

A NEW HOLISTIC FRAMEWORK FOR DESIGN OF COST
EFFECTIVE MINIMUM WATER NETWORK

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To my beloved family:

Whose love has nourished and sustained me always.

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ABSTRACT

Water pinch analysis (WPA) is a well-established tool for the design of a maximum water recovery (MWR) network. MWR, which is primarily concerned with water recovery and regeneration only partly addresses water minimisation problem. Strictly speaking, WPA only leads to *MWR targets* and not the *minimum water targets* as widely claimed by researchers over the years. The *minimum water targets* could be achieved when all options for water minimisation including elimination, reduction, reuse/recycling, outsourcing and regeneration have been holistically applied. To date, research towards water conservation from the holistic water minimisation viewpoint has lagged behind. This thesis presents the development of a new holistic framework for designing a minimum water network for industry and urban systems. The framework consists of five key steps, i.e. (1) Specify the limiting data, (2) Determine the MWR targets, (3) Screen process changes using water management hierarchy (WMH), (4) Apply *Systematic Hierarchical Approach for Resilient Process Screening* (SHARPS) strategy, and (5) Network design. Six key contributions have emerged from this work. First is the development of a minimum water targeting and design procedures for urban system. Second is the development of a new holistic framework to systematically guide, prioritise and quantitatively evaluate water minimisation options for grassroots and retrofit designs for urban and industrial systems. Third is the introduction of a unique and comprehensive water management hierarchy for screening process changes. Fourth is the new SHARPS technique which provides a quick and efficient means to screen inferior process changes and to predict the fresh water savings and desirable investment limits prior to design/retrofit. Fifth is the multiple utility targeting method using source-sink composite curves and the sixth contribution is the new network design technique using source-sink composite curves. The methods were successfully implemented on semiconductor and mosque case studies and yielded significant savings within designers' payback period criterion.

ABSTRAK

Analisis jepit air adalah kaedah yang mashyur bagi rekabentuk rangkaian perolehan semula air maksima. Keutamaan perolehan semula air maksima melibatkan perolehan dan penjanaan semula air dan hanya merupakan sebahagian dari penyelesaian masalah peminimuman air. Analisis jepit air sebenarnya bertujuan mencapai *sasaran perolehan semula air maksima* dan bukannya *sasaran air minima* seperti diwarwarkan oleh para penyelidik dewasa ini. *Sasaran air minima* hanya boleh dicapai dengan mengambil kira setiap langkah penjimatan air seperti kaedah penghapusan, pengurangan, perolehan semula, penggunaan sumber luar dan penjanaan secara holistik. Sehingga kini, penyelidikan terhadap penjanaan air berdasarkan pendekatan peminimuman air secara holistik ini masih baru. Tesis ini membincangkan pembangunan kerangka kerja holistik baru bagi membina rangkaian air minima bagi sistem industri dan domestik. Kerangka kerja ini merangkumi lima langkah iaitu; (1) Menetapkan had data, (2) Menentukan sasaran perolehan semula air maksima, (3) Memilih perubahan proses berdasarkan hierarki pengurusan air (HPA), (4) Aplikasikan strategi *Systematic Hierarchical Approach for Resilient Process Screening* (SHARPS), dan (5) Rekabentuk rangkaian. Enam sumbangan utama telah muncul dari penyelidikan ini. Pertama ialah pembangunan teknik penetapan sasaran jumlah air minima dan tatacara rekabentuk bagi sektor domestik. Kedua adalah pembangunan kerangka kerja holistik baru yang memberi garis panduan sistematik keutamaan dan menilai secara kuantitatif pilihan rangkaian proses peminimuman air bagi bangunan baru dan sedia ada untuk sektor industri dan domestik. Ketiga ialah pengenalan satu hierarki pengurusan air yang unik dan menyeluruh bagi pemilihan perubahan proses. Ke-empat ialah teknik SHARPS bagi pemilihan perubahan proses dengan cepat dan cekap dan bagi meramal penjimatan air dan had pelaburan yang dikehendaki. Kelima ialah kaedah penetapan sasaran sumber air berbilang dengan menggunakan lengkuk komposit sumber-sinki, dan sumbangan yang keenam ialah teknik rekabentuk rangkaian baru melalui lengkuk komposit sumber-sinki. Teknik-teknik ini telah berjaya dilaksanakan ke atas kajian kes kilang semikonduktor dan masjid dengan penjimatan yang memberangsangkan yang menepati kriteria masa bayar balik yang ditetapkan oleh pengguna.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	TITLE PAGE	i
	DECLARATION OF ORIGINALITY AND EXCLUSIVENESS	ii
	DEDICATION	iii
	ACKNOWLEDGEMENTS	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	xiii
	LIST OF FIGURES	xvi
	LIST OF NOMENCLATURES	xxiii
	LIST OF APPENDICES	xxx
1	INTRODUCTION	1
	1.1 Introduction	1
	1.2 Global Water Outlook	2
	1.3 Outlook of the Water Industry in Malaysia	3
	1.4 Problem Background	6
	1.5 Problem Statement	7
	1.6 Research Objective	8
	1.7 Scope of Work	8
	1.8 Research Contributions	9
	1.9 Summary of this Thesis	13

2	LITERATURE REVIEW	15
2.1	Introduction	15
2.2	A review on maximum water recovery method for urban system	18
2.2.1	Literature review	18
2.2.1.1	Greywater reuse and rainwater harvesting	18
2.2.1.2	Water and waste re-use	23
2.2.2	Research gap on urban WPA	25
2.3	A review on using water pinch analysis for minimum water network targeting in industrial sector	26
2.3.1	Literature review	26
2.3.2	Research gap in minimum water targeting for industrial sector	29
2.4	A review on cost effective water system design	33
2.4.1	Literature review	33
2.4.2	Research gap on design of cost-effective minimum water network	35
2.5	A review on single and multiple utilities targeting	35
2.5.1	Literature review	35
2.5.2	Research gap in single and multiple utilities targeting	38
2.6	A review on water network design using composite curve	40
2.6.1	Literature review	40
2.6.2	The gap in water network design	42
2.7	The State-of-the-art on Water Minimisation Techniques in Industry and Urban Sectors – Addressing the Research Gap	43
3	FUNDAMENTAL THEORY	48
3.1	Introduction	48

3.2	Urban or domestic wastewater	49
3.3	Water Pinch Analysis	52
3.3.1	Significance of Water Pinch Analysis	52
3.3.2	Routes to water minimisation	54
3.3.3	Water Pinch Analysis Steps	55
3.3.3.1	Step 1: Analysis of water network	56
3.3.3.2	Step 2: Data extraction	60
3.3.3.3	Step 3: Targeting of minimum utility	61
3.3.3.4	Step 4: Water network design/retrofit	70
3.3.3.5	Step 5: Economic evaluation	74
4	METHODOLOGY	75
4.1	Introduction	75
4.2	Urban water pinch concept (Contribution 1)	76
4.3	A holistic framework for cost effective minimum water network (Contribution 2)	81
4.3.1	The Water Management Hierarchy (Contribution 3)	82
4.3.2	A Holistic Framework for Design of Cost Effective Minimum Water Network (CEMWN)	85
4.3.2.1	Step 1: Specify the limiting water data	87
4.3.2.2	Step 2: Determine the MWR targets	87
4.3.2.3	Step 3: Screen process changes using WMH	88
4.3.2.4	Step 4: Apply SHARPS strategy (Contribution 4)	92
4.3.2.5	Step 5: Network design	99
4.4	Targeting multiple utilities using composite	100

	curves (Contribution 5)	
4.4.1	Targeting the minimum flowrate for a single utility using <i>water composite curves</i>	101
4.4.1.1	Pinched problems	102
4.4.1.2	Threshold problem	112
4.4.2	Targeting Multiple F_{mu} Using Source and Sink Composite Curves	115
4.5	Network design using composite curves (Contribution 6)	118
4.5.1	A Generic Graphical Technique for Simultaneous Targeting and Design of Water Networks	118
4.5.1.1	Case Study 1: Simultaneous targeting and design using Approach 1	126
4.5.1.2	Case Study 2: Simultaneous targeting and design using Approach 2	135
4.5.2	Step 4 –Water Network Evolution (EVOLVE)	142
4.5.3	Exploring Mixing Possibilities Using NAD	145
4.6	Chapter Summary	148
5	RESULTS AND DISCUSSION	149
5.1	Introduction	149
5.2	Case Study Industry, A Semiconductor Plant	149
5.2.1	MySem background	149
5.2.2	Statement of needs	150
5.2.3	Process description	151
5.2.4	Current plant consumption analysis	152
5.2.5	Water balance	153

5.2.6	CEMWN analysis	162
5.2.6.1	Step 1: Specify the limiting water data	162
5.2.6.2	Step 2: Determine the MWR targets	164
5.2.6.3	Step 3: Screen process changes using WMH	166
5.2.6.4	Step 4: Apply SHARPS strategy	175
5.2.6.5	Step 5: Network design	180
5.3	Case Study Urban, A mosque	184
5.3.1	SIM description	184
5.3.2	Process description	184
5.3.3	Water Recycling Scheme for Sultan Ismail Mosque Proposed by IEWRM (IPASA, 2004)	186
5.3.4	CEMWN analysis on SIM	187
5.3.4.1	Step 1: Specify the limiting water data	187
5.3.4.2	Step 2: Determine the MWR targets	191
5.3.4.3	Step 3: Screen process changes using WMH	198
5.3.4.4	Step 4: Apply SHARPS strategy	202
5.3.4.5	Step 5: Network design	207
5.4	Results Comparison	213
5.5	Using CEMWN Target As Reference Benchmark	215
5.6	Chapter Summary	216
6	CONCLUSIONS AND RECOMMENDATIONS	217
6.1	Conclusions	217
6.2	Recommendations	219

REFERENCES

221

Appendices A – E

233-248

LIST OF TABLES

TABLE	TITLE	PAGE
1.1(a)	Refereed national and international journals and magazines, conference papers published, accepted or submitted; exhibitions participated and medals won; patents approved or applied towards contribution of knowledge from this thesis.	11
1.1(b)	Refereed national and international journals and magazines, conference papers published, accepted or submitted; exhibitions participated and medals won; patents approved or applied towards contribution of knowledge from this thesis (continue).	12
2.1	Water Quality Cascade with End Uses (Chanan <i>et al.</i> , 2003).	20
2.2	Water pinch analysis research <i>gaps</i> involving industry and urban sectors.	46
3.1	Naming of components of domestic wastewater (from households) (Ujang and Henze, 2005).	50
3.2	General structure of a water cascade table.	62
4.1	Water quality standards and criteria suitable for domestic water recycling.	80
4.2	Limiting Water Data from Polley and Polley (2000).	103
4.3	Limiting data for example 3.	111
4.4	Limiting data for threshold problem (example 4).	113
4.5	Limiting data for example 1.	127
4.6	Limiting data for example 2.	136

5.1	Wet bench flowrate in idle mode.	161
5.2	Wet bench flowrate in operation mode.	161
5.3	Limiting water data for MySem.	163
5.4	Base-case maximum water recovery targets for MySem (without process changes).	165
5.5	Amount of IWT and domestic wastewater before and after integration.	166
5.6	Various process changes options applicable for MySem.	167
5.7	Various effects of EDI options on water targets.	170
5.8	Effects of abatement options on water targets.	172
5.9	MySem water targets after implementation of MWN technique.	174
5.10	Summary of the water demands for Sultan Ismail Mosque.	188
5.11	Summary of the water sources available in Sultan Ismail Mosque.	188
5.12	Summary of water quality standards and criteria suitable for domestic water recycling (Al-Jayyousi, 2003).	189
5.13	Results of water quality tests conducted on the graywater collected from the place of ablution at King Abdullah Mosque (CSBE, 2003).	190
5.14	Typical Pollutant Concentrations in Stormwater in Eastern Europe (Janikowski, 2000).	190
5.15	The interval water balance table for Sultan Ismail Mosque.	192
5.16	Water Cascade Table (WCT) for Sultan Ismail Mosque case study.	197
5.17	Various process changes options for SIM.	199
5.18	Comparison of MWR, MWN and CEMWN results for MYSEM case study.	213
5.19	Comparison of MWR, MWR with rainwater	214

	harvesting and regeneration by Manan <i>et al.</i> (2006) and CEMWN for SIM case study.	
A.1	Categories of Municipal Wastewater Reuse and Potential Constraints (Asano, 2002)	233
C.1	Total estimated system operating cost per month (2004) for DI production.	237
D.1	$OC_{base\ case}$ formula for MYSEM case study.	235
D.2	OC_{new} formula for MYSEM case study.	239
D.3	CC_{new} formula for individual equipment for MYSEM case study.	240
D.4	MWN targets for MySem.	241
D.5	CEMWN targets for MySem.	242
E.1	$OC_{base\ case}$ formula for SIM case study.	243
E.2	OC_{new} formula for SIM case study.	243
E.3	$CC_{base\ case}$ formula for individual equipment for SIM case study.	243
E.4	CC_{new} formula for individual equipment for SIM case study.	244
E.5	MWN analysis for SIM.	245
E.6	CEMWN analysis for SIM (Strategy 1)-change toilet flush to dual flush instead.	246
E.7	CEMWN analysis for SIM (Strategy 2): retrofit – do not change toilet flush and reduce regeneration.	247
E.8	CEMWN analysis for SIM (Strategy 2): grassroots - do not change toilet flush and reduce regeneration.	248

LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	Global water use (World Bank, 2001)	3
1.2	Flow diagram illustrating the conceptual links among the chapters.	14
2.1	Gaps associated with water pinch analysis (WPA) research.	
2.2	A closed water loop for a residential building. (Bakir, 1999)	17
2.3	Water Management in a commercial building (Chanan <i>et al.</i> , 2003).	18
2.4	Typical greywater production and toilet flushing requirements in a college (Al-Jayyousi, 2003).	20
2.5	New sanitation concepts with gravity separation toilets in the office building and with vacuum separation toilets in the apartment house of the WWTP Stahnsdorf. (Peter-Fröhlich <i>et al.</i> , 2003).	21 23
2.6	Pollution prevention hierarchy (Perry's, 1998).	29
2.7	Wang and Smith (1995) limiting composite curve to target multiple freshwater flowrate. (a) Target with the highest quality (demineralised) water. (b) Target with a mixture of high quality demineralised) water and intermediate quality (portable) water. (c) Target with a mixture of high quality (demineralised) water, intermediate quality (potable) water and low quality (borehole) water.	36
2.8	Gaps in water pinch analysis research related to	39

	targeting multiple water utilities.	
2.9	Satisfying the cleanest demand with cleanest water source using source and sink allocation composite curve (a) demand mass load not satisfied, (b) demand flowrate not satisfied.	42
3.1	Flow of the fundamental theory chapter.	49
3.2	Pinch Analysis Critical Success Factor – The Design Targets.	54
3.3	Categorisation of water reuse/recycling strategies (Wang and Smith, 1994).	55
3.4	Transfer of species from a rich to lean stream in a mass exchanger.	57
3.5	Mass transfer-based water-using operations: (a) Vessel washing; (b) Sour gas absorption where water demand and water source exist.	58
3.6	Two other common types of the non-mass transfer-based water-using operations: (a) cooling tower make up; (b) boiler blow-down (Manan <i>et al.</i> , 2004).	59
3.7	Non-mass transfer-based water-using operations: (a) a reactor that consumes water in aniline production; (b) a reactor that produces water as a byproduct in acrylonitrile (AN) production (Manan <i>et al.</i> , 2004).	59
3.8	The principle of water cascading.	62
3.9	Source/sink composite curve. (a) Before shifting source composite, (b) After shifting source composite.	66
3.10	Source and sink (demand) allocation using composite curve by El-Halwagi <i>et al.</i> (2003) for freshwater with zero mass load.	67
3.11	Source and sink (demand) allocation using composite curve by Kazantzi and El-Halwagi (2005) for freshwater with non zero mass load.	68

3.12	Network design by source and demand.	73
4.1	The Water Management Hierarchy.	82
4.2	Pinch location and concentration regions in a water cascade table.	84
4.3	A holistic framework to achieve CEMWN.	86
4.4	The Onion Diagram as a conceptual model of the hierarchy of the components of a chemical process (Smith, 1995).	90
4.5	IAS plot covering all levels of WM hierarchy. m_4 is the positive steepest gradient and TPP is the total payback period for a water network.	95
4.6	IAS plot showing the revised total payback period when the magnitude of the steepest gradient is reduced using <i>SHARPS</i> substitution strategy.	96
4.7	Linearisation of concave curves moving upwards (a) without peak (b) with peak. Convex curves moving upwards linearization (c) without valley (d) with valley.	97
4.8	IAS plot showing the revised total payback period with a shorter steepest gradient curve.	98
4.9	The overall <i>SHARPS</i> procedure.	99
4.10	Location of various water sources relative to the utility line, S5.	103
4.11	Utility line (S5) creates a utility pinch.	104
4.12	SLA shifted along S5. Final composite curve with minimum utility addition.	106
4.13	SLB (S1) and S5 shifted along the Cum $m = 0$ line.	108
4.14	SLA (S2 to S4) shifted upwards along S5 from the new pinch point until SLA created another pinch point at $C_{pinch} = 100$ ppm.	109
4.15	Final composite curves with addition of S5.	110
4.16	Composite curves with utility (S7) addition.	112
4.17	Water composite curves for Example 3 – A	114

	threshold problem.	
4.18	Composite curves for threshold problem with addition of S4 utility.	114
4.19	Water composites with addition of U1 (S5) at C = 10 ppm.	116
4.20	Shifting of SLB and U2 line (C=80 ppm) along U1 (C=10 ppm) line until a pinch point occurred.	117
4.21	Final water composites after addition of U1 and U2. Water composites with addition of U1 (S5) at C = 10 ppm.	117
4.22	Four key steps of generic simultaneous graphical targeting and design methodology.	119
4.23	A comprehensive procedure for overall source and demand allocation	120
4.24	Demand allocation on a network allocation diagram (NAD).	123
4.25	Sources allocation on an NAD.	124
4.26	The Final NAD for Case Study 1.	125
4.27	Source and sink mapping diagram for Sorin and Bedard (1999) example that was generated using Polley and Polley (2000) 'cleanest to cleanest' rule.	128
4.28	SDCC for Case Study 1.	129
4.29	SDAC for Case Study 1 – region below the pinch.	130
4.30	SDAC for Case Study 1 - D4 mass load is not satisfied for the region between pinches.	131
4.31	SDAC for Case Study 1 - shifting of dirtiest source to satisfy D4 for region between pinches.	132
4.32	SDAC for Case Study 1 - satisfying D4 for region between pinches.	132
4.33	SDAC for Case Study 1 - satisfying D5 for region between pinches.	133
4.34	SDAC for Case Study 1 for the region above the pinch.	134

4.35	Final SDAC for Case Study 1.	134
4.36	SDCC for Case Study 2.	137
4.37	Use of <i>Approach 2</i> for Case Study 2 - Application of ‘cleanest to cleanest’ rule satisfies D1 flowrate but not the mass load.	138
4.38	Use of <i>Approach 2</i> for Case Study 2 - Application of ‘cleanest and dirtiest’ rule satisfies both D1 flowrate and mass load.	138
4.39	Final SDAC for Case Study 2 for the region below the pinch.	139
4.40	SDAC for Case Study 2 for the region above the pinch.	140
4.41	Final SDAC for Case Study 2.	140
4.42	Final NAD for Case Study 2.	141
4.43	The SDAC using step 2 (allocate) for Case Study 3.	143
4.44	Alternative source and demand allocation achieving the same minimum freshwater and wastewater flowrate targets.	143
4.45	Alternative source and demand allocation with freshwater and wastewater penalties.	144
4.46	Illustration of cases involving direct reuse and sources mixing: (a) direct mapping and reuse of sources and demands, and (b) mixing of sources for D1 and D2 as well as D3 and D4 before reuse.	146
4.47	Illustration of cases involving direct reuse and sources mixing: (a) mixing of sources for D1, D2 and D3 before reuse and one direct reuse, and (b) mixing all sources to before reuse in demands.	147
5.1	MySem JBA water load apportioning (Oct 05).	151
5.2	MySem Fabs DI water uses (Oct 05).	152
5.3	MySem DI water balance (October – November 05).	154
5.4	MySem non-process water balance (October –	155

	November 05).	
5.5	MySem Fab 1 and Fab 2 water balance.	159
5.6	The effects of WMH-guided process changes on the maximum water reuse/recovery targets and pinch location.	169
5.7	IAS plot for MWN retrofit.	176
5.8	IAS plot after eliminating regeneration curve.	177
5.9	F_{opt} for cooling tower concave curve moving upwards (without peak).	178
5.10	Final IAS plot after <i>SHARPS</i> analysis.	178
5.11	Final CEMWN targets after <i>SHARPS</i> analysis.	179
5.12	Source and sink composite curves for MySem.	180
5.13	Source and sink allocation composite curves for MySem.	181
5.14	Source and sink mapping diagram based on simplified SSACC for MySem retrofit.	182
5.15	MySem retrofit DI water balance and non-process water balance after CEMWN analysis, achieving 85.5% freshwater and 97.7% IWT reductions within 4 months payback.	183
5.16	Breakdown of the end use in SIM.	184
5.17	Water distribution network for Sultan Ismail Mosque.	185
5.18	Retrofit for the mosque by IWERM (IPASA, 2004). (a) Water cascade diagram with an assumed fresh water flowrate of 0 t/day; (b) Pure water cascade is used to check the feasibility of the water cascade; (c) Interval fresh water demand to determine the fresh water amount needed in each purity interval.	186
5.19	(a) Water cascade diagram with an assumed fresh water flowrate of 0 t/day; (b) Pure water cascade is used to check the feasibility of the water cascade; (c) Interval fresh water demand to determine the	193

	fresh water amount needed in each purity interval.	
5.20	A feasible water cascade for the SIM case study.	195
5.21	The effects of WMH-guided process changes on MWR targets and pinch location.	200
5.22	IAS plot for SIM.	203
5.23	IAS plot after changing from composting toilet to dual-flush toilet for SIM.	204
5.24	IAS plot after eliminating toilet flush process change for SIM.	204
5.25	IAS plot after eliminating toilet flush process change and reducing regeneration for SIM.	205
5.26	WMH-guided process changes after CEMWN analysis (grassroots).	206
5.27	WMH-guided process changes after CEMWN analysis (retrofit).	207
5.28(a)	Source and sink composite curves for SIM (grassroots).	208
5.28(b)	Source and sink composite curves for SIM (retrofit).	208
5.29(a)	Source and sink allocation composite curves for SIM (grassroots).	209
5.29(b)	Source and sink allocation composite curves for SIM (retrofit).	209
5.30	Source and sink mapping diagram for SIM (grassroots).	210
5.31	Source and sink mapping diagram for SIM (retrofit).	211
5.32	CEMWN design for SIM (grassroots).	212
5.33	CEMWN design for SIM (retrofit).	212
5.34	Savings achieved by MySem in comparison to savings predicted through CEMWN technique.	216

LIST OF NOMENCLATURES

C	-	Contaminant concentration, ppm
C_C	-	Costs per unit time for chemicals used by water system
$CC_{base\ case}$	-	Capital cost of base case water system
$CC_{new\ system}$	-	Capital cost of new water system
C_{EOC}	-	Costs per unit time for energy for water processing
C_{FW}	-	Costs per unit time for freshwater
C_{IC}	-	Instrumentation cost
C_{PE}	-	Purchased equipment cost
C_{PEI}	-	Purchased equipment installation cost
C_{piping}	-	Piping cost
Cum	-	Cumulative
C_{WW}	-	Costs per unit tile for wastewater disposal
D	-	Demand/sink
F	-	Flowrate of water denabd or source
$F_{Demand\ initial}$	-	Initial demand flowrate
F_{DI}	-	Deionised water flowrate
$F_{EDI\ initial}$	-	Initial electrodeionisation flowrate before analysis
$F_{EDI\ new}$	-	New electrodeionisation flowrate after analysis
F_{FW}	-	Freshwater flowrate
$F_{FW\ initial}$	-	Initial freshwater flowrate before analysis
$F_{FW\ new}$	-	New freshwater flowrate after analysis
$F_{HeaterWB101\ initial}$	-	Initial heater WB101 flowrate before analysis
$F_{HeaterWB101\ new}$	-	New heater WB101 flowrate after analysis

$F_{Internal\ new}$	-	New internal pumping flowrate after analysis
$F_{Internal\ initial}$	-	Initial internal pumping flowrate before analysis
F_{IWT}	-	Industrial wastewater flowrate
$F_{IWT\ initial}$	-	Initial industrial wastewater flowrate before analysis
$F_{IWT\ new}$	-	New industrial wastewater flowrate after analysis
F_{min}	-	Minimum point
$F_{MMF\ initial}$	-	Initial multimedia filter inlet flowrate before analysis
$F_{MMF\ new}$	-	New multimedia filter inlet flowrate after analysis
F_{MU}	-	Minimum utility flowrate
F_{opt}	-	Optimum point
$F_{outsource}$	-	Outsource flowrate
F_{reg}	-	Regeneration flowrate
F_{reuse}	-	Reuse flowrate
$F_{Si,Dj}$	-	Amount of source i flowrate used to satisfy demand j flowrate
kg/h	-	Kilogram per hour
kg/s	-	Kilograms per second
m	-	Gradient
m	-	Mass load
m_i	-	Gradient of line i
$M_{Si,Dj}$	-	Amount of source i mass load used to satisfy demand j mass load
n	-	number of purity intervals
N	-	number of water demands or sources
NU	-	New utility
$OC_{base\ case}$	-	Operating cost of base case water system
OC_{new}	-	Operating cost of new water system
P	-	Purity
ppm	-	Parts per million
S	-	Source
SLA	-	Sources line after new water source line
SLB	-	Sources line before new water source line

t/h	-	Tonne per hour
TPP	-	Total payback period
TPP_{AS}	-	Total payback period after SHARPS
TPP_{BS}	-	Total payback period before SHARPS
TPP_{set}	-	Desired payback period specified by designer
U	-	Utility

Greek Letters

Δ	-	difference
Σ	-	Summation

Subscripts

C	-	Cumulative
D	-	Water demands/sinks
DP	-	Duplicate purities
est	-	Estimated fresh water
FW	-	Freshwater
FWU	-	Fresh water utility
i	-	Source number
i	-	sources
j	-	Demand number
j	-	Demands/sinks
max	-	Maximum
$Max\ water$	-	Maximum external water source addition
$source$	-	
MU	-	Minimum utility
reg	-	Regenerated water
S	-	water sources
WW	-	Wastewater

Acronym

AHU	-	Air handling units
BOD	-	Biological oxygen demand
CEMWN	-	Cost effective minimum water network
COD	-	Chemical oxygen demand
CT	-	Cooling tower
D	-	Demand
DI	-	Deionised water
EDI	-	Electrodeionisation
Fab	-	Fabrication plant
FW	-	Freshwater
HF	-	Hydrogen fluoride
IAS	-	Net capital investment vs. net annual savings plot
IPA	-	Isopropyl-butanol
IWT	-	Industrial wastewater treatment
MAU	-	Make-up air units
MMF	-	Multimedia filter
MWN	-	Minimum water network
MWR	-	Maximum water recovery
MySem	-	Semiconductor company
NAS	-	Net annual savings
NAD	-	Network Allocation Diagram
NCI	-	Net capital investment
ppm	-	Parts per million
RO	-	Reverse osmosis
RW	-	Rainwater

S	-	Source
SDAC	-	Source and demand allocation composite curves
SDCC		Source and demand composite curves
SHARPS	-	Systematically Hierarchical Approach for Resilient Process Screening
SLA	-	Sources line above newly added utility line
SLB	-	Sources line below newly added utility line
TDS	-	Total dissolved solids
TSS	-	Total suspended solids
U	-	Utility line
UF	-	Ultra filtration
UPW	-	Ultra pure water
UV	-	Ultraviolet
WB	-	Wet bench
WCA	-	Water cascade analysis
WPA	-	Water pinch analysis
WMH	-	Water management hierarchy
WPA	-	Water pinch analysis
WW	-	Wastewater

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Municipal Wastewater Reuse And Potential Constraints	233
B	Obtaining Pre-Design Capital Cost Estimation	235
C	DI Production Cost Calculations	237
D	MySEM Cost Formula	238
E	SIM Cost Formula	243

CHAPTER 1

INTRODUCTION

1.1 Introduction

Water is one of the most valuable resources to mankind. It is used for various activities such as for washing, rinsing, cooling, heating, water recirculation and fire-fighting. This chapter provides an overview of the local and global water issues. The current water problems faced throughout the world as well as the existing measures implemented will be highlighted. This is followed by an introduction of the problem background, problem statement, research objective and the scope of work for this study which aims to develop new methodologies to minimize water usage and wastewater generation through a new holistic framework for water minimisation. The six key contributions of this thesis towards knowledge are also presented in this chapter.

1.2 Global Water Outlook

Water demands are growing every year as the result of the booming world population. A population report on environment and water issues had estimated that more than 2.8 billion people in 48 countries will lack access to adequate water supplies by 2025 (Hinrichsen *et al.*, 1998). The Middle-Eastern countries have long relied on non-conventional water supplies due to water scarcity. For example, four Gulf states—Bahrain, Kuwait, Saudi Arabia, and the United Arab Emirates—have so little fresh water available that they resort to desalination, the costly conversion of sea water into fresh water. Saudi Arabia now must mine fossil groundwater for three-quarters of its water needs. Jordan and Yemen withdraw 30% more water from groundwater aquifers every year than replenish. Also, Israel's annual water use already exceeds its renewable supply by 15% (McCarthy, 2003).

Global water use can be divided into three main sectors i.e. agriculture, industry and domestic sector. Agricultural uses comprise of up to 70% of world water consumption followed by 22% industry and 8% domestic (**Figure 1.1**). Note that in high-income country, industrial water uses contribute to 59% of water consumption followed by 30% agricultural uses and 11% domestic uses. Huge investments have been spent to expand water supply to increasing number of consumers in industry and housing estates world-wide. Rapid increase in water tariff has spurred water conservation efforts particularly in industrial sector. It has been reported that industrial water use in some developed countries has been falling as a result of greater efficiency in the use, reuse and recycling of water. For example, industrial water use in England and Wales has fallen by 900 million m³ since the year 1998 (Graham, 2001). While industries and commercial enterprises have made significant progress in water efficiency, the achievement of the general public have been extremely poor, thereby resulting in urban water demand to increase steadily (Cheng, 2002). This discrepancy can be attributed to the low water-tariff and wide availability of potable water in urban areas. Consequently, the general

public, particularly the urban population, has little consciousness on water savings and hence, the energy savings associated with water use.

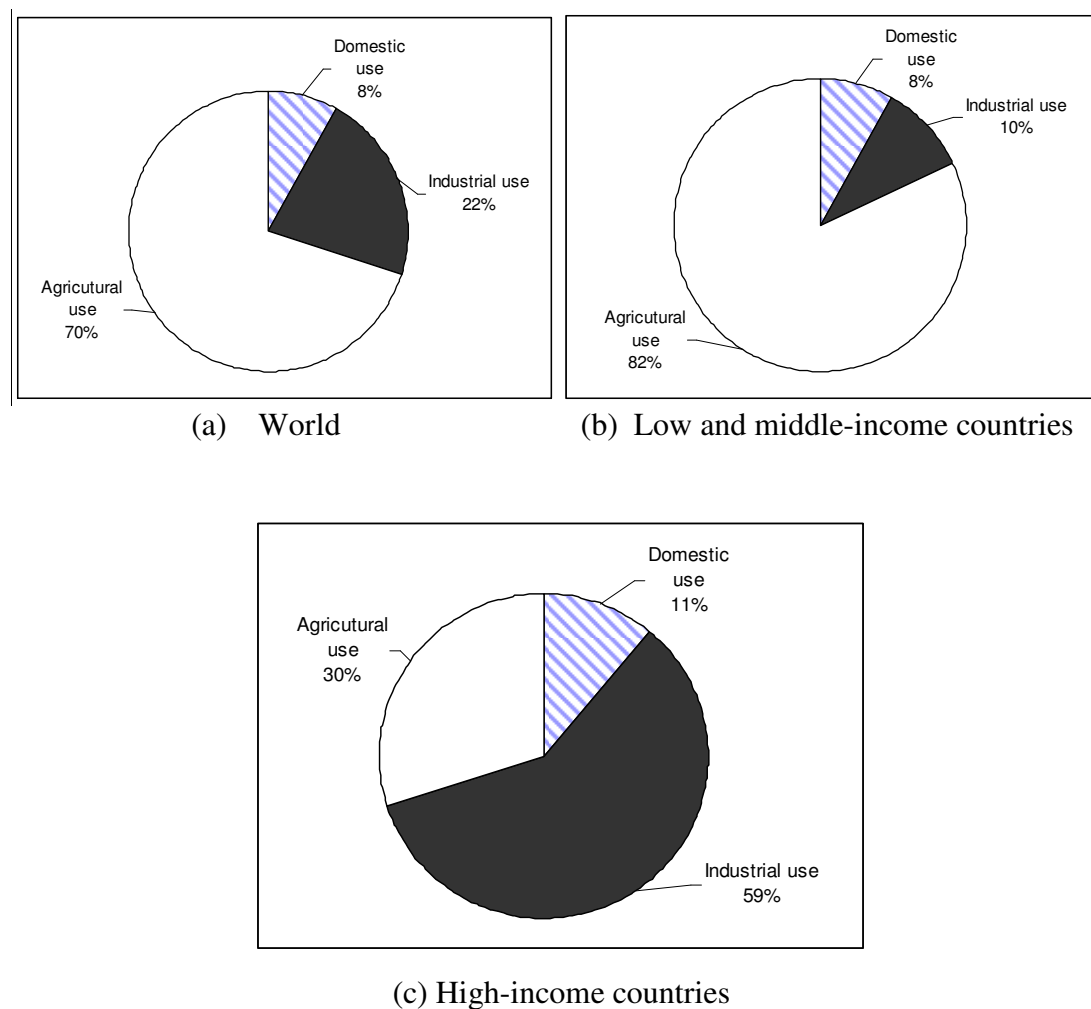


Figure 1.1. Global water use (World Bank, 2001)

The urban sector contributes a significant percentage of water consumption particularly in developed countries of warmer climates. In Malaysia for example, the domestic sector contributes 68% of the total water consumption compared to the other sectors (The Malaysian Water Association, 2003). The need for efficient water management in urban sector is getting ever more crucial due to sharp increase in the price of fresh water. This trend is likely to continue in the near future due to the

predicted shortage of fresh water, and hence, the possibilities of resorting to wastewater treatment, desalination, groundwater extraction and, interstate water purchase as well as water transfer.

1.3 Outlook of the Water Industry in Malaysia

Even though Malaysia is not among the countries predicted to experience water scarcity countries by 2025, it currently faces some water problems in certain states. For example, due to the uneven distribution of rainfall and economic development, some states such as Melaka has experienced water shortage to the extent that interstate water transfer became necessary to overcome the water shortage (Puncak Niaga Holdings Berhad, 2002). Similarly, as a result of sustained rapid economic development over the last decades, Penang and Selangor will soon have to rely on interstate water transfer from Perak and Pahang respectively, to meet their increasing demand (Puncak Niaga Holdings Berhad, 2002). By 2050, it is predicted that fresh water for Johor needed to be bought from other states. It is expected that many other west coast states will have to do the same in the future. Non- revenue water (NRW) in the water supply sector is high, with a national average of 40.6%, and a range of between 18.0 to 73.9% in 2002 (Raja Zainal Abidin, 2005).

Water consumption in Malaysia is predicted to increase to 15.3 billion m³ per year by the year 2010 compared to 9.5 billion m³ per year that was recorded in year 2000 (Utusan Malaysia, 2004a). Water demand is increasing due to the increase of population and modernisation that result in diminishing supply of fresh water. It is estimated that Malaysia's per capita renewable water stands at more than 5300 m³ per annum, whilst according to the United Nations' recommendation, each citizen should be

allocated only 1000 m³ per annum (Abdul Mukti *et al.*, 2005). Rivers are getting polluted by various chemicals and wastes from industries. Wastewater has to go through extensive cleaning process that may include activated sludge, trickling filters, rotating biological contactors and oxidation ponds in order to be safely discharged back to the environment. In order to maintain a sustainable clean water supply, Malaysian government has embarked on initiatives that can be categorised into three water management approaches:

(i) Management of water supply and distribution

- Preserving water catchments areas; e.g. declaration of 880, 000 hectare of reserved areas for water catchments in all states. Hence, no illegal deforestation is allowed (Utusan Malaysia, 2004a).
- Groundwater exploration to identify potential aquifers and outline protection zones to conserve groundwater resources (9MP Plan).
- Non-revenue water solutions e.g. a RM20 million grant were given by the ministry to the state of Negeri Sembilan to replace old water pipes (Utusan Malaysia, 2004b). Stricter enforcement and rehabilitation of water distribution networks will also be carried out to reduce the rate of non-revenue water in the country from 38 per cent in 2005 to 30 per cent by 2010 (9MP Plan).
- Water infrastructure such as intakes, treatment plants and dams will be constructed and upgraded (9MP Plan).
- Inter-state water transfer; e.g. The Yen Loan Agreement for funding the Pahang-Selangor Raw Water Transfer Project which will commence in the Ninth Plan and will be completed in the Tenth Plan, involves the transfer of 2260 million litres of water per day (Raja Zainal Abidin, 2005).

(ii) Water demand management

- Water conservation efforts will be promoted through awareness programmes (9MP Plan). Water conservation campaign has been organized since 1993. This involves programmes such as *Cintailah Sungai Kita (1998)*, *Air untuk Kehidupan (2004)*, *Hari Air Sedunia, Air dan Malapetaka (2004)*.

- Introducing water saving gadgets; e.g. the use of vacuum toilets that require much less water than the conventional 12 l flush toilet.
- Announcing stricter effluent discharge regulations for industry; e.g. the Environmental Quality (Sewage and Industrial Effluents) (Amendment) Regulations 2000 [P.U (A) 398/00].
- Considering the use of market-based instruments such as rebates, tax credits, and disincentives such as charging actual costs, penalties and fines to help convey to users the true value of water and reduce wastage (8MP Plan).
- Water recycling; e.g. studying the feasibility of rainwater harvesting (Jaafar, 2004).

- Stormwater management to improve the quality of receiving waters to satisfy increasing water demand.
- Reviewing the existing water tariff (9MP Plan). The 2004 water tariffs in Malaysia ranges from between RM0.31/m³ to RM0.9/m³ for domestic; and from RM0.90/m³ to RM2.93/m³ for industrial sectors (The Malaysian Water Association, 2005).

(iii) Wastewater management

- Greywater and blackwater separation programme, a new water project introduced by Natural Resource and Environmental Board (NREB), Sarawak in 2003.
- Building new water and wastewater treatment plant e.g. Semanggar water treatment plant.
- Improving sewage system (Raja Zainal Abiddin, 2005).

However, the general public, particularly those from the domestic sector are largely ignorant of the water problems as compared to those from the industrial sector. Industrial sector have already initiated water reusing and recycling program (e.g. Malaysian Newsprint Industry) in order to reduce its water consumption and wastewater generation.

1.4 Problem Background

Until today, the idea of minimum water design was unknown for *urban system* even though there has been extensive work on the design and improvement of industrial processes to achieve maximum water efficiency through maximum water recovery as well as process changes. The development of novel systematic techniques to maximise water efficiency in *urban buildings* proposed in this work represents a shift in the global traditional process engineering paradigm to allow maximum water savings beyond the frontiers of process industry, into the domain of urban sector. Maximum water recovery can be defined as the maximum amount of water recoverable via water reuse and recycling. Minimum water design is the optimum network design that achieves the maximum water reduction, and hence, maximum savings after considering not only reuse and recycling, but all conceivable methods to holistically reduced water usage through elimination, reduction, reuse/outourcing and regeneration. The notion of minimum water network design has been introduced and applied for the first time in this work. A new cost short cut cost screening technique known as Systematically Hierarchical Approach for Resilient Process Screening (SHARPS) has also been introduced to screen inferior process changes based on investment and savings and subjected to the desired payback period set by a designer. The development of SHARPS theory enabled the establishment of a cost-targeting tool for Cost Effective Minimum Water Network (CEMWN) analysis for retrofit and grassroots designs that are applicable for both urban and industrial sectors.

1.5 Problem Statement

Given a set of water using operations and setting total payback period desired, it is desired to design the *cost effective minimum water network* for urban and industrial systems using a new holistic framework based on water pinch analysis, process changes guided by water management hierarchy and SHARPS screening technique to maximise net annual water savings for both grassroots and retrofit designs.

1.6 Research Objective

The main aim of this research is to develop a new holistic framework for designing a cost-effective minimum water network for urban and industrial sectors. It is envisioned for such framework to be powerful and resilient and applicable for grassroots and retrofit designs.

1.7 Scope of Work

The scope of this work includes:

1. Analysis of the state-of-art procedure on current related approach, their advantages and disadvantages and the improvement required.

2. Development of an integrated water minimisation procedure for urban and industrial sectors incorporating *water pinch* analysis to yield minimum water utilisation network.
3. Development of new techniques (within the holistic framework) to target and quantitatively evaluate process changes in terms of priority and economics.
4. Development of a new water network design procedure that achieves the minimum water targets.
5. Assessment of the impact of process changes on the savings and investment on urban and industrial case studies for new design and retrofit scenarios.

1.8 Research Contributions

The key specific contributions that had emerged from this work include:

- (1) Development of a minimum water targeting and design procedure for urban system.
 - Introducing the concept of ‘pinch’ points or bottleneck in urban system water management to achieve maximum water recovery.
- (2) A powerful new holistic framework to systematically guide, prioritise and quantitatively evaluate water minimisation options for grassroots and retrofit designs for urban and industrial water networks
 - This covers a new technique to integrate water management strategy and water pinch analysis for mixing, recycling, reuse, regeneration and process changes in order to achieve the minimum water design.
- (3) A *water management hierarchy* as a tool to guide water minimisation strategy based on priority.

- (4) A novel tool known as *SHARPS technique* for screening options for process changes to achieve a desired payback period.
 - Introducing a new cost targeting method that clearly shows how process changes should be approach to give the desired payback period. This method is applicable for grassroots as well as retrofit design; both for the urban as well as industrial sectors.

- (5) New techniques to target single and multiple water sources using composite curves.
 - The graphical representation provides insights on the effect of adding new water sources and a convenient visualization tool for setting multiple utility targets. The minimum new (multiple) water sources addition and the sequence that gives the most savings can be targeted prior to design by using the composite curves proposed in this work.

- (6) A new technique and a set of new heuristics to design a water-utilization network based on source and sink allocation composite curves.
 - A maximum water recovery network can now be simultaneously targeted and designed using the source and sink composite curves.

Table 1.1 (a to c) list all the publications and outputs of this work and the associated key contributions of this thesis towards global knowledge on water minimisation.

Table 1.1 (a). Refereed national and international journals and magazines, conference papers published, accepted or submitted; exhibitions participated and medals won; patents approved or applied towards contribution of knowledge from this thesis.

No	Paper title	Publication type	Status	Contribution towards knowledge
1	Manan. Z. A., Wan Alwi, S. R. and Ujang Z. (2006). Water pinch analysis for urban system: a case study on the Sultan Ismail Mosque at Universiti Teknologi Malaysia (UTM). <i>Desalination</i> . 194: 52-68.	International Journal	Published	Contribution (1)
2	Wan Alwi, S. R. and Manan. Z. A. (2006). SHARPS – A New Cost-Screening Technique To Attain Cost-Effective Minimum Water Utilisation Network. <i>AiChe Journal</i> . November, 11 (52).	International Journal	Published	Contribution (4)
3	Wan Alwi, S. R. and Manan. Z. A. A new holistic framework for cost effective minimum water network in industrial and urban sector. <i>Environmental Management Journal</i> . (In proof).	International Journal	In proof	Contribution (2), (3) and (4)
4	Wan Alwi, S. R. and Manan. Z. A. A generic graphical technique for simulataneous targeting and design of water networks. <i>Chemical Engineering Journal</i> . (in review).	International Journal	In review	Contribution (6)
5	Wan Alwi, S. R. and Manan. Z. A. Targeting multiple water utilities using composite curves. <i>Industrial & Engineering Chemical Research</i> . (Reviewed).	International Journal	Reviewed	Contribution (5)
6	Manan. Z. A., Wan Alwi, S. R. and Ujang Z. (2005). A new look at urban water saving. <i>Water21</i> . Febuary 2005. Pg 52.	International Magazine	Published	Contribution (1)
7	Manan Z. A., Wan Alwi, S. R. , Samingin, M. H. And Misran, N. Customize Water Retrofit the SHARPS Way. <i>Chemical Engineering Progress</i> . Nov 2006.	International Magazine	Published	Contribution (4)
8	Manan Z. A., Wan Alwi, S. R. , Samingin, M. H. And Misran, N. Assess Your Plant's True Water-Saving Potential. <i>Chemical Engineering</i> . Dec 2006.	International Magazine	Published	Contribution (2) and (3)
9	Wan Alwi, S. R. , Manan Z. A., Samingin, M. H. And Misran, N., Maximise Semiconductor Plant Water Savings. <i>Semiconductor International</i> . In review.	International Magazine	In review	Contribution (2)
10	Manan. Z. A., Wan Alwi, S. R. and Ujang Z. (2005). Systematic Design of a Maximum Water Recovery Network for an Urban System Based on Pinch Analysis. <i>IEM Journal</i> . 1 (67): 57-64.	National journal	Published	Contribution (1)

Table 1.1 (b). Refereed national and international journals and magazines, conference papers published, accepted or submitted; exhibitions participated and medals won; patents approved or applied towards contribution of knowledge from this thesis. (continue).

No	Paper title	Publication type	Status	Contribution towards knowledge
11	Manan. Z. A. and Wan Alwi, S. R. (2006). Stretching the Limits on Urban and Industrial Water Savings. Jurutera. The Monthly Bulletin of the Institution of Engineers, Malaysia. January 2006. Pg 24-27.	National magazine	Published	Contribution (1), (2) & (3)
12	Wan Alwi, S. R. , Manan, Z. M., ang Ujang, Z. (2004). Systematic technique for water minimization in urban water system using water pinch analysis. <i>Proceedings of ASIA WATER 2004</i> (30-31 March 2004).	International conference	Published	Contribution (1)
13	Wan Alwi, S. R. , and Manan, Z. M. (2006). A cost effective minimum water design for urban sector. <i>INRET2006 proceedings</i> (24-26 July 06)	International conference	Published	Contribution (3)
14	Wan Alwi, S. R. , Manan, Z. M., ang Ujang, Z. (2004). Efficient Water Demand Management for Urban Systems based on Pinch Analysis. <i>SOMChe 2004 Proceedings</i> (13 – 14 December 2004).	National conference	Published	Contribution (1)
15	Manan, Z. Wan Alwi, S. R. , M., Ooi, B, L., Foo, C. Y., Tan, Y. L., and Tea, S. Y. (2005). Water-MATRIX, Your Ultimate Water Conservation Tool,. IENA 2005.	International exhibition EINA, Germany	Exhibited	Contribution (1)
16	Manan, Z. M., Ooi, B, L, Foo, C. Y., Tan, Y. L., Tea, S. Y. and Wan Alwi, S. R. (2004). <i>WATER-MATRIX: Revolution and Innovation in Water Minimisation</i> . EXPO Science 2004.	National exhibition	Silver medal	Contribution (1)
17	Manan, Z. M., Wan Alwi, S. R. (2006). MATRIX. Software for Maximising Water and Energy Reductions for Industry and Urban Sectors, IPTA 2006.	National exhibition	Gold medal	Contribution (1)
18	Manan, Z. M., Ooi, B, L, Foo, C. Y., Tan, Y. L., Tea, S. Y. and Wan Alwi, S. R. (2004). <i>WATER-MATRIX: Revolution and Innovation in Water Minimisation</i> . INATEX 2004.	UTM exhibition	Silver medal	Contribution (1)
19	Manan. Z. A., Wan Alwi, S. R. and Ujang Z. New Technique for Maximum Water Recovery for Urban System. UTM patent. (in review).	UTM patent	In review	Contribution (1)

1.9 Summary of this Thesis

This thesis consists of 6 Chapters. Chapter 1 introduces the objectives of the research, introduction of the research, problem background and the scope of the research. Chapter 2 provides a critical review on the development of research in water targeting and network design techniques using water pinch analysis for urban system. Also reviews the cost effective minimum water network, process changes and maximum new water source addition works. Chapter 3 includes the fundamental theory of domestic wastewater and water pinch analysis. Chapter 4 presents a detailed methodology of this research to achieve the targeted objectives. Chapter 5 shows the results and discussion from the implementation of the new method on an urban and industry case study to prove the effectiveness and reliability of the developed methodology. Finally, Chapter 6 summarises the contributions of this research. The possible future work is recommended in this chapter. The flow and linkages of the chapters are shown in **Figure 1.2**

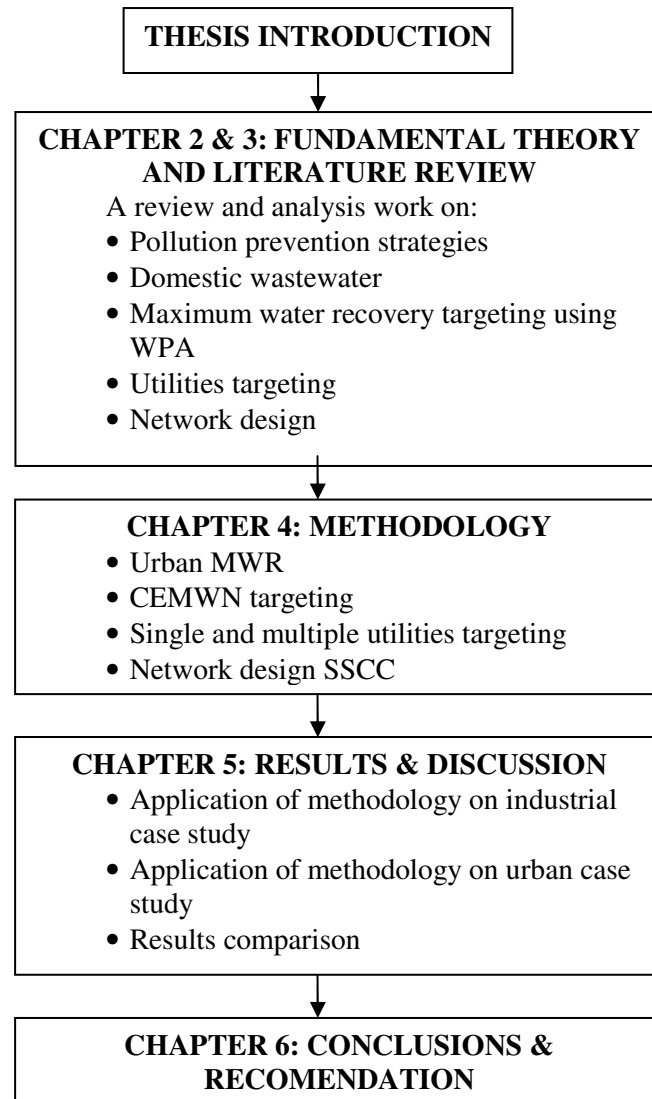


Figure 1.2. Flow diagram illustrating the conceptual links among the chapters.

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