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HOLISTIC WATER MINIMISATION

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ABSTRACT

Water is a vital resource to mankind. Many religions regard a person's attitude towards conservation of resources, namely water, as an indication of her faith. The Holy Quran says (Al-Araf, 31), *"But waste not by excess: for Allah loveth not the wasters"*. Sustainable management of water resources entails the use of a systems approach because educating to change public attitudes is not expected to result in a high degree of domestic water saving. This contribution describes a framework for holistic water minimisation that was applied to Sultan Ismail Mosque in Universiti Teknologi Malaysia (UTM). The framework employs a systems approach that revolves around the hierarchy of water management to maximise water savings.

Keywords: *water minimisation; mosque; water pinch analysis; reuse; water management hierarchy*

1.0 INTRODUCTION

"We made from water every living thing", The Holy Quran; Sura 21, verse 30.

The earth is a timeless evidence that water forms the essence of life. It is well-known that about three-quarter of the earth surface is made up of water. This is perhaps the source of a common misconception that there is abundance of water on the surface of the earth to last for generations to come. In truth, of the total amount of water available, only about 2.5% is fresh water. 97.5% is salt water that is not readily available for use. Only a mere 0.5% of the total amount of fresh

PERINTIS E-Journal, **2015**, Vol. 5, No. 2, pp. 31-45

water is from lakes and rivers, while a significant 99.5% needs costly techniques to extract 69% of water that is locked in glaciers and 30.5% which is buried beneath the earth as ground water.

For ages, water has been one of the most vital resources to human being. Demand for fresh water has increased sharply with steady growth in world population and rapid development, bringing about rising consumption, climate change and widespread water pollution from domestic, agricultural and industrial sectors. Rising demand and shortage of fresh water supply have caused the price of fresh water to steadily increase over the years. Statistics from the United Nations (UN) has indicated that, about 1.8 billion people will be living in countries or regions with absolute water scarcity, and two-thirds of the world's population could be living under water stressed conditions by the year 2025 [1]. The need for water conservation and efficient water management is becoming more crucial than ever.

Many religions regard a person's attitude towards conservation of resources, namely water, as a sign of her faith. The Holy Quran says (Al-Araf, 31), *"But waste not by excess: for Allah loveth not the wasters"*.

It is with this realisation that the Faculty of Chemical Engineering of Universiti Teknologi Malaysia (UTM) has developed tools and strategies for the optimal design of *systems* to maximise water savings through water minimisation and recovery. This is aimed at complementing the more challenging effort of changing public attitudes, and to ensure a development that is sustainable for the future generations.

The *Water Pinch Analysis (WPA)* has been one of the most significant advances in the design of a maximum water recovery (MWR) network over the last two decades. Since its introduction [2], various important developments on water targeting (benchmarking), design and improvement of MWR networks have emerged. Readers are referred to state-of-the-art reviews on the detailed development of WPA [3],[4].

2.0 WATER-PINCHING AT HOME

The WPA concept is best illustrated using a domestic application of water recovery. Figure 1 shows several domestic activities like drinking, ablution, toilet-flushing, laundry, dish-washing, car-washing, and bathing that consume fresh water. Altogether, the total amount of fresh water demand for these activities is 1000 L/day. Assuming that it is possible to *directly reuse* 60 L/day of spent water from ablution for bathing, it is possible not only to save 60 L/day of fresh water, but also to prevent the discharge of 60 L/day of wastewater into the drain. Further 180 L fresh water and wastewater could be saved if it is possible to reuse some wastewater from washing clothes for flushing toilet (Figure 2).

The domestic water recovery system is a classic application of the concept of Water Pinch Analysis.

PERINTIS E-Journal, **2015**, Vol. 5, No. 2, pp. 31-45

Water Pinch Analysis is a systematic approach for implementing strategies for maximising water recovery through integration of water-using activities or processes.

Note that, in some cases like for bathing, direct water reuse may not be acceptable. Further *water-pinching* maybe achieved by treating (or regenerating) kitchen wastewater to enable it to be reused for flushing toilet. For example, 130 L/day of water (and hence, 100 L/day of wastewater) can be saved after *regeneration-reuse* (Figure 2). Treating wastewater from bathing and reusing it for bathing is known as *regeneration-recycling.*

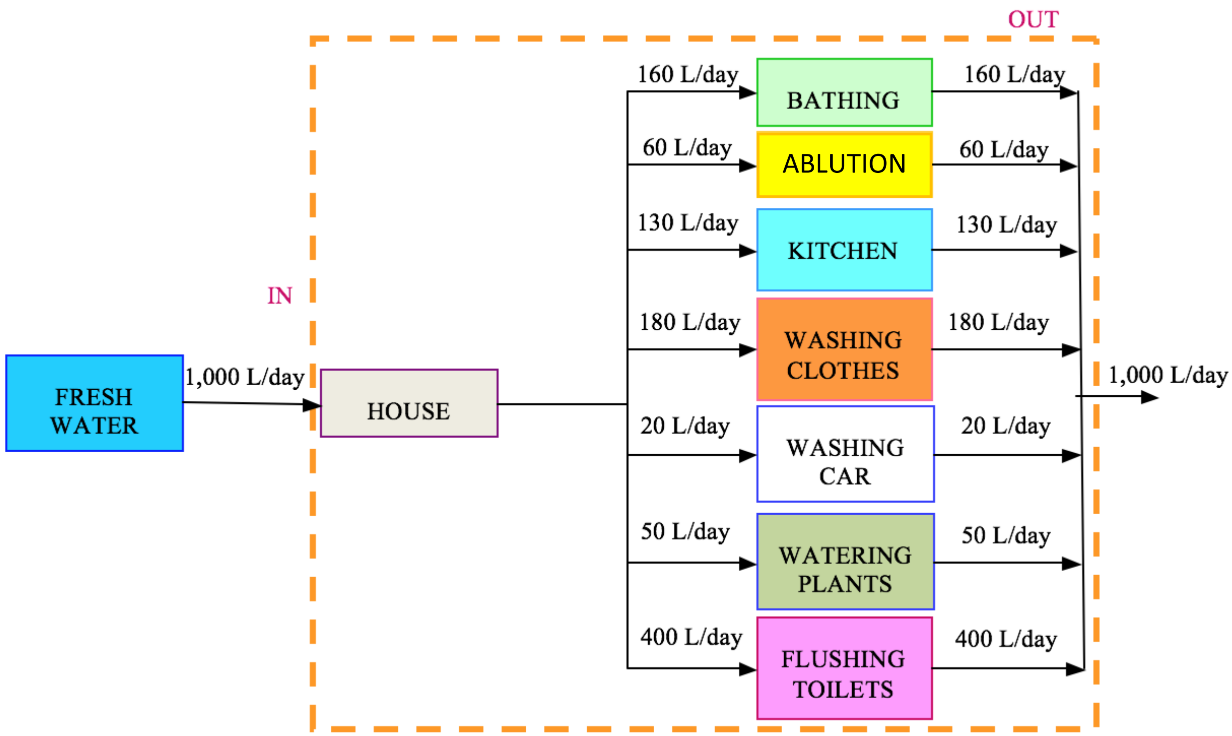

Figure 1: Sample of water activities in a household of 6 person

PERINTIS E-Journal, **2015**, Vol. 5, No. 2, pp. 31-45

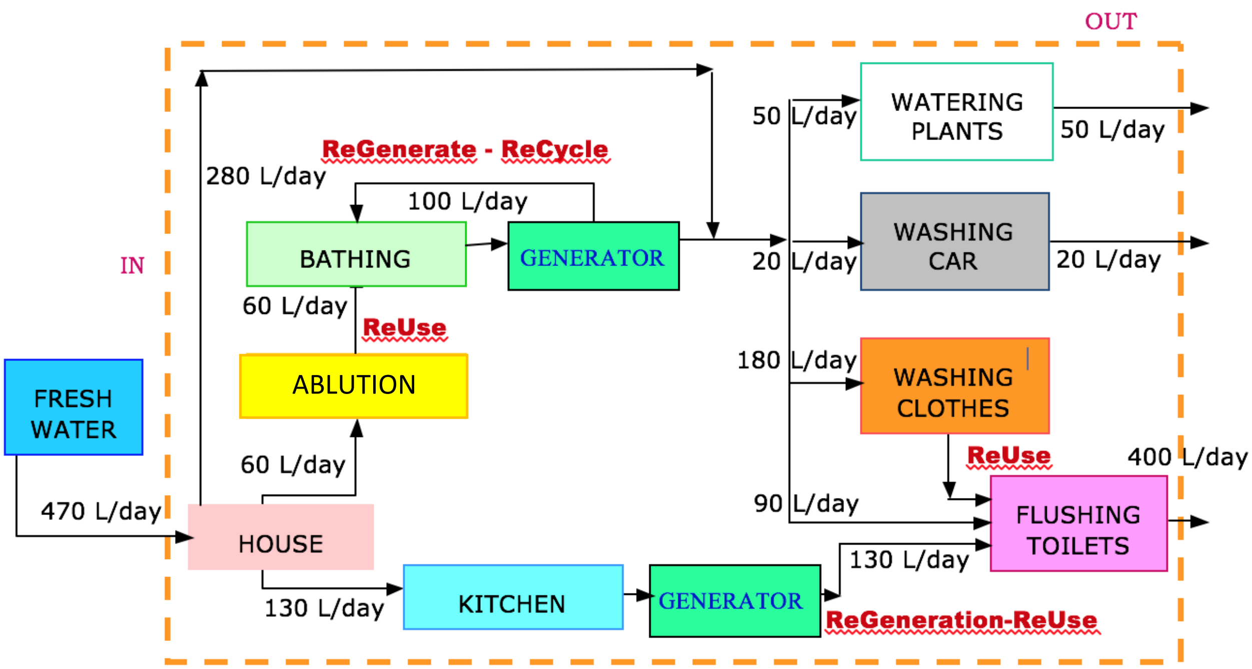

Figure 2: Example of direct reuse, regeneration-reuse and regeneration-recycling

3.0 WATER-PINCH ANALYSIS AND HOLISTIC WATER MINIMISATION

The concept of MWR based on WPA mainly relates to the maximum reuse and recycling as well as regeneration of wastewater. The MWR only partly addresses the goal of water minimisation that should holistically consider all conceivable methods to reduce water usage through elimination, reduction, reuse/recycling, outsourcing and regeneration [5]. Since MWR focuses on water reuse and regeneration, strictly speaking, it could only lead to the MWR targets as opposed to the minimum water targets. Strictly speaking, the minimum water targets can only be achieved when all options for water minimisation including elimination, reduction, reuse/recycling, outsourcing and regeneration have been holistically applied.

Central to the notion of holistic water minimisation is the Water Management Hierarchy (WMH). Figure 3 shows the WMH consisting of five levels, namely (1) source elimination, (2) source reduction, (3) direct reuse/outsourcing of external water, (4) regeneration, and (5) use of fresh water.

Source elimination at the top of the hierarchy involves avoiding the use of fresh water altogether. At times, it may be possible to avoid using water rather than to reduce, reuse or recycle water. Examples include using a vacuum toilet, and choosing an air-cooler instead of a water-cooler to cool equipment. Even though source elimination is desirable, often, it may not be possible to completely avoid using water. One must then try to explore the source reduction option (level 2 of the WMH), which involves reducing water quantity at the source of water usage. Common examples of water source reduction gadgets include automatic tap and the 6 and 12 liters dual-mode toilet flush.

When fresh water usage cannot be avoided or reduced at source, wastewater recycling should be considered. Level 3 of the WMH involves direct reuse and outsourcing of wastewater or external water source to perform tasks that can accept lower quality water. Direct reuse involves using wastewater from within facility. For example, wastewater from a sink may be directly reused for toilet flushing. Outsourcing involves using water sources from the environment. For example, rainwater may be used for washing purposes.

However, water regeneration (level 4) may be necessary prior to reuse and recycling as explained earlier in the example involving domestic water-pinching. The Council of Leading Islamic Scholars (CLIS) in Saudi Arabia [6] has issued a fatwa on water reuse after treatment. It postulated that "Impure waste water can be considered as pure water and similar to the original pure water, if its treatment using advanced technical procedures is capable of removing impurities with regard to taste, colour and smell, as witnessed by honest, specialized and knowledgeable experts. Then it can be used to remove body impurities and for purifying, even for drinking".

Note that WPA is concerned with maximising water reuse and regeneration-reuse at levels 3 and 4 of the WMH.

Use of fresh water at level 5 of the WMH is to be avoided whenever possible as it is the least desirable option from the holistic water minimisation perspective. Fresh water should only be used when wastewater cannot be recycled, or when it is necessary to dilute wastewater by mixing it with fresh water in order to obtain a desired purity. Note that wastewater has to undergo the end-of-pipe treatment before discharge to meet the environmental regulations. Using the WMH, fresh water usage may not be avoided, but will become economically legitimate. The cost effectiveness of applying the WMH options can be evaluated by using the Systematic Hierarchical Approach for Resilient Process Screening (SHARPS) by [5, 7].

PERINTIS E-Journal, **2015**, Vol. 5, No. 2, pp. 31-45

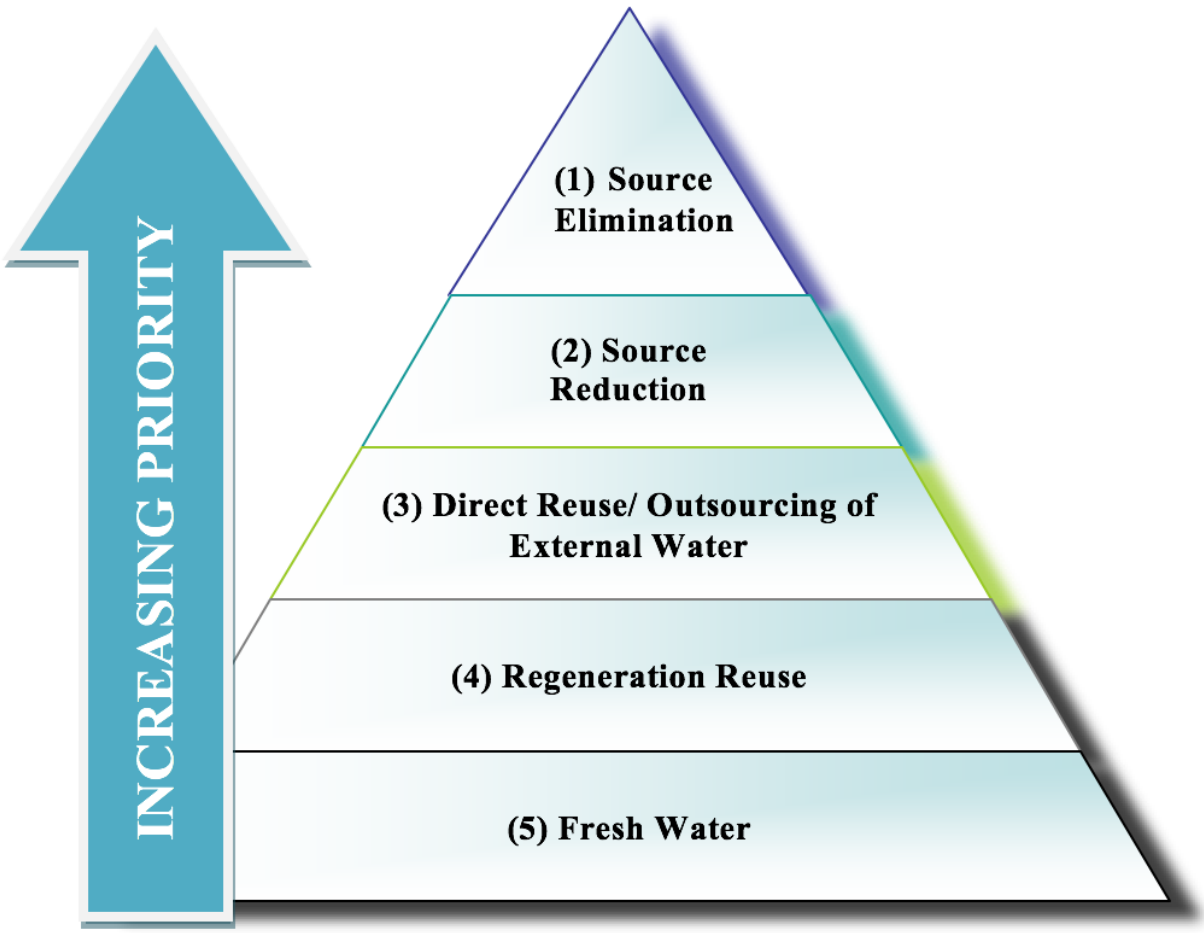

Figure 3: Water Management Hierarchy [4].

4.0 THE FRAMEWORK FOR HOLISTIC FOR WATER MINIMISATION

The holistic framework to design the minimum water network has been applied to the Sultan Ismail Mosque (SIM) in UTM (Figure 4**)**. The framework involves four key steps (see Figure 5) [8]. In step 1, the appropriate water demands (inputs) and water sources (outputs) in a water distribution system are identified and listed in terms of flow rate and maximum contaminant concentration (See Table 1).

Figure 4: Sultan Ismail Mosque in Universiti Teknologi Malaysia

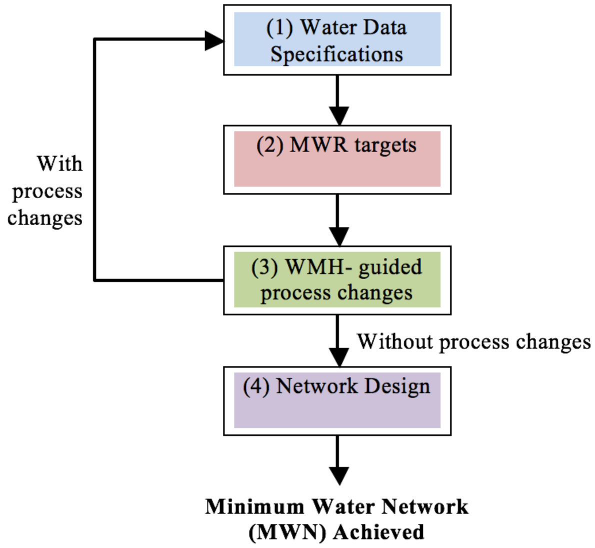

Figure 5: A holistic framework for design of a minimum water network [8].

Table 1: Limiting water data for mosque case study [8].

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

PERINTIS E-Journal, **2015**, Vol. 5, No. 2, pp. 31-45

Next, the MWR targets are established using a water benchmarking technique called the Water Cascade Analysis (WCA) [9] in step 2. The *water cascade table* (Table 2) shows that at least 16.5 t/day fresh water is required and a maximum of 13.0 t/day wastewater is 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.

After targeting to maximise water reuse, various water management options were systematically and quantitatively explored in line with the WMH to ultimately achieve the minimum water targets. It is possible to quantify the maximum potential water savings and ultimately generate the minimum water network by observing some fundamental water-pinching rules involving process changes, and by prioritising all possible process changes options according to the WMH [4]. In order to evaluate the effect of a process change option on the MWR targets, steps 1 and 2 were repeated each time an option is proposed. For example, changing from a conventional flushing toilet to a waterless vacuum toilet will affect the water source and demand data (Step 1), and will require the MWR targets to be recalculated (Step 2). Figure 6 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 prio*r 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 various design heuristics for the design of the minimum water networks [10-12]. The flow diagram for the final SIM water network is shown in Figure 7.

PERINTIS E-Journal, **2015**, Vol. 5, No. 2, pp. 31-45

Table 2. Water Cascade Table (WCT) for SIM case study [8].

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} =16.5	
	0	1.000000	-0.03		-0.03		
1						16.4	
	10	0.999990	-29.07	0	-29.07		0.000164
2						-12.6	
	23	0.999977		25.17	25.17		**0 (Pinch)**
3						12.5	
	216	0.999784		0.14	0.14		0.002418
4						12.7	
	472	0.999528		0.29	0.29		0.005662
5						13.0	
	536	0.999464		0.03	0.03		0.006492
6						**F_{WW} =13.0**	

WMH levels	Specific process changes considered	New FW target, t/day	New pinch point concentration, ppm
Reuse		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
= **Minimum water network**			

Figure 6: The effects of WMH-guided process changes on the MWR targets and pinch location [8].

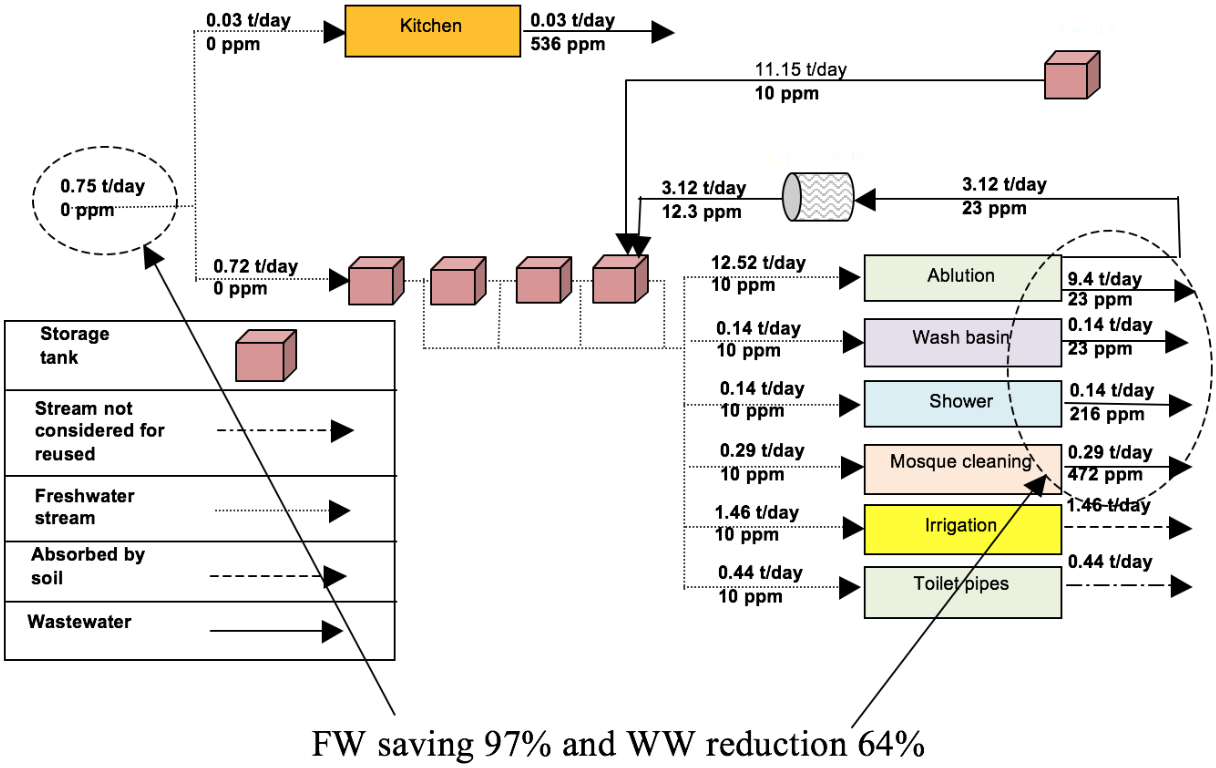

Figure 7: Flow diagram for SIM water network (Freshwater savings: 97%, and Wastewater reductions: 64%) [8].

5.0 CONCLUSION

A systems approach for holistic water conservation that employs the WMH is a practical strategy for water minimisation in urban systems because educating to change public attitudes is not expected to result in a high degree of domestic water saving. Maximising water reuse and recovery using traditional WPA solution yielded 43.4% freshwater and 19.3% wastewater reductions (see Table 2). Selective application of the WMH options, namely outsourcing and regeneration by Manan et al. [13] managed to significantly extend the reductions to 85.5% freshwater and 67.7% wastewater. The limits on water savings were ultimately stretched when all options for water management were systematically and quantitatively explored using the holistic framework for cost-effective minimum water network (MWN) design. Application of the holistic water minimisation framework yielded 97.4% potential reductions of freshwater and 64.5% wastewater [8]. Table 3 shows the freshwater and wastewater reduction potentials predicted by the three approaches 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. The holistic water minimisation strategies has also been applied to a semi-conductor plant to give and estimated 85.2 % freshwater savings and 97.9% wastewater reduction [5] and a chlor-alkali plant with 35.8% fresh water and 100% wastewater reduction [14]. The method has also been applied for batch processes with minimum storage capacity and inter-connections such as a mosque [15]. Recent works have seen the application of the same WMH concept adapted to become the Carbon Management Hierarchy (CMH) for carbon reductions in buildings [16] and industries [17-18].

Table 3. Freshwater and wastewater reductions for MWR network, conventional water network and MWN [8].

	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%

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