

A CASE STUDY RESEARCH INTO URBAN WATER REUSE

AMIT PREMPAL CHANAN

Faculty of Engineering
University of Technology, Sydney

A dissertation submitted to the University of Technology, Sydney
in fulfilment of the requirements for the degree of Doctor of
Philosophy (Engineering).

June 2012

Certificate of Authorship/Originality

I certify that the work in this thesis has not been previously been submitted for a degree, nor has it been submitted as part of the requirements for a degree, except as fully acknowledged within the text

I also certify that the thesis has been written by me. Any help that I have received in my research work and preparation of the thesis itself has been acknowledged. In addition, I certify that any information sources and literature used indicated in the thesis.

Production Note:
Signature removed prior to publication.

Signature of Candidate

Acknowledgement

Education is not the filling of a vessel, but the kindling of a flame.

Socrates

First and foremost, I would like to thank my parents for kindling the flame for education. This thesis is a symbol of my lifelong learning journey that my parents and my elder siblings inspired me to follow, right from my childhood.

In the Indian culture the role of a teacher is described to be akin to God. I have been fortunate to have really great teachers who guided me through this research. Prof Vigid Vigneswaran always encouraged me to capture my point of view in academic papers for high profile journals, his guidance in structuring and conduct of this research was greatly appreciated. I am also grateful to A/Prof Jaya Kandasamy, who over the last four years has played the vital roles of a mentor, good friend and a constant encourager.

I am particularly thankful to my wife Vinita, who has very capably shouldered all the responsibilities on the domestic front, allowing me to dedicate my weekends to work on this research. Her help in lifting me out of every performance trough over the last four years and finally in editing this thesis is also greatly appreciated.

I am also indebted to Dr Bruce Simmons for his guidance in structuring this thesis, as well as valuable words of encouragement over the duration of this research.

In compiling this thesis there are many other friends and colleagues who assisted me, and whose help I have greatly appreciated. I would particularly like to mention my best friend and long-term study partner Qasim Malik,

whose company and support on Saturdays at the UTS helped me to stay focussed. I am thankful to economist extraordinaire Daniel Masters for his assistance with the IO modelling work. I would also like to acknowledge the support of Gurmeet Singh, Isabelle Ghetti, Paul Woods and other staff from Kogarah City Council.

Last but not least, I would like to thank Eisha and Rohan for allowing their dad to be absent from weekend sports, while working on this research.

Contents

Certificate of Authorship/Originality.....	i
Signature of Candidate.....	i
Acknowledgement.....	ii
Contents.....	iv
List of Figures	viii
List of Tables	x
List of Pictures	xii
List of Acronyms	xiii
List of Publications.....	xiv
Abstract.....	xvi
Chapter 1. INTRODUCTION	1
1.1 Demand-side Options for Urban Water Supply Security	3
1.2 Water Reuse as Supply-side Option for Urban Water Security	7
1.3 Research Justification.....	9
1.4 Research Objective	11
1.5 Structure of the Study.....	12
1.6 Summary	15
Chapter 2. LITERATURE REVIEW.....	16
2.1 Introduction	16
2.2 Water Supply and Sanitation in Early Civilisations.....	18
2.3 Greco-Roman Influence on Water Management.....	21
2.4 Water Management and the Industrial Revolution	22
2.5 Water Engineering in 20th Century.....	25
2.6 Water Management of the Future.....	28
2.6.1 A Soft Path for the Future	30
2.6.2 The Desalination Dilemma	35
2.7 Role for Water Recycling and Reuse	38
2.7.1 Types of Water Reuse	40
2.7.3 Decentralised Reuse Systems	42
2.7.4 Water Mining.....	46

2.8	Summary	50
Chapter 3.	RESEARCH METHODOLOGY	51
3.1	Introduction	51
3.1.1	Contemporary Water Management.....	52
3.2	Rationale for Case Study Research.....	55
3.3	Research Objectives	58
3.4	Case Study Method.....	60
3.5	Summary	64
Chapter 4.	CASE STUDY CONTEXT	65
4.1	Kogarah Local Government Area.....	65
4.2	Kogarah's Water Demand	69
4.3	Total Water Cycle Management.....	72
4.4	Summary	76
Chapter 5.	WATER MINING TECHNOLOGY	77
5.1	Water Mining.....	77
5.2	Advantages of Water Mining	78
5.2.1	Transportation Costs Advantage.....	78
5.2.2	Organic Solids Treatment Advantage.....	80
5.2.3	Security and Disaster Recovery Advantage.....	82
5.2.4	Community Engagement Advantage	84
5.2.5	Environmental Advantage.....	85
5.2.6	Volume Stripping Advantage	85
5.2.7	Fit for Purpose Advantage.....	87
5.2.8	Equity Advantage	87
5.3	Planning a Water Mining Project.....	88
5.3.1	Preliminary Exploration.....	89
5.3.2	Feasibility Study	90
5.3.3	Proposed Location:	91
5.3.4	Demand/Supply Balance:.....	94
5.3.5	Sewage Quality:.....	97
5.3.6	Reclaimed Water Quality Objectives:.....	99
5.3.7	Confirm Water Market:	104

5.3.8	Possible Treatment Options:.....	105
5.3.9	Cost-Effectiveness Analysis:.....	115
5.3.10	Stakeholder Engagement:	116
5.3.11	Final Design and Obtaining Approvals/Agreements	117
5.4	Summary	121
Chapter 6.	WATER MINING OPERATIONAL RISKS	123
6.1	Introduction	123
6.2	Water Recycling Risks	124
6.2.1	Human Health Risks.....	124
6.2.2	Environmental Risks.....	125
6.3	Hazard Analysis and Critical Control Points (HACCP)	126
6.3.1	HACCP in the context of Water Supply	128
6.3.2	Application of HACCP at Case Study Site	130
6.4	Nutrient Risk Management	157
6.4.1	Phosphorus: A Finite Resource	158
6.4.2	Phosphorus: As Environmental Contaminant.....	160
6.4.3	Phosphorus Removal from Wastewater	162
6.4.4	Phosphorus Recovery from Wastewater	166
6.4.5	Phosphorus Recovery Potential for Sydney Basin	171
6.5	Summary	173
Chapter 7.	BENEFITS OF NON-POTABLE REUSE	175
7.1	Urban Irrigation	175
7.2	Investment in Non-Potable Reuse	178
7.3	Methodology for Valuing Urban Irrigation	182
7.3.1	User Hours Method	182
7.3.2	Hedonic Price Method.....	183
7.3.3	Input Output Analysis Method.....	185
7.4	Results of Urban Irrigation Evaluation.....	197
7.4.1	Other Methods.....	200
7.5	Summary	202
Chapter 8.	WATER PRICING POLICY FRAMEWORK	203
8.1	Background.....	203

8.2	Water Reform Framework.....	205
8.2.1	National Water Initiative	206
8.3	Supply and Demand Economics for Recycling Industry	208
8.4	Water Pricing in Australia	211
8.4.1	Recycled Water Pricing	214
8.5	Pricing Water at the Case Study Site.....	218
8.6	Conclusion	221
Chapter 9.	CONCLUSION AND FUTURE RESEARCH.....	223
9.1	Research Outcomes.....	223
9.2	Future Research.....	227
APPENDICES	230
REFERENCES	236

List of Figures

Figure 1.1: Rainfall deciles across Australia 1/1/1997 – 31/12/2009 (CSIRO, 2010)	1
Figure 1.2: Available total storage in Sydney’s dams on 8/2/2007 (SCA, 2007).....	3
Figure 1.3: Deferral of augmentation works due to DM (White, 1998)	5
Figure 1.4: Sydney’s Projected Population 1999-2049 (McDonald and Kippen, 2002) ..	6
Figure 1.5: Structure of the Study	13
Figure 2.1: Traditional versus Sustainable Urban Water Cycle Management (Stenkes et. al. 2004).....	29
Figure 2.2: Desalination increases the amount of imported water and reinforces the current once through water use approach (Chanan et. al. 2009).....	37
Figure 2.3: Close Loop Water Cycle Concept (Hakim, 2002).....	40
Figure 2.4: Types of Planned Wastewater Reuse (Modified from Keremane, 2007) .	41
Figure 2.5: Conventional, Embedded and Decentralised Systems (Fane, 2005)	43
Figure 2.6: Types of decentralised reuse scheme (Modified from Gikas and Tachobanoglous, 2009)	44
Figure 2.7: Schematic Illustration of Water Mining Facility (Adapted from Gikas & Tchobanogloukas, 2007, Figure 2).....	46
Figure 2.8: Sewer Mining Vs Centralised Reuse (Chanan and Kandasamy, 2009)....	48
Figure 3.1: Inquiry lens and technological practice phenomenon (Modified from Pacey, 1983)	62
Figure 4.1: Location Map of Kogarah Local Government Area	65
Figure 4.2: Institutional barriers to water cycle management in Sydney (Chanan, 2006a).	68
Figure 4.3: Breakdown of Non-Residential Water Use in Kogarah (Chanan et al. 2009)	70
Figure 4.4: Kogarah Council’s own water use profile (Chanan et al, 2009).....	71
Figure 4.5: Water Savings & Levelised Costs of Various TWCM Options (Chanan and Ghetti, 2006).....	75
Figure 5.1: Typical Schematic of a Water Mining Plan (Chanan, 2009).....	77
Figure 5.2: Sewer Mining Vs Centralised Reuse (Adopted from Rimer et al, 2004. Fig 1)	80
Figure 5.3: Particle sizes and appropriate treatment processes (Advanced Water Filters, 2011)	81
Figure 5.4: Malabar STP catchment and the Case study site (Sydney Water, 1998)..	84
Figure 5.5: Volume Stripping Benefit of Water Mining Plants (Modified from White, 1998)	86
Figure 5.6: Planning & Implementing Water Mining Project (Chanan and Kandasamy, 2009)	89
Figure 5.7: Site selected for Beverley Park Water Mining Plant.....	92
Figure 5.8: Typical Diurnal Flow Patterns in Sewer (Adopted from Enfinger and Stevens, 2006).....	94
Figure 5.9: Supply & Demand Balance (US EPA, 2004 Fig 3-9).....	95
Figure 5.10: Doppler flow sensor uses ultrasonic sound waves for flow gauging (Mace Meters, 2011).....	96
Figure 5.11: October 2006 flow pattern in Ramsgate sewer carrier (Manly Hydraulics Laboratory, 2006).....	98

Figure 5.12: Schematic of Sequential Batch Reactor Process (Adopted from US EPA, 2002)	107
Figure 5.13: Schematic of MBR processes, popularly used in water mining schemes (Adopted from Landcom, 2006)	107
Figure 5.14: Schematic of ReAqua CAS Technology based Water Mining Plant (Adopted from CDS Technologies).....	109
Figure 5.15: Direct Filtration Vs Non-blocking Continuous Deflective Separation Method (Heist & Davey, 2002)	110
Figure 5.16: Chemical Assisted Fine Solid Separation as Pre-screening for Biological Treatment	111
Figure 5.17: Biological Treatment in Submerged Aerated Filter (Chanan et al. 2010)	113
Figure 5.18: Ultraviolet disinfection of product water (Chanan et al. 2010).....	115
Figure 5.19: Chart showing diurnal variation of flows, TDS and tide levels	118
Figure 5.20: Chart showing Infiltration rates in the sewer versus tide levels	119
Figure 5.21: Revised final schematic of Beverley Park Water Mining Plant.....	120
Figure 6.1: A plain English schematic of HACCP Process (Davison et al. 2001)	126
Figure 6.2: Twelve Steps of HACCP Planning (Davison, Davis and Deere, 1999) ..	131
Figure 6.3: Process Flow Diagram Beverley Park water mining facility (Kogarah Municipal Council, 2007).....	137
Figure 6.4: Critical Control Point Decision Tree (Kogarah Municipal Council, 2007 p.26).....	150
Figure 6.5: Global sources of phosphorus for fertilizers (Cordell, 2009).....	159
Figure 6.6: Biological Phosphorus Removal (Vigneswaran et al, 2004)	165
Figure 6.7: Phosphorus Recovery Options	167
Figure 6.8: Schematic of a Struvite Production Plant (modified from Ueno & Fujii, 2001)	169
Figure 6.9: Experimental set-up MBR followed by purolite ion-exchange column (Johir et al, 2011)	170
Figure 6.10: Key Phosphorus Movements in Sydney household Sector (Modified from Tangsubkul, 2005).....	172
Figure 7.1: Illustration of typical financial analysis for water recycling (Biagtan, 2008)	180
Figure 7.2: Structure of an Input Output Table (Cox, 2006).....	186
Figure 8.1: Supply Target based policy impacts on equilibrium pricing (Chanan et al. 2011)	209
Figure 8.2: Typical process of determining Australian water utilities' revenue requirements (NWC, 2008).....	212
Figure 8.3: Predicted increase in household water bills due to Desalination costs (The Australian, 2010).....	214
Figure 8.4: Recycled water pricing arrangements in Australia (WSAA, 2005)	216
Figure 8.5: Recycled water price ceiling posed by potable water price (WSAA, 2005)	217
Figure 8.6: Comparison of Willingness to Pay and Potable Water Price for Beverley Park Water Reuse Project (Chanan et al. 2011)	220

List of Tables

Table 2.1: Broad patterns of community water access and disposal	17
Table 2.2: Status of Australian Water Infrastructure.....	27
Table 2.3: Water Management Paradigm Shift	32
Table 2.4: Status of Desalination for Major Australian centres	35
Table 4.1: Water Use in Kogarah.....	69
Table 4.2: Identified TWCM Measures for Kogarah	72
Table 4.3: Results of the End Use and SWITCH Modelling of TWCM Options	73
Table 4.4: Levelised Costs of TWCM Options.....	74
Table 5.1: Comparison of Transportation & Production Costs in the Utility Sector .	79
Table 5.2: Settling times for various solids	82
Table 5.3: Water demand from Kogarah Council’s Water Mining Facility at Beverley Park	96
Table 5.4: Observed water quality in the raw sewage upstream of the plant	99
Table 5.5: Suggested Water Quality Objectives for Recycled Water	101
Table 5.6: Summary of proposed water quality targets for case study project	103
Table 6.1: Standard procedures for HACCP introduction	127
Table 6.2: Beverley Park Water Mining Facility Product Description Table	133
Table 6.3: Verification Monitoring Requirements	135
Table 6.4: Ongoing Monitoring Requirements	136
Table 6.5: Hazards and their control measures at Beverley Park Plant.....	140
Table 6.6: Critical Control Points and identified Control Loops	151
Table 6.7: Specified performance parameters and observed performance of the plant	155
Table 6.8: Observed Nutrient Levels in Product Water - Grab Samples week 4	156
Table 6.9: Observed BOD ₅ Levels in Product Water - Grab Samples	156
Table 7.1: Key Environmental and Social benefits of urban green space.....	177
Table 7.2: Providers of Sporting Fields/ovals in Sydney Metropolis.....	179
Table 7.3: Median House Prices in Adjoining Suburbs within Kogarah Municipality	201
Table 7.4: Calculation of St George Regional Location Quotient	194
Table 7.5: Calculation of St George-Sutherland Regional Location Quotient	195

Table 7.6: Direct water requirement coefficient 197

Table 7.7: Water Multipliers for St George Region..... 199

Table 7.8: Average User Hours for Winter Sports at Kogarah’s Sports fields..... 200

List of Pictures

Picture 2.1: An ancient well at Mohanjo Daro, Indus Valley Civilisation	18
Picture 2.2: Over 4000 years old sanitary drainage system, Indus Valley Civilization	19
Picture 2.3: Roman Aqueduct, Nimes, France	21
Picture 2.4: 'A new broom much wanted in Sydney'.	23
Picture 5.1: Ramsgate Sewer carrier	93

List of Acronyms

BOD	Bio-chemical oxygen demand
CSIRO	Commonwealth Scientific and Industrial Research Organisation
HRT	Hydraulic retention time
IO	Input Output
IWCM	Integrated water cycle management
LGA	Local government area
LQ	Location quotient
MBR	Membrane bioreactor
ML	Megalitres (1,000,000 Litres)
MLD	Megalitres per day
SS	Suspended solids
TSS	Total suspended solids
TWCM	Total water cycle management
UV	Ultra violet
WSAA	Water Services Association of Australia

List of Publications

1. Chanan, A.P., Kandasamy, J.K., and Sharma, D., (2008). A Role for Input-Output Analysis in Urban Water Policy Decisions in Australia, In *Proc. of The IIOA Input - Output & Environment Conference*, (ed.) Prof. Dr. Thijs ten Raa, Saville, Spain, July 2008, pp. 1-18.
2. Chanan A. and Kandasamy J. (2009). Water Mining: Planning and Implementation Issues For A Successful Project. In *Water and Wastewater Treatment Technologies*, [Ed. Saravanamuthu (Vigi) Vigneswaran], Encyclopedia of Life Support Systems (EOLSS), Developed under the Auspices of the UNESCO, Eolss Publishers, Oxford, United Kingdom.
3. Vigneswaran S., Davis C., Kandasamy J., and Chanan A., (2009), Urban Wastewater Treatment: Past, Present and Future, in *Water and Wastewater Treatment Technologies*, [Ed. Saravanamuthu (Vigi) Vigneswaran], Encyclopedia of Life Support Systems (EOLSS), Developed under the Auspices of the UNESCO, Eolss Publishers, Oxford, United Kingdom.
4. Chanan, A., Kandasamy, J., Vigneswarans V., and Sharma, D.,(2009). Urban Irrigation: A Productive Use of Water or an Optional Extra? In *Proceedings of 7th International Conference of the European Water Resources Association*, 25 – 27 June 2009, Limassol, Cyprus.
5. Chanan, A., Kandasamy, J., Vigneswarans V., and Sharma, D., (2009a). A gradualist approach to address Australia's urban water challenge, *Desalination*, vol. 249, no. 3, pp. 1012-1016.
6. Chanan A. Vigneswaran S. and Kandasamy J. (2010) Valuing stormwater, rainwater and wastewater in the soft path for water management: Australian case studies, *Water Science and technology*, 62:12, pp. 2854 -2861.

7. Chanan, A., Saravanamuth, V., Kandasamy, J., and Shon, H.K., (2010). Chemical-assisted physico-biological water mining system, *Proceedings of the ICE - Water Management*, Volume 163, Issue 9, pp. 469 –474.
8. Chanan, A.P., Vigneswaran, S., Kandasamy, J., and Simmons, B. (2011). Lessons for a viable water recycling industry, *Proceedings of the ICE - Water Management*, Volume 164, Issue 5, pp. 213 –219.
9. Chanan, A.P., Ghetti, I.B., and Kandasamy, J.K., (2011). Challenges of managing coastal areas through climate change, *Proceedings of the ICE - Municipal Engineer*, Volume 164, Issue 2, pp. 83 –88.
10. Chanan, A.P., Kandasamy, J., and Vigneswaran, S., (2011). Role of case study research in training the renaissance water engineer, *Global Journal of Engineering Education*, Vol 13, Issue 3, pp. 110-116.
11. Chanan, A.P., Vigneswaran, S., and Kandasamy, J., (2012). Case Study Research: Training Interdisciplinary Engineers with Context-dependent knowledge, *European Journal of Engineering Education*, Vol 37, Issue 1, pp. 97-104.
12. Chanan, A.P., Vigneswaran, S., and Kandasamy, J., (2012). Wastewater Management Journey – From Indus Valley Civilisation to the Twenty first Century, In *Wastewater Reuse and Management* [Eds. Sanjay K. Sharma and Rashmi Sanghi], Springer Publishing, London, United Kingdom.
13. Chanan, A., Vigneswaran, V., Kandasamy, J., and Singh, G., (Submitted – under review). Beverley park water mining plant: getting the salt just right, *Desalination and Water Treatment*.

Abstract

Climate change could lead to longer and more frequent droughts for Australia. The option of water reuse, being independent of rainfall variations, provides a major source of water supply security for our growing cities. A '*soft path*' for water management is widely acknowledged to be the sustainable future of water management. Decentralised wastewater reuse schemes form an important supply option in this '*soft path*' approach.

Discussion on water reuse and its role in sustainable water resource management in Australia has been on the agenda for the last three decades. Despite its long presence on the agendas of policy makers and scientific community, promulgation of water reuse in Australia has been a rather slow process. The research efforts to date have focussed on the technological aspects of water reuse, leaving behind a gap in the area of policy and implementation aspects. This knowledge gap is even more severe when considering decentralised urban water reuse. Australian literature on decentralised reuse schemes owned and operated by entities other than the major water utilities is virtually non-existent.

This research assists in bridging the knowledge gap identified above, by investigating the decentralised water reuse technique of 'water mining' in detail. The concept of water mining is defined and range of technologies available for water mining are described, along with discussion on planning and risk management aspects of such schemes. A comprehensive literature review is also provided on urban water reuse, examining centralised and decentralised water reuse in Australia.

As opposed to traditional engineering line of enquiry, this research is of interdisciplinary nature, looking at socio-economic, environmental management, pricing policy, as well as technical aspects of a decentralised water reuse project. Using Beverley Park Water Reclamation Project (Sydney's first water mining scheme) as a case study, this research analyses design, planning, and implementation phases of this project. Operational risks to human as well as environmental health are also reviewed in context of the case study site.

A regional economic Input Output (IO) Model for the St George – Sutherland Statistical Region is developed to analyse the economic impacts of the case study project on the local economy. In addition to the IO method, other benefit estimation methods such as Hedonic pricing and sports fields Usage Hours are also discussed in context of the case study site.

On policy front, pricing of recycled water is further explored and lessons from solid waste recycling applied. The community's reluctance to accept potable reuse indicates that recycled water is not yet considered a direct substitute for virgin water. A sound water pricing regime that reflects the true costs of water and a competitive water industry is discussed as a critical policy platform for viable water recycling industry.

With 21st century water management transforming into a multi-dimensional challenge of water security, a holistic multi-dimensional approach is essential. By applying different aspects of the case study inquiry lens, this research adopted a multi-dimensional approach in exploring social, economic and technical characteristics of a single water mining case study.