Stretching the Limits on Urban and Industrial Water Savings

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INTRODUCTION

The world is on the brink of a water crisis. United Nations in World Water Day 2002 has warned that more than 2.7 billion people will face severe water shortages by 2025 [1]. Shortage of quality raw water, rising costs of water management and drive towards environmental sustainability have encouraged widespread water conservation efforts and stimulated the development of systematic techniques for *water minimisation*.

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 minimisation. Water pinch analysis is a systematic technique for implementing strategies to maximise water reuse and recycling through integration of water-using activities or processes. Since its introduction by Wang and Smith [2], various noteworthy WPA developments on targeting, design and improvement of an MWR network have emerged. Most authors claimed that their methods lead to the *minimum fresh water and wastewater targets*. It is important to note that the concept of MWR based on WPA which relates to maximum reuse, recycling and regeneration (partial treatment before reuse) has two limitations. Firstly, MWR only partly addresses the issue of water minimisation which should holistically consider all conceivable methods to reduce water usage through elimination, reduction, recycling, outsourcing and regeneration [3]. Secondly, since MWR focuses on water reuse and regeneration, strictly speaking, MWR only leads to MWR targets as opposed to the *minimum water targets* as widely claimed by researchers over the years. Note that, the minimum water targets can only be achieved when all options for water minimisation including elimation, reduction and outsourcing have been holistically applied.

Even though WPA has been well-established for synthesis of MWR networks, research towards water conservation from the holistic water minimisation viewpoint has significantly lagged behind. There is a clear need to develop a holistic framework to effectively and systematically generate a *minimum water utilisation* network to maximise water savings for the industry and urban sectors.

A HOLISTIC FRAMEWORK FOR DESIGN OF A MINIMUM WATER NETWORK

Application of an MWR network for grassroots and existing water distribution systems have solely focused on industrial sectors and have only recently been introduced into the urban system [4]. Manan *et al.* [5] had applied reuse, outsourcing of rainwater and regeneration to Sultan Ismail Mosque (SIM) using the water pinch technique to yield what was thought to be colossal savings of up to 85.5% freshwater and 67.7% wastewater. However, the potential savings could be further stretched by implementing the holistic framework described as follows:

The new holistic framework to generate a minimum water network involves four key steps (see Figure 1). The first step is water data specifications which involves identifying the appropriate water demands (inputs) and water sources (outputs) in a water distribution system having potential for integration. The limiting data for the water demands and sources is as summarised in Table 1 in terms of flow rate and maximum contaminant concentration.

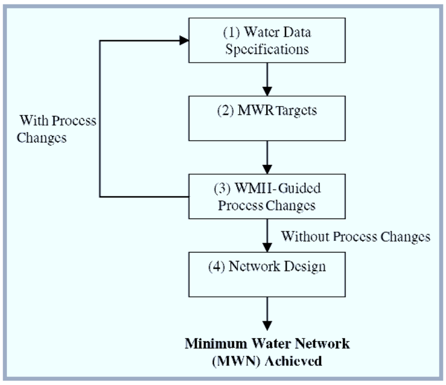


Figure 1: A holistic framework for design of a minimum water network

The MWR targets were established using the WCA technique [6] in step 2. The *water cascade table* (Table 2) shows that at least 16.46 t/day fresh water was required and a maximum of 12.99 t/day wastewater was generated for SIM by maximising reuse, recycling and regeneration. This represents a potential of 43.4% fresh water savings and 49.3% of wastewater reduction.

Table 1: Limiting water data for mosque case study (Manan et al., 2004b)

Demand j	Stream	F (t/day)	C, ppm
1	Kitchen	0.03	0
2	Ablution	25.03	10
3	Wash basin	0.14	10
4	Showering	0.14	10
5	Mosque cleaning	0.29	10
6	Irrigation	1.46	10
7	Toilet pipes	0.44	10
8	Flushing toilet	1.57	10
Source i	**Stream**	**F (t/day)**	**C, ppm**
1	Ablution	25.03	23
2	Wash basin	0.14	23
3	Showering	0.14	216
4	Mosque cleaning	0.29	472
5	Kitchen	0.03	536

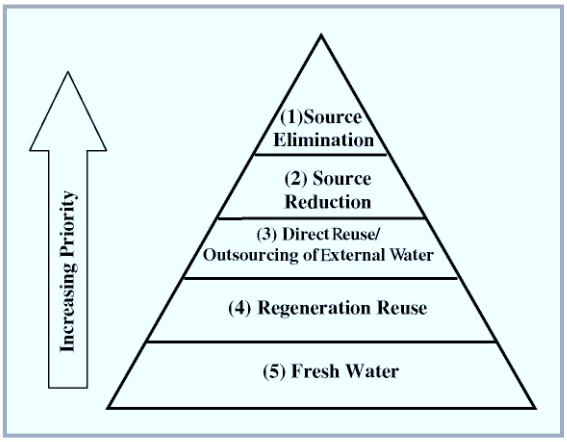


Figure 2: The water management hierarchy

After targeting to maximise water reuse, various water management options were systematically and quantitatively explored in line with the water management (WM) hierarchy to ultimately achieve the minimum water targets. Figure 2 shows the WM hierarchy consisting of five levels, namely (1) source elimination, (2) source reduction, (3) direct reuse or outsourcing of external water, (4) regeneration, and (5) use of fresh water. Water minimisation is concerned with the first to the fourth level of the WM hierarchy. It is possible to quantify the potential maximum water savings and ultimately generate the minimum water network by observing the fundamental pinch rules for process changes and prioritising as well as assessing all possible options for process changes according to the WM hierarchy [7]. To evaluate the effects of each water management option on the MWR targets, Steps 1 and 2 were repeated each time an option was proposed. Figure 3 illustrates the quantitative impact of applying each water management option on SIM water utilisation. Note that the *true minimum water targets* were established using WCA prior to *network design* once all options were explored in line with the WM hierarchy.

The fourth and final step is to design a minimum water network to achieve the true minimum water targets. This was done using the source-sink mapping diagram and design heuristics from Polley and Polley [8], Hallale [9] as well as from Manan *et al.* [10]. The flow diagram for the final SIM water network is shown in Figure 4.

COMPARISON OF RESULTS FROM VARIOUS *WATER MINIMISATION* TECHNIQUES

The current WPA solution which aims to maximise water reuse and recovery yielded 43.4% freshwater and 19.3% wastewater reductions (see Table 2). Manan *et al.* [5] managed to significantly extend the reductions to 85.5% freshwater and 67.7% wastewater by implementing additional water management options from the WM hierarchy, namely outsourcing and regeneration. However, the limits on water savings were ultimately stretched when all options for water management were systematically and quantitatively explored using the new holistic framework for minimum water network (MWN) design. Application of the holistic framework yielded 97.4% potential reductions of freshwater and 64.5% wastewater. Table 3 compares the freshwater and wastewater reduction potentials predicted by the three methods mentioned. The results show that holistic framework for MWN design gives the best savings as compared to using the established MWR technique or selective application of WM-hierarchy levels.

Table 2: Water cascade table (WCT) for SIM case study

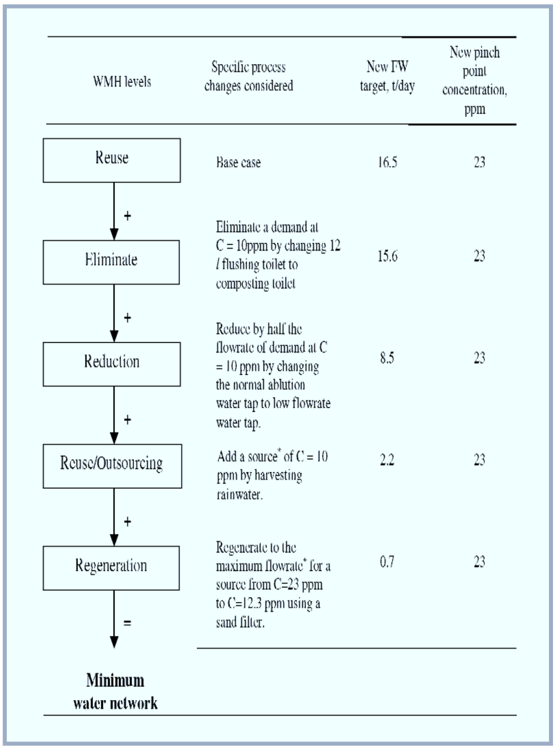
Interval n	Concentration C_n (ppm)	Purity, P_n	$\Sigma F_{D,j}$ (t/day)	$\Sigma F_{S,i}$ (t/day)	$\Sigma F_{D,j} + \Sigma F_{S,i}$ (t/day)	F_C, (t/day)	Cumulative pure water surplus (t/day)
						F_{FW} =16.46	
	0	1.000000	-0.03		-0.03		
1						16.43	
	10	0.999990	-29.07	0	-29.07		0.000164
2						-12.64	
	23	0.999977		25.17	25.17		**0 (Pinch)**
3						12.53	
	216	0.999784		0.14	0.14		0.002418
4						12.67	
	472	0.999528		0.29	0.29		0.005662
5						12.96	
	536	0.999464		0.03	0.03		0.006492
6						**F_{WW} =12.99**	
	1000000	0					12.990398

Table 3: Freshwater and wastewater reductions for MWR network, conventional water network and MWN

	MWR Network (Reuse)	MWR Network (Reuse, outsourcing and regeneration)	MWN with holistic framework
Freshwater reduction	43.4%	85.5%	97.4%
Wastewater reduction	49.3%	67.7%	64.5%

CONCLUSION

A holistic framework for design of minimum water networks for industry and urban systems has been established. The water management hierarchy provided systematic as well as quantitative guidelines to approach *water minimisation* and ultimately achieve the *minimum water network design*. Application of the technique to the Sultan Ismail Mosque in UTM revealed potentials for freshwater and wastewater reductions of up to 97.4% and 64.5% respectively. The same technique has also been applied to an industrial plant, i.e. an acrylonitrile process, to give freshwater savings and wastewater reduction of up to 100% and 57.3% respectively [7]. Three key contributions have emerged from our work. First is the development of a powerful new holistic framework to systematically guide, prioritise and quantitatively evaluate water minimisation options for grassroots and retrofit designs. Second is application of the new holistic framework and water pinch analysis on urban systems. Third is the introduction of a unique water management hierarchy with new insights for prioritising process changes according to elimination, reduction, water reuse, outsourcing and regeneration. ■



WMH levels	Specific process changes considered	New FW target, t/day	New pinch point concentration, ppm
Reuse	Base case	16.5	23
Eliminate	Eliminate a demand at C = 10ppm by changing 12 *l* flushing toilet to composting toilet	15.6	23
Reduction	Reduce by half the flowrate of demand at C = 10 ppm by changing the normal ablution water tap to low flowrate water tap.	8.5	23
Reuse/Outsourcing	Add a source* of C = 10 ppm by harvesting rainwater.	2.2	23
Regeneration	Regenerate to the maximum flowrate* for a source from C=23 ppm to C=12.3 ppm using a sand filter.	0.7	23

Figure 3: The effects of WMH-guided process changes on the MWR targets and pinch location

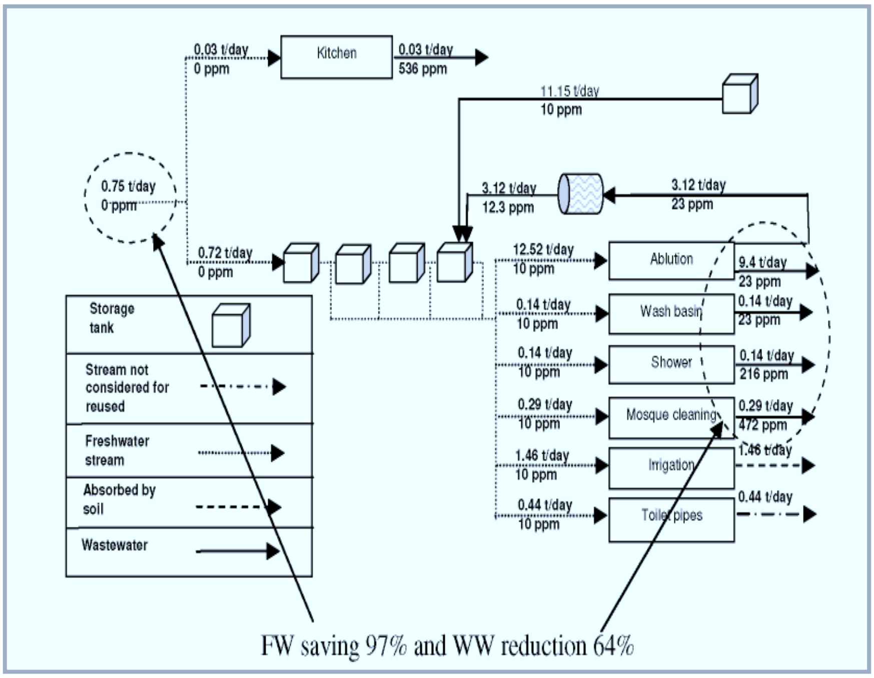


Figure 4: Flow diagram for SIM water network
(Freshwater savings: 97% and Wastewater reductions: (64%)

REFERENCES

[1] BBC News (22 March 2002). UN warns of looming water crisis.

[2] Wang, Y. P. and Smith, R. Wastewater Minimisation. *Chem. Eng. Sci.* 1994; 49, 981–1006.

[3] Manan, Z. A., Wan Alwi, S. R. and Ujang, Z. A new look at urban water saving. *Water21 magazine*. February 2005 Issue. IWA Publishing, 2005.

[4] Wan Alwi, S. R., Manan, Z. A., & Ujang, Z., 2004, Systematic technique for water minimisation in urban water system using water pinch analysis, *Proceedings of ASIAWATER 2004*, 2005, Kuala Lumpur, Malaysia.

[5] Manan, Z. A., Wan Alwi, S. R. and Ujang, Z. Water Pinch Analysis for Urban Systems: Setting the Minimum Water Targets. *Desalination*. Under review (Ref: DES 3270), 2004.

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

[7] Manan, Z. A. and Wan Alwi, S. R. A Holistic Framework for Design of Minimum Water Utilisation Networks. *AiChe Journal*. Under review (MS # 09486), 2005.

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

[9] Hallale, N. A new graphical targeting method for water minimisation. *Advances in Environmental Research*. 2002; 6 (3): 377-390.

[10] Manan, Z. A., Wan Alwi, S. R. and Ujang, Z. Systematic Design of a Maximum Water Recovery Network for an Urban System Based on Pinch Analysis. *IEM Journal*. Submitted 2005.