 | 3 | 4 | 0.24 | 0.24 |
| Currong Place | Left | 50 | 1 | 3 | 1 | 3 | 4 | 0.2 | 0.22 |
| Currong Place | Right | 50 | 2 | 6 | 1 | 4 | 6 | 0.31 | 0.26 |
| Currong Place | Right | 50 | 2 | 6 | 1 | 3 | 5 | 0.29 | 0.24 |
| Currong Place | Right | 50 | 1 | 5 | 1 | 3 | 4 | 0.25 | 0.21 |
| Holmes Street | Left | 50 | 4 | 7 | 1 | 4 | 4 | 0.28 | 0.31 |
| Holmes Street | Left | 50 | 3 | 3 | 0.5 | 3 | 4 | 0.16 | 0.2 |
| Holmes Street | Left | 50 | 2 | 5 | 0.5 | 2 | 4 | 0.22 | 0.17 |
| The Landings | Right | 75 | 0.5 | 5 | 2 | 3 | 6 | 0.29 | 0.23 |
| The Landings | Right | 75 | 0.5 | 4 | 2 | 3 | 7 | 0.31 | 0.23 |
| The Landings | Right | 75 | 0.5 | 8 | 2 | 3 | 5 | 0.32 | 0.2 |
| Beaufort Close | Right | 75 | 2 | 8 | 3 | 4 | 6 | 0.38 | 0.4 |
| Beaufort Close | Right | 75 | 2 | 8 | 3 | 4 | 7 | 0.38 | 0.38 |
| Beaufort Close | Right | 75 | 2 | 8 | 3 | 4 | 6 | 0.35 | 0.33 |
| Benning Avenue | Right | 75 | 3 | 9 | 2 | 4 | 6 | 0.38 | 0.37 |
| Benning Avenue | Right | 75 | 2 | 7 | 1 | 3 | 5 | 0.29 | 0.27 |
| Benning Avenue | Right | 75 | 2 | 7 | 1 | 3 | 5 | 0.29 | 0.24 |
| Du Faur Street | Left | 100 | 5 | 10 | 1 | 4 | 6 | 0.39 | 0.37 |
| Du Faur Street | Left | 100 | 4 | 8 | 2 | 4 | 6 | 0.34 | 0.36 |
| Du Faur Street | Left | 100 | 4 | 6 | 1 | 3 | 5 | 0.3 | 0.3 |
| Long Road | Right | 150 | 4 | 9 | 3 | 5 | 9 | 0.48 | 0.51 |
| Long Road | Right | 150 | 4 | 7 | 2 | 5 | 8 | 0.4 | 0.43 |
| Long Road | Right | 150 | 4 | 4 | 2 | 4 | 8 | 0.32 | 0.37 |
| Eden Place | Left | 200 | 4 | 20 | 4 | 7 | 7 | 0.67 | 0.59 |
| Eden Place | Left | 200 | 4 | 14 | 2 | 6 | 5 | 0.48 | 0.45 |
| Eden Place | Left | 200 | 3 | 15 | 2 | 4 | 4 | 0.46 | 0.36 |

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**Table 3. ANOVA results.** F statistics and associated probabilities from analysis of variance of water chemical attributes (pH, anions, cations, calcium, bicarbonate potassium, sodium and chloride) varying according to distance travelled in concrete gutters.

| Comparison | Degrees Freedom (treatment, error) | F values | P values |
|---|---|---|---|
| pH | 8, 955 | 1297.7 | <0.0001 |
| Anions | 5,22 | 14.49 | <0.0001 |
| Cations | 5,22 | 10.38 | <0.0001 |
| Calcium | 5,22 | 4.99 | 0.003 |
| Bicarbonate (alkalinity) | 5,22 | 17.35 | <0.0001 |
| Potassium | 5,22 | 9.33 | <0.0001 |
| Sodium | 5,22 | 8.31 | <0.0001 |
| Chloride | 5,22 | 13.03 | <0.0001 |

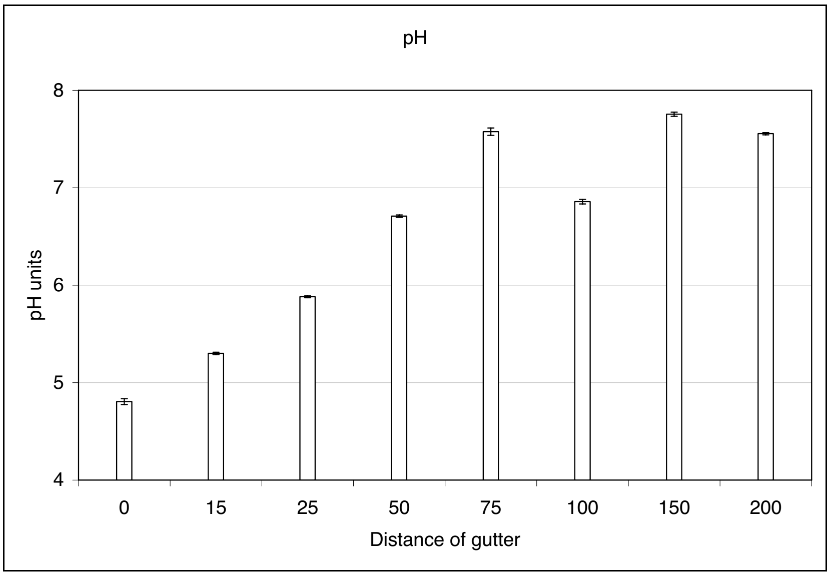


**Figure 2. Mean pH levels (plus/minus standard error) in water samples, measured prior to the sample release (distance 0) and after running down different lengths of concrete gutter (15m, 25 m, 50m, 75m, 100m, 150m and 200m).**

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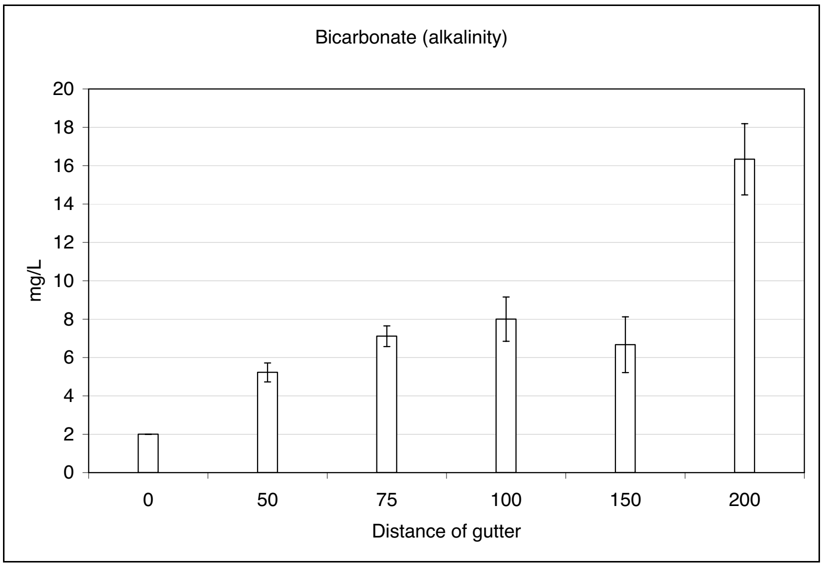


**Figure 3. Mean bicarbonate (total alkalinity) levels (plus/minus standard error) in water samples, measured prior to the sample release (distance 0) and after running down different lengths of concrete gutter (50m, 75m, 100m, 150m and 200m).**

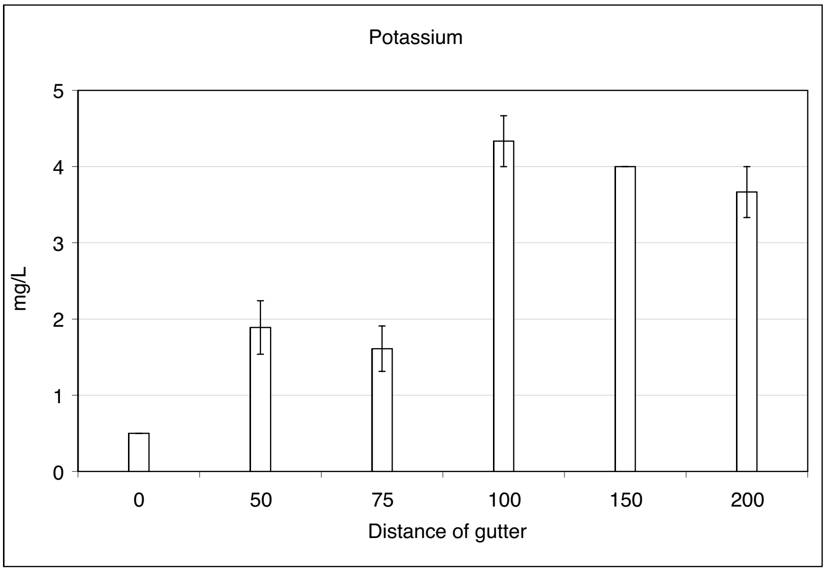


**Figure 4. Mean potassium levels (plus/minus standard error) in water samples, measured prior to the sample release (distance 0) and after running down different lengths of concrete gutter (50m, 75m, 100m, 150m and 200m).**

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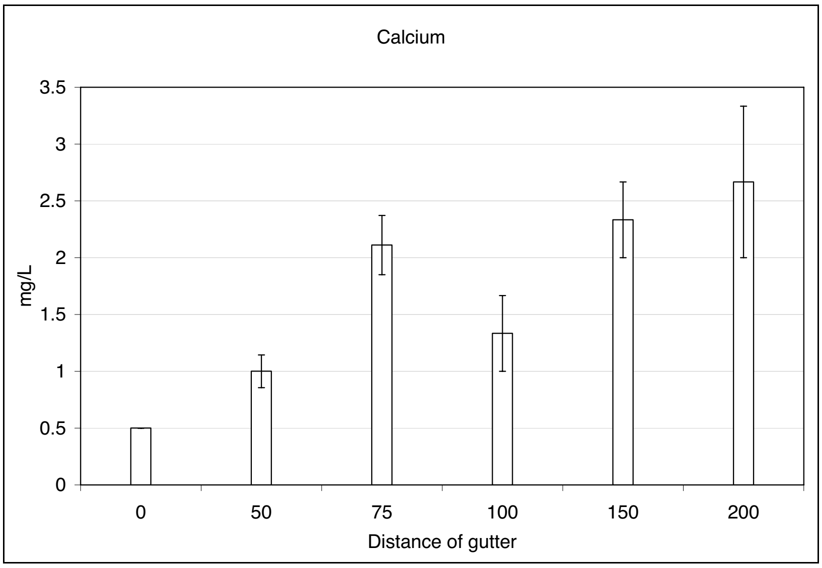


**Figure 5. Mean calcium levels (plus/minus standard error) in water samples, measured prior to the sample release (distance 0) and after running down different lengths of concrete gutter (50m, 75m, 100m, 150m and 200m).**

## Discussion

One of the key differences in water quality in northern Sydney urban waterways compared to waterways in naturally vegetated non-urban catchments, was the difference in the alkalinity level. Alkalinity was typically nearly 10 times higher in urban streams (Wright et al. 2007). The current study adds to the weight of evidence that the concrete drainage system is contributing to the contamination of waterways with unnaturally high levels of alkalinity. The highest concentration and change in Bicarbonate Alkalinity was recorded at the longest stretch of gutter (200m) with longest flush time (8 minutes). This gutter was constructed in 1965. Okochi et. al. (2000) suggested that when comparing fixed quantities of rainwater with varying flow rates, carbonation or the dissolution of calcium hydrates from concrete, will increase as the period of contact between the rainwater and concrete increases. This is consistent with the results of the current gutter study and also is similar to previous studies with concrete pipes (Davies et al 2009, 2010a and 2010b). Notable is that the longest gutter was also the oldest indicating that the degradation in the concrete over time is less significant than with the pipes.

Calcium and potassium concentrations also increased according to length of travel in the concrete gutter. The scale of the increase was similar to that recorded through recirculation of rainwater in a concrete pipe (Davies et al, 2010a).

An earlier study found that all non-urban reference streams were acidic, with a mean pH of 5.8 (Wright et al. 2007). In comparison the urban streams had an average pH of 6.9. The current study confirms that concrete drainage materials are likely to make a strong contribution to the rise in urban stream pH. We found that rainwater was highly acidic (mean 4.8) (likely attributed to industrial pollution that contributes to acidic deposition), and that the level of pH rose according to distance travelled in concrete gutter. In the pipe experiments (Davies et.al. 2009) the levels of pH tended to level off at 8.0 after 100 minutes. This is equivalent to 84 metres of pipe/gutter in the current experiment. In the current study, the level of pH rose steeply, from less than 5 to average levels of 7.5 to 7.7 (Figure 1) after the water sample ran through 75 to 200 m of gutter.

### Conclusions

This paper has confirmed the findings of the previous studies that the in-transport process of concrete drainage system results in the dissolution of cement products that affects the quality of urban runoff. From an urban drainage design perspective, it is the combined time of contact of both the gutter and pipe that will influence the overall changes in water chemistry. While newer gutters and pipes report a greater change in water chemistry than older ones, this of lower overall importance given the magnitude and cumulative impact associated with contact time.

Given the rapid influence of the acidic rain with the alkaline cement products it is suggested that alternative drainage materials may be necessary if an outcome of the urban design project is to minimise the impact on receiving water bodies, particularly those that are naturally acidic and minerally poor.

We suggest that protection of natural stream geochemistry from the adverse effects of urban development (urban geochemistry) deserves further attention. The ANZECC water quality guidelines endorse a process for development of regional water quality guidelines based on local studies. The south-eastern Australia guidelines recommend that pH be within the range of 6.5 to 8.5. We suggest that protection of fragile aquatic ecosystems in urban creeks actually need to retain natural pH levels that are generally below this range. Concrete drainage materials (pipes, gutters, and concrete paved areas) will react with acidic rainwater even over short distances and contact times and will quickly modify stream geochemistry.

These findings also suggest that the suite of stormwater pollutants typically associated with the runoff from urban catchments (such as dissolved oxygen, sediment and nutrients) need further attention. In particular, the analysis of urban runoff and in-transport drainage processes should examine both water quality and water chemistry. We recommend that pH, electrical conductivity and major anions and cations warrant greater attention in urban water monitoring programs.

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# A new type of water pollution: concrete drainage infrastructure and geochemical contamination of urban waters

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# A new type of water pollution: concrete drainage infrastructure and geochemical contamination of urban waters

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## Additional key words

Hydrochemistry, urban water quality, Sydney, concrete stormwater systems

## Abstract

Stormwater and other urban runoff is often conveyed by concrete infrastructure and it is plausible that the chemistry of urban streams is modified by the leaching of minerals from this infrastructure. We tested this hypothesis by analysing major anions, cations and other chemical variables from urban and reference freshwater streams in northern Sydney. Urban streams tended towards neutral pH while non-urban streams were acidic. Bicarbonate levels were more than 10 times higher and calcium concentrations were more than six times higher in urban streams than reference streams. Experimental analysis revealed the chemistry of rainwater changed when passed through concrete pipes and down concrete gutters, suggesting dissolution of cement products from various concrete materials used for urban drainage. This study concluded that the use of concrete and particularly its application for urban drainage is responsible for some of the modifications to urban stream geochemistry and that urban geology should be considered as an important factor that contributes to the urban stream syndrome.

## Introduction

Urban runoff is one of the major contributors to the modification of water chemistry in urban waterways (Klein 1979; US EPA 2000). Urban runoff also affects the hydrology and ecological condition of urban streams and associated riparian systems (e.g. Paul and Meyer 2001). This collective group of environmental problems has been termed 'the urban stream syndrome' (Meyer *et al.* 1995). However, the variable nature of land uses, activities and climatic variation makes it difficult to accurately determine the sources and extent of urban water contamination (Duncan 1999). From a management perspective, this makes it challenging to identify and appropriately control urban pollutants (Novotny and Olem 1994). Within urban areas, catchment imperviousness and the drainage infrastructure have been recognised as important elements affecting water quality, hydrology and form of urban rivers (Leopold 1968, Chin 2006). More recently, Hatt *et al.* (2004) found a positive correlation between the impervious areas of a catchment connected to streams by pipes to various water chemistry attributes. Walsh *et al.* (2001) reported that ecosystem condition, as measured by stream macroinvertebrates, is significantly impaired once catchments exceed 10% connected imperviousness. These research outcomes have informed and encouraged the uptake of various 'water sensitive urban design' (WSUD) or low-impact development techniques (Wong 2006) that seek to reduce or reverse the negative environmental effects of urban development on water quality and improve the ecological condition of waterways (Walsh *et al.* 2005).

It is well known that urban waterways are characterised by impaired water quality and degraded ecological communities (Walsh *et al.* 2001; Meyer *et al.* 2005). Most waterway managers and researchers focus on the well known contaminants in urban waterways, such as nutrients, heavymetals, sediment and other physical and chemical contaminants (e.g. Breen and Lawrence 2003; Walsh 2004). Other water chemistry attributes (including pH, electrical conductivity and ionic composition) are also known to influence freshwater ecosystems. For example, diatoms have an integral role in stream food webs and have respond strongly to changes in pH, salinity and the relative concentration of major anions and cations (e.g. Potopova and Charles 2003). It is possible that inadequate recognition has been given to the contribution of modified ionic composition (and pH and electrical conductivity) that may contribute to the degradation of the ecological health of urban streams.

In northern suburbs of Sydney, Australia, Davies *et al.* (2010*a,b*) and Wright *et al.* (2007) reported a significant difference in the chemical characteristics of base flows of urban and reference (non-urban) streams. Reference streams were defined by catchments covered by natural vegetation, with less than 5% total impervious surfaces and were generally located within National Parks. Urban steams were within residential catchments that averaged about 30% total imperviousness. Reference creeks were acidic (mean pH 5.2), dilute (mean electrical conductive 152 μS $cm^{-1}$), poorly buffered (mean total alkalinity of 1.7 mg $L^{-1}$), and dominated ionically by sodium and chloride. In comparison, the urban streams were circumneutral to mildly alkaline, less dilute (mean 358 μS $cm^{-1}$) moderately buffered (mean total alkalinity of 36 mg $L^{-1}$), and also dominated by sodium and chloride but with significantly higher levels of calcium and bicarbonate. The geology, climate and proximity to the coast (~ 10 km) were similar between the two groups of streams. In response to these observations, the authors sought to identify what processes could be driving such geochemical differences.

The theory proposed in this research was to test if the dominant material comprising the urban stormwater drainage system, concrete, might be responsible for changes in water chemistry, described as the 'in-transport process'. An initial study compared water circulating through two treatments: a concrete and a polyvinyl chloride (PVC) pipe (Davies *et al.* 2009). It was found that rainwater (collected from rainwater tanks within the study area) was initially highly acidic (mean 4.79 pH) and dilute (26 μS $cm^{-1}$) with very low bicarbonate and calcium levels (both 0.5 mg $L^{-1}$) and much higher sodium and chloride (2 and 5.9 mg $L^{-1}$). After recirculation of the rainwater through a concrete pipe for 100 minutes, the pH rose to 7.9, the bicarbonate levels rose more than 30 times and the calcium levels increased more than 7 times. Variations of this initial study were undertaken to ascertain if the age of a concrete pipe had any influence (Davies *et al.* 2010*a,b*) and also to assess if the results were similar to rainwater passing over concrete gutters (Davies *et al.* 2010*c*). Similar trends were reported in all cases. Although the concentrations of the major anions and cations in rainwater that had passed through the pipe and over the gutter did not reach those reported in the urban streams, the studies found that even a relatively short exposure of rainwater to concrete resulted in both rapid and significant changes in chemistry and ionic composition. The same finding was also found by Sujeeva *et al.* (2009). The authors suggest that it now appears that urban stream chemistry, at a sub-catchment scale, is being influenced by an anthropogenic 'rock-dominance' or urban geology process (see Gibbs 1970) due to the influence of concrete drainage materials.

The research presented in this paper seeks to determine whether streams of similar size, climate and geology have significantly modified ionic composition in urban compared to naturally vegetated non-urban reference catchments. The authors also sought to assess whether ionic differences had any similarity to earlier experiments that exposed rainwater to concrete drainage materials (e.g. Davies 2010 a, b, c).

## Materials and methods

### Study area

The study was focused on three local government areas (LGAs) in south eastern Australia, Ku-ring-gai, Hornsby and Warringah, ~ 15 - 25 km north of the central business district of Sydney (33° 10′ S, 151° 40′E). The region has a temperate climate. There are three broad soil groups across the region. The more fertile soils are derived from Wianamatta and Narrabeen Shales overlying less fertile soils derived from Hawkesbury Sandstone (DMR 1983). The deeply incised valleys and streambeds are dominated by exposed Hawkesbury sandstone (DMR 1983). The natural bushland areas are dominated by *Eucalyptus* species, with several remnant vegetation communities of conservation significance.

The urban and reference waterway groups were selected on the basis of physical similarity, except for the coverage of urban land in their catchments (Table 1). The reference streams had less than 5 % urban development and were predominantly naturally vegetated, being located within National Parks or council bushland. The urban catchments had urban development across 30 - 70 % of their area, characterized by low-density detached dwellings with blocks typically around 940 m? (Curby and Macleod 2006). Each sample site was located on coastal incised sandstone streams, under 200 m Australian Height Datum. Previous studies (Wright *et al.* 2007; Davies *et al.* 2010*b*) had demonstrated that several of the non-urban reference sites had ecological condition (macroinvertebrate communities) and water quality that were typical of clean and unmodified water chemistry (Hayes and Buckney 1995). In contrast, the same studies also showed that several of the urban streams were highly degraded in terms of aquatic ecosystems, and it appeared that water quality was also strongly modified. All streams were small (average 1– 3 m wide), shallow (average 0.1–1.0 m deep) and generally had permanent flow, except during prolonged periods of drought. Most waterways had well-vegetated riparian zones, although weeds typically dominated urban stream banks across the study area (Lake and Leishman 2004).

## Sampling and analytical methods

Sampling of each stream was conducted at seven locations along their longitudinal profile starting from the headwaters. The longitudinal site location was dependant on accessibility, with most samples being 50 m to 100 m apart. Sampling effort was evenly balanced between urban and non-urban streams with 42 water samples being collected from each (a total of 84 samples). Samples were collected on six sampling days between November 2009 and January 2010 during periods of base flow, at least seven days following a storm event. To ensure that the date of sampling did not compromise the study design, on each sampling day a pair of waterways was sampled. This comprised an urban stream and a nearby non-urban reference stream.

At each sampling location, a sample (250mL) of water was taken mid stream and stored in an unused and refrigerated sampling water container. Samples were analysed at a commercial NATA (National Association of Testing Authorities) accredited laboratory (Australian Laboratory Services, Smithfield) for total alkalinity (divided into bicarbonate, hydroxide and carbonate components) and other major dissolved major anions and cations (calcium, sodium, magnesium, potassium, chloride and sulfate). Sulfate, chloride, bicarbonate, hydroxide and carbonate were determined using titration and cations were measured using inductively coupled plasma atomic absorption spectrometry (ICP-AES). All major ions were reported with a lower detection limit of 1 mg $L^{-1}$. Ionic balance (total anions and total cations) was reported to a lower detection limit 0.01 meq $L^{-1}$. The sample analysis included several quality assurance and control procedures. All tests were in accordance with published methods (APHA 2006).

At the same time as water samples were taken, a Yeo-Kal 615 Water Quality meter (Sydney) was used to measure electrical conductivity and pH. Three replicate readings were recorded for each variable from the water meter.

The water quality data were compared by Student's t-test to test for significance differences for each water chemistry attribute between urban and non-urban streams. Data were checked for normality using probability-probability plots and for homogeneity of variance using Levene's test. The major ion ratio between calcium, sodium and total dissolved solids (TDS) was calculated and plotted for all sites. This followed the 'Gibbs diagram' used by Hart and McKelvie (1986) drawing on the earlier work of Gibbs (1970).

## Results

Major differences were evident between the water chemistry of the two stream types (Table 2). Non-urban stream water was strongly acidic (mean pH 5.69), and significantly lower in pH than in urban streams (mean pH 6.84, Table 2; Figure 1). The mean electrical conductivity (EC) of urban streams (433 µS cm $^{-1}$) was more than twice as high as that recorded for reference streams (194 µS cm $^{-1}$) (Table 2; Figure 1).

For all ionic attributes, mean levels were significantly higher within urban than reference streams, especially calcium and bicarbonate (Table 2; Figure 1). Mean calcium and bicarbonate concentrations were >6 times and >10 times higher, respectively, in urban than in reference streams.

All other major ions (sodium, sulfate, chloride, magnesium and potassium) were significantly higher in urban streams compared to reference streams (Table 2; Figure 1). There was an increase between 1.68 and 1.97 times, according to their mean concentration in mg L $^{-1}$, from reference to urban stream waters (Table 2). Sulfate levels increased least (of approximately 1.5 times) and were only mildly elevated in urban compared to non-urban sites).

All reference and urban waters in this study were dominated by sodium and chloride, according to their mean concentration in mg L $^{-1}$ (Table 2). However, the relative proportion of this ionic dominance differed with urban steams displaying calcium and bicarbonate sub-dominance. Reference streams exhibited cation Na>Mg>Ca>K dominance compared to the urban streams Na>Ca>Mg>K. The anion dominance also shifted between the reference streams Cl> $SO_4$> $HCO_3$ and at urban sites the pattern of dominance was Cl> $HCO_3$> $SO_4$.

These ionic results were plotted on the model developed by Gibbs (1970) to represent the range of total dissolved salts across the world's range of surface freshwaters. The urban stream and reference stream results each formed discrete clusters (Figure 2). The reference cluster was orientated closer to the 'Na-Cl precipitation' dominance zone than the urban cluster. The urban cluster was located closer to the centre of the Gibbs diagram, closer to 'rock dominance' and 'evaporation' zones in the Gibbs (1970) model.

## Discussion

Our results shared many similarities to previous Australian freshwater ionic data on the Gibbs diagram by Hart and McKelvie (1986). Reference streams in the study were consistent with the ionic chemistries that Hart and McKelvie reported to be typical of waterways in coastal-flowing streams in south-east Australia. The streams were dominated by sodium and chloride ions with magnesium and sulfate ions having a sub-dominant influence (Hart and McKelvie 1986). Urban streams were also dominated by sodium and chloride ions but the sub-dominant influence was from calcium and bicarbonate ions. This shift within the Gibbs model suggests a greater influence by geology, though recognising that evaporation may also have some influence (i.e. higher electrical conductivity – total dissolved solids). In comparison to various Australian waterways that Hart and McKelvie (1986) displayed on a Gibbs' diagram, the ionic chemistry of our urban streams resembles rivers in inland NSW.

## Concrete as an urban source of calcium and bicarbonate ions

A key anthropogenic factor that differentiates the geology between the urban and reference catchments is the ubiquitous presence of concrete used in most urban drainage infrastructure. The results suggest that the changes observed in urban stream chemistry are strongly influenced by this material with significantly higher calcium and bicarbonate ions and pH. This is supported by small-scale studies that demonstrated that concrete drainage materials quickly and significantly modify water chemistry (Davies 2009; Davies *et al.* 2010*a,b,c*). For example, when 20 L of rain water was recirculated through a concrete pipe for 100 minutes, EC doubled, pH rose from 4.8 to 7.9, calcium concentrations increased seven-fold and bicarbonate rose 34-fold (Davies *et al.* 2010*a*). Similarly, when rainwater passed down concrete gutters of 15-

200 m, pH rose by two or more units, and bicarbonate and calcium levels rose by up to four times (Davies *et al.* 2010*c*).

Rose (2003), in a catchment study in Georgia, U.S.A., reported elevated levels of calcium and bicarbonate in urban rivers when compared with a less developed catchment. The differences were greater in base flow conditions. He suggested that the cause was likely to be related to urbanisation and concrete, though these conclusions were not supported by other experimental data. However, the two catchments investigated by Rose (2003) contained waste-water that combined both stormwater with sewerage in a single pipe. This may have cumulatively been responsible for the changes in water chemistry. In northern Sydney, stormwater and sewerage systems are separated and no sewerage treatment systems discharge into any of the waterways tested.

Although we found that the EC of urban streams was twice as high as in non-urban streams, this may not necessarily be explained by higher evaporation rates. Evapotranspiration modelling approaches developed for forested areas can be suitable for application to urban areas (Grimmond and Oke 1991) and the urban waterways sampled are generally characterised by riparian zones which retain trees and shrubs. Thus, it is unlikely that urban development itself would change evapotranspiration rate to result in a higher EC. However, in light of the limited data, any interpretation regarding the influence of evaporation on urban water chemistry would need more detailed investigation.

## Water sensitive urban design and utilisation of concrete drainage materials

From a land management perspective the study results suggest expanding the horizons of current water quality monitoring programs and to consider the composition of materials in the urban drainage system. This is particularly timely in Australia where by 2050 it is estimated that 42% of the coastline between Nowra and Noosa (a 1200-km arc of south eastern Australia) will be urbanised (Theobald *et al.* 2000). To reduce the environmental impact of urbanisation on local waterways, many councils are implementing 'water sensitive urban design' (WSUD) features that are largely focused on removing nutrients and sediment and reducing peak flows (Walsh *et al.* 2005). For some Australian jurisdictions, such as Victoria and south-east Queensland, this is required by legislation, while for others it is promoted by voluntary guidelines (e.g. CSIRO 1999, Wong 2006). However, most WSUD treatment systems still rely on extensive use of conventional concrete urban drainage networks.

One of the aims of a WSUD program is to reverse the adverse impacts of urbanisation on stream ecosystems. Consideration, therefore, should be given on how to return uncontaminated runoff to streams, particularly in areas such as coastal south-eastern Australia where natural waterways are often dilute, acidic and poorly buffered (Hart and McKelvie 1986). In such locations, the ionic balance can be easily and rapidly modified by changes to the surface or the 'urban geology'. This may have implications for in-stream aquatic ecosystems. For example, benthic diatom communities in the United States were reported by Potopova and Charles (2003) to be strongly influenced by ionic composition. Variation in the concentration of each anion and cation, along with changes in electrical conductivity and pH, were all found to strongly affect diatom species composition. Other repercussions may occur throughout the food web when anthropogenic geochemical changes modify algal communities at the base of aquatic food chains. Such impacts should be particularly considered for healthy waterways near the urban fringe that may receive stormwater runoff from future urban development. The planning, construction and materials used in the stormwater infrastructure should be given much greater attention in such circumstances.

The results support the hypothesis that urban streams in northern Sydney have strongly modified ionic chemistries compared to nearby reference streams. The elevated sub-dominance of calcium and bicarbonate ions in urban streams is likely to reflect the inclusion of an artificial geological influence (Gibbs 1970). Other studies (Davies *et al.* 2009; 2010*a,b,c*) provide support that concrete, being the major material used in most urban drainage systems in Australia, readily leaches minerals and provides both the source of the ionic contamination and the pathway into urban waterways of calcium and bicarbonate ions. The shift in position within the Gibbs diagram resulting from ionic changes to the urban water chemistry in northern Sydney suggests a combination of a greater degree of rock weathering, evaporation and crystallisation are driving change away from the natural dominance of precipitation. While this study is narrow in geographic area, the results nevertheless indicate that urban designers and engineers should consider the materials used as part of drainage networks if there is a desire to comprehensively address the many causal factors influencing the 'urban stream syndrome' (Meyer *et al.* 1995).

**Table 1.** Number, name and location (including latitude and longitude) of urban and reference waterway samples. Total and connected impervious (imperv.) values of catchments are given. N/A indicates locations where inadequate drainage information was available for calculation.

| Site Number | Creek | Locality | Approx. lat. and long. | Approx. imperv. (%) | | Category | Date of sampling |
|---|---|---|---|---|---|---|---|
| | | | | Total | Connected | | |
| 1 | Berowra Creek Tributary | Berowra Heights, Berowra Valley Bushland Park | 33°35'37.43"S 151°07'46.79"E | 0.4 | N/A | Reference | 25January 2010 |
| 2 | Deep Creek | Davidson, Garrigal National Park | 33°42'08.63"S 151°13'52.83"E | 2.5 | 0.7 | Reference | 20 November 2009 |
| 3 | Salvation Creek | West Head Road, Ku-ring-gai Chase National Park | 33°37'32.05"S 151°15'33.96"E | 1.5 | 0.0 | Reference | 22 January 2010 |
| 4 | McCarrs Creek | Terry Hills, Ku-ring-gai Chase National Park | 33°39'57.54"S 151°15'15.94"E | 1.8 | 0.0 | Reference | 4 December 2009 |
| 5 | Cowan Creek | St Ives | 33°41'53.48"S 151°10'59.58"E | 1.3 | 0.9 | Reference | 27 November 2009 |
| 6 | Tree Fern Gully | St Ives | 33°42'01.82"S 151°10'39.85"E | 8.8 | 3.6 | Reference | 13 November 2009 |
| 7 | Ku-ring-gai Creek | St Ives Chase | 33°42'17.94"S 151°10'17.75"E | 29.5 | 29.3 | Urban | 13 November 2009 |
| 8 | Branch of Cowan Creek | Turramurra | 33°42'42.03"S 151°09'59.26"E | 23.8 | 23.7 | Urban | 20 November 2009 |
| 9 | Blackbutt Creek | Pymble | 33°45'37.80"S 151°08'31.89"E | 31.5 | 31.5 | Urban | 22 January 2010 |
| 10 | Stony Creek | Lindfield | 33°44'56.93"S 151°10'03.71"E | 32.1 | 32.0 | Urban | 27 November 2009 |
| 11 | Carroll Creek | Frenchs Forest | 33°45'14.60"S 151°12'26.09"E | 29.9 | N/A | Urban | 4 December 2009 |
| 12 | Washtub Gully | Berowra Heights | 33°36'50.80"S 151°08'13.95"E | 12 | N/A | Urban | 25 January 2010 |

**Table 2.** Summary statistics comparing water chemistry for non-urban and urban streams

**Table 2. Summary statistics comparing water chemistry of non-urban and urban streams**

| Water chemical attribute (units) | Non-urban | | | Urban | | | *t*- statistic (*P*-values) |
|---|---|---|---|---|---|---|---|
| | Range | | | Range | | | |
| | Min | Max | Mean | Min | Max | Mean | |
| pH (pH units) | 4.36 | 6.56 | 5.69 | 6.04 | 8.01 | 6.84 | 9.85 (<0.0001) |
| Electrical conductivity ($\mu S\ cm^{-1}$) | 148 | 255 | 194 | 269 | 743 | 433 | 11.95 (<0.0001) |
| Total alkalinity (Bicarbonate) ($mg\ L^{-1}$) | 0.5 | 14.0 | 4.49 | 28.0 | 113.0 | 46.91 | 17.17 (<0.0001) |
| Calcium ($mg\ L^{-1}$) | 0.5 | 6.0 | 3.30 | 12.0 | 34.0 | 20.24 | 17.21 (<0.0001) |
| Sodium ($mg\ L^{-1}$) | 16.0 | 45.0 | 23.55 | 20.0 | 100.0 | 46.55 | 7.70 (<0.0001) |
| Chloride ($mg\ L^{-1}$) | 31.0 | 82.0 | 48.57 | 42.0 | 190.0 | 90.05 | 7.60 (<0.0001) |
| Magnesium ($mg\ L^{-1}$) | 2.0 | 7.0 | 4.05 | 4.0 | 12.0 | 6.84 | 8.16 (<0.0001) |
| Potassium ($mg\ L^{-1}$) | 0.5 | 4.0 | 1.87 | 2.0 | 6.0 | 3.90 | 9.30 (<0.0001) |
| Sulfate ($mg\ L^{-1}$) | 0.5 | 24.0 | 8.87 | 0.5 | 27.0 | 13.46 | 3.11 (p=0.002) |
| Total Anions ($meq\ L^{-1}$) | 1.1 | 2.8 | 1.6 | 2.3 | 6.5 | 3.7 | 11.9 (<0.0001) |
| Total Cations ($meq\ L^{-1}$) | 1.0 | 2.6 | 1.6 | 2.1 | 6.3 | 3.7 | 11.2 (<0.0001) |

**Figure 1.** Mean (plus standard error) water chemistry results (a) pH, (b) Bicarbonate concentration, (c) Chloride concentration, (d) Electrical Conductivity, (e) Sodium concentration, (f) Potassium concentration, (g) Calcium concentration, (h) Sulfate concentration, (i) Magnesium concentration from 7 water samples from each non-urban reference creek (white bar), numbered 1 to 6, and from each urban creek (black bar), numbered 7 to 12. See Table 1 for waterway name and details.

*Figure 1(a)*

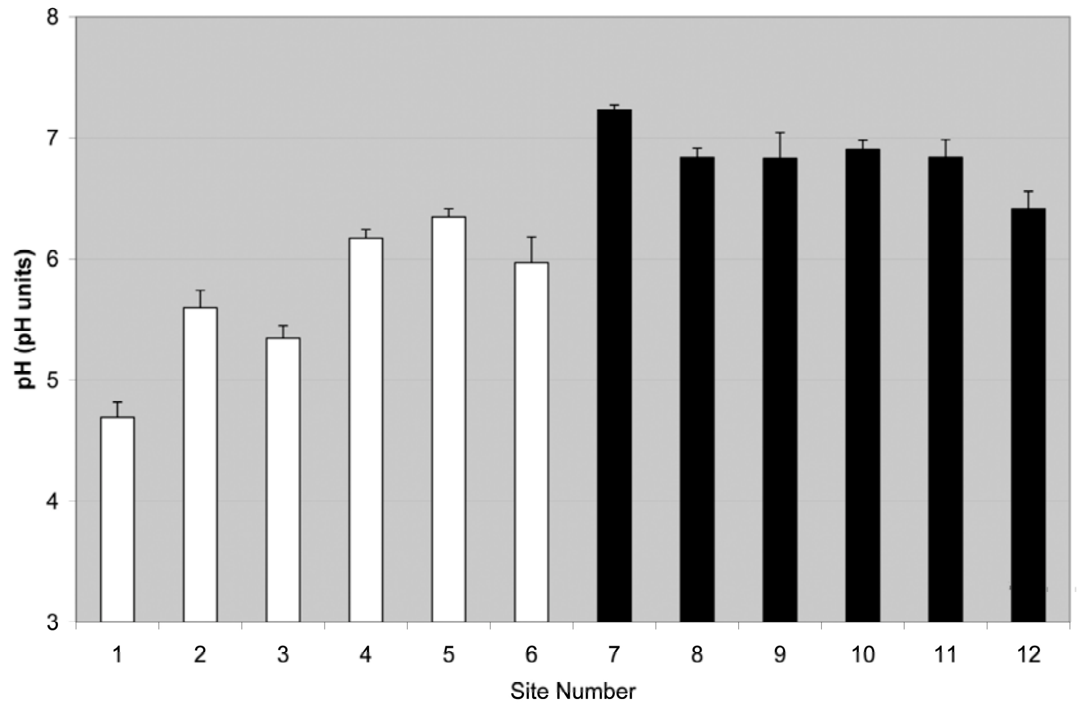



*Figure 1(b)*

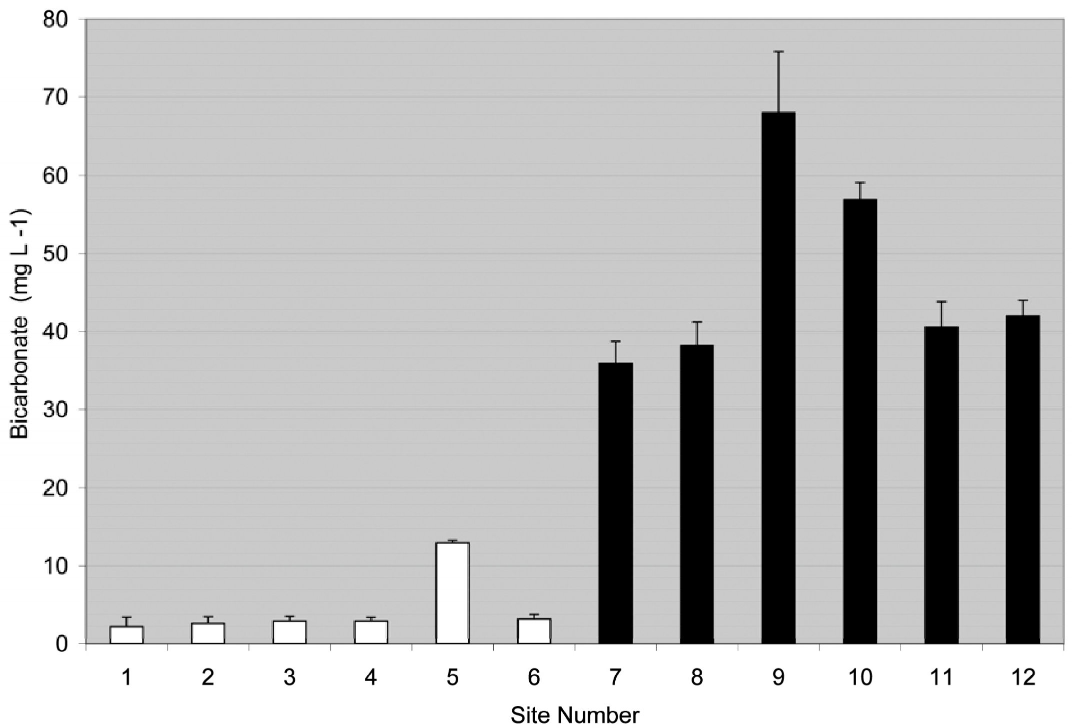


*Figure 1(c)*

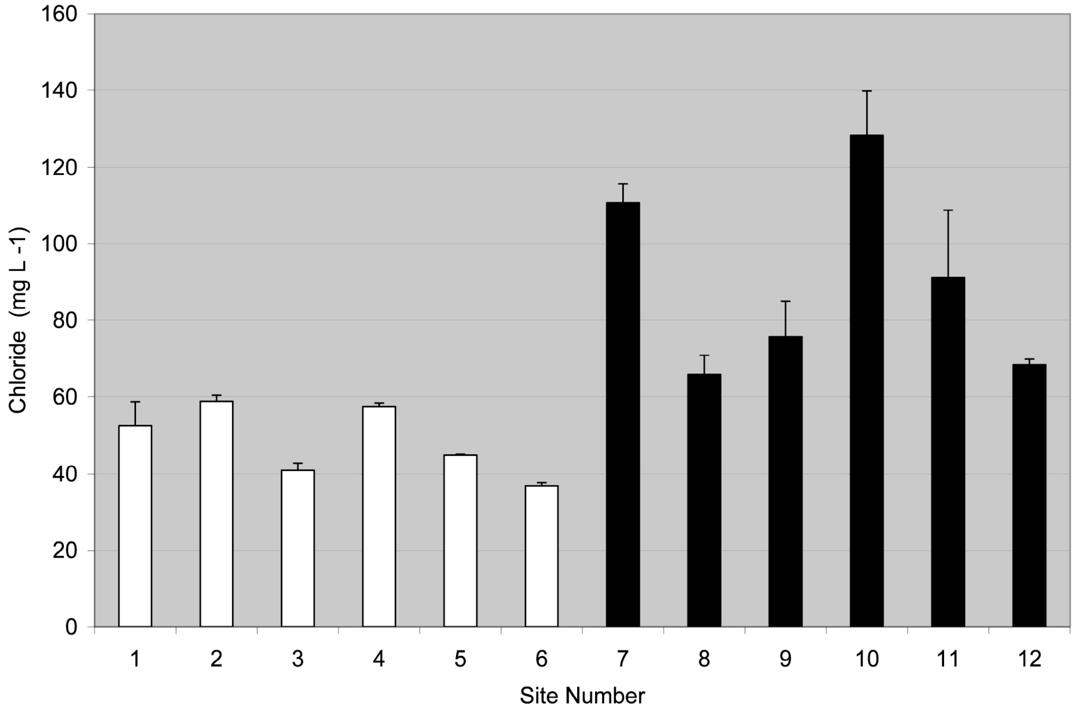



*Figure 1(d)*

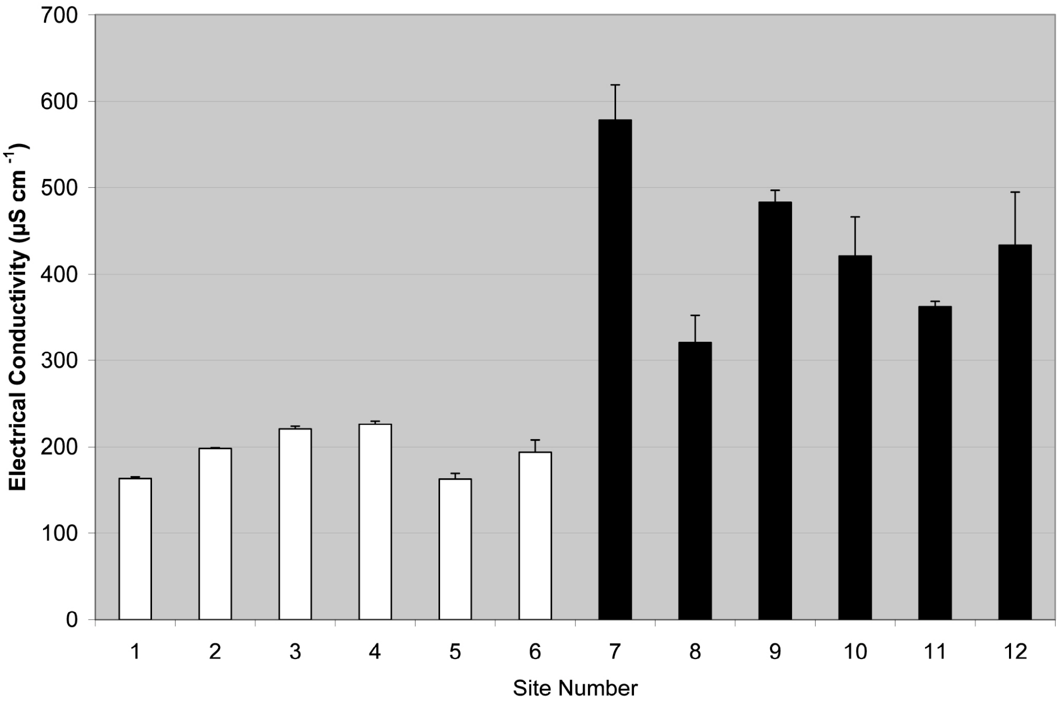


*Figure 1(e)*

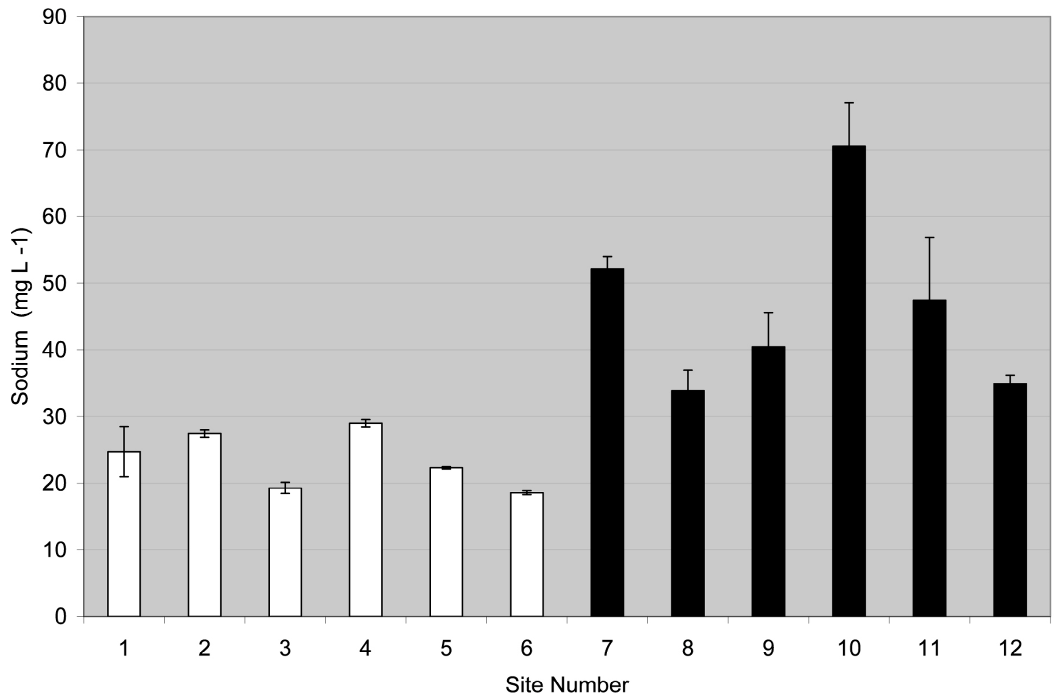



*Figure 1(f)*

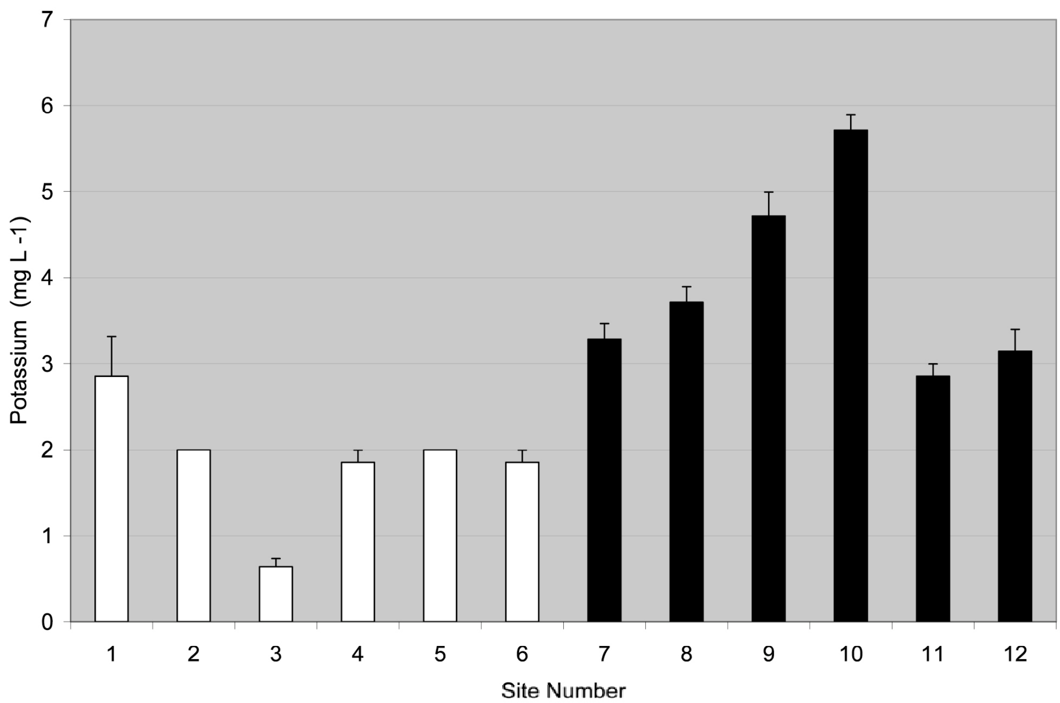


*Figure 1(g)*

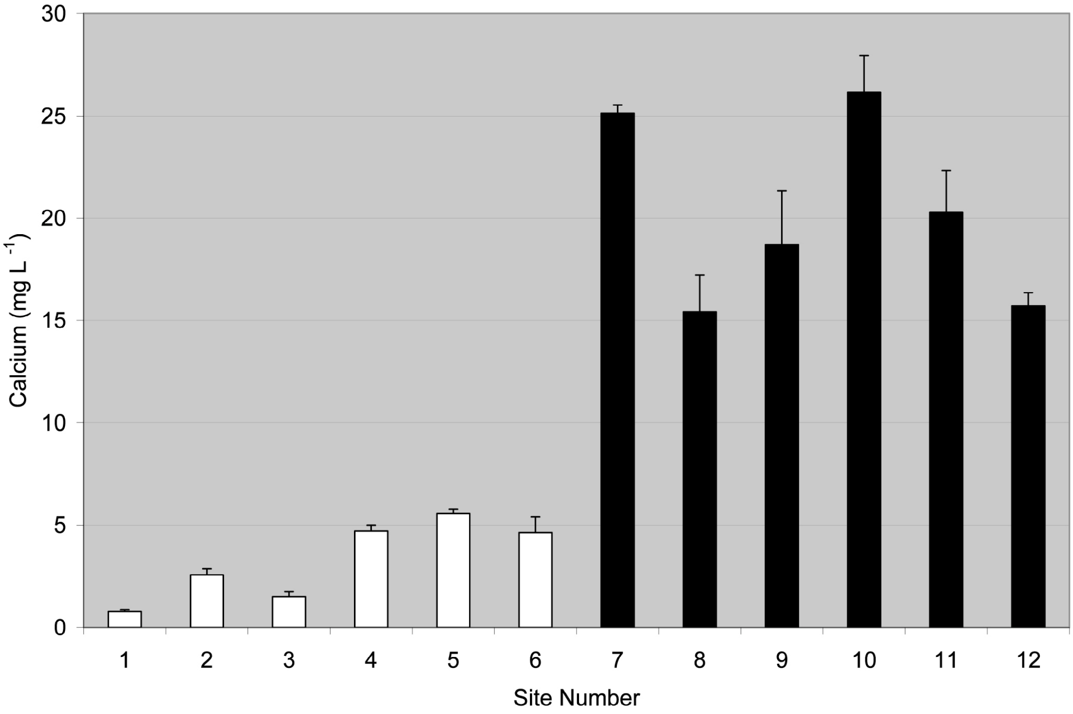



*Figure 1(h)*

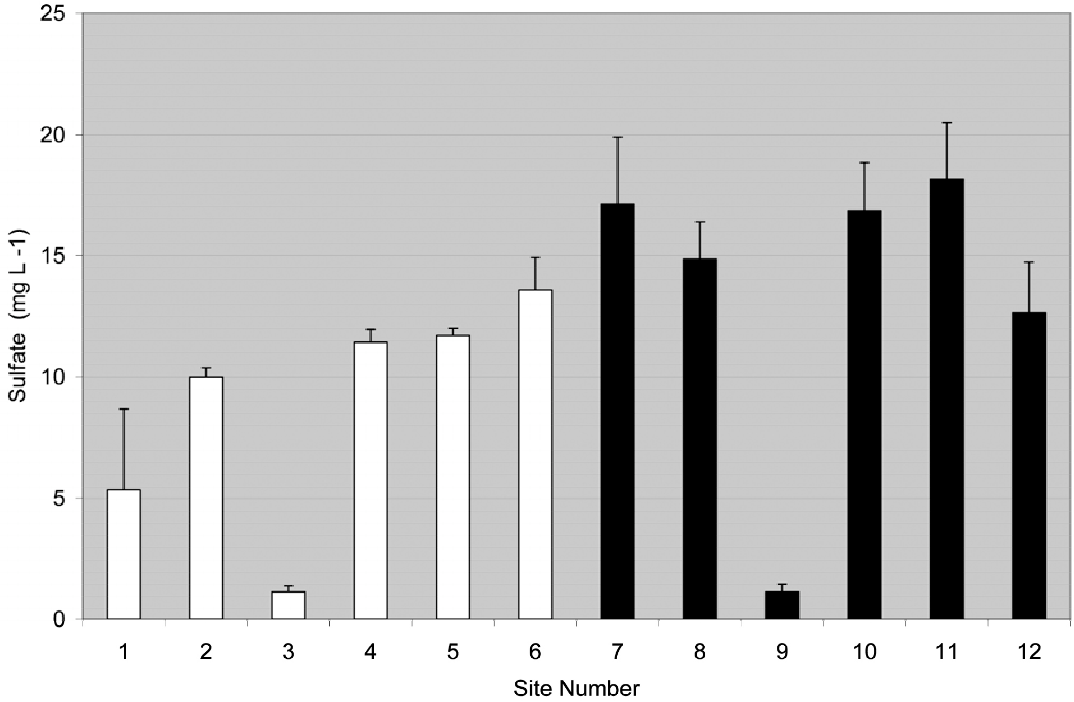
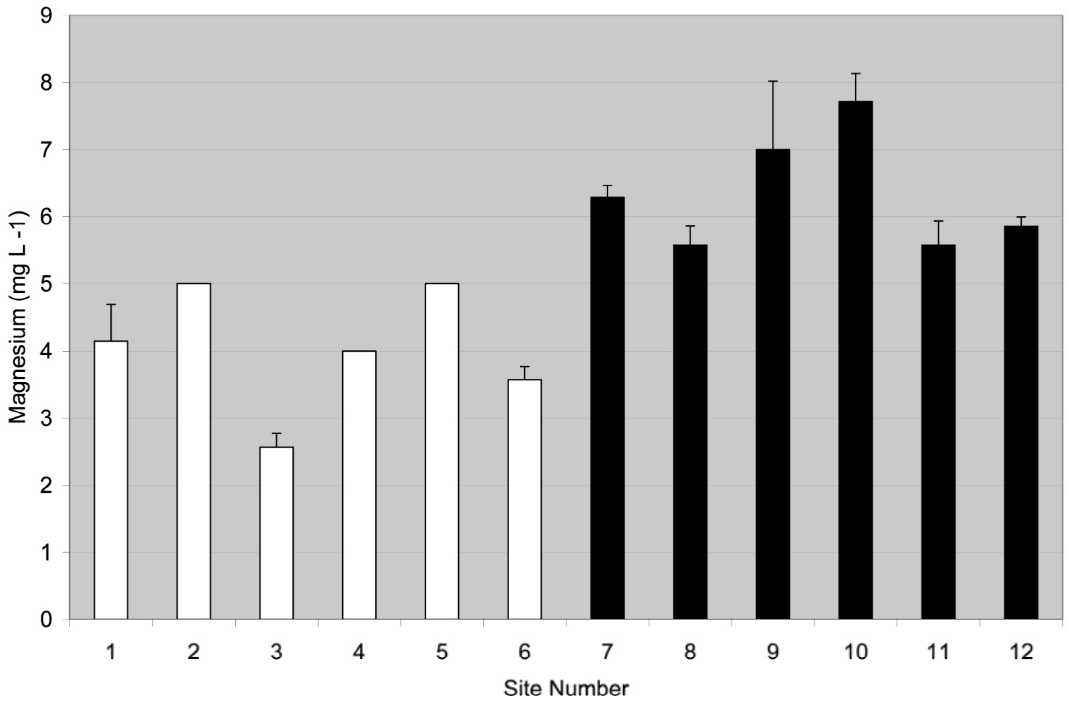


*Figure 1(i)*



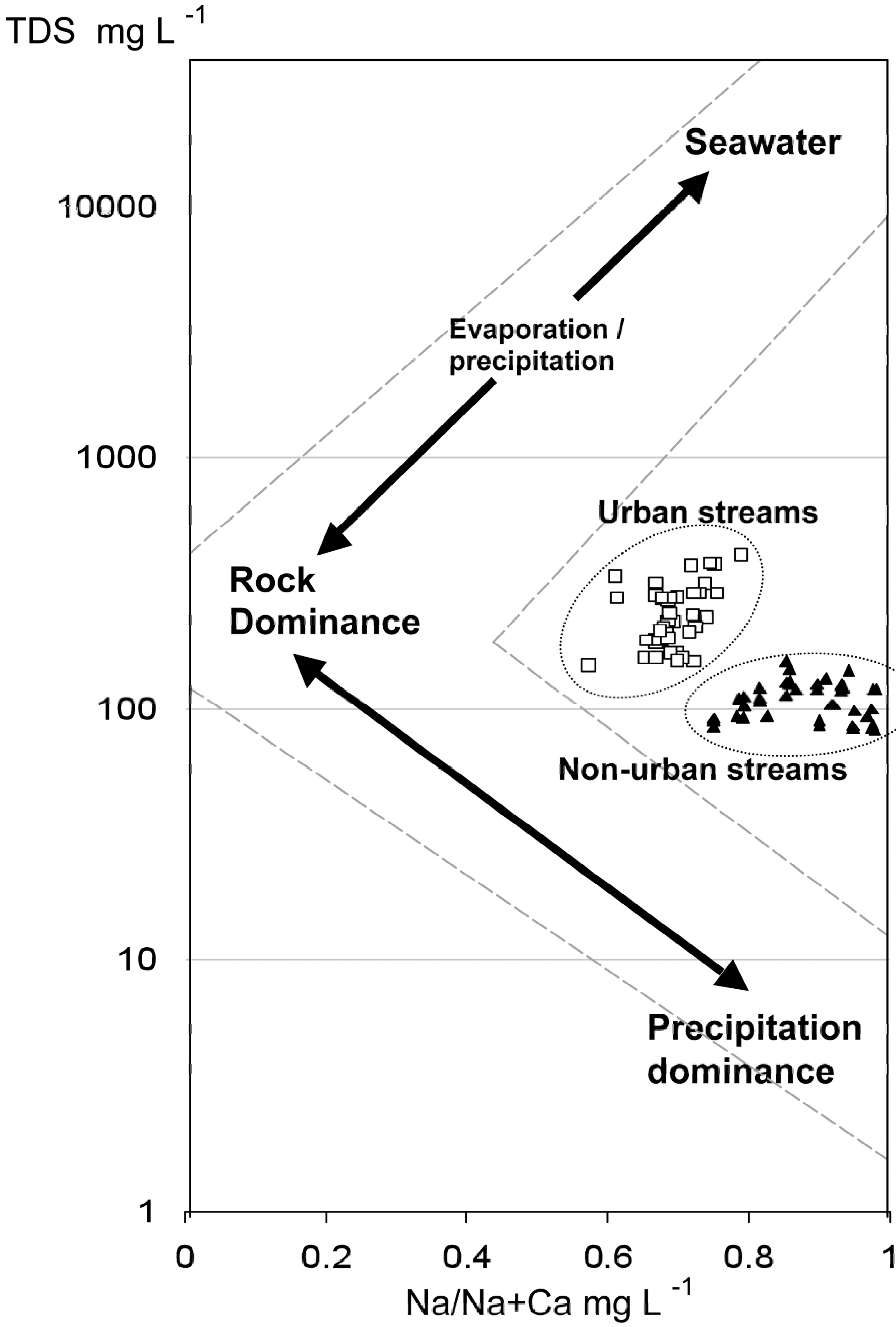



**Figure 2.** The relationship between Na/(Na + Ca),and 'total dissolved solids' (TDS). The group of results from northern Sydney non-urban streams and urban stream are labelled. The diagram follows that used by Gibbs (1970), representing the global variation in composition of the world's surface freshwaters.

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# Chapter 6: Case studies in stormwater harvesting, water recycling and water sensitive urban design

The creation of water sensitive cities demands significant changes to the way our water systems are designed and managed. As noted by Birrell et al (2005), the recent drivers for integrated urban water management in Australia have been linked to the need to meet the water demand of an increasing population coupled with the current drought. Ecologists, such as Walsh and Meyer, have steered the agenda to improve the condition of waterways affected by urban runoff, while Brown and Farrely (2007) have focused on the need for institutional reform to enable organisations to respond to industry best practice. For local government, the new direction represents both opportunities and challenges. This can be largely positioned around changing professional and organisational perceptions as to what is core urban water business for local government and how it can respond in a policy context (as discussed in Chapters 2 and 3) and also through the delivery of on-ground works (Chapters 6 and 7).

In this chapter, eleven conference papers are presented. These profile a range of on-ground projects undertaken by Ku-ring-gai Council and provide examples of how the council has responded to its policy frameworks and applied evidenced-based research to connect theory and practice as part of the council's move to become a more water sensitive city.

This work approach is consistent with the direction of the National Water Commission that has set two water sensitive cities priority projects, responding to paragraph 92 of the National Water Initiative (Commonwealth Government (2004)). These include: water sensitive urban developments (National Water Initiative paragraph 92(iii)) that aim to draw out key lessons on water sensitive urban design (WSUD) developments in the context of problems and practical constraints faced by those planning, building, and maintaining these developments; and incentives to stimulate innovation (National Water Initiative paragraph 92(v)) that will review implementation of existing projects and provide guidance on incentives to stimulate innovation that will drive integrated water cycle management, including water sensitive urban design (www.nwc.gov.au/www/html/500-water-sensitive-cities-.asp?intLocationID=500 accessed 23 January 2011). Furthermore, the projects serve as examples to the local community to demonstrate how the council is proactively managing the environment and urban water resources, a theme further explored in Chapter 7.

The papers have been grouped against six themes (as listed in Table 6.1). These include: WSUD design; WSUD operation; stormwater harvesting; biofiltration; health risks; and sewer mining. Many of the papers discuss more than one theme – to aid the reader shading has been used in the table to identify the major areas of focus.

*Table 6.1 Major themes of the case study papers in Chapter 6*

| Paper number and brief title | WSUD design | WSUD operation | Stormwater harvesting | Bio-filtration | Health risk | Sewer mining |
|---|---|---|---|---|---|---|
| 11. WSUD case studies | | | | | | |
| 12. Stormwater harvesting case study | | | | | | |
| 13. Water balance modelling | | | | | | |
| 14. Biofiltration case study | | | | | | |
| 15. Hydraulic conductivity of biofiltration systems | | | | | | |
| 16. Runoff generation for stormwater harvesting | | | | | | |
| 17. Stormwater harvesting and need for disinfection | | | | | | |
| 18. Stormwater harvesting health risks | | | | | | |
| 19. Biofiltration filter media comparison | | | | | | |
| 20. Water reuse case study | | | | | | |
| 21. Sewer mining implementation case study | | | | | | |

Key insights offered in this chapter include:

- WSUD in existing developed catchments is fraught with challenges that ultimately lead to compromises to design standards and industry guidelines. Consequently, there is a need to set and prioritise objectives for WSUD projects and use these to inform design decisions (**Papers 11** and **12**). This is particularly relevant in determining the optimal size and type of soil media used in biofiltration systems to treat stormwater (**Papers 14, 15** and **19**).

- There are no standard industry water balance models that can be relied on to provide an accurate estimate of water demand and supply for stormwater harvesting schemes. As a consequence, it is recommended that hydraulic models be developed and calibrated with local data to improve accuracy. This should include information on the physical properties of the catchment (such as imperviousness and soil type), rainfall, evaporation, runoff, stream flow and irrigation (although the behavioural practices by staff are likely to significantly influence the amount of water used for irrigation if they are not informed by quantitative data) (**Papers 13** and **16**).

- The presence of *E-coli* in stormwater inflow is not always a reliable indicator of the bacterial health risk associated with the use of harvested stormwater. While this in itself is not new, the research found that a delay in the use of stormwater for irrigation by a few days following rain (ie after the filling of the tank and when the soil moisture has reduced) will result in a natural decay in certain bacteria that will reduce the health risk. Depending on the typical concentrations of *E-coli* entering the stormwater tank, this may obviate the need for expensive UV or other chemical disinfection treatment (**Papers 17** and **18**).

- The use of sewage as a water supply source for irrigation systems is more reliable, although more costly, than stormwater harvesting schemes. However, there is limited uptake of this approach in Sydney and it will remain a boutique solution for some time until local government, Sydney Water Corporation, the Independent Pricing and Regulatory Tribunal and other regulatory bodies become more familiar and experienced in this area (**Papers 20** and **21**).

paper eleven

# Water sensitive urban design and stormwater harvesting – on the path to sustainable urban development: case studies from Sydney, Australia

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paper eleven

# WATER SENSITIVE URBAN DESIGN AND STORMWATER HARVESTING – ON THE PATH TO SUSTAINABLE URBAN DEVELOPMENT – CASE STUDIES FROM SYDNEY, AUSTRALIA

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## ABSTRACT

In Australia, Water Sensitive Urban Design (WSUD) or Sustainable Urban Drainage (SUDS) is being used to integrate urban drainage and water supply infrastructure planning and design with elements of hydrology, ecology, land use planning and landscaping. To support this direction, various National and State guidelines and legislation have been developed that are aimed at changing traditional engineering and urban design practice.

Recent droughts affecting most of Eastern Australia, including three capital cities, has led to a focus on urban water management. This has increased the attention and recognition of integrated water management including water conservation, demand management, diversification of supply, protecting environmental flows and improving water quality at the receiving bodies. Within Australia, stormwater reuse is being promoted as one way to lessen the demand on drinking water supplies for non-potable uses. Important for urban areas is the need for appropriate levels of treatment (depending on use) and sufficient storage to provide a reliable supply. From an integrated water management perspective such projects can have multiple benefits through managing the discharge and improving the quality from low frequent storms at the local scale while providing broader water conservation gains across the urban area.

This paper discusses two case studies from Australia that have applied integrated water management principles within an existing urban catchment. These include a stormwater harvesting project to irrigate a sports field and a car park bioretention system to treat road runoff before it discharges to a natural stream.

## KEYWORDS

Water Sensitive Urban Design; Integrated water management; Stormwater harvesting; Stormwater treatment.

## 1 INTRODUCTION

Ku-ring-gai local government area (LGA) is located approximately 15 km north of the Sydney CBD in New South Wales, Australia. The LGA covers an area of 85.4 km$^2$ [1] and is characterised by low density residential housing set on individual lots. The population is approximately 101,000 [2]. The landscape is characterised by low density urban development located on the flatter ridge tops with the steeper slopes to the three major catchments comprised of bushland much of which is within National Park estate. The annual rainfall is approximately 1,430 mm per year [3].

Urban areas continue to impact on natural systems. Stormwater runoff contains a range of pollutants such as litters, sediments, metals and nutrients. Changes to the hydraulics, physical, chemical and biological conditions of receiving water bodies are also experienced due to the increase in impervious areas and construction of engineered drainage networks [4,5,6]. Across the Ku-ring-gai LGA this has been measured across water chemistry, biology and hydrology studies [7].

Integrated water management or water sensitive urban design (WSUD) seeks to address these changes through recognising the relationships of urban drainage and water supply infrastructure planning with design elements of hydrology, ecology, land use planning and landscaping [8]. Supporting this approach has been a range of government polices, guidelines and in some states legislation that have drawn from research, case studies and pilots undertaken by various institutions and land managers [8,9,10,11,12,13,14,15,16].

For local government in Australia, WSUD is still an emerging path. Within Sydney, references is made to this through various government policies such as the 2006 Metropolitan Water Plan [17] that identifies and promotes various water recycling and reuse projects. However, for local government, the ability to introduce these projects is often left to the motivation of individual officers and Councils and all too often turns on opportunistic projects, trials or demonstration sites as a means to progress better stormwater and whole or water cycle management. While stormwater reuse scheme are promoted as good practice [13] their design and performance are not subject to minimum mandatory health standards as are water recycling plants that may leave local councils and others in a precarious legal position in the future [18].

Ku-ring-gai Council is currently implementing a water management program that will see 12 stormwater harvesting system being built in the next five years, with an estimated saving of approximately 36 ML of potable water per year. In addition, the Council is also committed to constructing a sewer mining facility to irrigate open space areas as well as implementing various water sensitive urban design features across our developed landscape.

### 1.1 Water quality requirements

The NSW Department of Environment and Conservation [13] has published a guideline on stormwater harvesting and reuse. This is mostly concerned with public health, relying on faecal coliforms as an indicator of the suitability of water for indirect human contact, and in the case of performance of irrigation infrastructure nutrients and suspended solid loads. In part the use of guidelines rather than mandatory standards or laws reflects the high variability of stormwater quality and may impact on the cost of treatment for reuse projects. Importantly however, it has been recognized that a “fit for purpose” ethos acknowledges that it is not necessary to have potable standard water for all applications.

*Table 1. NSW Department of Environment and Conservation's guidelines, stormwater quality criteria for public health risk management for stormwater reuse [13].*

| Level | Criteria (1) | Applications |
|---|---|---|
| | E. coli <1 cfu/100 mL | |
| | Turbidity 2 NTU (2) | |
| | pH 6.5–8.5 | |
| Level 1 | 1 mg/L $Cl_2$ residual after 30 minutes or equivalent level of pathogen reduction | Reticulated non-potable residential uses (e.g. garden watering, toilet flushing, car washing) |
| | E. coli <10 cfu/100 mL | Spray or drip irrigation of open spaces, parks and sportsgrounds (no access controls) Industrial uses – dust suppression, construction site use (human exposure possible) |
| | Turbidity 2 NTU2 | |
| | pH 6.5–8.5 | Ornamental water bodies (no access controls) |
| Level 2 | 1 mg/L $Cl_2$ residual after 30 minutes or equivalent level of pathogen reduction | Fire-fighting |
| | E. coli <1000 cfu/100 mL | Spray or drip irrigation (controlled access) or subsurface irrigation of open spaces, parks and sportsgrounds |
| Level 3 | pH 6.5–8.5 | Industrial uses – dust suppression, construction site use, process water (no human exposure) |
| | | Ornamental water bodies (access controls) |
| (1) values are median for E. coli, 24-hour median for turbidity and 90th percentile for pH | | |
| (2) maximum is 5 NTU | | |

This paper discusses two case studies within the Ku-ring-gai Council LGA that have applied sustainable urban development principles in retrofit situations. These include a sports field stormwater harvesting irrigation scheme and a car park bioretention system to treat road runoff. Each project has considered a range of factors in its design including the local importance of the receiving water bodies, proximity and value of adjacent bushland, social and community benefits need to improve water quality and manage runoff volumes.

## 2 CASE STUDY 1: SPORTSFIELD STORWMATER HARVESTING IRRIGATION SCHEME

The sports field irrigation scheme described in this case study is located at Edenborough sportsfield, Lindfield NSW (Latitude 33:46:59, Longitude 151:09:43). The field is mainly used for soccer in winter and cricket in summer. It is also used for archery and as a dog off-leash area all year around. The field is currently not irrigated.

Due to the popularity of sport especially soccer, demand and consequent wear is beyond what is sustainable in terms of providing a sound playing surface. Reconstruction of the oval soil profile and providing irrigation are two mechanisms that can improve its condition and longevity. Water restrictions imposed by the State Government as a consequence of a longer term drought affecting much of Eastern Australia, limits the use of potable supplies for irrigating open space areas so therefore a more sustainable source of water must be found if the social and community benefit of this asset is to be continually realized.

As part of the identification of this site for its suitability for a stormwater reuse project, the catchment and site was assessed and a water balance model was built. These factors were used to evaluate levels of water security from a supply and demand perspective in response to differential storage volumes and historical rainfall characteristics. Modelling was conducted using a water balance model developed by Ku-ring-gai Council that incorporated 64 years of daily rainfall data from Turramurra (Australian Bureau of Meteorology site 066158 located approximately 3 km from the site) between 1936 and 2000. The model incorporated soil water holding capacity and losses from storage through evaporation (standard daily evapo-transpiration data for Sydney Observatory Hill, located approximately 14 km from the site) and deep soil infiltration to determine irrigation demand. Impacts on modeling outcomes as a result of limitations in pipe capacity, weir heights, treatment capacity of water quality devices, pump capacity and other design factors were not considered as part of the initial assessment. Above ground irrigation system (sprinklers) was assumed for all irrigation scenarios.

After this initial investigation and modeling it was determined that the harvesting system would best operated by collecting stormwater runoff from only a portion of the upstream catchment that could drain by gravity to the proposed storage location. Whilst this reduced the potential supply, through collecting runoff from a smaller catchment, advantages were realized via a simpler design, reduced cost, elimination of pumps and lower longer term maintenance. All designs and investigation was done in-house by Council staff.

Total storage was sized at 310 kL in two 155 kL concrete storage tanks located adjacent to the playing field. This provided an estimated security of water supply of 70% by volume, providing about 2,000 kL of reused water per year. The tanks were design to have a viewing platform for spectators on top and a soccer practice rebound wall in front.

### 2.1 Water quality treatment

The upstream catchment covers about three hectares of residential areas. Of the three hectares, approximately 1 hectare is roads and other hard surfaces that are connected to the drainage system. Stormwater is diverted from an existing stormwater line and is passes through a 5 mm mesh screen designed to capture litter and large sediments. The water is then conveyed to the sand filter. A sand filter was incorporated into the design for its good ability to remove fine sediments and *faecal coliforms* from stormwater [19].

Stormwater is distributed into the filter through an internal slotted pipe, with some perculation also occurring through the surface of the filter. A schematic of the filter is shown in *Figure 1*. Depending on the rainfall intensity, excess volumes will pond on top of the filter before bypassing the filter through a surcharge pit and into the storage tanks. The bypass pit is equipped with a 100 micron pit litter basket.

The sand filter is designed to treat the first 5-10 mm of stormwater runoff on the assumption that the initial flow or “first flush” is more likely to carry a higher concentration of pollutants than successive flows [20]. Once in the storage tanks, further sedimentation of fine sediment not captured in the sand filter will occur.

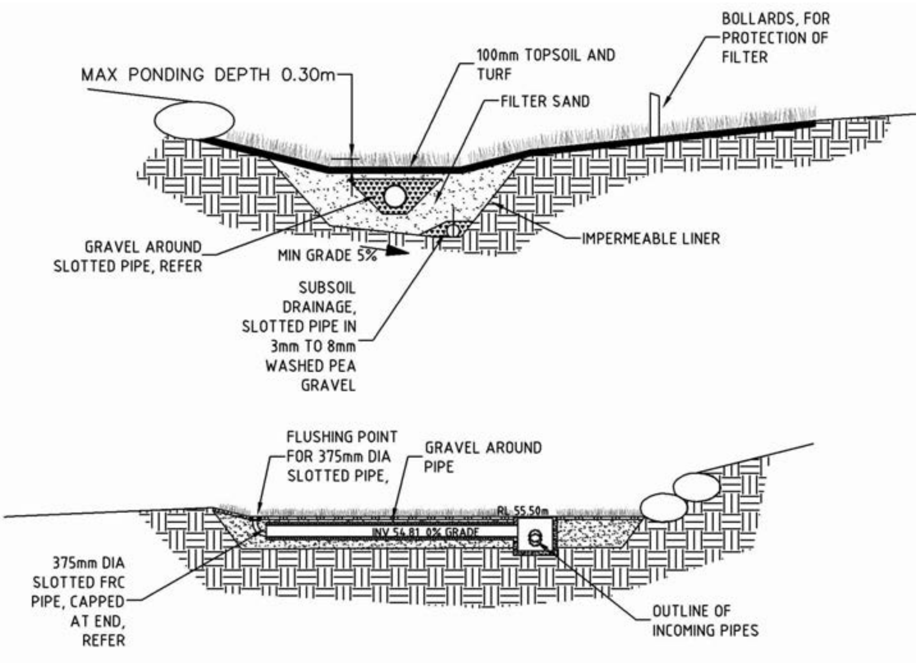


*Figure 1. Sand filter schematics.*

**2.2 Expected water quality**

The expected water quality performance of the system was assessed using the Model for Urban Stormwater Improvement Conceptualisation (MUSIC) as developed by the Australian Cooperative Research Centre for Catchment Hydrology. This computer model can assess the likely water quality improvements that can be expected from different stormwater quality improvement strategies [21].

For the litter screen, it was assumed that 80% of gross pollutants (pollutants that is retained by a 5 mm screen) would be captured, with no reduction in nutrients or suspended solids. For sand filters or bioretention systems (as similarly defined by MUSIC) and the storage tanks, standard treatment nodes as provided in MUSIC were used. It is recognized that the bioretention systems as modeled in the MUSIC program assumes more vegetation and biological activity than what can be expected in a sand filter. A high hydraulic conductivity (360 mm/hour) was therefore chosen to reflect the sand filter medium. The MUSIC model used 6 minutes rainfall data from 1959 (Sydney Observatory Hill), with a mean annual rainfall of 1490 mm/year. The overall imperviousness of the catchment was assumed to be 30%.

The predicted runoff and pollutant quantities are presented in *Table 2*. The predicted water quality improvement for each of the treatment measures as part of the stormwater harvesting system is presented in *Table 3*. It should be noted that the water quality modeling does not include reuse of the harvested water. Reuse of harvested water will further reduce the load of nutrients and fine sediments to the receiving waters. Notable in this modeling is that *faecal coliforms*, indicator of the presence of Escherichia coli, is not modeled due to its extreme variability across catchments and storm flows [22].

*Table 2. Predicted runoff and pollutant quantities.*

| | | |
|---|---|---|
| Total catchment | Flow (ML/yr) | 17 |
| | Total Suspended Solids (kg/yr) | 2,700 |
| | Total Phosphorus (kg/yr) | 6.04 |
| | Total Nitrogen (kg/yr) | 44.8 |
| | Gross Pollutants (kg/yr) | 460 |
| Diverted to harvesting system | Flow (ML/yr) | 12.2 |
| | Total Suspended Solids (kg/yr) | 1,930 |
| | Total Phosphorus (kg/yr) | 4.32 |
| | Total Nitrogen (kg/yr) | 32.1 |
| | Gross Pollutants (kg/yr) | 400 |
| Bypass harvesting system | Flow (ML/yr) | 4.8 |
| | Total Suspended Solids (kg/yr) | 767 |
| | Total Phosphorus (kg/yr) | 1.72 |
| | Total Nitrogen (kg/yr) | 12.7 |
| | Gross Pollutants (kg/yr) | 59.8 |

*Table 3. Predicted water quality improvement for each of the treatment measures.*

| **Litter screen** | Inflow | Outflow | Reduction |
|---|---|---|---|
| Flow (ML/yr) | 12.2 | 12.2 | 0% |
| Total Suspended Solids (kg/yr) | 1930 | 1930 | 0% |
| Total Phosphorus (kg/yr) | 4.32 | 4.32 | 0% |
| Total Nitrogen (kg/yr) | 32.1 | 32.1 | 0% |
| Gross Pollutants (kg/yr) | 400 | 80 | 80% |
| **Sand filter** | Inflow | Outflow | Reduction |
| Flow (ML/yr) | 12.2 | 12.2 | 0% |
| Total Suspended Solids (kg/yr) | 1930 | 601 | 69% |
| Total Phosphorus (kg/yr) | 4.32 | 1.99 | 54% |
| Total Nitrogen (kg/yr) | 32.1 | 22.9 | 29% |
| Gross Pollutants (kg/yr) | 80 | 0 | 100% |
| **Storage tanks** | Inflow | Outflow | Reduction |
| Flow (ML/yr) | 12.2 | 12.2 | 0% |
| Total Suspended Solids (kg/yr) | 601 | 393 | 35% |
| Total Phosphorus (kg/yr) | 1.99 | 1.94 | 3% |
| Total Nitrogen (kg/yr) | 22.9 | 21 | 8% |
| Gross Pollutants (kg/yr) | 0 | 0 | 0% |
| **Total reduction, diverted flow** | Inflow | Outflow | Reduction |
| Flow (ML/yr) | 12.2 | 12.2 | 0% |
| Total Suspended Solids (kg/yr) | 1930 | 393 | 80% |
| Total Phosphorus (kg/yr) | 4.32 | 1.94 | 55% |
| Total Nitrogen (kg/yr) | 32.1 | 21 | 35% |
| Gross Pollutants (kg/yr) | 400 | 0 | 100% |
| **Total reduction from catchment** | Inflow | Outflow | Reduction |
| Flow (ML/yr) | 17 | 17 | 0% |
| Total Suspended Solids (kg/yr) | 2700 | 1160 | 57% |
| Total Phosphorus (kg/yr) | 6.04 | 3.66 | 39% |
| Total Nitrogen (kg/yr) | 44.8 | 33.7 | 25% |
| Gross Pollutants (kg/yr) | 460 | 59.8 | 87% |

For stormwater reuse projects the quality of water affecting plants (turf) and irrigation system is a significant design and operational issue. For irrigating of sports facilities, suspended solids levels below 50 mg/L are unlikely to result in operational problems with the irrigation infrastructure in so far as blocking irrigation systems [13]. High concentrations of nutrients can lead to a build up of bio-films that may cause clogging of irrigation and affect plant health. Long-term (100 years) and short-term (20 years) maximum recommended concentrations of TN and TP in irrigation water are presented in *Table 4*. The predicted concentrations of TN, TP and TSS (leaving the storage tank) are presented as cumulative frequency graphs (flow weighted daily mean) in *Figures 2-4*. These show the harvested stormwater at Edenborough sportsfield is not predicted to cause any problems to the irrigation infrastructure in the short (20 year) term, but should be monitored for long term performance.

*Table 4. Maximum recommended concentrations of TN, TP [13].*

| Element | Long term (up to 100 years) | Short term (up to 20 years) |
|---|---|---|
| Total phosphorus (mg/L) | 0.05 | 0.8–12* |
| Total nitrogen (mg/L) | 5 | 25.0–125* |

* Requires site-specific assessment (refer to ANZECC & ARMCANZ 2000 [22])

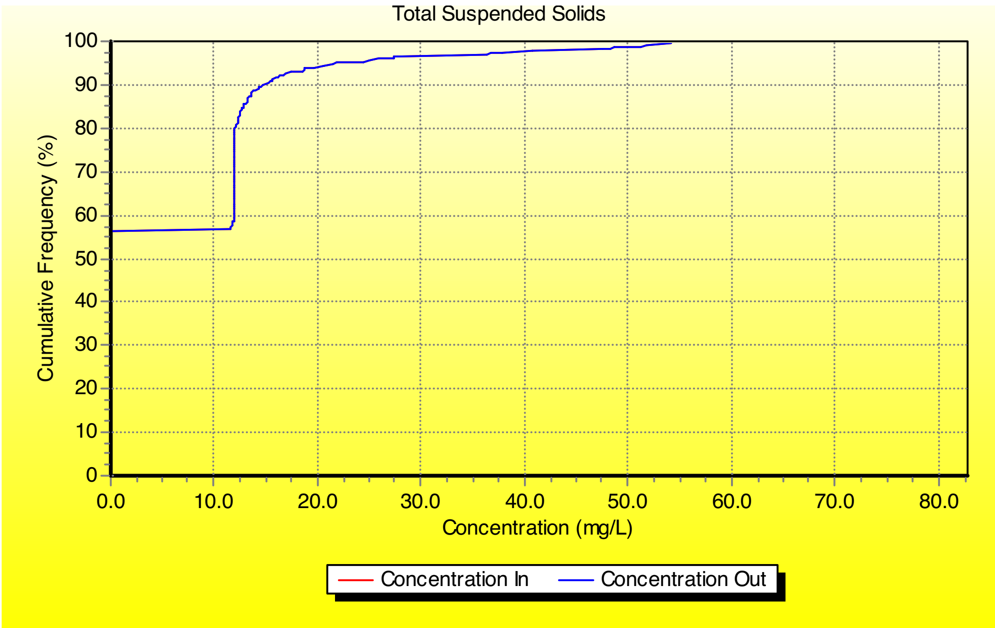


*Figure 2. Cumulative frequency graphs (flow weighted daily mean), TSS.*

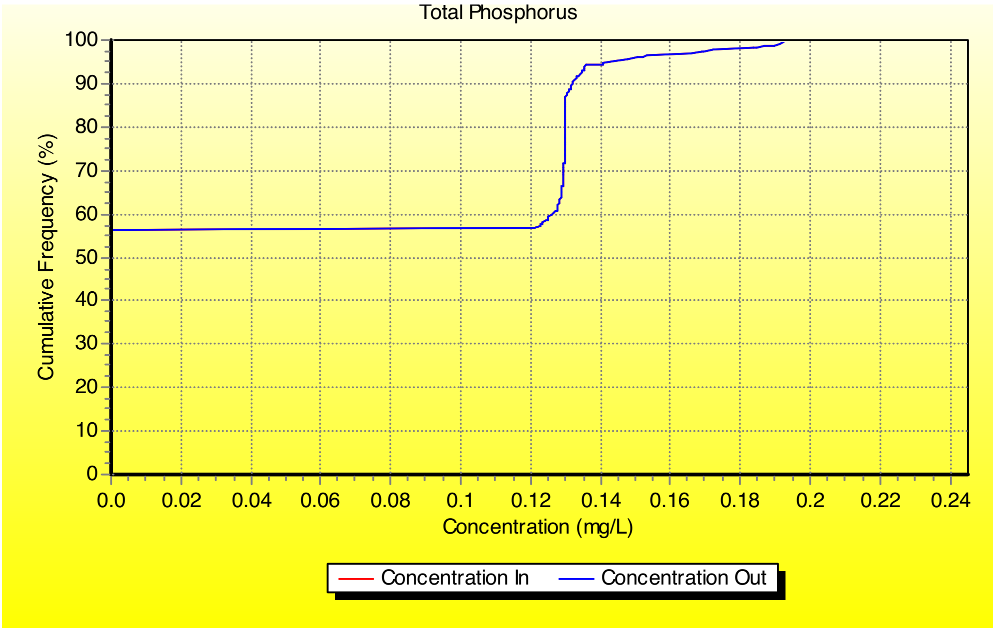


*Figure 3. Cumulative frequency graphs (flow weighted daily mean), TP.*

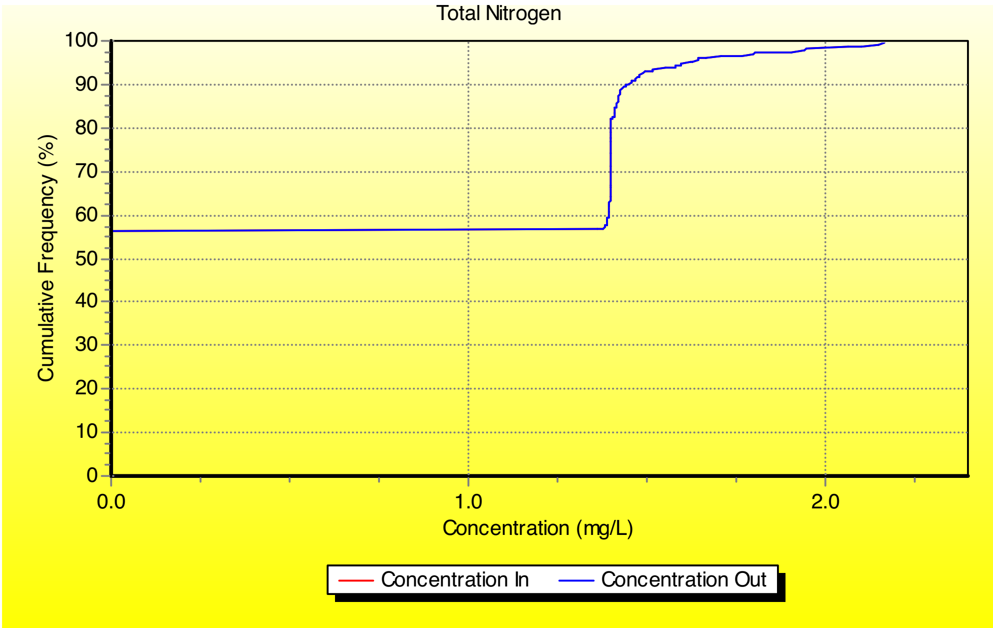


*Figure 4 Cumulative frequency graphs (flow weighted daily mean), TN*

## 3 CASE STUDY 2: BIORETENTION SYSTEM FOR TREATING STORMWATER RUNOFF FROM ROAD SURFACE

The sports ground car park bioretention system described in this case study is located adjacent to Turramurra Memorial Oval, Turramurra (Latitude 33:43:35, Longitude 151:07:49). The carpark is located immediately upstream of Lovers Jump Creek, that discharges into the

Hawkesbury River. A litter screen was installed within the creek in 2004 that captures gross pollutants such as leaves, bottles and food wrappers.

The bioretention systems were designed to reduce pollutants entering Lovers Jump Creek and in the longer term contribute to a stormwater harvesting project to irrigate the oval and surrounds. Three bioretention pits were installed. Two contained a sandy loam soil mix and their third incorporated soil conditioned with recycled organics. Ongoing monitoring will seek to evaluate the effectiveness of this media against the engineered soil to absorb various pollutants such as metals and hydrocarbons. Three individual bioretention gardens were designed to treat approximately 95% of the average annual runoff by volume with a catchment area of approximately 1,000 m$^2$.

### 3.1 Water quality treatment

Each garden was designed to complement the existing stormwater quality measure (litter screen) and targets pollutants that the litter screen is not able to capture. This includes sediments, and dissolved pollutants such as nutrients and metals. The individual gardens were equipped with a grated inlet that effectively separates leaves and litter from entering the bioretention gardens. The litter is captured by the litter screen downstream or by street sweepers. Water is designed to pond in the gardens to a depth of 300 mm, allowing a significant percentage of the runoff to be treated by the gardens.

### 3.2 Expected water quality

The expected water quality performance of the system was assessed using MUSIC [21]. Standard treatment nodes as provided in MUSIC were used for the bioretention systems, with a hydraulic conductivity chosen to reflect the sandy soil used as the filter medium. The MUSIC model used 6 minutes rainfall data from 1959 (Sydney Observatory Hill), with a mean annual rainfall of 1490 mm/year. The overall imperviousness of the catchment was set to 100%.

The predicted runoff and pollutant quantities are presented in *Table 5*.

*Table 5. Predicted water quality improvement for carpark bioretention system.*

| Bio retention gardens | Inflow | Outflow | Reduction |
|---|---|---|---|
| Flow (ML/yr) | 1.31 | 1.31 | 0% |
| Total Suspended Solids (kg/yr) | 207 | 15.5 | 93% |
| Total Phosphorus (kg/yr) | 0.464 | 0.104 | 78% |
| Total Nitrogen (kg/yr) | 3.44 | 1.57 | 54% |
| Gross Pollutants (kg/yr) | 31.7 | 31.7 | 0% |

## 4. CONCLUSIONS

The case studies presented in this paper show examples of WSUD in practice within a retrofit situation. The efficacy of these projects is yet to be validated against the modeling outcomes. Monitoring will be undertaken during rainfall within the catchment.

Within Australia, stormwater reuse is being promoted as one way to lessen the demand on drinking water supplies for non-potable uses. Water reuse and recycling project must be of suitable quality or "fit for purpose", however when dealing with stormwater this presents many challenges due to the variability in quality. Modeling tools such as MUSIC provide a mechanism though which engineers can estimate the efficiency of their designs through specific monitoring of constructed projects is needed to provide greater certainty to land mangers, designers and the community.

The community's acceptability towards WSUD projects and their understanding of the limitations of designs to treat water to potable standard will take time and must be a consideration in the planning and promotion of such project. Facilitating this to some degree in Australia is the current drought and subsequent water restrictions that is raising the understanding and value of water as a limited resource. How this influences risk in the context of public health remains unknown though must be a primary consideration for designers and managers if acceptability and confidence of such schemes is to gain a permanent foothold within the engineering, park management and community physic.

From an integrated water management perspective projects such as the ones presented in this case study should be designed and promoted as having multiple benefits through managing the discharge and improving the quality from low frequent storms at the local scale, providing broader water conservation gains across the urban area and importantly improving community facilities.

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# Stormwater harvesting – case study of Edenborough sportsfield, Lindfield, NSW

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# Stormwater harvesting – Case study of Edenborough sports field, Lindfield, NSW

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## ABSTRACT

The recent droughts affecting most of Eastern Australia has heightened the focus on integrated urban water management. In particular stormwater reuse for open space irrigation is being promoted as a way to lessen the demand on drinking water supplies for non-potable uses and deliver improvements to local water quality. To enable reuse schemes to occur it is necessary to manage the stormwater collection, treatment capture and storage as part of an integrated treatment train.

Ku-ring-gai Council in NSW has adopted an integrated water management program that will see 12 stormwater harvesting system implemented at local sports fields over a period of eight years. Three systems have been constructed with two more to be completed by the end of 2008. The second of these systems has been constructed at the Edenborough sports field, located in Lindfield. This site was identified as suitable for stormwater harvesting for sports field irrigation in 2005 as part of the development of Council's Environmental Levy. Planning and design commenced in 2006 with construction completed September 2007.

This paper provides insight into the planning, construction and monitoring of the facility. For planning this involved both technical and social considerations including determining the type and location of the water quality treatment and storage, setting suitable water quality and quantity targets whilst responding to community concerns of odors and safety. Construction issues covered geotechnical concerns, site conditions and weather during the final stages, and highlights the need for careful consideration of all options and close control during construction to ensure the intent of the design is delivered.

Monitoring has involved sampling of water upstream, through the treatment train and at the end-of the storage. This data has been compared to predicted quality outcomes as modeled through MUSIC. Initial monitoring has indicated that the stormwater treatment train adopted for the Edenborough playing field stormwater harvesting project is successful in its objectives to treat stormwater to a level suitable for reuse through irrigation of open spaces with restricted access.

The variability in stormwater quality presents many challenges. Modelling tools such as MUSIC provide a mechanism though which engineers can estimate the efficiency of their designs, however risk to human health can currently not be modeled using commonly available software used for stormwater system design. Specific monitoring of constructed projects is needed to provide greater certainty to land mangers, designers and the community. It is only through the construction and monitoring of actual systems can the industry get a level of certainty as to the performance in the field.

**KEYWORDS**
Water sensitive urban design, stormwater harvesting, water reuse, stormwater treatment

**INTRODUCTION**

Ku-ring-gai local government area (LGA) is located approximately 15 kilometres north of the Sydney CBD in New South Wales, Australia. The LGA covers an area of 85.4 km$^2$ and is characterised by low density residential housing set on individual lots [1]. The population is approximately 101,000 [2]. Urban development is located on the flatter ridge tops with the steeper slopes to the three major catchments comprised of bushland much of which is within National Park estate. The annual rainfall is approximately 1,430mm per year [3].

Ku-ring-gai Council is currently implementing a water management program that will see 12 stormwater harvesting system for irrigation of playing fields being built over eight years . This is estimated to save approximately 36 ML of potable water per year and significantly improve the condition and longevity of the playing fields.

The sports field irrigation scheme described in this case study is located at Edenborough sports field, Lindfield NSW (Latitude 33:46:59, Longitude 151:09:43). The field is mainly used for soccer in winter and cricket in summer. It is also used for archery and as a dog off-leash area all year around. The field is currently not irrigated.

Due to the popularity of sport across the LGA especially soccer, demand and consequent wear of the turf is beyond what is sustainable in terms of providing a sound playable surface. Reconstruction of the sports field soil profile and providing irrigation are two important mechanisms to improve the condition and use of many sporting venues.

Adding to the wear of the turf are recent drought conditions particularly the long inter-rain periods. In response Level 3 water restrictions were introduced by the State Government in June 2005. This limited the use of potable water for irrigating open space areas, a direction likely to continue into the future. As a consequence open space managers such as local government must find a more sustainable source of water if the social and community expectations and benefits of these assets are to be continually realised.

A schematic of the site is presented in Figure 1.

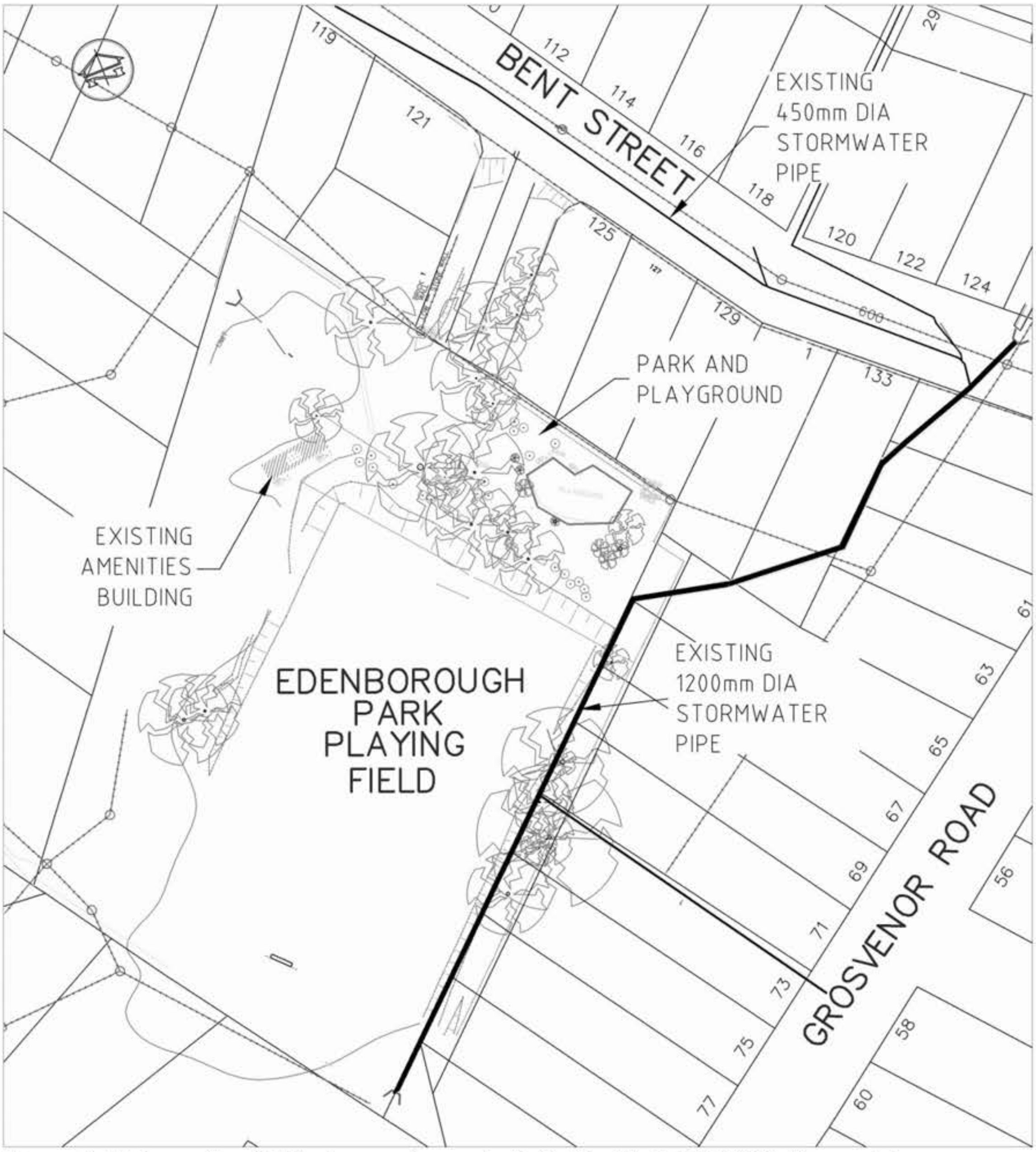


*Figure 1. Schematic of Edenborough sports field, Lindfield NSW (Not to scale)*

**PLANNING**

The selection of this site as a potential location for a stormwater reuse scheme considered a number of physical and social characteristics. Adjacent to the sports field is a 1,200mm diameter stormwater conduit draining an upstream catchment of 20.3ha. No sewer overflows are known to occur within the catchment and land use is dominated by low density residential development with a minimum lot size of 940m$^2$. The average grade of the catchment is approximately 6%. The sports field is not lit and has an average booking rate of 14 hours per week during the winter months. Down slope of the site is council owned bushland contiguous to Lane Cove National Park. The stormwater system dischargs into a natural creek that flows into Land Cove River near the tidal wier.

Initial investigation assessed a number of options for the off-take, storage location and size and type of stormwater treatment as discussed below.

**Off-take location and structure options**

1. Diversion of stormwater from the 1,200mm diameter stormwater conduit at the field. This involved a gravity driven diversion to treatment and storage. The depth and exact location of the stormwater conduit was not initially known. This was refined through prodding of the surface that revealed the pipe was deep and therefore possibilities for a gravity off-take to storage were limited. Due to the fall of the land any storage would need to be located at the southern corner or far end of the field. This would necessitate access across the field for maintenance impacting on the playing surface.
2. Diversion of stormwater from the 1,200mm diameter stormwater conduit to a pump well then pump to further treatment and storage. Pumping generally was not preferred as high pump rates would be necessary to capture sufficient storm flows. There was also a lack of power supply at the site. If pumping of storm flows was to be necessary it would be preferable to pump treated water to storage, rather than untreated water to treatment in order to reduce wear and consecutive maintenance requirements for the pump. This could be achieved through installing a Gross Pollutant Trap (GPT) before the pump sump. However this would require a large area in the vicinity of the large stormwater pipe that in turn would impact directly on the playing surface in terms of construction and particularly maintenance (as per option1)
3. Diversion of stormwater from the 1,200mm diameter stormwater conduit further upstream from the oval, and convey the diverted flow through a small pipe bolted onto the large stormwater conduit. This would provide enough head to allow both treatment and storage at the surface level of the field. However problems during construction due to confined spaces, the numerous bends and drops within the existing network and that it passes under private properties were all constraints limiting the feasibility of this option.
4. Diversion of low or base flow through treatment and pump to a storage using solar pump. This was investigated as it was observed that the large conduit retained a small flow, approximately 0.2L/s, for a period of approximately two weeks after moderate rainfall. To maintain environmental flows to downstream areas it was estimated that no more than 50% of the base flow should be diverted. The option of pumping low flows using a solar pump would avoid the problem with lack of power supply at the site, and through careful design could avoid the need for a GPT as part of the diversion structure (as the base flow is fairly clean). This option would also require a significantly smaller area for the off-take structure.
5. Diversion of stormwater from a 450mm diameter stormwater conduit north of the field. This would allow diversion by gravity. Depending on the treatment chosen there were opportunities to provide both treatment and conveyance to storage by gravity, eliminating the need for pumping. The conduit investigated conveys runoff from a smaller (2.75ha) catchment, comprising low density residential areas and roads. The smaller catchment size would impact on the storage size and the security of supply.

**Storage location options**

A. Underground storage under playing surface. Bedrock is visible at the edge of the playing field at a number of locations. As such it was assumed that a large underground storage would be costly due to the need for significant rock excavation. Any structure located under the playing field would also need to be strong enough to allow heavy maintenance vehicles to drive over it on occasions.

B. Semi buried tanks along the east side of the field. The field has mature trees along all sides limiting the area available given the importance of trees to the site. Visual impact and future screening also needed to be considered due to proximity of houses to the southwest. An informal walking track along the east side of the field also limited this area being used for storage.
C. Buried or semi buried tanks in the park area to the northwest of the playing field. This would impact on the playground located in the park. Opportunities could be derived if the storage was located under the playground as it would experience only pedestrian traffic. The playground itself is only four years old and is not scheduled to be replaced within the foreseeable future. There are also mature trees in the vicinity of the proposed location.
D. Semi buried tanks in the embankment to the northwest of the playing field. This option would not impact on the usage of the field, and would not require structures that could withstand vehicle loadings.

**Water balance and storage sizing options**

After assessing options provided at the site a water balance model was built. The model was used to evaluate levels of water security from a supply and demand perspective in response to differential diversion locations and storage volumes. Security of supply is expressed as the percentage of total annual irrigation demand by volume that can be provided by the stormwater harvesting scheme. Modelling was conducted using a water balance model developed by Ku-ring-gai Council that incorporated 64 years of daily rainfall data from Turramurra between 1936 to 2000 (Australian Bureau of Meteorology site 066158 located approximately 3 kilometers from the site). To assess the security of supply during a dry year, modelling was also conducted separately for the year of 1964-1965 that received only 750mm of rainfall, the average being 1,430mm/year. The model incorporated soil water holding capacity and losses from storage through evaporation (standard daily evapo-transpiration data for Sydney Observatory Hill, located approximately 14 kilometres from the site) and deep soil infiltration to determine irrigation demand. Above ground irrigation system (sprinklers) was assumed for all irrigation scenarios.

To assess the impact of modelling outcomes as a result of limitations in diversion structures, treatment capacity of water quality devices and the option for pumping a second model was built using one year of data in 12 minute time-steps with flow generated using MUSIC. This allowed a rough assessment on the likely impact of pumps and diversion weirs on the security of supply.

The results of the water balance modelling are presented in Table 1.

*Table 1. Security of supply as a result of altered storage sizes*

| Option | Tank size required to meet target of 80% security of supply (by volume) in average year (1936-2000) | Days where irrigation demand is met in average year (1936-2000) | Security of supply in dry year (1964-1965) | Days where irrigation demand is met in dry year (1964-1965) |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| 2. Pump from 1,200mm dia. Stormwater pipe (stormflow and base flow) | 120kL | 91% | 78% | 81% |
| 4. Pump from 1,200mm dia. Stormwater pipe (base flow only) | 500kL | 91% | 64% | 75% |
| 5. Diversion by gravity from 450mm dia stormwater pipe north of field | 470kL | 93% | 56% | 61% |
| Combination of options 4 and 5. Diversion by gravity from 450mm dia stormwater pipe north of field and pump base flow only from 1200mm dia. stormwater pipe | 230kL | 91% | 70% | 77% |

The water balance modelling showed that diverting both storm and base flow from the large stormwater conduit and pump to storage would provide the greatest security of supply relative to the storage size. The capacity of the pump was found not to have any major impact on the results for pumps with a capacity in excess of 5 litres per second. Even though the storage size could be significantly reduced by diverting flow from the large stormwater conduit, the physical limitations of the site, including significant trees in the vicinity, made this option not feasible.

The preferred option from the modeling and considering site constraints was to divert flow by gravity from a smaller catchment to storage located within the embankment on the north side of the field. A future option to augment supply would be to pump base flow from the major drainage system using a solar powered pump should this be required. The benefit of this option was that the system could operate by gravity thus negating the need to bring power to the site. With careful design no large GPT would be needed and issues associated with deep excavation could be avoided.

Whilst this option reduced potential supply as it drew from a smaller catchment, advantages were realised via a simpler design, lower construction and maintenance costs, and elimination of pumps and power. All designs and investigations were undertaken in-house by Council staff.

An assessment of the impact of security of supply as a result of changes to the storage size was then conducted for the preferred option only. The result is presented in Figure 2.

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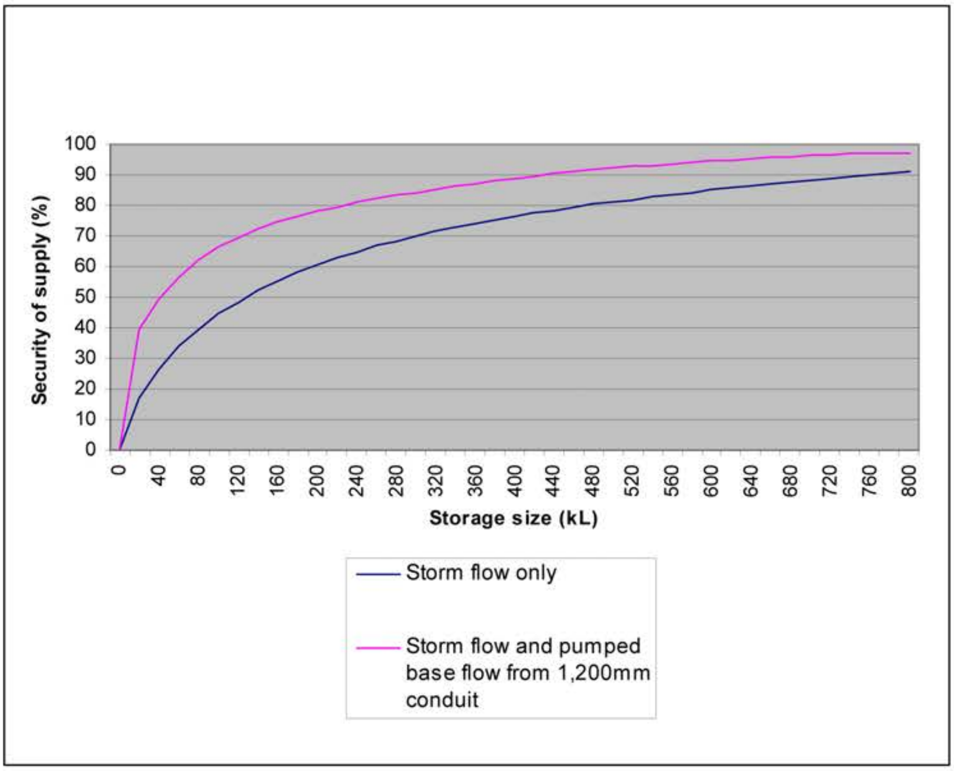


*Figure 2. Security of supply vs. storage size (diversion from 450mm diameter stormwater conduit)*

By using a storage size of 300kL a security of supply of 70% can be achieved without pumping baseflow from the larger conduit. If in the future this is deemed necessary, the security of supply can be increased to 85%.

Total storage was increased to 310kL as part of the procurement process due to the availability and cost of two cast in situ 155kL concrete storage tanks. This volume has the potential to provide up to 2,000kL of reused water per year (excluding the based flow option). The final design also included a spectator viewing platform on top of the tanks, as well as a soccer practice wall in front of the tank.

## Treatment train

The process for the treatment of stormwater involved diversion from the existing stormwater line and passing it through a 5mm mesh screen. This screen was designed to capture litter and large sediments. Initially it was envisaged to include a wet sump GPT though this was later changed to a dry sump following concerns of odors to nearby residents and users of the field and playground. Stormwater is then conveyed to a sand filter able to remove fine sediments (benefiting the irrigation system), *faecal coliforms* (for public health) and other contaminants. [4]

Stormwater is distributed into the filter through an internal slotted pipe, with some percolation also occurring through the surface of the filter. A schematic of the filter is shown in Figure 3. The sand filter was designed to treat the first 5-10mm of stormwater runoff on the assumption that the initial flow or "first flush" is more likely to carry a higher concentration of pollutants than successive flows [5]. Depending on the rainfall intensity, excess volumes were designed to pond on top of the filter. This provided extended detention and settlement of fine sediments before bypassing the filter through a surcharge pit and into the storage tanks. The bypass pit is equipped with a 100 micron pit litter basket. Once in the storage tanks, further sedimentation of fine sediment not captured in the sand filter or pit litter basket will occur.

Initial design included a separate bypass preventing water not treated through the sand filter from entering the tank. Due to site constraints the bypass line could not be constructed. Under very high intensity storms, the absence of a separate bypass may cause part of the first flush volume to bypass the filter, however the design ensures that no water is conveyed to the tank without being subject to extended detention and sediment settlement as well as screening through a 100 micron filter.

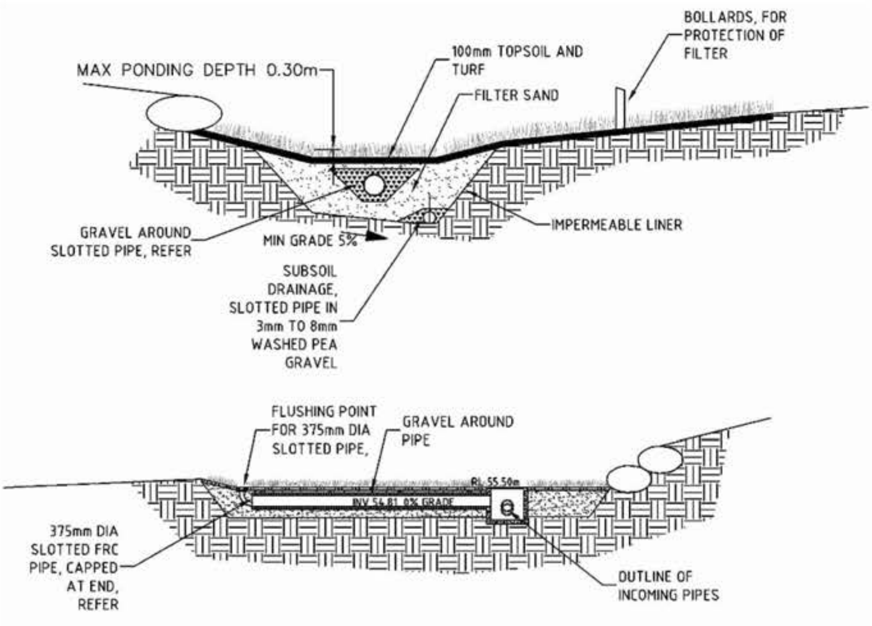


*Figure 3 Schematic diagram of the sand filter*

**Planning consideration and public consultation**

As the project forms part of the stormwater system, Council was not required to obtain development approval pursuant to the *Environmental Planning and Assessment Act 1979* Public notification was however carried out according to council's guidelines as if a development approval was required. This included a notification letter to nearby residents and users of the field outlining project and the proposed concept design. The public was encouraged to submit comments on the project for a period of three weeks. Only one response was received, expressing their strong support for the project and Councils effort to harvest stormwater for irrigation use.

## CONSTRUCTION ISSUES

A thorough briefing was held with the contractor prior to commencement to provide an overview of the project and to stress the importance of maintaining the design intent. The site was visited by Council's superintendent during construction every second day or as required. The contractor was also instructed to contact the designer if there were any questions during the construction phase, rather than make alterations to the design without consultation. This relationship worked well, and there were no delays due to site constraints.

Due to the small size of the project, no geotechnical report was obtained before construction commenced, and quotes were sought assuming excavation in materials Other Than Rock (OTR). The amount of rock excavation exceeded expectations causing a significant variation to the original contract fee.

The contractor was instructed to keep the sand filter off-line until construction was complete and to protect the sand filter by sediment fences to prevent local surface runoff clogging the sand media. In the final stages, the contractor removed the sediment fences and spread topsoil over the filter in preparation for the laying of turf. However due to an unexpected delay from the turf supplier, turf was not delivered on the agreed date. Heavy rainfall then followed. Even though there was a temporary diversion on the stormwater system, the intensity of the storm event caused stormwater to break through causing severe erosion of the site. This was compounded by surface flows, as the final levels around the overflow pit had not been achieved effectively directing runoff towards the field resulting in severe erosion around the tanks. A large volume of soil was then washed onto the now waterlogged field. Fortunately the slotted delivery line in the sand filter had been sealed off by using a geo textile "plug", effectively preventing sediment from washing into the sand filter and clogging the sand media. If this had not been installed it would have been necessary to reconstruct the entire sand filter.

## PERFORMANCE OF SYSTEM

### Expected water quality improvement

The expected water quality performance of the system was assessed using the Model for Urban Stormwater Improvement Conceptualisation (MUSIC) as developed by the Australian Cooperative Research Centre for Catchment Hydrology. This computer model can assess the likely water quality improvements that can be expected from different stormwater quality improvement strategies [6]. The predicted performance of the system at Edenborough playing field is included in Table 2 and has been described in previous paper [7].

*Table 2 Predicted water quality improvement for each of the treatment measures*

| **Litter screen** | Inflow | Outflow | Reduction |
|---|---|---|---|
| Flow (ML/yr) | 12.2 | 12.2 | 0% |
| Total Suspended Solids (kg/yr) | 1930 | 1930 | 0% |
| Total Phosphorus (kg/yr) | 4.32 | 4.32 | 0% |
| Total Nitrogen (kg/yr) | 32.1 | 32.1 | 0% |
| Gross Pollutants (kg/yr) | 400 | 80 | 80% |
| **Sand filter** | Inflow | Outflow | Reduction |
| Flow (ML/yr) | 12.2 | 12.2 | 0% |
| Total Suspended Solids (kg/yr) | 1930 | 601 | 69% |
| Total Phosphorus (kg/yr) | 4.32 | 1.99 | 54% |
| Total Nitrogen (kg/yr) | 32.1 | 22.9 | 29% |
| Gross Pollutants (kg/yr) | 80 | 0 | 100% |
| **Storage tanks** | Inflow | Outflow | Reduction |
| Flow (ML/yr) | 12.2 | 12.2 | 0% |
| Total Suspended Solids (kg/yr) | 601 | 393 | 35% |
| Total Phosphorus (kg/yr) | 1.99 | 1.94 | 3% |
| Total Nitrogen (kg/yr) | 22.9 | 21 | 8% |
| Gross Pollutants (kg/yr) | 0 | 0 | 0% |
| **Total reduction, diverted flow** | Inflow | Outflow | Reduction |
| Flow (ML/yr) | 12.2 | 12.2 | 0% |

| | | | |
|---|---|---|---|
| Total Suspended Solids (kg/yr) | 1930 | 393 | 80% |
| Total Phosphorus (kg/yr) | 4.32 | 1.94 | 55% |
| Total Nitrogen (kg/yr) | 32.1 | 21 | 35% |
| Gross Pollutants (kg/yr) | 400 | 0 | 100% |
| **Total reduction from catchment** | Inflow | Outflow | Reduction |
| Flow (ML/yr) | 17 | 17 | 0% |
| Total Suspended Solids (kg/yr) | 2700 | 1160 | 57% |
| Total Phosphorus (kg/yr) | 6.04 | 3.66 | 39% |
| Total Nitrogen (kg/yr) | 44.8 | 33.7 | 25% |
| Gross Pollutants (kg/yr) | 460 | 59.8 | 87% |

**Results from water quality testing**

Water quality testing was undertaken during two storm events. Samples were taken at stormwater pipe at diversion point, in the sump pit before the sand filter, after passing through sand filter and from the overflow point on the storage tank. The results of *Faecal coliforms*, suspended solids, metals and nutrient are presented in Figures 4-10.

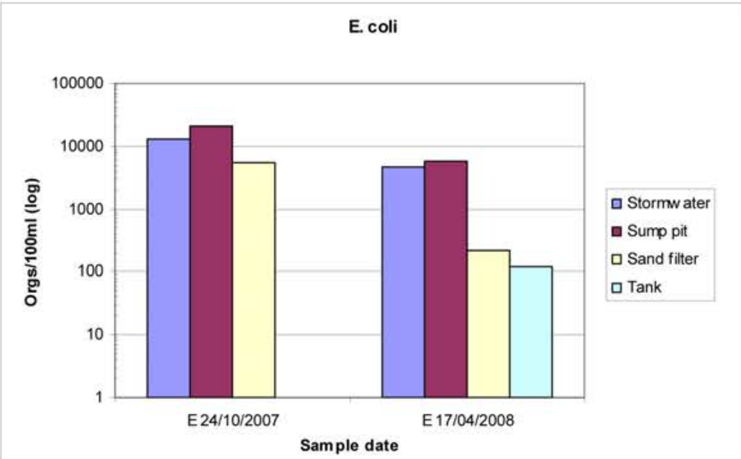


*Figure 4. Faecal coliforms (E. coli.) levels*

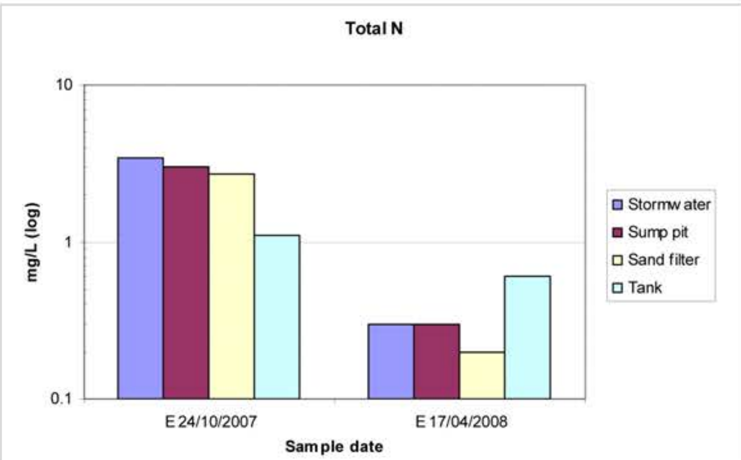


*Figure 5. Total Nitrogen (N) concentrations*

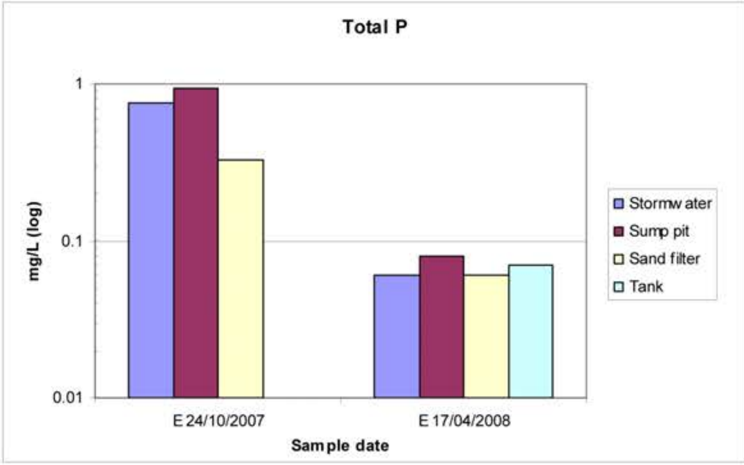


*Figure 6. Total Phosphorous (P) concentrations*

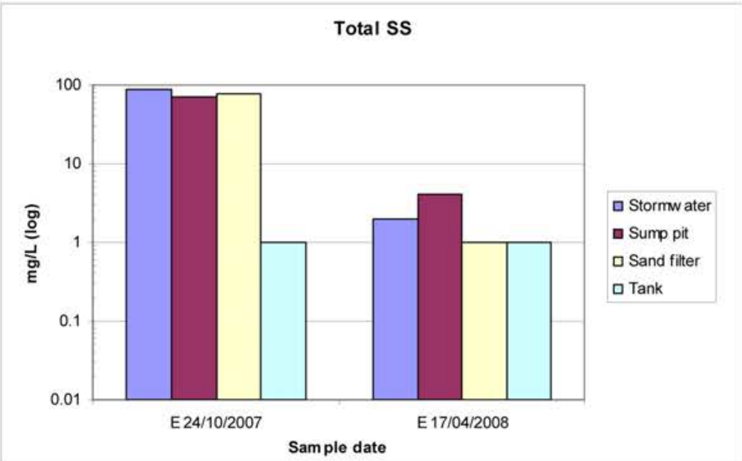


*Figure 7. Total Suspended Solid (TSS) concentrations*

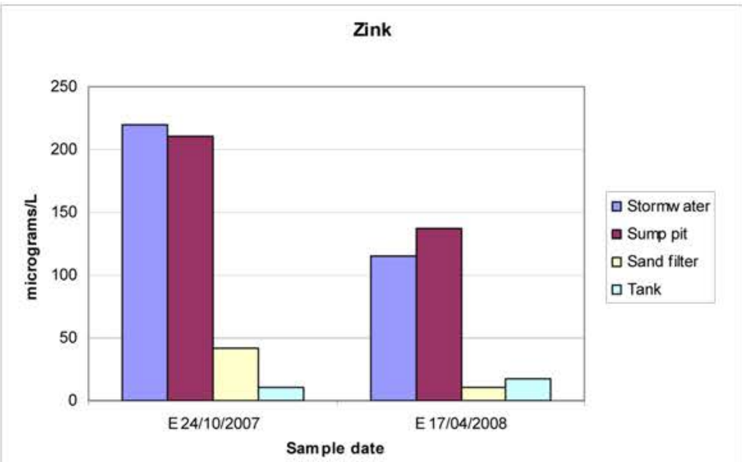


*Figure 8. Zinc (Zn)* concentrations

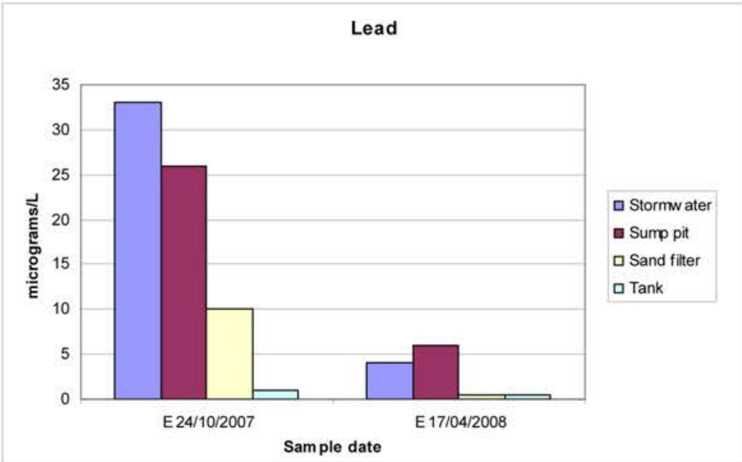


*Figure 9. Lead (Pb)* concentrations

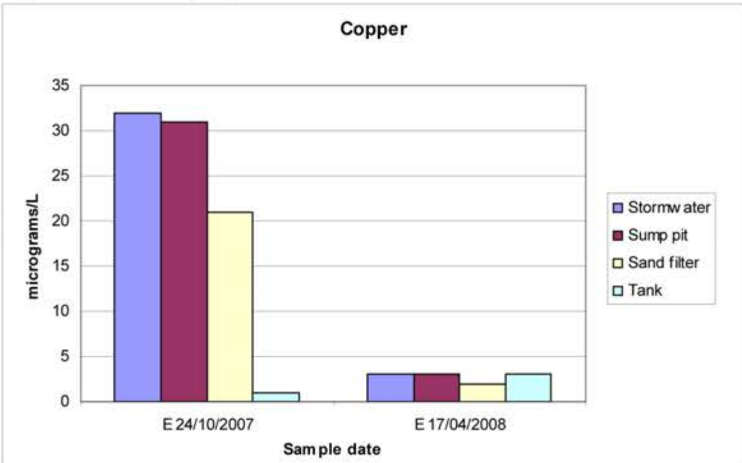


*Figure 10. Copper (Cu)* concentrations

As shown, there is reduction in pollutant concentrations of all analytes from the stormwater inflows to overflow of the tank. The sand filter is shown to be particularly efficient in the removal of *Faecal coliforms* and metals. A summary of the average percentage removal from the sand filter is presented in Table 3.

*Table 3. Pollutant removal efficiency from the sand filter*

| Pollutant | Average removal (%)[1] |
|---|---|
| Faecal Coliforms | 85% |
| TN | 22% |
| TP | 45% |
| TSS | 33% |
| Zinc | 86% |
| Lead | 61% |
| Copper | 33% |

1. Based on two sample dates only

There is also a significant reduction of *Faecal coliforms*, suspended solids and nutrient after prolonged detention within the storage tank. In the 10 days preceding sampling on the 24th October 2007 there was no recorded rainfall, and samples taken from the tank are assumed to have been stored without disturbance over this period [15]. The recorded rainfall for the 10 days prior to sampling on the 17th April 2008 was 32.8mm [15] and samples taken from the tank are assumed to have mixed within the tank and stored for a shorter period of time than was the case for previous sampling occasion.

In addition to the sampling presented above, *Faecal coliform* testing was carried out on two additional occasions, as shown in Table 4. Samples were collected at the outflow from the tank.

*Table 4. Faecal coliforms present at outflow of storage tank*

| Faecal Coliforms | | |
|---|---|---|
| **Sampling date** | **CFU/100ml** | **Rainfall in preceding 10 days (mm)** |
| 19/12/2007 | 52 | 24.0 |
| 6/02/2008 | 1091 | 80.8 |

**MUSIC predicted results compared with monitoring data**

The predicted performance of the sand filter as modeled via MUSIC was compared with the sampling data from the 24th October 2007. In order to allow comparison of one single sample with the continuous modelling as performed by MUSIC, the predicted outflow concentration from MUSIC for a given interval of inflow concentration for a whole year was compiled. The inflow and outflow concentrations were obtained using the default stochastic pollutant generation in MUSIC. The MUSIC data was then sorted and plotted with the monitored inflow and outflow concentrations for TP, TN and TSS as shown in Figures 11-13. It should be noted that rainfall data from October 2007 was not used in the MUSIC model.

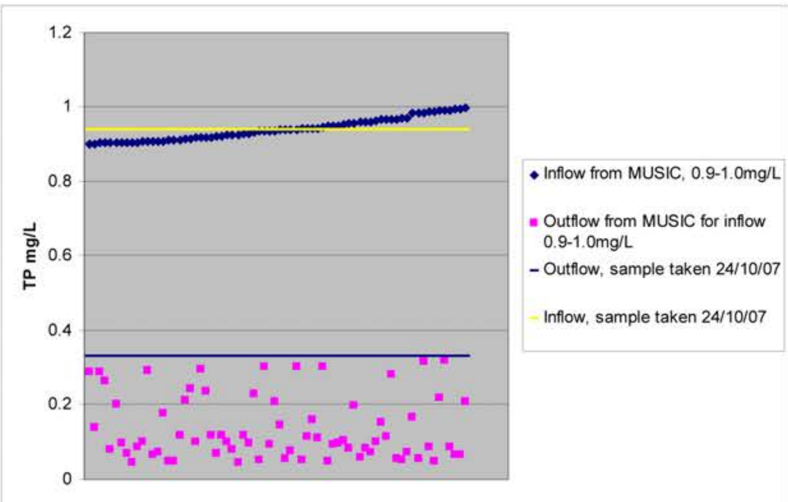


*Figure 11. Comparison between monitoring data from inflow and outflow from sand filter compared with MUSIC modelling results for Total Phosphorous*

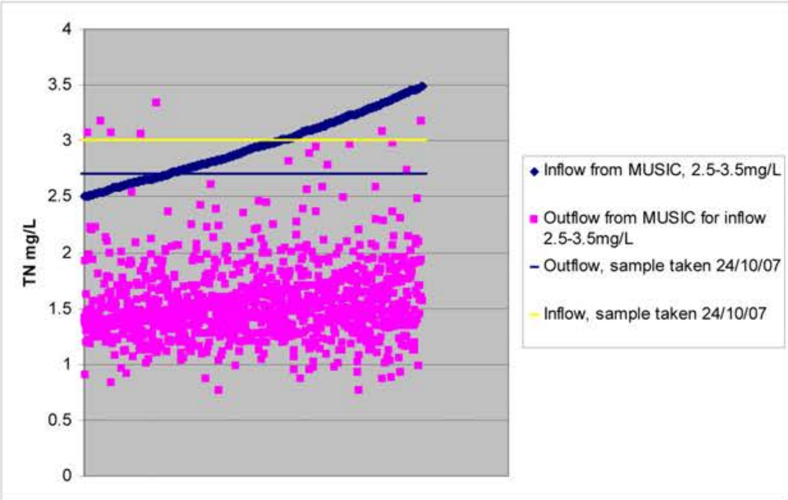


*Figure 12. Comparison between monitoring data from inflow and outflow from sand filter compared with MUSIC modelling results for Total Nitrogen*

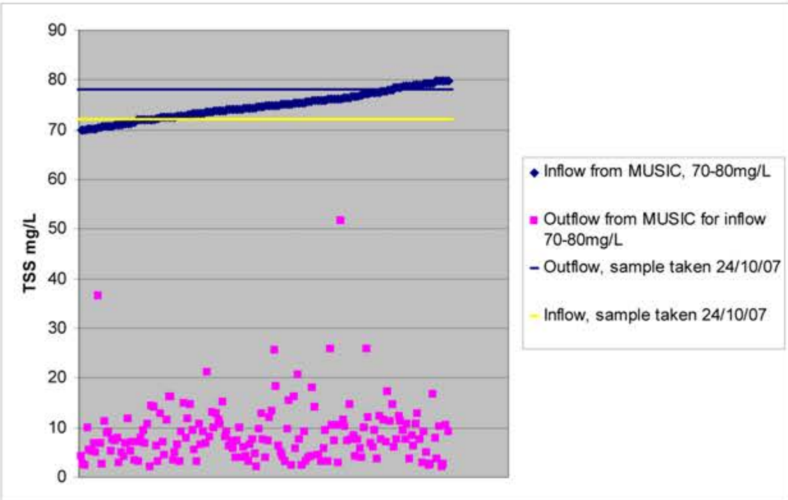


*Figure 13. Comparison between monitoring data from inflow and outflow from sand filter compared with MUSIC modelling results for Total Suspended Solids*

## DISCUSSION

### Performance of the system

While the treatment train of the whole system has only been sampled on two occasions, it would appear that the performance is satisfactory given the use of the water for irrigation. When comparing the monitoring data with other studies [11] the results to date are similar.

Pollutant removal through the sand filter is lower than results reported for sand filter in laboratory based studies [13], [14]. Further monitoring is required to establish the long term performance of the system and if any alteration to the design is required.

### Modelling results compared with monitoring data

The removal of total phosphorus through the sand filter is slightly lower than the predicted average removal obtained using MUSIC for an inflow concentration of 0.94mg/L.

For total nitrogen actual outflow concentrations from the sand filter is significantly higher than the average predicted by MUSIC, though noting outflow concentrations predicted by MUSIC is highly variable as shown in Figure 12. Predicted outflow concentrations from MUSIC are as high or higher than the concentration obtained through sampling on a number of occasions. The result obtained through sampling on the 24 October 2007 is therefore considered to be in line with the predicted performance as obtained by using MUSIC. More sampling is required as well as using actual site rainfall data for the sample period in order to further evaluate the accuracy of the MUSIC model.

The monitoring showed a slight increase in total suspended solids through the sand filter. This is incomparable with the performance of the sand filter as predicted by MUSIC and requires further monitoring.

**Water quality targets and guidelines**

There are a number of government guidelines in relation to water quality targets for stormwater reuse schemes [8,9] These are mostly concerned with matters of public health, commonly relying on faecal coliforms (indicated by the presence of E. coli.) as an indicator of the suitability of water for indirect human contact. The guidelines also relate to the performance of irrigation infrastructure that may be impacted by nutrients and suspended solid loads.

The presence of faecal coliforms in urban stormwater can vary widely depending on the site [10] and also on other factors such as rainfall intensity and antecedent climate conditions [12]. In part the use of guidelines rather than mandatory standards or laws reflects the high variability of stormwater quality and impact this may have on the cost of treatment for reuse projects. Importantly however has been the recognition of a “fit for purpose” ethos that acknowledges that it is not necessary to have potable standard water for all applications.

To ensure a consistent quality of stormwater, disinfection using UV lights has been proposed as a possible treatment measure [9]. In order to ensure full efficiency of UV disinfection, water is required to have turbidity lower than 5NTU. This would require a higher level of treatment than the current sand filter.

The draft guidelines by the Environment Protection and Heritage Council also recognizes that for open space irrigation using spray irrigation, health risks can be adequately managed by minimising exposure to the irrigation water through controlled access to irrigated areas. Examples of suitable approaches for controlling access to irrigation areas include: irrigating at times when there is no intended, permitted or organised public access to the irrigation area and the likelihood of persons being present within the are is low (eg late at night); and implementing an appropriate withholding period to allow the irrigation area to dry before access is permitted (depending on the application rate, soil conditions and climate, this withholding period is typically between one and four hours in temperate zones).

As previously mentioned, Edenborough sports field is used as a dog off leash area all year around. Faecal coliforms can therefore be assumed to be present on the ground during its normal operation even when the field is not irrigated.

**Adopted strategy**

The design philosophy for this project was based on trialing a conventional stormwater treatment train approach to provide a high level of treatment. Monitoring would be undertaken to assess the performance as part of a broader risks assessment approach. In accepting this approach, it is recognized that there are some risks to human health however these were considered within a framework of providing fit for purpose water, ensuring a energy efficient design, minimizing environmental impact and footprint at the site, extending the social benefits of an improved playing surface, providing an opportunity for community education and to deliver the project within a budget.

Public health issues remain a issue of concern. Monitoring to date shows that the level of faecal coliforms in the storage tanks varies between less than 2 cfu/100ml to 1,091 cfu/100ml. This reflects the variability of faecal coliforms within the stormflows, treatment and resident time in the tank. It is proposed to undertake further monitoring of die-off rates of coliforms within the tanks between rain events to help establish internal guidelines as to minimum holding time required in the tanks before irrigation. Further it is proposed to undertake irrigation when the risk of contact are lowest considering informal use, bookings and the requirements of the turf. Should further treatment is necessary the system can be amended to include disinfection post storage.

## CONCLUSION AND LESSONS LEARNT

Initial monitoring has indicated that the stormwater treatment train adopted for the Edenborough playing field stormwater harvesting project is successful in its objectives to treat stormwater to a level suitable for reuse through irrigation of open spaces with restricted access. Water quality results are comparable with data from other studies.

The study highlights the need for careful consideration of all options and close control during construction to ensure the intent of the design is delivered. This is particularly relevant for treatment systems relying on filters rather than mechanical or chemical treatments.

Water reuse and recycling project must be of suitable quality or “fit for purpose”, however when dealing with stormwater this presents many challenges due to the variability in quality. Modelling tools such as MUSIC provide a mechanism though which engineers can estimate the efficiency of their designs, however risk to human health can currently not be modeled using commonly available software used for stormwater system design. Specific monitoring of constructed projects is needed to provide greater certainty to land mangers, designers and the community. It is only through the construction and monitoring of actual systems can the industry get a level of certainty as to the performance in the field.

The community’s acceptability towards stormwater reuse project and their understanding of the limitations of designs to treat water to a suitable standard will take time and must be a consideration in the planning and promotion of such project. It is envisaged that this acceptance and understanding will influence future risk analysis and possibly guidelines. This case study indicated that public support for projects such as this is high, to some extent facilitated by the current drought and subsequent water restrictions that is raising the understanding and value of water as a limited resource.

While recognizing there are public health risks in this project, they also form part of other council policy decision such as allowing dog off leash areas on playing fields. It is the collective understanding of open space uses, limitations of treatment systems and appreciation of a restricted potable water future that will drive change to projects such as at Edenborough sports filed.

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# Stormwater management – water balance modelling and impact on project costs: case study from Ku-ring-gai Council NSW

Authors: Jonasson O J and Davies P J

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# Stormwater management – Water balance modelling and impact on project costs – *A case study from Ku-ring-gai Council NSW*

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## INTRODUCTION

Water restrictions and community concerns on water conservation have lead many land mangers to investigate alternative water sources such as stormwater to meet irrigation and other non-potable needs. To meet this challenge water balance modelling is used to determine the feasibility of projects and inform the design process. Water balance models for stormwater harvesting usually consist of two parts. The first is runoff generation or supply, the second in water usage or demand.

A lack of broadly accepted commercial water balance models has led many consulting engineers to develop their own in-house product. For clients such as local government who have many projects and utilize a number of consultants this has meant the comparison of model outputs has not been possible due to variations in methods and assumptions. This in turn impacts on the robustness of prioritization processes to deliver capital works against water conservation and open space strategies.

The experience of Ku-ring-gai Council has found the majority of models are built using Microsoft Excel. The input and the general theories on which the models are based are usually provided, however due to concerns about intellectual property actual models are not revealed as part of the final report and analysis. Results obtained from the different models can vary greatly when it comes to yield and required storage volumes, in turn influencing the viability of projects.

The supply side of models usually relies on parameters derived from event based peak flow modeling, subject to the judgment of individual engineers. Demand is subject to the knowledge and understanding of a range of variables such as soil condition, turf type, irrigation techniques, climate and operational practices. The outcomes of both supply and demand analyses have direct impact on eventual viability, capital and ongoing costs of projects.

This paper will evaluate runoff generation model outputs from an in-house water balance model developed by Ku-ring-gai Council and compare this against an output from the Model for Urban Stormwater Improvement Conceptualisation MUSIC) as developed by the Cooperative Research Centre for Catchment Hydrology. Results will focus on local rainfall and runoff data. The findings are then used to case study the application of this type of approach for the modeling of stormwater harvesting for sports fields. Recommendations are made to guide future modelling and analysis for water reuse schemes for the local government area.

**BACKGROUND**
The catchment used for this case study is a fully developed residential catchment in Gordon, NSW, approximately 18 kilometers north of the Sydney CBD. The catchment covers an estimated 23.1hectares, with an overall imperviousness of around 40 percent. There are a number of stormwater lines through the catchment that connect to a major trunk line that discharges into an open creek, located within a golf course.

**Flow Gauging and Rainfall Data**
The flow gauging station used in this study is an American Sigma 950, located at the trunk line outfall within the local golf course. Flow data was collected using 15 minute or 2 minutes time steps.

Site specific rainfall data used was colleted using a tipping bucket rainfall gauge of model RRDL-3 located on the roof of the council chambers in Gordon, 0.9 kilometers from the outlet in the adjacent sub-catchment. Rainfall data was compiled for two time periods for which flow gauging data was available and depending on the model used the data was adjusted to be presented in 6 minutes, 15 minutes or daily time steps. Two periods were 24th December 2004 to 24th March 2005, collected in 15 minute time-steps and 15th November to 20th November 2006, using two minute time-steps.

A third rainfall data set was also used based on the Bureau of Meteorology BOM) site 066158 Turramurra Kissing Point Road) that comprise daily rainfall data from 1936-2000. This data was used to evaluate the long term impact on differences in modelling assumptions.

Flow gauging and rainfall intensity for the first and second period are shown in Figures 1 and 2 respectively.

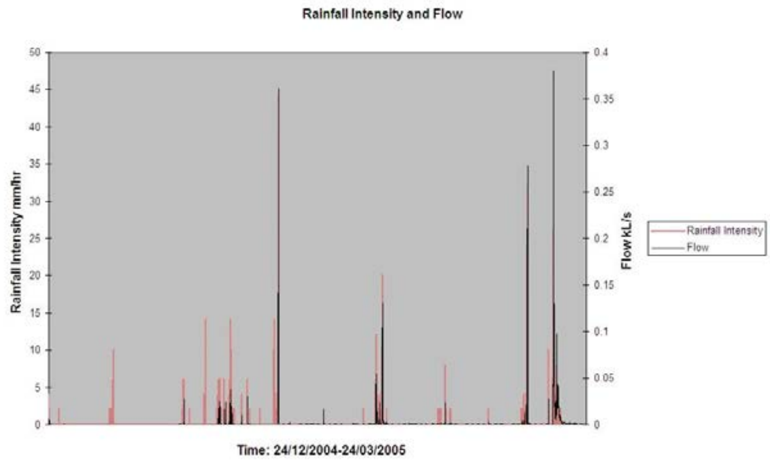


**Figure 1 Flow gauging and rainfall intensity for the period 24th December 2 4 to 24th March 2 5 using 15 minute time steps**

Although the second data set is limited, the shorter time step highlights a variation in the baseflow over the duration of the day. As shown in Figure 2, baseflow is virtually 0.0 0L/s during the night, rising to approximately 1-2 liters/second between 06:00 and 21:00. This would suggest that this flow is mainly from anthropogenic sources, and should therefore not be included when comparing total flow volumes derived from runoff modelling.

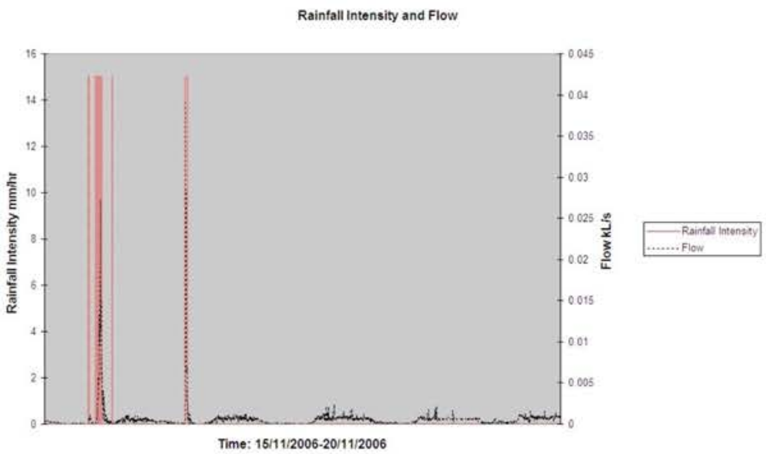


**Figure 2 Flow gauging 15th November to 20th 2006 using 2 minute time steps**

The total runoff volume as measured by the gauging station for the time between 24$^{th}$ December 2004 and 24$^{th}$ March 2005 is 10,271kL. When subtracting flows during the day from days where no rainfall was recorded, the total volume of runoff generated by precipitation for the period of 24$^{th}$ December 2004 to 24$^{th}$ March 2005 is 8,703kL

## RUNOFF MODELLING

### Spread Sheet Based Models

Most models seen by the authors have used rainfall data using daily time step for a number of 'representative' or 'dry' years. Shorter time steps while possibly yield a more detailed outputs require larger file sizes making the model impractical to run.

Model parameters and methods are typically transferred from peak flow event based modelling. This includes adopting impervious percentage determined from aerial photos, site visits or averages cited in literature. When determining losses from the supply side, modelers often assume the first 1 mm to 2.5 mm of rain falling on impervious surfaces will not generate flow, being lost within the cracks of the pavement for example. Runoff from pervious surfaces is more complex and rely on, among other things, infiltration rates, soil storages and recharge rates.

Assumptions used in the development of the Ku-ring-gai Council model are shown in Table 1, with Table 2 presenting the modeled results, adopting an average impervious area of 40%.

**Table 1 Runoff modelling inputs for impervious and pervious areas**

| | | |
|---|---|---|
| Impervious area initial loss | 1 | mm/day |
| Soil storage capacity | 300 | mm |
| Field capacity | 172 | mm |
| Soil percolation rate | 1 | mm/day |

**Table 2 Modelling results, 40% impervious area**

| | | |
|---|---|---|
| Rainfall days | 30 | |
| Rainfall depths | 316.5 | mm |
| Runoff days, impervious areas | 23 | |
| Runoff days, pervious areas | 0 | |
| Runoff volume, impervious area | 26738.3 | kL |
| Runoff volume, pervious area | 0 | kL |
| Runoff volume | 26738.3 | kL |

As shown in Table 2, the model is conservative in that no runoff is generated from the pervious areas of the catchment. The volume generated from the impervious areas is however significantly greater than the volume obtained through flow gauging.

In the field of pollutant export modelling, the use of "effective impervious areas" has been adopted as a way of estimating the percentage of the total impervious area that is directly connected to a drainage system, and thus will generate runoff in smaller events. Brisbane City Council has done work in this field and suggests that about 31% of total impervious area should be considered as the "effective impervious" area[1]. This assumption was also used in the Ku-ring-gai model, resulting in an impervious percentage of 12.4%. The results are presented in Table 3 and show the adoption of "effective impervious area" gives a result more consistent with the gauged volume of 8,703kL.

**Table 3 Modelling results, 31% "effective impervious area", 12.4% total impervious area**

| | | |
|---|---|---|
| Rainfall days | 30 | |
| Rainfall depths | 316.5 | mm |
| Runoff days, impervious areas | 23 | |
| Runoff days, pervious areas | 0 | |
| Runoff volume, impervious area | 8288.9 | kL |
| Runoff volume, pervious area | 0 | kL |
| Runoff volume | 8288.9 | kL |

## MUSIC Modelling

A MUSIC model was developed for the catchment, using modelling parameters developed as part of a catchment study[2] and 6 minute time step rainfall data. Two scenarios were modeled, one using an overall imperviousness of 40%, as determined from aerial photos, and one with an "effective imperviousness" of 31% of total impervious area (12.4% total imperviousness). In order to account for any lag time as a result of the catchment size, the model was split up in 4 separate nodes, representing roads or residential areas. The layout of the model is presented in Figure 3, and the modelling parameters are presented in Table 4.

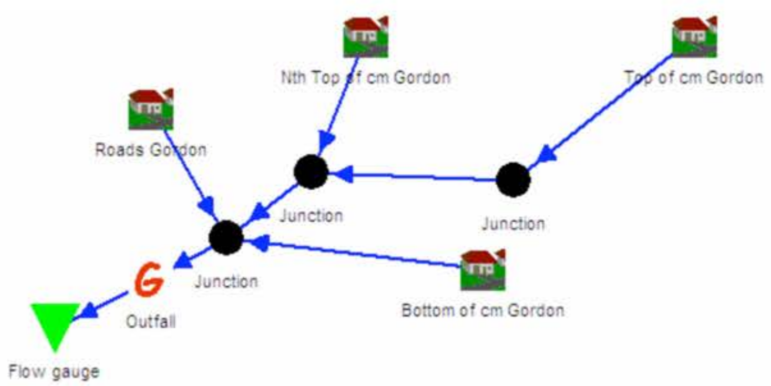


**Figure 3 Layout of MUSIC model, Gordon Golf Course catchment**

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**Table 4 Modelling input, MUSIC**

| | | |
|---|---|---|
| **Impervious Area Properties** | | |
| Rainfall Threshold | 1 | mm/day |
| **Pervious Area Properties** | | |
| Soil storage capacity | 300 | mm |
| Initial Storage (% of Capacity) | 20 | |
| Field capacity | 172 | mm |
| Infiltration Capacity Coefficient - a | 200 | |
| Infiltration Capacity Exponent -b | 1 | |
| **Groundwater properties** | | |
| Initial Depth | 0 | mm |
| Daily Recharge Rate | 0 | % |
| Daily Baseflow Rate | 0 | % |
| Daily Deep seepage rate | 0 | % |

The MUSIC modelling results (volume only) are presented in Table 5

**Table 5 Modelling result, MUSIC**

| Percent total impervious area | Runoff volume | |
|---|---|---|
| 40% | 26,640 | kL |
| 12.40% | 8,124 | kL |

Table 5 shows that the results obtained by MUSIC correspond well with the values obtained by using a spreadsheet model.

As shown in Figure 4, the results from the 12.4% total impervious area MUSIC model corresponded with the flow regime and peak flows with that of the flow gauging.

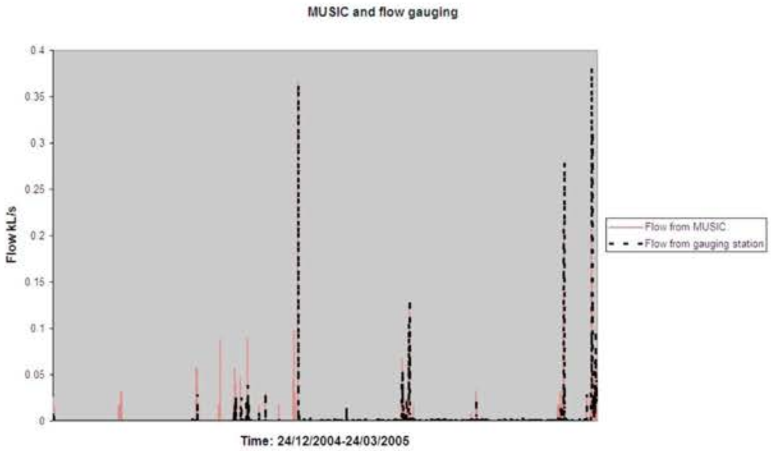


**Figure 4 Results using MUSIC, 12.4% total impervious area, and flow from gauging station**

## WATER USAGE

Water usage, or demand, can be divided into indoor and outdoor. Indoor usage can include toilet flushing while outdoor usage comprises such activities as irrigation and vehicle wash-down. Demand can therefore be calculated from the number of people using the facilities each day, more typically used for indoor use, and historical water use reflecting generic water consumption data for the irrigation of open space.

In the case of irrigation, demand can be estimated by modelling of soil water storage capacities. In Ku-ring-gai Council's experience most models adopt a soil storage and evaporation loss approach when determining irrigation requirement and water demand. The soil on site is assigned a certain water holding capacity, and water is assumed to be lost from storage through evaporation and deep infiltration. Other modelling approaches for irrigation demand includes a set irrigation depth on days when there is no recorded rainfall, and adoption of historical water consumption data where this is available.

## WATER BALANCE EXAMPLE

To illustrate the impact the different modelling approaches have on project outcomes and costs, a case study was prepared for an area located at Gordon Golf Course. Modelling was conducted using Ku ring gai Council's spreadsheet water balance model, using 64 years of daily rainfall data from Turramurra (BOM site 066158) from 1936-2000, with an average precipitation of 1,430mm/year. Standard daily evapo-transpiration data for Sydney was also adopted. The model uses soil water holding capacity and losses from storage through evaporation and deep infiltration to determine irrigation demand. Any impact on modelling outcome as a result of limitations in pipe capacity, weir heights, treatment capacity of water quality devices, pump capacity etc. has not been considered in this study. Identical irrigation system (sprinklers) has been assumed for all scenarios.

### Modelling Input

| | | |
|---|---|---|
| Catchment Area: | 23.1 | ha |
| Catchment type: | Residential | |
| Impervious Percentage: | 12.4 - 40.0 | % |
| Area to be Irrigated: | 0.9 | ha |
| Sequrity of supply target using harvested stormwater in an | 90 | % |
| Infiltration Capacity Exponent -b | 1 | |
| Initial Depth | 0 | mm |
| Daily Recharge Rate | 0 | % |
| Daily Baseflow Rate | 0 | % |
| Daily Deep seepage rate | 0 | % |

A range of different scenarios were modelled to assess the impact on modelling results as a result of changes to:

- Irrigation regime
- Impervious catchment area
- Pervious catchment area

The modelling setups are presented in Table 6, and the modelling results presented in Table 7.

**Table 6 Scenario modelling setup**

| Scenario | Impervious area | Pervious area | Interception storage for impervious areas | Soil moisture store capacity for irrigated area (SMSC) | Field capacity for irrigated area | Soil percolation | % of field capacity when irrigation cycle is initiated | Irrigation depth per cycle | Soil moisture store capacity for non-irrigated areas (SMSC) | Field capacity for non-irrigated areas | Soil percolation rate for non-irrigated area |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 9.2ha (40% of 23.1ha) | 13.9ha (60% of 23.1ha) | 0.5mm/day | 75mm | 68mm | 1.0mm/day | 60% | 10mm | 300mm | 172mm | 1.0mm/day |
| 2 | 9.2ha (40% of 23.1ha) | 13.9ha (60% of 23.1ha) | 0.5mm/day | 45mm | 36mm | 2.0mm/day | 60% | 5mm | 300mm | 172mm | 1.0mm/day |
| 3 | 2.9ha (31% of 9.2ha (40% of 23.1ha)) | 20.2ha (87.6% of 23.1ha) | 1.0mm/day | 45mm | 36mm | 2.0mm/day | 60% | 5mm | 300mm | 172mm | 1.0mm/day |
| 4 | 2.9ha (31% of 9.2ha (40% of 23.1ha)) | 20.2ha (87.6% of 23.1ha) | 1.0mm/day | 75mm | 68mm | 1.0mm/day | 60% | 10mm | 300mm | 172mm | 1.0mm/day |
| 5 | 9.2ha (40% of 23.1ha) | 0ha | 0.5mm/day | 45mm | 36mm | 2.0mm/day | 60% | 5mm | 300mm | 172mm | 1.0mm/day |
| 6 | 2.9ha (31% of 9.2ha (40% of 23.1ha)) | 0ha | 1.0mm/day | 45mm | 36mm | 2.0mm/day | 60% | 5mm | 300mm | 172mm | 1.0mm/day |

**Table 7 Scenario modelling results**

| Scenario | Average annual total volume of runoff | Average annual irrigation demand | Tank size required to meet target of 90% security of supply of (volume) in average year | Average annual volume of water supplied through stormwater harvesting | Average annual percentage of days where irrigation demand is met |
|---|---|---|---|---|---|
| 1 | 172,803kL/year | 349mm/yr | 210kL | 2,833kL | 90% |
| 2 | 172,803kL/year | 447mm/yr | 300kL | 3,635kL | 93% |
| 3 | 106,072kL/year | 447mm/yr | 570kL | 3,635kL | 95% |
| 4 | 106,072kL/year | 349mm/yr | 460kL | 2,833kL | 93% |
| 5 | 125,714kL/year | 447mm/yr | 300kL | 3,635kL | 93% |
| 6 | 37,321kL/yr | 447mm/yr | 570kL | 3,635kL | 95% |

## IMPLICATIONS

In this case study, the required storage size to meet a security of supply of 90% using harvested stormwater varies by over 40% depending on the assumptions made for soil properties of the irrigated area and the irrigation regime adopted.

The required storage size to meet the target of 90% also varies more than 2.5 times depending on the approach adopted for modelling impervious areas. In reality, a security of supply of 90% volume is not feasible when the impervious catchment is small, and for Scenarios 3, 4, and 6, any tank size with a volume above 400kL will have insignificant impact on the volume of harvested water in an average year.

Assuming the model characteristics in scenario 1 were used for design, the security of supply as designed at 90% would actually yield 72%, based on actual monitored flow data. When using scenarios 3 and 4, incorporating effective impervious area the modelled data more accurately refects actual conditions. This re-enforces the need to consider effective imperviousness as part of the model, not simply the percentage of impervious surfaces, to maximise the use of modelling.

The outcome of the model was found to be insensitive to the inclusion of the pervious catchment areas. This is an area for further investigation.

**CONCLUSIONS**

The case study has demonstrated that the use of effective impervious area has a significant impact on the reliability of the water balance model for open space irrigation areas when compared against actual flow monitoring. On the demand side, site characteristic that drive the irrigation regime will impact on the size of storage and in turn security of supply. This has the potential to significantly impact overall project cost as storage volumes are altered. The variation in project cost for the different modelling scenarios has the potential to be significant. The difference in installing two above ground tanks with a volume of 250kL each is likely to be in the order of 40,000, and up to four times if below ground storage is used.

Based on the findings of this paper, it is recommended that the use of "effective impervious area" be adopted in water balance modelling for stormwater harvesting applications. It is appreciated that the data used to calibrate the adoption of "effective impervious area" for Ku ring gai Council is limited, but the results are consistent with those obtained by other local councils. Further research to confirm the preliminary results are necessary.

An emerging trend is the need for industry standards in this field to streamline and optimize the way water balance in stormwater harvesting applications is utilized. This would allow a more transparent design process, and would reduce the reliance on "black box" models currently commonly being used by consultants for work with local Council. This would in turn maximize water savings and optimize value for money.

**REFERENCES**

1 Brisbane City Council (October 2003) *Guidelines for Pollutant Export Modelling in Brisbane Version – Draft*

2 URS Pty Ltd (March 2006) *Local Catchment Plan – Land Cove River South Region Catchments*

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# Biofiltration design – a case study of biofiltration systems in residential areas using different filter media

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paper fourteen

**WSUD INFRASTRUCTURE: AN ASSET TO BE MANAGED**

# BIOFILTRATION DESIGN – A CASE STUDY OF BIOFILTRATION SYSTEMS IN RESIDENTIAL AREAS USING DIFFERENT FILTER MEDIA

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**Abstract**

In 2004, Ku-ring-gai Council commenced an environmental capital works program to deliver a range of Water Sensitive Urban Design (WSUD) projects. As waterways from the council area drain into three national parks, a focus of the program was to quantify the performance of various treatment systems to evaluate their impact on improving water quality and also to improve future design and operation. This case study investigates the design and function of two biofiltration systems using different filter media. The results suggest that sand may be a preferred filter media when targeting nutrients and metals, while sandy loam performed better in terms of removal of faecal coliforms. In relation to the capture and treatment of metals the research indicates there is an export of some of these contaminants from both filter media possibly due to the source of the media. However, the data set was small and more testing is required to further explore these preliminary finding. The results highlight the need to consider the type of filter media when designing stormwater treatment biofilters along with other design parameters such as hydraulic conductivity and surface area.

## 1 INTRODUCTION

The Ku-ring-gai local government area (LGA) is located approximately 15 kilometres north of the Sydney CBD in New South Wales (NSW), Australia and covers an area of 85.4 km2 (ABS 2006). It is characterised by low density residential housing set on individual lots. Formalised drainage systems are present in most developed areas and the connected impervious percentage is approximately 29.3% (Davies et al, 2010).

In 2004 Ku-ring-gai Council introduced a seven year environmental levy program of which one of the funding areas was the implementation of Water Sensitive Urban Design (WSUD) projects. This responded to the degraded state of many of the urban waterways, the high importance the local community placed on these natural assets and the need for water conservation and reuse that responded to the drought affecting Sydney at the time.

Some of the major challenges of the WSUD program were the difficulties in retrofitting devices into catchments with limited space and the emerging body of research informing the design and function of systems. While the developed areas of the catchment are dominated by low density development, services such as electricity, water, gas and telecommunications present ongoing design and site constrains. This is particularly so for biofiltration systems (also called raingardens or bioretention systems), where it can be difficult if not impossible to secure the surface area required to comply with existing design guidelines. In many cases this results in a smaller sized unit with lower treatment capacity therefore reducing the effectiveness of the system and in turn may compromise the project's objectives.

The Australian guideline informing the design of biofiltration systems recognises the relationship between ponding depth, size and hydraulic conductivity of a filter media to its overall ability to capture and retain pollutants (FAWB 2009). However, much of the research focuses on the efficiency of the filtration media in removing target pollutants and has been largely based on laboratory studies. Limited research has been undertaken to validate laboratory results with that experienced in the field. Reflecting on these limitations, one of the elements of Council's WSUD program is to measure the performance of the various devices installed to improve future design and operation, and contribute to the applied research in this field.

This paper presents a case study of the design and performance of two biofiltration systems using different filter media. Water quality test results and hydraulic conductivity tests are used to compare against assumptions made during design.

## 2 BACKGROUND

In 2006 and 2007 Council completed a number of small biofiltration systems. These were designed in accordance with then current design guidelines (Ecological Engineering et al 2006). However, once in operation they encountered problems with the hydraulic conductivity being considerably lower than what was designed and indicated as part of the soil specification. Water quality testing conducted in 2008 also returned results that were not consistent with results reported in other studies. The test results have been discussed in a previous paper (Findley et al 2008). This data coupled with observations that large amounts of fine sediments were exported from the systems during establishment led council to investigate alternative design approaches for biofiltration systems. The objectives were to identify design solutions to enable the construction of smaller systems and to reduce export of sediments from the system itself without compromising the overall performance of the system.

Many organisations in Australia are using the Model for Urban Stormwater Improvement Conceptualisation (MUSIC) as developed by the Australian Cooperative Research Centre for Catchment Hydrology (CRCCH) when designing and evaluating the performance of biofiltration systems used to treat urban runoff. As part of this process, hydraulic conductivity of the filter media is a key input into the modelling and the use of realistic values is essential for both design and during evaluation.

The specification of a soil media intended for biofiltration applications often include a value for saturated hydraulic conductivity as tested by the supplier. However, time and financial constraints often limits the ability to test filter media as supplied to site and therefore verify that the media complies with the specifications. If the supplier has provided a value for the saturated hydraulic conductivity, this is often relied upon when making design decisions and evaluating the performance and benefits of a biofiltration system.

In 2007 Council undertook a modelling exercise using MUSIC version 3.01 to investigate the sensitivity of hydraulic conductivity as part of the design and performance of biofiltration systems. This found that small systems that used filter media with a high hydraulic conductivity would lead to an improved treatment of stormwater runoff compared to using a filter media with a lower hydraulic conductivity (Jonasson et al 2010). A hypothesis was developed that by utilising a sand filter media rather than sandy loam the overall performance of the system could be improved. This approach could support the use of systems with a smaller footprint than the traditional approach using a sandy loam media.

In order to assess the hypothesis, a sand filter biofiltration system was constructed in 2008 at Kooloona Crescent, West Pymble (Latitude -33.7667, Longitude 151.1322). Coarse washed river sand was used and was amended with water absorbing polymers in an attempt to provide some longer term water availability for the plants. During construction the filter was unfortunately covered with decomposed granite containing fines that may have impacted on the overall hydraulic conductivity of the system (reflecting the inherent challenges faced by devices in the field). The garden was planted with a mix of Juncus usitatus, Dianella caerulea and Dichelachne micrantha.

The sand filter biofiltration system at Kooloona Crescent was compared with one of three biofiltration raingardens constructed at Karuah Road adjacent to Turramurra Memorial Park, Turramurra (Latitude -33.7264, Longitude 151.1303), called Karuah Road 3. The Karuah Road raingarden used for comparison were constructed in 2007 using sandy loam filter media and has been described in previous papers (Findlay et al

2008, Jonasson et al 2007). All gardens included a subsoil drainage system, collecting filtered water and returning it back to the drainage system.

## 3 METHODOLOGY

### 3.1 Hydraulic conductivity measurement

Hydraulic conductivity of soil in laboratory was assessed using two different methods:

1. Australian Standard AS4419-2003 for permeability testing
2. United States Golf Association (USGA) (ASTM F1815 (2006)).

The field method recommended for use in Australia by the Facility for Advancing Water Biofiltration (FAWB) (FAWB 2009) and used in this study is the single ring, constant head infiltration test method (shallow test), as described by Le Coustumer et al. (2007). The test utilises a single ring infiltrometer inserted 50mm into the filter media and applies a constant head. The saturated hydraulic conductivity is calculated using flow rates from two different constant heads, 50mm and 150mm.

As a comparison, field tests were also carried out using the method described in Bouwer (1986) by an external consultant. This method uses a single ring infiltrometer similar to the shallow test described by Le Coustumer et al (2007) but this is inserted approximately 100mm into the soil media. Saturated hydraulic conductivity is calculated using flow rates from a constant head of approximately 150mm. Bouwer (1986) applies Darcy's Law when calculating the saturated hydraulic conductivity as opposed to the shallow test method described by Le Coustumer et al (2007) that assumes a Gardner's behaviour of the soil (Le Coustumer et al. (2007)).

### 3.2 Water quality testing

Semi-controlled sampling was conducted to determine the removal of various pollutants from Kooloona Crescent biofiltration system and Karuah Road 3 rain garden. The analysis included electrical conductivity, suspended solids, total nitrogen, total phosphorus, hydrocarbons, faecal coliforms and dissolved and total metals (Hg; Ca; As; Cu; Cr; Ni; Pb & Zn). This sought to provide an understanding of water quality function of the respective biofiltration systems against the design of the filter media.

The concentration of pollutant in stormwater runoff can vary significantly (Duncan 1999), and will also change during a storm event. Synthetic stormwater was created for the experiment in an attempt to create water that contained a representative level of pollutants. This involved mixing dry weather flow water from a local creek (that drains a residential catchment) with decanted water from a street sweeper. By sampling water of a known concentration at the inflow to the filter and at the outflow, change in concentration through the filter can be demonstrated. The method used to apply and sample the water was the same for each occasion, using a 1,000L water tank to store and mix the water before application.

One sample was taken from the untreated inflow from each garden and two samples were taken from the designed sampling well or outflow. The first outflow sample was collected as soon as water had passed through the media into the sampling well. To address concern that some of the water in this first outlet sample may be influenced by water of a previous storm event stored within the filter media, a second sample was taken after all water ponding on the surface had filtered into the biofiltration system.

At Kooloona Crescent, a grab sample was also collected during a storm event with one sample collected from water entering the filter from the road and one sample collected from the outflow pipe of the filter.

# 4 RESULTS

## 4.1 Hydraulic conductivity

The top layer of a bioretention system is most susceptible to clogging from fine sediments getting washed into the system and therefore limiting the overall hydraulic performance. Tests were therefore only performed on the top layer of the filters.

Field testing of the hydraulic conductivity of the Kooloona Crescent system was performed in 2009. Testing was carried out using both the single ring (shallow test) infiltrometer as described by Le Coustumer et al (2007) and the method described by Bouwer (1986). The results from hydraulic conductivity tests from Kooloona Crescent have previously been presented elsewhere (Jonasson et al 2010) and summarised in Table 1. The single ring infiltration test (shallow test) as described by Le Coustumer et al. (2007) indicated a lower hydraulic conductivity than other methods where the difference in flow rate is small between the two heads used as part of this method.

The method described by Bouwer (1986) applies Darcy's Law and appears to overestimate the hydraulic conductivity. Where the hydraulic conductivity is high, that is for the sand media, using the method described by Bouwer (1986) would appear to provide a more reliable result.

**Table 1 Results from Hydraulic conductivity testing for Kooloona Crescent.**

| | Hydraulic conductivity Kfs (mm/h), Single ring infiltration test (shallow test) as described by Le Coustumer et al. (2007) | Hydraulic conductivity Kfs (mm/h), Single ring infiltration test as described by Bouwer (1986). | Laboratory testing performed (by SESL) on actual sand (called +425) delivered for use in biofiltration systems, using USGA |
|---|---|---|---|
| A (washed sand) | 34 | 1009 | 740 |
| B (washed sand) | 45 | 1077 | 740 |
| C (washed sand) | N/A | 1127 | 740 |
| D (washed sand) | N/A | 758 | 740 |
| Average (washed sand): | 39.5 | 993 | 740 |

(Jonasson et al 2010)

The Karuah Road 3 raingarden used for comparison was tested for hydraulic conductivity in 2008 using the infiltration test as described by Le Coustumer et al. (2007) and the method described by Bouwer (1986) in 2009. As the different tests were carried out at different times it is noted that the results may not be directly comparable. A summary of the hydraulic conductivity is presented in Table 2.

**Table 2. Saturated Hydraulic conductivity for Karuah Road Number 3.**

| | Hydraulic conductivity Kfs (mm/h), Single ring infiltration test (shallow test) as described by Le Coustumer et al. (2007) | Hydraulic conductivity Kfs (mm/h), Single ring infiltration test as described by Bouwer (1986). | Laboratory testing performed (by SESL) for the soil supplier, using AS 4419 |
|---|---|---|---|
| A (sandy loam) | 21 | 46 | 203 |
| B (sandy loam) | 77 | 87 | 203 |
| C (sandy loam) | 37 | 118 | 203 |
| Average (sandy loam): | 45.0 | 83.7 | 203 |

### 4.1.1 Field observations

The rain garden at Karuah Road 3 has a rectangular shape with vertical walls, and allows calculating the hydraulic performance during a storm event with reasonable accuracy. During water quality tests, the rate of which the water level dropped in Karuah Road 3 was recorded after inflow to the biofiltration bed had ceased. The water level was recorded as dropping by 155mm over a period of 108 minutes (from 155 to 0). Adopting Darcy's Law (though not taking into account the falling head) this would be equivalent to a saturated hydraulic conductivity of approximately 57mm/hr. For the Karuah Road 3 biofiltration system both methods returned results comparable to field observations.

During storm events at the Kooloona Crescent biofiltration system it was observed that water did pond on top of the filter during high inflows. Though no detailed recording was carried out of water levels and the rate of which the level dropped, it was observed that the water subsided rapidly in a matter of minutes once flow into the garden decreased.

## 4.2 Water quality

The pollutant concentrations from untreated water (inflow, A) for sampling of Kooloona (K) and Karuah Road 3 (3) compared with stormwater contaminant characteristics for roads and urban runoff as described by Duncan (1999) (dark grey shading) are presented in Figures 1-3. The figures also include inflow concentration for grab sample at Kooloona biofiltration system (K1)

As illustrated in Figures 1-3, with the exception of Mercury (Hg), nutrients and bacteria, none of the inflow mixtures provided stormwater with concentrations of pollutants within the "typical" range of stormwater runoff from roads and urban areas. However as water was tested at both the inflow and outflow the results allowed comparison of the pollutant removal performance for the two filters tested. It should be noted that for some pollutants such as Suspended Solids and Total Nitrogen, the inflow concentration was similar to the background concentration expected in a biofiltration system (CRC for Catchment Hydrology 2005).

The outflow data was used to compare the function of the different filter media used in each rain garden. There were some discrepancies in the sampling regime and not all tests included the same parameters. The results of the water quality analysis are provided in Table 3. The analysis of the results below recognises that further sampling is required to provide statistical confidence.

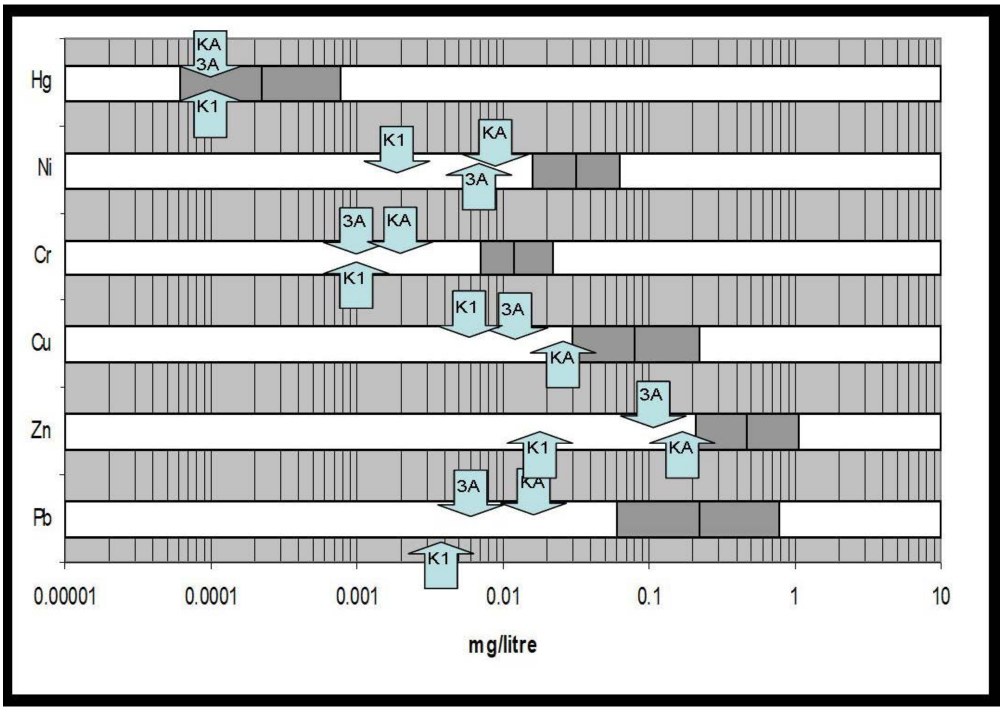


**Figure 1. Concentrations of total metals in untreated water for Kooloona (K) and Karuah Road 3 (3) compared with stormwater contaminant characteristics for roads and urban runoff as described by Duncan (1999) (dark grey shading).**

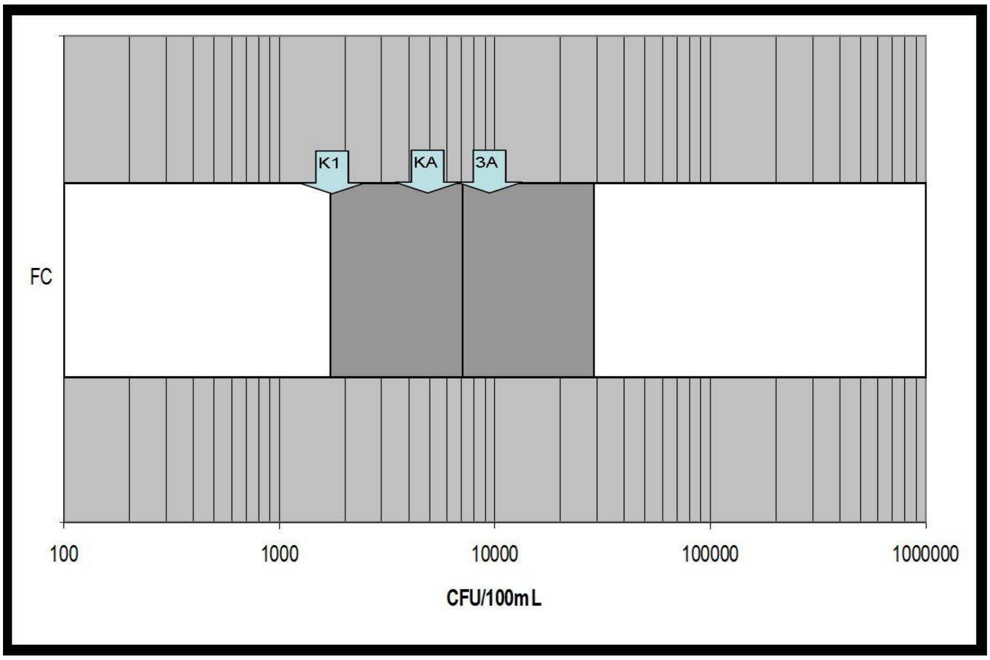


**Figure 2. Faecal Coliforms in untreated water for Kooloona (K) and Karuah Road 3 (3) compared with stormwater contaminant characteristics for roads and urban runoff as described by Duncan (1999) (dark grey shading).**

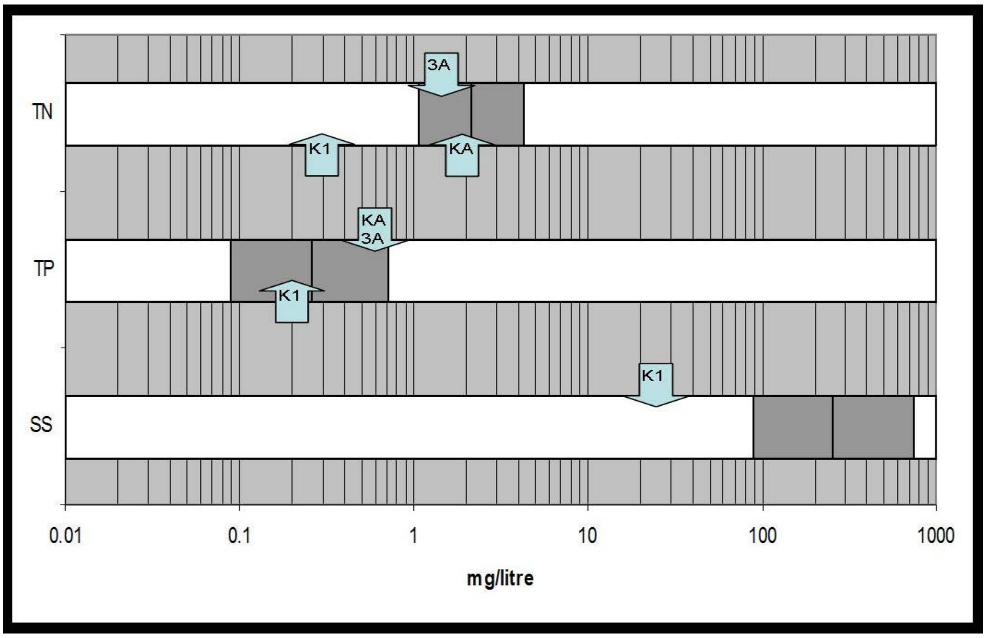


**Figure 3. TN, TP and TSS concentrations in untreated water for Kooloona (K) and Karuah Road 3 (3) compared with stormwater contaminant characteristics for roads and urban runoff as described by Duncan (1999) (dark grey shading).**

The notable results from the in-situ water quality analysis are as follows:

E-coli:

- The sandy loam filter reduced E-coli concentration with a maximum of 86% (outflow 1).
- During the 'controlled' test water filtered through the sand filter had a maximum reduction of 24% (outflow 2), with no reduction in outflow 1
- Results from the event based grab sample showed a reduction of 72%

Total Nitrogen (TN) and total phosphorus (TP):

- Both the sandy loam and the sand export TN. The sandy loam had a minimum increase of 235% (outflow 2) while the sand had a minimum increase of 6% (outflow 2).
- Sandy loam reduced TP with a maximum of 88% (outflow 2) compared to sand which had a maximum of 90% reduction (outflow 1).

Total Petroleum Hydrocarbons(TPH):

- TPH was exported from the sand filter during the controlled sampling; the largest increase (outflow 2) was 42%. No TPH were detected in either the inflow or outflow for the event based sample. The sandy loam filter demonstrated a maximum of 62% reduction (outflow 1).

Turbidity and total dissolved solids (TDS):

- Turbidity initially increased for both systems before returning to values that closely resemble the inflow. Only the outflow from the grab sample from Kooloona Cr and outflow 2 from the sand complies with current guidelines for reuse (NRMMC et al, 2009)

- TDS significantly increased (over 1100%) in the grab sample from Kooloona biofiltration system. As TDS and TSS were not analysed in the controlled sample events no thorough comparison is possible.

Metals:

- The sand filter appears to export trace amounts of As and Cr, both Total and Dissolved.
- Dissolved Cu was exported from both gardens (Sand controlled 100% increase; Sand grab 150% increase; sandy loam 150% increase). Sandy loam also exported Total Cu (514% increase), while the sand reduced Total Cu on the controlled sample occasion (24% decrease). There was no change in Total Cu for the grab sample.
- The removal of Pb through the sand was 80% (outflow 1 and 2) while the sandy loam initially was exporting Total Pb before returning to a removal of 16%. No dissolved Pb was detected in any of the samples.
- Sand had the highest removal of Total Zn at 96% (outflow 2). Maximum removal of Zn for the sandy loam was 89% (outflow 2). Both media showed high removals of dissolved Zn.

**Table 3: Results of the water quality analysis**

| | | Kooloona (sand) | Kooloona (sand) grab sample during storm | Karuah (sandy loam) |
|---|---|---|---|---|
| **E.coli** | Inflow (A) | 4900 | 1800 | 9700 |
| (org/100ml) | Outflow 1 (B) | 4900 | 500 | 1300 |
| | Outflow 2 ( C) | 3700 | - | 1800 |
| **TN** | Inflow (A) | 1.8 | 0.3 | 1.4 |
| (mg/L) | Outflow 1 (B) | 4 | 0.2 | 6.8 |
| | Outflow 2 ( C) | 1.9 | - | 4.7 |
| **TP** | Inflow (A) | 0.63 | 0.2 | 0.56 |
| (mg/L) | Outflow 1 (B) | 0.06 | 0.26 | 0.25 |
| | Outflow 2 ( C) | 0.1 | - | 0.07 |
| **TPH** | Inflow (A) | 0.69 | Not detected | 0.65 |
| (mg/L) | Outflow 1 (B) | 0.79 | Not detected | 0.25 |
| | Outflow 2 ( C) | 0.98 | - | 0.3 |
| **Turbidity** | Inflow (A) | 38.2 | 26.3 | 30.1 |
| NTU | Outflow 1 (B) | 109 | 19.7 | 99 |
| | Outflow 2 ( C) | 42.1 | - | 18.6 |
| **TDS** | Inflow (A) | - | 13 | - |
| (mg/L) | Outflow 1 (B) | - | 162 | - |
| | Outflow 2 ( C) | - | - | - |
| **TSS** | Inflow (A) | - | 24 | - |
| (mg/L) | Outflow 1 (B) | - | 2 | - |
| | Outflow 2 ( C) | - | - | - |
| **Total metals** | | | | |
| **Hg** | Inflow (A) | <0.0001 | <0.0001 | <0.0001 |
| (mg/L) | Outflow 1 (B) | <0.0001 | <0.0001 | <0.0001 |
| | Outflow 2 ( C) | <0.0001 | - | <0.0001 |
| **As** | Inflow (A) | <0.001 | <0.001 | <0.001 |
| (mg/L) | Outflow 1 (B) | 0.006 | 0.007 | <0.001 |
| | Outflow 2 ( C) | 0.006 | - | <0.001 |

| | | | | |
|---|---|---|---|---|
| **Cr** | Inflow (A) | 0.002 | <0.001 | <0.001 |
| (mg/L) | Outflow 1 (B) | 0.013 | 0.002 | 0.002 |
| | Outflow 2 ( C) | 0.01 | - | <0.001 |
| **Cu** | Inflow (A) | 0.025 | 0.006 | 0.014 |
| (mg/L) | Outflow 1 (B) | 0.019 | 0.006 | 0.086 |
| | Outflow 2 ( C) | 0.02 | - | 0.034 |
| **Pb** | Inflow (A) | 0.015 | 0.004 | 0.006 |
| (mg/L) | Outflow 1 (B) | 0.003 | 0.001 | 0.031 |
| | Outflow 2 ( C) | 0.003 | - | 0.005 |
| **Ni** | Inflow (A) | 0.009 | 0.002 | 0.007 |
| (mg/L) | Outflow 1 (B) | 0.003 | <0.001 | 0.003 |
| | Outflow 2 ( C) | 0.003 | - | 0.001 |
| **Zn** | Inflow (A) | 0.183 | 0.017 | 0.11 |
| (mg/L) | Outflow 1 (B) | 0.008 | 0.007 | 0.053 |
| | Outflow 2 ( C) | 0.007 | - | 0.012 |
| | **Dissolved metals** | | | |
| **Hg** | Inflow (A) | <0.0001 | <0.0001 | <0.0001 |
| (mg/L) | Outflow 1 (B) | <0.0001 | <0.0001 | <0.0001 |
| | Outflow 2 ( C) | <0.0001 | - | <0.0001 |
| **As** | Inflow (A) | <0.001 | <0.001 | <0.001 |
| (mg/L) | Outflow 1 (B) | 0.005 | 0.008 | <0.001 |
| | Outflow 2 ( C) | 0.006 | - | <0.001 |
| **Cr** | Inflow (A) | <0.001 | <0.001 | <0.001 |
| (mg/L) | Outflow 1 (B) | 0.007 | 0.002 | <0.001 |
| | Outflow 2 ( C) | 0.009 | - | <0.001 |
| **Cu** | Inflow (A) | 0.009 | 0.002 | 0.01 |
| (mg/L) | Outflow 1 (B) | 0.016 | 0.005 | 0.02 |
| | Outflow 2 ( C) | 0.018 | - | 0.025 |
| **Pb** | Inflow (A) | <0.001 | <0.001 | <0.001 |
| (mg/L) | Outflow 1 (B) | <0.001 | <0.001 | 0.001 |
| | Outflow 2 ( C) | <0.001 | - | <0.001 |
| **Ni** | Inflow (A) | 0.005 | <0.001 | 0.006 |
| (mg/L) | Outflow 1 (B) | 0.002 | <0.001 | <0.001 |
| | Outflow 2 ( C) | 0.002 | - | 0.001 |
| **Zn** | Inflow (A) | 0.083 | <0.005 | 0.086 |
| (mg/L) | Outflow 1 (B) | <0.005 | 0.005 | 0.014 |
| | Outflow 2 ( C) | <0.005 | - | 0.009 |

## 5 DISCUSSION

### 5.1 Hydraulic conductivity

The biofiltration systems were tested at multiple points (between two and four locations) using two different methods (refer to Table 1 and 2).

The hydraulic conductivity as measured using the single ring infiltration test (shallow test), as described by Le Coustumer et al. (2007) reported a low hydraulic conductivity for the sand, inconsistent with field observations. The results did not compare favourably with the results obtained using the field method described by Bower (1986). The average hydraulic conductivity of the sandy loam was 45mm/hr. This was similar to both field observations and results obtained using the field method described by Bower (1986).

The single ring infiltration test (shallow test) as described by Le Coustumer et al. (2007) and recommended by current Australian guidelines (FAWB 2009), calculates the saturated hydraulic conductivity using a different equation than the field method described by Bower (1986), and utilises the difference in flow rate from 50mm and 150mm of head. For the sand, many tests carried out as part of this study showed only minor differences in flow between 50mm and 150mm head. The resulting hydraulic conductivity was calculated as low in these cases irrespective of the actual flow rate. The significant impact on the results where the difference in flow between the 50mm and 150mm heads is low is identified as a limitation of this method. This could potentially impact on the calculated effectiveness of the system during evaluation.

The method described by Bouwer (1986) appears to overestimate the hydraulic conductivity for the sand media. For Karuah 3 the results were largely consistent with field observations. There are some questions whether the testing was carried out for a sufficient duration of time to achieve saturated conditions and this may have impacted on the test results. If a higher hydraulic conductivity is assumed as part of the design or evaluation process this may overestimate the performance of the treatment system.

Le Coustumer et al (2007) and later in Le Coustumer et al (2008) reported variability in the hydraulic conductivity using shallow and deep tests on the same sites, noting that the deep test applied Darcy's Law. This is consistent to the results reported in this study. Whilst some of the differences can be attributed to variability within the individual systems this presents difficulties for stormwater managers to evaluate the performance of their systems. The results obtained by using methods applying Darcy's Law appear to be more consistent. This method shows a clear difference in hydraulic conductivity between sand and sandy loam. This is not the case for results obtained using the (shallow test) method described by Le Coustumer et al. (2007). Uncertainty will be further compounded over the life of the system as the hydraulic conductivity will change due to a range of variables including settlement of soil layers, compaction and establishment of vegetation (FAWB 2009).

Given the spatial and temporal variability of any system, it is appropriate to recommend multiple testing within each individual system and that testing is performed using different heads. Importantly, the results should be read as indicative rather than definitive.

### 5.2 Water quality testing

Semi-synthetic runoff was used in this study, noting that repeatability and representativeness of inflow sample varied significantly. Although the semi-synthetic stormwater did not provide concentrations within the "typical" range of stormwater runoff for some pollutants, testing the water at both the inflow and outflow allowed comparison of the pollutant removal performance for these systems. The use of a spiked creek sample from contaminated street sweeper water was therefore considered a viable alternative and was able to demonstrate the performance of the two types of biofiltration systems.

The heavy metals Cr and Cu did not show the changes as found in column experiments as reported by Hatt *et al.* (2007) who found mean reductions in excess of 92% across a range of analytes. However, the inflow concentrations in this field study were considerably lower than "typical" stormwater runoff (Duncan 1999). Notable was that the sand and the sandy loam both reported a reduction in total Zn by around 90%.

There was a net export of Cu and As in both media and for Cr in the sand media. This may be due to the source of the media. This may also explain the apparent net export of TPH from the sand media, however this may also be due to earlier hydrocarbons being washed into the system. The sand may be less effective in absorbing and retaining hydrocarbons within the media and it is possible this is being slowly released back over time. The data in Table 3 suggest that sand may be a preferred filter media when targeting metals, while sandy loam performed better in terms of removing faecal coliforms. Even though both filter media was found to export TN, sand exported considerably less and showed a reduction for the grab sample. This, coupled with a higher removal rate of TP may suggest that sand is the preferred filter media when targeting nutrients. However, as the data set was small more testing is required to further investigate this preliminary finding.

### 5.3 Implications of using a sand filter media compared to sandy loam

In laboratory studies sand based filter media has been found to be comparable to or in some cases better than sandy loam in capturing metals, TSS, TP and TN in a biofiltration application (Hatt et al 2007, Bratieres et al 2009).

Investigations into the use of sand based filter media instead of the sandy loam (Bratieres et al 2009) showed that compared to sandy loam, sand based filter media has quite poor treatment performance for the first six months. The difference is however less profound after one year. Bratieres et al (2009) also reported that a sand based filter media is less likely to leach nitrogen, while soil based biofiltration systems may be net producers of nitrogen (Hatt et al 2007). Results obtained as part of this study supports these findings, and provides further support for using sand based filter media. The poor performance during the first six months observed by Bratieres et al (2009) from the sand filter may be offset by the fact that a washed sand will contain less fines than a sandy loam and is thus less likely to export sediment during the initial period after installation. Such export has been observed from a number of biofiltration systems constructed using a sandy loam filter media across the Ku-ring-gai local government area. This observation is of some concern and is an area for more investigation. Anecdotal evidence from other councils in the Sydney region indicates that this is a common problem. There is little literature that reports on the amount and characteristic of exported sediment during the establishment phase of a biofiltration system and the potential impact this has on downstream ecosystem.

A filter media with a high hydraulic conductivity is however unlikely to support plant growth (FAWB 2009). As this is an important part of the effectiveness of a biofiltration system (Bratieres et al., 2009, 2010, Hatt et al., 2007a, Henderson et al.,2007) it may limit the use of sand as a filtration media, especially in areas regularly experiencing prolonged periods of drought. Measures such as incorporating water holding polymers or the use of a saturated zone can counteract some of these problems.

The long-term hydraulic performance of sand in a biofiltration application should also be considered. It is likely that fine sediment present in the stormwater runoff will be washed into the biofiltration system and reduces the hydraulic conductivity. This may transform the sand media to a sandy loam after prolonged exposure to urban runoff. Bratieres et al. (2010) also reported a significant decrease in the hydraulic conductivity for the sand based filter media after vegetation is fully established. This may however have been due to the extremely high plant density used in the test. No significant decrease in hydraulic conductivity for sand filter media was observed as part of this case study.

The overall capacity of the system to store captured pollutants should also be considered when designing systems that receive runoff from a large impervious catchment. A larger system will have more capacity to handle pollutant loads especially if maintenance is infrequent. Smaller biofiltration systems may not be advisable unless regular maintenance can be assured.

## 6 CONCLUSION

While different techniques used to measure hydraulic conductivity reported significantly different results when compared with field observations, the study shows that sand retains a significantly higher hydraulic conductivity compared to a sandy loam. Given the similar water quality improvement that can be expected from using sand compared to sandy loam in a biofiltration application (Hatt et al 2007), the findings from this study support the hypothesis that sand may be a preferable filtration media in small biofiltration systems. In retrofit situations where available land is limited this is an important finding, and verifies the importance of considering all aspects of a system (hydraulic conductivity, size and ponding depth) during the design of new systems.

As previously reported by Jonasson (2010) and further supported by this study the findings indicates that the method used to assess hydraulic conductivity may significantly influence the results. The single ring infiltration test (shallow test) as described by Le Coustumer et al. (2007) will report a lower hydraulic conductivity than other methods where the difference in flow rate is small between 50mm and 150mm head. The method described by Bouwer (1986) on the other hand appears to consistently overestimate the hydraulic conductivity. Where the hydraulic conductivity is high (sand media), using the method described by Bouwer (1986) (applying Darcy's Law), appear to provide a more reliable result.

Some questions are raised in relation to export of metals from both filter media tested. Water quality test results obtained as part of this study do however suggest that sand may be a preferred filter media when targeting metals, while sandy loam performed better in terms of removing faecal coliforms. In terms of nutrients sand had a higher removal rate of TP and while both filter media was found to export TN, sand exported considerably less and also showed a reduction for the grab sample. This would suggest that sand may be a preferred filter media when targeting nutrients. As the data set is small more testing is required to further investigate this preliminary finding.

When testing the performance of a biofiltration system to verify modelling and quantify the benefits of such WSUD treatments results need to be critically assessed. Hydraulic conductivity test results should ideally be verified by field measurements, including flow gauging at the outflow of the system, or by comparison with anecdotal evidence to ensure they are representative of the function of the filter. Importantly, all results should be considered as indicative not definitive.

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paper fifteen

# Hydraulic conductivity and impact on retrofit stormwater biofiltration – case study of the design, assessment and function of retrofit raingardens using different filter media in Sydney

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paper fifteen

# Hydraulic conductivity and impact on retrofit stormwater biofiltration - case study of the design, assessment and function of retrofit raingardens using different filter media in Sydney.

# Impacts de la conductivité hydraulique sur la biofiltration des eaux pluviales : étude de la conception, du fonctionnement et du suivi de jardins d'eau utilisant différents systèmes de filtration à Sydney, Australie

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## RÉSUMÉ

Cet article présente une étude de cas sur la conception de divers systèmes de biofiltration au moyen de différents matériaux de filtration et de différentes méthodes de mesure de la conductivité hydraulique. La modélisation mise en œuvre dans le cadre de cette étude a montré que pour les petits systèmes, une conductivité hydraulique élevée entraîne globalement de meilleurs résultats. L'évaluation des performances hydrauliques des systèmes existants a été effectuée au moyen de deux méthodes différentes utilisant toutes deux un infiltromètre à anneau unique, mais selon deux formules différentes de calcul de la conductivité hydraulique. Les résultats ont montré, en comparant les deux méthodes, que la biofiltration sur argile sableuse donnait une conductivité hydraulique notablement plus basse que celle précédemment rapportée dans les essais en laboratoire. Tous les essais ont fait apparaître une large variabilité dans les résultats, suggérant un besoin de prudence quant à l'utilisation d'un seul test ou d'une seule méthode pour mesurer la conductivité hydraulique avec précision. Du point de vue de la conception et de l'exploitation, cette étude approuve l'utilisation de sable plutôt que d'argile sableuse comme milieu de filtration, particulièrement lorsqu'il n'y a pas assez d'espace pour dimensionner le système de biofiltration suivant les recommandations des bonnes pratiques.

## ABSTRACT

This paper presents a case study of the design and performance of various biofiltration systems using different filter media and different methods to measure hydraulic conductivity. Modelling undertaken as part of this study indicated that for small systems a high hydraulic conductivity will result in a better overall performance. Assessment of the hydraulic performance of four biofiltration systems was carried out using two different methods, both using a single ring infiltrometer but using different formulas to calculate the hydraulic conductivity. The results showed that biofiltration using sandy loam reported significantly lower hydraulic conductivity using both methods than that previously reported in laboratory tests. In all testing there was great variability in the results suggesting the need for caution to rely on any single test or method to accurately report the hydraulic conductivity. From a design and operational perspective this study supports the use of sand over sandy loam as a filter media particularly where there is insufficient space to size the biofiltration system according to best practice guidelines.

## KEYWORDS

Hydraulic conductivity, biofiltration, bioretention, raingarden, Water Sensitive Urban Design, stormwater modelling, stormwater quality, filter media, urban drainage

# 1 INTRODUCTION

In a fully developed catchment, retrofitting stormwater quality devices can be challenging due to space limitations and the presence of underground services such as electricity, water and gas. This is particularly so for biofiltration systems, also called raingardens or bioretention systems, where it can be difficult if not impossible to secure the necessary surface area required to comply with current design guidelines. When designing and assessing the performance of a biofiltration system, the hydraulic conductivity of the filter media is a vital design consideration. Current Australian design guidelines for biofiltration systems acknowledge the relationship between ponding depth, size and hydraulic conductivity of a filter media on the performance of a biofiltration system (FAWB 2008), but it is left to the individual designer to quantify the relationship between these design parameters.

While sand is effective in capturing TSS, TP and TN in a biofiltration application (Hatt et al 2007a), a filter media with a high hydraulic conductivity is unlikely to support plant growth (FAWB 2008). This is an important consideration as plants are a vital component of biofiltration systems (Bratieres et al., 2009, Hatt et al., 2007a, Henderson et al.,2007). Plant growth and root mass will counter the effect of compaction over time and help to maintain hydraulic conductivity (FAWB 2008). Sandy loam is therefore commonly used in biofiltration applications and is considered a suitable growing media (Henderson et al., 2007, Fletcher et al., 2007). However, much of the available research focuses on the efficiency of the filtration media in removing target pollutants with limited fieldwork being undertaken on existing systems to validate the relationship with other design parameters.

Since 2004, Ku-ring-gai Council has implemented a range of Water Sensitive Urban Design (WSUD) projects as part of its capital works and environmental programs. The Ku-ring-gai local government area (LGA) is located approximately 15 kilometres north of the Sydney CBD in New South Wales (NSW), Australia and covers an area of 85.4 $km^2$ (ABS 2006). It is predominately characterised by low density residential housing set on individual lots. A formalised drainage system is present across most of the developed area with the connected impervious percentage being approximately 29% (Davies et al, in review).

A focus of Ku-ring-gai Council's WSUD program is to quantify the performance of various devices installed to improve future design and operation and also to contribute to the applied research in this field of study. The performance of biofiltration systems for treating stormwater is assessed by water quality sampling before and after water passes through the filter and hydraulic conductivity testing using different methods (Le Coustumer et al. 2007, Bouwer 1986). This paper presents a case study of the design of various biofiltration systems using different filter media and field methods to measure hydraulic conductivity and to verify assumptions made during the design

# 2 BACKGROUND

Many organisations in Australia are using the Model for Urban Stormwater Improvement Conceptualisation (MUSIC) as developed by the Australian Cooperative Research Centre for Catchment Hydrology (CRCCH) for the design and evaluation of biofiltration systems treating urban runoff. Hydraulic conductivity of the filter media is an important variable in the modelling and the use of realistic values is key for both design and during evaluation.

The specification of a soil media intended for biofiltration applications often includes a value for saturated hydraulic conductivity as tested by the supplier. However, time and financial constraints often limits the ability to test filter media supplied to site and figures provided by the supplier is often relied upon when making design decisions and evaluating the performance and benefits of a biofiltration system.

In 2006 Ku-ring-gai Council constructed a number of small biofiltration systems. These were designed in accordance with then current design guidelines (Ecological Engineering et al 2006). However once in operation problems were observed related to the hydraulic conductivity being considerably lower than what was designed and indicated as part of the soil specification. Performance was further compromised by having limited space in the developed catchment to construct larger systems, something that would have counteracted the decline in hydraulic performance. As a consequence, the majority of runoff was discharged to the receiving environment without any treatment at all. As a result of this, Council started to investigate alternative design approaches for biofiltration systems in a fully developed catchment.

Modelling undertaken in 2007 using MUSIC version 3.01 indicated that for small systems, using a filter media with a high hydraulic conductivity would result in improved overall treatment of stormwater runoff compared to filter media with a lower hydraulic conductivity. A hypothesis was developed that by utilising a sand filter media rather than sandy loam the overall performance of the system could be improved. This approach could support the use of systems with a smaller footprint than the traditional approach using a sandy loam media.

In order to assess the field performance of filtration media with a high hydraulic conductivity, a sand filter biofiltration system was constructed in 2008 at Kooloona Crescent, West Pymble (Latitude -33.7667, Longitude 151.1322) (Figure 1). Coarse washed river sand was used and was amended with water absorbing polymers in an attempt to provide some longer term water availability for the plants. The filter was densely planted with mix of *Juncus usitatus, Dianella caerulea* and *Iseolepsis sp.* Runoff that has passed through the system is collected at the base of the filter and discharge back to the drainage network. During construction the filter was unfortunately covered with decomposed granite containing fines that may have impacted on the overall hydraulic conductivity of the system.

Figure 1. Biofiltration system at Kooloona Crescent, West Pymble (Left), and at Nimbrin Street, Turramurra (Right)

When the vegetation was fully established in 2009, field testing of the hydraulic conductivity was performed to verify design assumptions. Two different methods were used and results were compared with field test results from three other biofiltration beds of a similar age constructed using filter media complying with design guidelines at the time of construction.

Three raingardens were constructed adjacent to Nimbrin Road, Turramurra (Latitude -33.7483, Longitude 151.1160) in 2008 (Figure 1). The gardens were designed in series, intended to focus most of the maintenance on the first bed (as this would receive the bulk of the sediment load). The first two gardens also included a small section of un-vegetated sand in an attempt to increase the hydraulic performance of the systems. Coarse washed river sand was used, the same sand as for the raingarden at Kooloona Crecsent, Gardens are planted with a mix of *Juncus usitatus, Dianella caerulea* and *Dichelachne micrantha*. All three gardens included a subsoil drainage system, collecting filtered water for reuse.

# 3 METHODOLOGY

## 3.1 Modelling of biofiltration systems

Modelling of a hypothetical system with different filter media characteristics and surface areas was performed using MUSIC version 3.01 to assess how a change in hydraulic conductivity is likely to impact on the overall performance of a biofiltration system. This computer model can assess the likely water quality improvements that can be expected from different stormwater quality improvement strategies (CRCCH 2005). Modelling parameters and values are presented in Table 1.

| | | |
|---|---|---|
| **Extended detention depth** | | 100mm |
| **Seepage loss** | | 0 mm/hr |
| **Surface area/filter area** | | 0.2-2.5% of connected impervious catchment |
| **Filter depth** | | 500mm |
| **Depth below underdrain pipe** | | 0 % of filter depth |
| **Overflow weir width** | | 2.00m |
| **Filter specifications** | | |
| **Ksat** | **Median particle size** | **Source** |
| 1000mm/hr | 0.6mm | Median particle size from material specification (coarse sand) |
| 750mm/hr | 0.6mm | Median particle size from material specification (coarse sand) |
| 315mm/hr | 0.6mm | Median particle size from material specification (coarse sand) |
| 170mm/hr | 0.15mm | Median particle size from material specification (sandy loam) |
| 40mm/hr | 0.15mm | Median particle size from material specification (sandy loam) |

Table 1. Input in MUSIC model assessing alternative filter media in biofiltration systems

## 3.2 Hydraulic conductivity measurement

Hydraulic conductivity of soil in laboratory was assessed using three different methods:

1. permeability testing as per Australian Standard AS4419-2003
2. *Hydraulic Conductivity Compaction Curve* (HCCC) developed by McIntyre & Jacobsen (1998)
3. method proposed by the Unite States Golf Association (USGA) (ASTM F1815 (2006)).

The field method recommended for use in Australia by FAWB 2008 and used in this study is the single ring, constant head infiltration test method (shallow test), as described by Le Coustumer et al. (2007). The test utilises a single ring infiltrometer inserted 50mm into the filter media and applies a constant head. The saturated hydraulic conductivity is calculated using flow rates from two different constant heads, 50mm and 150mm.

As a comparison, tests were also carried out using the field method described in Bouwer (1986) by an external consultant. This method uses a single ring infiltrometer similar to the shallow test described by Le Coustumer et al (2007) but this is inserted approximately 100mm into the soil media. Saturated hydraulic conductivity is calculated using flow rates from a constant head of approximately 150mm. The later method applies Darcy's Law when calculating the saturated hydraulic conductivity as opposed to the shallow test method described by Le Coustumer et al (2007) that assumes a Gardner's behaviour of the soil (Le Coustumer et al. (2007)).

In MUSIC version 3.01 the flow through rate of a bioretention system appears to be calculated using Darcy's Law. Consequently the flow through rate will depend on the hydraulic conductivity as specified in the model, as well as filter depth and ponding depth. The flow through rate will increase with an increased ponding depth and will decrease with a deeper filter layer.

# 4 RESULTS

## 4.1 Modelling of biofiltration systems

MUSIC modelling indicated that for small systems where the available surface area of the biofiltration system is limited (with a surface area of 0.25%-0.75% of the upstream impervious catchment) a filter media with a higher hydraulic conductivity will result in an improved overall treatment performance in terms of percentage mass removal of pollutants. (Figure 2). The total % of pollutants removed is related to the volume of water that is treated (increases with an increased hydraulic conductivity) and the pollutant concentration reduction achieved (increases with a decrease in hydraulic conductivity

(Bratieres et al 2009)). Larger systems with a hydraulic conductivity of 40-315mm/hr are predicted to remove a greater percentage of target pollutants. This is consistent with current design guidelines, recommending a hydraulic conductivity of between 100-300mm/hr (FAWB 2008). These guidelines however assume that the biofiltration systems can be sized to be approximately 2% of the contributing catchment. This is not always possible in a developed catchment.

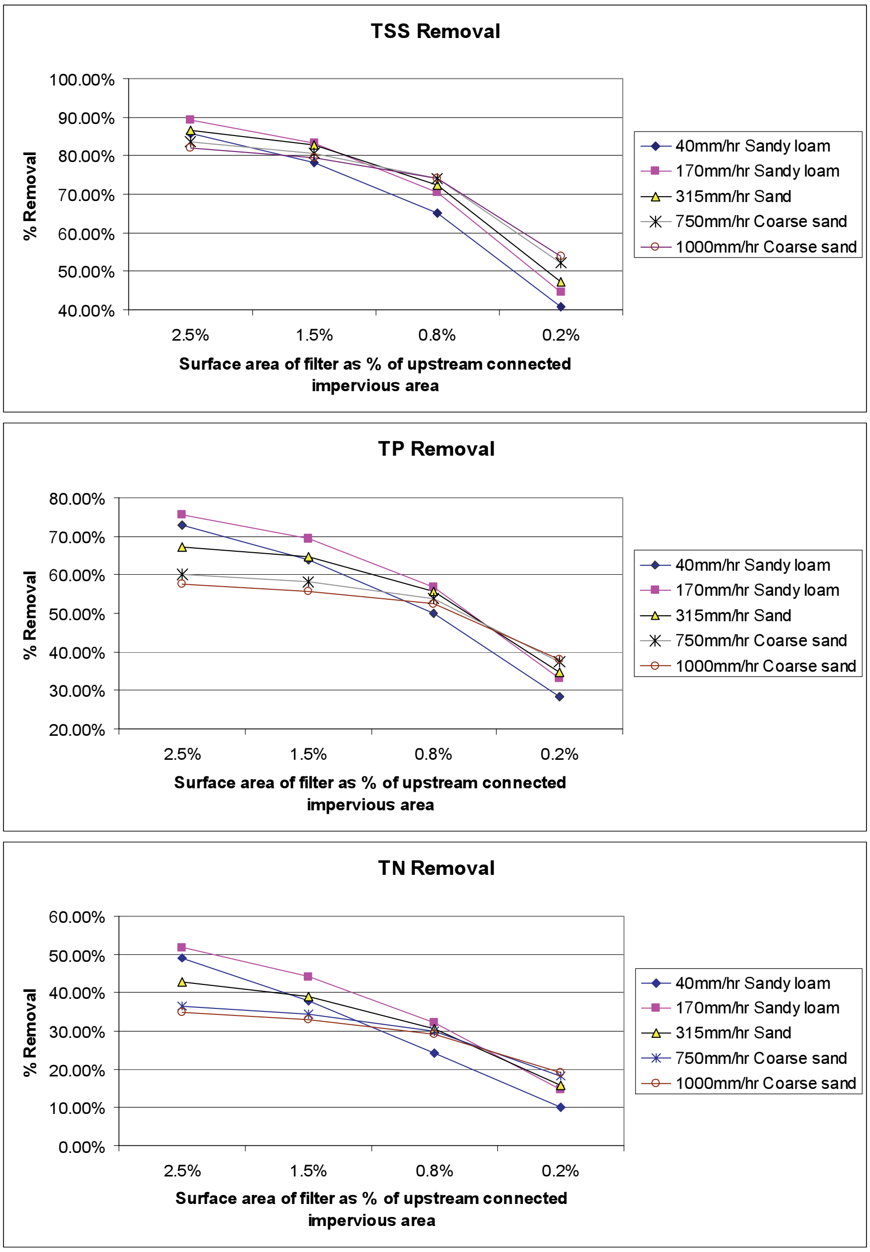


Figure 2. Results, MUSIC modelling of different filter media in biofiltration systems

## 4.2 Hydraulic conductivity

### *4.2.1 Laboratory testing of hydraulic conductivity*

Results from laboratory testing of hydraulic conductivity for the sandy loams used for the filter gardens at Nimbrin Street were provided by the supplier. The sand media used at Kooloona Crescent was tested by an external laboratory. The results are presented in Table 2.

| Filter media | Supplier Code | Site used | Saturated hydraulic conductivity (mm/hr) | Test method used | Comments |
|---|---|---|---|---|---|
| Sandy loam | M165 | Nimbrin Street | 460 (after 32 drops) | HCCC | Information from product specification. Three methods were used in assessing hydraulic conductivity of the soil media. |
| | | | 400 | AS 4419 | |
| | | | 332 | USGA | |
| Coarse washed river sand | +425 Sand | Kooloona Crescent | 740 | USGA | Laboratory testing performed (by Sydney Environmental & Soil Laboratory, SESL) on actual sand delivered for use in biofiltration systems |

Table 2. Hydraulic conductivity test results, laboratory testing

### 4.2.2 *Field testing of hydraulic conductivity*

Testing for all four biofiltration systems were carried out using both the single ring (shallow test) infiltrometer as described by Le Coustumer et al (2007) and by Bouwer (1986).

For comparative reasons a third calculations was carried out using the flow rates obtained from the single ring (shallow test) infiltration test as described by Le Coustumer et al. (2007), but applying Darcy's Law in calculating the hydraulic conductivity. This is in effect a variation of the method described in Bouwer (1986). Darcy's Law assumes that there is zero pressure head below the single ring infiltrometer. Even though this is unlikely to be the case the top layer of a bioretention system is often limiting the overall hydraulic performance of a biofiltration system as this layer is most susceptible to clogging from fine sediments washed into the system. For this reason it can be assumed that the underlying filter media has a higher hydraulic conductivity that the top layer, and applying Darcy's Law should give a conservative low result. The results for all three methods are presented in Table 3.

| | Hydraulic conductivity Kfs (mm/h), Single ring infiltration test (shallow test) as described by Le Coustumer et al. (2007) | Hydraulic conductivity Kfs (mm/h), Single ring infiltration test as described by Bouwer (1986). | Hydraulic conductivity Kfs (mm/h), calculated by adopting Darcy's Law to flow rates obtained using Single ring infiltration test (shallow test, 50mm head) as described by Le Coustumer et al. (2007) | Hydraulic conductivity Kfs (mm/h), calculated by adopting Darcy's Law to flow rates obtained using Single ring infiltration test (shallow test, 150mm head) as described by Le Coustumer et al. (2007) | Hydraulic conductivity Kfs (mm/h) from laboratory test using USGA |
|---|---|---|---|---|---|
| **Nimbrin St 1** | | | | | |
| A (sandy loam) | 46 | 87 | 91.7 | 80.2 | |
| B (sandy loam) | 18 | 207 | 105.4 | 66.5 | |
| C (sandy loam) | N/A | 70 | N/A | N/A | |
| Washed sand section | -55 | 756 | 664.6 | 292 | |
| Average (sandy loam): | *32* | *121* | *98.6* | *73.4* | *332* |
| **Nimbrin St 2** | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| A (sandy loam) | 17 | 426 | 213.1 | 119.2 | |
| B (sandy loam) | 18 | 190 | 105.4 | 66.5 | |
| C (sandy loam) | N/A | 84 | N/A | N/A | |
| Washed sand section | 2 | N/A | 520.2 | 261.3 | |
| Average (sandy loam): | *17.5* | *233* | *159.25* | *92.9* | *332* |
| **Nimbrin St 3** | | | | | |
| A (sandy loam) | 4 | 142 | 261.3 | 132.9 | |
| B (sandy loam) | -6 | 173 | 348.4 | 170.7 | |
| C (sandy loam) | -24 | 64 | 153.6 | 58.4 | |
| Average (sandy loam): | *-8.7* | *126* | *254.4* | *120.7* | *332* |
| **Kooloona Cr** | | | | | |
| A (washed sand) | 34 | 1009 | 634.8 | 342.6 | |
| B (washed sand) | 45 | 1077 | 325.4 | 196 | |
| C (washed sand) | N/A | 1127 | N/A | N/A | |
| D (washed sand) | N/A | 758 | N/A | N/A | |
| Average (washed sand): | *39.5* | *993* | *480.1* | *269.4* | *740* |

Table 3. Saturated Hydraulic conductivity as tested in the field using single ring infiltration test (shallow test) as described by Le Coustumer et al. (2007), field method described Bouwer (1986) and using flow rates obtained through (shallow test) method proposed by Le Coustumer et al (2007) (50 and 150mm head), adopting Darcy's Law. Results compared to laboratory test results using USGA

#### *4.2.3 Field observations*

The rain gardens at Nimbrin Street all have a rectangular shape with vertical walls. This allows the calculation of the hydraulic performance during a storm event with reasonable accuracy. Following a period of rainfall, the rate of which the water level dropped in Nimbrin 3 was recorded after inflow to the biofiltration bed had ceased. Nimbrin 3 is constructed using only M165 sandy loam. The water level was recorded as dropping by approximately 7mm every 10 minutes over a period of 30 minutes (from 103 to 81). Adopting Darcy's Law this would be equivalent to a hydraulic conductivity of approximately 35mm/hr.

During storm events at the Kooloona Crescent biofiltration system it was observed that water did pond on top of the filter during high inflows. Though no detailed recording was carried out of water levels and the rate of which the level dropped, it was observed that the water subsided rapidly (in a matter of minutes) once flow into the garden decreased.

## 5 DISCUSSION

### 5.1 Hydraulic conductivity

The four biofiltration systems were tested at multiple points (between two and four locations) using two different methods (refer to Table 3).

The hydraulic conductivity as measured using the single ring infiltration test (shallow test), as described by Le Coustumer et al. (2007) reported a high variability for the washed sand. This was inconsistent with field observations. The average hydraulic conductivity of the sandy loam between the four systems varied from -24mm/hr to 46mm/hr. The results did not compare favourably with the results obtained using the field method described by Bower (1986).

The single ring infiltration test (shallow test) as described by Le Coustumer et al. (2007) and recommended by current Australian guidelines (FAWB 2008) calculates the saturated hydraulic conductivity using a different equation than the field method described by Bower (1986), and utilises the difference in flow rate from 50mm and 150mm of head. Many of the tests carried out as part of this study showed only minor differences in flow between 50mm and 150mm head. The resulting hydraulic conductivity was calculated as low in these cases irrespective of the actual flow rate. During testing of Nimbrin 3, the results were calculated as negative using the method (shallow test) described by Le Coustumer et al. (2007), as a slightly higher flow rate was recorded at 50mm head compared to 150mm head. This raises suspicion that testing was not carried out long enough for the flow to stabilise. Testing in Nimbrin 3 was however carried out for a duration of 80 minutes for a head of 50mm, and a further 60 minutes for a head of 150mm.  These were longer durations than the tests done for Nimbrin 1 and 2. The significant impact on the results where the difference in flow between the 50mm and 150mm heads is low is identified as a limitation of this method. This could potentially impact on the calculated effectiveness of the system during evaluation.

The method described by Bouwer (1986) appears to overestimate the hydraulic conductivity and is also inconsistent with field observations from Nimbrin 3. There are some questions whether the testing was carried out for a sufficient duration of time to achieve saturated conditions. This may have impacted on the test results. If a higher hydraulic conductivity is assumed as part of the design or evaluation process this may overestimate the performance of the treatment system.

The hydraulic conductivity is considerably higher when applying Darcy's Law to the flow rates measured during field testing than using the method (shallow test) described by Le Coustumer et al. (2007) (Table 3). Using the result from the 50mm head test to calculate the hydraulic conductivity using Darcy's Law resulted in the hydraulic conductivity being approximately twice that determined using the result from the 150mm head test. This shows some uncertainty in this method and indicates that multiple tests using different heads should be undertaken when Darcy's Law is used to calculate the hydraulic conductivity. The results are generally more in line with the results obtained by using the method described by Bouwer (1986) for all sandy loams, as would be expected. However this is not the case for the coarse sand used at Kooloona Crescent, where the results vary considerably between all methods used.

Le Coustumer et al (2007) and later in Le Coustumer et al (2008) reported variability in the hydraulic conductivity using shallow and deep tests on the same sites, noting that the deep test applied Darcy's Law. This is consistent to the results reported in this study. Whilst some of the differences can be attributed to variability within the individual systems, further noting that the hydraulic conductivity will vary over the life of the system (FAWB 2008), this presents difficulties for stormwater managers to evaluate the performance of their systems. The results obtained by using methods applying Darcy's Law appear to be more consistent.  This method shows a clear difference in hydraulic conductivity between sand and sandy loam. This is not the case for results obtained using the (shallow test) method described by Le Coustumer et al. (2007).

Given the spatial and temporal variability of any system, it is appropriate to recommend multiple testing within each individual system and that testing is performed using different heads. Importantly, the results should be read as indicative rather than definitive.

## 5.2 Implications of using a sand filter media compared to sandy loam

Sand is effective in capturing TSS, TP and TN in a biofiltration application (Hatt et al 2007). As sand is likely to have a higher hydraulic conductivity than sandy loam, this would suggest that sand may be a preferred filter media where the size of the filter is limiting the overall performance of a biofiltration system.

Recent research undertaken by Monash University has further investigated the use of sand based filter media instead of the sandy loam media as recommended by current design guidelines (Bratieres et al 2009). The Monash study showed that sand based filter media has quite poor treatment performance for the first six months however the difference is less profound after one year. Bratieres et al (2009) also reported that a sand based filter media is less likely to leach nitrogen. Other studies have shown that soil based filter media used in biofiltration systems may be net producers of nitrogen (Hatt et al 2007), providing further support for using sand based filter media.

The findings by Bratieres et al (2009) support the hypothesis proposed that using sand based filter media have some benefits over a sandy loam filter media in certain applications. The poor performance during the first six months observed by Bratieres et al (2009) from the sand filter may be offset by the fact that a washed sand will contain less fines than a sandy loam and is thus less likely to export sediment during the initial period after installation. Such export has been observed from a number of biofiltration systems constructed using a sandy loam filter media across the Ku-ring-gai local government area. This observation is of some concern and is an area for more investigation. Anecdotal evidence from other councils in the Sydney region indicates that this is a common problem. There is little literature that reports on the amount and characteristic of exported sediment during the establishment phase of a biofiltration system and the potential impact this has on downstream ecosystem.

A filter media with a high hydraulic conductivity is however unlikely to support plant growth (FAWB 2008). As this is an important part of the effectiveness of a biofiltration system (Bratieres et al., 2009, Hatt et al., 2007a, Henderson et al.,2007) it may limit the use of sand as a filtration media, especially in areas regularly experiencing prolonged periods of drought. Measures such as incorporating water holding polymers or the use of a saturated zone can counteract some of these problems.

The long-term hydraulic performance of sand in a biofiltration application should also be considered. It is likely that fine sediment present in the stormwater runoff will be washed into the biofiltration system and reduce the hydraulic conductivity. This may transform the sand media to a sandy loam after prolonged exposure to urban runoff.

The overall capacity of the system to store captured pollutants should also be considered when designing systems that receive runoff from a large impervious catchment. A larger system will have more capacity to handle pollutant loads especially if maintenance is infrequent. Smaller biofiltration systems may not be advisable unless regular maintenance can be assured.

## 6 CONCLUSION

Modelling undertaken as part of the study indicates that for small biofiltration systems a high hydraulic conductivity will result in a better overall performance. The assessment of the hydraulic performance of existing systems showed that in biofiltration systems where sandy loam is used, the hydraulic conductivity was typically significantly lower than results from laboratory studies. Even though the assessment of hydraulic conductivity reported different results depending on the method applied, when compared with field observations it confirms that sand retains a significantly higher hydraulic conductivity compared to a sandy loam. Given the similar water quality improvement that can be expected from using sand compared to sandy loam in a biofiltration application (Hatt et al 2007), the findings from this study support the modelling results. In retrofit situations where available land is limited this is an important finding, and verifies the importance of considering all aspects of a system (hydraulic conductivity, size and ponding depth) during the design of new systems.

The field study has showed that the method used to assess hydraulic conductivity may significantly influence the results. The single ring infiltration test (shallow test) as described by Le Coustumer et al. (2007) will report a lower hydraulic conductivity than other methods where the difference in flow rate is small between 50mm and 150mm head. The method described by Bouwer (1986) on the other hand appears to consistently overestimate the hydraulic conductivity, however results are generally more consistent. When flow is measured over a longer period of time, results obtained applying Darcy's law are lower and highlight the importance of allowing the filter media to be truly saturated before recording the flow rates used to calculate the hydraulic conductivity.

Neither of the field methods used to measure hydraulic conductivity in sandy loam provided consistent results comparable to field observations. Where the hydraulic conductivity is high (sand media), using the method described by Bouwer (1986) (applying Darcy's Law), appear to provide a more reliable result.

When testing the hydraulic conductivity to verify modelling and quantify the benefits of biofiltration in a stormwater management system, results need to be critically assessed. Hydraulic conductivity test results should ideally be verified by field measurements, including flow gauging at the outflow of the system, or by comparison with anecdotal evidence to ensure they are representative of the function of the filter. Importantly, the results should considered as indicative not definitive.

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paper sixteen

# Stormwater management – runoff generation in the Sydney region and impact on stormwater harvesting design

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Stirling B Room

# Stormwater management – Runoff generation in the Sydney region and impact on stormwater harvesting design

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## Introduction

The use of models to assist in the planning and design of urban stormwater management systems are an integral tool for engineers and scientists. They provide quantitative means through which to explore treatment options and controls prior to implementation. Their accuracy relies on many factors and results should be calibrated and verified using data from similar catchments. Ideally this should be undertaken with information from the area under investigation to reflect local nuances and complexities. Unfortunately this seldom occurs and when it does rarely uses locally specific data.

The aim of this paper is to present the findings of a study that monitored flows and rainfall to estimate runoff coefficients across four catchments in the Ku-ring-gai Local Government Area (LGA). This data was compared with and used to improve the set up for the Model for Urban Stormwater Improvement Conceptualisation (MUSIC) and other water balance models. Most importantly the outcome of the study seeks to improve the design of stormwater harvesting schemes and other water sensitive urban design treatments across the Ku-ring-gai LGA.

## Background

Ku-ring-gai Council is located 14 kilometres north of Sydney CBD, NSW. The experience of Ku-ring-gai Council is that most consulting engineering firms use a combination of MUSIC and their own commercial in-confidence water balance models in the design of stormwater harvesting schemes. Invariably each use different methods and assumptions regarding various parameters to determine the desired security of supply. This is most commonly reflected in the size of the storage for the harvested stormwater—simply the larger the storage the greater the security. While the cost of getting stormwater into the system can be relatively insensitive to changes in capacity, storage and to some extent treatment is not and this has a significant impact on the cost and viability of a project. Underestimating the runoff will lead to a larger and therefore more expensive storage while an overestimate may result in storage being undersized, thus not delivering the expected benefit to the community asset.

In most situations the modeller does not have access to relevant data to allow calibration and verification of the modelling outputs. One way to approximate the accuracy of a rainfall-runoff model is by calculating the Volumetric Runoff Coefficient (VRC), or where long term data is available average Annual Volumetric Runoff Coefficient (AVRC). This can then be compared to typical AVRC for that land-use and region. However, within the Sydney region there is a shortage of AVRC's that have been derived from monitoring, limiting the opportunities to verify modelling outputs.

In 2006 Ku-ring-gai Council commenced a study that compared local rainfall and flow gauging data from specific sites across the LGA with modelling results obtained using MUSIC and an in-house developed spreadsheet model (Jonasson and Davies 2007). The first part of the study assessed one site using 3.5 months of continuous flow and rainfall data. The measured runoff generation showed significant variation to modelling that incorporated commonly used parameters in model setups. When this was assessed against the designs for a number of stormwater harvesting applications with the same security of supply to irrigate a sportsfield, storage volumes were found to vary up to 250%. In the second phase of the study, continuous flow and rainfall data was collected at a further four sites, including a largely undeveloped or reference catchment. The results of which are presented in this paper.

## Method

Runoff coefficients were derived through gauging the pipe or stream flow across four catchments coupled with catchment specific rainfall data. The urban catchments included Blackbutt Creek, The Glade and Lofberg Creek and Treefern Gully as the reference catchment. Imperviousness and connected imperviousness percentages were assessed for each catchment. This data was used to calibrate two different computer models for the monitoring period. Following this, ten years of rainfall data was used to estimate the longer term AVRC.

## Gauged data

### Rainfall data

Rainfall data was collected within each catchment. For Treefern Gully, The Glade and Lofberg Creek this was collected by Manly Hydraulics Laboratory as part of the flow gauging, while data for Blackbutt Creek was collected using Council's own rain gauge also located within the catchment. At all sites Hydrological Services 0.5mm tipping bucket rain gauges were used with data provided in 1-minute time steps. All gauging equipment was calibrated on installation.

### Flow gauging

Sampling of stormwater flow across the four sites was carried out from the 12 May 2007 to the 13 September 2007 by Manly Hydraulics Laboratory. Flow was calculated using Hydromace HVFlo Doppler velocity meter/level sensors with all equipment calibrated at the time of installation.

Where possible, stormwater flow was calculated using two methods, Continuity and Rating. Both methods rely on field calibration to improve the level of accuracy and confidence. As noted in Table 1 there are differences in both values of peak flow and total runoff volume between the methods. This is especially significant for The Glade. While Manly Hydraulics Laboratory has recommended the rating method as the preferred method for all sites, it is important to note that there remains some degree of uncertainty to the results.

**Table 1. Summary of the stormwater flow and rainfall gauging results**

| Site | Monitoring period | Total rainfall (mm) | Method of calculating flow | Total runoff volume ($m^3$) | Maximum peakflow ($m^3/s$) |
|---|---|---|---|---|---|
| Lofberg Quarry Creek | 12/05/2007–13/09/2007 | 661.0 | RATING<br>CONTINUITY | 325,747<br>273,588 | 3.43<br>1.78 |
| Blackbutt Creek | 12/05/2007–13/09/2007 | 693.5 | RATING<br>CONTINUITY | 68,056<br>N/A | 0.46<br>N/A |
| The Glade Creek | 12/05/2007–13/09/2007 | 598.0 | RATING<br>CONTINUITY | 52,352<br>110,237 | 0.10<br>0.27 |
| Treefern Gully | 12/05/2007–13/09/2007 | 632.0 | RATING<br>CONTINUITY | 433,553<br>385,258 | 4.36<br>4.50 |

## Catchments assessment

A detailed assessment was carried out to determine the total imperviousness and connected imperviousness within each catchment. Using council's Geographic Information System (GIS) the catchment area upstream of the flow gauge was assessed against three types of land uses: detached residential housing; other hard surfaces (such as car parks, office buildings and apartment blocks); and roads. From this, an assessment was made as to whether the area was connected to a drainage system or otherwise performed hydraulically similar as a result of the urban landscape (Table 2). This method was similar to that used by Walsh *et al* (2002) for studies in Melbourne.

### Detached residential housing

Each residential lot was identified using information from Council's GIS system. Aerial photos were assessed in detail to identify any vacant lots or neighbourhood parks so as not to overestimate the number of residential lots. As the size of residential lots and buildings varies throughout the LGA, an average residential hardstand area was calculated for each catchment using between 40 to 90 random sample of lots within each catchment. The total area of impervious surface for each lot (i.e. residential houses, awnings, paved areas etc.) was determined from shape files drawn as a separate GIS layer. This was averaged and multiplied by the number of lots for each catchment.

### Roads

Centrelines of all roads within each catchment were marked as polylines. Roads were then further divided into residential roads or arterial roads. An average road width was calculated for residential roads and this was multiplied by the total length of residential roads in the catchment. For arterial roads (being more variable), the average width and length for each individual road was calculated using aerial photographs.

### Other hard surfaces

All other hard surfaces not classified as detached residential houses or roads were individually mapped and classified as discrete polygons.

### Connected impervious area

In the 2002 study by Walsh *et al* the connected impervious area was determined where a site had a drainage system that discharged directly into a receiving stream or water-body. In addition, where the discharge was into a dry earthen or grassed channels or to unchannelized dry land and the overland flow distance to stream was along a high-slope path (defined as ≥ 4%) it was also considered connected.

While 40% of roads within the Ku-ring-gai LGA do not have formal kerb and gutter, all residential areas in the LGA have a formal stormwater drainage system. Roads without gutters drain to stormwater inlet pits through roadside swales comprised of compacted road base or in some cases grass. In most situations these do not provide any significant infiltration or flow attenuation. As most residential areas are located on ridge tops, the piped drainage systems do not necessarily discharge directly into the receiving stream but in most cases into unformed earthen channels with many having grades in excess of 25%. For these reasons and following the method by Walsh *et al* (2002), the majority of impervious surfaces are considered connected.

The same method was used to calculate connected imperviousness in the reference catchment.

**Table 2. Summary of catchment characteristics**

| Catchment | Total area (ha) | % Impervious | % Connected imperviousness | % Roads | % Other impervious areas | % Hardstand and roofs |
|---|---|---|---|---|---|---|
| Blackbutt Creek | 14.05 | 47.60 | 47.60 | 6.90 | 23.00 | 17.80 |
| Quarry Creek | 87.44 | 34.10 | 34.10 | 9.50 | 4.30 | 20.20 |
| The Glade (Coups Creek) | 20.93 | 35.70 | 35.70 | 4.90 | 17.90 | 12.90 |
| Treefern Gully (*) | 108.19 | 8.80 | 3.60 | 5.70 | 2.80 | 0.20 |

* Reference catchment

## Computer modelling

### MUSIC Modelling

A MUSIC model was developed for each of the catchments. These were calibrated using the flow gauging from this study to derive total runoff volume and peak flows. Once a good correlation between gauged data and modelling output was achieved the modelling input was recorded (Table 3). All models were run using 6-minute time steps. Once a model had been calibrated it was run using 6-minute rainfall from the years 1961–1971 from a local Bureau of Meteorology site (BoM Wahroonga Reservoir site 66063) to estimate the long term AVRC.

**Table 3. MUSIC model input (Calibrated models)**

| **Catchment** | **Catchment area (ha)** | **% Connected imperviousness** | **Connected imperviousness in MUSIC (%)** | **Impervious rainfall threshold (mm/day)** | **Pervious area soil storage capacity (mm)** |
|---|---|---|---|---|---|
| Treefern Gully | 108.19 | 3.6% | 4.0% | 1 | 120 |
| The Glade | 20.93 | 35.7% | 11.0% | 1 | 300 |
| Lofberg | 87.44 | 34.1% | 34.0% | 1 | 300 |
| Blackbutt | 14.05 | 47.6% | 34.0% | 1 | 300 |
| Catchment | Initial storage (%) | **Field capacity (mm)** | **Infiltration capacity coefficient a** | **Infiltration capacity exponent b** | **Initial groundwater depth (mm)** |
| Treefern Gully | 30 | 80 | 200 | 1 | 10 |
| The Glade | 30 | 80 | 200 | 1 | 10 |
| Lofberg | 30 | 80 | 200 | 1 | 10 |
| Blackbutt | 30 | 80 | 200 | 1 | 10 |
| **Catchment** | **Daily Groundwater recharge rate** (%) | **Daily Groundwater baseflow rate** (%) | **Daily Groundwater deep seepage rate** (%) | **Muskingum-Cunge routing K (min)** | **Muskingum-Cunge routing Theta** |
| Treefern Gully | 50 | 25 | 5 | 120 | 0.25 |
| The Glade | 50 | 40 | 29 | 10 | 0.25 |
| Lofberg | 50 | 50 | 30 | 20 | 0.25 |
| Blackbutt | 50 | 50 | 15 | 12 | 0.25 |

It should be noted that for two of the models, Blackbutt Creek and The Glade (Coupes Creek) the impervious area had to be reduced by 13.6% and 24.7% respectively to limit excessive runoff volumes and peak flows.

### Spreadsheet modelling

An in-house water balance model was also used to assess runoff to allow calculation of AVRC. The model uses a daily time step and was calibrated against the flow gauging data. As the model does not incorporate interaction with groundwater (i.e. it does not allow re-enter of infiltrated water to the drainage system further down the catchment) a constant base flow similar to that identified from the gauged values was added to the runoff model. The input into the spreadsheet models is presented in Table 4. Once a spreadsheet model had been calibrated it was also run using local daily rainfall from the years 1961–1971 from Wahroonga Reservoir rain gauge.

**Table 4. Spreadsheet modelling input**

| | Catchment | | | |
|---|---|---|---|---|
| | Treefern Gully Creek | The Glade | Lofberg Creek | Blackbutt Creek |
| Impervious area (ha) | 3.89 | 7.47 | 29.82 | 6.69 |
| Pervious area, non irrigated (ha) | 104.30 | 13.46 | 57.62 | 7.36 |
| Initial loss, imp. areas (mm) | 1 | 1 | 1 | 1 |
| Baseflow (L/s) | 7.5 | 1 | 2 | 2 |
| Pervious area soil percolation (mm/day) | 10 | 10 | 5 | 9 |
| Soil storage capacity (mm) | 100 | 300 | 200 | 300 |
| Field capacity FC (mm) | 90 | 80 | 80 | 80 |
| Evaporation for pervious areas, as % of daily pan evaporation | 100 | 100 | 100 | 100 |

## Results

## Model calibration

### MUSIC Modelling

A comparison of the output from the MUSIC modelling compared with gauged data is presented in Figure 1 (accumulated volume of runoff has been shown for clarity). The calibrated MUSIC models demonstrates a similar flow pattern to that obtained through gauging, the main difference being a higher base-flow present in the gauged data than that modelled in MUSIC.

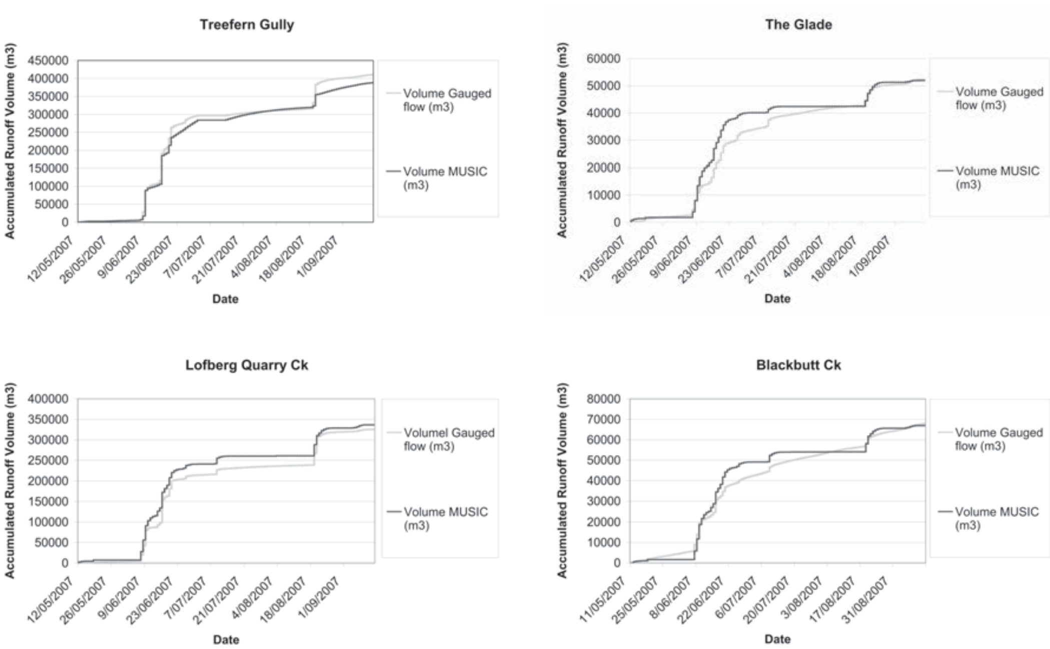


**Figure 1. Comparison of gauged data and MUSIC output expressed as accumulated runoff volumes ($m^3$)**

Base flow was identified as flow that is largely independent of recent rainfall with the assumption that flow in excess of the threshold value is stormwater surface runoff. The impact of baseflow on overall flow volumes was assessed by discounting flows under a determined threshold value for both gauged flow data and from MUSIC modelling results (Table 5). It was found that baseflow was especially significant for Blackbutt Creek where this accounted for a relatively large fraction of the total flow volume. For all catchments the majority of the volume of runoff is generated during storm events, as shown in Table 5.

**Table 5. Comparison of MUSIC modelling output with gauged data**

| | **Catchment** | | | |
|---|---|---|---|---|
| | Treefern Gully | The Glade | Lofberg Quarry Ck | Blackbutt Ck |
| **Runoff volumes all data ($m^3$)** | | | | |
| MUSIC model (calibrated) | 388,558 | 51,931 | 336,493 | 66,946 |
| Gauging | 410,572 | 52,352 | 325,747 | 68,056 |
| Difference | –5.67% | –0.81% | 3.19% | –1.66% |
| **Peakflow ($m^3/s$)** | | | | |
| MUSIC model (calibrated) | 4.97 | 0.20 | 3.39 | 0.53 |
| Gauging | 4.36 | 0.10 | 3.43 | 0.46 |
| Difference | 12.23% | 50.45% | –1.19% | 12.77% |
| Baseflow (L/s) | 7.50 | 1.00 | 2.00 | 2.00 |
| **Runoff volumes baseflow discounted** | | | | |
| MUSIC model (calibrated) | 329,169 | 47,981 | 328,552 | 59,818 |
| Gauging | 355,057 | 42,969 | 305,255 | 46,952 |
| Difference | –7.86% | 10.45% | 7.09% | 21.51% |
| **Peakflow ($m^3/s$)** | | | | |
| MUSIC model (calibrated) | 4.96 | 0.20 | 3.39 | 0.52 |
| Gauging | 4.35 | 0.10 | 3.43 | 0.46 |
| Difference | 12.25% | 50.20% | –1.19% | 12.82% |
| % of total flow as baseflow | **13.52%** | **17.92%** | **6.29%** | **31.01%** |

## Water balance spreadsheet model

The results from the Excel based water balance models are compared with gauged data in Figure 2 (also presented as accumulated runoff volume). As shown, the calibrated models demonstrates a similar runoff generation as the gauged data. Total runoff volumes from the calibrated spreadsheet models, including assessment of impact by baseflow, are presented in Table 6.

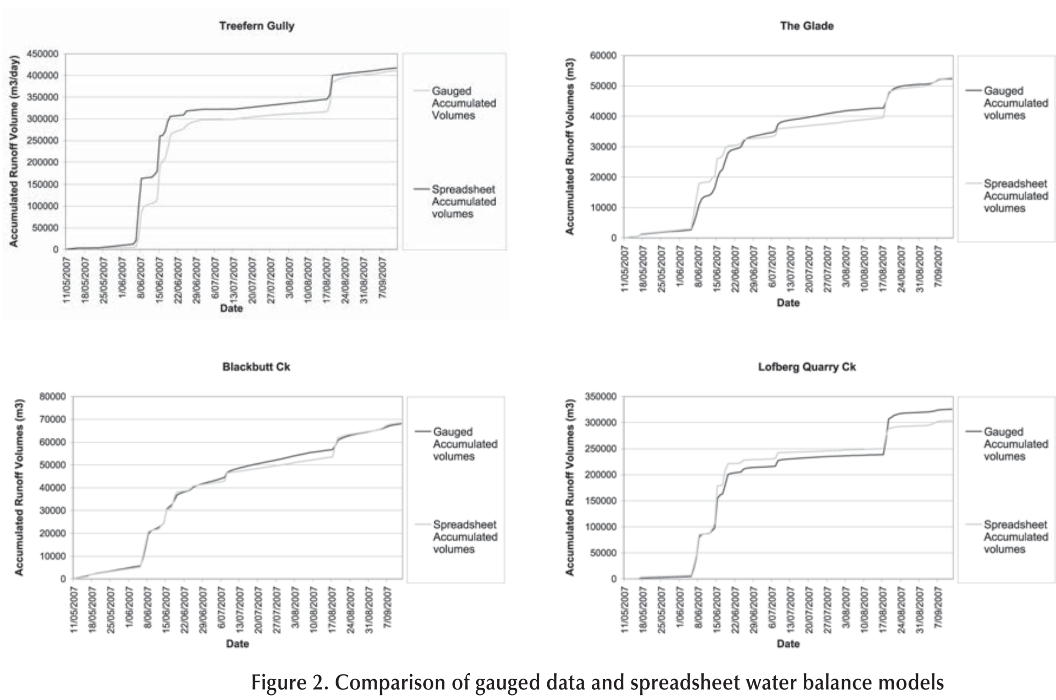


**Figure 2. Comparison of gauged data and spreadsheet water balance models**

**Table 6. Water balance spreadsheet modelling results compared to gauged data**

| | Catchment | | | |
|---|---|---|---|---|
| | **Treefern Gully** | **The Glade** | **Lofberg Quarry Ck** | **Blackbutt Ck** |
| **Total Runoff Volumes (m³)** | | | | |
| Gauging | 410,572 | 52,352 | 325,747 | 68,056 |
| Spreadsheet model total (calibrated) | 417,447 | 52,718 | 303,560 | 68,582 |
| Impervious surface runoff (m³) | 22,737 | 41,918 | 186,226 | 44,151 |
| Pervious surface runoff (m³) | 325,374 | 0.00 | 95,735 | 2,861 |
| (Baseflow runoff (m³)) | 69,336 | 10,800 | 21,600 | 21,600 |
| Difference total flows | 1.67% | 0.70% | –6.81% | 0.77% |
| % of total runoff from impervious surfaces | 5.45% | 79.51% | 61.35% | 64.38% |
| % of total runoff from pervious surfaces | 77.94% | 0.00% | 31.54% | 4.17% |
| % of total runoff from baseflow | 16.61% | 20.49% | 7.12% | 31.50% |

## Calculating average annual volumetric runoff coefficients

After both models were calibrated, VRC for the period May – September 2007 and AVRC for the period 1961 – 1971 were calculated (Table 7). It should be noted that AVRC's were calculated for each individual year and the average was calculated as an average of the individual AVRC rather than on the runoff volume for the whole time period.

**Table 7. Average Annual Volumetric Runoff Coefficients as calculated**

| | Catchment | | | |
|---|---|---|---|---|
| | Treefern Gully | The Glade | Lofberg Quarry Ck | Blackbutt Ck |
| **Gauges data** (13/05/07–13/09/07) | 0.63 | 0.42 | 0.56 | 0.70 |
| **MUSIC Model** (13/05/07–13/09/07) | 0.57 | 0.41 | 0.58 | 0.69 |
| **Water balance spreadsheet model** (13/05/07–13/09/07) | | | | |
| Including baseflow in total runoff volume | 0.61 | 0.42 | 0.53 | 0.70 |
| Excluding baseflow in total runoff volume | 0.51 | 0.33 | 0.49 | 0.48 |
| | | | | |
| **MUSIC Model** (08/01/61–01/01/71) | 0.26 | 0.28 | 0.45 | 0.51 |
| **Water balance spreadsheet model** (08/01/61–01/01/71) | | | | |
| Including baseflow in total runoff volume | 0.41 | 0.47 | 0.41 | 0.85 |
| Excluding baseflow in total runoff volume | 0.21 | 0.33 | 0.34 | 0.44 |

## Assessing existing models against AVRC

A total of five MUSIC models that have been supplied to Council from consultants for various projects were assessed using the rainfall data from the years 1961–1971 from Wahroonga Reservoir (Bureau Of Meteorology Site 66063). Some of the models included the same catchments for which flow gauging have been carried out. It was found that for urban or developed catchments the models supplied were likely to underestimate the annual average runoff volume with AVRC of between 0.2 and 0.3.

No water balance spreadsheet models have been supplied to council from consultants on the basis that it contains the intellectual property of the consultant. As such it is not possible to undertake a detailed assessment on such models. A review of spreadsheet modelling outputs from two projects assessing runoff from developed catchments within Ku-ring-gai LGA nevertheless suggests AVRC are underestimated when compared to the monitored data, being in the range of 0.27–0.32

## Discussion

### MUSIC Modelling

While MUSIC is not specifically developed for stormwater harvesting, it provides some capabilities, especially at a concept stage. It is the experience of the authors that even though spreadsheet based models are the most common modelling tool for sizing storage in stormwater harvesting design, MUSIC is often used to model parts of the harvesting systems such as off-take structures and/or pre-treatment.

Other studies have previously concluded that the hydrology of catchments with a significant portion of pervious areas are complex and that MUSIC may not be the appropriate tool for modelling runoff from such catchments (Wainwright *et al*, 2007). The findings of this study would concur as calibration of runoff from pervious surfaces was far more complex than for impervious surfaces. If detailed catchment specific information is not available, modelling of pervious areas will have greater uncertainty being dependent on many more assumptions. Modelling of impervious areas in a catchment with a high degree of connected drainage is likely to provide more reliable results using MUSIC.

In this study the interaction of subsurface flows in open channels and piped drainage appears to have a significant impact on flow behaviour especially in less developed catchments. This presents a number of challenges when attempting to calibrate outflow hydrograph from MUSIC. The calibration carried out as part of this study investigated a number of different modelling options and how this impacted on flow hydrographs, specifically attenuating peak flows and reducing overall runoff volumes. The study did not undertaken detailed field investigations of soil properties for pervious areas from the respective catchments that would be necessary if the number of assumptions was to decrease.

The hydrographs obtained through MUSIC were initially highly irregular with flow varying in excess of 1,000% between individual 6-minute time steps. Peak flows were also on the whole considerable higher than the results from the flow gauging. In order to produce smoother and more realistic hydrographs consistent with the flow gauging results, Muskingum-Cunge routing was included in the model links. Calibration was carried out to evaluate how changing the routing parameters, K and Theta, impacted the hydrograph. K is equivalent to a translation time while Theta measures the relative effect of inflow and outflow on the behaviour in a reach (CRCCH, 2005). It was found that using a K similar to the estimated Time of Concentration for the catchment and Theta of 0.25 (default in MUSIC) produced modelling outcomes similar to the flow gauging, with a longer K resulting in reduced peak flows. It was found that similarities in the timing of hydrographs from the gauging compared to those obtained through MUSIC increased when routing was included in the model.

When modelling pervious areas as part of this study, the deep seepage rate was found to be sensitive in terms of overall runoff volume as this is the only means of loosing water from the model except for evaporation. Groundwater recharge and baseflow rates were important in seeking to replicate the gauged hydrographs that showed continuing but declining flows following large rainfall events.

As previously noted, the impervious areas for Blackbutt Creek and The Glade (Coupes Creek) catchment had to be reduced in the MUSIC and spreadsheet water balance models to align with runoff volumes and peak flows as monitored. This concurs with the findings of the first study undertaken in Ku-ring-gai (Jonasson and Davies, 2007), in which the total imperviousness of the catchment also had to be reduced using MUSIC to obtain a good correlation between modelled flow behaviour and gauged data. However this was not the case for all catchment in this study, supporting the importance of obtaining local data. While the reduction of impervious surfaces in MUSIC resulted in a better correlation with the gauged data it may be that uncertainties in the gauged data could also account for the difference.

### Water balance spreadsheet modelling

While there is some limited scope to model ground water seepage in daily time-step water balance models, this variable is rarely included. When calibrating the model against gauged data, the inclusion of base-flow lead to a good correlation between model behaviour and that observed in the field. However, as the developed catchments in this study are relatively small (less than 90 ha), the baseflow is likely to cease after some time with no rain. It should also be noted that while a portion of groundwater will provide baseflow in open channels in less developed catchments, baseflow in highly developed and pervious catchments with piped drainage is often the result of anthropogenic activities (such as leaking pipes and watering). No attempt was made as part of this study to identify the origin of baseflow as reported by the gauging.

Irrespective of the fact that baseflow may not be available for harvesting for environmental reasons, its inclusion in spread sheet modelling as part of stormwater design should be used with caution as it may overestimate the harvestable water.

### Runoff coefficients

Good correlation for the VRC was obtained for both MUSIC models and water balance spreadsheet models when compared to gauged data. The inclusion of baseflow in the spreadsheet model increased the overall VRC with between 0.04 and 0.22.

The AVRC obtained for developed catchments range between 0.28 for The Glade catchment and 0.51 for Blackbutt Creek catchment (not including results from spreadsheet models that considered baseflow). Adopting the equation described by (Fletcher *et al*, 2004), a catchment with approximately 35% connected impervious area and an annual mean rainfall of 1,177mm would have an AVRC of 0.49 (+/– 0.1). A catchment with approximately 4% connected impervious area would have an AVRC of 0.30 (+/– 0.1). As can bee seen from Table 7, these values are generally within this range. The Glade is the exception and produced AVRC's slightly lower than those expected, though as noted earlier this may be a consequence of the difficulties in measuring the flow from this catchment.

Treefern Gully, the largely undeveloped catchment, generated one of the highest VRC using the data from May to September 2007, contrary to what would be expected. This may be due to the rocky and steep nature of this catchment. When models were run for the ten year period from 1961 to 1971, the AVRC for Treefern Gully was lower than those for the developed catchments, as expected. For all catchments the AVRC for the period 1961–1971 from both MUSIC and the spreadsheet model was lower than for May–September 07. This would indicate that the period for which gauging was carried out was wet in comparison with annual averages.

The inclusion of baseflow in the spreadsheet models had a greater impact on the AVRC for the period 1961–1971 than for the period May – August 2007, increasing it with between 0.07 and 0.41.

### Impact on stormwater harvesting design

While AVRC will not be used directly for designing stormwater harvesting systems, it is a helpful tool to assess the validity of models used in the design process. As discussed, un-calibrated models may underestimate the total runoff volumes from a specific catchment, resulting in treatment measures not appropriately sized in turn compromising the long term viability of the system.

## Conclusion

In this study locally specific monitoring data was used to develop approximate AVRC for different land uses across the Ku-ring-gai Council local government area. The study found a relatively good correlation between the gauged data and modelling outputs from MUSIC and other water balance spreadsheet models. Longer term AVRC was also shown to be largely consistent with expected AVRC for the land uses assessed.

The study concurred with previous studies in that MUSIC may not be the most appropriate model to use when modelling hydrological behaviour of largely pervious catchments where little or no site-specific data is available due to the more complex hydrology in these catchments. It also confirmed that the inclusion of baseflow as part of a daily time step water balance spreadsheet models might overestimate the volumes of stormwater available.

The results from the study were inconclusive in relation to the need to adjust the connected impervious fraction as measured in the field when modelling surface runoff. While two of the catchment required the impervious surface to be reduced in the model in order to limit runoff volumes and peak flows, two did not. More investigation as to the reasons for this variation is required.

By obtaining locally relevant data, Ku-ring-gai Council has developed approximate AVRC that can be used to verify modelling results and obtain a higher degree of confidence in modelling output. For stormwater harvesting applications, this will allow more accurate modelling and in-turn improve the efficiency of new systems.

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paper seventeen

# Stormwater reuse: can health risks be adequately managed without disinfection?

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Poster Presentations
Lens: Stormwater Harvesting

# Stormwater Reuse: Can Health Risks Be Adequately Managed Without Disinfection?

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## Introduction

The recent drought conditions affecting much of Eastern Australia has increased public and industry awareness for the importance of integrated urban water management. Stormwater reuse for open space irrigation is being promoted as one way to reduce demand on potable water supplies and also lessen the impact on downstream riparian environments. Balancing these benefits is the need to ensure public health concerns and consequent liability is incorporated within the design and operation of the systems.

Ku-ring-gai Council is located 14 kilometres north of the Sydney CBD. It has adopted an integrated water management policy and accompanying works program that will construct 12 stormwater harvesting systems at local sports fields and public parks over an eight year period. Four of these systems have been constructed and are operational.

Informing the design criteria for stormwater reuse schemes has been various guidelines related to water sensitive urban design and water quality targets with a particular focus on public health risks. The Australian and New Zealand Environment and Conservation Council (ANZECC) 2000 have set guideline values for water quality that focus on health risks that relate to recreation contact with open water bodies, usually primary or secondary contact. These guidelines are used for the NSW Beachwatch and Harbourwatch programs as well as other local monitoring regimes on open water bodies. In some cases water quality targets have been based directly on the risk exposure associated with the use of sewerage or wastewater, where the probability and consequence of water borne disease can be catastrophic. In 2006 the Department of Environment and Conservation released its position with a specific focus on the health risks from stormwater harvesting and reuse schemes. More recently, the Commonwealth Government released draft guidelines in 2008 for water recycling that also has a specific focus on stormwater harvesting and reuse. The draft national guideline has recognised that health risks can be adequately managed by minimising exposure to the water through controlled access to storage and the irrigated area, even where spray irrigation is utilised in public open space. Both the NSW and Commonwealth re-use guidelines strongly advocate disinfection via chemical or ultraviolet radiation (UV) treatments as a means of achieving the appropriate standard.

Consistent across each of the guidelines mentioned above is the use of the counts of faecal coliform, particularly Escherichia coli (*E-coli*) bacteria as an indicator of the suitability of water for reuse. Table 1 provides a summary of the value for faecal coliforms/*E-coli* for each of the three guidelines. Depending on the source and intended use of the water, more detailed sampling and limits can be set reflecting public health risks. These can involve sampling for and managing exposure to faecal streptococci, viruses, protozoa and helminths (parasitic worms). In general the levels of indicator bacteria (such as *E-coli*) are used as the primary means to identify the presence and significance of other potentially harmful organisms in water. From a stormwater perspective, high levels of contamination are most often attributed to leaks and illegal connections from the sewerage system.

The presence of faecal coliforms in stormwater runoff has previously been described in a number of studies and exhibits significant variability over location and time. Duncan (1999) found more than six orders of magnitude difference in coliform forming units (cfu) per 100mL across various urban land use types. While this data represents contamination from runoff there is little information on faecal coliform contamination in fully operational stormwater harvesting systems in Australia and specifically the levels of contamination at the time of irrigation, not simply wet weather inflow. This data gap and knowledge of the decay in faecal coliform levels under certain conditions has lead to an examination of this issue in relation to the actual public health risks and in turn appropriate treatment for stormwater harvesting schemes within the Ku-ring-gai local government area.

During 2008, Ku-ring-gai Council sampled faecal coliform levels from two stormwater harvesting systems in order to evaluate changes in contamination as a result of inflow / rainfall and time-in-storage. This paper presents the results of this sampling and discusses the implications for the design and management of public health risks as part of stormwater harvesting schemes.

Edenborough stormwater harvesting system is located at Edenborough Oval in Lindfield (329828.64; 6260353.46). This system captures stormwater from a 2.8 hectare catchment, which is diverted from street drainage through a litter screen to a gravity (passive) sand filter. Filtered water is piped to two 155kL above ground covered concrete storage tanks. Edenborough oval is used for soccer in winter, cricket in summer and is one of Council's 'dog off-leash' areas.

The Barra Brui stormwater harvesting system is located at Barra Brui Oval in St Ives (330274.39; 6264786.78). The upstream catchment is approximately 16 hectares and the system consists of a settling pond/ephemeral wetland that serves as a treatment and extended detention system. During rainfall events water is diverted to an underground tank with 250kL storage capacity. Barra Brui oval hosts soccer and rugby in the winter months, cricket in the summer months and is also one of Ku-ring-gai Council's 'dog off-leash' areas.

Throughout the year there is high demand for these two sportsfields. This results in excessive stress on the playing surface, particularly during times of low rainfall. To assist in the operational management, stormwater irrigation systems were installed as potable water is limited due to the current water restrictions. From a sportsfield perspective, these schemes have improved the playing surface, offered greater safety to players though avoiding dry and hard surfaces and have eliminated the need to rely on potable water.

**Table 1. Summary of water quality guideline values for faecal coliforms/** *E-coli*

| | | **Contact Level** | **Guideline Value Faecal coliform units per 100mL (or otherwise stated)** | **Sample Frequency** |
|---|---|---|---|---|
| Australian Guidelines for Water Recycling (Draft 2008) | Option 1A | Municipal use – open spaces, sports grounds, golf courses, dust suppression (unrestricted access) OR Irrigation of non-food crops | <10 | Weekly |
| | Option 1B | Municipal use, with restricted access and application | Not applicable | N/A |
| | Option 1C | Municipal use, with drip irrigation | Not applicable | N/A |
| | Option 2 | Dual reticulation with indoor and outdoor use OR Irrigation of commercial food crops | <1 | Weekly |
| NSW Managing urban stormwater Harvesting and re-use (2006) † | Level 1 | Reticulated non-potable residential uses (such as garden watering, toilet flushing, car washing) | <1 | 5 days/ week |
| | Level 2 | Spray or drip irrigation of open spaces, parks and sports grounds (no access controls)<br>Industrial uses – dust suppression, construction site use (human exposure possible)<br>Ornamental water bodies (no access controls)<br>Fire-fighting | <10 | Weekly |
| | Level 3 | Spray or drip irrigation (controlled access) or subsurface irrigation of open spaces, parks and sports grounds<br>Industrial uses – dust suppression, construction site use, process water (no human exposure)<br>Ornamental water bodies (access controls) | <1000 | weekly |
| ANZECC (2000) | Primary | Primary contact recreation* eg. swimming | Median of 150 (second highest sample containing less than 600 organisms/100mL) | Minimum of 5 samples taken at regular intervals not exceeding one month. |
| | Secondary | Secondary contact recreation such as boating and fishing | Median of 1000 (second highest sample containing less than 4000 organisms/100mL) | Minimum of 5 samples taken at regular intervals not exceeding one month. |

* Guideline used by NSW Beachwatch program. † Guide for median over a year of sampling, however trigger values should be set to alleviate any problems during the collection period. Trigger should be 50% above the guideline value.

## Methods

A grab sample was collected from each stormwater storage tank three times per week over a ten week period. The first sample was collected in September 2008 and the last sample taken in November 2008. These samples were analysed for *E-coli* using membrane filtration (AS 4276.7 – 2007) at a NATA accredited laboratory. Sampling was conducted on scheduled days regardless of rain.

Daily rainfall data from Terry Hills (located approximately 10km north-east of Ku-ring-gai Council) was used to compare *E-coli* levels with rainfall events in each of the systems. This data was sourced from the Bureau of Meteorology where daily rainfall is provided as the total rainfall up to 9am. As samples were consistently collected in the late morning/afternoon of the sample day the rainfall data for the following day was used for comparison with the *E-coli* data.

Results were analysed to determine the die-off rates of the *E-coli* in each system. Two approaches were used to determine the pattern and significance of the *E-coli* die-off within the stormwater harvesting storage system. The first involved a comparison of the measured *E-coli* concentrations against each of the three guidelines (Table 1). The second approach examined the *E-coli* die-off pattern whilst stormwater is in storage. Peak *E-coli* concentrations were used as a series of events from which die-off rates were estimated. A 'peak' in the *E-coli* results was considered as an occasion where the amount of *E-coli* detected increased suddenly between sample occasions.

## Results

Figure 1 compares *E-coli* levels with rainfall. This shows a strong relationship between *E-coli* and rainfall for both harvesting systems. Between the stormwater systems *E-coli* levels were generally greater at Barra Brui than Edenborough. The median *E-coli* levels at Edenborough over the study period were 10 *E-coli*/100ml and at Barra Brui it was 195 *E-coli*/100ml. This difference is also demonstrated in Figure 1.

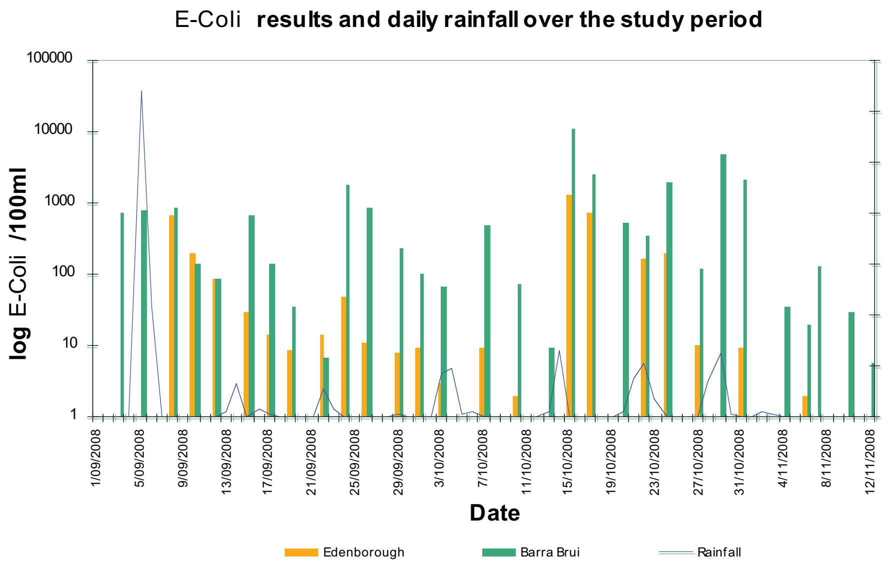
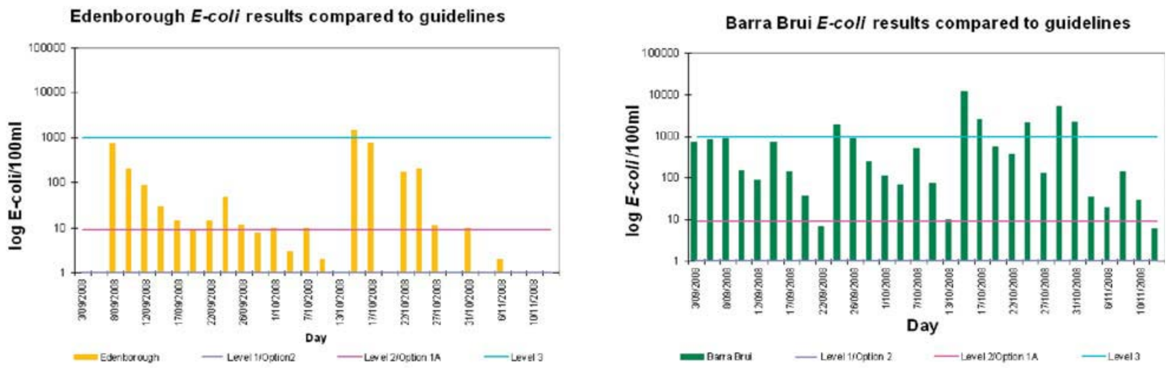



**Figure 1.** *E-coli* **results in comparison to rainfall over the sample period**

Figures 2 a) and b) provide a comparison of the *E-coli* results from this study to the draft National (2008) and NSW (2006) guidelines, noting however that both guidelines require compliance against a median value based on 12 months of monitoring. Both systems report *E-coli* levels higher than Level 2 for the NSW standard and Option 1A for the draft National Standard for the majority of time in absolute terms. Decay in *E-coli* falls close to or below these respective thresholds on a number of occasions as time from the rain event increases.




a) b)

**Figure 2. a) Edenborough and b) Barra Brui results in comparison to the draft National (2008) (Option 1A, Option 2) and NSW (2006) (Level 1, Level 2, Level 3) stormwater harvesting and re-use guideline levels.**

Table 2 provides the median values over the study period and for each individual month. The median value did not reach NSW (2006) guideline for stormwater harvesting and reuse level 3 *controlled access* during irrigation for either system. However, Edenborough is sitting on the threshold. The NSW (2006) guidelines also suggest a 'trigger value' of 50% above the desired level of compliance should be used to action any potential breaches and problems during the sample period. Table 2 reports the number of times each system reached this trigger value for the NSW level 2 and level 3 guideline. As shown, the sampling for Edenborough does not, reach the level 3 guideline trigger value, however it does reach the level 2 trigger on nine occasions. Barra Brui does not perform as well, reporting six occasions where the Level 3 trigger was reached and 27 (out of 30) occasions where the level 2 trigger was reached.

**Table 2. Median results (*E-coli*/100ml) and trigger value* occurrences (number) for each month of sampling and the total study period at Edenborough (Eden) and Barra Brui (Barra).**

| | September | | | October | | | November† | | | Total Study | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *E-coli* | Trigger 2 | Trigger 3 | *E-coli* | Trigger 2 | Trigger 3 | *E-coli* | Trigger 2 | Trigger 3 | *E-coli* | Trigger 2 | Trigger 3 |
| Eden | 15 | 5 | 0 | 10 | 4 | 0 | 0 | 0 | 0 | 10 | 9 | 0 |
| Barra | 480 | 11 | 1 | 490 | 12 | 5 | 30 | 4 | 0 | 195 | 27 | 6 |

* Trigger values (Refer to Table 1) for NSW (2006) level 2 (15 *E-coli*/100ml) and Level 3 (1500 *E-coli*/100ml) guidelines were used.

† November is only represented by a half month of samples.

Results from the monitoring were also compared to the ANZECC (2000) guideline for recreation and aesthetics. This guideline requires at least five samples, evenly spread over the investigation period. Data was split to ensure that both example a and b from September and October represented a full month of readings. For example the September samples (dates 3, 5, 8, 10, 12, 15, 17, 19, 22, 24, 26 and 29) were split into two groups a (5, 10, 15, 19, 24 & 29) and b (3, 8, 12, 17, 22 & 26) to replicate the guideline sampling procedure whilst providing a repeat.

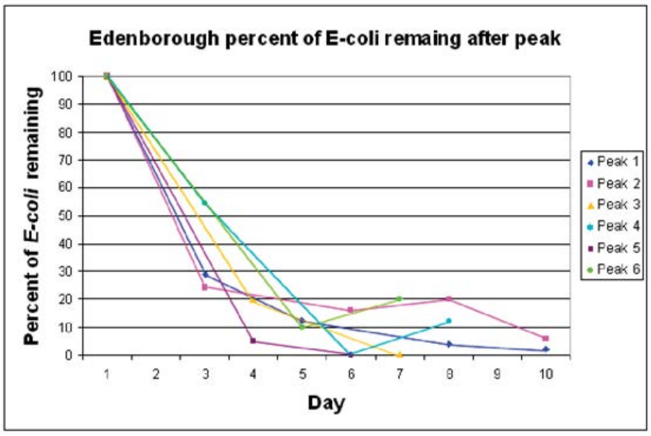
As shown by the data in Table 3 all the results for Edenborough met the guideline for primary recreation, i.e. it is considered suitable for swimming (though noting this is an oval not a lake). Barra Brui results generally comply with the secondary contact recreation values (acceptable for fishing and boating) the majority of the time. However, there was one occasion where the guidelines were no adhered to.

**Table 3. Comparison of Edenborough and Barra Brui *E-coli* results with ANZECC recreation guidelines.**

| | Edenborough | | | | | Barra Brui | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Sept a | Sept b | Oct a | Oct b | Nov | Sept a | Sept b | Oct a | Oct b | Nov |
| Median | 19.5 | 15 | 10 | 2.5 | 0 | 447.5 | 480 | 380 | 1320 | 30 |
| Second highest | 50 | 90 | 170 | 210 | 1 | 880 | 830 | 2200 | 5200 | 36 |
| Recreation guideline met | P | P | P | P | P | S | P | P | N | P |

ANZECC guideline levels: P—primary (swimming); S—secondary (boating and fishing);
N—Non-compliant (beyond ANZECC recommended guidelines for any recreation activities).

Figures 3 a) and b) report the percentage of die-off of *E-coli* from each peak that occurred within the tanks during the sampling. Six peak events were identified for Edenborough and eight were identified for Barra Brui. It should be noted that the rainfall data is based on daily records while *E-coli* levels were collected only three times per week. The results reported the smallest increase between events of 23% while the greatest increase between events was almost 1200%. Die-off rate is represented as the percentage difference between the peak sample concentration and the next sample taken. As shown by the graphs, there is generally a rapid decline in the levels of *E-coli* over the first 3–5 days, between 50–90% reductions. After five days, *E-coli* levels tend to stabilise or die-off at a much slower rate.




a)

b)

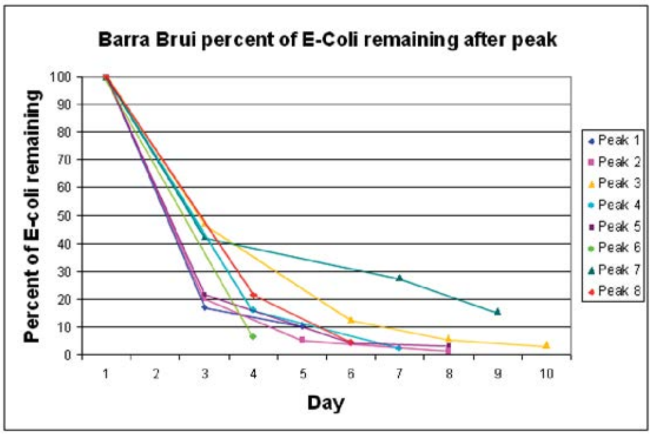
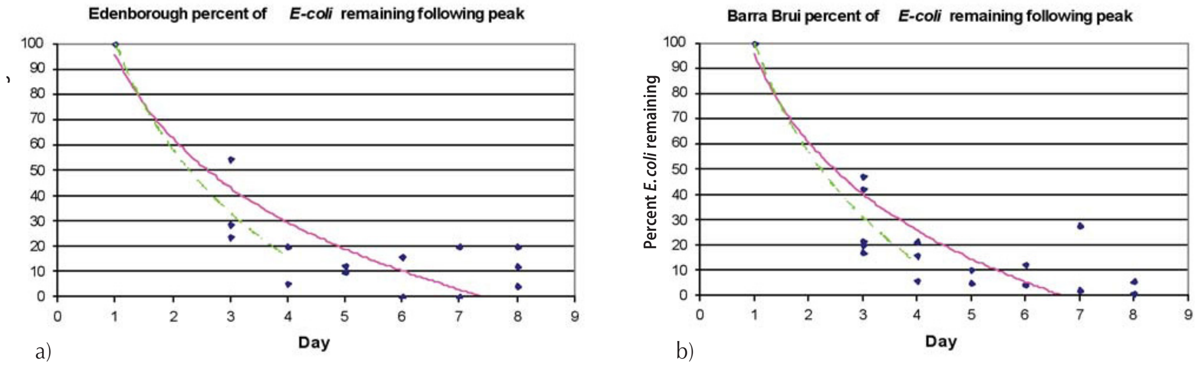



**Figure 3. Percent of *E-coli* remaining from peak events for a) Edenborough and b) Barra Brui Systems**

To further understand the pattern of die-off, Figures 4 a) and b) show the percent of *E-coli* remaining for each system with two different trend lines: from the peak to day four and the peak to day eight. This was designed to take into account the 'predicted' trend for the whole system and the trend for the initial rapid die-off that occurred. Table 4 shows the equations and $R^2$ value for these trend lines which shows that during the first four days the $R^2$ value was 0.9578 for Edenborough and 0.9623 for Barra Brui. Another point of interest for days one to four is the similarity in the equations for Edenborough and Barra Brui, which indicate that a similar pattern of die-off is occurring over this period. The $R^2$ values for the period from day one to eight were also strong 0.9104 (Edenborough) and 0.9182 (Barra Brui). Again the equations are also similar though not as strong suggesting slightly more variation in longer term die-off predictions.




a) b)

**Figure 4. Trend lines for Percent of *E-coli* remaining in a) Edenborough and b) Barra Brui Systems. Green dash line—Logarithmic regression days one to four; solid pink line—logarithmic regression days one to eight.**

**Table 4. Equations and $R^2$ values for the curves in Figure 4 a) and b)**

| | | Days one to four | Days one to eight |
|---|---|---|---|
| **Edenborough** | Equation | y = –61.066Ln(x) + 100.26 | y = –47.576Ln(x) + 95.543 |
| | $R^2$ value | $R^2$ = 0.9578 | $R^2$ = 0.9104 |
| **Barra Brui** | Equation | y = –62.722Ln(x) + 99.841 | = –50.226Ln(x) + 95.445 |
| | $R^2$ value | $R^2$ = 0.9623 | $R^2$ = 0.9182 |

## Discussion

The study and management of stormwater harvesting systems must recognise the large variability in water quality, particularly bacterial levels. In urban environments leakages of sewage and other contamination from domestic animals within the catchment will be highly variable along with turbidity levels. Both factors can have a substantial impact on the design and operation of treatment systems. Further compounding the catchment variability is that many of Ku-ring-gai's sports ovals are used as dog off leash areas, reflecting a policy position of Council. This use places faecal matter directly onto the playing surface circumventing the best treatment endeavours.

The study has confirmed die-off patterns similar to lab-based experiment by Easton *et al.* (2005) who reported the general pattern of *E-coli* decay consisted of a rapid initial die-off followed by a slower, more gradual die-off. It also found that where the level of *E-coli* in the untreated stormwater is limited and where the water is left in storage for up to four days following rain, natural die-off rates of faecal coliforms appear to be sufficient to reduce the bacterial count to near Level 2 guideline levels (NSW). This was notable for Edenborough. Where there are higher levels of faecal coliforms entering the stormwater harvesting schemes, such as at Barra Brui, natural decay is not achieving levels of the various guidelines for irrigating an un-controlled public space.

As most sports fields managed by local councils are not used for representative competition, irrigation is would not be expected to occur directly following a rainfall event sufficient to generate runoff. When developing strategies to manage health risks associated with stormwater harvesting systems, the initial rapid die-off rates of *E-coli* should to considered and included into the design, management and operation of the irrigation system. This could take the form of not permitting irrigation with reused stormwater for at least four days following a rainfall event over a certain amount. Such protocols, and with the appropriate catchment conditions, may reduce the need for additional treatment such as disinfection using UV.

For example, historic and anecdotal evidence on irrigation demands across sportsfields within the Ku-ring-gai LGA point towards that on average a field would receive approximately 10mm of irrigation every seven days in spring and autumn (as represented by the sampling period) assuming no rainfall. In reality however, many fields within Ku-ring-gai with automatic irrigation are set to irrigate the fields on a pre-determined day of the week, subject to water restrictions. This approach does not have the capability to take into account actual rainfall, and if not manually overridden the irrigation system may be activated during or shortly after rain with no or adverse benefit to the turf. This 'business as usual' irrigation pattern with 10mm of irrigation on Mondays has been modelled for the study period as shown in Figure 5 (red).

An irrigation regime that takes rainfall into account was also modelled for the study period. This adopted an application rate of 15mm per cycle, reflecting common rates of between 10 and 25 mm. This irrigation pattern for the study period is also shown in Figure 5 (light blue).

Table 5 shows the days of irrigation adopting both a weekly irrigation on Mondays (business as usual) and an irrigation regime that considers rainfall. The table also reports the *E-coli* levels at the time of irrigation for each regime. For days when no sampling was carried out the *E-coli* levels have been interpolated from the nearest reported value.

As shown in Table 5, an irrigation regime that takes rainfall into account (allowing more time for *E-coli* to die off), is likely to reduce the risk to public health caused by elevated levels of faecal coliforms in reused stormwater. Irrigating on a strictly weekly basis and using harvested stormwater is likely to increase the risk that irrigation is undertaken during periods when the levels of *E-coli* in the tanks are high. This is particularly the case for Barra Brui. Such modelling further emphasises the need to consider irrigation design and technology and couple this with appropriate management practices when irrigating with reused stormwater.

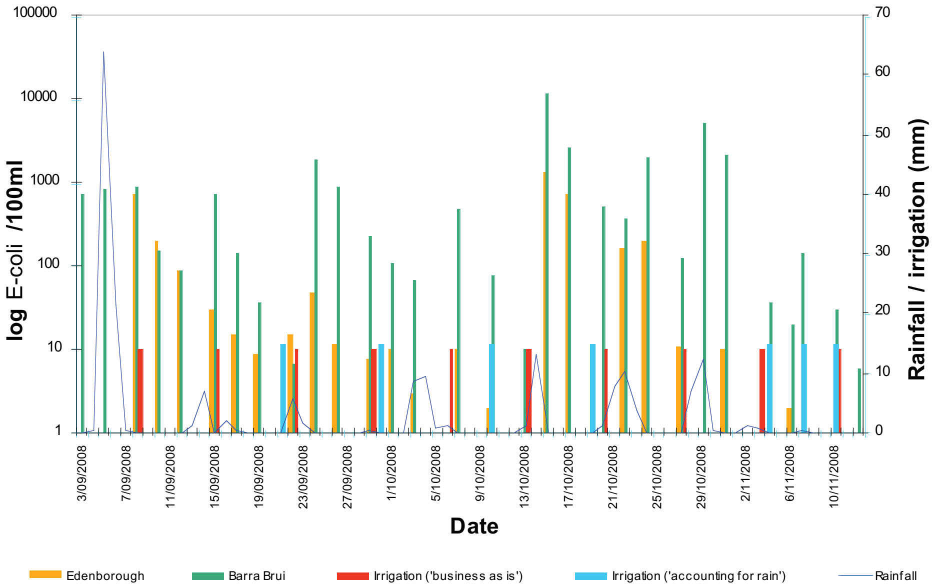



**Figure 5. Rainfall and *E-coli* results showing rainfall and modelled irrigation regime results.**

| | Date | Edenborough *E-coli* /100ml | Barra Brui *E-coli* /100ml |
|---|---|---|---|
| Business as usual irrigation (Mondays) 10mm | 8/09/2008 | 730 | 880 |
| | 15/09/2008 | 30 | 720 |
| | 22/09/2008 | 15 | 7 |
| | 29/09/2008 | 8 | 240 |
| | 6/10/2008 | 20 | 980 |
| | 13/10/2008 | 0 | 10 |
| | 20/10/2008 | 0 | 540 |
| | 27/10/2008 | 11 | 130 |
| | 3/11/2008 | 2 | 72 |
| | 10/11/2008 | 0 | 30 |
| | Median | 9.5 | 185 |
| Irrigation modelled (considering rainfall) 15mm | 21/09/2008 | 18 | 17 |
| | 30/09/2008 | 9 | 180 |
| | 10/10/2008 | 2 | 78 |
| | 19/10/2008 | 253 | 1226 |
| | 4/11/2008 | 1 | 36 |
| | 7/11/2008 | 0 | 140 |
| | 10/11/2008 | 0 | 30 |
| | Median | 2 | 78 |

Grey cell indicates interpolated value.

**Table 5. Days of irrigation adopting both a weekly irrigation on Mondays (business as usual) and an irrigation regime that considers rainfall showing *E-coli* levels at the time of irrigation for each regime.**

While the practice of harvesting rainwater from roofs in residential areas is common place for many areas in Australia and a number of studies have been carried out related to potential risks associated with this practice, little research has been carried out on public stormwater harvesting reuse schemes. Studies into rainwater reuse from residential tanks conclude that the low likelihood of human contamination present in roof water will result in a lower likelihood of infection (Sinclair *et al* 2005). However the nature of stormwater harvesting catchments, particularly in Sydney, results in a higher likelihood that human derived micro-organisms will be present. As such it should be noted that more specific tests are required to determine if any specific organisms or viruses are present that can pose a risk to human health. This study has only assessed the presence of *E-coli* in harvested stormwater and thus only part of the potential risk. Ultimately the management strategy will need to be informed by additional site specific monitoring and ongoing performance of the systems.

In relation to the compliance with guidelines, this study has highlighted the need to monitor water quality at the time of irrigation, not inflow, assuming sound management practices. It is argued that this should inform future review and development of revised guidelines and extend these from their present scope of simply relating to access to the site during and the period following irrigation.

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paper eighteen

# What level of disinfection do we need for stormwater reuse and why?

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paper eighteen

# WHAT LEVEL OF DISINFECTION DO WE NEED FOR STORMWATER REUSE AND WHY?

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## ABSTRACT

Risk management is a vital part of any project, and stormwater reuse projects are no exception. For stormwater harvesting, risks are largely unknown and vary depending on the catchment, inter-rain periods, rainfall intensity, storm duration and intended reuse to name a few factors. When the intended reuse is irrigation a common approach in urban environments is to pre-treat water using a Gross Pollutant Trap (GPT) before storage and disinfect the water using Ultra Violet (UV) light prior to reuse. Current guidelines provide advice on the expected or desired level of reduction of indicator organisms (commonly E. coli.) prior to reuse, as well as maximum turbidity levels (NTU), which has commonly been used as an indicator of the expected performance of the UV disinfection.

Ku-ring-gai Council has adopted stormwater harvesting as a way of improving the quality of sports fields to accommodate increasing demands. There are six fully operational systems with a further two under construction and only one is equipped with UV disinfection.

This paper presents the results of water quality sampling undertaken by Council as part of a risk management review. The data from this study suggests that with appropriate design and management regimes, stormwater reuse schemes are likely to comply with the intent of current NSW and National guidelines without necessitating disinfection to address health risks associated with the presence of pathogens. However these conclusions are based on a limited data set and are only valid for the systems assessed as part of this study. These results may not necessarily be directly transferable to other systems.

## 1 INTRODUCTION

Urban stormwater pollution is a well known and understood problem. Since the 1990s Australian government agencies have been promoting the need to decrease pollutants such as sediments, rubbish, nutrients, pesticides, detergents, hydrocarbons and other chemicals. Slogans such as *"the drain is just for rain"* were used to encourage the community to be mindful of what they wash down the stormwater system (DEC 2004). In NSW this and similar campaigns arose from the concern associated with the impact of urban stormwater on the natural environment and areas used for recreation. Even though the impacts on human health from stormwater have been a concern for many years, practitioners have been encouraged towards reuse and recycling schemes as part of a move to integrated urban water management.

In 2004 Ku-ring-gai Council introduced a seven year environmental levy. One of the major funding areas was the implementation of stormwater harvesting systems to provide irrigation for playing fields. These schemes were to provide fit for purpose water from a sustainable source with the outcome of improving the quality of sports fields. Environmentally, the project sought to provide benefit to the local waterways and lessen the demand on potable supply. The genesis of this program also stemmed from the drought affecting Sydney and subsequent water restrictions limiting the use of potable water for irrigating open space areas.

The development and delivery of this program has been cognisant of the many risks associated with stormwater reuse. Institutionally these ranged from the acceptance and subsequent maintenance of the systems. Environmentally, risks include whether the designed water quality treatment systems would perform to their expected standard. Social risks include whether the provision of non-potable standard of water would cause unnecessary risks to public health. It is the latter factor that is of interest to this paper.

In New South Wales (NSW) risk management procedures are outlined by both the State Government (DEC 2006) and Australian national guidelines for stormwater harvesting and reuse (NHMRC 2009). These outline the large array of risks and associated factors that need to be considered when planning, designing, constructing and operating stormwater harvesting systems. When the intended reuse is irrigation, a common approach in the urban environment has been to pre-treat water using a Gross Pollutant Trap (GPT) before storage, followed by disinfection of the water using Ultra Violet (UV) light prior to reuse. Current guidelines provide advice on the expected or desired level of reduction of indicator organisms (commonly *E. coli.*) prior to reuse as well as maximum turbidity levels, as NTU (NTU - nephelometric turbidity units), commonly used to provide an indication for the expected UV disinfection efficiency.

This investigation has been undertaken in recognition that the recommended indicator organisms, Faecal coliforms, *E-coli* and enterococci, are not necessarily indicative of other pathogens that may be present (ANZECC 2000). Currently, *E-coli* is regarded as a preferred indicator when testing fresh waters for recreation (ANZECC 2000) and for harvesting systems (DEC 2006). However, only a small number of *E-coli* species are pathogenic to humans and these usually occur in very low numbers (NHRMC 2009).

In 2010 Ku-ring-gai Council had six fully operational stormwater harvesting systems with a further two under construction. Of these eight systems, one is equipped with UV disinfection, while the others rely on access control as a means to manage risk to public health. Access controls include closed storage, signage, sub-surface irrigation (Lindfield Soldiers Memorial) and irrigation at night for overhead sprinkler systems.

This paper focuses on analysing the potential risks to human health as a result of exposure to micro-organisms that arise from using stormwater for irrigation of urban sports fields. These risks have been evaluated to guide the future management of these and future facilities.

## 2 BACKGROUND

### 2.1 Overview of the Guidelines

National and State guidelines currently provide a variety of approaches and protection levels that can be implemented in order to mitigate risks depending on the intended use of harvested stormwater (NHMRC 2009, DEC 2006). The guidelines include a variety of actions such as coarse treatment (litter screening); biofiltration; wetland treatment; chemical treatment; cartridge/disc filtration; and treatment with ultraviolet (UV) light. The guidelines do not specify the use of particular treatment techniques; rather they offer background information on relevant scientific research. They indicate the most appropriate method and level of treatment will depend on the intended end-use of the water. Both guidelines have been produced to encourage the use of recycled water, which is generally viewed as an underused resource (NHMRC 2009).

One of the major areas of difference between the National and State guidelines is the disinfection and turbidity criteria. The NSW guideline for stormwater harvesting has similar criteria to the National guideline for water recycling Phase 1 for wastewater irrigation (NHMRC 2006). The National guideline

Phase 2 for stormwater harvesting is less strict. The reason for this is that levels of faecal-derived microbial indicators and pathogens in stormwater are commonly less than 1% of those found in sewage (NHMRC 2009) and less stringent treatment or exposure control requirements will achieve the same degree of health risk management.

*NSW State Government Guidelines*

Managing urban stormwater – Harvesting and Reuse published by the NSW Department of Environment and Conservation in 2006 provides guidance on key considerations for future stormwater harvesting and reuse projects based on the experiences of the pilot projects that had been constructed up until that time (DEC 2006). It provides information for planning, project design, operation, maintenance and monitoring and has been used to inform the risk assessment and monitoring regime for the majority of Ku-ring-gai Council's stormwater harvesting systems.

The public health risk management assessment, resulted in Ku-ring-gai's systems focussing heavily on a coarse (e.g. GPT) to medium (sand filter/ rain garden) pre-treatment with access controls including signage, restricted access to any open water and irrigation during unoccupied hours and/or sub-surface irrigation. These approaches were taken to ensure that the systems meet the criteria of Level 2 or 3 systems as listed in Table 1 (DEC 2006). The guidelines identify *E-coli* as the preferred pathogen indicator and recommend that sampling should be done weekly. It should be noted however that monitoring performed by Ku-ring-gai Council was restricted and therefore was less extensive than what is recommended in the DEC 2006 guidelines.

***Table 1 NSW guidelines for stormwater quality criteria for public health risk management (Table 6.4, DEC 2006).***

| Contact Level | | Guideline Value |
|---|---|---|
| Level 1 | Reticulated non-potable residential uses (such as garden watering, toilet flushing, car washing) | *E. coli.* <1cfu/100mL |
| | | Turbidity ≤ 2 NTU |
| Level 2 | Spray or drip irrigation of open spaces, parks and sports grounds (no access controls) | *E. coli.* <10cfu/100mL |
| | Industrial uses – dust suppression, construction site use (human exposure possible) | Turbidity ≤ 2 NTU |
| | Ornamental water bodies (no access controls) | |
| | Fire-fighting | |
| Level 3 | Spray or drip irrigation (controlled access) or subsurface irrigation of open spaces, parks and sports grounds | *E. coli.* <1000cfu/100mL |
| | Industrial uses – dust suppression, construction site use, process water (no human exposure) | |
| | Ornamental water bodies (access controls) | |

*Australian National Guidelines*

The National guidelines (NHMRC 2009) provide additional background data and scientific information that is designed to be used to plan and evaluate system risks and performance. A summary of the guideline values is presented in Table 2 (NHMRC 2009).

***Table 2 Stormwater treatment criteria for public, open-space irrigation (no access control) — managing health risks (Table 3.3, NHMRC 2009)***

| Parameter | Stormwater treatment criteria |
|---|---|
| Disinfection | >1.5 log10 (96%) reduction of viruses and bacteria<br>>0.8 log10 (82%) reduction of protozoan parasites<br>*E. coli* <10 colony forming units (CFU)/100 mL (median) |
| Turbidity | <25 nephelometric turbidity units (NTU) (median)<br>100 NTU (95th percentile)<br><br>provided the disinfection system is designed for such water quality and that, during operation, the disinfection system can maintain an effective dose by using up all disinfectant demand and providing free disinfectant residual and/or provides adequate UV dose even in the presence of elevated turbidity and UV absorbing materials |

**2.2** Previous water quality monitoring in Ku-ring-gai

Due to limitations in time, budget and available information, Ku-ring-gai has previously been restricted to implementing a largely qualitative risk based assessment, based on the information provided by the NSW guideline document (DEC 2006) and an assessment of the individual projects. The assessments place a great emphasis on reducing risks through preventative planning to minimise the requirement for curative measures in the long run. While the NSW guidelines propose a weekly monitoring regime for stormwater reuse systems (monitoring *E. Coli.),* funding and time restrictions have meant this regime can not be supported. Rather a monthly program was implemented from July to December 2009. Results are presented in Table 3, with samples collected from the irrigation system at each site.

***Table 3: E-coli (CFU/100ml) Results of monthly irrigation monitoring (July – December 2009 Water harvesting site quality analysis).***

| | Lindfield Soldiers Memorial | Edenborough | Barra Brui* |
|---|---|---|---|
| Highest | 22 | 2 | 4 |
| Lowest | 1 | 1 | - |
| Median | 1.5 | 1 | - |

* Only one sample was able to be collected during this time, with the storage being inaccessible at other occasions.

The results presented in the Table 3 show that each of the systems broadly meets the Level 2 criteria of the NSW Guidelines and are definitely below the level of 1000/100ml required for Level 3. In all cases but one the water would also comply with the National guidelines for open space irrigation without access control.

These results appear to indicate that there is little cause for concern relating to pathogens in these stormwater harvesting systems. These results also indicate that the simple pre-treatment, access and management controls are sufficient to mitigate against health risks, as identified by council's qualitative pre-construction risk assessment.

It should be noted that the data from Table 3 was gathered on occasions that had relatively low rainfall. The highest readings occurred when there had been only 14.2mm in the 7 days up to and including the sample day. However, previous investigations by the authors have demonstrated that there is a large influx of *E-coli* into stormwater harvesting systems during high rainfall events (Findlay et al 2009) with values as high as 12,000 cfu/100mL recorded. Nevertheless, it was demonstrated that the bacteria appear to die-off to safer levels whilst in storage within days following a rainfall event (Findlay et al 2009). From an irrigation perspective, it would be unusual for the ovals to require watering after such rain events, allowing the die off of pathogens and therefore reducing the health risk. However, this high input of Coliforms during a rainfall event created a concern that there was potential for other pathogens, possibly more hazardous and persistent ones, to also be present.

Having completed a number of systems Ku-ring-gai has undergone a more quantitative risk assessment as outlined in the National guidelines (NHMRC 2009) for the quality of the irrigation water. This assessment has been undertaken to validate those assumptions that have previously been made, and indicate whether any curative measures need to be retrofitted to the systems to minimise risk to public health.

## 3 METHODS

This paper presents the results of a two part investigation, which involved data collection and then an assessment of risk based on the results.

The first part of the investigation involved collecting water samples to enable parasite and virus analysis to be conducted on water from the stormwater harvesting systems. The samples were collected from either the storage tank or irrigation infrastructure to ensure that the water had already passed through the available treatment. The three longest established systems were included in the sample regime.

These three sample sites include:

- Barra Brui Oval (St Ives)
  - completed in 2005
  - GPT/ Wetland treatment
  - 250 000L below ground metal storage tank
  - Pop-up sprinkler irrigation (automated)
- Edenborough Oval (Lindfield)
  - completed in 2007
  - GPT/ Sand filter treatment
  - 300 000L above ground concrete tank
  - Manual irrigation (QCV for travelling irrigator)
- Lindfield Soldiers Memorial Oval (Lindfield)
  - completed in 2008

- GPT (CDS) treatment
- 500 000L above ground metal storage tank
- Disc filter
- Sub-surface irrigation (automated)

Each site was sampled on 07 June 2010 (Sample A) and 24 June 2010 (Sample B). For Sample A the samples were taken for the storage tank at each site. For Sample B the samples were taken from an irrigation valve/ sprinkler at each site. For Barra Brui and Edenborough, the irrigation is pumped straight from the storage, and as such the samples are considered comparable. At Lindfield Soldiers Memorial there is a disc filter between the tank and the irrigation. Even though the sample events can not be directly compared, the samples were used to gain a broader understanding of the levels of indicator organisms in relation to other pathogens present in the stormwater.

Samples were collected in a 20L Jerry can (provided by council) and microbiological sample bottles provided by Sydney Water analytical services. The Jerry cans were rinsed with a quantity of the subject water prior to formal collection of the sample. Sample A was collected following a large rainfall event (143mm for the 7 days up to and including when the sample was taken) whilst Sample B was collected during a week with significantly less rainfall (20.8mm for the 7 days up to and including when the sample was taken), as demonstrated in Figure 1.

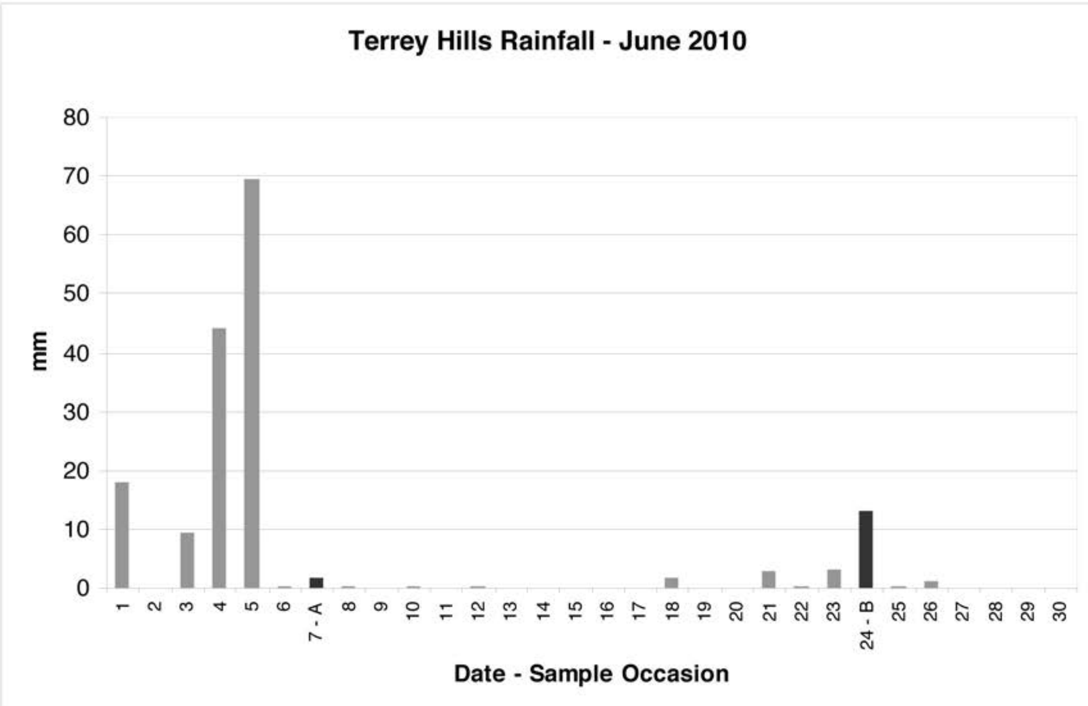


***Figure 1. Rainfall (up to 9am) from Terrey Hills AWS (5km north of Ku-ring-gai LGA) for June 2010. Sample occasions A and B are listed in the x-axis identified by the darker bars.***

Samples were analysed by Sydney Water monitoring services (NATA accredited) for Total coliforms, *E. Coli*, Enterococci, primary bacteria, Cryptosporidium, Giardia, Rotavirus; Adenovirus; Reovirus and Enterovirus.

The second part of the investigation comprised of a semi-quantitative risk analysis of the pathogens identified by this sampling. This was undertaken to determine how well existing treatment and risk controls are predicted to manage risk to public health.

The microbiological health risk assessment was undertaken using information provided in the Australian national guidelines (NHMRC, 2009). This process involves a quantitative approach which uses the disability adjusted life years (DALY) approach (NHMRC, 2009), which compares the severity of different hazards (pathogens) for any given concentration.

The National guidelines outline the DALY value as the appropriate unit for which to assess health risk as it can:

- *"define the acceptable level of risk to public health*
- *compare impacts from different hazards; for example, those that cause acute impacts (eg a brief episode of diarrhoea) and those that cause chronic impacts (eg arthritis)*
- *ensure that control efforts are directed at hazards with the greatest potential impacts on public health"* (NHMRC, 2009 p57).
-

Of particular interest to local government authorities is the ability to compare the impacts from different hazards, allowing justifiable prioritisation and mitigation of particular risks.

The acceptable risk to human health outlined by the National guidelines has been set to a level of one-millionth of a DALY ($10^{-6}$) per person per year. The guidelines indicate that this roughly represents one person in a thousand contracting diarrhoea in one year as a result of a water recycling scheme (NHMRC, 2009).

Using the approach outlined by the National guidelines (NHMRC, 2009), the following factors are considered as part of this assessment:

- *Hazard Identification* – This includes hazardous pathogens likely to be present. In our case we chose the reference pathogens given in the Phase 1 guidelines (*Cryptosporidium and* Rotavirus) in addition to Giardia (a well known pathogen in drinking water) and have measured their concentration during sampling. It should be noted that *E. coli.* is not used as a reference pathogen (as most *E. coli* are non-pathogenic) and is used only as an indicator organism in the guidelines.
  - For this analysis we assessed the residual risk (that which is still present after the treatment). Consequently the data provided from the post treatment sample results are taken as the maximum possible risk.
  - In the guidelines the 95$^{th}$ percentile concentration is used, however due to the restricted data available for the Ku-ring-gai Systems the highest value was used to allow a conservative assessment.
- *Determination of Dose Response* – The values provided in the phase 1 guidelines were used for this assessment.
- *Exposure Assessment* – The default values for "Municipal Irrigation" given in Phase 1 guidelines was used (NHMRC 2006).
- *Risk characterisation* – This is where the exposure assessment and dose response is combined, and as a result the DALY is calculated.

## 4 RESULTS

### 4.1 Pathogen analysis

The results of the water quality analysis for pathogens undertaken on the harvested water from Barra Brui (BB), Lindfield Soldiers Memorial (LSM) and Edenborough (Eden) Ovals are presented in Tables 4 and 5. As expected, since these samples were gathered during rainfall events the indicator organism levels are much higher than those gathered during the 6 month analysis (Table 3). Analysis of the data during these high rainfall events provided confidence that a 'worst case' scenario was targeted and results of interest would be obtained. It should be noted that due to the high rainfall, irrigation of these ovals did not occur during this time.

***Table 4. Results from the Bacteria Analysis***

| Site | Total Coliforms (Orgs / 100mL) | | *E-coli* (Orgs / 100mL) | | Enterococci (CFU/100mL) | | Primary bacteria identified (MI15) | |
|---|---|---|---|---|---|---|---|---|
| | A 07/06 | B 24/06 | A 07/06 | B 24/06 | A 07/06 | B 24/06 | A 07/06 | B 24/06 |
| BB | 5500 | 38 | 440 | 2 | 250 | ~7 | Enterobacter Genus | *Citrobacter youngae* |
| LSM | 5700 | 3400 | 370 | 86 | 200 | ~59 | *Raoultella terrigena*<br>*Enterobacter cloacae* | *Providencia alcalifaciens/ rustigianii* |
| Eden | 16000 | 2 | 2400 | <1 | ~730 | <1 | *Serratia liquefaciens* | *E coli* |

***Table 5. Parasites: Results from the Parasite Analysis***

| Site | Cryptosporidium DAPI positive (10L sample) | | Giardia (5L Concentrated) | |
|---|---|---|---|---|
| | A 07/06 | B 24/06 | A 07/06 | B 24/06 |
| BB | 2 | 2 | - | 4 |
| LSM | - | - | - | - |
| Eden | 4 | 1 | - | - |

The samples from each site were also tested for Rotavirus; Adenovirus; Reovirus and Enterovirus and these all returned negative results.

### 4.2 DALY Calculations

Sampling at Lindfield Soldiers Memorial Oval did not return any positive results for Cryptosporidium or Giardia. As such the DALY calculations were only completed for Barra Brui and Edenborough Ovals. For Giardia, information on infection probability was derived from Rose et al (1991), while the ratio of illness to infection was conservatively assumed to be 100%. The DALY per case was assumed to be the same for Giardia as for Cryptosporidium (Haagsma et al 2009) Result of the DALY calculations is presented in Table 6.

***Table 6. Result of the DALY calculations for Barra Brui and Edenborough***

| | **Barra Brui** | | **Edenborough** |
|---|---|---|---|
| | Cryptosporidium | Giardia | Cryptosporidium |
| Organism count/ litre (N) (Maximum result) | 0.2 | 0.4 | 0.4 |
| **DALY/year** | **$6.19 \times 10^{-7}$** | **$5.95 \times 10^{-7}$** | **$1.239 \times 10^{-6}$** |
| **Log reduction required to comply with tolerable risk (NHMRC, 2009)** | **N/A** | **N/A** | **0.093** |

## 5 DISCUSSION

Results of the water quality investigation showed that despite the high levels of indicator organisms such as Total coliforms, E-coli and enterococci, reference pathogens such as parasites *Cryptosporidium* and Giardia are not detected in significant numbers. For example, ingestion of around 100 oocysts has been shown to be the median infective dose for Cryptosporidium (DuPont et al 1995). The highest number of infective oocysts identified was 4 in a 10L sample of water. As the purpose of this water is for irrigation, it is highly unlikely that a person will manage to consume enough oocysts to result in an occurrence of Cryptosporidiosis. The calculation of DALY/year for *Cryptosporidium* for Edenborough Oval does however indicate that further treatment / management would be required in order to reduce the risk to human health to acceptable levels. A list of indicative exposure reduction provided by on-site preventative measures is included in NHMRC (2006). Here "No public access during irrigation" is given a reduction in exposure to pathogens equivalent to a log reduction of 2. This is well in excess of the required 0.09 and as such the system at Edenborough complies with the intent of current guidelines in terms of exposure to *Cryptosporidium*.

The results from this study show no clear correlation between high readings of *E.coli* and *Cryptosporidium* or Giardia. *Cryptosporidium* was present at Edenborough in both samples while no *E.coli* was detected in the second sample. At Barra Brui, *Cryptosporidium* was detected in both samples at the same level while the *E.coli* count differed significantly between the two samples. This finding support previous investigations that have not been able to find any clear relationship between *E. coli* as an indicator organism and pathogens such as *Cryptosporidium* and Giardia (NHMRC, 2009).

The National guidelines do not provide enough information to calculate DALY/year for Giardia and information had to be obtained from other sources. In any case, given the low annual volume that is assumed to be ingested the risk of contracting illness due to Giardia in reused stormwater is considered low.

As no viruses were detected in any of the samples taken as part of this study, it is not possible to comment on the relationship between *E. coli* and the presence of viruses in stormwater.

Both the NSW (DEC 2006) and National guidelines (NHMRC 2006 & 2009) provide a value for turbidity as turbidity levels can impact on the operation of irrigation infrastructure and the effectiveness of disinfection treatments such as UV radiation. The NSW guidelines for turbidity provides a median of ≤2 (maximum of 5) for level 1 and level 2, no value is listed for level 3 management (Table 1). However, the NHMRC (2009) (Table 2) sets a level of <25 NTU (median) on the basis that there is likely to be significantly lower pathogen levels in stormwater than in recycled water (which is used to derive most of the indicator values). Where a relatively low concentration of pathogens is targeted (such as for the systems in this study) the efficiency of the UV treatment would need to be high to ensure that required reductions are achieved and this may be compromised by NTU levels over 2. Recent test results from Ku-ring-gai's systems have been ranging from 1.8 to 28 NTU in which case it may be more feasible to rely on the access controls and other management strategies that achieve the required log reductions as outlined in (NHRMC 2009) than to rely on UV disinfection.

## 6 CONCLUSION

Previous sampling of Ku-ring-gai Council's stormwater harvesting schemes has shown that elevated levels of indicator bacteria such as *E-coli* commonly occur following and during rainfall events (Findlay 2009). This data indicates a potential for other hazardous organisms including parasites such as *Cryptosporidium* that prove to be more persistent in the harvesting environment (for instance storage tanks) to be present.

The monitoring undertaken as part of this study suggests that by relying on Faecal coliforms, enterococci and particularly *E-coli* (as tends to be used as the indicator organism) to evaluate the risk to public health, the risk is likely to be overestimated for these systems.

From a practical perspective there exist major limitations to local government and others to undertake a valid testing program for pathogens, most specifically the cost and frequency of comprehensive testing. The catch is to rely on an indicator organism that, as this study has found, is not always a reliable predictor of the health related risks associated with the water. UV treatment could be used to provide a higher security to an alternative water supply, however in many cases effective pre-treatment followed by appropriate access controls would suffice as demonstrated by the DALY calculations undertaken for Edenborough Oval.

In terms of risk management, the data from this study suggests that appropriate management regimes such as irrigating at night and not allowing public access to irrigated areas is most likely sufficient to comply with the intent of current NSW and national guidelines for stormwater reuse without necessitating disinfection.

It is important to note however that the conclusions from this study are only valid for the systems assessed as part of this study and is not necessarily directly transferable to other systems. Furthermore these findings are based on a very limited data set and further investigations are required to confirm these preliminary findings.

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# Comparison of filter media in raingardens – Ku-ring-gai council case study

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paper nineteen

# Comparison of filter media in rain-gardens – Ku-ring-gai Council case study.

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**ABSTRACT**
Ku-ring-gai Council has been implementing a range of water sensitive urban design projects as part of its capital works program. Across its road and drainage areas this has included the incorporation of bio-filtration systems, swales and rain-gardens, as well as stormwater harvesting, outlet protection and creek restoration. The focus of this paper is an examination of the stormwater treatment performance of two filter media used in a series of rain-gardens installed in 2007.

Three rain-gardens were installed along Karuah Road as part of the road pavement and water sensitive urban design capital works programs. Three separate structures were integrated into the parking streetscape and drainage design for the site. Each of the rain-gardens was designed with a permanent sample point to enable water quality testing at the base of the filter. One system was constructed with 'Landscape Garden Ecomedia', containing a compost component the other two systems used a sandy loam mix as recommended by then current guidelines.

Semi-controlled sampling was conducted to determine the efficiency of pollutant removal from two of the rain gardens, one constructed with sandy

loam and one constructed with 'Landscape Garden Ecomedia'. Monitoring analysed electrical conductivity, pH, biological oxygen demand, suspended solids, total nitrogen, total phosphorus, hydrocarbons, faecal coliforms and various metals. Infiltration rates were also measured to assess variation between the two media.

While accepting the limited sampling data and issues with construction of the rain-gardens not complying with specifications, the sandy loam garden in particular demonstrates a degree of robustness through the sustained reduction in pollutant concentrations. The Ecomedia appears to require more exacting construction standards to achieve its predicted effectiveness.

The case study presented in this paper demonstrates an example of WSUD in practice within a retrofit situation. As this initial report relies on a limited amount of data, the efficacy of this project is yet to be fully validated. As such, monitoring will continue to be undertaken during rainfall events within the catchment and through the use of synthetic stormwater.

## INTRODUCTION

Since 2004, Ku-ring-gai Council has implemented a range of water sensitive urban design (WSUD) projects as part of its capital works and environmental programs. This has included bio-filtration systems, swales and rain-gardens to better manage stormwater quantity and quality from local roads; stormwater harvesting schemes to irrigate sports fields; protection of stormwater outlets to reduce erosion and creek restoration to improve the riparian environment. An increasing focus of the program is to quantify the impact and effects against the various objectives such as improving stormwater quality, reducing the hydraulic impact of storm flows on natural water courses and reducing reliance on potable water. The focus of this paper is an examination of the performance of two filter media used in a series of rain-gardens installed in 2007.

The rain-gardens described in this case study are located on Karuah Road adjacent to Turramurra Memorial Park, Turramurra (Latitude 33:43:35, Longitude 151:07:49). The area is located immediately upstream of Lovers Jump Creek, tributary to Cowan Creek which discharges to the Hawkesbury River estuary.

## BACKGROUND

### *Planning*

The project to construct three rain-gardens at Karuah Road arose through a combination of Council programs. Karuah Road was identified for resurfacing through council's road improvement program; the adjoining sports ovals were recognised as possible locations for stormwater harvesting to provide a more sustainable source of irrigation through the Council's town centre planning and the precinct site was identified for the development of a landscape master plan as part of a council wide open space program. These elements were brought together through WSUD program capital funding from an environmental Levy.

The immediate catchment is dominated by road and car parking that is likely to increase the proportion of hydrocarbons and metals in the runoff (Duncan, 1999). As such, it was suggested that special filtration media containing a compost component be used to increase the filtering efficiency for these target pollutants. The reasoning for this is the assumption that organic particles will increase the absorption of dissolved heavy metals and provide a greater surface area for the filtering of hydrocarbons (Jang *et al.* 2007; Seelsaen *et al.* 2007).

Karuah Road is used as a thoroughfare by local residents and the adjacent unpaved road verges were utilised for moderate to high level parking by those using the park or sport fields throughout the week. Preliminary options, discussed in the preparation of the landscape masterplan for the site identified the partial or full closure of the road to increase parking and park amenity. It was important that the current usage levels and proposed future options were not adversely affected by the design for the site.

***Design***

The catchment draining to the site is 1,300m$^2$ of road and car parking areas. In order to meet Council's stormwater quality requirements of 80% reduction in TSS and 45% reduction in TP and TN, the initial design included a single garden of 26m$^2$ with 300mm extended detention depth, equivalent to approximately 2% of the contributing catchment. The initial design was assessed using MUSIC. However, site constraints including 5% cross and longitudinal falls restricted this option as it would require relatively high retaining walls. For this reason, three smaller rain-gardens of about 8.5m$^2$ each were proposed. Due to the narrow car parking area, the design had to allow for 30 degree angle parking in order to comply with Australian Standard 2890. To maximise the use of the space, triangle shaped gardens were proposed, resulting in a total surface area of approximately 45m$^2$, or 3.5% of the catchment area.

Each rain garden was designed according to guidelines provided by FAWB (2007). This included a flat bed with 500mm of filter media over 100mm of transition layer, which overlays a 100mm drainage layer. Each garden is drained by a common subsoil drainage line that runs along the road and discharges to a nearby open channel, a tributary of Lovers Jump Creek. The use of a connected drainage line was to enable integration to any future stormwater reuse scheme for the adjacent Turramurra Oval and Karuah Park. Each rain garden was designed with a permanent sample point to enable water quality testing at the base of the filter.

The first and third gardens used a sandy loam mix as recommended in the best practice guidelines by the Facility for Advancing Water Bio-filtration FAWB 2007). The middle garden contained a 'Landscape Garden Ecomedia' developed by the Centre for Organic and Resource Enterprises CORE).

Inlets to each of the gardens were designed with a longitudinal grate to exclude litter and other gross pollutants. These pollutant are subsequently collected in a Gross Pollutant Trap GPT) installed 80 metres downstream of the site as part of a NSW Stormwater Trust project in 2002. Fine sediments and dissolved pollutants such as nutrients and metals are directed into filter beds for treatment. The original design of the grates was to incorporate longitudinal bars in stainless steel. However, concerns expressed by others in the industry that these may be subject to theft were considered and grates were changed to a standard galvanised class D grate with a heel proof pedestrian grate welded on top.

A schematic of the site is presented in Figure 1. A section of rain-garden 3 is presented in Figure 2.

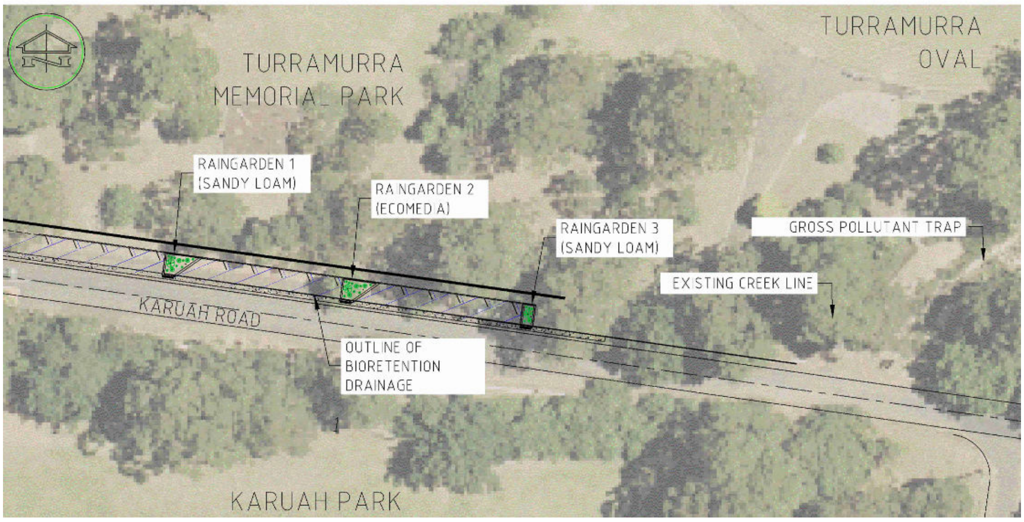


**Figure 1:** Schematic of Karuah Road rain-gardens and surrounds

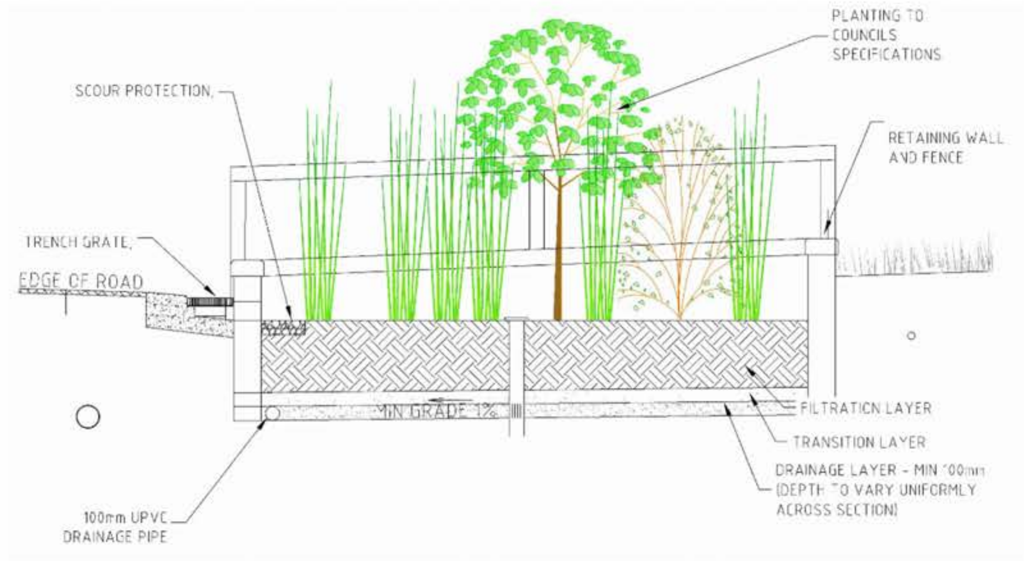


**Figure 2:** Section of rain-garden 3

### *Construction*

On completion of the design the construction plans were given to the road works coordinator to supervise the construction. The same contractor carrying out the road upgrade was used for construction of the rain-gardens. No briefing meeting was held with the contractor and the designer, and the designer was not asked to regularly visit the site. As a result there were a number of misunderstandings of the design intent during the construction phase causing delays and the need for alterations.

## EVALUATION

The rain-gardens were allowed to settle and establish for 6 months prior to commencement of testing. Before testing commenced it was found that Garden 2 and Garden 3 were not constructed with flat beds as per design. The filter surface differed in height by up to 200mm across the beds. For Garden 2 containing the Ecomedia this resulted in stormwater being directed from the inlet towards one corner of the filter, not evenly distributed as designed. The depths of filter media across all rain-gardens did not comply with the design of 500mm and varied in depth between 150mm up to 230mm. The largest discrepancy was found to be in Garden 2, where the filter depth in the lowest corner was only 150mm. Garden 3 was found to have a minimum filter depth of 160mm.

### *Hydraulic conductivity*

Hydraulic conductivity (infiltration rate) was measured in Garden 2 (Ecomedia) and Garden 3 (sandy loam) in order to allow a comparison between the different filtration media used. The method used to determine infiltration rates was the in situ method described by Hatt and Le Coustumer (2008) in the FAWB note *"Condition assessment and performance evaluation of* *bioretention systems practise note 1: In Situ Measurement of Hydraulic Conductivity"*. The test utilises a single ring infiltrometer under a constant head. As the size of each garden is under 50m$^2$ it is recommended three points are sampled in each garden. Due to the uneven surface of Garden 2, only one test was carried out in the lowest corner of the filter, as this is the only area of the filter that will receive frequent runoff. For Garden 3, three samples were completed.

Results

The results of the hydraulic conductivity testing are presented in Table 1. This shows the hydraulic conductivity for Garden 2 (Ecomedia) to be within the guidelines given by FAWB of 100-300mm/hr (FAWB 2008), while Garden 3 (sandy loam) has a hydraulic conductivity lower than that recommended.

**Table 1:** Hydraulic conductivity, Karuah Road rain-gardens. Note FAWB guideline range: 100-300 mm/hr (FAWB 2008).

| **Rain-garden 2 (Ecomedia)** | | **Rain-garden 3 (Sandy Loam)** | |
|---|---|---|---|
| Sample site | Hydraulic conductivity Kfs (mm/h) | Sample site | Hydraulic conductivity Kfs (mm/h) |
| A | 183 | A | 21 |
| | - | B | 77 |
| | - | C | 37 |
| *Average:* | *183* | *Average:* | *45* |

It should however be noted that it took between 5-20 minutes before a continuos flow rate was obtained in Garden 3 (sandy loam), with the initial infiltration rate being approximately 50% higher than the final rate. In Garden 2 (Ecomedia), it took in excess of 60 minutes before a continuos flow rate was obtained, with the initial flow rate being approximately 500% of the final infiltration rate. This is concurrent with field observations during water quality testing and during rainfall. Water diverted into Garden 2 does not pond on the surface even during relatively high flows, and passes through the filter rapidly. In Garden 3, water ponds on the surface, due to the lower hydraulic conductivity.

***Water Quality***

The expected water quality performance of the system was assessed using MUSIC (2005) and has been described in previous report (Jonasson and Davies, 2007). A summary of the predicted water quality improvement (using 6 minute rainfall data from 1959 - Sydney Observatory Hill) is shown in Table 2.

**Table 2:** Predicted water quality improvement for car park bio-retention system

| Bio-retention gardens | Inflow | Outflow | Reduction |
|---|---|---|---|
| Flow (ML/yr) | 1.31 | 1.31 | 0% |
| Total Suspended Solids (kg/yr) | 207 | 15.5 | 93% |
| Total Phosphorus (kg/yr) | 0.464 | 0.104 | 78% |
| Total Nitrogen (kg/yr) | 3.44 | 1.57 | 54% |
| Gross Pollutants (kg/yr) | 31.7 | 31.7 | 0% |

It should be noted that due to the increase of the garden sizes, the volume of runoff treated is about 95% of the annual runoff. Therefore the MUSIC modelling indicates a greater reduction rate than Council's requirements of 80% reduction in TSS and 45% reduction in TP and TN.

In-situ filter testing

Semi-controlled sampling was conducted to determine the removal of various pollutants from Garden 2 (Ecomedia) and 3 (sandy loam). Monitoring analysed electrical conductivity, pH, biological oxygen demand, suspended solids, total nitrogen, total phosphorus, hydrocarbons (not on sample day 2), faecal coliforms and total metals (Hg; Ca; As; Cu; Cr; Ni; Pb & Zn). This sought to provide an understanding of function of the respective garden against the design of the soil media.

Rather than using potable water for the investigations, water was pumped from the tributary of Lovers Jump Creek just downstream of Karuah Road. On the first sampling occasion this water was used unaltered on the gardens. On the second and third sampling occasions the creek water was mixed with contaminated water from a street sweeper to create "synthetic" stormwater. The use of synthetic stormwater ensured the water contained a more representative level of pollutants to demonstrate a change of concentration through the filter. The method used to apply the water and test it was the same for all sampling occasions, using a 1,000L water tank to store and mix the water before application.

Before testing commenced, each of the sampling wells were emptied to ensure that any treated water from previous storms did not influence the analysis. One sample was taken from the untreated inflow for each garden and two samples were taken from the designed sampling well, being the outflow of each garden. The first outflow sample was collected as soon as water had passed through the media into the sampling well. To eliminate any concern that some of the water in this first outlet sample may be influenced by water of a previous storm event stored within the filter media, a second sample was taken once the well had re-filled. Water was collected by suction, and to prevent any sediments that may have accumulated in the bottom of the sump water was siphoned from 30mm above the invert of the sampling well.

On the second sampling occasion, only one sample could be collected from Garden 2 (Ecomedia), as water drained from the filter more rapidly than expected. Due to concerns that a second batch of synthetic stormwater could not be guaranteed to be of the same quality as the first application, no further testing was carried out on this occasion.

Results

*Inflow:* On each of the three separate sampling occasions a different stormwater solution was applied to the rain-gardens. On the first occasion water straight from the tributary of Lovers Jump Creek was used to test the filter media. Although this creek receives the majority of its water from stormwater runoff, including the Turramurra retail area, testing of the inflow demonstrated that contaminant characteristics were generally well below that expected for stormwater runoff, as outlined by Duncan (1999).

On the second and third sampling occasion creek water was mixed with contaminated street sweeper water, resulting in pollutant concentrations higher than those obtained on the first sampling occasion. The pollutant concentrations from untreated water (inflow) for sampling occasions a), b) and c) for Garden 2 (E) and Garden 3 (S) compared with stormwater contaminant characteristics for roads and urban runoff as described by Duncan (1999) (dark grey shading) are presented in Figures 3-5.

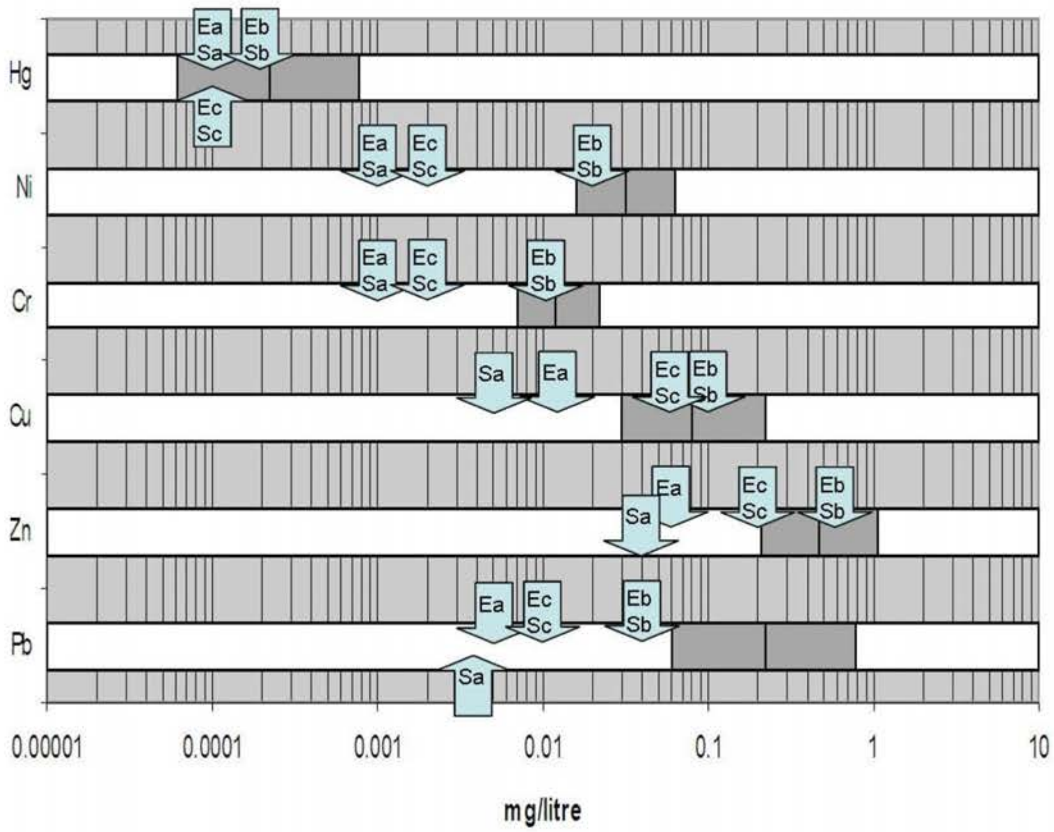


**Figure 3.** Concentrations of total metals in untreated water for sampling occasions a), b) and c) for Garden 2 (E) and Garden 3 (S) compared with stormwater contaminant characteristics for roads and urban runoff as described by Duncan (1999) (dark grey shading).

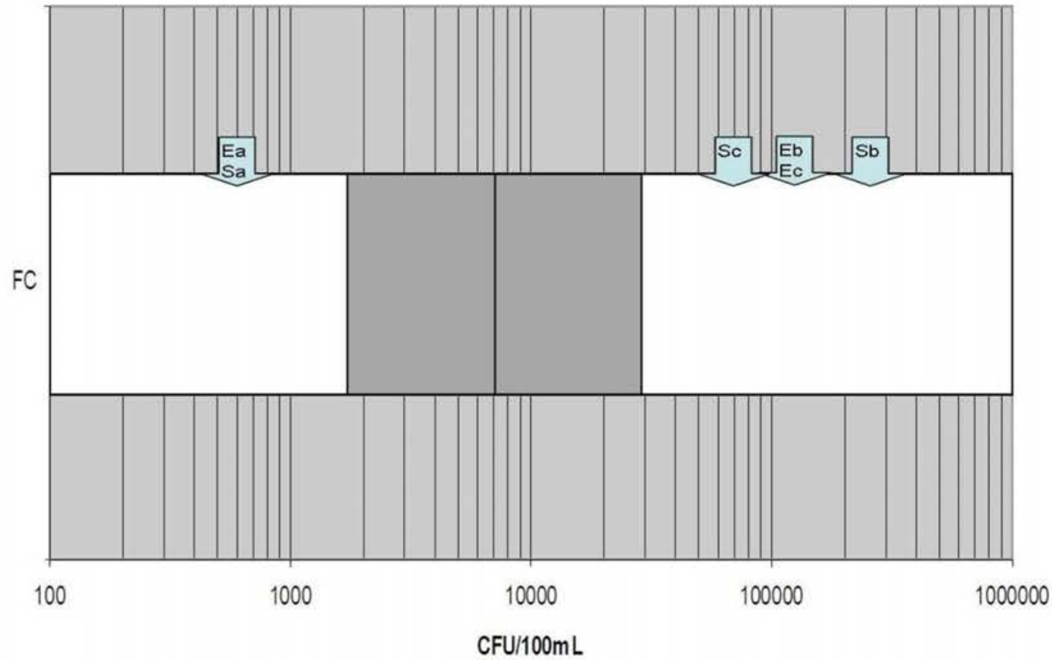


**Figure 4.** Faecal Coliforms in untreated water for sampling occasions a), b) and c) for Garden 2 (E) and Garden 3 (S) compared with stormwater contaminant characteristics for roads and urban runoff as described by Duncan (1999) (dark grey shading).

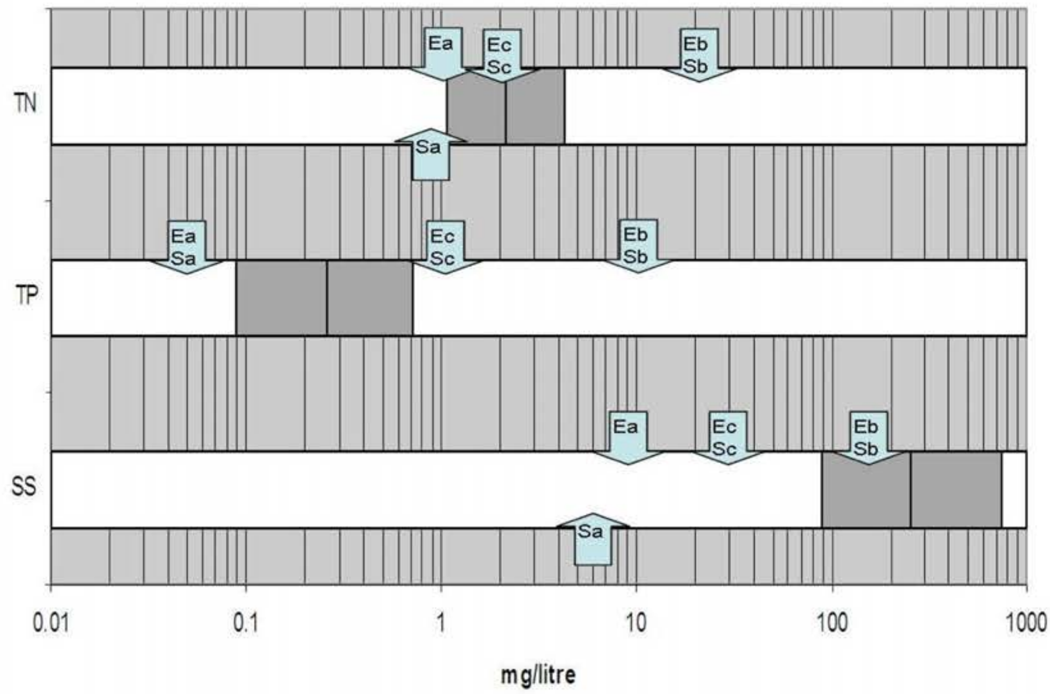


**Figure 5.** TN, TP and TSS concentrations in untreated water for sampling occasions a), b) and c) for Garden 2 (E) and Garden 3 (S) compared with stormwater contaminant characteristics for roads and urban runoff as described by Duncan (1999) (dark grey shading).

As illustrated in Figures 3-5, none of the inflow mixtures provided stormwater with concentrations of all monitored pollutants within the "typical" range of stormwater runoff from roads and urban areas. However as water was tested at both the inflow and outflow the results allowed comparison of the pollutant removal performance for the two filters tested.

*Outflow:* The outflow data was used to compare the function of the different media used in each rain garden. However, it should be noted that there was not sufficient data collected for Petroleum Hydrocarbons and Mercury to draw any valid conclusions. The results of the water quality analysis are demonstrated in Table 3 for the Ecomedia and Table 4 for the Sandy Loam. The analysis of the results below recognises that further sampling is required to provide statistical confidence.

The notable results from the in-situ water quality analysis are as follows:

- On the first sampling occasion (sample a) there were increases in pollutant concentrations for many pollutants, however the overall concentration in both inflow and outflow were generally within or below the range for what could be expected as background concentration leaving a bio-retention system, defined as the C* value in MUSIC (CRC for Catchment Hydrology,2005).
- The sandy loam filter reduced *E-coli* concentration with a maximum of 90% (outflow 2, sample b). Water filtered through the Ecomedia resulted in a maximum reduction of 49% (outflow 2, sample c)
- Sandy loam reduced TN by a maximum of 74% (outflow 1 sample a) compared to a maximum of 17% (outflow 1, sample b) for Ecomedia.
- Sandy Loam reduced TP by 92% (both outflows sample b) compared to Ecomedia which had a maximum of 38% reduction (both outflows, sample c).
- Sandy loam reduced TSS by a maximum of 84% (outflow 2, sample b) whereas the maximum TSS reduction for the Ecomedia was 33% (outflow 2, sample c).
- Overall Cu was exported from both gardens. The sandy loam returned the only evidence of a reduction of 3% (outflow 2, sample c). However this media also returned the largest increase of 260% (outflow 1, sample a). The largest Cu increase for Ecomedia was 179% (outflow 1 sample a) while and the smallest increase was 103% (outflow 2, sample c).
- The maximum removal of Pb through the sandy loam was 75% (outflow 1, sample b) and the maximum removal from the Ecomedia was 19% (outflow 1, sample b) .
- The sandy loam had a maximum removal rate for Ni of 67% (outflow 1, sample b). The maximum Ecomedia removal was 40% (both outflows, sample c).

- The sandy loam had the highest removal of Zn at 86% (outflow 1, sample b). Maximum removal of Zn for the Ecomedia was 41% (outflow 2, sample c).

Results for As were generally inconclusive, however the Ecomedia appears to be exporting trace amounts. Bio-filtration appears to increase the pH of water as it filters through both of the media, however the Ecomedia increase is smaller that that produced by the sandy loam. Both conductivity and BOD demonstrate large reductions from the sandy loam compared to the Ecomedia.

Results could not be directly compared to the predicted water quality improvements (Table 2) as the small data set does not allow calculation of load reduction over a longer period, nor was the quality of the untreated synthetic stormwater used in the pilot study representative of stormwater from an urban area for pollutants modelled by MUSIC.

**Table 3:** Results of the Ecomedia water quality analysis

| | | Sample a | Sample b | Sample c |
|---|---|---|---|---|
| ***E.coli*** | Inflow | 650 | 130000 | 120000 |
| (org/100ml) | Outflow 1 | 2900 | 120000 | 49000 |
| | Outflow 2 | 1400 | – | 61000 |
| **TN** | Inflow | 0.87 | 20.6 | 2.14 |
| (mg/L) | Outflow 1 | 0.87 | 17 | 2.64 |
| | Outflow 2 | 0.86 | – | 2.1 |
| **TP** | Inflow | 0.038 | 11.1 | 1.26 |
| (mg/L) | Outflow 1 | 0.228 | 8.28 | 0.78 |
| | Outflow 2 | 0.23 | – | 0.78 |
| **TPH** | Inflow | 0.2 | – | 0.1 |
| (mg/L) | Outflow 1 | 0.2 | – | 0.1 |
| | Outflow 2 | 0.2 | – | 0.1 |
| **EC** | Inflow | 41.8 | 105.5 | 37.4 |
| (mS/m) | Outflow 1 | 37 | 94.3 | 35.2 |
| | Outflow 2 | 40.4 | – | 36.9 |
| **BOD** | Inflow | 2 | 892 | 180 |
| (mg/L) | Outflow 1 | 2 | 874 | 134 |
| | Outflow 2 | 2 | – | 145 |
| **pH** | Inflow | 7.2 | 4.8 | 6.7 |
| (pH units) | Outflow 1 | 7.1 | 4.8 | 6.9 |
| | Outflow 2 | 7 | – | 6.9 |
| **TSS** | Inflow | 9 | 150 | 33 |
| (mg/L) | Outflow 1 | 32 | 118 | 28 |
| | Outflow 2 | 51 | – | 22 |
| **Hg** | Inflow | 0.0001 | 0.0002 | 0.0001 |
| (mg/L) | Outflow 1 | 0.0001 | 0.0002 | 0.0001 |
| | Outflow 2 | 0.0001 | – | 0.0001 |
| **Ca** | Inflow | 19.5 | 68.9 | 18 |
| (mg/L) | Outflow 1 | 29.7 | 87.9 | 27.2 |
| | Outflow 2 | 28.3 | – | 27.5 |
| **As** | Inflow | 0.001 | 0.003 | 0.001 |
| (mg/L) | Outflow 1 | 0.003 | 0.006 | 0.003 |
| | Outflow 2 | 0.002 | – | 0.004 |
| **Cr** | Inflow | 0.001 | 0.011 | 0.002 |
| (mg/L) | Outflow 1 | 0.002 | 0.009 | 0.003 |
| | Outflow 2 | 0.002 | – | 0.003 |
| **Cu** | Inflow | 0.014 | 0.106 | 0.06 |
| (mg/L) | Outflow 1 | 0.039 | 0.236 | 0.139 |
| | Outflow 2 | 0.031 | – | 0.122 |
| **Pb** | Inflow | 0.006 | 0.037 | 0.012 |
| (mg/L) | Outflow 1 | 0.007 | 0.03 | 0.012 |
| | Outflow 2 | 0.006 | – | 0.01 |
| **Ni** | Inflow | 0.001 | 0.02 | 0.005 |
| (mg/L) | Outflow 1 | 0.002 | 0.015 | 0.003 |
| | Outflow 2 | 0.001 | – | 0.003 |
| **Zn** | Inflow | 0.063 | 0.594 | 0.243 |
| (mg/L) | Outflow 1 | 0.136 | 0.536 | 0.176 |
| | Outflow 2 | 0.11 | – | 0.143 |

**Table 4:** Results of the sandy loam water quality analysis

| | | Sample a | Sample b | Sample c |
|---|---|---|---|---|
| ***E.coli*** | Inflow | 650 | 240000 | 73000 |
| (org/100ml) | Outflow 1 | 730 | 37000 | 33000 |
| | Outflow 2 | 290 | 24000 | 17000 |
| **TN** | Inflow | 0.8 | 22 | 2.42 |
| (mg/L) | Outflow 1 | 0.21 | 10 | 1.58 |
| | Outflow 2 | 0.28 | 11.7 | 1.69 |
| **TP** | Inflow | 0.037 | 11.8 | 1.22 |
| (mg/L) | Outflow 1 | 0.095 | 0.93 | 0.267 |
| | Outflow 2 | 0.088 | 0.91 | 0.28 |
| **TPH** | Inflow | 0.1 | – | 0.1 |
| (mg/L) | Outflow 1 | 0.1 | – | 0.2 |
| | Outflow 2 | 0.2 | – | 0.1 |
| **EC** | Inflow | 42.1 | 110.9 | 32.7 |
| (mS/m) | Outflow 1 | 22.8 | 69.8 | 28 |
| | Outflow 2 | 34.6 | 88 | 32 |
| **BOD** | Inflow | 2 | 992 | 170 |
| (mg/L) | Outflow 1 | 2 | 658 | 95 |
| | Outflow 2 | 2 | 699 | 96 |
| **pH** | Inflow | 7 | 4.8 | 6.7 |
| (pH units) | Outflow 1 | 7.2 | 5.1 | 7 |
| | Outflow 2 | 7.1 | 5.2 | 7.4 |
| **TSS** | Inflow | 6 | 154 | 29 |
| (mg/L) | Outflow 1 | 45 | 62 | 37 |
| | Outflow 2 | 50 | 25 | 26 |
| **Hg** | Inflow | 0.0001 | 0.0002 | 0.0001 |
| (mg/L) | Outflow 1 | 0.0001 | 0.0001 | 0.0001 |
| | Outflow 2 | 0.0001 | 0.0001 | 0.0001 |
| **Ca** | Inflow | 19.3 | 68.3 | 16.7 |
| (mg/L) | Outflow 1 | 22.4 | 90.3 | 23.6 |
| | Outflow 2 | 31.5 | 102 | 24.9 |
| **As** | Inflow | 0.001 | 0.005 | 0.001 |
| (mg/L) | Outflow 1 | 0.001 | 0.005 | 0.002 |
| | Outflow 2 | 0.001 | 0.004 | 0.002 |
| **Cr** | Inflow | 0.001 | 0.012 | 0.002 |
| (mg/L) | Outflow 1 | 0.003 | 0.006 | 0.002 |
| | Outflow 2 | 0.002 | 0.006 | 0.001 |
| **Cu** | Inflow | 0.005 | 0.116 | 0.066 |
| (mg/L) | Outflow 1 | 0.018 | 0.203 | 0.07 |
| | Outflow 2 | 0.014 | 0.219 | 0.064 |
| **Pb** | Inflow | 0.004 | 0.04 | 0.013 |
| (mg/L) | Outflow 1 | 0.008 | 0.01 | 0.009 |
| | Outflow 2 | 0.009 | 0.012 | 0.005 |
| **Ni** | Inflow | 0.001 | 0.021 | 0.005 |
| (mg/L) | Outflow 1 | 0.003 | 0.007 | 0.002 |
| | Outflow 2 | 0.001 | 0.008 | 0.002 |
| **Zn** | Inflow | 0.051 | 0.628 | 0.223 |
| (mg/L) | Outflow 1 | 0.61 | 0.089 | 0.067 |
| | Outflow 2 | 0.663 | 0.226 | 0.053 |

## DISCUSSION

There are three critical points for discussion related to the research undertaken to date. The first turns on the adequacy of the rain-garden construction and how this may affect performance. The second relates to field based sampling of rain-gardens.  The third relates to the need for more sampling to achieve a greater confidence in the level of statistical significance of the gardens, particularly given the variability of inflows.

The hydraulic conductivity of the sandy loam is somewhat lower than expected but is comparable with results obtained by Monash University (FAWB 2008) for filters of a similar age. The hydraulic conductivity is expected to increase once the vegetation is fully established. The initial hydraulic conductivity of the Ecomedia was 500% greater than the saturated hydraulic conductivity. While this reduced with swelling of the organic fraction, it suggests this first flush of stormwater may not benefit from the filtering from the media as expected. This could be particularly notable for the management of frequent low flow events. It is noted that laboratory based column studies of the hydraulic conductivity of filter material containing recycled organics have used a continuos flow of water onto the filter, ensuring that the filter media is wet at all times (McLaughlan 2006). In this study, hydraulic conductivity varied significantly depending on the level of water in the filter media, thus it is unreasonable to expect field based results to mimic lab results.

Laboratory studies of organic enriched filter media using batch testing have shown that a contact time of 15-30minutes is enough to ensure a good pollutant removal, using synthetic stormwater (McLaughlan 2006). During the testing done as part of this study the polluted water passed through the Ecomedia very rapidly, which is unlikely to have allowed sufficient contact time to obtain optimum pollutant removal. This would also apply for first flush scenarios during a storm event, when the filter is relatively dry, as the first volume diverted to the filter would pass through the media before the hydraulic conductivity reaches its saturated rate.

As the gardens were not constructed to design it is likely that this will impact on their performance as stormwater filters. This is particularly the case for Garden 2, containing the highly permeable Ecomedia, where flows are directed to one corner that has the shallowest filter media. Alterations to Garden 2 are proposed to ensure sufficient contact time with the Ecomedia is achieved, particularly for the more contaminated first flush stage of an event. These will include adjusting the filter surface slope and filter depth as well as adjusting the garden design to ensure that water is retained in the filter to allow sufficient contact time.  This is important as the small catchment size is likely to result in rapid changes in water quality during a storm event thus, if the initial flush consistently does not interact with the filter material overall pollutant load reductions will be reduced.

The challenges of field based bio-filtration testing have had a large impact on this investigation. As discussed above the first relates to the level of confidence in the construction against the design. The second relates to the measuring actual rain events. In this study there was not a rainfall event significant enough to allow event-based testing of the filter performance and collection of such data remains a priority. As a consequence synthetic runoff was generated, noting that repeatability and representativeness of inflow sample varied significantly. While there is no "standard" stormwater runoff used, the use of a spiked creek sample from contaminated street sweeper water provided a viable alternative. While this method resulted in exceptionally concentrated runoff against a range of parameters it nevertheless was able to demonstrate the performance of the two types of rain-gardens.

Cu, Pb, Zn did not show the changes as found in column experiments such as reported by Hatt *et al.* (2007) which found mean reductions in excess of 92% across a range of analytes. Notable however was that the sandy loam reported a reduction in reduced total Pb by 75% and total Zn by 86%.

Results from the Ecomedia indicate a lower removal rate that that obtained in laboratory studies. The maximum removal rates in Garden 2, containing Ecomedia, was 19% for Pb and 41% for Zn. Laboratory studies reported removal rates of Zn to be as high as 93% (Seelsaen *et al.* 2006). It is however acknowledged that the main focus of studies using organic material in stormwater filtration devices is the capture of dissolved metals (Seelsaen *et al.* 2007, Seelsaen *et al.* 2006). No testing was carried out to determine what percentage of the total metal concentration was in dissolved form as part of this pilot study. An apparent net increase of Cu from both media may be due to the source of the media. As the data set is small more testing is required to further investigate this preliminary finding.

The data in Table 3 and 4 suggest that sandy loam is better at removing total heavy metals than the Ecomedia.

Overall the study tends to suggest that sandy loam is better than the Ecomedia at reducing the pollutants as monitored. Of the 16 analyses conducted for each garden, eight analytes returned no conclusive indication of a difference between the media, while eight others indicated sandy loam media as a better media, including four heavy metals (Cr, Ni, Pb and Zn).

## CONCLUSION

As with numerous WSUD projects many issues encountered during the construction phase would have been avoided if a proper briefing session had been held with the contractor and the designer, and if the design engineer was required to inspect the works at key points. This again reinforces the need for closer liaison between the design engineer and the contractor as both sides of the industry increase their knowledge and practice in this emerging field.

The results from the hydraulic conductivity testing reinforce the need to obtain a better understanding between the three major drivers of rain-garden design: surface area, conductivity and ponding depth. While laboratory testing is necessary to refine the relationship between these variables to achieve best management practice, field testing of units should not be overlooked to validate modelled and laboratory tested claims. This applies equally to the design parameters of soil characteristics and other materials and how readily the construction and materials market can respond to and deliver against these exacting requirements.

While accepting the limitation in sampling data and construction of the rain-gardens contrary to specifications, the sandy loam garden in particular demonstrates a degree of robustness through the sustained reduction in pollutant concentrations. The Ecomedia appears to require more exacting construction standards to achieve its predicted effectiveness.

The case study presented in this paper demonstrates an example of WSUD in practice within a retrofit situation. As this initial report relies on a limited amount of data, the efficacy of this project is yet to be fully validated. As such, monitoring will continue to be undertaken during rainfall events within the catchment and through the use of synthetic stormwater.

From an integrated water management perspective projects such as the one presented need to be designed and promoted as having multiple benefits. These include managing the discharge and improving the quality from small frequent storms at the local scale, providing broader water conservation gains across the urban area whilst also providing important improvements to community facilities through stormwater reuse. Without this broader perspective, investment into these emerging technologies may be short lived particularly if results are seen as one off trials involving minor sub-catchments, rather than their application as part of a broader catchment based treatment train.

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paper twenty

# Water reuse for golf course irrigation – a case study within the Ku-ring-gai local government area

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paper twenty

# Water reuse for golf course irrigation – a case study within the Ku-ring-gai local government area

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## Abstract

The use of treated effluent or stormwater to irrigate open space recreation facilities is not new; however, integrating these water sources to meet all current water demands for recreation areas, including high quality salt sensitive turf grasses, is fast becoming a reality. This paper provides a case study in the development of an integrated water management project to secure a long-term supply of water to irrigate a public and a private golf course. The project grew from a review of potential water options for two public golf courses at Gordon and at North Turramurra. This review focused on stormwater and groundwater reuse and wastewater and leachate recycling. Later investigations identified a potential opportunity to hydrologically link Gordon Golf Course to Killara Golf Course, a nearby private facility. This analysis narrowed the project to stormwater reuse and wastewater recycling. Underlying the development of this project has been the need to: secure a reliable and cost efficient source of water; improve the condition of the courses; minimise off-site impacts from stormwater; other runoff to the adjacent bushland areas; ensure unrestricted access to the golf courses; and protect the health of residents and users. The project has evolved amid changing legislation, government policy and industry standards. To its advantage, the project has occurred throughout a period of extended drought, which in turn has driven community awareness of the need to explore new options to reduce the reliance on potable water supplies. The paper outlines the process undertaken in developing the project and in particular the lessons learned that are relevant to other similar projects.

*Keywords:* Golf course, irrigation, integrated water management, stormwater reuse, sewer mining and wastewater recycling.

## 1. Background

The current drought cycle affecting Sydney commenced in 1998. The NSW Government introduced Level 1 water restrictions in October 2003, which were subsequently increased to the current Level 3 which limits, among other things, the use of potable water to irrigate open space areas with sprinklers and watering systems certain times on Mondays only. In October 2003 Sydney's dams were at 58% of capacity and they have since fallen to a low of 33.8% in February 2007 [1]. These restrictions, coupled with the prospect of an extended drought and an increase in population as projected by the NSW Government's metropolitan strategy [2], prompted the then Minister for Utilities and Energy to say, in *The Sydney Morning Herald* 17 April 2004 that "*within 5 years, certainly 10 years there will be no outdoor playing field or golf course that will be using potable water*". This situation, in combination with the foreseeable tightening of access to potable water and promotion of alternative demand and supply strategies as identified in the Metropolitan Water Plan [3], has led many land managers such as Ku-ring-gai Council to investigate alternative options for water supply.

The Ku-ring-gai Local Government Area (LGA), situated on Sydney's North Shore, is approximately 16km from the city centre. It is characterised by low density residential housing situated within landscaped gardens. Three National Parks adjoin the LGA with a skyline dominated by canopy trees. The LGA has two public and four private golf courses as well as 164 parks and ovals. The combined water use for all council owned sites in 2002/2003, pre-water restrictions, was 151,932 kL, of which 16,928 kL and 9,072 kL was used at the two public golf course of North Turramurra and Gordon respectively.

Unlike many public golf courses in NSW, Gordon and North Turramurra Golf Courses return an income to council through green fees. This contributes to their maintenance and funds future capital improvements. In order to ensure the sustainability of these facilities, there is a need to continually upgrade the courses to meet player expectations. In the past this has been achieved through the redesign of the course layout and upgrade of greens and tees. More recently the focus has been on improving the player surfaces requiring among other things the investment in an automated irrigation system. The obvious impact of this strategy will be an increase in the use and cost of water that must be considered in an otherwise potable water restricted environment would reduce the dependence on rainfall to provide natural watering. Water consumption averaged over the 5 years to February 2003 at Gordon Golf Course was 25.4 kL/day and at North Turramurra Golf Course was 30.4 kL/day. In the period of below average rainfall from October 2002 to February 2003 the average daily water use increased from 44 kL/day to 62 kL/day at Gordon Golf Course and 50 kL/day to 118 kL/day at North Turramurra Golf Course.

### *1.1. Management of water by local government in Sydney*

The primary role of metropolitan councils in the management of the urban water cycle is focused on stormwater for the purpose of flood protection and maintaining water quality. Planning and other regulatory powers related to water quality and lesser extent water conservation are controlled though State Environmental Planning Policy such as the Building Sustainability Index (BASIX) 2004 [4], various government publications such as the Floodplain Development Manual [5], guidelines from the Department of Environment and Climate Change [6, 7, 8, 9 and 10] and industry associations such as the Institution of Engineers Australia [11] and 12].

More recently, the gazettal of the *NSW Water Industry Competition Act 2006* has enabled all councils to become water service providers. This was a function previously held under monopoly Sydney Water Corporation. This Act, in combination with the direction of the NSW Government's Metropolitan Water Plan [3], has resulted in a new set of policies and guidelines that are providing direction and certainty for water reuse and recycling projects in Sydney and elsewhere.

For Ku-ring-gai Council, various water supply strategies have been investigated including stormwater, groundwater, leachate from retired landfill sites and recycled sewerage (Muston & Associates [13]). An analysis of these options identified that for Gordon Golf Course, located at the bottom of a 68 ha residential catchment (including the total course area), stormwater reuse and sewer mining would be the most reliable options to meet long term supplies.

### *1.2. Stormwater*

While Ku-ring-gai receives approximately 1300 mm of rainfall per year, the reliability and regularity of stormwater to meet the irrigation needs of open space areas requires large and often expensive storage solutions. This is further limited by the location of open space areas within the stormwater catchment was undertaken by Storm Consulting [14], focusing on the capacity of stormwater to meet the irrigation needs of Gordon Golf Course, identified a shortfall in supply based on a cost/benefit analysis that specifically costed the size of various tank storages. In the Storm Consulting study the potential harvestable yield was assessed through a daily rainfall time-step water balance model. A maximum harvestable right of up to 10 per cent of the catchment runoff was assumed, based on advice from the (former) Department of Infrastructure, Planning and Natural Resources. This equated to a maximum storage volume of 3.2 ML, based on an area of 24.6 ha available for harvest average rainfall of 1,300 mm/year and a runoff rate of 10 percent. From the water balance model, the cost/benefit from increasing storage beyond 2 ML fell significantly against a number of irrigation regimes. These regimes included a lean watering schedule (limited to tees and greens being watered 3–5 times per week) to generous (including the full watering of fairways once every 2–3 weeks in summer). The estimated percentage of demand met by the two scenarios with a 2 ML storage is summarised in Table 1. The approximate water consumption was 200–250 KL/day for greens and tees and 525 KL/day for irrigating the entire course. Rainfall was modelled against the mean and 33 percentile rainfall years as determined from local rainfall records from 1947 to 2002. Based on this modelling the security of supply was calculated against the demand (irrigation) regimes for the various storage options, as shown in Table 1 for the 2ML storage.

**Table 1 Percent of total demand supplied by stormwater with 2ML storage**

| | Average year (1995) | | Low rainfall year (2001) | |
|---|---|---|---|---|
| | Lean watering regime | Generous watering regime | Lean watering regime | Generous watering regime |
| Tees and greens | 92 | 85 | 80 | 74 |
| Tees, green and fairways | 76 | 68 | 60 | 53 |

### *1.3. Groundwater*

In the northern suburbs of Sydney groundwater resource are found deep within the Hawkesbury sandstone. There are a number of wells in the region that require a depth of greater than 150 m to extract around 1 to 4 L/s. Further to the north, yields reduce to 0.5 to 1 L/s with required well depths ranging from 100 m to 150 m. The groundwater is generally high in salts with concentration of total dissolved salts (TDS) from 1100–1200 mg/L (Roseville) to 2000 mg/L (Chatswood) with one bore reported to have salinity of 1400 mg/L (advice from former Department of Natural Resources in Muston & Associates [13]).

There are a number of challenges associated with the use of groundwater including significant extraction costs, the need for further treatment or dilution to meet the horticultural needs of certain turf species (particularly those used in golf course greens and tees that have a maximum salinity tolerance of 800 mg/L TDS), the long term sustainability of the supply and the risks associated with establishing a productive bore. All of these factors tend to suggest that this supply option is not viable for many applications in the LGA.

### *1.4. Sewer mining*

The sewer network across the LGA forms part of the North Head sewerage treatment catchment operated by Sydney Water Corporation. With 95 per cent of developed areas in the council being residential, the quality and reliability of the effluent is generally good. Like the stormwater system, the sewerage network is predominately catchment-based, relying on gravity flow. This limits the siting of any potential sewer mining plants and/or their ongoing pumping and operational costs. There are three sewer lines located within the Gordon golf course, joining near the western boundary. These sewer lines have a combined sewage flow rate of 450 kL/day. Approximately two thirds of this would be available for recycling with the remainder needed to maintain a minimum flow in the sewage system, it is important to note that the majority of the 450 water recycling schemes in Australia are larger centralised municipal schemes. Sewer mining operations in Australia are still limited in number and size, although support for such schemes has been growing since finalisation of the Management of Private Recycling Water Systems guideline by the former Department of Energy, Utilities and Sustainability [15] and sewer mining policy by Sydney Water Corporation [16]. Internationally, there are examples of growing trends for more decentralised reuse schemes. For example, in Japan there are some 1500 urban reuse schemes, many of which are in-building schemes using membrane bio-reactors and with integrated low footprint, high product quality treatment. In Japanese cities such as Fukuoka, larger buildings are required to adopt water saving measures including rain-water harvesting and in-building greywater treatment and reuse systems (Wintgens *et.al* [17]).

### *1.5. Landfill leachate*

In the Ku-ring-gai LGA there are two retired landfill sites that currently require leachate control under licence from the Department of Environment and Climate Change. One is located adjacent to the North Turramurra Golf Course; the other is near the St Ives Showground on Mona Vale Road. Flows vary with rainfall but the long-term average flow for treatment is estimated to be 26 L/day [13]. Utilising this supply both reduces the trade waste cost and potential environmental impact to discharge the leachate to the Sydney Water sewer as well as utilising a reasonably reliable water source that is in close proximity to the golf course.

## 2. Sustainable options

Following the decision to investigate both sewer mining and stormwater harvesting as a combined strategy to meet the irrigation needs of Gordon golf course, Ku-ring-gai Council commenced discussion with Sydney Water Corporation, the Department of Energy Utilities and Sustainability (DEUS, now the Department of Water and Energy), Department of Health and Department of Commerce, all of which were co-operative and assisted with the conceptual development and progress of the project.

During the early stages of the project Sydney Water Corporation and DEUS were in the midst of reviewing the regulations, policies and procedures needed for sewer mining projects and associated private recycled water systems. The Federal Government was also revising the national guidelines for water recycling projects, as released later in 2006. The changes to the approval and regulatory process and determining what standards would apply were, and still are, causing some confusion as to the eventual process for the passage of the project.

In 2005, as part of the NSW Government's commitment to water conservation, the Water Savings Fund was announced. In the course of developing an application to the Water Savings Fund, Council explored an opportunity to hydraulically link a sewer mining plant located at Gordon golf course with Killara golf course, which is only 500 m away. This would maximise the use and provide some economy of scale for any infrastructure required for this project. Presently Killara golf course operates a significant river extraction and storage scheme via an existing 12.5 ML dam drawing from Lane Cove River through a licence administered jointly by the (then) Department of Natural Resources and the Department of Environment and Conservation. This licence is due to expire in 2017, and as such the Killara Golf Club saw an opportunity to plan for its long-term water needs.

Ku-ring-gai Council secured financial assistance to offset the costs associated with the pioneering nature of the project from the first round of the NSW Water Savings Fund. The project as funded proposed to employ stormwater reuse and waste water recycling as combined water supply options for Gordon and Killara golf courses.

### *2.1. Feasibility study*

A feasibility study was undertaken by Storm Consulting [18] to assess the capacity of a stormwater reuse and water recycling / sewer mining to meet the irrigation and other non-potable needs of Gordon and Killara golf courses. This study investigated three water demand scenarios including operating the courses as separate facilities, being hydraulically linked (with Killara still able to draw water from Lane Cove River under their existing licence) and finally, with Killara no longer having access to this supply (once the licence expires in 2017). The Storm report investigated the options for integration and optimised water balances, storage and transfer capacities for three different watering regimes (lean, median and generous) across average and dryer rainfall years. The report also investigated the impact on soil and turf across both courses arising from the quality and quantity of treated effluent and stormwater from the potential build-up of nitrogen, phosphorus and salts.

The report concluded that the option of integrating stormwater harvesting on both sites and sewer mining located at Gordon golf course was a feasible and sustainable water supply option. There would be some stress occurring in dry years, particularly when Killara golf course did not have access to extracted river water owing to the limits in available sewerage. While there is a current flow rate in the sewer is of 450 kL/day, only 300 kL/day was estimated to be available to ensure a minimum operational flow for the sewerage system. In terms of stormwater harvesting, the report concluded that there would be no benefit in transferring these flows between courses. This is because both the current and proposed capture and storage regimes at the facilities would benefit from any local rain event as the golf courses are only 500 m apart. The report also investigated and made recommendations on potential efficiencies in irrigation systems to reduce water demand.

The quality of water was a specific concern given the sensitivity of bent grass to salt. This turf type is most commonly used for greens and tees with an upper limit tolerance of 800 mg/L of total dissolved solids (TDS) [19] compared to the more tolerant varieties used on fairway having tolerances up to 1200 mg/L of TDS. The report concluded that even during dry years, when salt is most likely to accumulate, there would be no effect on plant growth. An analysis of the phosphorus and nitrogen concentrations from reclaimed water reported no leaching of nitrogen or leaching of phosphorus beyond 1 metre in depth over 15 years of irrigation. It did however suggest current fertiliser rates would need to be reviewed for appropriate nutrient management in light of the use of recycled water.

### *2.2. Risk management*

In September 2005 Council hosted a Risk Management Workshop involving all potential project partners, stakeholders and relevant regulatory agencies. The methods of the workshop sought to identify the major risks across four areas including business, technical, environmental and occupational health and safety and community and public relations. This differed somewhat from the (then) draft National Guidelines for Water Recycling 2005 [20], though still adopted a proactive approach to identifying the major risks of the project in its entirety. The risks were assessed against a likelihood and consequence matrix. Those risks that were identified as highly likely and or almost certain to occur and with major or catastrophic consequences are summarised in Table 2. Possible responses to each of these were identified and have been factored into the overall project plan.

This risk planning focused on operational aspects at Gordon Golf course only, as at that time, Killara Golf Club management had not committed to the project. Representatives from the Killara Golf Club were, however, involved in the workshop along with other nearby land managers such as Macquarie University that were investigating opportunities for sewer mining. The absence of a risk analysis relating to the involvement of Killara Golf Club was a short coming though the project though later the deficiencies in terms of contractual arrangements between Ku-ring-gai Council and Killara Golf Club, particularly access, entitlement, water quality and other matters regarding the capital and operational costs of the project have been noted and pursued.

**Table 2 Summary of significant risks based on likelihood and consequence matix**

| | **Major consequence** | **Catastrophic consequence** |
|---|---|---|
| **Almost certain** | Reliability of sewerage supply<br>Quality of supply<br>Reliability of power<br>Need for appropriate levels of water storage<br>Need to assess groundwater contamination | Nil |
| **Highly likely** | Need for appropriate levels of treatment<br>Need to manage plumbing cross connections<br>Need to manage salinity<br>Manage irrigation and operating hours to minimise impact on public | Operational and maintenance costs |

### *2.3. Guidelines, regulatory framework and legislation*

#### 2.3.1. Quality

The water quality standards established for the project were based on the high risks posed by the location of the golf course. There was a need to manage potential pathogen exposure for players and nearby residents, reflecting unrestricted access of the public to the golf course. At the time the most appropriate guidelines were the then draft National Water Quality Management Strategy guidelines [20] and the Australian Water Association water quality guidelines for recycled water [21]. It was considered that these two documents would meet the requirements of the NSW regulatory agencies including DEUS and NSW Health, while building on the NSW Department of Environment and Conservation guideline on use of effluent for irrigation [22]. Table 3 provides a summary of the four-star rating Council has set for the level of water quality treatment for the project. [21].

**Table 3. Wastewater recycling standards**

| Star rating | Treatment type | Compliance values | | End use |
|---|---|---|---|---|
| Four Star ☆☆☆☆ | Advanced Treatment Further treatment in addition to primary, secondary and tertiary treatment. Treatment may involve natural processes such as artificial wetlands or conventional, multimedia or membrane filtration and other advanced processes. May be 'tailored' to a quality suitable for the specific end use | SS | < 10 mg/L | Dual reticulation<br>Unrestricted residential use<br>Industrial processes<br>Irrigation of food crops eaten raw |
| | | $BOD_5$ | < 10 mg/L | |
| | | Thermo-tolerant coliforms | < 1 in 100 ML (in 95% of samples) | |
| | | Total coliforms | < 10 in 100 mL | |
| | | Virus | < 2 in 50 L | |
| | | Parasites | < 1 in 50 L | |
| | | Turbidity | < 2 NTU geometric mean | |
| | | pH | 6.5 – 8.0 | |
| | | Colour | < 15 NTU | |
| | | Disinfection | Dependent on disinfection type | |

### 2.3.2. Approvals

For this project Ku-ring-gai Council must obtain approval from the Minister for Land and Water Conservation pursuant to section 60 of the *Local Government Act 1993* to (b) construct or extend any water treatment works and to (c) provide treated sewage to any person. The new Department of Water and Energy (DWE) would be the determining authority for the approval; however, there are no specific guidelines yet for local government related to sewer mining plants. The most relevant document relates to private recycling water, a guideline that is still in draft form [23]. It is, however, envisaged that most of the requirements for private schemes would also apply to local councils when seeking approval from DWE in terms of the approval, validation, operation and reporting on the sewer mining scheme.

As the proposed project will connect to and discharge into Sydney Water Corporation's sewer infrastructure, the approval of Sydney Water is also required. According to the guidelines and policies that apply when connecting to Sydney Water's sewerage systems, and when extracting and returning waste to the sewerage systems [16], three agreements are required:

- A "works agreement", governing the construction of the connection point to the sewer
- A "sewer mining agreement" outlining the terms and conditions of the sewer mining connection
- A "trade waste agreement" defining the allowed discharge of by-products into Sydney Water's sewerage system.

In the course of discussions with Sydney Water since the inception of this project in 2004, Sydney Water has indicated that there would be no fee for the taking of sewerage. However, Sydney Water's sewer mining policy explicitly states that it cannot guarantee or give any warranty regarding the quality and quantity of sewage that may be taken and that its permission to take sewage is conditional on there being sufficient sewage flows as determined by Sydney Water to ensure the minimal operational requirements of the sewer. In effect such approvals would constitute a licence agreement for the project.

In terms of the approvals process under the *Environmental Planning and Assessment Act 1979 (EPAA)*, a recent amendment to the Regulation (the *Environmental Planning and Assessment Amendment (Designated Development) Regulation 2007* (gazetted 1 March 2007)) has clarified that certain sewer mining facilities would not be prescribed or designated development. Relevantly for Council's project, the new Regulation requires the intended processing capacity to be less than 750 kL per day. This means that Council's project would require Part V development approval under the EPAA and relevant local planing instrument.

Notably, the Independent Pricing and Regulatory Tribunal (IPART) has undertaken a review of the pricing arrangements for recycled water and sewer mining covering the Sydney Water Corporation area [24]. The Tribunal decided not to make a price determination for sewer mining, instead stating that any terms and conditions for a sewer mining agreement should be negotiated between the respective parties [24. pp 4-5, 67]. Importantly the Tribunal acknowledged that sewer mining is likely to become a more prominent alternative source of water to meet growing demand and that the private sector will play an increasing role in balancing the supply/demand for water and related services [24. p69]. Sydney Water, DWE and others acknowledge the increasing role of the private sector in the water and waste water market, there has been a notable absence of discussion of the role of local government in urban areas where large utilities such as Sydney Water Corporation have, until now, held the monopoly for water and waste water services.

### *2.4. Community consultation*

During the development of the project Council has taken an open approach to keeping key stakeholders informed and has involved them at all stages of the planning. Regular briefings have been held with the Gordon Golf Club Board, club representatives were involved in the Risk Management Workshop, and the broader community and nearby residents have been advised of plans and developments through newsletters and direct mailing of relevant information.

In 2006 a community survey was undertaken as part of a research project by the Cooperative Research Centre for Irrigation Futures and University of Western Sydney to establish the level of awareness of local communities of the environmental issues associated with stormwater harvesting and sewer effluent reuse on golf courses and playing fields within the Ku-ring-gai local government area [25, 26]. A survey was sent to 4472 residents in the sub-catchments around Gordon and Killara golf courses as well as to golf club members. A total of 468 responses from residents and 505 responses from club members and players were received.

The responses to four key questions regarding the use of alternative sources of water for irrigation reported:

- 85% of residents and 88% of golf club players and members would accept alternative water sources under current water restrictions
- 89% of residents and 93% club players and members did not object to the use of alternative water for irrigation
- 86% of residents and 81% of golf club players and members saw the greatest benefit of an alternative water supply as being a reduction in potable water use

- The greatest concern regarding alternative water supply reported by residents was health (43%) and, by golf club players and members, cost (39%).

In terms of objections to alternative water sources, the main issues raised included the need to use alternative water sources for irrigation only, ensure the water is safe, the cost of treating effluent, general health concerns, the possibility of runoff damaging creek water quality, smell, not being fully informed and not knowing the standard of the water quarter/ treatment. Further consultation and briefings will be undertaken as part of the project development once the technology and timetable have been determined through the procurement process.

### 2.5. *Expression of interest and selective tendering process*

A two-part procurement process was used to identify selected companies to undertake the design, construction and operation of the project. An expression of interest (EoI) was called in August 2006 seeking interested companies to design, gain the necessary approvals, construct and operate a recycled water facility (sewer mining plant) and a stormwater reuse facility and to design and construct the associated irrigation within Gordon golf course. The EoI identified a single contract would be awarded for the whole project. Information was sought across nine areas including the proposed methodology, capability, experience and indicative costing for the design, construction and operation of the sewer mining, stormwater harvesting and irrigation infrastructure. A total of 13 companies responded to this EoI from which three were invited to the selective tender phase, following an evaluation and interview with a smaller number of companies.

The three tenders were then assessed across four main areas including a general evaluation, technical assessment specifically looking at the sewer mining proposal, financial assessment of the tendering company and a review of the costs by a quantity surveyor. These tenders are currently being evaluated and a decision from this process has not yet been concluded.

## 3. Lessons learnt

Recognising that this project is one of the first of its type undertaken by local government, there is much experience to be gained and lessons to be learned.

### 3.1. *Modelling*

There is a need for careful and considered planning including good modelling based on sound data. Water balance modelling must consider a range of rainfall scenarios and have agreed methods to determine runoff that inform the potential of stormwater harvesting [28] and how this supply option may integrate with sewer mining plants where such facilities will need to be flexible in terms of their supply. Different tolerance levels to salts presents a range of challenges to size and optimisation of the irrigation system components including storage and supply source.

The type and cost of water storage too is an important consideration. This needs to factor the security of supply and capacity of any treatment system, the benefits and limitations of open storages such as partial UV disinfection versus evaporative losses, maintenance and aesthetic costs of above and below ground storage tanks and so forth. The requirement to look at soil/ nutrient balance and potential for salt build-up is also an important aspect as part of the modelling to ensure no long term health implications for turf, soil or groundwater. While not applicable for this site, acid sulphate soils or saline affected groundwater/soils would also need to be considered as part of the project design.

### 3.2. *Guidelines and approvals*

Given the emerging nature of sewer mining as a water recycling strategy, guidelines and policies are still being developed. To a large extent these are drawing from those developed for sewage treatment plants and agricultural reuse applications. There is growing recognition of stormwater harvesting as a reuse strategy. As a consequence, new guidelines are emerging, however most of these lack legislative enforcement. This project developed against an environment of emerging and changing legislation and policies. This was a major challenge – the partnerships Council developed with relevant government department and agencies assisted greatly in managing this challenge.

It is important to note the absence of specific guidelines for urban councils. Regulators appear to be using the same approach used for the private sector; greater clarity on this important aspect is necessary.

### 3.3. *Risk management*

A key challenge was the need to manage risks associated with technology and ensuring appropriate water quality, maintenance costs, asset deprecation and replacement while avoiding adverse environmental impacts or impacts of noise or odour on nearby residents. The arrangement between Ku-ring-gai Council and Killara Golf Club is yet to be finalised. Each party will need to evaluate the final risks and benefits of the project.

### 3.4. *Tendering and contract*

The tendering and contracts (design, construct and operate) process presented many new and varied challenges to a metropolitan local government council which is not a water supply authority. Whilst the Department of Commerce provided some assistance, the contract documentation and evaluation process has been unnecessarily complex in the absence of a template tender, reporting schedules and evaluation framework.

### 3.5. *Financial management*

The costs of the project are such that the real cost of water is higher than the current potable supply, although this assumes some degree of availability. This is in part offset by the NSW Government's grant as part of the water saving fund. The costs of constructing and operating large storage facilities, particularly covered or underground storage tanks, are substantial, as are the costs for above ground storages given the impact of evaporative losses. These are important issues to be assessed for project and could be offset through other management practices. Technology for sewer mining is in a rapid growth phase, resulting in the costs for operations varying considerably between proponents. This directly impacts on the ultimate financial evaluation and long term financial planning for the maintenance of such facilities. Assessment of construction costs also requires a greater understanding of associated utility expenses such as access to energy.

### 3.6. *Partnerships and water service providers*

The development of an agreement between Ku-ring-gai Council and the private Killara Golf Club, as well as with the relevant agencies and regulators, were important aspect of the project. Any arrangements need a firm contractual basis; this has not, as yet, been developed as part of this project. Changes to the water market have meant that urban councils, and others, can now enter the water market to complement and compete for supply options. However the regulatory processes for this are not yet fully developed.

### *3.7. Consultation*

An important aspect of any project of this nature is maintaining an open and ongoing dialogue with the key community stakeholders. In particular, it has been important to engage members of the golf clubs and nearby residents to develop community support for the project. The success of any consultation tends not to be known until the final planning approval and operation begins.

## 4. Conclusion

In Australia the improved performance and reduced capital and operating costs of small scale treatment plants suitable for sewer mining (mostly including a membrane treatment phase) has enhanced the potential for recycling. Adoption and acceptance of such plants, however, has been limited. As a result their use is still seen as a higher risk proposition. As waster restrictions and government policy drive greater efficiencies and innovations in water demand and supply, sewer mining and stormwater reuse will become mainstream. Presently, there is much to learn from projects such as this one for government agencies, utilities, local councils, community and the private sector. It is clear the process and answers are still being developed.

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paper twenty one

# Implementing a water recycling scheme by local government in Sydney

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paper twenty one

# IMPLEMENTING A WATER RECYCLING SCHEME BY LOCAL GOVERNMENT IN SYDNEY

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## ABSTRACT

The paper summarises the experience of Ku-ring-gai Council in the planning, procurement and approval of a sewer mining facility to supply recycled water to irrigate Gordon Golf Course. The project faced a number of challenges including a rapidly evolving and in some cases novel waste water technologies, proliferation of companies wanting a share of this emerging market, changing regulatory and legislative requirements, having to respond to emerging national and state water recycling guidelines and changes to the project's scope. Within the Sydney metropolitan area, this project is one of only a few water recycling facilities of this type operated by local government or the private sector. This in itself can be seen as a significant policy shift by the NSW Government towards a decentralised water market particularly noting it has financially assisted all three approved sewer mining projects. For Sydney Water Corporation the development of guidelines to facilitate such projects also heralds a change in the management and reuse of sewerage. While the project is small in scale (300 kl/day), it nevertheless represents a valuable demonstration exercise from which other local councils, golf course managers and others can learn. This paper discusses the lessons from the project which are particularly relevant to those within and planning to enter the water recycling industry.

## BACKGROUND

The Ku-ring-gai Local Government Area (LGA) is situated on Sydney's North Shore, approximately 16 km from Sydney. There are two public and four private golf courses as well as 164 parks and ovals in the LGA. The combined water use for all council owned sites in 2002/2003 (pre-water restrictions) was 151,932 kL, of which 16,928 kL and 9,072 kL was used at the two public golf course of North Turramurra and Gordon respectively. The irrigation system at both of council's golf courses has been gradually upgraded and automated and is presently limited to irrigation of greens and tees.

Following extended periods of drought and introduction of water restrictions, options for an alternative water supply to make the irrigation of the golf courses independent of the potable supply were investigated. Alternatives included stormwater, groundwater, leachate (from retired landfill at North Turramurra) and sewer mining (Muston & Associates (2005).

An analysis of these options identified that for Gordon Golf Course an integrated supply system combining harvested stormwater and sewer mining would be the most reliable option to meet long-term supplies (Davies and Muston 2007). Further studies by Storm Consulting (February 2006) identified the potential to harvest stormwater. This study also modelled the impact of different irrigation scenarios and their respective storage requirements (Storm Consulting March 2006). During the investigation phase of the project Killara Golf Club, located less than 500 metres from Gordon golf course, approached council in relation to its future water requirements. This golf course has an existing licence to extract water from Lane Cover River that is due to expire in the medium term. These discussions identified a potential partnership to integrate the water recycling supply option to both courses and provide long term water security as well as sharing in the capital and operating costs. From a demonstration project perspective, it also provided an additional dimension as a public and private collaboration.

## PLANNING

Project planning considered five outcome areas including water management, asset management, community and stakeholder engagement, technology and the approval and procurement process.

### Water management

Water management focused on reuse and recycling and improving the condition of the stream within the Gordon Golf course. A primary objective was to reduce the use and reliance on potable water supply. Demand management was also considered as part of a future design of an expanded irrigation scheme resulting in no watering of flight areas (approximately the first third of the fairways).

During the early stages of the project it was envisaged that the creek running through Gordon Golf Course would be rehabilitated. This was to incorporate bed and bank stability providing habitat through pool and riffle sequences with connectivity to the adjacent bushland area.

**Asset management**

A major factor influencing significant upgrades to the golf course has been the limitations of the irrigation scheme. While it has been progressively improved over the past 10 years to cover the greens and tees, the fairways and general landscaping have had to rely on rainfall and occasional manual watering. This is labour intensive and is a major contributor to the operational cost of the facility. It has also limited the redesign and configuration of the course to meet the ongoing expectations of users.

As Gordon Golf Course is an income generating asset to council, its ability to meet player needs and expectations is directly related to its immediate and long term financial sustainability.

**Engagement**

Engagement covered five identified stakeholder groups including those within council, community, users of the facility, Killara Golf Club and relevant government agencies.

For Ku-ring-gai Council the scale and complexity of the project necessitated a cross organisational focus. This included asset planning, development control, environment, finance, legal, media, operations, policy and procurement sections. Staff were brought together at relevant stages to ensure all aspects were considered and to work towards collective agreement to the final project outcomes. The project itself was instrumental in justifying the development of an integrated water cycle management policy and strategy adopted in 2008 (Ku-ring-gai Council 2008).

For the local community, incorporating residents and golf users, the project provided an opportunity to shift social norms on the use of recycled sewer and harvested stormwater. The level of community acceptance of stormwater harvesting and sewer reuse on golf courses and playing fields was measured through a social survey project in collaboration with the University of Western Sydney and Cooperative Research Centre for Irrigation Futures (Schwecke *et al* 2006, Schwecke and Davies 2007). The responses to four key questions regarding the use of alternative sources of water for irrigation found:

- 85% of residents and 88% of golf club players and members would accept alternative water sources under current water restrictions;
- 89% of residents and 93% club players and members did not object to the use of alternative water for irrigation;
- 86% of residents and 81% of golf club players and members believed the greatest benefit of an alternative water supply scheme would be a reduction in potable water use; and
- the highest concern for alternative water supply schemes reported by residents was health (43%) and by golf club players and members was cost (39%).

The main issues raised included in the survey included:

- that the use of alternative water sources be limited to irrigation;
- that the water would be safe;
- potential health concerns;
- odours;
- not knowing the standard of the water quality/ treatment;
- the cost of treatment;
- the impact of runoff damaging creek water quality; and
- not being fully informed of the project.

Notwithstanding these issues, the users of the public course at Gordon saw the project as being able to deliver a “greener” (and presumably better) course moving closer to the standard of the private courses in the area.

Following the discussions with Killara Golf Club in regards to its medium term water future, a memorandum of understanding was developed between the Club and Council to progress the project as a joint initiative. This was initially scoped around sharing the financial cost of undertaking relevant studies related to the project planning with a view to entering into a contract. The most obvious benefit from this arrangement was the potential to share in the financial costs and risks associated with such a project. At the time, Killara Golf Club identified that while the recycled water would not be needed immediately, it would be required in the medium term when its existing river extraction licence expired.

Assisting with the project at various levels were Sydney Water Corporation, Department of Commerce, Department of Water and Energy (formally Department of Energy, Utilities and Sustainability) and Department of Health.

Initially this was one of only two such projects in Sydney, the others being at Beverley Park Golf Club under the direction of Kogarah Council (Chanan and Ghetti 2006). As such there was considerable interest in determining where and how such projects fit with government policy and regulation as well as who would be the approval authority. More recently Pennant Hills Golf Club (Dahl 2008) also became an early adopter of sewer mining and that project, which was developed in a shorter time frame, became the test case for the draft guidelines for private water recycling schemes using sewer mining (DEUS 2006).

**Technology**

Technologically there were very limited numbers of water recycling plants in Sydney that had obvious comparability in terms of size and performance for open space irrigation and were at a cost relevant to local government. The two closest examples were Taronga Zoo that is within the confines of the zoological park and Sydney Olympic Park which is much larger in scale (Radcliffe 2004). As such it was necessary to investigate the merits of various technological solutions interstate and internationally. This in itself presented a project risk with the relatively conservative nature of local government wanting to see first hand successful applications of what was on offer. Added to this is that within Sydney, local councils are not responsible for water treatment, supply and waste water management and so projects of this type effectively expand responsibilities and risks without the internal staff expertise and experience in this field.

**Approval and Procurement Process**

At the time of commencement of the project, there were no guidelines on how to plan or obtain approval for sewer mining projects. Similarly there were no adopted national or state water quality standards for sewer mining projects. To overcome this, the water quality standards used at the expression of interest stage specified that the water quality was to meet the needs for irrigation of the golf courses (and within the documentation it was noted access was unrestricted) and for other non-potable needs (such as toilet flushing in club house amenities and green keeping equipment washdown). In effect this left the respondents to determine if and how their respective treatment technologies could manage the health risks that was then considered as part of the evaluation criteria. The evaluation of performance used within the expression of interest and tender drew from the NSW Recycled Water Co-ordination Committee (1993) and star rating system developed by the Australian Water Association (2002).

From a procurement perspective, there was no tender documentation or contract from which to immediately draw upon. With the assistance of the NSW Department of Commerce, the NSW Government GC 21 (edition 1) as amended contract was used in the tender process.

**Changing Operating Environment**

The approval process for a sewer mining project for a metropolitan council within the jurisdiction of a water authority (such as Sydney Water Corporation) was not well established. During the project there were a number of government policy changes that progressively clarified this situation. Most notably were the release by Sydney Water in May 2006 of the *Sewer Mining – How to establish a sewer mining operation* guideline (SWC 2006), and various draft guidelines by the Department of Energy, Utilities and Sustainability from 2006 to the most recent Interim Guideline for Management of Private Water Recycling Schemes (DWE 2008). This particular guideline however does not formally apply to local government being a public entity. In the absence of other directions, the tender specification and conditions of approval referred to the then draft guideline (DEUS 2006) in term of the standards of documentation, management, reporting and monitoring.

As the proposed project would connect to and discharge into Sydney Water Corporation's sewer infrastructure, its approval was also required. During the planning phase the draft Sewer Mining Guideline and Policy was released (Sydney Water Corporation, 2006) that removed previous uncertainty and spelt out the requirement for three agreements:

1) a "works agreement", governing the construction of the connection point to the sewer;

2) a "sewer mining agreement" outlining the terms and conditions of the sewer mining connection; and

3) a "trade waste agreement" defining the allowed discharge of by-products into Sydney Water's sewerage system.

Also occurring during the project planning was a review of the pricing arrangements for recycled water and sewer mining covering the Sydney Water Corporation area by The Independent Pricing and Regulatory Tribunal (IPART 2006). The Tribunal decided not to make a price determination for sewer mining, instead stated that any terms and conditions for a sewer mining agreement should be negotiated between the respective parties (IPART 2006, pp 4-5, 67). Importantly the Tribunal acknowledged that sewer mining was likely to become a more prominent alternative source of water to meet growing demand and that the private sector will play an increasing role in balancing the supply/demand for water and related services. This had the potential to impact on future negotiations with Killara Golf Club as to the price or access to water.

***Legal framework***

Under the NSW *Local Government Act 1993 section 60* requires approval by the Minister for Land and Water Conservation for any council to construct or extend any water treatment works or to provide sewerage from its area to be discharged, treated or supplied to any person unless it falls within the Area of Operation of Sydney Water (*Sydney Water Act s56 (1)(a)*). As Ku-ring-gai Council falls within the jurisdiction of Sydney Water (*Sydney Water Act section 10(1)*), approval is subject *to section 68* of the *Local Government Act* unless it is deemed that the proposal is to be operated under the authority of a licence pursuant to the *Protection of the Environment Operations Act 1997 (NSW)*.

From a planning perspective, amendments to the *Environmental Planning and Assessment Amendment (Designated Development) Regulation 2007* (gazetted 1 March 2007)) clarified that certain sewer mining facilities (approximately twice the size of the one proposed) would not be prescribed or classed as designated development, therefore subject to *Part IV of the Environmental Planning and Assessment Act* 1997 (EPPA). As a consequence *Part V* of the *EPAA* formed the mechanism from which development approval was determined along with relevant local planing instruments.

For Ku-ring-gai Council this meant it would be both the applicant, approval authority (s68 LGA) and determining authority (Part V EPAA). From a licensing perspective the scale of the water recycling plant also meant that it is was not subject to an operating licence pursuant to *Schedule 1* of the *Protection of the Environment Operations Act 1997*.

Amidst these changes to legislation, Ku-ring-gai Council had a Planning Panel appointed by the Minister for Planning on 3 March 2008. This Planning Panel has various roles including determining development applications worth more than $30 million or which have not been determined within 90 days. In the case of the development application lodged to council on this project, its review extended beyond the 90 days and therefore fell to the Planning Panel to determine. Prior to this and as part of the internal review by council staff, the application was referred to the Department of Water and Energy (DWE) and NSW Department of Health for their comment. Responses from these organisations formed part of the council officers' report to the Planning Panel that was eventually incorporated within the 46 approved conditions of consent.

**Risk Management**

A risk management workshop held in October 2005 early in development stages of the project. This involved the actual project partners at the time and also potential project partners (such as Killara Golf Club), relevant regulatory agencies and other stakeholders including adjacent landholders and users of the golf course. The methods of the workshop sought to identify the major risks across four areas including business, technical, environmental and occupational health and safety and community and public relations. Risks were assessed against a likelihood and consequence matrix. Those risks identified as highly likely or almost certain to occur and with major or catastrophic consequences are summarised in Table 1

*Table 1 Summary of significant risks based on likelihood and consequence matrix*

| | **Major consequence** | **Catastrophic consequence** |
|---|---|---|
| **Almost certain** | Reliability of sewerage supply<br>Quality of supply<br>Reliability of power<br>Need for appropriate levels of water storage<br>Need to assess groundwater contamination | Nil |
| **Highly likely** | Need for appropriate levels of treatment<br>Need to manage plumbing cross connections<br>Need to manage salinity<br>Manage irrigation and operating hours to minimise impact on public | Operational and maintenance costs |

For many of these risks, it was determined that these could be overcome as part of the design specifications for the project, in effect ensuring adequacy back-up or system capacity. Storage volumes and potential impact on ground water were raised resulting in further technical investigations (Storm Consulting Pty Ltd March 2006). The quality and reliability of treatment of the sewage and subsequent health risks was a significant factor that was the subject of the specification and review at both the expression of interest and tender stages.

WATER QUALITY SPECIFICATION

The specification for the water quality was determined by two factors health risk and impact to turf and soil.

As the a site has unrestricted access, the human health criteria adopted early on in the project was one consistent with third or purple pipe water reuse schemes in urban areas (NSW Recycled Water Co-ordination Committee 1993) or four star water (AWA 2002). This standard sought to increase public confidence in the project particularly given that there are many households and a primary school that back onto the site. There was also a potential for use of the recycled water in the clubhouse for toilet flushing and maintenance shed for washing down of green keeping equipment that added to the health risks. From the research undertaken as part of a social research project (Schwecke *et al* 2006; Schwecke and Davies 2007), the standard went a long way towards reflecting the expectations regarding treatment of the community and golf course users.

As guidelines for recycled water were being reviewed or developed during the planning of this project, the specific performance criteria for treated water created an additional level of uncertainty as part of the tender process.

At the time the most appropriate guidelines were the draft National Water Quality Management Strategy Guidelines (EPHC and NRMMC 2005) and the Australian Water Association water quality guidelines for recycled water (AWA 2002). It was considered that these two documents would likely meet the requirements of the NSW regulatory agencies. As noted previously, a draft guideline was in preparation by the NSW Department of Energy, Utilities and Sustainability that was released in March 2006. This has since been issued as an Interim Guideline in 2008 (DWE 2008). The approach adopted by the Department has followed a risk exposure risk matrix, consistent with the national standards (Natural Resource Management Ministerial Council Environment Protection and Heritage Council Australian Health Ministers' Conference 2006). This has sound rational decision protocols necessary for any regulatory compliance regime and for professionals. However from a communication perspective to the broader community a simple "star" rating system (one to five star, the latter being drinking water) as outlined by the Australian Water Association (AWA 2002) has been found to be more easily understood.

For the golf course, the major factor was the capacity of the turf and soil to endure higher levels of salts than otherwise present in potable water. In particular the concentration of total dissolved solids (TDS) had to be within the upper limit tolerances (less than 800 mg/L) of the sensitive turf grasses used on the course especially during prolonged dry periods (South Australian Department of Water, Land and Biodiversity Conservation 2007). For this reason additional limits on TDS to match the application for turf grass irrigation were specified.

PROCUREMENT

The procurement model chosen was a two stage tender with a public call for Expression of Interest followed by a selective tender. For council this allowed for flexibility in the choice of technology, performance and as a means to manage financial risks. For industry this reduced the time and cost demands required of an open tender and for the selected tenderers enabled them to finalise sub-contractors. Evaluation of both stages utilised the skills of the Department of Commerce and various technical specialists consultants and government department representatives across water, engineering, quantity surveying, legal and financial areas.

An Expression of Interest (EoI) was called in August 2006. This divided the project into two phases. The first was for the design, construction and obtaining of the necessary approvals for a recycled water facility, stormwater harvesting scheme and irrigation system. The water recycling scheme was to be built at Gordon Golf Course and was to provide the water needs to this course and to Killara Golf Course. The stormwater harvest facility was specifically for the benefit of Gordon Golf Course to provide a supplementary water source. Similarly the upgrade of the irrigation scheme was limited to Gordon given the limitations of the current system. The second phase was the operation and maintenance of the sewer mining and stormwater harvesting facilities.

Information was requested across nine broad themes including the proposed treatment method for both water recycling and stormwater harvesting, capability of lead and subordinate parties, past experience (both general construction and that related to the water sector) and an indication of the cost to design, construct and operate the water treatment facilities.

From this EoI process three companies were invited to submit a tender for the project. The tenders were assessed on similar criteria but with greater weighting on the financial criteria. As a risk management process, an independent financial assessment was undertaken on the tenderers as well as having the technology independently reviewed and construction estimates revised by a quantity surveyor.

Just prior to making a recommendation to Council in respect of the tender process, Killara Golf Club unexpectedly withdrew from the project. As a consequence Council resolved to reject all tenders and commence negotiations with each of the tenderers with respect to a change in scope. This included removing all works associated with the supply of water to Killara Golf Course and eliminating the stormwater harvesting element at Gordon Golf course as this additional supply would not be necessary to meet the local water demands. The decision to preference the sewer mining over stormwater harvesting was based on two main factors:

- a greater reliability in the supply of sewerage that was not weather dependent; and
- the need for less storage on the course (space and cost considerations).

The tender review and subsequent negotiations with the selected tenderers were inherently difficult. Technologically each system was different ranging from established processes (such as membrane bioreactors) to newer relatively untested technologies (while promising these were not yet operating in similar applications and so represented a high risk). Combined with the other weighting factors of price, experience and other externalities, the successful tender was Econova Pty. Ltd. Their treatment process consisted of screen, flow balance tank, sequence batch reactor followed by a flat plate submerged ultra-filtration (UF) membrane bioreactor and disinfection using both UV and chlorination. Capacity was caped to 300 kL/day based on early discussion with Sydney Water Corporation as to the maximum off take from the sewage system.

The most recent development at the end of 2008 was that the tenderer has had an administrator appointed under the *Corporations Act 2001* (cth). At the time of writing the Council had yet determined the future course of action, though noting the contract with the tenderer was conditional on a deed of agreement with a guarantor.

## LESSONS LEARNT

### Time and learning processes

The more obvious lesson from this project has been the time it has taken from moving the project from a concept in early 2005 to obtaining planning approval mid 2008. Construction is anticipated to start early 2008, once the Sewer Mining Agreement has been granted by Sydney Water Corporation and following resolution arising from the appointment of an administrator.

In many respects this project along with Beverley Park (Chanan and Ghetti 2006) and Pennant Hills (Dahl 2008) has provided local and state government with an iterative learning process that has informed the development of interim guidelines for private recycled water schemes (DWE 2008) and the development of the guide by Sydney Water on how to establish a sewer mining facility (SWC 2006).

For local government the rules and process for procurement and determining who is the approval entity and for what have been the most significant factors contributing to the project's delay. On reflection it is probable that these elements will contribute the greatest with respect to future local government projects for councils that are within the operations of larger water authorities.

### Collaboration and partnerships

Collaboration and partnerships have been both a strength and in some perspectives a downfall to the project. Engagement with and support from key government agencies, specialists and consultants enabled a more robust process and outcome. The time the project has taken however has meant many individuals present at the start of the project have since moved on, necessitating continual briefings and updates.

The fortuitous collaboration with the University of Western Sydney and Cooperative Research Centre for Irrigation Futures provided an additional element of social science and rigour. Ascertaining community understanding and support for the project as part of a Doctoral research thesis lessened the need for a more extensive education program to inform and "sell" the idea of a local water recycling and reuse facility to the community.

The initial agreement with Killara Golf Club and mutual benefits that the project partnership could have achieved may well have been realised if this was subject to a formal contract from the outset of the partnership rather than a memorandum of understanding. However as with all organisations, views and priorities shift and this must be recognised as an ongoing matter for consideration in all collaborations, particularly for project that seek to change institutional priorities and norms.

### Financial and economic issues

As is the case for most early adopting projects, risks are a significant area of concern. This is true for both government and private schemes. Financial support from the NSW Government Water Saving grant program played a vital role in securing the initial and ongoing support by Ku-ring-gai Council.

The future for similar projects however remains a little uncertain. This mostly turns on financial resources and policy drivers at all levels of government and global trends in manufacturing and construction of relevant technologies.

In NSW, local government is subject to rate capping effectively limiting the ability to raise the capital necessary for such projects. While other funding sources are available (such as grants and special rates) the perceived risks for metropolitan councils to enter the water market (albeit as an internal supplier) may be too great. At a state government level, the cost and access to potable water has not reached the critical threshold that would drive substantial reform to the water market (such as decentralisation in supply).

In recent years the current State Government has concentrated much of its water planning and resources towards a desalination plant at Kurnell in combination with a range of demand management and large scale recycling initiatives by Sydney Water. While the 2006 Metropolitan Water Plan (NSW Government 2006) offers a diversity of supply, demand and environmental policy directions, on-ground investment in similar smaller scaled decentralised water-recycling schemes in the Sydney area have to date been few and far between.

**Technology**

Within the manufacturing industry membranes and associated technologies have become more efficient and have lower unit costs per litre of water However, in the last 12 months these gains have been off-set by the general rise in construction and materials cost associated with demands for commodities in China and elsewhere.

The technology used in this project is relatively complex. It is foreseeable that in order to get greater buy in by local government and the irrigation industry, future schemes need to be made more robust and flexible. This should be accompanied by an increase in the standardisation of treatment performance and the provision of modular systems allowing for up and down scaling and differential treatment levels if standards increase in the future.

Future technologies also need to be such that they can be easily and reliably operated with routine maintenance capable of being undertaken by staff who do not have high levels of specialised skills or training. While some other schemes do already use greenkeeping staff for the day to day operations (such as Pennant Hills Golf Club) there are still inherent risks in this approach that need to be managed.

**Community acceptance**

Notwithstanding these concerns, community and government acceptance of and expenditure towards water use and recycling has been never higher. The proliferation over the past five years of government policies and guidelines, legislative reforms (enabling smaller sewer mining projects easier passage), improvements to technology and business interest in this area suggest continued growth. The question however is how much, by whom and when.

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# Chapter 7:
# Community understanding of water reuse and recycling

This chapter discusses the results of two social research projects that assessed the awareness and receptivity of the residents of Ku-ring-gai Council to alternative water supplies. Both surveys were undertaken towards the middle of the drought and during the period when the NSW Government had introduced water restrictions. This perceived 'crisis' may have contributed to the community placing a higher value on potable water and the need for alternative water supplies. In addition to the value of this research to explore community preferences and values, it also underscores the high expectations local communities have of their council to deliver community services and facilities.

**Paper 22** presents the results of a broader social research study that asked the community questions related to their general environmental awareness and specific questions on their attitudes to recycled water and use of stormwater with varying levels of contact. The results showed that as the level of personal contact increased (ie from irrigation towards drinking) the acceptance of recycled water decreased. While this is not surprising, the results point towards the respondents having a solid understanding of water recycling, health concerns and to have seriously considered the extent to which they are willing to modify behaviour to achieve environmental outcomes. The results also provides insights into the value of ongoing education and awareness about the health and environmental risks associated with recycled water.

**Paper 23** reports the results of a survey of residents and golf club members on their attitudes and concerns about a proposed sewer mining (water recycling) facility to irrigate Gordon Golf Course (a council owned facility) and Killara Golf Course (a private course). This study reports a high level of acceptance of the use of treated effluent to irrigate the golf courses, provided adequate treatment process are applied. Given that both golf courses are located in the middle of a residential area, this support by both users of the golf course and households immediately adjacent bodes well for the success of water recycling projects in these locations.

paper twenty two

# Understanding community receptivity to water reuse: Ku-ring-gai Council case study

Authors: Brown R R and Davies P J

Publishing details: *Water Science and Technology* (2007) 55(4): 283-290

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paper twenty three

# Community understanding of the use of alternative water sources for irrigation of golf courses: Ku-ring-gai Council case study

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paper twenty three

# Community Understanding of the Use of Alternative Water Sources for Irrigation of Golf Courses: Ku-Ring-Gai Council Case Study

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**Abstract**

As Australian cities have grown, the demand for potable water has gone close to matching, and in more recent times has exceeded, the sustainable supply. Whilst many water authorities procrastinate on constructing new supply schemes, others are increasingly turning to demand management and alternative supply options to achieve a more sustainable balance. New initiatives rely on customer acceptance, understanding and appreciation of the limited supply of potable water and the proposed alternatives.

This research project assessed community awareness of and receptivity toward a proposal to use alternative water sources to irrigate two golf courses. The project was based in the Ku-ring-gai Council local government area, located in the northern region of Sydney. The results were also compared against a 2004 social research study that investigated community receptivity to using rainwater and grey water as alternative domestic water services.

The results reveal very strong support for the use of alternative water supplies for irrigation of golf courses. Public health was the major issue identified by respondents that could affect the feasibility of the proposed water recycling scheme. Users of the golf course were slightly more supportive than residents, and were also more concerned with the cost of such a proposal. A comparison of data from this project with the 2004 study showed slightly higher levels of acceptance of the use of alternative water as a potable supply. While the use of recycled water for various domestic purposes was not specifically examined in this current study, the results suggest a growing understanding, awareness and confidence in the use of new technologies to meet urban water demands.

## Introduction

The current drought and projected impacts of climate change are forcing most cities in Australia to re-examine their water futures. With this has come a significant push for reuse of stormwater, recycling of effluent and changes to building design that seek to minimise the use of potable water (NSW Department of Planning, 2005; NSW Government, 2006; Bowmer, 2004; and Connell, 2005).

In Sydney the Minister for Utilities and Energy was quoted in *The Sydney Morning Herald*, 17 April 2004, as saying that "*within 5 years, certainly 10 years there will be no outdoor playing field or golf course that will be using potable water*". It is certainly the case that the drought has led to deterioration in the quality of urban playing fields, golf courses, parks and gardens. In some cases facilities have been closed, resulting in immediate social consequences within the affected communities (Frew 2006). To offset this dilemma, many open space managers are looking at alternative solutions such as more drought tolerant plants, synthetic turf or water reuse and recycling schemes (Parry 2005). While technical feasibility of these solutions is one aspect, the most significant consideration in the decision making process is the community's acceptance (Po *et al*, 2005; Marks *et al*, 2002; Leviston *et al,* 2006; Marsden and Pickering, 2006).

The community's acceptance of water reuse schemes has been the subject of significant social research in recent years that has found decreasing levels of acceptance as the degree of contact has increased (Po *et a*., 2004; Melbourne Water, 1998; Sydney Water, 1999; Brown and Davies, 2006; Clarke and Brown, 2006). More recently, research undertaken by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia has found that trust and emotions are strongly involved in people's decision to accept or reject reuse schemes, although surprisingly health risks were found to be not as significant as previously thought (Po *et al* 2005). Interestingly these results do not reflect the continual advancements in the treatment process for recycled water making it safe for direct potable reuse, with Leviston *et al* (2006) finding public health continuing to be the main reason for not completely accepting alternative water sources.

Ku-ring-gai local government area (LGA) is located approximately 15 kilometres north of the Sydney CBD and is characterised by low density residential housing (86 per cent live in a separate houses) set within highly landscaped gardens with significant amounts of canopy trees. The age structure of the community reflects a significant number of persons in the family age group most notably children in school age groups (5-17) and their parents in their thirties and forties, but also had a notable share of its population in the 'empty-nester' and retiree age groups (50-69). The majority of residents are from an English speaking background with education levels across the LGA being amongst the highest in Australia (ABS 2002).

This follows an earlier study in 2004 (Brown and Davies 2006). It also sought to provide more up to date information following Council's detailed investigation and feasibility study into the construction of a combined stormwater harvesting and sewer mining facility at Gordon to meet the irrigation and other non-potable water needs of Gordon and near-by Killara Golf Course (Table 1). During the development of the questionnaire, Council was awarded a grant by the NSW Government to progress this project under the first round of the Water Savings Fund.

It can be seen from Table 1 that the amount of water used between the two golf courses varies considerably. Significantly, the Gordon golf course is owned by Council, while the Killara course is privately owned. The higher water usage may reflect a higher standard of greens upkeep required by managers of the privately owned course.

**Table 1**: Irrigation needs of Killara and Gordon Golf Courses and size (ha)

| | **Gordon Golf Course** | **Killara Golf course** |
|---|---|---|
| **Ownership** | Public – owned and managed by Ku-ring-gai Council | Private – owned and managed by Killara Golf Club Limited |
| **Area (ha)** | 33 | 50.5 |
| **Average water use pre restrictions (ML/yr)** | 9.3 (1) | 51.5 (2) |
| **Number of surrounding residential properties** | 71 | 147 |
| **Rounds of golf played per year (2006)** | 48,634 | 40,000 |

Notes
1. potable water only
2. water extracted from Lane Cover River under licence

## Research methodology

The researchers developed a questionnaire in order to ascertain the community's awareness of and attitudes alternative water sources. The survey was sent to 4372 households bounded approximately by the hydraulic catchments upstream and immediately downstream of the golf courses across the suburbs of Gordon and Killara, and to members of Killara Golf Club.

Copies of the survey were made available to members and players of Gordon Golf Club. The questionnaire consisted of 27 (twenty-seven) questions, including 12 (twelve) demographic questions, that sought quantitative and qualitative responses on the community's opinions regarding Council's proposal to use recycled effluent and harvested stormwater to irrigate golf courses and playing fields within the Ku-ring-gai LGA. Surveys and responses to the questionnaires were divided into four groups: residents adjacent to or living within 50 metres of the golf courses; other residents outside the 50 metre buffer area although within the immediate hydraulic catchment of the golf courses; member/players of Killara golf club/course; and member/players of Gordon golf club/course. This was undertaken to identify any differences in proximity to the golf courses and that of public and private course members and users.

All questionnaires received were entered and analysed using Statistical Package for the Social Science (SPSS) software. Frequencies and cross tabulations between receptivity and the four groupings were conducted to identify trends and relationships. The data from this survey was then compared against the 2004 survey undertaken by Brown and Davies (2006).

**Results**

Of the 4372 questionnaires distributed, a total of 932 were returned. The highest response rate (26%) to the questionnaire came from Killara golf club members, whilst questionnaires sent to the residential areas had a response rate of 18%. The response rate from residents living within 50 metres of the courses was 18% whilst the rate for those living further away from the courses within the catchment was 17%. Questionnaires were not mailed to Gordon golf club members/players as this information was not made available; it is therefore not possible to obtain a response rate from this questionnaire, although 39 were completed.

The representativeness of the respondents suggests that the data cannot be generalised to other parts of Australia. Most notably 52.5% of respondents were aged over 56 years with a further 24% between 46 to 55 years. These proportions are much higher than similar age cohorts for the Ku-ring-gai LGA and the Sydney Statistical Division area being 26.4 % and 20.4 % for the over 55+ and 15.5 % and 13.2 % for the 45 to 54 ages respectively (ABS 2001). Further 82.8 % reported having some type of tertiary qualification compared with 44.5 % for the LGA and 23.4 % Sydney Statistical Division. Unknown from this data is the representativeness of the responses when taking into account membership and players of both golf courses and residents. Anecdotally, most golf club members within the two clubs would be part of the older age group.

Unlike the Brown and Davies (2006) study, the current study found a lack of statistical variation in the demographics of the responses. Brown and Davis (2006) identified two key demographical variables that influenced the receptivity to water use: Gender; and Cultural Background (Language). Brown and Davies (2006) also noticed a limitation in the cultural background demographic with Non-English Speaking Background (NESB) respondents being under-represented. This finding was similar to the current study that found that NESB respondents made up only 3.9% of the overall responses. Nevertheless, the current study establishes that those from English Speaking Backgrounds (ESB) were found to be significantly more accepting of alternative water sources for irrigating and also had the least concerns with its use (91% for ESB compared with 75% for respondents with NESB).

***Receptivity to alternative water supplies***

The results of the questions seeking respondent's receptivity to alternative water sources for irrigation reported a very strong response rate. For residents, this was 92% and golf club members and users was 97%. Overall eighty three percent (83%) stated a reduction in the use of potable drinking water by the courses as the major benefit of Council's proposal. When asked if they had any concerns or objections about the use of stormwater or effluent treated to the standards set for irrigation by the NSW Government, 89% of residents and 93% of golf club members and users reported they had no concern. However, later in the survey, when asked what they perceived to be the greatest concern with the use of alternative water supplies for irrigation, public health ranked highest (34%), followed by practicality (18%), financial (16%), impacts on the environment (15%) and quality of water (13%) (table 2).

When comparing this result within the individual groups, the impact on the environment from such schemes ranks lower with the golf course members/players that that of the residents. Table 2 provides a summary of the reported issues perceived by respondents as being of greatest concern in using alternative water supplies.

**Table 2:** Perceived issues in using recycled water for irrigation

| Issues | Residents within 50 metres of the courses | Residents in the wider catchment | Killara Golf Club members and users | Gordon Golf Club members and users | Average |
|---|---|---|---|---|---|
| Water quality | 11% | 13% | 14% | 10% | 13% |
| Public health | 32% | 35% | 32% | 39% | 34% |
| Practicality | 23% | 17% | 22% | 18% | 18% |
| Impact on the environment | 17% | 15% | 10% | 3% | 15% |
| Financial | 15% | 16% | 18% | 28% | 16% |

Whilst potable water savings was identified as the major benefit, improvement to the aesthetics of the courses was noted by 13% of respondents as the second most significant benefit. Interestingly 23% of the responses from Gordon Golf Club members and players reported this as the greatest benefit, which may reflect the lower standard of green-keeping of the public course compared with the private course at Killara.

In terms of the feasibility of the uptake of alternative water supplies, cost and health were reported as the main issues, with cost more important to members and players of the golf courses while health was more important to residents. Table 3 provides a breakdown of key aspects reported by survey group. Notably cost was a more significant factor for Killara Golf Club members than Gordon Golf Club members and residents. This presumably reflects the fact that Killara members would pay for the infrastructure and maintenance of a new recycled water system through their membership fees, which could rise with the introduction of such schemes.

**Table 3:** Reported issues affecting the feasibility of the use of alternative water supplies

| Issue | Residents within 50 metres of the courses | Residents in the wider catchment | Killara Golf Club members and users | Gordon Golf Club members and users | Average |
|---|---|---|---|---|---|
| Health | 42% | 43% | 36% | 57% | 40% |
| Cost | 38% | 33% | 40% | 34% | 37% |
| Impact on plants & animals | 9% | 11% | 8% | n/r | 10% |
| Water quality | 8% | 11% | 15% | 9% | 13% |

Note: n/r = no response

In the 2004 survey by Brown and Davies (2006), the focus was primarily of residential reuse and recycling. This survey reported similarly high responses for reuse and recycling schemes with 94% receptive to the use of filtered rainwater for garden use and 95% for treated recycled grey water for garden use. The issues raised by respondents were similar, citing safety, health and the need for regulated standards. Other issues raised in the focus groups in 2004, but not raised in this 2007 survey, included lack of trust of government agencies and difficulties with changing community attitudes and perceptions. These latter two factors arguably may have changed over the period as water reuse and recycling has been a key area of public debate by media, politicians and government agencies. Of note, Po *et al* (2006) found that those with high levels of education tended to have higher trust in authorities and also perceived greater pressure (to drink) recycled water than those with lower education levels. Given the high levels of eduction generally in Ku-ring-gai and specifically by respondents such recycling schemes may encounter less trust concerns as identified by Po *et al* (2006) within the LGA.

### *Behaviour changes*

The community's acceptance of recycled water appears to be dependent on its source. Rainwater harvesting into rainwater tanks from household rooftops is considered to be more acceptable than the use of greywater and treated wastewater at a domestic household scale (Po *et al.* 2003). In this study at the household level, 60.5% of respondents said they were willing to install a rainwater tank, with 24.5% responding 'maybe' and 7.3% having already done so. In terms of modifications to landscaping within households, 28.3% were willing to reduce the amount of impervious surfaces and 46.7% were willing to increase vegetation on their property. The higher figure for vegetation may reflect the strong garden culture in the Ku-ring-gai LGA enabled by large block sizes.

### *Environmental concerns*

Over all 24% of residents perceived a potential environmental risk (terms of affecting creek biodiversity or environmental flow) in using alternative supplies and 35% were uncertain (Table 4). This indicates a need to establish an environmental risk management plan and communicate this to players and residents. Golf course members/players (17%/14%) were less concerned than residents (18%/25%). The residential response could be due to their stronger association with the adjacent or near by bushland and creeks than golf club members and players that may live further a field.

**Table 4:** Respondents' reply to whether they could see any perceived environment risk in harvesting stormwater

| Response | Residents within 50 metres of the courses | Residents in the wider catchment | Killara Golf Club members and users | Gordon Golf Club members and users | Average |
|---|---|---|---|---|---|
| **Yes** | 18% | 25% | 17% | 14% | 24% |
| **No** | 39% | 41% | 56% | 73% | 41% |
| **Maybe** | 43% | 33% | 27% | 14% | 35% |

Differences between responses are also seen in the question that asked respondents to identify the top priority for stormwater management. As summarised in Table 5, golf course members/players had a much stronger positive response to the option of harvesting stormwater for irrigation than residents, with immediate environmental benefits of stormwater being of less priority for golf members/players.

**Table 5:** Top priorities for the management of stormwater

| Stormwater Management Priority | Residents within 50 metres of the courses | Residents in the wider catchment | Killara Golf Club members and users | Gordon Golf Club members and users | Average |
|---|---|---|---|---|---|
| **Flood management** | 19% | 19% | 15% | 21% | 19% |
| **Protecting rivers** | 15% | 15% | 12% | 10% | 15% |
| **Protecting bushland** | 2% | 4% | 3% | 0% | 4% |
| **Improving water quality** | 15% | 11% | 6% | 3% | 11% |
| **Harvesting for irrigation** | 48% | 51% | 64% | 67% | 50% |

## Research implications and Conclusion

The research findings identify a very strong support for the use of alternate water schemes to provide irrigation across public and private golf courses. This is not surprising given previous research within the LGA and more broadly as it relates to water recycling projects that involve lower levels of contact. The priority for the management of stormwater revealed some interesting results that could suggest an increase in the perceived value of potable water and the need for better use of alternative water supplies to meet lower standard water needs.

Whilst these results suggests a growing understanding of the water supply problems facing much of Australia, further examination could be undertaken as to how the community prioritises and accepts a range of alternate water options from stormwater harvesting to sewer mining and leachate recycling, all projects that are have been tentatively identified as sustainable water options for the management of public open spaces within the Ku-ring-gai LGA.

This study did not reveal any demographic difference in responses, with the exception of respondents from NESB who had lower acceptability rates towards the use of alternative water for irrigation, and more concerns/objections about its use than those of ESB. However NESB respondents only made up 3.9% of the total responses. A variation between residents and club members and players was also identified in relation to the perceived risks for establishing alternative use schemes.

The news is good for space managers contemplating water reuse schemes. It seems the community is becoming increasingly aware and supportive of projects that recycle water for non-potable use. This would indicate the community placing a higher value on potable water and an awareness of the threats to its continuing sustainable supply. The community's rider would appear to be that such projects need to be meet health expectations and standards and be affordable. Similarly the type or source of water and the standards of treatment along with environmental risk management must be clearly articulated to avoid any health and environmental concerns in addition to avoiding any misunderstanding by the community.

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# Chapter 8: Discussion

This thesis examines some of the primary drivers influencing the management of urban water resources in Sydney from a local government perspective. It demonstrates that local government plays a major role in land use decisions and environmental planning and policy and how these impact on the direction and management of urban water resources.

Three major themes of urban water management are discussed in this thesis.

1. Land use planning and development control, with a particular emphasis on riparian systems (Chapters 2 and 3)
2. Environmental protection and management, examining pressures on natural waterways (Chapters 4 and 5)
3. Water demand and supply, through case studies of stormwater harvesting and water recycling (Chapters 6 and 7).

To illustrate the factors influencing urban water management from a local government perspective in Sydney, a theoretical framework has been developed (Figure 8.1). For the purpose of this thesis, local government has been positioned at the centre of this framework. The triangles that intersect within the local government realm represent areas of shared responsibility and are the areas of focus. In reality the centrality of local government in urban water management will depend on where legislative responsibility for direct potable supply and wastewater treatment sits as well as local government's role in assessing and regulating environmental impacts related to catchment management. In many parts of regional NSW water supply and wastewater disposal are the responsibility of local government. In contrast, within the Sydney metropolitan area, these functions are the responsibility of Sydney Water Corporation. The triangle representing this function is therefore disconnected from local government and is not discussed in great detail in this thesis except as a historical driver for urban water management reform (Chapter 2).

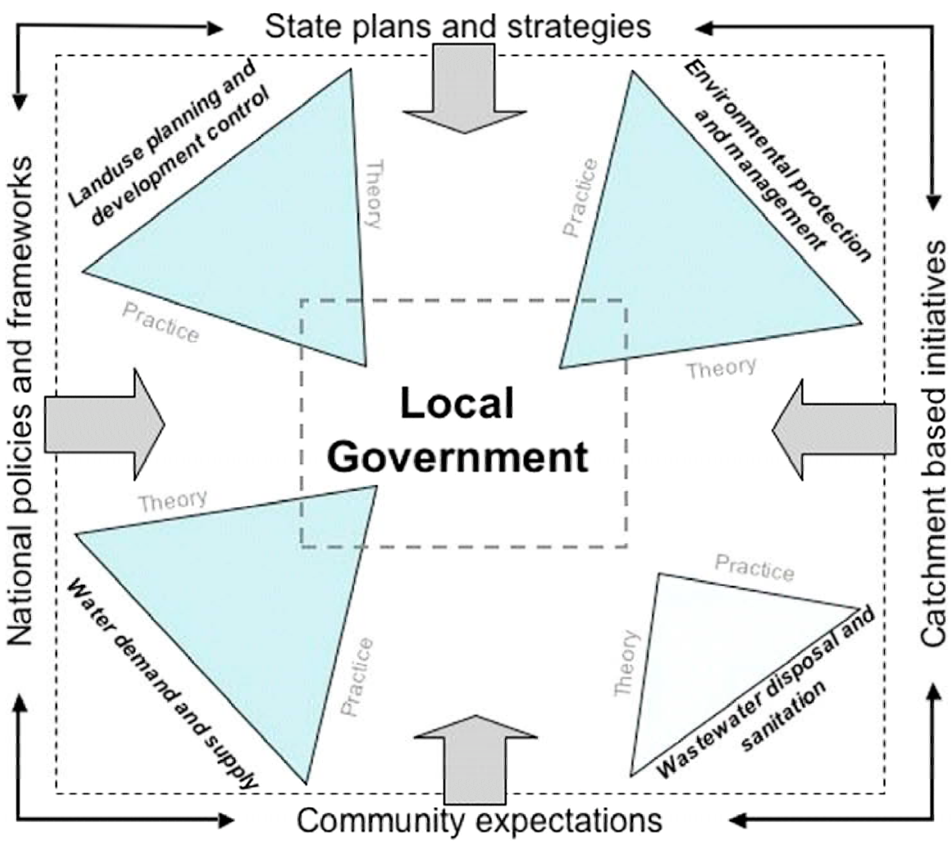


*Figure 8.1 Theoretical framework for factors influencing urban water management from a local government perspective*

Influencing each of the urban water management themes is a tapestry of strategies and policies that guide development and regulation (Figure 8.1). This cascades from broad sweeping priorities set at the national level to local council guidelines for the design and maintenance of on-ground projects (refer to Figure 1.1, Thesis p 3). These policies and guidelines are not always aligned, complementary or consistent, as evidenced by the many shortcomings of the current suite of documents (as discussed in Chapters 2, 3 and 6). Competing priorities and differences in interpretation and site attributes mean the strategic policy objectives within the tapestry are hard to identify and even more difficult to realise. In an ideal world, legislation, policies, guidelines and other planning documents would inform a process of best practice review and continuous improvement incorporating spatial and project scales. This would inform decisions by governments, courts and practitioners. In practice, such review and continuous improvement are uncommon, resulting in a gap between the ideal or theory that emanates from laboratory based research and what occurs in practice and application.

## 8.1 Summary of thesis aims

This thesis has focused on three main these:

1. Land use planning and development control, with a particular emphasis on riparian systems (Chapters 2 and 3)
2. Environmental protection and management, examining pressures on natural waterways (Chapters 4 and 5)
3. Water demand and supply, through case studies of stormwater harvesting and water recycling (Chapters 6 and 7).

Chapter 1 set six aims of this thesis as part of its examination of how water and catchments a re managed across Sydney in a local government context. These aims are achieved by:

- Providing a review and commentary on the historical development and current direction of urban water management in Sydney (Chapter 2)
- Analysing the existing legal and policy frameworks in NSW influencing the management of urban rivers, riparian systems and biodiversity (Chapter 3)
- Using urban and reference streams in Northern Sydney to quantify the difference in the biological heath and chemical characteristics of the two types of waterways (Chapters 4 and 5)
- Assessing the applicability of current guidelines and standards for water sensitive urban design techniques through various case study projects by evidenced based review and evaluation (Chapters 6 and 7)
- Identifying new areas of discovery for the urban water sector, specifically the effect of the concrete drainage systems on urban water chemistry (Chapter 5)
- Proposing a new direction for the urban water sector in terms of policy and planning (Chapter 2), legislation (Chapter 3), scientific understanding (Chapter 5) and WSUD practice (Chapter 6).

Most of the research informing the analysis in this thesis was undertaken within the Northern suburbs of Sydney, specifically in the Ku-ring-gai local government area. The research responded to a range of issues: community expectations to manage and protect the environment, specifically water resources (as discussed in Chapter 7); the drought and subsequent water restrictions (as discussed in Chapters 2 and 7); and statutory directions by the State Government to manage local catchments (Chapters 2 and 3). I have been in the fortunate position, as a senior manager at Ku-ring-gai Council, to influence environmental policy, strategic planning and budgeting and enable the integration of best practice science linking theory to practice and application. Documenting and evaluating the impact of policy reform and operational direction has been a key driver for this thesis. While the development pattern, geology and policy frameworks are specific to this region, the findings in this thesis have relevance for the direction of water sensitive cities for local government in Sydney, nationally and internationally as well as the broader urban water sector.

The following discussion draws on key insights presented in the preceding chapters. As the published papers and conference proceedings present their own discrete discussion and conclusions, this chapter seeks to distill the major findings of each in the context of the three major themes of this thesis as stated above, and to identify some guiding principles and opportunities to better manager urban water resources.

## 8.2 Land use planning and development control

Legal, planning and policy arrangements in NSW have historically provided limited protection to urban riparian environments. As presented in Chapter 3 Paper 1, this is due to four main factors:

- inadequate legal definition of a 'river' as defined in legislation and interpreted by the courts in Australia and specifically NSW
- the traditional approach to rivers as having only a utilitarian function to manage flooding (Brown (2005))
- a limited appreciation of riparian areas as a biodiversity resource
- a failure to recognise the cumulative impacts of development on biodiversity described as 'death by a thousand cuts' (Bradsen (1992)) and on river health as 'death by a thousand pipes'.

### *8.2.1 Revised definition for rivers*

Chapter 3 Paper 1 proposes a new legislative definition for a river to include intermittent streams. This would simplify much of the legal discussion by the NSW Land and Environment Court as to whether a water course is defined as a river under the *Water Management Act 2000* NSW, but more importantly recognise that Australia's geomporphology and climate are different from England where the current common law definition has evolved (as discussed by Taylor and Stokes (2005)). This would formalise the judgment by Lloyd J in *O'Keefe v Water Administration Ministerial Corporation* [2010] NSWLEC 9 at 53, who accepted (although possibly for the wrong reasons) that 'in the science of the fluvial geomorphology the words intermittent and ephemeral are regarded as being synonymous'.

### 8.2.2 Definition of a riparian area

New South Wales legislation does not define a riparian area. This is a notable omission given the significant role these systems play in biodiversity management, flood protection and providing a place for recreating. Chapter 3 Paper 1 therefore offers the following definition for a riparian area:

> *The area of land adjacent to a water body showing visible signs of inundation, geomorphic reworking by fluvial processes; or, occupied by organisms that require environmental conditions provided by river processes for all or part of their life cycle.*

### 8.2.3 Value and function of rivers and riparian areas

Chapter 3 advocates for greater emphasis on the value and function of rivers and riparian systems in urban areas (Chapter 3 Paper 1). It reflects on past management practices that, particularly in Australia, have traditionally viewed urban waterways as utilitarian with little regard to their environmental (Chapters 2, 3 and 4) and social functions (Chapters 2 and 7). Contemporary metropolitan water planning has by and large ignored the waterways outside the systems feeding into or from metropolitan water supply systems. Management of these intra urban water resources has, by omission, been left to other urban planning and policy documents. This deficiency was noted by the Chair of the Independent Review Panel for the 2010 Metropolitan Water Plan, Chris Davis, who stated that future plans need to be integrated into urban planning and need to include, among other factors, biodiversity (NSW Government (2010) p 2).

### 8.2.4 Protecting urban water resources and biodiversity using land use plans and policies

Chapters 2 and 3 present a case on how land use plans and policies can support the protection and management of urban water resources and biodiversity. These can summarised into five steps:

1. Review planning instruments
2. Support local planning controls
3. Set realistic and informed targets
4. Consider the impact of changes to urban hydrology
5. Set policy based on area, time and hydrology.

1. Review existing State Environmental Planning Policies (SEPPs), Local Environmental Plans (LEP), regional and local government policies and strategies. As part of such a review the following proposals should be considered.

(a) Develop a consistent set of urban water planning principles. A set of nested objectives should cascade from the National Water Initiative through to local and site controls (scale), as illustrated in Figure 8.2 (also refer to Northern Territory Department of Planning and Infrastructure (2009)). The planning hierarchy (y-axis) should be informed by iterative review and evaluation (as advocated by the findings of this thesis). This would form the basis for a process of continuous improvement driven by the development of theoretical approaches that are then implemented and evaluated in practice at various scales (x axis). A similar approach has been adopted by the NSW Land and Environment Court to inform various planning matters under its jurisdiction, drawing on case law (refer to http://www.lawlink.nsw.gov.au/lawlink/lec/ll_lec.nsf/pages/LEC_planningprincipleshttp://www.lawlink.nsw.gov.au/lawlink/lec/ll_lec.nsf/pages/LEC_planningprinciples, accessed 23 January 2011)

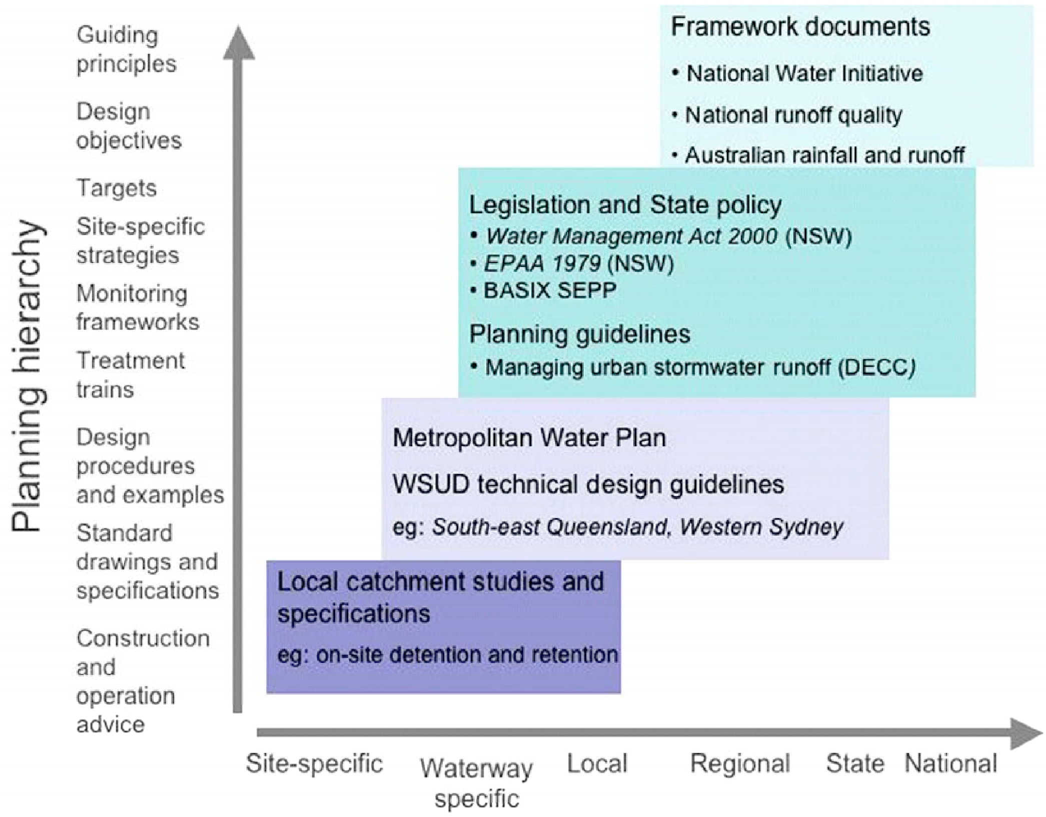


*Figure 8.2 Hierarchy of planning and spatial documents to support integrated urban water management.*

(b) Utilise performance-based controls that relate to land use and the objectives of the catchment. Some environments may be particularly sensitive to changes in the environment such as water chemistry that are influenced by urban geology (particularly concrete, as detailed in Chapters 4 and 5). As advocated in Chapter 3, Paper 1, such performance based controls could follow the lead taken by Queensland in amending their *Sustainable Planning Act 2009* (Qld) to require certain types of development (but not all) to achieve minimum pollution reduction standards to manage impacts on the geomorphology and hydrology of local waterways across various design storms (Queensland Government (2009a), (2009b)), State Planning Policy 4/10 Healthy Waters (Queensland Government (2010b)). This would provide some flexibility as to permissibility of development, underscored by clear minimum standards as to the impact of the activity on the environment.

(c) Provide greater clarity as to what development activities should be exempt or regarded as complying for the purpose of development approval. Exemptions currently permit the installation of many rainwater tanks in an effort to streamline their use in the residential sector. However, as discussed in Chapter 3, Paper 3, there is a lack of policy related research that applies to decisions by local government in relation to biodiversity management. The risk therefore of increasing the types of activities classified as exempt or complying may lead to inappropriate planning decisions if more detailed environmental assessments are not undertaken. With this in mind a traffic light approach could be adopted for both biodiversity and riparian management that could 'green light' certain activities (such as rain tanks and biofiltrations systems to manage stormwater quantity and quality) as exempt or complying, while 'red light' development would result in refusal if a threatened species, ecological community or vulnerable ecosystem may be compromised (Paper 3 p 263).

(d) Support policy objectives that have been underpinned by appropriate and scientifically validated technical documents (ie peer reviewed). This would help bridge the gap between theory and application as advocated by this thesis. These should:

- be catchment specific, as advocated in Chapter 6 and specifically Papers 13 and 16 in relation to the design of stormwater harvesting systems. Evidence of this is emerging in Sydney such as the draft guidelines for MUSIC modelling in NSW (BMT WBM (2010))

- establish best practice in design that would build on the Australian Runoff Quality document published by the Institute of Engineers (Wong (2006)). This should draw on the interim conclusions for the performance of certain soil media in biofiltration systems (Papers 14 and 19), the value of disinfecting stormwater for bacteria control as part of harvesting systems used for irrigation (Papers 17 and 18) and the contribution of concrete and its influence on water chemistry in urban rivers (Chapter 5)
- be informed by relevant and unambiguous technical notes (for example, the South-east Queensland Healthy Waterways Program (Water by Design (2009)) and
- should reflect on the evaluation of past techniques (as discussed in Papers 11–19 in Chapter 6 and in CSIRO (2004)).

2. Encourage and support planning and controls at local level. This could draw on the approaches being actively pursued by some councils in the absence of a state or regional framework. However such an approach needs to be supported by the State Government, for example through an enabling State Environmental Planning Policy (SEPP) or model provisions within Local Environment Plans (LEPs) if it is to gain support from the NSW Land and Environment Court (as discussed in Chapter 3 Paper 1). An example of such a local planning approach (without the explicit support of the Department) has been developed by Ku-ring-gai Council (under my direction), where the Council has:

(a) Mapped the location and condition of most of its urban streams against a validated and peer reviewed mapping protocol (Findlay et al (2005) and Paper 2))

(b) Developed a riparian policy based on best practice and available science (Ku-ring-gai Council (2004))

(c) Linked the riparian policy to its existing Development Control Plan (Ku-ring-gai Council (2005)), and

(d) Developed an Integrated Urban Water Management Policy and Strategy to inform ongoing works and programs (Ku-ring-gai Council (2008a) and (2008b)).

Developing specific and appropriate planning controls at the local level has been the catalyst for many of the projects documented in this thesis in Chapters 3 to 7.

3. Establish realistic goals and targets supported by informative monitoring programs based on and responsive to local conditions. Monitoring programs must respond to the existing condition of the environment, be sensitive to the measurement of the effect of land use policies and also recognise that impacts are complex and variable. Evaluation of the results of monitoring programs should be informed by and be part of the evaluation of the planning hierarchy (Figure 8.2) and be used to critically review past and current data sets to determine if there are any discernable trends in the data. The value of this is evidenced in Chapter 4 Papers 4 and 5 that confirmed the significant difference in macroinvertebrate assemblages between reference and urban waterways but also led to the discovery of the effect of concrete drainage systems on urban water chemistry (Chapter 5). As advocated in Chapter 3 Paper 3, a review of environmental monitoring programs in urban areas should:

- recognise the lack of funding across all levels of government to obtain data of relevant quality
- acknowledge that the data review process is complex and often beyond the scientific skills that reside in local government, and
- prompt the formation of collaborative partnerships within and between all levels of government and with research institutions to broaden the skills base for data analysis, to integrate monitoring programs and combine data sets.

4. Managers of urban rivers should consider the hydraulic changes that arise from the construction of drainage systems (Walsh et al (2010) Chin (2006) and Paper 2), the increase in impervious surfaces (causing a rise in runoff as discussed in Paper 16) and reduction in vegetated areas (lowering evapo-transpiration). Land use control and public drainage infrastructure must be assessed in terms of their effectiveness against various storm events or flows within the catchment. For example, strategies to manage pollutants from urban runoff through biofiltration systems may be effective for showers and certain rain events (Papers 12, 14 and 19) but will be unable to manage the quantity of water experienced in extreme storms. Similarly, flood management policies need only target storm events (Davies and McManus (2004)). Another variable that has not been given attention in this thesis, but is of increasing importance, is the impact of climate change on rainfall and catchment hydrology.

5. Set multi-dimensional policy outcomes covering area, time and hydrology. Drawing on the historical development of urban water management in Sydney (Chapter 2), the planning hierarchy presented in Figure 8.2 and the multi-scale land use planning approach in Chapter 3, Paper 3, spatial scales should form the

basis of both land use and water management decisions. Adapted from Ives et al (2010) (Paper 3), Figure 8.3 (below) is used to illustrate the spatial relationship of land use and water planning decisions.

Panel A represents the extent of the Sydney Metropolitan Water Plan (with a water supply catchment of 16,500 $km^2$) (NSW Government (2010)). At this scale, land use planning decisions would relate to the protection of the urban water supply and consider the impact of wastewater discharges. This scale would also enable consideration of inter-catchment water transfers and the establishment of water grids between water authorities (such as exist in South-East Queensland). At this scale, Federal and State legislation and policy would be the major drivers. Panel B would extend to the developed area of Sydney (exclusive of the water supply catchments). This is informed by the Sydney Metropolitan Plan (NSW Government (2005), catchment action plans (eg NSW Government (2009)), Regional Environmental Plans, Local Environment Plans and State Environmental Planning Policies.

Panel C represents regional to neighbourhood land use planning and policy. At this level the following are appropriate: specific technical guidelines (such as exist for water sensitive urban design for Western Sydney (eg Upper Parramatta River Catchment Management Trust (2004)); local government catchment studies (to consider land use capability in relation to flooding and other water risks[1]); local policies that respond to specific environmental attributes or community priorities (Ku-ring-gai Council 2004)); and the relationship of development to decentralised water supply and waste water treatment schemes (as discussed in Papers 20 and 21).[2]

Panel D represents planning at a lot scale and would be affected by decisions by home-owners, builders and architects. While these would be controlled by higher level planning instruments such as Development control policies (DCPs), many activities would be exempt for example, the installation of certain sizes of rainwater tanks, paving and landscaping.

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1 For example, the Fairfield city overland flood study (http://www.fairfieldcity.nsw.gov.au/upload/ehdnc94953/Fairfield_Overland_Flood_Study.pdf accessed 2 October 2010) that informs the Fairfield City Wide Development Control Plan. Refer to Chapter 11 Flood Risk management (http://www.fairfieldcity.nsw.gov.au/upload/Chapter%2011-%20Flood%20Risk%20Management%20PDF.pdf accessed 2 October 2010)

2 For example, sewer mining facilities may have exclusion zones such as Gordon Golf Course (http://www.sydneywater.com.au/Water4Life/recyclingandreuse/RecyclingAndReuseInAction/SewerMining.cfm accessed 2 October 2010)

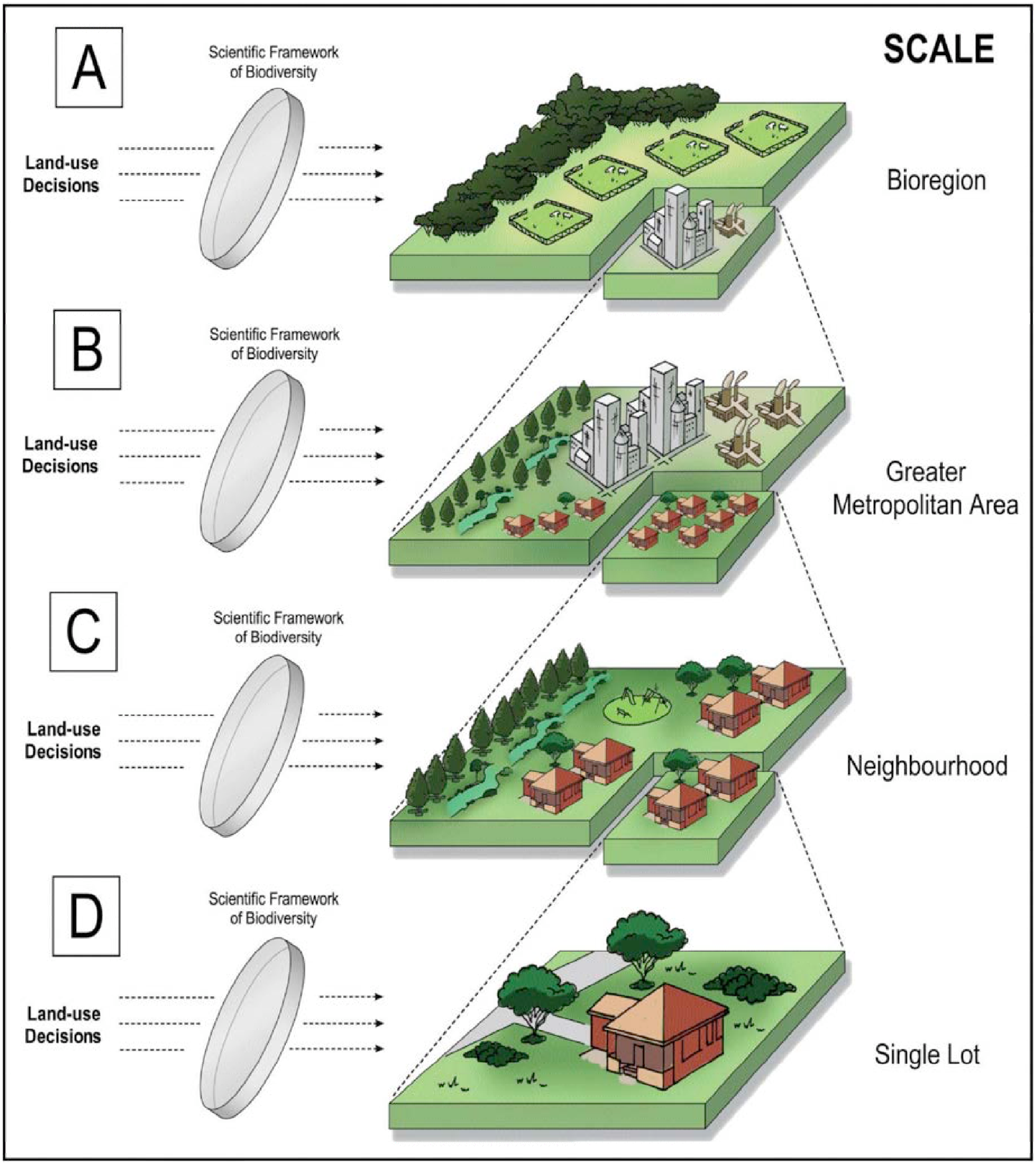


*Figure 8.3 Schematic diagram of the application of biodiversity planning principles at multiple spatial scales (Ives et al 2010)*

## 8.3 Environmental protection and management

The condition of the streams in northern Sydney was investigated primarily in Chapter 3 (Paper 2 – riparian assessment), Chapter 4 (Papers 4 and 5 – macroinvertebrate and water quality) and Chapter 5 (Papers 6 and 10 – water chemistry). These investigations were undertaken to better understand the differences between urban and reference streams in relation to their physical characteristics, steam biota and water chemistry. Table 8.1 below provides a summary of the major findings that are also discussed below.

The research undertaken as part of this thesis (refer to Chapters 4 and 5) concludes that urban streams are distinctly different to reference streams across northern Sydney. The major finding related to the differences in water chemistry between urban and reference streams (Chapter 4 Paper 4 and Chapter 5 Papers 6 and 10), with urban streams highly alkaline (up to nine times greater than reference streams), having a pH approximately one unit higher and having electrical conductivity twice as high as reference streams. In terms of macroinvertebrates (Papers 4 and 5), urban streams contained: lower family richness; fewer pollution sensitive families (lower EPT scores (Lenat and Penrose (2006)), particularly *Leptophlebiidae* taxa; lower SIGNAL scores (Chessman (1995)); and contained two types of snail (*Hydrobiidae* and *Physidae*) that were absent from naturally vegetated streams. Geomorphically, urban streams were characterised by greater similarity in habitat specific assemblages (pool edges, riffles and pool rocks) than naturally vegetated streams that resulted in pool habitats reporting the lowest EPT and SIGNAL scores and using the semi-quantitative rapid riparian assessment method (Paper 2), 61 per cent of the urban reaches measured reported a 'good' or excellent' condition rating, although this is likely a result of the geomorphic features being less influential than the vegetation features as an overall measure of their health (Findlay et al 2005).

The significance of these results is that they confirm urban streams in northern Sydney are degraded and suffer from many of the causative factors contributing to urban stream syndrome (Meyer et al (2005) and Walsh et al (2005)). This research provides insights as to how to protect sensitive environments, which can help set a direction for environmental planning (as discussed in section 8.2 above).

*Table 8.1 Key catchment, water chemistry and macroinvertebrate summary statistics (range and mean) from streams in urban and non-urban impacted areas of Ku-ring-gai local government area*

| **Attributes (catchment, water chemistry, macroinvertebrate)** | **Reference** | | **Urban** | |
|---|---|---|---|---|
| | Range | Mean | Range | Mean |
| Total catchment imperviousness (%) (a)<br>(b) | 0.6-2.5<br>0.4-8.8 | 1.5<br>2.7 | 8.8-36.6<br>12.0-32.1 | 29.5<br>26.5 |
| Connected catchment imperviousness (%) (a) | 0-0.9 | 0.5 | 3.6-36.6 | 29.3 |
| Catchment area (ha) (a) | 133-3277 | 1036.7 | 75.0-742.0 | 482 |
| Total catchment roads (%) (a) | 0.3-1.0 | 0.7 | 5.0-9.5 | 6.4 |
| Total catchment natural bushland (%) (a) | 82.4-93.7 | 89.2 | 0-58.8 | 15.1 |
| pH(a)<br>(b) | 5.1-6.7<br>4.36-6.56 | 5.8<br>5.69 | 5.4-7.4<br>6.04-8.01 | 6.9<br>6.84 |
| Electrical conductivity ($\mu$S/cm) (a)<br>(b) | 144-315<br>148-255 | 189.5<br>193.9 | 133-1084<br>269-743 | 391.3<br>433.1 |
| Alkalinity (bicarbonate) (mg/l) (a)<br>(b) | 1.5-9.0<br>0.5-14.0 | 4.6<br>4.49 | 32.5-53.0<br>28.0-113.0 | 41.3<br>46.91 |
| Calcium (mg/l) (b) | 0.5-6.0 | 3.30 | 12.0-34.0 | 20.24 |
| Sodium (mg/l) (b) | 16.0-45.0 | 23.55 | 20.0-100.0 | 46.55 |
| Chloride (mg/l) (b) | 31.0-82.0 | 48.57 | 42.0-190.0 | 90.05 |
| Magnesium (mg/l) (b) | 2.0-7.0 | 4.05 | 4.0-12.0 | 6.84 |
| Potassium (mg/l) (b) | 0.5-4.0 | 1.87 | 2.0-6.0 | 3.90 |
| Sulfate (mg/l) (b) | 0.5-24.0 | 8.87 | 0.5-27.0 | 13.46 |
| Total macroinvertebrate richness (a) | 10.0-33.0 | 21.4 | 4.0-24.0 | 14.55 |
| SIGNAL score (a) | 5.2-7.8 | 6.3 | 3.6-6.8 | 4.62 |
| EPT richness (a) | 1-8 | 4.3 | 0-5.0 | 0.7 |

Notes: (a) refers to data reported in Paper 4 (b) refers to data reported in Paper 10

## 8.3.1 In-transport processes and urban geology

Prior to undertaking this thesis, there was very limited literature that reported and discussed the variation and possible causes of the difference in water chemistry between urban and reference streams and other waterways. The research presented in Chapter 5 Papers 6 to 10 followed an iterative process of inquiry that has contributed to local and international knowledge on the water chemistry impacts of concrete as a major material used in stormwater drainage and generally in the building industry.

The studies support the findings of increasing levels of conductivity along gradients of urbanisation (eg Rose (2007)) and identify a major cause of this, the concrete drainage system. Of particular note, this thesis has discovered that there is a significant rise in pH, electrical conductivity (EC), bicarbonate levels and concentrations of potassium and calcium recorded in rainwater passing through concrete pipes and gutters over relatively short distances and time (Papers 6–9).

In line with the aims of the thesis, this discovery has questioned the assumption that the concrete drainage system is a benign conduit for stormwater. Rather, Papers 6–9 demonstrate that the in-transport process arising from rainwater passing over gutters (Paper 9) and through pipes (Papers 6, 7 and 8) is significantly altered in terms of its chemistry. The implications with respect to the current management of urban water resources are significant. The findings strongly suggest the need to consider the material composition of the urban drainage network if this is likely to have an effect on the chemistry of the water in the downstream receiving bodies. Presently no WSUD guideline or best practice manual mentions the role of the concrete drainage system on water chemistry. The findings from this thesis support this consideration, particularly if downstream environments may be vulnerable to changes in water chemistry.

At a local level, the research has identified that urban and reference streams across northern Sydney are clearly differentiated by their ratios of cations (sodium and calcium) and anions (chloride and bicarbonate) to their saltiness (total dissolved solids) (Table 8.1 and Paper 10). Reference streams reported ionic chemistries typical of waterways in coastal flowing streams in southeast Australia that are dominated by sodium and chloride with magnesium and sulfate having a sub-dominate influence (Hart and McKelvie (1986)). While urban streams were also dominated by sodium and chloride ions, the sub-dominant influence of calcium and bicarbonate ions (as influenced by cement products) was clearly evident.

At a landscape level, the studies in this research (Chapter 5 and particularly Paper 10) have contributed to the understanding of the chemistry in freshwater streams as proposed by Gibbs (1970) and Hart and McKelvie (1986). Analysis of the water chemistry in urban and reference streams across northern Sydney (Paper 10) has concluded that new materials in the urban landscape (such as concrete) or the 'urban geology' has a significant role in elevating calcium and bicarbonate ions in urban streams. Gibbs (1970) suggests these particular ions play a sub-dominate role in determining the overall influence of freshwater chemistry at a landscape scale. However, as cities and their drainage networks continue to expand, the research from this thesis suggests that urban geology will play an increasing role in influencing the water chemistry of freshwater streams in and downstream of major cities.

Arising from the discovery of the significance of concrete drainage systems on stream water chemistry (Chapter 5) are a number of questions for urban water researchers and professionals. This thesis specifically calls for an examination of the impact of urban geology and the in-transport process of the urban drainage network on water quality, ecology and microbial communities. These areas of inquiry should add to the areas of investigation posed at the Second Symposium on Urbanisation and Stream Ecology (Wenger et al (2009)).

### 8.3.2 Urban development and stream health

The upstream reaches of waterways are generally poorly mapped (possibly because of their ephemeral nature (Meyer and Wallace (2001)), lack of statutory recognition (eg Taylor and Stokes (2005)) and are not well understood in terms of their contribution to downstream function (Gooderham et al (2007)and Chin and Gregory (2009)). This is in spite of their important ecological function (Naiman et al 1993). The research studies in this thesis address many of these shortcomings.

Paper 2 (Chapter 3) presents the results of a rapid riparian assessment tool developed to assess the condition of urban stream networks (refer to Findlay et al 2005). It uses a qualitative assessment of six categories including: site features; channel features; depositional features; erosion features; riparian vegetation; and vegetation structure. While geomorphologically focused, the tool can identify many of the consequences of changes to hydrology and hydraulics as a result of urban development and the drainage system. From an applied perspective the data from this assessment can identify appropriate locations for stream remediation as part of capital works programs designed to improve the condition of local waterways (refer to Ku-ring-gai Council Environmental Levy projects for remediation of the waterway at The Glade http://www.kmc.nsw.gov.au/www/html/2573-major-projects.asp (accessed 25 January 2011)).

The rapid riparian assessment method (Paper 2) demonstrates the value of identifying and describing the state of and pressures on urban riparian environments, particularly stemming from changes to lower order streams (Strahler (1952)) and their supporting swales, rills and minor gullies. This method enables the development of effective policy to mitigate and remediate the pressures on urban systems, as outlined in Paper 1 and Section 8.2. Specifically, Development Control Policies should contain quantifiable standards that relate to: biology and riparian habitat (that may define specific setbacks and landscaping requirement); hydraulics standards at the point of discharge to public drainage systems (that seek to improve flows towards pre-development conditions in order to protect bed and bank stability); water quality standards (to reduce nutrients and sediments); and limiting new piping of watercourses (in order to maintain continuity in watercourses for flora and fauna).

Paper 1 (Chapter 3) presents a new direction for environmental legislation in NSW that seeks to broaden the definition of rivers to include ephemeral streams and proposes a definition for riparian areas (also refer to Section 8.2). This paper outlines the shortcomings of the current legislation and policy settings and also proposes a new direction for the urban water sector, consistent with the aims of the thesis. While the demands for greater urban development will continue to be balanced against environmental protection and conservation, a more inclusive statutory framework will provide a stronger foundation for the implementation of water sensitive urban design solutions and achievement of a water sensitive city.

Walsh (2006) reported a strong relationship between connected imperviousness and the health of aquatic ecosystems in Melbourne (discussed in Chapter 4). This observation has also been noted by others in various international studies as reported in Chin (2006) and has acceptance by urban water researchers. Past practices saw drainage engineers channelling, guttering and piping watercourses to reduce overland flow and flooding on private property, thereby significantly increasing connected imperviousness. A quandary exists between the approach of the traditional drainage engineer guided by documents such as the Australian Rainfall and Runoff (Pilgram (1987)) and the contemporary environmental engineer informed by Australian Runoff Quality (Wong (2006)) and similar guidelines. This is particularly so in existing urban areas (retrofit situations) where drainage systems were designed using the traditional drainage approach rather than that espoused by contemporary WSUD guidelines. This thesis highlights examples of the challenge presented to environmental engineers as part of the implementation of various WSUD features, such as the sizing of systems and type of soil media contained in biofiltration systems (Chapter 6, Papers 14 and 15).

As noted in the introduction to Chapter 4 (Figure 4.1), the pattern of development in a catchment is likely to have an influence on aquatic ecosystem health, due to its relationship to the percentage of connected imperviousness (Walsh (2006)). By quantifying both ecosystem health (macroinvertebrate) and the chemical state of urban waterways in catchments across the Ku-ring-gai local government area, this thesis provides robust data to support this link. In Ku-ring-gai development occurs exclusively on the plateau and upper reaches of the catchment, with the steeper lower reaches generally remaining as natural forested areas. This development typology is the reverse of many other urban environments (typically forested and sparse development in the steeper upper reaches and higher densities on the lower and flatter floodplain) (as illustrated in Figure 4.1). Further research is warranted to investigate this difference and determine if there is a longitudinal change in the ecological condition (macroinvertebrate SIGNAL score) as the percentage of connected imperviousness decreases in an urban creek that initially drains a developed upper catchment into a naturally forested lower catchment. In other words, does the effect of urbanisation on stream health become diluted as the proportion of the catchment in a natural state increases downstream from a ridge top development or is it already constrained because of the impact of the upper drainage system?

The discovery that concrete drainage systems have a significant effect on the water chemistry in urban creeks (as discussed in Chapter 5 and section 8.3.1) further compounds the technical decisions water engineers and ecologists face. Concrete gutters and pipes are widely used in public drainage systems and as part of WSUD systems. While previous researchers have demonstrated the importance of the chemical ionic proportion to freshwater diatom communities (eg Patapova and Charles (2003)), one hypothesis of this thesis is that the ubiquitous use of concrete in drainage systems is likely to influence urban diatom communities (Papers 6 and 10) which is then expected to have a negative ecological impact in urban streams.

## 8.4 Water demand and supply

The historical review of urban water management in Sydney presented in Chapter 2 provides an account of how potable supply, wastewater disposal, stormwater, urban rivers and the role of metropolitan water planning and urban planning authorities have evolved and determined the position that exists today. This multidisciplinary perspective contextualises how urban water planning has developed outside the traditional examination of water demand and supply (eg Aird (1961)). The approach adopted by this thesis places greater focus on the role of other players in the urban water sector, such as local government. The findings build on the documented activities and achievements of Sydney Water Corporation and its predecessors (refer to Aird (1961) and Beasley (1988)), critiques of the decisions by Sydney Water Corporation or the Water Board (such as Beder (1989)) and more recently an examination of the management of stormwater (Brown (2005)). Given that planning for urban water management has been dominated by a central water monopoly for nearly 150 years, it is not surprising that the role of local government has not been well documented. This reflects a lack of coordination, planning and investment by local government in water supply and wastewater services in the early days of the settlement of Sydney, its inability to develop a proportional capital and maintenance funding arrangement for major stormwater systems that crossed local government boundaries (Aird (1961)) and its limited capacity to continue carriage of stormwater quality management (Brown (2005)).

As discussed in Chapter 2, the NSW State Government has played an increasingly dominant role in urban water management through strategic planning and policy for water demand and supply and the management of drinking water catchments. The recently formed NSW Office of Water is now playing the lead role with other responsibilities being allocated to the Independent Pricing and Regulatory Tribunal and the Department of Planning. However, as reflected in the 2010 Metropolitan Water Plan (NSW Government 2010), local government remains a minor player in potable and non-potable water supply and wastewater management, despite the potential of this sector to facilitate and manage decentralised water systems. As discussed in Papers 20 and 21, there is strong community support for water recycling and the involvement of local government. Papers 18 and 19 document the emergence of policy challenges, including an unwillingness by approval bodies to facilitate alternative water supply systems such as sewer mining plants by local government. Health authorities, similarly, remain highly cautious in relation to treatment standards for stormwater harvesting schemes (Papers 17 and 18) and so continue to influence standards that can financially constrain the viability of stormwater harvesting as an alternative non-potable water supply.

### 8.4.1 Stormwater as a source of water supply

Stormwater management has undergone a transformation from a policy perspective. Once seen only as a nuisance and cause of flooding, many storm flows are now being used to augment water supply schemes at the household (for example, the BASIX SEPP encourages the use of rainwater tanks – refer to BASIX SEPP http://www.basix.nsw.gov.au/

information/about.jsp (accessed 4 October 2010)) to sub-catchment scale, although at this stage overwhelmingly the water is used for non-drinking water purposes (as documented in Chapter 6 particularly in Papers 11 and 12). This change can be directly attributed to the drought affecting much of Eastern Australia from the late 1990s to 2009 and reflects the often reactive planning and policy response to urban water resources as discussed in Chapter 2.

Public stormwater reuse schemes have been encouraged through a variety of approaches. This has included the early Stormwater Trust grant program and its current incarnation, the Urban Sustainability Program that has set as one of its objectives 'to improve urban water management with a particular focus on stormwater and urban runoff to achieve sustainable water quality and conservation outcomes' (NSW Government Urban Sustainability Program http://www.environment.nsw.gov.au/grants/urbansustainability.htm (accessed 10 October 2010)). Councils in NSW are now able to raise a stormwater charge via the new section 496A to the *Local Government Act 1993* (inserted by *Local Government Amendment (Stormwater) Act 2005* (Department of Local Government (2006). Through the promotion of best practice guidelines through policy documents, such as the 'Managing urban stormwater: harvesting and reuse' publication (Department of Environment and Conservation (2006)) there are now guidelines more relevant to Sydney. The response to these enabling mechanisms has been the construction of over 70 major stormwater reuse schemes saving two billion litres of drinking water per year. The success of these schemes is acknowledged in the 2010 Metropolitan Water Plan (NSW Government 2010) that estimates that the stormwater harvesting schemes contribute six per cent of the total use of recycled water in Sydney in 2010 (NSW Government 2010 p 27). This suggests Sydney may slowly be becoming a water sensitive city, although the distribution of these schemes is not even, with a few of the leading councils initiating nearly10 schemes each while many of the 42 councils in Sydney still watch and wait.[3]

As evidenced by the discussion in Papers 11, 12, 13, 16 and 20 presented in Chapter 6, the design and operation of these stormwater reuse schemes is still evolving and there are many areas for improvement that need to inform industry guidelines such as Australian Runoff Quality (Wong (2006)) and Managing urban stormwater: harvesting and reuse (Department of Environment and Conservation (2006)). Key

3 Refer to NSW Government's Water For Life Website for the location of stormwater harvesting schemes across Sydney http://www.waterforlife.nsw.gov.au/recycling/stormwater/stormwatermap (accessed 3 November 2010)

insights identified by the research in this thesis are:

1. The interaction of sub-surface flows in open channels, streams and piped drainage can have a significant impact on flow behaviour, and in turn hydraulic models used to inform the design of stormwater harvesting schemes. This is particularly relevant in less developed catchments and those with a lower percent of connected imperviousness where subsurface flows would ordinarily have a greater role in stream flow (Paper 16).

2. Base flow in small steep urban catchments (less than 90ha) with shallow soils (as tend to occur in northern Sydney) is likely to be intermittent. This tends to respond to the high impervious area, efficiency of the urban drainage system and underlying soil and geology. In northern Sydney this seems to outweigh anthropocentric additions to base flow from leaks to the sewer or potable supply, garden watering and other outdoor water use. This may also reflect the development pattern where urbanisation has occurred in the upper reaches that would ordinarily play a major role in the flow characteristics of higher order streams (Meyer and Wallace (2001) and Gooderham et al (2007)). If stormwater harvesting schemes are designed to rely on base flows within smaller urban catchments (as was initially envisaged for the design at Edenborough Oval (Paper 12)), caution should be exercised as their supply regularity may be influenced by water use behaviours within the catchment and also by the asset management program of water authorities (Papers 12 and 16).

3. There is considerable value in calibrating hydrologic models with local stream or drainage monitoring and actual irrigation use. This will lead to more accurate estimates of supply and, in turn, the size, type and cost of storage (Paper 16)

4. Early investigations by Ku-ring-gai Council to define the maximum storage of stormwater harvesting schemes for the initial design of the stormwater harvesting scheme related to the Gordon golf course irrigation project (Paper 20) drew from the harvestable rights policy framework regulating farm dams as advised by the former Department of Infrastructure, Planning and Natural Resources (refer t o NSW Office of Water, www.water.nsw.gov.au/Water-licensing/Basic-water rights/Harvesting-runoff/Harvesting-runoff/default.aspx (accessed 4 October 2010)). While this policy has not been raised in subsequent discussions with the relevant State Government department regarding the design of more recent stormwater harvesting schemes, there remains a significant policy gap as to what volume and where in the

hydraulic profile stormwater can be captured by harvesting schemes (for example, first flush, base, low or high flows), how it can be stored (dams to tanks), what is the maximum size of the tanks as a function of the catchment (area or land use), whether the water can be used for other purposes (such as for fighting bushfires), and what environmental assessment should be carried out as part of the approval process (for example, a Part 5 assessment under the *Environmental Planning and Assessment Act 1979* (NSW)). The responses to these questions reflect on the changing value of stormwater and evolving clarity in legal processes (as discussed in Paper 1) and the need to address the significant problem that urban creeks are subject to too much flow (Walsh et al (2010)).

5. Health risks from stormwater harvesting schemes remain an ongoing area of concern. The findings presented in this thesis quantified the presence and decay of indicator bacteria in two stormwater harvesting schemes over a ten-week period with monitoring related to rainfall events (Paper 17). This study reported a rapid initial die-off of *E-coli* over the first four days followed by a slower, more gradual die-off. This was a similar trend to the laboratory-based experiments (such as Easton et al (2005) and McCartney et al (2007)) confirming similarity in theory and practice. For stormwater harvesting schemes, the results suggest that the use of a detention period of at least four days following rain and prior to use for irrigation can be used as a strategy to reduce the potential health risks of contact with harvested stormwater that may contain *E-coli*.

The research presented in Paper 17 also modelled an irrigation regime for two ovals against the measured indicator bacteria. The results for these systems indicated they were likely to comply with the National (National Health and Medical Research Council (2006) and State (Department of Environment and Conservation (2006)) health standards.

To further assess the health risks of stormwater harvesting, a study was undertaken to quantify the presence of both indicator bacteria and various pathogens (Paper 18). The results of this study confirmed that the stormwater harvesting schemes monitored had elevated levels of indicator bacteria such as *E-coli* following and during rainfall events (as reported in Paper 17), although unlike the indicator bacteria, parasites such as *Cryptosporidium* are more persistent (ie have less decay) in the storage tanks.

The data in Paper 18 also identified that bacteria counts for faecal coliforms, enterococci and particularly *E-coli* (which tends to be used as the indicator organism) to determine the risk to public health is likely to overestimate the health risk of stormwater harvesting systems based on the presence of other parasites. From a practical perspective the findings in Papers 17 and 18 suggest major limitations exist for the operators of stormwater harvesting systems relying on indicator organisms as the sole determinant of health risk. For the systems investigated in these studies, it was concluded that effective pre-treatment of stormwater inflows (excluding UV or chlorination as recommended by national and state guidelines) coupled with restricting access during irrigation should suffice as a strategy to minimise the potential for infection. To assist those involved in the use and maintenance of stormwater harvesting systems for open space irrigation, the research undertaken in this thesis supports the development of a generic model that can be used to predict the decay of specific bacteria of concern to public health authorities. This would draw on the theoretical and observed decay in certain bacteria (Paper 17) and other pathogens (Paper 18) and would relate to the inflow, storage and outflow of the harvesting systems based on actual rainfall, time of use, inter-rain periods and initial bacterial concentrations.

### *8.4.2 Use of recycled water*

Water recycling has become a viable and mainstream alternative non-potable water supply in Sydney and by the end of 2010 approximately 51 billion litres per year of recycled water was used that may otherwise have come from the potable supply (NSW Government (2010) p 27). Water recycling is not new to Sydney. Since 1967, Sydney Water has supplied water to irrigate the Richmond Golf Course from the local sewerage treatment plant (Sydney Water Corporation (2005)). However, the entry of local government in Sydney to the recycled water sector is a more recent development. In 2008 Kogarah Council opened the first sewer mining facility managed by local government in Sydney and Ku-ring-gai Council anticipates opening the next two schemes in 2011. For both Kogarah and Ku-ring-gai Councils these schemes followed the adoption of water cycle management policies (eg Chanan and Woods (2006) and Ku-ring-gai Council (2008a)), emphasising the importance of policy political, funding and operational support, coupled with the determination of individuals to champion and implement innovative urban water reforms (Taylor (2009)).

For the Beverley Park golf course in Kogarah Council (Chanan and Ghetti (2006)) and the Gordon golf course (Papers 21 and 22), the initial route to progress these projects by local government had no clear policy context, water quality guidelines or legislative clarity. As discussed in Chapter 2, this stemmed largely from the long-standing dominance of Sydney Water as the monopoly water utility that effectively precluded local government in the Sydney metropolitan area from involvement in water supply and wastewater treatment arena. Subsequent to (or because of) the initiation of these projects, policies have been established providing clarity to the approval process (Sydney Water Corporation (2006)), recommendations for pricing of reclaimed water have been determined (Independent Pricing and Regulatory Tribunal (2006)), guidelines have been produced regarding the use of recycled water for irrigation (Department of Water and Energy (2008) and Natural Resource Management Ministerial Council Environment Protection and Heritage Council Australian Health Ministers' Conference (2006)) and legislation has been introduced clarifying and assisting the development assessment process for small-scaled sewer mining schemes (*Environmental Planning and Assessment Amendment (Designated Development) Regulation 2007*). It is unlikely that these reforms would have occurred in such a narrow window if it were not for the drive of a small number of local councils and other land managers (such as Pennant Hills golf club, NSW Government (2010) p 32) to pursue decentralised water sources in response to the immediate pressures of the drought and also a desire to lead urban water reform.

As raised in Papers 20 and 21, and following additional insights gleaned from the ongoing approval processes, design and construction of the two sewer mining projects at Ku-ring-gai Council (over which I have strategic oversight), the following points are offered. These have a practical focus for application in the urban water sector as opposed to scholarly insight, and are included as they identify shortcomings and may assist in setting determining new directions for this sector, reflecting on the major themes of this thesis (Chapter 1).

1. There is no guideline for public sewer mining schemes in NSW (as noted in Papers 20 and 21). As a result, local councils and other public authorities rely on the guideline for private schemes (Department of Water and Energy (2008)). This policy gap has led to confusion as to which should be the approval body. Currently council must wear two hats as applicant and determining authority, subject to Sydney Water Corporation granting approvals to take and return sewer within the sewer mining catchment.

2. As discussed in Chapter 2 Paper 20 local councils in Sydney are not water authorities. Consequently they generally lack the necessary technical skills and experience to develop, assess or operate their own sewer mining projects. In Sydney, this expertise lies within Sydney Water, NSW Office of Water and Department of Environment, Climate Change and Water (as both the regulatory authority for licensed sewerage treatment facilities and within National Parks for smaller sewerage treatment schemes). To overcome this shortcoming, it is recommended

that section 68 of the *Local Government Act 1993* (NSW) be amended by NSW Parliament to make the Minister for Land and Water Conservation the approval authority for sewer mining schemes (this would be similar to section 60 of the *Local Government Act 1993* that relates to works for which councils must have the approval of the Minister for Land and Water Conservation). This would formalise a referral to the NSW Office of Water (as is required for private water recycling schemes) and be subject to determination by the Minister.

3. As of 4 June 2010, the NSW Independent Pricing and Regulatory Tribunal (IPART) has assumed the role of reviewing and approving infrastructure and developer contributions charges imposed by local government as well as recommending to Government water and sewerage charges.[4] This reform by the NSW Government recognises the dual approval and service functions provided by Sydney Water[5] and local government as part of their: approval functions for development activities (under the *Local Government Act 1993* and *Environmental Planning and Assessment Act 1979* (NSW)); levying for development contributions; and general rating determination (excluding water and sewerage within the Sydney metropolitan area).

With this expanded power, IPART has the opportunity to provide greater coordination of the various water service and infrastructure charges. This provides it with an expanded and importantly strategic role in land use and water planning, an area that arguably requires greater coordination, although it could be argued that this should be the core function of the NSW Office of Water. As discussed in Chapter 2, raised by White et al (2006) as part of the review of the 2004 Metropolitan Water Plan (Department of Infrastructure Planning and Natural Resources (2004b)) and most recently foreshadowed in the terms of reference of the review of Australian's urban water sector by the Australian Government's Productivity Commission (Productivity Commission (2010)), greater coordination can only lead to improvements in the delivery of water services.

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4 This further extends to its functions to provide recommendations to government in relation to water and energy such as the 2008 review of prices for Sydney Water Corporation from 1 July 2008 http://www.ipart.nsw.gov.au/files/Fact%20Sheet%20Water%204%20%20Review%20of%20SWC%20prices%20from%2001%20July%202008%20-%20Jennie%20Cooper%20-%2010%20July%202008%20-%20WEBSITE%20DOCUMENT%20Version.PDF (accessed 20 October 2010)

5 On 17 December 2009 the NSW Government abolished developer charges for water, wastewater and stormwater services although charges still apply for developer charges and capital contributions for recycled water in accordance with IPART's determination. Approvals and fees are still required by Sydney Water under section 73 of *Sydney Water Act 1994* for dual occupancy, subdivision and constructing a residential, commercial or industrial building

4. Where water reuse and recycling facilities have been developed or are in planning, approval bodies should be empowered to influence the capacity of a treatment system and require other water users to connect to and use the alternative water supply. For example, local projects potentially able to connect to alternative water supply schemes could be encouraged and facilitated by councils' Development Control Plans or form part of developer agreements with current and future applicants. For regional projects, the Department of Planning or Joint Regional Planning Panels should seek opportunities for major projects or within the growth centres (as identified in the Growth Centres SEPP).[6] Development consent conditions could be imposed to require the installation of plumbing connections that enable connection to future water recycling facilities or require connection to a water recycling facility if it can be conditioned as part of the development consent. Sydney Water (under the *Sydney Water Corporation Act 1994* Division 7, customer contracts) could require connection to alternative water supply schemes. The NSW Office of Water could also play a role in facilitating larger recycling schemes such as the Rosehill-Camellia and Wollongong Recycling Water Plants (which also play a key part in achieving the NSW Government's water recycling targets (NSW Government (2010) p 28).

### 8.4.3 Community receptivity to recycled water

National (eg Po et al 2003 and 2006), state (eg EPA 1997, 2000, 2003 and 2006) and local (Papers 22 and 23) community surveys are used to understand the community's understanding and receptivity to water reuse and conservation. The results have been presented to support the implementation of innovative projects such as the sewer mining scheme for Gordon golf course (Papers 20–23) and also used to stop projects such as the proposed inclusion of recycled water to form part of Toowoomba's potable water needs (Hickey and Austin (2007) and Harding et al (2009)).

The use of community surveys and other forms of consultation to guide decision-making is now a statutory requirement for councils in NSW (Prior and Herriman

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6 These would usually be assessed under Part 3A of the *Environmental Planning and Assessment Act 1979*. Presently the environmental assessments (section 75F) and concept plans (section 75M) can take into consideration how water should be managed as part of the approval process. This can have broad-reaching influence and may extend to water supply and wastewater as well as riparian management. In order to promote a greater uptake of alternative water supplies, the provisions of this section should be encouraged and arguably extended to other types of development that may be contained in Development Control Plans (Division 6) and play a greater role in integrated development determinations (Division 5).

2010). This has arisen from the *Local Government Amendment (Planning and Reporting) Act 2009* (NSW) supported by the Division of Local Government guidelines (2010). While these reforms are in their early days, the value of such an approach is clearly shown by the studies presented in this thesis (Papers 22 and 23). In this thesis the research demonstrated the community of Ku-ring-gai strongly supported water recycling as a core value and one they were willing to pay for.

A further insight offered by the community surveys reported in Papers 22 and 23 relates to the development and implementation of environmental education programs. In Paper 22 there was a clear expressed difference between English and non-English speaking backgrounds as to how they wish to receive environmental messages. In this study people from English speaking backgrounds had a preference for education materials while those from non-English speaking backgrounds were more motivated by regulation. While this finding is not new it reinforces previous research such as that undertaken by the NSW Environment Protection Authority (EPA (1997b)) and has informed various environmental and water management projects (such as the Cooks River environmental assessment and education project (http://www.environment.nsw.gov.au/stormwater/casestudies/cooksdetailed.htm accessed 23 January 2011)).

## 8.5 Contribution to local and global knowledge

This thesis is the first multidisciplinary examination of the role of local government in the management of urban water resources in Sydney. Although the case studies for many of the research projects are focused within northern Sydney and specifically the Ku-ring-gai local government area, the findings have significant regional, national and international relevance due to the undeniable need for urban water reform.

The historical account of the evolution of urban water management in Sydney (Chapter 2) provides insight as to the causative factors leading to the rise and dominance of a central water authority in potable and wastewater planning and operation. This review also highlights the conservative and often under reported role of local government and its traditional and arguably constrained focus on the delivery of stormwater services to enable urban development and minimise flooding. The research from this chapter clearly points towards a need for a multidisciplinary and collaborative approach to urban water planning.

The scientific methods and research techniques used in this thesis are not unique but have drawn on many years of analysis of aquatic environments and more recently the evaluation of WSUD systems. However, the data and analysis provides new insight into the contributing effects of urban environments on natural systems. The thesis reaffirms the findings of many Australian and international studies that have demonstrated a relationship between a rise in catchment imperviousness and a decline in river health. Importantly the thesis builds on this knowledge in its discovery of the in-transport effect on urban water quality of concrete drainage systems (Chapter 5 and Chin (2006)).

Analysis of the performance of the WSUD systems against theoretical design has provided quantitative data that will contribute to ongoing refinement of design and maintenance guidelines. This is particularly the case for stormwater harvesting and biofiltration systems (Chapter 6). While acknowledging that additional research on the systems needs to be undertaken to provide greater certainty in the results, the contribution of field based (albeit limited) evaluation should not be undervalued by those who undertake experiments in the laboratory.

The review of policy and legislative frameworks that inform and determine land use and environmental management in NSW has broader application to other jurisdictions nationally and internationally (Chapter 3). For the management of urban rivers, riparian and other natural systems, legislation must have clear, specific and inclusive definitions. The assessment processes for future development must be rigorous, founded on evidence-based research and be supported by consistent policy cascading from the national to local level.

This thesis offers insights to the role of various government agencies involved in urban water management and planning for other cities, nationally and internationally. However the transferability of the scientific discoveries and relevance of policy and legislative reforms will be unique to specific situations, populations and locations. Just as the renaissance of urban water supply and treatment emerged at various times and with different solutions (Chapter 2), the socio-economic, environmental and political considerations that inform change remain as the major factors that influence when and to what extent cities become more water sensitive. Nevertheless, it remains important for politicians, practioners and researchers to learn from the successes (and failures) from other emerging water sensitive cities.

Finally, the structure of the research and the dissemination of the findings in this thesis have sought to inform urban water professionals in a timely and appropriate manner. This is particularly important given the rapid pace of reforms, release of new guidelines and standards and projects that are being implemented nationally and internationally. The use of informal networks and industry conferences to document and present findings provides far greater traction to the local government sector than academic journals. However, given the plethora of WSUD systems being implemented nationally, iterative improvements in design, construction and maintenance are still in their infancy and largely informed by laboratory-based studies. If governments genuinely wish to progress towards the ideals of a water sensitive city, theory and practice must move closer, environmental analysis must consider community perceptions and understanding, and reflection and review must form key parts of the urban water sector's collective learning (refer to Figures 1.1 and 8.1).

# Chapter 9: Conclusion

The central aim of this thesis has been to explore how urban water resources are managed in Sydney from a local government perspective. Many of the insights detailed in this thesis have been gained through my work at Ku-ring-gai Council applying an integrated urban water management approach to a range of issues and projects.

This thesis progresses the urban water literature by providing for the first time a complete history and integrated analysis of how urban water resources in Sydney have been managed. Key elements of this history include the emergence of a central water authority (Sydney Water Corporation and its predecessors) and consolidation of functions and responsibility in this authority; the evolving role and contribution of local government, particularly stormwater management and urban land use planning; and the multiplicity of bodies sharing responsibility for urban water planning.

Key findings and recommendations of this thesis include:

1. Discovering and documenting the significant impacts concrete drainage systems have on the water chemistry of urban creeks (Chapter 5). This finding supports the recommendation to recognise the in-transport process of the urban drainage system as a contributor to urban stream syndrome and to consider this as a factor when planning for and designing infrastructure. Such consideration should also extend to the role of urban geology and other anthropocentric materials that similarly affect the chemistry of freshwater streams.

2. The current legislative system in NSW is neither reflective of nor responsive to the cumulative impacts of urban development on natural systems (Chapter 4). Environmental and planning legislation needs to be reviewed to create legal, policy and regulatory frameworks that take into consideration contemporary scientific knowledge of the causes and effects of urban stream syndrome, as well as the 'death by a thousand pipes and cuts' that causes biodiversity loss in terrestrial and aquatic habitats. This review should incorporate a new definition for rivers that recognises ephemeral systems and introduces for the first time a definition of riparian areas.

3. Water sensitive urban design (WSUD) solutions should form an important part of transitioning urban environments towards a water sensitive city (Chapter 6). Current guidelines offer theoretical design standards that are near impossible to achieve in retrofit locations. Compounding this, existing water infrastructure has been designed and maintained to achieve a different outcome (primarily flood

control). To overcome these challenges, design engineers and land managers need better skills and understanding of WSUD in order to make pragmatic design, construction and maintenance decisions.

4. The principles of total catchment management need to be revived within the decision-making frameworks of local government and state agencies (Chapter 3) and be supported by the local community (Chapter 7). The benefits of currently small-scaled WSUD features could be greatly increased if they formed part of a comprehensive and integrated program. This thesis recommends setting appropriate objectives and targets for local and regional waterways to help achieve this outcome. This is particularly relevant for environments that are vulnerable to the effects of urbanisation (Chapters 4 and 5).

5. Researchers seeking improvements in the performance of WSUD systems need to better understand on-ground catchment conditions and variability in construction quality and maintenance practices (Chapter 6). These variables have far greater influence on the performance of a WSUD system than the minor improvements that can be achieved by changing filter media, type of vegetation or setting the minimum percentage of land area needed for a treatment system. Improved understanding could be achieved via education programs for the construction and maintenance sector working for and in local government. While recognising the value of research and continuous improvement to the design of WSUD systems, this recommendation seeks to emphasise the importance of field-based research and validation.

6. There is a clear differentiation in macroinvertebrate and water chemistry characteristics between reference and urban streams in northern Sydney (Chapter 4). The research also reported differences between habitats edges being taxonomically richer than pools and riffles. The findings suggest these habitats could serve as default sampling locations, particularly if monitoring budgets of government agencies are low and compromises to sampling protocols must be made.

7. Local councils can play an important role in achieving the water recycling and reuse targets set by the NSW Government (Chapters 2 and 6). Given the number of councils that operate in Sydney this will be limited to small-scale water recycling and catchment based stormwater harvesting projects. While the contribution of individual projects is modest, the cumulative potential as part of the NSW Government's commitment to the Metropolitan Water Plan should not

be underestimated. Equally, the value of small scale, decentralised water supply and treatment projects needs to be promoted above current uptake levels to make the systems more efficient (through improvements in design and construction), serve as local demonstration projects to the community and to increase local government sector buy-in to its role in urban water management.

8. Community support is crucial as a key enabler for the success of integrated urban water management (Chapter 7). This is evidenced by the response by the residents of Ku-ring-gai to water reuse and recycling, which has contributed to the success of many of the council's projects.

9. Political support for urban water reform is frequently reactive (such as responding to droughts or outbreaks in water borne disease) and is often characterised by major funding programs such as grants for major and innovative projects (Chapter 2). Such financial commitment often precedes the institutional support, capacity and sometime willingness of state government departments and agencies and local government to assist and implement new projects. This is evidenced by the slow approval process by Sydney Water for sewer mining projects (Chapter 6) and in the Department of Planning's embryonic holding pattern regarding land use policies that recognise the environmental value of urban riparian systems (Chapter 3).

In distilling the essential insights of this thesis, the following seven points are suggested to guide the future direction for urban water management in Sydney:

1. Urban water management is complex and therefore the approaches to improving it must be based on a diversity of solutions.

2. There is a need for collaboration within and between all levels of government.

3. Leadership must occur in all sectors and should not rest solely with a central authority or agency.

4. Policy and legislative reform is necessary and must be informed by contemporary science and policy.

5. Decisions by government to invest in high cost/modest return technologies or approaches (as measured by $ per litre as for sewer mining or desalination)

should be encouraged. These provide the testing ground for technologies and often provide the only learning opportunities for institutions and the community to adapt to a new future.

6. Innovation that accepts risk should be encouraged.

7. There needs to be an ongoing commitment to multidisciplinary research linking theory and practice.

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