AIChE WILEY InterScience DISCOVER SOMETHING GREAT

SHARPS: A New Cost-Screening Technique to Attain Cost-Effective Minimum Water Network

Sharifah Rafidah Wan Alwi and Zainuddin Abdul Manan
Chemical Engineering Dept., Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia

DOI 10.1002/aic.10986
Published online September 13, 2006 in Wiley InterScience (www.interscience.wiley.com).

Keywords: pinch analysis, minimum water network, cost-screening, process synthesis, environmental engineering

Introduction

Over the past decade, the advent of water pinch analysis (WPA) as a tool for the design of a maximum water recovery (MWR) network has been one of the most significant advances in the area of water minimization. Since its introduction by Wang and Smith,[1] various noteworthy WPA developments on targeting, design, and improvement of an MWR network have emerged. These include works on processes with fixed flow rate and fixed concentration,[2-5] regeneration targeting,[6,7] numerical water targeting,[5] network design to achieve water targets,[1,4,7-11] mathematical modeling, network superstructure optimization and problems with multiple contaminants,[8,12-19] water network retrofit,[20] water targeting for batch systems,[21-23] and capital cost targeting and optimization.[24,20] Wan Alwi et al.[25] recently made the first attempt to implement WPA on an urban system by using their *Water Cascade Analysis* (WCA) technique to establish water targets and design an MWR network for a mosque. Most authors claimed that their methods lead to the minimum fresh water and wastewater targets.

MWR, which relates to maximum reuse, recycling, and regeneration, has two limitations. First, it addresses the problem of water minimization only partially because crucial water minimization options such as elimination and reduction are neglected. Second, given that MWR focuses on water reuse and regeneration, strictly speaking, it does not lead to the *minimum water targets* as widely claimed by researchers over the years. To overcome these limitations, we propose the use of a minimum water network (MWN) technique together with the water management hierarchy (WMH) by Manan and Wan Alwi,[26] shown in Figure 1, to guide and prioritize process changes qualitatively as well as quantitatively toward maximizing water savings for industry and urban systems. The MWN considers not only reuse and recycling, but all conceivable methods to holistically reduce fresh water usage according to the WMH hierarchy, that is, through elimination, reduction, reuse/outsourcing, and regeneration.

Even though the MWN could yield significant water reductions, however, some process changes may be costly and thus unattractive to plant owners. Thus, we propose the *Systematic Hierarchical Approach for Resilient Process Screening* (*SHARPS*) as a new cost-screening tool for design and retrofit of minimum water network for urban and industrial sectors. *SHARPS* is used to screen various water management options before design based on the cost estimates for network investment and savings subject to a desired payback period set by a designer.*

Methodology: SHARPS Technique

To obtain a cost-effective and affordable water network that achieves the minimum water targets [hereby termed the *cost-effective minimum water network* (CEMWN)] within a desired payback period, the new *SHARPS* technique was implemented as follows:

(1) *Step 1*: Set the desired payback period (PP_{set}). The desired payback period can be an investment payback limit set by a plant owner, such as two years.

(2) *Step 2*: Use the water cascade analysis (WCA) method of Manan et al.[5] to establish the maximum water recovery (MWR) targets associated with each water management option at each level of WMH. Begin at the top level of the WMH before going to the next level.

(3) *Step 3*: Generate an investment vs. annual savings (IAS) composite plot covering all levels of the WMH. Figure 2 shows a sample of the IAS plot. The gradient of the plot gives the payback period for each process change. The steepest positive gradient (m_4) giving the highest investment per unit of savings represents the most costly scheme. On the other hand, a neg-

*Note that the current *SHARPS* methodology is applicable to water systems involving a single contaminant.

Correspondence concerning this article should be addressed to Z. A. Manan at zain@fkkksa.utm.my.

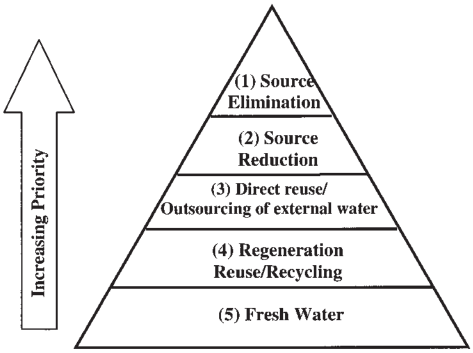

Figure 1. The water management hierarchy.

ative slope (m_3) indicates that the new process modification scheme requires lower investment compared to that of the grassroots equipment.

Note that, because most equipment cost is related to equipment capacity through a power law, one is more likely to generate a curved line such as m_5. Thus, in such cases, several data points should be taken to plot a curve for each process change. As in the case of a linear line, a curve moving upward shows that more investment is needed and a curve moving downward shows less investment is needed with increasing annual savings.

(4) *Step 4*: Draw a straight line connecting the starting point and the end point of the IAS plot (Figure 2). The gradient of this line is a preliminary cost estimate of the total payback period (TPP) for implementing all options in line with the WM hierarchy. The TPP_{BS} is the total payback period before implementing *SHARPS*.

(5) *Step 5*: Compare the TPP_{BS} with the PP_{set} (the desired payback period set by a designer). The total payback period (TPP_{BS}) should match the maximum desired payback period set (PP_{set}) by a designer. Thus, it is possible to tailor the minimum water network according to the requirement of a plant/building owner.

If $TPP_{BS} \leq PP_{set}$, proceed with network design.

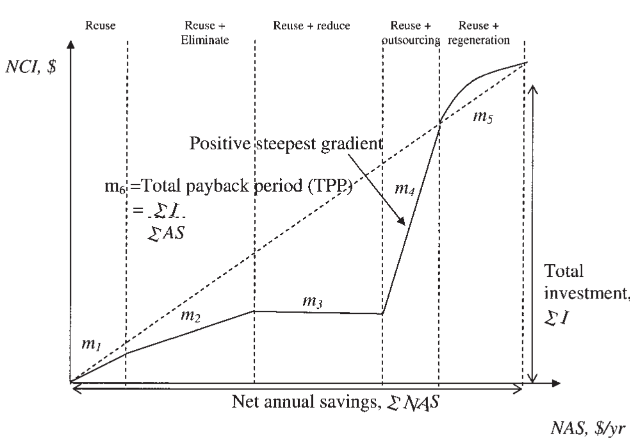

Figure 2. Investment vs. annual savings (IAS) plot covering all levels of water management hierarchy (WMH).

m_4 is the positive steepest gradient and TPP is the total payback period for a water network.

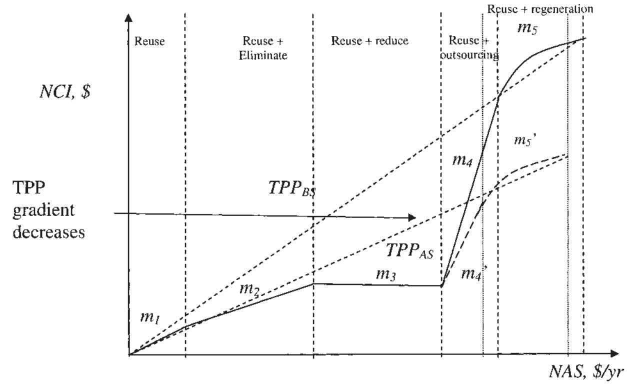

Figure 3. IAS plot showing the revised total payback period when the magnitude of the steepest gradient is reduced using *SHARPS* substitution strategy.

If $TPP_{BS} > PP_{set}$, two strategies may be implemented.

Strategy 1: Substitution. This strategy involved replacing the equipment/process that resulted in the steepest positive gradient with an equipment/process that gave a less steep gradient. Note that this strategy did not apply to the reuse line because there was no equipment to replace. To initialize the composite plot, the option that gave the highest total annual water savings should be used regardless of the total investment needed. Thus, to reduce the steepest gradient according to Strategy 1, the process change option giving the next highest total annual savings but with lesser total investment was selected to substitute the initial process option and trim the steepest gradient. Figure 3 shows that substituting the option causing the steepest positive gradient (m_4) with an option that gives a less steep gradient (m_4') yields a smaller TPP value. For example, a separation toilet may be changed to a much cheaper dual-flush toilet that uses a bit more water. TPP_{AS} is the TPP after implementing *SHARPS* strategies.

In the case of a curvature, linearization is necessary to determine the line of steepest gradient. For a projecting concave or convex curve, the linearization of a curve moving upward is as follows:

(1) Concave curves

Connect a straight line to the start (point A) and end (point B) points of the concave curve to obtain a positive gradient (line AB in Figures 4a and 4b). Connect a line from the graph origin (point O) going through point F_{opt} to the end point (point B) of the concave curve (line O–F_{opt}–B). To have beneficial TPP reduction, the concave curve must be reduced below point F_{opt} (for Strategy 2).

(2) Convex curves

Connect a line from the graph origin (point O) to the minimum point of the convex curve (F_{min}). Connect a line from F_{min} to the end point (point B) of the convex curve to obtain positive gradient (line F_{min}–B in Figures 4c and 4d). Do not further reduce the line on the left-hand side of F_{min} because this will increase TPP (for Strategy 2).

When the linearized line was the steepest positive gradient, *Strategy 1* was implemented to yield a linearized line with a smaller gradient. Note that the proposed linearization is only a preliminary guide to screen the most cost-effective option that satisfies a preset payback period.

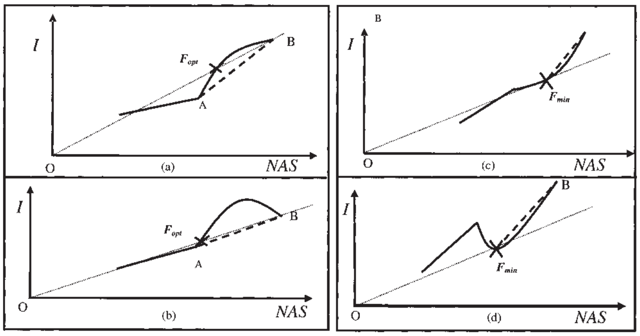

Figure 4. Linearization of concave curves moving upward (a) without peak and (b) with peak. Linearization of convex curves moving upward (c) without valley and (d) with valley.

Strategy 2: Intensification. The second strategy involved reducing the length of the steepest positive gradient until TPP_{AS} was equal to PP_{set}. This second strategy was also not applicable for the reuse line because there was no equipment to replace. Figure 5 shows that when the length of the steepest positive gradient (m_4) is reduced, the new gradient line (m_4') gives a less steep gradient and thus a smaller TPP. This means that instead of completely applying each process change, one can consider eliminating or partially applying the process change that gives the steepest positive gradient and thus a small annual savings compared to the amount of investment. For example, instead of changing all normal water taps to the infrared-type, only 50% of the water taps were changed. If TPP_{AS} was still more than the PP_{set} even after adjusting the steepest gradient, the length for the next steepest gradient was reduced until TPP was equal to PP_{set}.

Similarly, for the case of a projecting concave and convex curves moving upward, it was desirable to reduce the length of the curve until PP_{set} was achieved, if linearization of the curve gave the steepest gradient. Both *Strategies 1* and *2* should be tested or applied together to yield the best savings. The overall procedure for *SHARPS* is summarized in Figure 6.

Results and Analysis

SHARPS strategies were implemented on a semiconductor plant case study (SC).[27] Possible water-saving options applicable to the plant were assessed and screened according to the WM hierarchy. For a process change with various options such as those in the case of pollution abatement system, the option that yielded the highest water flow rate reduction was chosen. The selected process changes for SC after MWN analysis were given check marks in column 3 of Table 1. Based on these selected options, the final minimum water targets were generated using the water cascade analysis technique.[5]

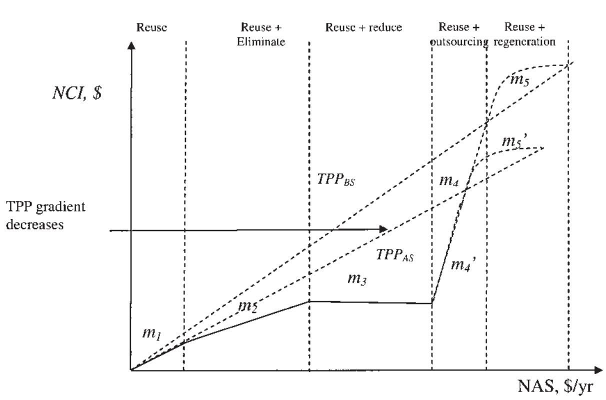

Figure 5. IAS plot showing the revised total payback period with a shorter steepest gradient curve.

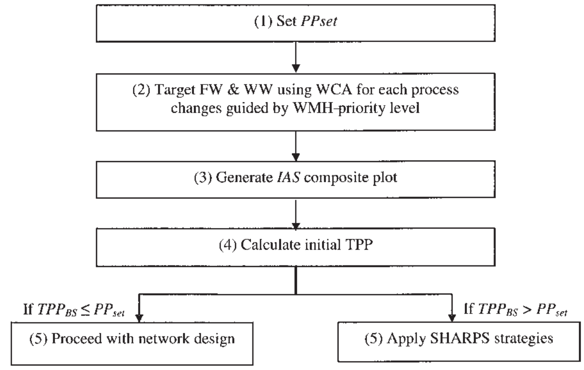

Figure 6. The overall *SHARPS* procedure.

Figures 7 and 8 show the IAS plot before and after applying *SHARPS* strategies for SC retrofit (refer to the Appendix for the cost formula used to generate the IAS plot). The TPP to attain the MWN targets before *SHARPS* screening was 0.5 years for the retrofit case. Figure 7 shows that *abatement option 3* gives the steepest gradient. Changing to *abatement option 4* resulted in an IAS plot with new steepest gradients along the curve segments representing *domestic* followed by *regeneration* process options. Eliminating the domestic process change option and reducing regeneration process change yielded the IAS plot shown in Figure 8. After *SHARPS* screening, the cost-effective

Table 1. Various Water Saving Options Applicable for the Semiconductor (SC) Plant*

WMH	Strategy	Selected Option (after MWN)
Elimination	Pollution Abatement System	
	• Option 2 (decommissioning)	X
	WB 202 and 203 cooling	√
Reduction	WB reduction in Fab 1 and 2	√
	Heater reduction	√
	Fab 1 return reduction	√
	Pollution Abatement System	
	• Option 1 (0.5 gpm during idle)	X
	• Option 3 (recirculation)	√
	• Option 4 (on demand)	X
	• Option 5 (pH analysis)	X
	Increase RO system recovery/install 3rd stage	√
	EDI return reduction	
	• Option 1 (decommissioning)	X
	• Option 2 (run intermittent)	√
	Domestic reduction	√
	Cooling tower reduction using N2	√
	MMF reduction by NTU analysis	√
Reuse	Total reuse	√
Outsourcing	Rain water harvesting	√
Regeneration	Treat all WB water	X

(√) for selected option; (X) for eliminated option.

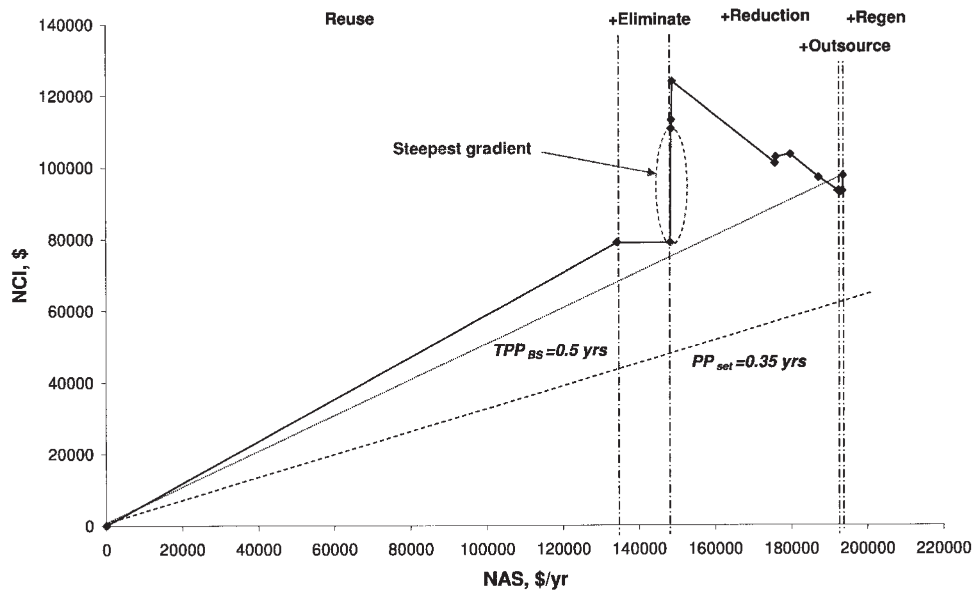

Figure 7. IAS plot for minimum water network (MWN) target before *SHARPS* for SC case study.

minimum water network (CEMWN) achieved the specified payback of 0.35 years.

Table 2 compares the results of using techniques such as MWR, MWN, and MWN after *SHARPS* screening (termed as CEMWN target). It can be seen that the CEMWN target gives a higher net annual savings (NAS) compared to MWR. The total payback period (TPP) is also lower and in line with the total payback period specified by the plant owner.

The *SHARPS* technique provides clear quantitative insights to screen various water management options. By applying the *SHARPS* technique in accordance with the water management hierarchy, it is possible to decide the schemes to partially apply or completely eliminate to satisfy a desired payback period, thereby allowing a designer to estimate the maximum potential annual savings ahead of design. *SHARPS* is a novel cost-screening technique that enables a designer to customize a cost-effective water network design that attains the minimum water targets according to the requirement of a plant or building owner.

Conclusion

A cost-effective minimum water network for urban and industrial sectors can be achieved by using the new *Systematic Hierarchical Approach for Resilient Process Screening* (*SHARPS*) technique. *SHARPS* provides a quick and efficient means to guide and screen inferior process changes and to predict the potential maximum fresh water savings and the desirable investment limits during the early design stage. An SC case study has shown that potential maximum freshwater

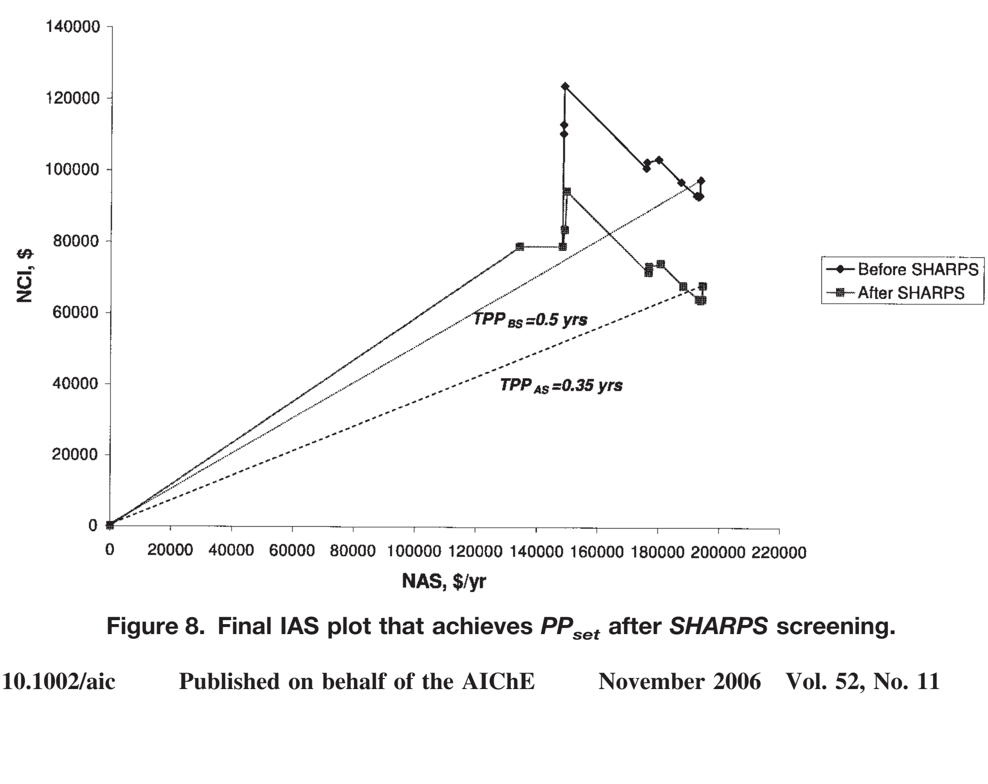

Figure 8. Final IAS plot that achieves PP_{set} after *SHARPS* screening.

Table 2. Comparison of MWR, MWN, and CEMWN Results for SC Case Study

Method	FW (kg/h)	WW (kg/h)	FW Reduction (%)	IWT Reduction (%)	NAS ($/yr)	NCI ($)	TPP (yrs)
Initial	39.94	34.85					
MWR	11.04	0.019	72.4	99.9	497,223	292,413	0.59
MWN	5.90	0	85.2	100.0	717,204	361,385	0.50
CEMWN	5.77	0.009	85.6	100.0	720,199	252,073	0.35

and wastewater reductions of 85.6 and 100%, respectively, for retrofit design are achievable within a payback period of 4.2 months.

Notation

C = cost
$CC_{\text{base case}}$ = capital cost of base case water system
$CC_{\text{new system}}$ = capital cost of new water system
F = flow rate
$F_{\min}$ = minimum point
F_{opt} = optimum point
m = gradient
$OC_{\text{base case}}$ = operating cost of base case water system
OC_{new} = operating cost of new water system
PP_{set} = desired payback period specified by designer
TPP = total payback period
TPP_{AS} = total payback period after SHARPS
TPP_{BS} = total payback period before SHARPS
$\sum$ = summation

Subscripts

Demand initial = initial demand flow rate
EDI initial = initial electrodeionization before analysis
EDI new = new electrodeionization after analysis
FW initial = initial freshwater before analysis
FW new = new freshwater after analysis
FW = freshwater
Heater WB101 initial = initial heater WB101 before analysis
Heater WB101 new = new heater WB101 after analysis
Internal initial = initial internal pumping before analysis
Internal new = new internal pumping after analysis
IWT initial = initial industrial wastewater before analysis
IWT new = new industrial wastewater after analysis
IWT = industrial wastewater
MMF initial = initial multimedia filter inlet before analysis
MMF new = new multimedia filter inlet after analysis
Outsource = outsource
Regen = regeneration
Reuse = reuse

Abbreviations

CEMWN = cost-effective minimum water network
CT = cooling tower
EDI = electrodeionization
Fab = fabrication
FW = freshwater
I = investment
IAS = net capital investment vs. net annual savings plot
MMF = multimedia filter
MWN = minimum water network
MWR = maximum water recovery
NAS = net annual savings
NCI = net capital investment
OC = operating cost
ppm = parts per million
RO = reverse osmosis
RR = rate of recover
RW = rainwater
SHARPS = Systematically Hierarchical Approach for Resilient Process Screening
TDS = total dissolved solids
UV = ultraviolet
WB = wet bench
WCA = water cascade analysis
WMH = water management hierarchy
WPA = water pinch analysis
WW = wastewater

Literature Cited

1. Wang YP, Smith R. Wastewater minimisation. *Chem Eng Sci.* 1994;49:981-1006.
2. Dhole VR, Ramchandani N, Tainsh RA, Wasilewski M. Make your process water pay for itself. *Chem Eng.* 1996;103:100-103.
3. Sorin M, Bédard S. The global pinch point in water reuse networks. *Tran IChemE B.* 1999;77:305-308.
4. Hallale N. A new graphical targeting method for water minimisation. *Adv Environ Res.* 2002;6:377-390.
5. Manan ZA, Tan YL, Foo DCY. Targeting the minimum water flow rate using water cascade analysis technique. *AIChE J.* 2004;50:3169-3183.
6. Kuo WCJ, Smith R. Design of water-using systems involving regeneration. *Trans IChemE B.* 1998;76:94-114.
7. Castro P, Matos H, Fernandes MC, Nunes CP. Improvements for mass-exchange networks design. *Chem Eng Sci.* 1999;54:1649-1665.
8. Takama N, Kuriyama T, Shiroko K, Umeda T. Optimal water allocation in a petroleum refinery. *Comput Chem Eng.* 1980;4:251-258.
9. Olesen SG, Polley GT. A simple methodology for the design of water networks handling single contaminants. *Trans IChemE A.* 1997;75:420-426.
10. Polley GT, Polley HL. Design better water networks. *Chem Eng Prog.* 2000;96:47-52.
11. Prakash R, Shenoy UV. Targeting and design of water networks for fixed flow rate and fixed contaminant load operations. *Chem Eng Sci.* 2005;60:255-268.
12. Alva-Argáez A, Kokossis AC, Smith R. Wastewater minimisation of industrial systems using an integrated approach. *Comput Chem Eng.* 1998;22:741-744.
13. Huang CH, Chang CT, Ling HC, Chang CC. A mathematical programming model for water usage and treatment network design. *Ind Eng Chem Res.* 1999;38:2666-2679.
14. Benkó N, Rév E, Fonyó Z. The use of nonlinear programming to optimal water allocations. *Chem Eng Commun.* 2000;178:67-101.
15. Bagajewicz M, Savelski M. On the use of linear models for the design of water utilization systems in process plants with a single contaminant. *Trans IChemE A.* 2001;79:600-610.
16. Xu D, Hu Y, Hua B, Wang X. Minimisation of the flow rate of freshwater and corresponding regenerated water in water-using system with regeneration reuse. *Chin J Chem Eng.* 2003;11(3):257-263.
17. Koppol APR, Bagajewicz MJ, Dericks BJ, Savelski MJ. On zero water discharge solutions in the process industry. *Adv Environ Res.* 2003;8:151-171.
18. Ullmer C, Kunde N, Lassahn A, Gruhn G, Schulz K. WADO: Water design optimization—Methodology and software for the synthesis of process water systems. *J Clean Prod.* 2005;13:485-494.
19. Gunaratman M, Alva-Araraez A, Kokossis A, Kim J-K, Smith R. Automated design of total water systems. *Ind Eng Chem Res.* 2005;44:588-599.
20. Tan YL. *Development of New Systematic Techniques for Retrofit of*

Water Network. MS Thesis. Johor, Malaysia: Universiti Teknologi Malaysia; 2005.
21. Wang YP, Smith R. Wastewater minimisation with flowrate constraints. *Trans IChemE A*. 1995;73:889-904.
22. Foo CY, Manan ZA, Yunus RM, Aziz RA. Synthesis of mass exchange network for batch processes—Part 1: Utility targeting. *Chem Eng Sci*. 2004;59:1009-1026.
23. Foo CY, Manan ZA, Yunus RM, Aziz RA. Synthesis of mass exchange network for batch processes—Part II: Minimum unit target and batch network design. *Chem Eng Sci*. 2005;60:1349-1362.
24. Feng X, Chu KH. Cost optimisation of industrial wastewater reuse systems. *Trans IChemE B*. 2004;82:249-255
25. Wan Alwi SR, Manan ZA, Ujang Z. Systematic technique for water minimization in urban water system using water pinch analysis. Proceedings of ASIA WATER, March 30–31; 2004.
26. Manan ZA, Wan Alwi SR. Stretching the limits on urban and industrial water savings. *Jurutera*. 2006;01:24-27.
27. MIMOS Semiconductor (M) Sdn. Bhd. (MySEM). UTM-MIMOS Water Minimisation Project (UMWMP). Malaysia: Universiti Teknologi Malaysia, Unpublished report; 2005.

Appendix: Cost Formula

Equations 1–4 constitute a set of formulas to obtain the payback period, net capital investment for retrofit, grassroots designs, and net annual savings. For the SC case study, the formulas for $OC_{base\ case}$, OC_{new}, and $CC_{new\ system}$ are listed in Tables A1–A3 . Tables A4 and A5 show the results of calculating the NCI and NAS using MWN and CEMWN methods respectively, for each WMH option:

$$Payback\ period\ (yrs) = \frac{Net\ Capital\ Investment\ (\$)}{Net\ Annual\ Savings\ (\$/yrs)} \tag{A1}$$

$$Net\ Capital\ Investment,\ \$\ (retrofit) = \Sigma CC_{new\ system} \tag{A2}$$

$$Net\ Capital\ Investment,\ \$\ (grassroots) = \Sigma CC_{new\ system} - \Sigma CC_{base\ case} \tag{A3}$$

$$NAS = \Sigma OC_{base\ case} - \Sigma OC_{new} \tag{A4}$$

Table A1. $OC_{base\ case}$ Formula for SC Case Study

Process	Type of OC	Cost Formula	Unit
Freshwater cost, C_{FW}	Freshwater	$0.518F_{FW\ initial}$	\$/h
Industrial wastewater cost, C_{IWT}	Wastewater	$0.042F_{IWT\ initial}$	\$/h
EDI cost	Other	$0.017F_{EDI\ initial}$	\$/h
Heater WB101 electrical cost	Other	$0.016F_{Heater\ WB101\ initial}$	\$/h
Overall DI water treatment	Chemical	$0.016F_{MMF\ initial}$	\$/h
Internal pumping cost	Electrical	$0.018F_{internal\ initial}$	\$/h

Table A2. OC_{new} Formula for SC Case Study

Process	Type of OC	Cost Formula	Unit
JBA cost, C_{FW}	Freshwater	$0.518F_{FW\ new}$	\$/h
Industrial wastewater cost, C_{IWT}	Wastewater	$0.042F_{IWT\ new}$	\$/h
EDI chemical and pumping cost	Chemical and electrical	$0.017F_{EDI\ new}$	\$/h
Heater WB101 electrical cost	Electrical	$0.018F_{Heater\ WB101\ new}$	\$/h
Overall DI water treatment	Chemical	$0.016F_{MMF\ new}$	\$/h
Reuse, outsource, and treatment pumping operating cost, C_{EOC}	Electrical	$0.018F_{reuse/oursource/regen}$	\$/h
Internal pumping cost	Electrical	$0.018F_{internal\ new}$	\$/h
Treatment OC	Chemical	$0.018F_{reg}$	\$/h

Table A3. CC_{new} Formula for Individual Equipment for SC Case Study

Process	New Equipment	No. of Unit	Cost Formula ($)	Unit	Cost/System ($)
Toilet flushing	4.5 1 toilet flush with installations	15	162	$/unit	2430
Wudhuk	Tap 1.9 lpm with installation	7	10.8	$/unit	75.6
Wash basin	Tap 1.9 lpm with installation	15	10.8	$/unit	162
Abatement	Option 1: Run each abatement at 0.5 gpm during idle. Need control system.	6	7020	$/system	7020
	Option 2: Decommissioning 3 abatement unit and new duct with installation (retrofit)	3	8640	$/system	8640
	Option 2: New duct with installation (grassroots)	3	7020	$/system	7020
	Option 3: Recirculation of water. Need treatment, piping and control system with installation	6	34,290	$/system	34,290
	Option 4: On demand abatement system. Need control system with installation.	6	7020	$/system	7020
	Option 5: Abatement flow reduction based on pH analysis.	6	Nil	$/system	Nil
WB 202 cooling	Teflon® tank with installation	1	1350	$/unit	1350
WB 203 cooling	Teflon® tank with installation	1	1350	$/unit	1350
WB in Fab 1 and Fab 2	Adjust WB flow valve during idle mode to minimum. No investment needed.	—	Nil	$/system	Nil
Heater WB101	Heater unused water recirculation and on demand heating. Need piping and control system.	1	1836	$/unit	1836
Fab 1 return	Variable speed pump with installations	1	4050	$/unit	4050
RO system	Increase RO system rate of recovery (RR) to maximum (RR = 80% 1st pass, RR = 90% 2nd pass). No investment needed.	1	Nil	$/system	Nil
EDI	Option 1: Decommissioning extra EDI unit and 3 variable speed pumps (retrofit)	3	6750	$/system	6750
	Option 2: Run EDI intermittently. Need control system.	—	1890	$/system	1890
Cooling tower	Using N_2 to cool cooling water return. Heat exchanger and piping with installations	1	10,800	$/system	10,800
MMF backwash and rinse	Reduce time of backwash and rinse to minimum. No need investment.	2	Nil	$/system	Nil
Total reuse	Reuse diversion system and pumps with installations (Retrofit)	—	$(52{,}634 \times F_{reuse}/F_{demand\ initial})^{0.6} \times 150\%$	$/system	
Rainwater harvesting (10 ppm)	RW diversion system and pumps (Retrofit)	—	$(52{,}634 \times F_{RW}/F_{demand\ initial})^{0.6} \times 170\%$	$/system	
Treatment (Treat WB WW to 52 ppm)	Treat all WB WW by using carbon bed, EDI and UV. Need treatment system, installations, control and piping (Retrofit)	—	$[261{,}900 \times (F_{reg}/45.5)^{0.6} \times 120\%] + [52{,}634 \times (F_{reg}/F_{demand\ initial})^{0.6} \times 150\%]$	$/system	

Table A4. MWN Targets before SHARPS

WMH Level	Strategy	Cumulative NAS ($/yr)	Cumulative Investment (retrofit) ($)
Reuse	Reuse	134,250	78,952
+Elimination	WB cooling	148,273	78,954
+Reduction	Abatement option 3	148,461	110,583
	Domestic	148,499	113,122
	CT	148,750	123,922
	WB reduction	175,796	101,014
	Heater reduction	175,977	102,714
	Fab 1 return reduction	179,803	103,426
	EDI return option 2	187,234	97,105
	RO recovery	192,363	93,274
	MMF	192,959	92,974
+Outsourcing	Add 0.11 m^3/h RW with 16 ppm TDS	193,469	93,246
+Regeneration	Regenerate to 52 ppm	193,645	97,574

Table A5. CEMWN Targets after SHARPS

WMH Level	Strategy	Cumulative NAS ($/yr)	Cumulative Investment (retrofit) ($)
Reuse	Reuse	134,250	78,952
+Elimination	WB cooling	148,273	78,954
+Reduction	Abatement option 4	148,951	83,758
	CT	149,626	94,431
	WB reduction	176,642	71,811
	Heater reduction	176,823	73,512
	Fab 1 return reduction	180,649	74,258
	EDI return option 2	188,080	68,040
	RO recovery	193,208	64,271
	MMF	193,805	63,976
+Outsource	Add 0.11 m^3/h RW with 16 ppm TDS	194,316	64,248
+Regeneration	Regenerate to 52 ppm	194,454	68,060

Manuscript received May 17, 2006, and revision received July 10, 2006.