

**USE OF STORMWATER AS AN
ALTERNATIVE SUPPLY SOURCE**

Thesis submitted in fulfilment of the requirements for the degree of

MASTER OF ENGINEERING

Carolyn Michelle Goonrey

School of Architectural, Civil and Mechanical Engineering

Victoria University

Melbourne, Australia

AUGUST 2005

ABSTRACT

Changing climate, increasing demand for potable water supplies and increased community interest for sustainable use of fresh water sources have resulted in a new focus on water use and sourcing. New sources are being sought, in conjunction with water demand minimisation strategies, to decrease the pressure on existing urban water resources.

At the same time, the management of stormwater is being re-examined with the focus changing from the traditional practice of rapid disposal of stormwater (to reduce the risks of flooding) to utilisation of stormwater as an alternative water supply source. The focus of this thesis is the use of stormwater as an alternative supply source in urban areas at a cluster (or neighbourhood) scale. A decision making framework was developed to assist the adoption of a holistic approach to determining the most appropriate stormwater use scheme option. It was developed as an integrated planning tool to be used in the initial stages of investigating water sourcing and stormwater management ideas.

Due to the time constraints of this project, the focus of the decision making framework was on the technical components (with associated issues) and financial costs. Since additional issues such as environmental, social and economic issues, are crucial to ensure a balanced view is taken in the decision making process, they are included in the process through additional information sources.

Development of the decision making framework considered the following steps:

- Development of stormwater use scheme options based on the technical components and associated issues of collection, storage, treatment, distribution and end use;
- Development of screening tools to screen out infeasible or clearly inferior stormwater use scheme options;

-
- Development of steps in the decision making framework; and
 - Demonstration of the decision making framework through the use of a case study.

The decision making framework consists of eleven steps. The initial six steps of the decision making framework relates to collection and end use issues and are based around matching stormwater runoff to demand and matching stormwater quality to required quality. Steps 7 to 9 of the decision making framework consist of examining and determining feasible storage, treatment and distribution options.

Step 10 of the decision making framework focuses on the integration of the feasible technical options identified in the previous steps, in order to develop stormwater use scheme options. The final step of the decision making framework is to determine costs of the stormwater use scheme options and compare the scheme options on the basis of cost, reliability of supply, quantity of stormwater utilised and end use demands met.

The decision making framework was demonstrated as an easy and practical tool for determining the most appropriate stormwater use scheme through the use of a case study. An existing urban area was chosen as the case study due to the potential for the greater impact in terms of minimising potable water use for non-potable end uses. Feasible collection, storage, distribution, treatment and end use options were determined and integrated into 19 stormwater use schemes. Comparison of all the stormwater use scheme options, as well as the base case with no stormwater use, determined four options as being superior in terms of financial costs, reliability, quantity of stormwater used and end uses met.

The decision making framework was developed based on existing constraints (such as the lack of guidelines directly examining stormwater use) and knowledge, while being flexible enough to include future scientific and practical knowledge, as it becomes available. Recommendations for future development of the decision making framework include expanding this decision making framework to identify the optimum scales of stormwater use schemes. Additionally, an effective yet simple to use costing tool needs to be developed so that all environmental, social and economic costs are determined and actual benefits of stormwater use schemes can be determined.

DECLARATION

I, Carolyn Goonrey, declare that the Master by Research thesis entitled Use of Stormwater as an Alternative Supply Source is no more than 60,000 words in length, exclusive of table, figure, appendices, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work.

Carolyn Goonrey

Date

ACKNOWLEDGEMENTS

This project would not have been possible without the support and assistance of CSIRO Manufacturing and Infrastructure Technology. CSIRO provided funding as well as invaluable assistance from my two industry supervisors Shiroma Maheepala and Grace Mitchell. I would also like to thank CSIRO Water for a Healthy Country Research Flagship for providing top-up funds for the project scholarship.

Victoria University of Technology also provided support, funding and resources, without which this project would never have proceeded. Again, invaluable support was provided by my two academic supervisors Chris Perera and Peter Lechte.

I would also like to thank my family for their unfailing support, assistance and understanding to help me refine my direction and ideas.

TABLE OF CONTENTS

ABSTRACT	i
DECLARATION.....	iii
ACKNOWLEDGEMENTS	iv
TABLE OF CONTENTS	v
LIST OF TABLES	x
LIST OF FIGURES.....	xiii
LIST OF ABBREVIATIONS	xvii
CHAPTER 1 INTRODUCTION.....	1-1
1.1 Background.....	1-1
1.2 Aims and Scope of the Study	1-2
1.3 Methodology in Brief	1-4
1.4 Significance of the Research	1-5
1.5 Outline of the Thesis.....	1-6
CHAPTER 2 STORMWATER MANAGEMENT PRACTICES.....	2-1
2.1 Introduction	2-1
2.2 Past Stormwater Management Practice	2-3
2.3 Current and Future Directions of Stormwater Management Practice	2-4
2.3.1 Disposal to the Environment	2-4
2.3.2 Stormwater Use	2-7
2.3.3 Technical Feasibility	2-8
2.3.3.1 Collection.....	2-10
2.3.3.2 Treatment	2-11
2.3.3.3 Storage	2-12
2.3.3.4 Distribution	2-13
2.3.4 Benefits or Motivators of Stormwater Use.....	2-15

2.3.5	Barriers to Stormwater Use	2-17
2.3.6	Future Research Needs	2-20
2.4	Summary and Conclusions	2-22
 CHAPTER 3 OVERVIEW OF A STORMWATER USE SCHEME		3-1
3.1	Introduction	3-1
3.2	Focus of Decision Making Framework	3-1
3.3	Stormwater Use Scheme Options	3-2
3.3.1	Generation of Stormwater Use Scheme Options	3-2
3.3.2	Screening of Stormwater Use Scheme Options	3-4
3.4	Components of a Stormwater Use Scheme	3-6
3.4.1	Collection and End Use	3-7
3.4.2	Storage	3-10
3.4.3	Treatment	3-12
3.4.4	Distribution	3-13
3.6	Summary	3-13
 CHAPTER 4 DECISION MAKING FRAMEWORK		4-1
4.1	Introduction	4-1
4.2	Outline of Decision Making Framework	4-2
4.3	Screening	4-4
4.3.1	Regulatory Prohibitions on the Use of Stormwater for Potable Uses	4-5
4.3.2	Insufficient Quantity of Water	4-5
4.3.3	End Use Demand Not Matching Stormwater Runoff	4-6
4.3.4	Stormwater Options Not Appropriate for Study Site	4-6
4.3.5	Insufficient Space or Funds for Treatment	4-7
4.3.6	Insufficient Space for Storage	4-7
4.4	Technical Issues of Decision Making Framework	4-7
4.4.1	Collection and End Use	4-7
4.4.1.1	General Study Site Conditions	4-8
4.4.1.2	Stormwater Runoff	4-14
4.4.1.3	End Use Demand	4-16

4.4.1.4	Comparison of Stormwater Runoff and End Use Demand.....	4-23
4.4.1.5	Determination of Feasible Collection Options.....	4-25
4.4.1.6	Comparison of Feasible Collection Options	4-30
4.4.1.7	Stormwater Quality	4-30
4.4.1.8	End Use Required Quality	4-32
4.4.2	Storage.....	4-36
4.4.2.1	Determination of Feasible Storage Options	4-37
4.4.2.2	Estimation of Storage Requirements.....	4-44
4.4.3	Treatment.....	4-46
4.4.3.1	Treatment Options Available	4-47
4.4.3.2	Treatment Requirements Based on Removal Rate.....	4-49
4.4.3.3	Treatment Requirements Based on End Use Requirements	4-53
4.4.3.4	Treatment Requirements Based on Case Studies.....	4-54
4.4.4	Distribution.....	4-56
4.4.5	Integration of Technical Components	4-59
4.4.5.1	Optimisation Based on Quantity Issues	4-60
4.4.5.2	Optimisation Based on Quality Issues	4-60
4.4.5.3	Optimisation Based On Dual Functions of Technical Components .	4-61
4.4.5.4	Optimisation Specific to Different Technical Components.....	4-61
4.4.6	Financial Costs	4-62
4.5	Additional Decision Making Framework Issues	4-64
4.5.1	Social, Environmental and Economic Costs and Benefits	4-64
4.5.2	Community Participation and Issues	4-66
4.5.3	Risk Assessment.....	4-66
4.5.4	Coordination with Relevant Authorities.....	4-69
4.6	Summary.....	4-70

CHAPTER 5 DEMONSTRATION OF THE DECISION MAKING

	FRAMEWORK	5-1
5.1	Introduction	5-1
5.2	Case Study Site.....	5-2
5.3	Collection and End Use	5-3
5.3.1	General Study Site Conditions	5-4

5.3.2	Stormwater Runoff	5-7
5.3.3	End Use Demand	5-8
5.3.4	Comparison of Stormwater Runoff and End Use Demand	5-11
5.3.5	Collection Options	5-14
5.3.6	Stormwater Quality	5-15
5.3.7	End Use Required Quality	5-16
5.4	Storage	5-17
5.4.1	Storage Options	5-17
5.4.1.1	Aquifer Storage and Recovery	5-17
5.4.1.2	In-Ground Open, Above-Ground Closed and Underground Storage	5-20
5.4.1.3	Existing Water Bodies or Storage Areas	5-22
5.4.1.4	Feasible Storage Options	5-22
5.4.2	Storage Requirements	5-22
5.4.2.1	Simulation of Outdoor or Outdoor and Indoor Non-Potable Demand with Closed Storage	5-24
5.4.2.2	Simulation of Outdoor or Outdoor and Indoor Non-Potable Demand with Open Storage	5-25
5.4.2.3	Simulation of Indoor Non-Potable Demand with Closed Storage	5-27
5.4.2.4	Simulation of All End Use Demands with Closed Storage	5-27
5.4.2.5	Summary of Storage Capacity Requirements for Simulated Options	5-28
5.5	Treatment	5-29
5.6	Distribution	5-31
5.7	Integration of Technical Components	5-32
5.8	Financial Costs	5-37
5.9	Social, Environmental and Economic Costs and Benefits	5-42
5.10	Community Participation, Risk Assessment and Coordination with Relevant Authorities	5-43
5.11	Summary	5-44

CHAPTER 6 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS 6-1

6.1	Summary and Conclusions	6-1
6.1.1	Literature Review	6-1
6.1.2	Overview of a Stormwater Use Scheme	6-2

6.1.3	Decision Making Framework	6-3
6.1.4	Demonstration of the Decision Making Framework	6-4
6.2	Recommendations	6-6
REFERENCES		R-1
APPENDICES		
APPENDIX A	Possible Stormwater Use Scheme Options	A-1 to A-3
APPENDIX B	Data Sources and References for Collecting Data Information.....	B-1 to B-6
APPENDIX C	Calculation Of Monthly Outdoor Water Demand Based on Perth Data	C-1 to C-3
APPENDIX D	Aerial Photograph of Case Study Area.....	D-1
APPENDIX E	Case Study Calculations	
APPENDIX E1	Collection and End Use Calculations.....	E1-1
APPENDIX E2	Sample Monthly Impervious and Pervious Runoff Volume Calculations	E2-1
APPENDIX E3	Yearly, Monthly and Daily Indoor Demand and Yearly Outdoor Demand Calculations.....	E3-1 to E3-2
APPENDIX E4	Alpha Value and Monthly Outdoor Demand Calculations	E4-1 to E4-2
APPENDIX F	Beneficial use map series maps for the South Western Victoria regional aquifer systems and water table aquifers	F-1 to F-3
APPENDIX G	UVQ Input Values	G-1 to G-5
APPENDIX H	Detailed Cost Estimates for Case Study	H-1 TO H-9

LIST OF TABLES

Table 4.1	Collection Area Residential Block Data.....	4-15
Table 4.2	Collection Area Overview Data.....	4-15
Table 4.3	End Use Area Residential Block Data.....	4-15
Table 4.4	End Use Area Overview Data.....	4-15
Table 4.5	Calculation of Monthly and Yearly Runoff Volume in Decision Making Framework.....	4-15
Table 4.6	Residential Yearly Water Use for Australian States.....	4-15
Table 4.7	Domestic Water Consumption.....	4-15
Table 4.8	Distribution of Household Water Use	4-15
Table 4.9	Monthly Distribution of Outdoor Water Demand Based on Perth Data.....	4-15
Table 4.10	Urban Stormwater Contaminant Concentrations from Mudgway et al. (1997).....	4-15
Table 4.11	Classes of Reclaimed Water and Corresponding Standards for Biological Treatment and Pathogen Reduction from EPA Victoria (2002).....	4-15
Table 4.12	Guidance for Stormwater and Treated Wastewater Injectant Quality Requirements from Dillon and Pavelic (1996).....	4-15
Table 4.13	Stormwater Utilisation Case Studies with Acceptable Performance....	4-15
Table 4.14	Comparison of HACCP and the Proposed Drinking Water Guidelines Framework.....	4-15

Table 5.1	Collection Area Residential Block Data for Case Study	5-15
Table 5.2	Collection Area Overview Data for Case Study	5-15
Table 5.3	End Use Area Residential Block Data for Case Study	5-15
Table 5.4	End Use Area Overview Data for Case Study	5-15
Table 5.5	Monthly and Yearly Runoff Volume for Case Study	5-15
Table 5.6	Percentage Monthly Temporal Distribution of Household Outdoor Usage for Study Area.....	5-15
Table 5.7	Monthly Residential Demand for Case Study Area.....	5-15
Table 5.8	Monthly Irrigation Demand for Tom O’Brien Reserve.....	5-15
Table 5.9	Comparison of Stormwater Runoff and End Use Demand for Case Study	5-15
Table 5.10	Percentage of Indoor Demand Met Assuming All Outdoor Residential Demand is Met for Case Study Area	5-15
Table 5.11	Indication Mean Values of Stormwater Quality for an Urban Area from Duncan (2003)	5-15
Table 5.12	Storage Capacity and Average Annual Reliability for Different Exposed Surface Areas	5-15
Table 5.13	Storage Options for Case Study.....	5-15
Table 5.14	Case Study Technical Component Options	5-15
Table 5.15	Summary of Cost Estimates for Case Study.....	5-15
Table C.1	Single Residential Ex-house Usage and Monthly Distribution for Perth (read from Loh et al., 2003)	C-2
Table E3.1	Indoor Water Use for Different Household End Uses	E3-2
Table E4.1	Case Study Monthly Household Irrigation Demand.....	E4-2

Table G.1	Project Information	G-1
Table G.2	Physical Characteristics of Land Blocks and Neighbourhoods ..	G-2 to G-3
Table G.3	Water Flow	G-3
Table G.4	Calibration Variables	G-4
Table G.5	Observed Neighbourhood Flow Volumes and Quality for Calibration	G-5
Table H.1	Detailed Costing of Technical Components for Case Study	H-1 to H-6
Table H.2	Summary of Technical Component Option Costs	H-7
Table H.2	Costing of Case Study Stormwater Use Scheme Options	H-8 to H-9

LIST OF FIGURES

Figure 1.1	Integration of Stormwater as Part of Total Urban Water Management	1-15
Figure 1.2	Research Focus	1-15
Figure 2.1	Past and Emerging Stormwater Management.....	2-15
Figure 2.2	Detail of Technical Components in Emerging Stormwater Management.....	2-15
Figure 3.1	Sample of Stormwater Use Scheme Options Matrix	3-15
Figure 3.2	Matrix of Broadly Screened Stormwater Use Scheme Options.....	3-15
Figure 3.3	Basic Components of a Stormwater Use Scheme.....	3-15
Figure 3.4	Stylised Seasonal Variation in Stormwater Flow and Consumer Demand for Water in Adelaide, South Australia.....	3-15
Figure 4.1	Outline of Decision Making Framework Including Technical and Additional Issues.....	4-15
Figure 4.2	Household End Uses	4-15
Figure 4.3	Example Graph Showing Non-matching Outdoor Demand and Stormwater Runoff Patterns.....	4-15
Figure 4.4	Example Graph Showing Matching Outdoor Demand and Stormwater Runoff Patterns	4-15
Figure 4.5	Methodology for Determining Feasible Collection Options	4-15
Figure 4.6	Methodology for Determining Feasible Storage Options.....	4-15
Figure 4.7	Effect of Topography on Storage Capacity (Nelson, 1985)	4-15

Figure 4.8	Effect of Topography on Excavation and Infill Requirements (adapted from Nelson, 1985)	4-15
Figure 4.9	Embankment Construction to Increase Natural Pond Storage Capacity (adapted from Nelson, 1985)	4-15
Figure 4.10	Treatment Requirements Based on Melbourne Water Corporation Treatment Train	4-15
Figure 4.11	Treatment Flowchart Based on Treatment Removal Rates	4-15
Figure 4.12	Treatment Flowchart Based on End Use Requirements (adapted from EPA Victoria, 2002)	4-15
Figure 4.13	Methodology for Determining Feasible Distribution Options.....	4-15
Figure 5.1	Location of Case Study Site.....	5-15
Figure 5.2	Decision Making Framework Steps Related to Collection and End Use.....	5-15
Figure 5.3	Street Layout and Contours of Case Study Area	5-15
Figure 5.4	Total Demand for Residential Case Study Area and the Tom O'Brien Reserve Compared to Stormwater Runoff.....	5-15
Figure 5.5	Indoor, Outdoor and Total Residential Demand Compared to Stormwater Runoff.....	5-15
Figure 5.6	Legend Used for Figures 5.7 to 5.10 (DCNR, 1995a,b).....	5-15
Figure 5.7	Lower Tertiary Aquifer System (DCNR, 1995b).....	5-15
Figure 5.8	Middle Tertiary Aquifer System (DCNR, 1995b).....	5-15
Figure 5.9	Upper Tertiary Aquifer System (DCNR, 1995b).....	5-15
Figure 5.10	Water Table Aquifers (DCNR, 1995a).....	5-15
Figure 5.11	Location of Possible Storage Areas for Case Study	5-15

Figure 5.12	Storage Capacity versus Average Annual Reliability for Case Study which meets Outdoor Demand	5-15
Figure 5.13	Stormwater Use Scheme Option Layout with Infiltration Trench Collection, Storage in Stormwater Reserve, Disinfection Treatment and Pipe Distribution	5-15
Figure 5.14	Stormwater Use Scheme Option Layout with Pipe Collection, Storage in Tom O’Brien Reserve, Wetland Treatment and Pipe Distribution.....	5-15
Figure 5.15	Stormwater Use Scheme Option Layout with Infiltration Trench Collection, Storage in Tom O’Brien Reserve, Wetland Treatment and Pipe Distribution	5-15
Figure 5.16	Costs versus End Use Demand for Stormwater Use Scheme Options .	5-15
Figure 5.17	Minimum Annual Reliability versus End Use Demand for Stormwater Use Scheme Options	5-15
Figure 5.18	Average Use of Stormwater versus End Use Demand for Stormwater Use Scheme Options	5-15
Figure A.1	Matrix of Possible Stormwater Use Scheme Options for Greenfield, Redevelopment and Infill Areas	A-1
Figure A.2	Matrix of Possible Stormwater Use Scheme Options for Existing Urban Areas	A-2
Figure A.3	Matrix of Possible Stormwater Use Scheme Options for Mixed Greenfield, Redevelopment Infill and Existing Urban Areas.....	A-3
Figure C.1	Estimates of Ex-House Water Demand from Perth for Single Residential Houses.....	C-1
Figure C.2	Comparison of Perth and Melbourne Mean Monthly Temperatures.....	C-3
Figure C.3	Comparison of Perth and Melbourne Rainfall and Evaporation.....	C-3
Figure D.1	Aerial Photograph of Case Study Area.....	D-1

Figure F.1	Beneficial Use Map for the South Western Victoria Regional Aquifer Systems (sourced from DCNR, 1995b)	F-2
Figure F.2	Beneficial Use Map for the South Western Victoria Water Table Aquifers (sourced from DCNR, 1995a).....	F-3