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

SHARIFAH RAFIDAH BINTI WAN ALWI

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Chemical Engineering)

Faculty of Chemical and Natural Resources Engineering
Universiti Teknologi Malaysia

MARCH 2007

To my beloved family:

Whose love has nourished and sustained me always.

ACKNOWLEDGEMENTS

Alhamdullilah, with Allah Al-Mighty's grace and blessing, I have succeeded in producing this thesis. There are many people to whom I am very grateful for their assistance in this work. However, it would be impossible to name every one here.

First and foremost, I would like to express my heartfelt thanks to my supervisor, P. M. Dr. Zainuddin bin Abdul Manan, for his dedication in guiding me until the end of this work. Thanks also for his valuable advice and suggestions. Without his tireless efforts and patience, it would have been impossible for me to complete this work. Furthermore, under his supervision I have learnt a lot during the course of my study.

I would like to express my warmest gratitude to Universiti Teknologi Malaysia for the financial support provided through UTM's scholarship.

Special thanks to those whom I have consulted and/or requested papers and reports from, namely Prof Ir. Dr Zaini Ujang (IPASA), Mr Norhisham Samingin (MySEM), Mr Norrazi Misran (MySEM), Mrs Norsiah Makujod (MySEM) Mr Andrew Dixon (Imperial College of Science, Technology & Medicine, London), Mr Haji Mohd. Ghazali Ibrahim (SAJ), Mr Zulkifli (IPASA), Ustaz Ajmain (Sultan Ismail Mosque), Dr Syed Iskandar (Fakulti Alam Bina), Mr Mahmud Jusan (Fakulti Alam Bina), Mr Wan Razali Wan Ahmad (Architect), Ms Tan Yin Ling (PSE), Dr Foo Chwan Yee (University of Nottingham, Malaysia Branch) and others that had contributed directly or indirectly. Thanks for your advice and kind help.

Last, I am most thankful to my family and my friends for their continuous spiritual support and encouragement.

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 h*anya 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) Applikasikan 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

LIST OF TABLES

LIST OF FIGURES

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
Fr_{euse}	-	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 source	-	Maximum external water source addition
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

CHAPTER 1

INTRODUCTION

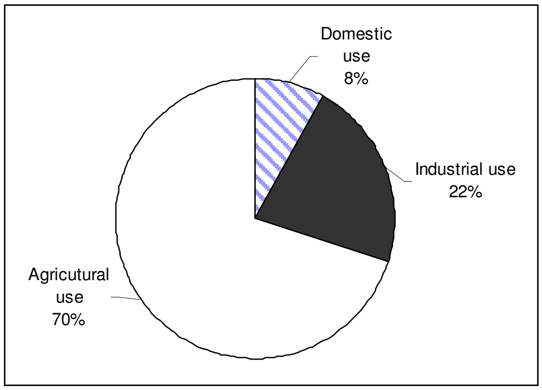
1.1 Introduction

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.

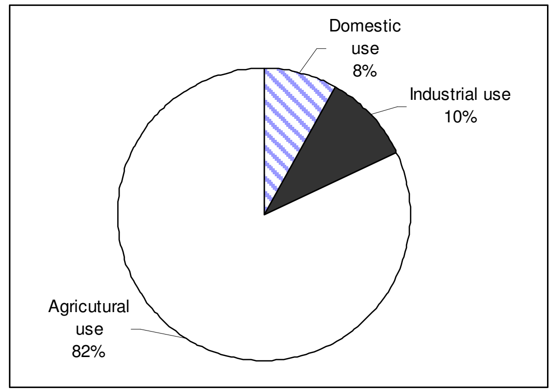
1.2 Global Water Outlook

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).

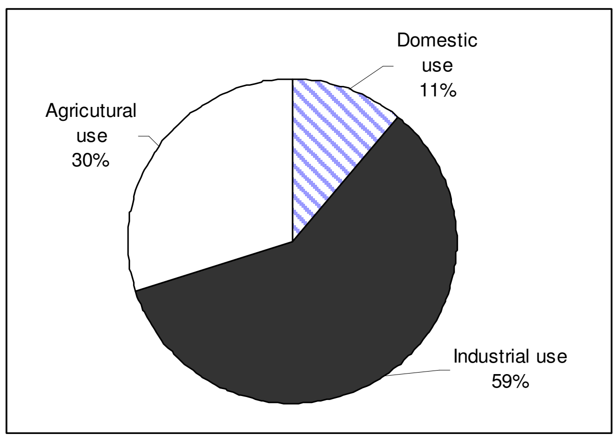
Global water use can be divided into three main sectors i.e. agriculture, industry and domestic sector. Agricultural uses comprise of up to 70% of world water consumption followed by 22% industry and 8% domestic (**Figure 1.1**). Note that in high-income country, industrial water uses contribute to 59% 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 m^3 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.



(a) World



(b) Low and middle-income countries



(c) High-income countries

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 m^3 per year by the year 2010 compared to 9.5 billion m^3 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 m^3 per annum, whilst according to the United Nations' recommendation, each citizen should be allocated only 1000 m^3 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/m^3 to RM0.9/m^3 for domestic; and from RM0.90/m^3 to RM2.93/m^3 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/outsourcing 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). *Desalination.* 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. *AiChe Journal*. 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. *Environmental Management Journal*. (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. *Chemical Engineering Journal*. (in review).	International Journal	In review	Contribution (6)
5	**Wan Alwi, S. R.** and Manan. Z. A. Targeting multiple water utilities using composite curves. *Industrial& Engineering Chemical Research*. (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. *Water21*. 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. *Chemical Engineering Progress.* 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. *Chemical Engineering.* 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. Semicondutor International. 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. *IEM Journal*. 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. *Proceedings of ASIA WATER 2004* (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. *INRET2006 proceedings* (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. *SOMChe 2004 Proceedings* (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). *WATER-MATRIX: Revolution and Innovation in Water Minimisation*. 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). *WATER-MATRIX: Revolution and Innovation in Water Minimisation*. 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**

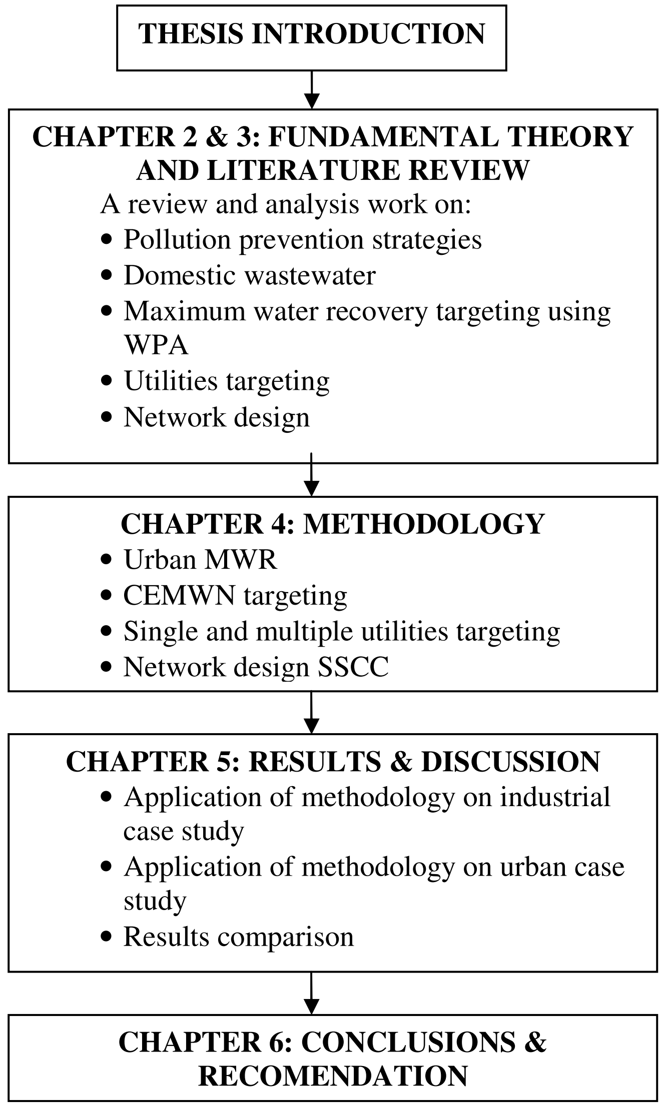


Figure 1.2. Flow diagram illustrating the conceptual links among the chapters.

REFERENCES

Abdul Mukti, M. A., Mohd. Noor, F. and The, S. P. (2005). Rainwater Harvesting - An Opportunity Neglected**.** *Water Malaysia*. Issue No:10 (August 2005).

Ahn, K. and Song, K. (1999). Treatment of domestic wastewater using microfilitration for reuse of wastewater. *Desalination. 126*: 7-14.

Al-Jayyousi, O. R. (2003). Greywater reuse: towards sustainable water management. *Desalination 156*: 181-192, Elsevier.

AlMutlaq, A. M. (2005). Algebraic Approaches to Resource Conservation via Process Integration. PhD Thesis. Texas A&M University.

Alva-Argáez, A., Kokossis, A. C. and Smith, R. (1998). Wastewater Minimization of Industrial Systems using an Integrated Approach. *Computers and Chemical Engineering*. 22: 741-744.

Alva-Argáez, A., Vallianatos, A. and Kokossis, A. (1999). A multi-contaminant transhipment model for mass exchange networks and wastewater minimisation problems. Computers and Chemical Engineering. 23: 1439–1453.

Alves, J. J. and Towler, G. P. (2002). Analysis of refinery hydrogen distribution systems. *Industrial and Engineering Chemistry Research*. 41: 5759-5769.

Aly, S., Abeer, S., Awad, M. (2005). A new systematic approach for water network design. Clean Techn Environ Policy. DO1 10.1007/s10098-005-0004-9.

Asano, T. (2002). The Role of Water Reuse in Sustainable Water Resources Management. *Annals of the European Academy of Sciences and Arts*. Vol 34, NR. XI; MMI.

Bagajewicz, M. and Savelski, M. (2001). On the use of linear models for the design of water utilization systems in process plants with a single contaminant. *Transactions of the Institute of Chemical Engineers*. Part A. 79: 600-610.

Bakir H. (1999). Water Demand Management and Pollution Control: Strategic but neglected elements in Integrated Water Resources Management Processes. In *Proceedings 4th Gulf WaterConference on CD-ROM,* Bahrain, Feb. 1999. Bahrain: Water Science and Technology Association.

Benkó, N., Rév, E., and Fonyó, Z. (2000). The use of nonlinear programming to optimal water allocations. *Chemical Engineering Communications*. 178: 67-101.

Burkhard, R., Deletic, A. and Craig, A. (2000). Techniques for water and wastewater management: a review of techniques and their integration in planning. *Urban Water*. **2**: 197-221.

Castro, P., Matos, H., Fernandes, M. C. and Nunes, C. P. (1999). Improvements for mass-exchange networks design. *Chemical Engineering Science*. 54: 1649-1665.

Center for the Study of the Build Environment (CSBE) (2003). *A Report on Graywater Reuse in Jordan.* CSBE Graywater Reuse project. Ministry of Planning and International Cooperation. Amman, Jordan.

Chanan, V., White, S., Jha, M., & Howe, C. (2003). Sustainable Water Management in Commercial Office Buildings. *Innovations in Water: Ozwater Convention & Exhibition*. Perth, 6-10 April 2003.

Cheng, C. (2002). Study of the inter-relationship between water use and energy conservation for a building. *Energy and Building*. 34: 261-266.

Dhole, V. R., Ramchandani, N., Tainsh, R. A., Wasilewski, M. (1996). Make your process water pay for itself. *Chemical Engineering*. **103**: 100-103.

Dixon, A., Butler, D. And Fewkes, A. (1999). Water saving potential of domestic water reuse systems using greywater and rainwater in combination. *Water Science and Technology*. 39 (5): 25-32.

El-Halwagi, M. M. (1997). *Pollution prevention through process integration: systematic design tools*. San Diego: Academic Press.

El-Halwagi, M. M. and Manousiouthakis, V. (1989). Synthesis of mass exchange networks. *AIChE Journal*. 35 (8): 1233-1244.

El-Halwagi, M. M., Gabriel, F. and Harell, D. (2003). Rigorous graphical targeting for resource conservation via material recycle/ reuse networks. *Ind. Eng. Chem*. Res. 42: 4319-4328.

El-Halwagi, M. M. and Almutlaq, A. (2004). An algebraic targeting approach to resource conservation via material recycle/reuse. International Journal of Environment and Pollution (IJEP) (In press).

Environmental Health Service. (2002). *Draft Guidelines for the Reuse of Greywater in Western Australia.* Department of Health. HP8122. Government of Western Australia.

Feng, X. and Chu, K. H. (2004). Cost Optimisation of Industrial Wastewater Reuse Systems. *Trans IchemE, Part B, Process Safety and Environmental Protection*. 82 (B3): 249-255.

Foo, C. Y., Manan, Z. A., Yunus, R. M. and Aziz, R. A. (2004). Synthesis of mass exchange network for batch processes – Part 1: Utility targeting. *Chemical Engineering Sciences*. 59: 1009-1026.

Foo, C. Y., Manan, Z. A., Yunus, R. M. and Aziz, R., A. (2005). Synthesis of mass exchange network for batch processes – Part II: Minimum unit target and batch network design. *Chemical Engineering Sciences*. **60** (5), 1349-1362.

Foo, D. C. Y., Manan, Z. A. and Tan, Y. L.(2006). Use Cascade Analysis Technique To Set Baseline Targets And Optimise Water Network. *Chemical Engineering Progress*. 7: 45-52.

Foo, D. C. Y. (2006a). Flowrate Targeting for Multiple Fresh Water Sources using Water Cascade Analysis. Proceedings of 20th Symposium of Malaysian Chemical Engineers (SOMChe).

Foo, D. C. Y. (2006b). Water Cascade Analysis Technique for Targeting Minimum Water Flowrate in Threshold Problems. Proceedings of 9th Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction (PRES 2006) in conjunction with 17th International Congress of Chemical and Process Engineering (CHISA).

Ghisi, E. and Oliveira, S. M. D. (2006). Potential for potable water savings by combining the use of rainwater and greywater in houses in southern Brazil. *Building and Environment.* In Press, Corrected Proof.

Graham, N. J. D. (2001). *Improving sustainability and quality in urban drinking water supplies.* Urban Water. International Conference on Sustainable Development and Green Enterprises, Macau G. E.

Gomes, J. F. S., Queiroz, E. M. and Pessoa, F. L. P. (2007). Design Procedure for water/ wastewater minimization: single contaminant. *Journal of Cleaner Production*. 15: 474-485.

Gunaratman, M., Alva-Araraez, A., A. Kokossis, A., Kim, J. –K. and Smith, R. (2005). Automated Design of Total Water Systems. *Ind. Eng. Chem. Res.* 44: 588-599.

Hallale, N. (2002). A new graphical targeting method for water minimization. *Advances in Environmental Research*. **6** (3): 377–390.

Hallale, N. and Fraser, D. M. (1998). Capital cost targets for mass exchange networks. A special case: Water minimization. *Chemical Engineering Science*. 53 (2): 293-313.

Hinrichsen D., Robey B., A. M., and Upadhyay U. D. (1998). *Population Reports (Volume XXVI, Number 1).* Center for Communication Programs, The Johns Hopkins School of Public Health, USA.

Huang, C. H., Chang, C. T., Ling, H. C. and Chang, C. C. (1999). A mathematical programming model for water usage and treatment network design. *Industrial and Engineering Chemistry Research*. 38: 2666-2679.

Janikowski, R. (2000). *Sourcebook of Alternative Technologies for Fresh water Augumentation in East and Central Europe, United Nations Environment Programme (UNEP).* Institute for Ecology of Industrial Areas (IETU).

Jenssen, P/ D. and Etnier, C. (1997). *Ecological engineering for wastewater and organic waste treatment in urban areas – an overview; in: Water Saving Strategies in Urban Renewal – European Approaches.* Dietrich Reimer Verlag, Berlin. Pg 51-60.

Jödicke, G., Fischer, U., Hungerbühler, K. (2001). Wastewater reuse: a new approach to screen for designs with minimal total costs. *Computers and Chemical Engineering.* 25: 203-215.

Kazantzi, V. and El-Halwagi, M. M. (2005). Targeting Material Reuse via Property Integration. *Chemical Engineering Progress*, 202 (8): pg 28.

Koppol, A. P. R., Bagajewicz, M. J., Dericks, B. J. and Savelski, M. J. (2003). On Zero water discharge solutions in the process industry. *Advances in Environmental Research*. 8: 151-171.

Kuo, W. C. J. and Smith, R. (1998). Design of water-using systems involving regeneration. *Transactions of the Institute of Chemical Engineers*. Part B, 76: 94-114.

Linnhoff, B., Townsend, D. W., Boland, D., Hewitt, G. F., Thomas, B. E. A., Guy, A. R., & Marshall, R. H. (1982). A user guide on process integration for the efficient use of energy. Rugby: *IChemE*.

Liu, Y. A., Lucas, B. And Mann, J. (2004). Up-to-date Tools for Water-System Optimization. *Chemical Engineering Magazine*. January 2004, 30-41.

Liu, Z-Y. (1999). Wastewater minimisation using heuristic procedure. Paper presented at AIChe Spring meeting, Houston, United States of America.

Manan, Z. A. and Wan Alwi, S. R. (2006). Stretching the Limits on Urban and Industrial Water Savings. *Jurutera*. January 2006, No. 01: 24-27.

Manan, Z. A., Ooi, B. L., Lim, F. Y., & Foo, C. Y. (2003). Heat-MATRIX - A Computer Software for the Reduction of Energy and Water in Process Plants. *31st Int. Exhibition of Invention, New Techniques and Products of Geneva, Switzerland.*

Manan, Z. A., Tan, Y. L. and Foo, D. C. Y. (2004). Targeting the minimum water flowrate using water cascade analysis technique. *AIChE Journal*. **50**(12), 3169-3183.

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. *IEM Journal*. 1 (67): 57-64.

Manan, Z. A., Wan Alwi, S. R. and Ujang, Z. (2006a). Water pinch analysis for an urban system: A case study on the Sultan Ismail Mosque at the Universiti Teknologi Malaysia (UTM). *Desalination.* 194, 52–68.

Manan, Z. A., Wan Alwi, S. R., Samingin, M. H. and Misran, N. (2006b). Assess Your Plant's True Water-Saving Potential. *Chemical Engineering.* In print for Dec 2006.

Mann, J. G., & Liu, Y. A. (1999). *Industrial water reuse and wastewater minimization*. New York: McGraw Hill.

McCarthy, M. (2003). Water Scarcity Could Affect Billions: Is This the Biggest Crisis of All? *lndependent UK.*

MIMOS Semiconductor (M) Sdn. Bhd. (MySem). (2005). UTM-MIMOS Water Minimization Project (UMWMP). Unpublished report.

Mustow, S., Grey, R., Smerdon, T., Pinney, C., & Waggett, R. (1997). *Water conservation: implications of using recycled greywater and stored rainwater in the UK.* Bracknell: BSRIA.

Naisby, C. (1997). *Greywater recycling and rainwater harvesting. A viable means of domestic water conservation?* Unpublished Masters Thesis. Department of Geography and Civil Engineering, University of Leeds.

Nolde, E. (1995). *Betriebswassernutzung im Haushalt durch Aufbereitung von Grauwasser.* Wasserwirtschaft und Wassertechnik.

Nolde, E. (1996). *Greywater re-use in households: experience from Germany*. In C. Etnier, J., Staudenmann, A. Schönborn (Eds.). Unpublished Masters Thesis. Department of Geography and Civil Engineering, University of Leeds.

Jaafar, N. A. (2004). Takung air hujan untuk pelbagai guna. *Utusan Malaysia*. 17 July 2004.

Olesen, S. G. and Polley, G. T. (1997). A simple methodology for the design of water networks handling single contaminants. *Transactions of IChemE* Part A. **75**: 420-426.

Perry, R. H. and Green, D. W. (1998). Perry's Chemical Engineers' Handbook Seventh Edition. McGraw-Hill, New York.

Peter-Fröhlich, A., Kraume, I., Lesouëf, A. and Oldenburg, M. (2003). *Separate discharge and treatment of urine, faeces and greywater pilot projects.* World Water & Environmental Resources Congress 2003. Philadelphia.

Peters, M. X., Timmerhaus, K. D., and West, R. E. (2003). Plant Design and Economics for Chemical Engineers Fifth Edition. McGraw-Hill, New York.

Polley, G. T., & Polley, H. L. (2000). Design better water networks. *Chemical Engineering Progress*. 96 (2): 47-52.

Prakash, R., Shenoy, U. V. (2005a). Targeting and design of water networks for fixed flowrate and fixed contaminant load operations. *Chemical Engineering Science*. 60 (1): 255-268.

Prakash, R., Shenoy, U. V. (2005b). Design and evolution of water networks by source shifts. *Chemical Engineering Science*. 60: 2089-2093.

Puncak Niaga Holdings Berhad (2002). *Source of Life. Annual Report 2002.* Puncak Niaga Holdings Berhad, Malaysia.

Raja Zainal Abidin, R. D. Z. (2005). Water Services Agenda In The Ninth Plan. *Water Malaysia*. Issue No:10, August 2005.

Sayers, D. (1998). *A study of domestic greywater recycling*, Interim Report. National Water Demand Management Centre, Environment Agency. Worthing, West Sussex.

Sims, B. (1998). Liquid asset - services for housing grey water recycling. *Building Services Journal*. Pg 30.

Smith, R. (1995). Chemical Process Design. McGraw-Hill, Inc.

Sorin, M. and Bédard, S. (1999). The global pinch point in water reuse networks. *Transactions of IChemE* Part B. **77**: 305-308.

Tainsh, R.A. and Rudman A. R. (1999). *Practical techniques and methods to develop an efficient water management strategy.* Linnhoff March International. Paper presented at: IQPC conference "Water Recycling and Effluent Re-Use".

Takama, N., Kuriyama, T., Shiroko, K. and Umeda, T. (1980). Optimal water allocation in a petroleum refinery. *Computers and Chemical Engineering*. 4: 251-258.

Tan, Y. L. (2005). *Development of New Systematic Techniques for Retrofit of Water Network.* MSc. Thesis. Universiti Teknologi Malaysia, Johor, Malaysia.

The Institution of Chemical Engineers. (2000). Guide to Industrial Water Conservation. Part 1. Water Re-use In Single Contaminant Systems. *ESDU 0020*.

The Malaysian Water Association (2003). *Malaysia Water Industry Guide, 2003*. The Malaysian Water Association, Malaysia. Pg 74.

The Malaysian Water Association (2005). *Malaysia Water Industry Guide, 2005*. The Malaysian Water Association, Malaysia.

Ujang, Z. (2004). *Kertas Cadangan Projek Penggunaan Semula Air di Masjid Sultan Ismail, UTM*. Institut Pengurusan Alam Sekitar & Sumber Air (IPASA), UTM.

Ujang, Z. and Henze M. (2006). Municipal Wastewater Management in Developing Countries. *IWA Publishing*. ISBN: 1843390302.

Ujang, Z., & Larsen M. (2000*). Development of Mass Balance & Quantitative Inventory of Water Management in UTM Skudai Campus for Reclamation and Reuse Program.* Research VOT 71498. Institute of Environmental & Water Resource Management Universiti Teknologi Malaysia. 33-35.

Ullmer, C., Kunde, N., Lassahn, A., Gruhn, G. and Schulz, K. (2005). WADO: water design optimization-methodology and software for the synthesis of process water systems. *Journal of Cleaner Production*. **13** (5): 485-494.

United Nations. (1958). *Water for industries use.* UN Report No. E13058ST/ECA/50. Economic and Social Council, New York.

United states EPA (1991). *Pollution Prevention Fact Sheet*. Washington, DC. March 1991.

Utusan Malaysia. (2004a). Semua Kawasan Tadahan Air Negara Diwartakan. *Utusan Malaysia.* 5 November 2004.

Utusan Malaysia (2004b). Pengurusan bekalan air lebih cekap melalui SPAN. *Utusan Malaysia*. 17 November 2004.

Wan Alwi, S. R. and Manan, Z. A. (2006). A new holistic framework for cost effective minimum water network in industrial and urban sector. *Environmental Management Journal*. (in review).

Wan Alwi, S. R., Manan, Z. A., & Ujang, Z. (2004). *Systematic technique for water minimization in urban water system using water pinch analysis.* Paper presented in Asia Water 2004 Conference.

Wang, Y. P. and Smith, R. (1994). Wastewater Minimisation. *Chem. Eng. Sci.*. **49**, 981–1006.

Wang, Y. P., Smith, R. (1995). Wastewater minimization with flowrate constraints. *Transactions of IChemE* Part A. **73**: 889-904.

Water-MATRIX© 2006 (2006). A software for water minimization, copyright owned by Universiti Teknologi Malaysia.

World Bank. (2001). *Executive Summary of the WWDR*. Washington DC.

Wu, M., Sun, D. and Tay, J. H. (2004). Process-to-process recycling of high-purity water for semiconductor wafer backgrinding wastes. *Resources, Conservation and Recycling*. 41: 119-132.

Xu, D., Hu, Y., Hua, B., Wang, X. (2003). Minimization of the flow rate of freshwater and corresponding regenerated water in water-using system with regeneration reuse. *Chinese Journal of Chemical Engineering*. 11(3): 257-263.

Yusoff, K. (2000). *Rainwater Harvesting System in UTM Skudai Campus*. Akademi Tentera Malaysia, Universiti Teknologi Malaysia.