ACHIEVING WATER SUSTAINABILITY via *HOLISTIC* WATER MINIMISATION

Zainuddin A. Manan

Process Systems Engineering Centre, Research Institute on Sustainable Environment (RISE), Universiti Teknologi Malaysia

10th Conference on Sustainable Development of Energy, Water and Environment Systems

September 27 - October 3, 2015, Dubrovnik, Croatia

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UNIVERSITI TEKNOLOGI MALAYSIA

PROSPECT
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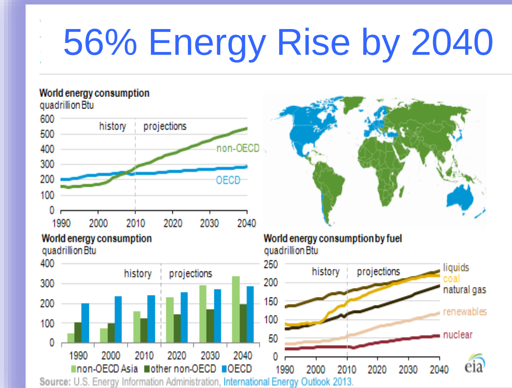
“Water shortage is one of highest global risks!”

WEF Global Risk Report, 2014

W3E Nexus



Environment

Water Shortage

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"By 2030, the world is projected to face a 40% global water deficit under the business-as-usual climate scenario"

UN WATER Report

The United Nations World Water Development Report 2015

What Can We Do?

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Content

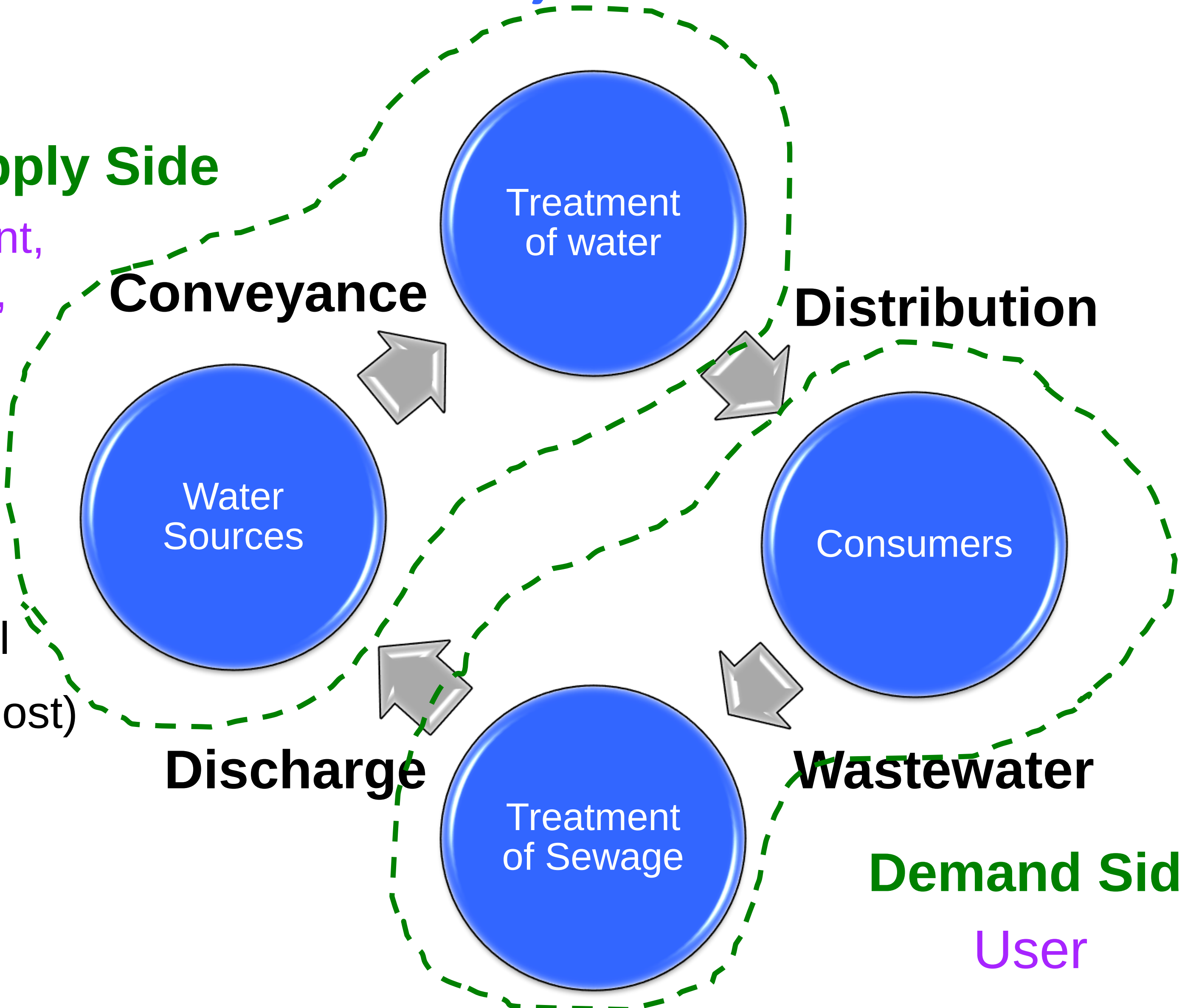
- ❑ The *W3E** Nexus ✓
- ❑ Achieving Water Sustainability :
  - ✧ Piece-meal vs Holistic Strategy
  - ✧ The Systems Approach
- ❑ Public Service Broadcast *(time permitting)*
- ❑ Take Home Messages

** Water, Energy, Environment & Economy*

Water value chain, *W3E Nexus*

Supply Side

Government,
Authority,



Demand Side

User

3 Es

1. **E**nergy
2. **E**nvironmental
3. **E**conomics (Cost)

- Energy
- Raw Water
- Chemicals
- Capital

User Take Charge

Industry*;
Public & Commercial Facilities;
Domestic & Individuals

Change Behavior!

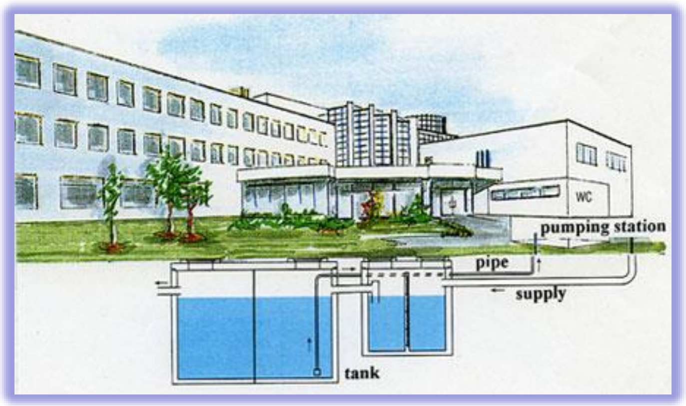
Engineer Sustainable Water Systems!

*Include agriculture

Some Typical Solutions?

Water treatment system – Self generation of fresh water?

Bigger WW Treatment Plants?



Rainwater Harvesting System?

Water-Efficient Gadgets?

Greener, and holistic ways?

Apply W3E!

1. Not to use?
2. Use less?
3. "Best-mix" options?

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Showcase Project

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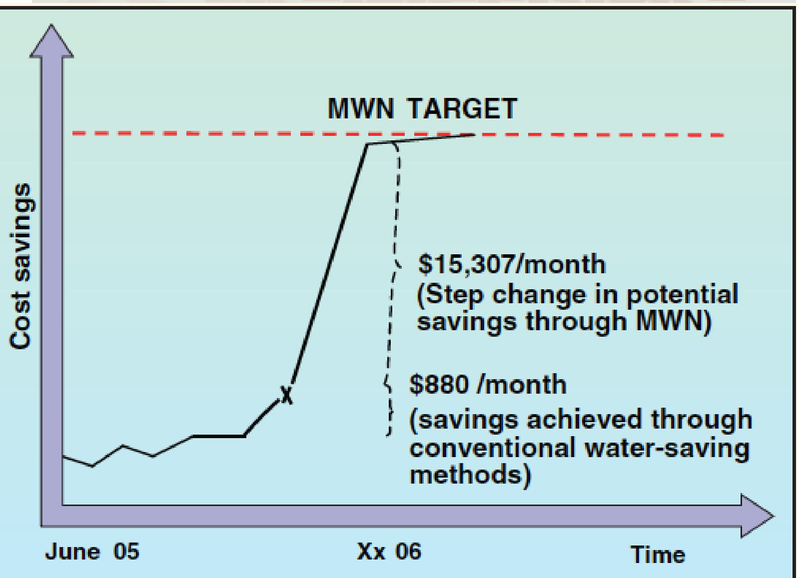
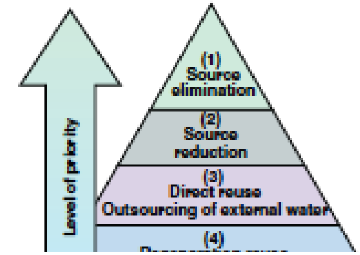
MIMOS

CHEMICAL ENGINEERING



Assess Your Plant's True Water-Savings Potential

Using the minimum water network involves detailed analysis of plant configuration and design, material and energy balances, design and thermodynamic constraints



A CASE STUDY: SETTING TARGETS FOR MINIMUM WATER NETWORK IN A SEMICONDUCTOR FABRICATION PLANT

Water is a major utility for many sectors of the chemical process industries, but for semiconductor manufacturers, it is also a precious commodity. The extreme water demands of a semiconductor fabrication plant — from the ultrapure water required for chipmaking processes to potable water and, increasingly, recycled water for plant operations and maintenance — provide an ideal case study for the application of MWN benchmarking techniques.

In this case, the facility is MySem, **a semiconductor fabrication** plan in Malaysia. ; While the facility's primary activity is research and development (R&D), **it produces 6-in. and 8-in. wafers. Figures 3** and **4** show the fab's water distribution network. Water demands include deionized (DI) process water for **solvent processes**, acid processes, wet cleaning and tools cleaning; the rest is for **plant operations such as abatement, scrubber, cooling tower** and wet bench cooling, and maintenance such as toilet flushing, office cleaning, wash basin, toilet pipes and ablution, as shown in **Figure 5**.

Total water consumption varied throughout the year, depending on wafer production and equipment conditions. During the month of the benchmarking study, the fab's estimated total freshwater consumption was 42.6 m^3/h. Of this value, 31.78 m^3/h was used for DI water production and the rest for plant operations and maintenance.

Step 1. Specify the limiting water data

This step involved detailed process survey and line tracing, establishing process stream material balances and conducting water quality tests. Stream flowrates were extracted from data collected by either the plant's distributed control system (DCS) or ultrasonic flowmeters. Depending on the stream audited, tests for total suspended solids (TSS), biological oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS) were conducted onsite. For processes that only used ultrapure water, TSS levels were negligible. BOD was absent since no biological contaminants were present. COD was a component of TDS. TDS

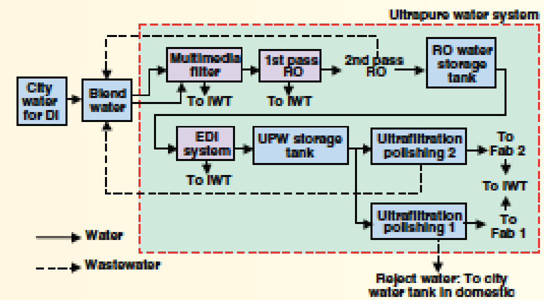


FIGURE 3. Process flow diagram for the ultrapure water system

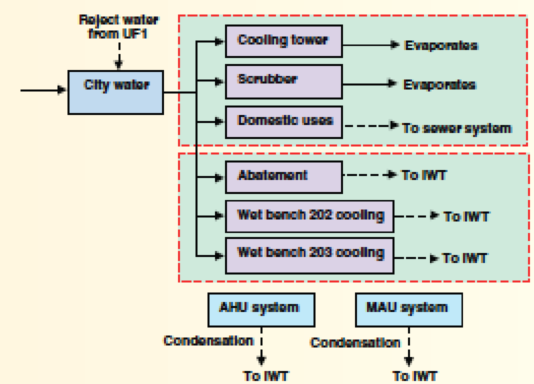
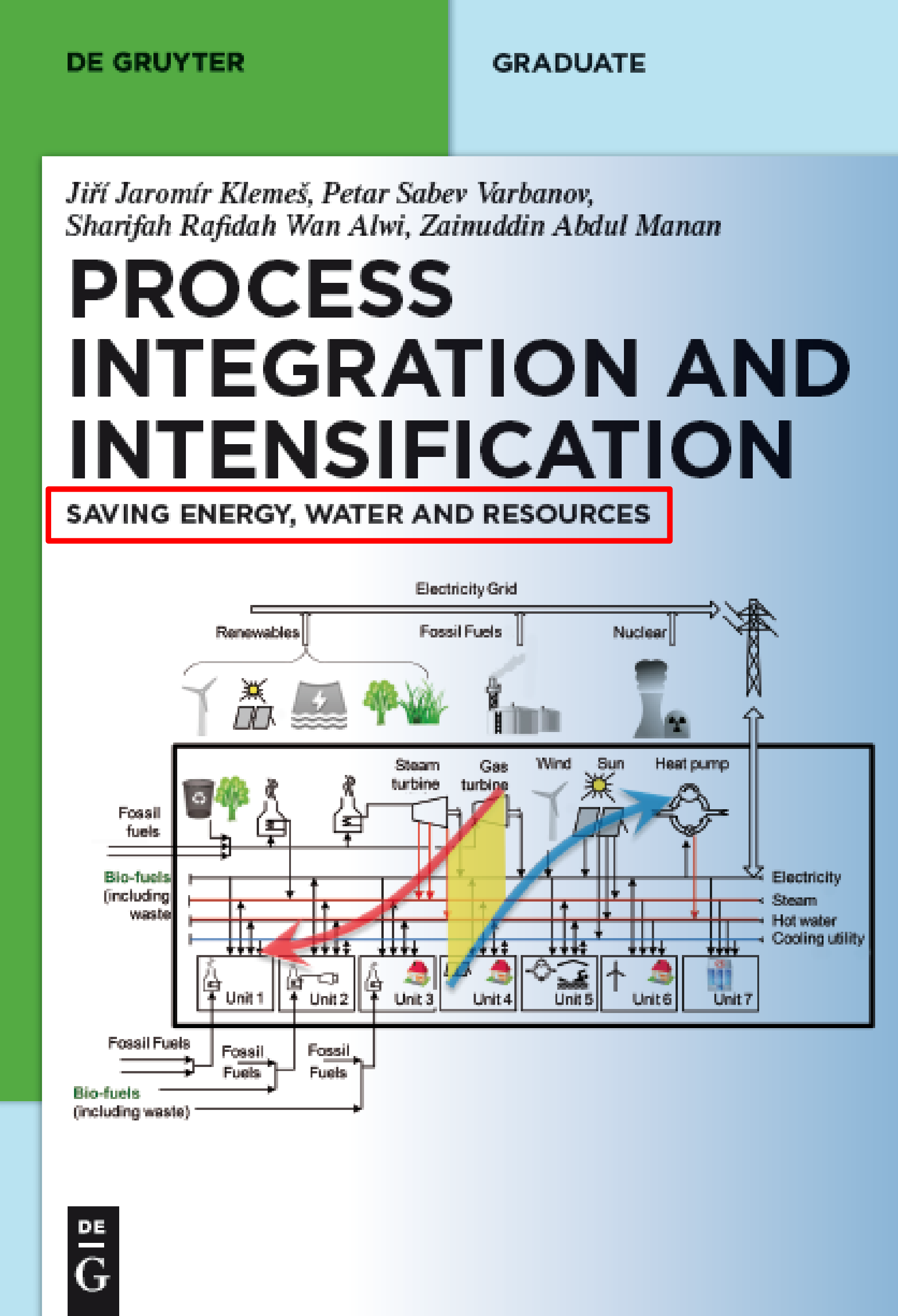
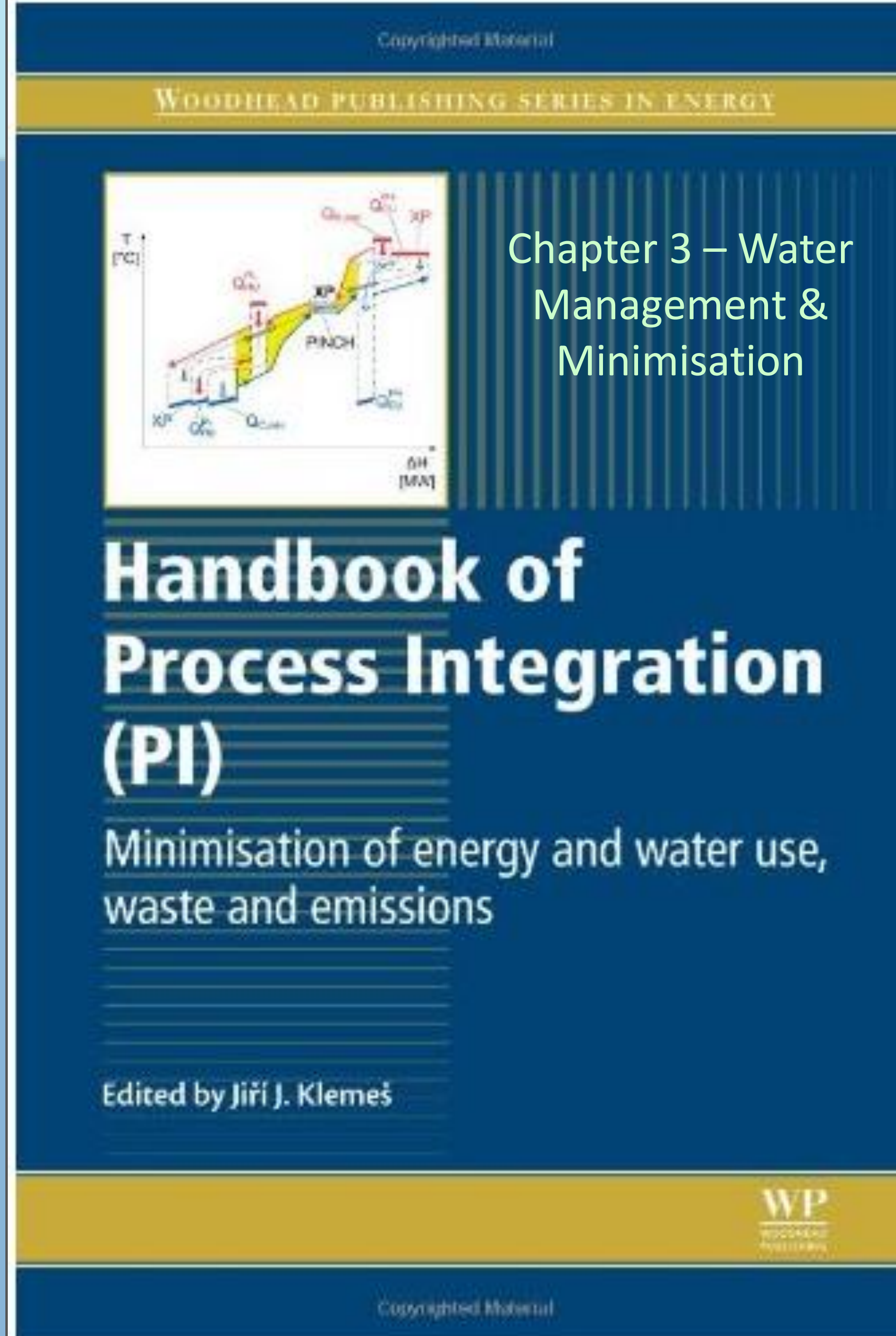


FIGURE 4. Water uses for plant operations and maintenance





Chapter 3 – Water Management & Minimisation

The Water Management Hierarchy (WMH)


RESEARCH & DEVELOPMENT

A new look at urban water saving

Cost cutting nitrate r... process

Manan, Wan Alwi & Ujang, Water21 Feb 2006

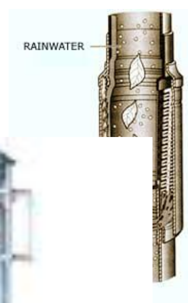

Dual flush toilet


Composting toilet

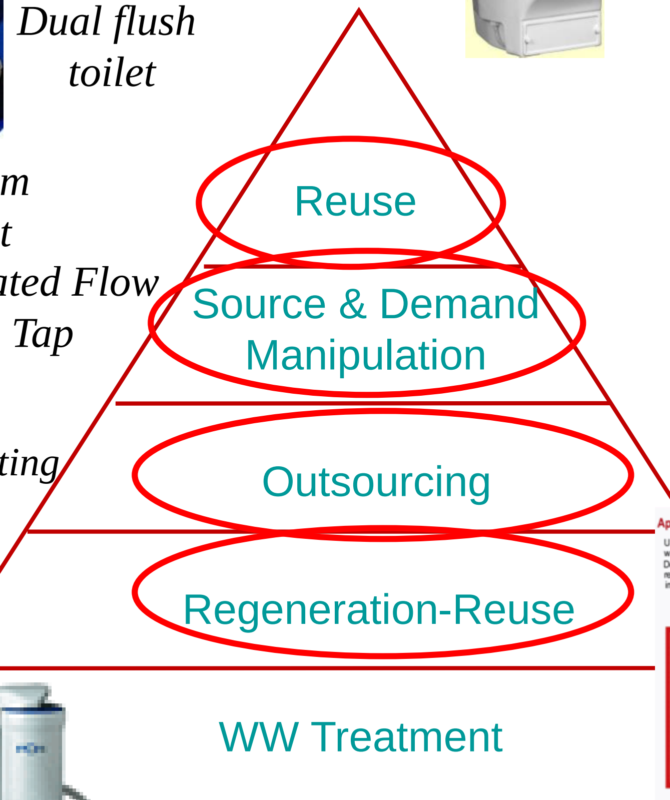

Normal electrical fan


Vacuum toilet


Aerated Flow Tap



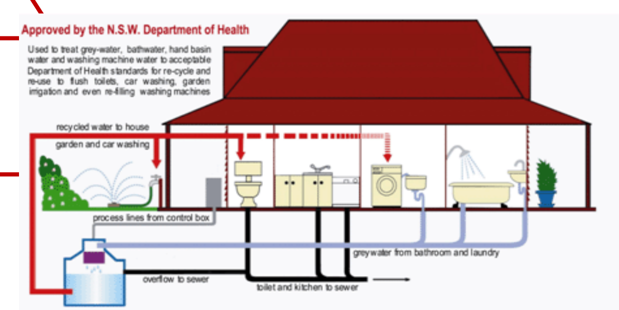
RW Harvesting



Increase priority


Sand filter with activated carbon


Microfiltration



What has been done so far?

Summary of State-of-the-Art on WM Research

Key Topics	**WPA**	**Mathematical Programming**
Network design	√	√
Minimum water targeting & Design for 3R	√	√
Process changes	*Highlighted here*	*Highlighted here*
Minimum water network	*Highlighted here*	*Highlighted here*
Holistic water minimisation options	*Highlighted here*	*Highlighted here*
Pure and impure fresh water feed	√	√
Cost estimation involve 3R	√	√
Batch Processes, Simultaneous Water & Energy	√	√
Inter-Plant Water Integration	X	√

Research Gap on Mathematical Programming Technique

Minimum Water Targeting

Gap: only consider water reuse, recycle and regeneration

Process Changes

Gap: does not consider source elimination, reduction and outsourcing

Preliminary cost estimation

Gap: does not include all water minimisation schemes in cost estimation

Rigorous Solution

*Handandani, Z.B., Wan Alwi, S.R., Hashim, H., **Z.A. Manan**, Holistic Approach For Design Of Minimum Water Networks Using The Mixed Integer Linear Programming (MILP) Technique, Industrial and Engineering Chemistry Research, Volume 49, Issue 12, 16 June 2010, Pages 5742-5751.*

Problem Statement

Given a set of global water operations for various water sources and demands containing multiple contaminants, it is desired to design an optimal and holistic water network with maximum net annual savings that considers all water management hierarchy options to achieve desired payback period for retrofit design using mathematical programming approach

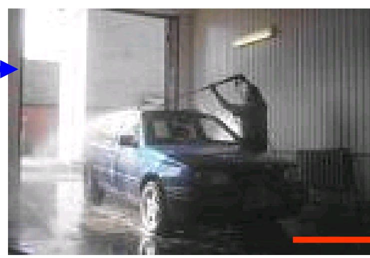
Water Sources and Demands

Water source
(output)

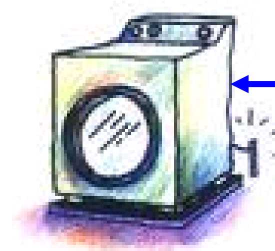
Water demand
(input)

Water demand
(input)

Water demand
(input)

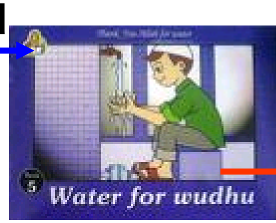


Water source
(output)

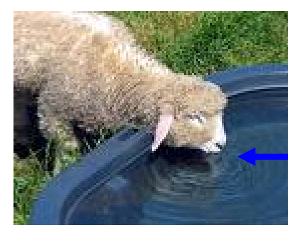


Water demand
(input)

Water demand
(input)



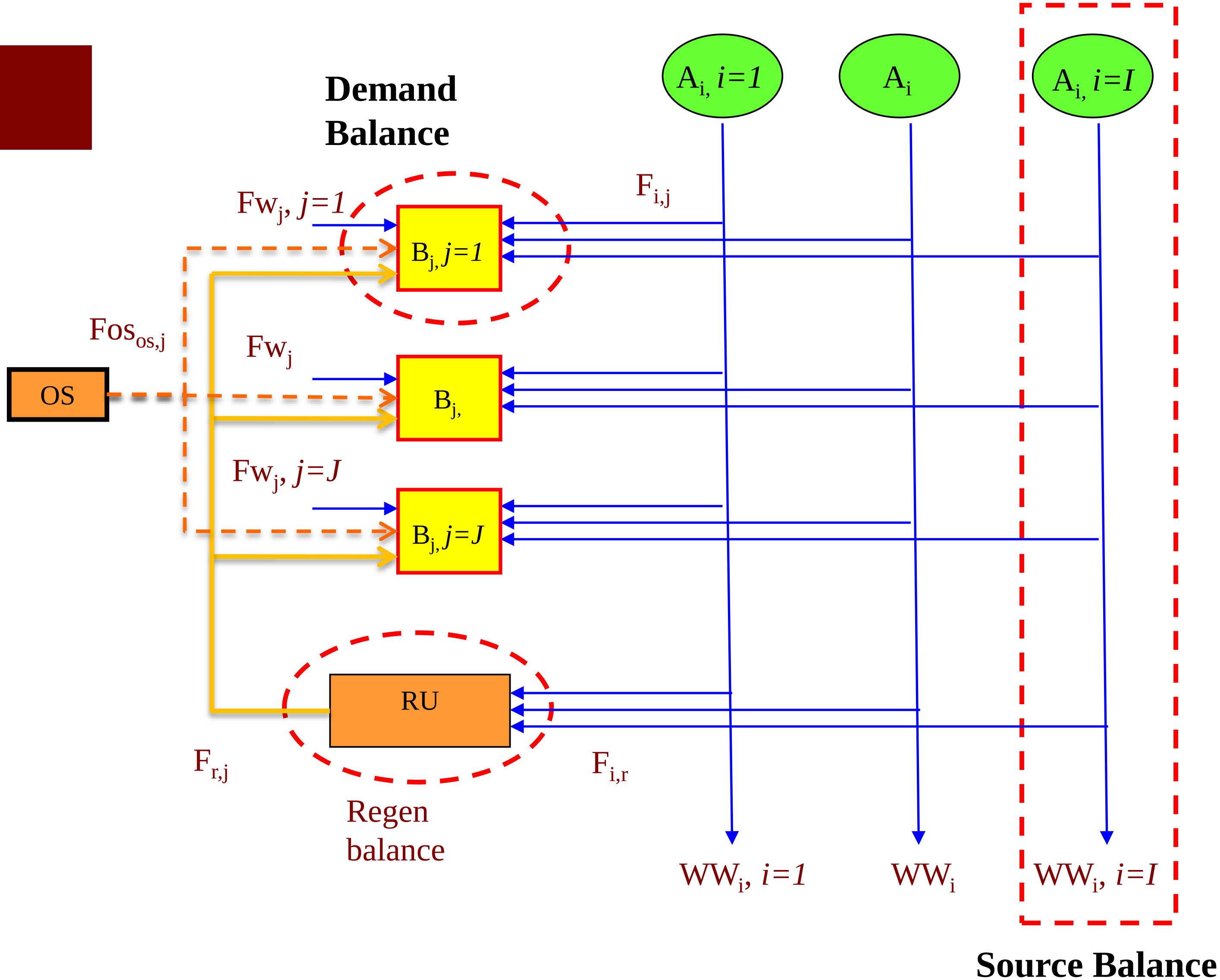
Water source
(output)



Water demand
(input)

Methodology

Step	Description
Step 1: Limiting water data extraction	consists of limiting contaminant data and flow rate for all water sources and demands available in the system
Step 2: Superstructure representation	Represents every possible connection in the water system
Step 3: Mathematical formulation	Developed mathematical model correspond to the superstructure
Step 4: GAMS coding	Code and Run in GAMS to find optimal results
Step 5: Results analysis	Analyse results
Step 6: Sensitivity analysis	to evaluate how sensitive the models to the optimal results



Superstructure for MWR network that includes outsourcing and regeneration options.

FW_j = Freshwater supplied to demand *j*
B_j = Adjusted flowrate of water demand *j*
A_i = Adjusted flowrate of water source *i*
WW_i = Flowrate of wastewater
$F_{i,j}$ = Flowrate of water from source *i* to demand *j*
$F_{i,r}$ = Flowrate of water from source *i* to regeneration unit *r*
$F_{r,j}$ = Flowrate of water from regeneration unit *r* to demand *j*
$Fos_{os,j}$ = Flowrate of water from outsource *os* to demand *j*

*Handani, Z.B., Wan Alwi, S.R., Hashim, H., **Manan, Z.A.**, Holistic Approach For Design Of Minimum Water Networks Using The Mixed Integer Linear Programming (MILP) Technique, Industrial and Engineering Chemistry Research, Volume 49, Issue 12, 16 June 2010, Pages 5742-5751.*

Objective function: MAXIMISE NET ANNUAL SAVINGS

Freshwater savings

Wastewater savings

Chemical savings

$$
\text{Max NAS} = \left[\begin{array}{l}
\sum_{j} \left(FW_{j}^{initial} - FW_{j} \right) CostFW + \sum_{i} \left(WW_{i}^{initial} - WW_{i} \right) CostWW \\
+ \sum_{i} \sum_{r} \left(F_{i,r}^{initial} - F_{i,r} \right) CostChemReg \\
+ \sum_{i} \left(WW_{i}^{initial} - WW_{i} \right) CostElecPOPump \\
+ \sum_{j} \left(FW_{j}^{initial} - FW_{j} \right) CostElecPOPump \\
+ \sum_{i} \sum_{j} \left(F_{i,j}^{initial} - F_{i,j} \right) CostElecPOPump \\
+ \sum_{j} \left(Fos_{os,j}^{initial} - Fos_{os,j} \right) CostElecPOPump \\
+ \sum_{i} \sum_{r} \left(F_{i,r}^{initial} - F_{i,r} \right) CostElecPOPump \\
+ \sum_{r} \sum_{j} \left(F_{r,j}^{initial} - F_{r,j} \right) CostElecPOPump
\end{array} \right] * AOT
$$

Energy savings

AOT: Annual operating time

Subject to :
- ➢ Constraint in STAGE 1
- ➢ Additional Constraints

✓ Total capital cost involving:
- Capital investment for external water sources unit
- Capital investment for regeneration unit
- Capital investment for reuse system
- Capital investment for elimination unit
- Capital investment for reduction unit

✓ Payback period constraint

MINLP: - capital cost is a function of the flow rate and calculated using sixth-tenth factor rule
- selection of water minimisation schemes

*Z. Bahiyah, S. R. Wan Alwi, H. Hashim, and **Z. A. Manan**, "Optimal Design Of Water Networks Involving Multiple Contaminants For Global Water Operations", Ind Eng Res and Design, 2010, 49, 5742-5751.*

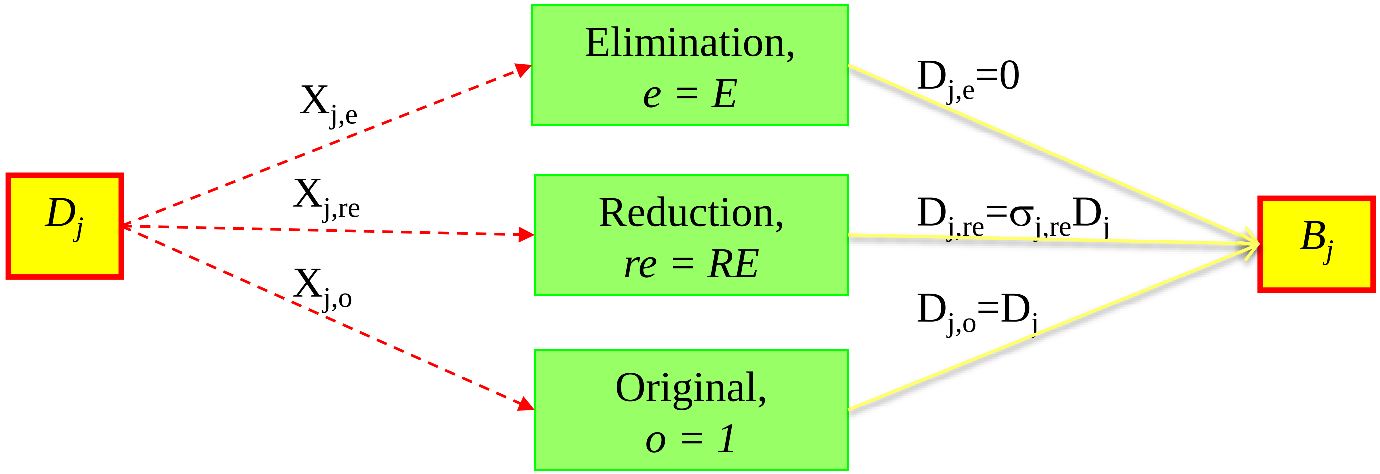
Payback period constraint

$$\frac{\text{Net Capital Investment (NCI)}}{\text{Net Annual Savings (NAS)}} \le \text{payback period}$$

$$\frac{\underbrace{CRegU}_{\text{Regeneration unit cost}} + \underbrace{COsU}_{\text{External water sources unit cost}} + \underbrace{CReuse}_{\text{Reuse system cost}} + \underbrace{\sum_{j}\sum_{e} X_{j,e}\,CostUE_{j,e}\,\varepsilon_j}_{\text{capital cost for elimination unit}} + \underbrace{\sum_{j}\sum_{re} X_{j,re}\,CostURe_{j,re}\,\varepsilon_j}_{\text{capital cost for reduction unit}}}{\left[\begin{array}{l} \sum_{j}\left(FW_j^{initial} - FW_j\right)CostFW + \sum_{i}\left(WW_i^{initial} - WW_i\right)CostWW \\ + \sum_{i}\sum_{r}\left(F_{i,r}^{initial} - F_{i,r}\right)CostChemReg \\ + \sum_{i}\left(WW_i^{initial} - WW_i\right)CostElecPOPump \\ + \sum_{j}\left(FW_j^{initial} - FW_j\right)CostElecPOPump \\ + \sum_{i}\sum_{j}\left(F_{i,j}^{initial} - F_{i,j}\right)CostElecPOPump \\ + \sum_{j}\left(Fos_{os,j}^{initial} - Fos_{os,j}\right)CostElecPOPump \\ + \sum_{i}\sum_{r}\left(F_{i,r}^{initial} - F_{i,r}\right)CostElecPOPump \\ + \sum_{r}\sum_{j}\left(F_{r,j}^{initial} - F_{r,j}\right)CostElecPOPump \end{array}\right] * AOT} \le \text{payback period}$$

Engineering Sustainable Water System, Holistically

Water network superstructure to obtain the adjusted demand flow rate, B_j when possible source elimination and reduction are considered.



✓$X_{j,e}$, $X_{j,re}$, $X_{j,o}$: BINARY/SELECTION VARIABLES

$\sigma_{j,re}$: Percentage of fresh water reduction

*Z. Bahiyah, S. R. Wan Alwi, H. Hashim, and **Z. A. Manan**, Optimal Design Of Water Networks Involving Multiple Contaminants For Global Water Operations, Ind Eng Res and Design, 2010, 49, 5742-5751.*

Issues

User interactions

Insights

Managing complexity

A new look at urban water saving

The Sultan Ismail Mosque, where the potential for saving water using water pinch analysis is being assessed.

Researchers at Universiti Teknologi, Malaysia, have described an approach to adapting an important industrial water minimisation technique for use in urban water systems.

The authors see the approach, water pinch analysis (WPA), as the most significant development in water minimisation design in the last ten years. Until now it has been applied only to industrial water networks. This work shows how the approach can be used in conjunction with a simple five-level water management hierarchy (the ZM water management hierarchy) to minimise water use in the urban setting and considers, as an example, the water system of the Sultan Ismail Mosque in Universiti Teknologi Malaysia (UTM).

Use of a conservation strategy such as the ZM hierarchy is seen as a more practical approach for urban systems where, as the authors say, educating to change public attitudes has not so far resulted in a high degree of domestic water saving.

The ZM hierarchy's five levels of options for water management range from the most preferred – source elimination (1) – to the least preferred – discharge after treatment (5). Levels 2 to 4 relate to source reduction, direct reuse and reclamation. Possibilities for minimisation are concerned with levels 1 to 4.

If eliminating or reducing water intake at source (1 or 2) is not possible, recycling comes into the picture, either as direct reuse (3) or reclamation (4). For these purposes direct reuse means a subsequent use without intervening treatment, as in hand basin water used to flush toilets. Reclamation implies intermediate treatment and is divided into regeneration-recycling where the reclaimed water is used in the same equipment or process after treatment. Regeneration-reuse is defined as reuse of treated water in other equipment after treatment.

Maximum water recovery within a system is achieved by making best use of the inherent reuse and regeneration-reuse opportunities. The systematic approach of WPA allows that goal to be achieved by integrating the various water use activities in the system. In the case of the mosque there were eight primary demands for water (kitchen, showers, toilets etc). With recycling there are six possible sources of water within the system - harvested rainwater together with used water from the kitchen, ablutions, wash basins, showers and mosque cleaning.

Following the first step of a system water audit, WPA goes on to identify these primary demands and possibilities for integration as a basis for the vital third step of establishing the minimum water and wastewater targets for the system. Here the UTM team developed a new technique that they call water cascade analysis (WCA), a numerical water targeting method that eliminates the time-consuming trial and error steps of a currently used graphical approach.

In this example WCA established a target fresh water requirement of 10.16tonnes/day as against a current daily demand of 29.1tonnes, giving a potential saving of 65.1%. The corresponding target for wastewater discharge showed a reduction of 51.5%. These figures were assessed as achievable with recycling but without any regeneration and can, of course, only be realised when the system is re-designed to incorporate the necessary water recovery features – the vital fourth step of pinch analysis. The final step considers the suggested process changes and evaluates the economics of any retrofit. If regeneration was considered the freshwater and wastewater reductions could be increased to 85.5% and 67.7% respectively.

With or without regeneration the savings were shown to be far in excess of those presented through a more conventional system analysis by another group at the university.

In the view of the authors the central advantage of the WPA approach is that it provides a true baseline target for the system. At present the engineer can only seek for an improvement based on a previous design achievement, in effect improving gradually on a learning curve always based on an apparent baseline target. He does not know what is the ultimate minimum water requirement for the network. ●

Based on a paper, Water pinch analysis for urban systems: a paradigm shift for water minimisation, provided by Z. A. Manan (zain@fkkksa.utm.my), S. R. Wan Alwi and Z. Ujang, Chemical Engineering Department, Universiti Teknologi Malaysia, Johor, Malaysia.

Cost cutting nitrate removal process

Global chemical group BASF has donated its patent for a novel nitrate removal process to America's Water Environment Research Foundation.

The process, called the Timeswitch method, allows nitrate removal, through nitrification and denitrification, to be achieved in a single reactor vessel rather than in separate aerobic and anoxic tanks which had previously been regarded as essential. Capital costs of constructing an additional tank in an existing plant can therefore be avoided when, as frequently happens now, nitrate becomes a critical factor in effluent discharge.

According to WERF, nitrogen control is one of North America's most significant environmental water quality issues. Nitrogen discharges are the primary cause of water quality and environmental problems in the Gulf of Mexico, Chesapeake Bay, the Outer Banks of North Carolina and other regions.

For BASF nitrate was a problem in the effluent output from the company's Freeport, Texas, manufacturing site. The site treatment plant had to be modified to address the problem. BASF's wastewater experts at Freeport and others from BASF locations in the United States and Germay jointly developed the Timeswitch technology using computer simulations and pilot plant testing. BASF did not implement the process, but has retained rights to practice the technology under the donation agreement with WERF.

The donation was made at a ceremony in Washington, D.C. on 16 December and was warmly welcomed by WERF Executive Director, Glenn Reinhardt. He said: 'We are very appreciative of BASF's donation and excited about the cooperation with BASF on a project that may be quite useful in adding to the available nitrogen removal methods.'

Contact: Jack Maurer, BASF. Email: maurerj1@basf.com

Making Sense of the WM Methodology

Lets Try Again..

Manan, Z. A., Wan Alwi, S. R. and Ujang, Z. Water Minimisation for Urban Systems: A Case Study on Sultan Ismail Mosque in Universiti Teknologi Malaysia, *Desalination Journal* Vol. 194 (2006) 52-68

Methodology

- **Step 1: Limiting water data extraction** – consists of limiting contaminant data and flow rate for all water sources and demands available in the system
- **Step 2: Superstructure representation** – Represents every possible connection in the water system
- **Step 3: Mathematical formulation** – Developed mathematical model correspond to the superstructure
- **Step 4: GAMS coding** – Coded into GAMS to find optimal results
- **Step 5: Results analysis** – Analysed the results
- **Step 6: Sensitivity analysis** – to evaluate how sensitive the models to the optimal results

Illustrative Case Study: Domestic Water Mimisation

Source Process Number	Cum F t/hr	Cum m t/hr	Demand Process Number	Cum F t/hr	Cum m t/hr
Abultion	20	2	**Abultion**	20	0
Bathing	120	12	**Bathing**	120	5
Washing car	160	44	**Washing car**	160	7
			Flushing toilet	170	11

Key parameters: Flowrate and Mass load

__Z. A. Manan__ and S. R. Wan Alwi, Water Pinch Analysis Evolution Towards a Holistic Approach for Water Minimisation, Asia-Pac. J. Chem. Eng., Volume 2, Issue 6, Pages 544 – 553, 2007.

Methodology

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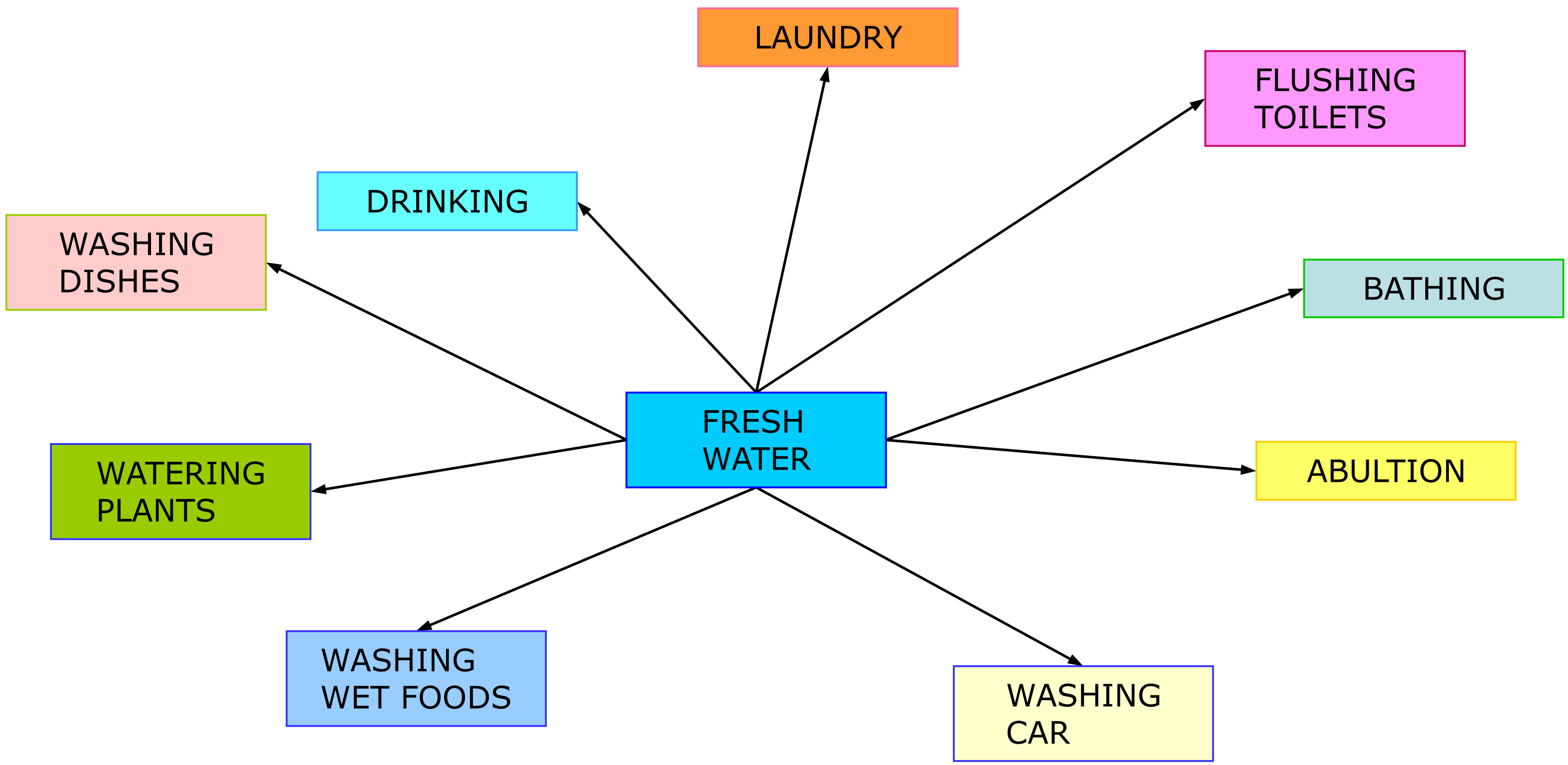
Base Case

[Down-to-earth WM Case]

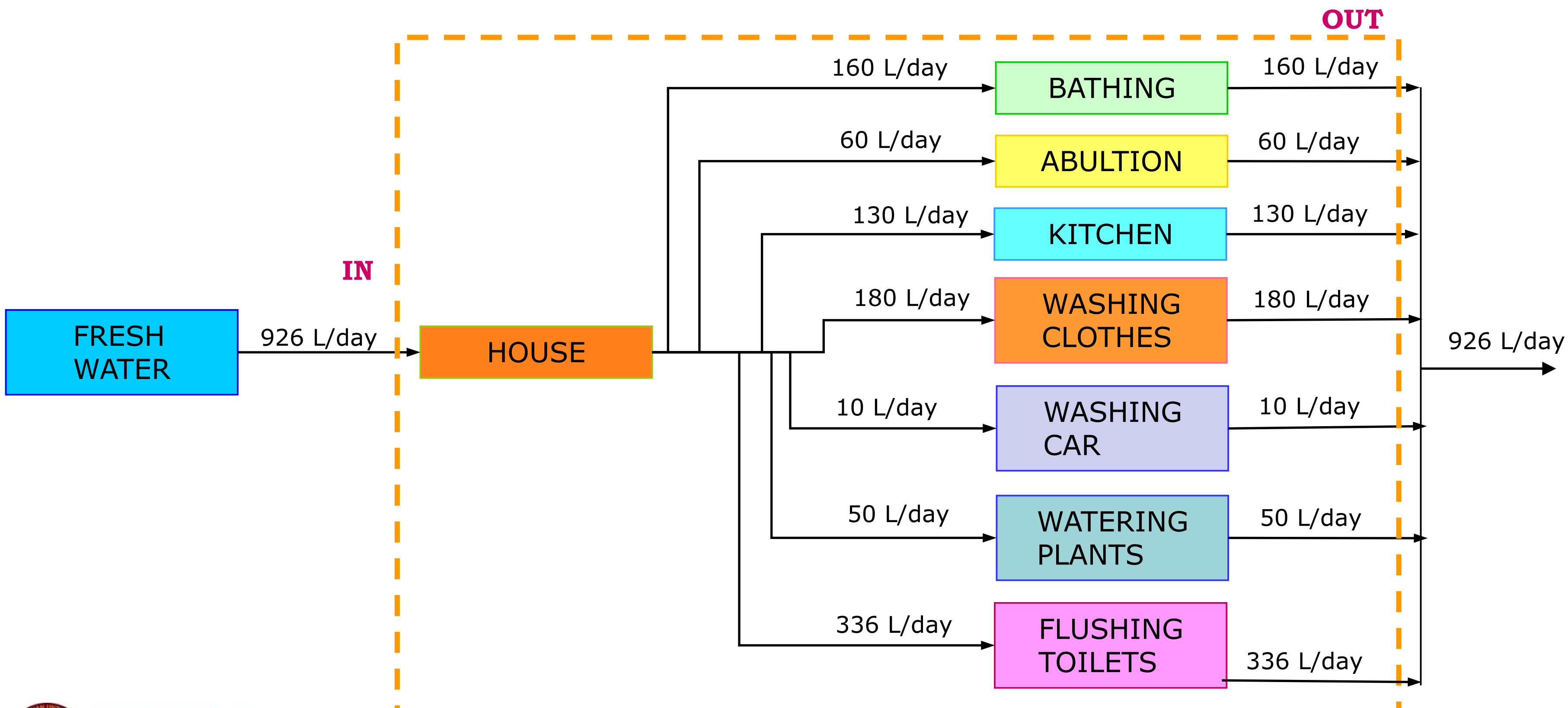
Household Water Uses



Water Audit (Quantitative)

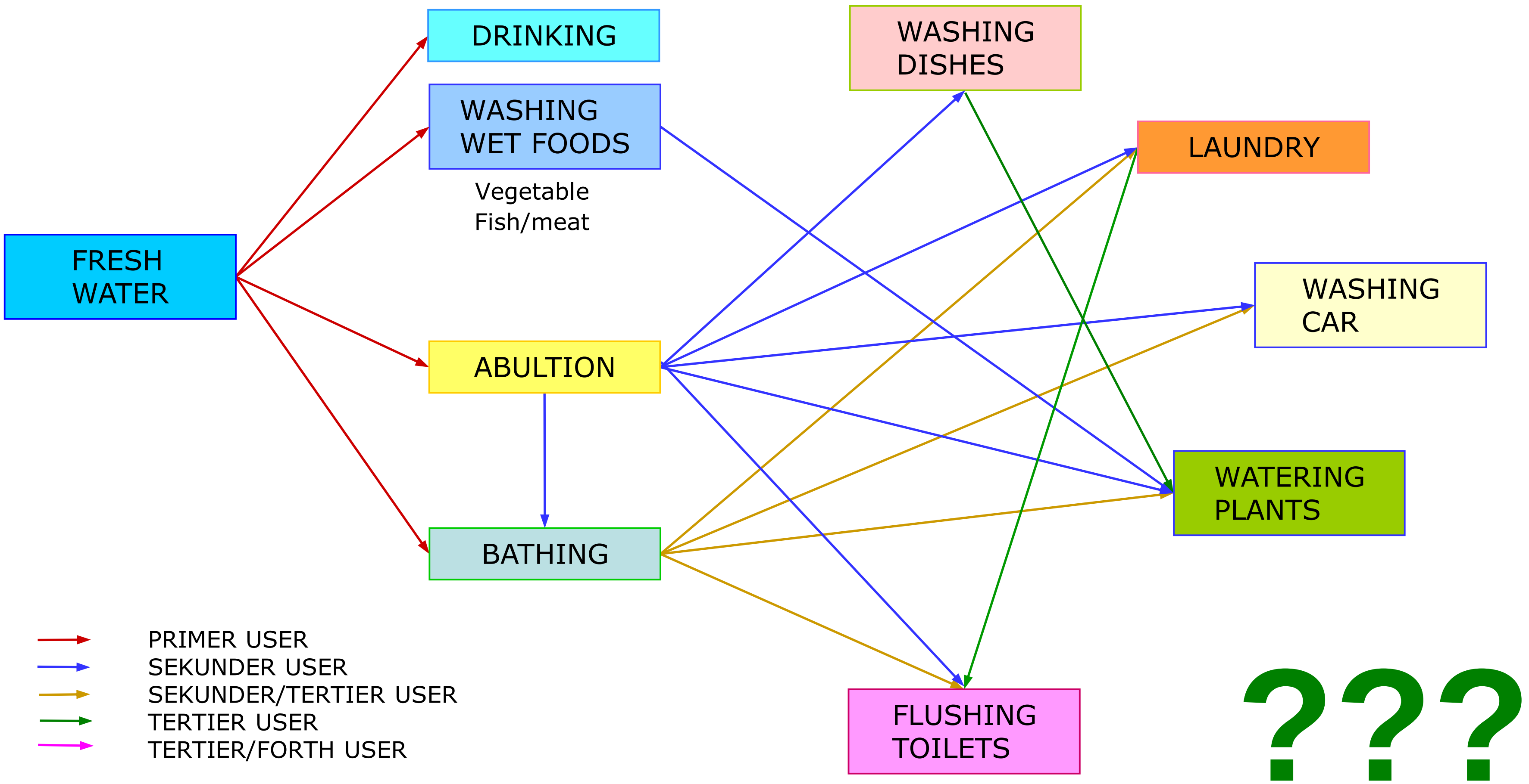
For a sample house:

ACTIVITIES	WATER(L/Day)
BATHING	160
ABULTION	60
KITCHEN	130
WASHING CLOTHES	180
WASHING CAR	10
WATERING PLANTS	50
FLUSHING TOILETS	336



“Superstructure”

Network of Water Reuse Options



Which are the best reuse matches?
How many blending options possible? Water ratios?
How do we ensure contaminants do not affect processes?

Methodology

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Problem Decomposition

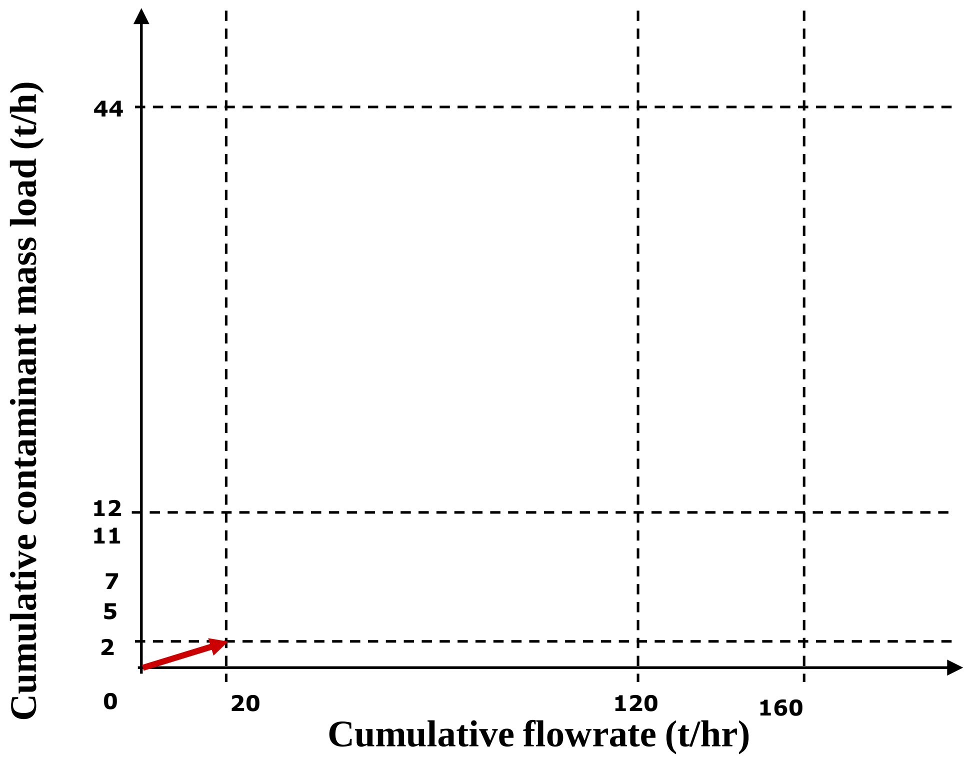
[Step-Wise Approach]

Break into manageable parts

Targeting

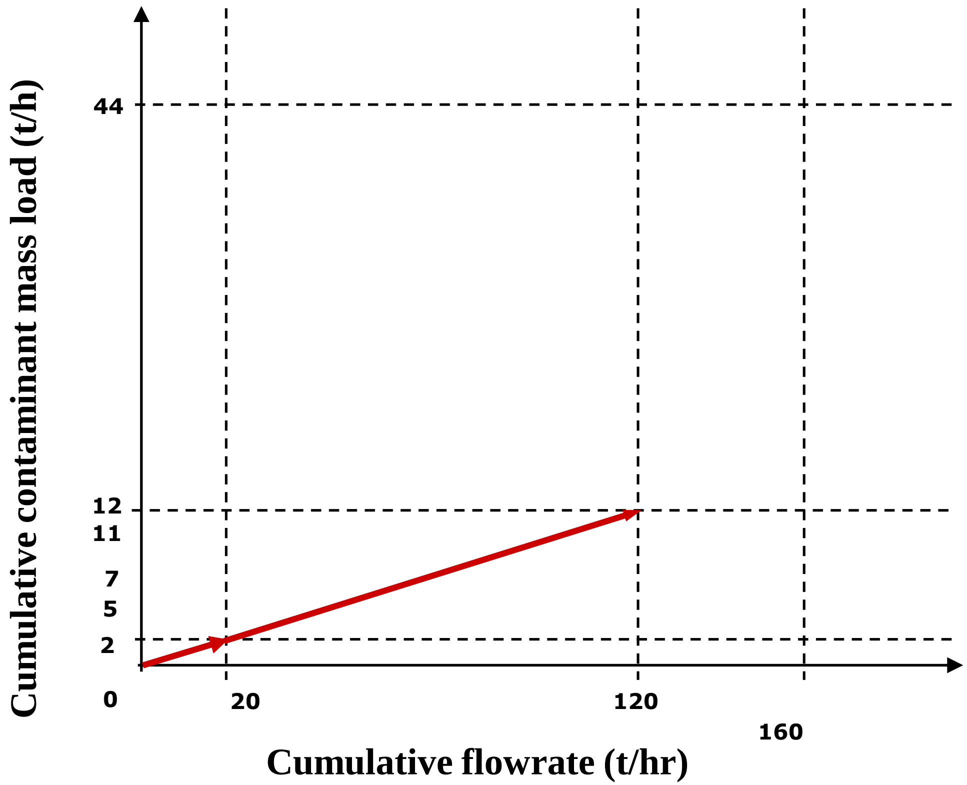
Source 1: Ablution

Source Process Number	Cum F	Cum m
	0	0
Abultion	20	2



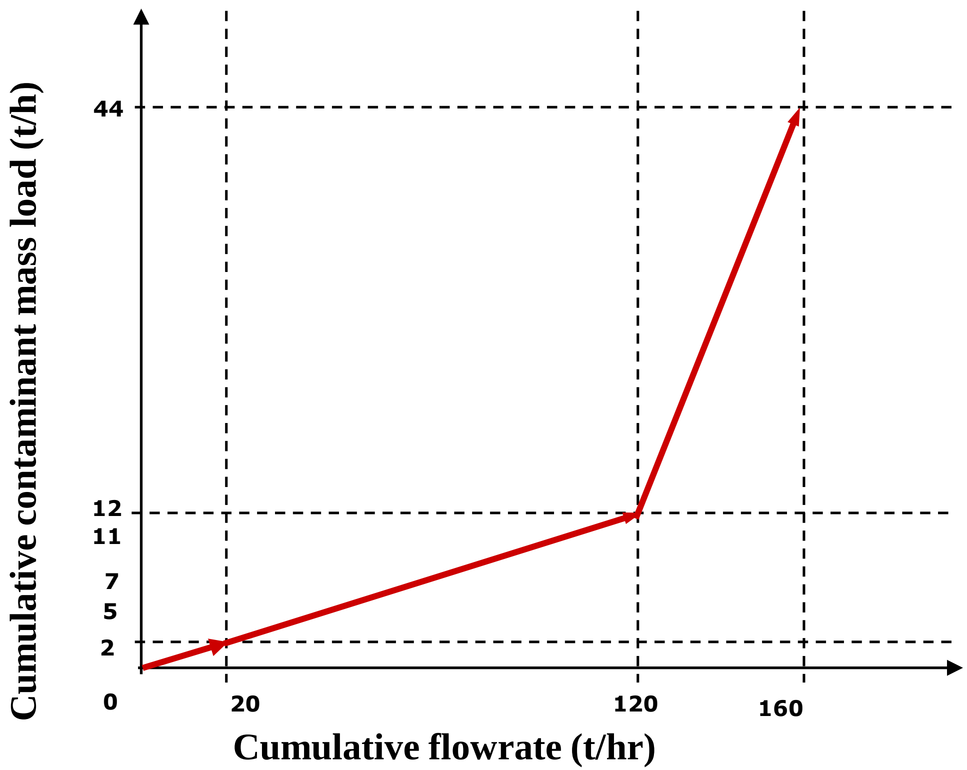
Source 2: Bathing

Source Process Number	Cum F	Cum m
	0	0
Abultion	20	2
Bathing	120	12



Source 3: Washing car

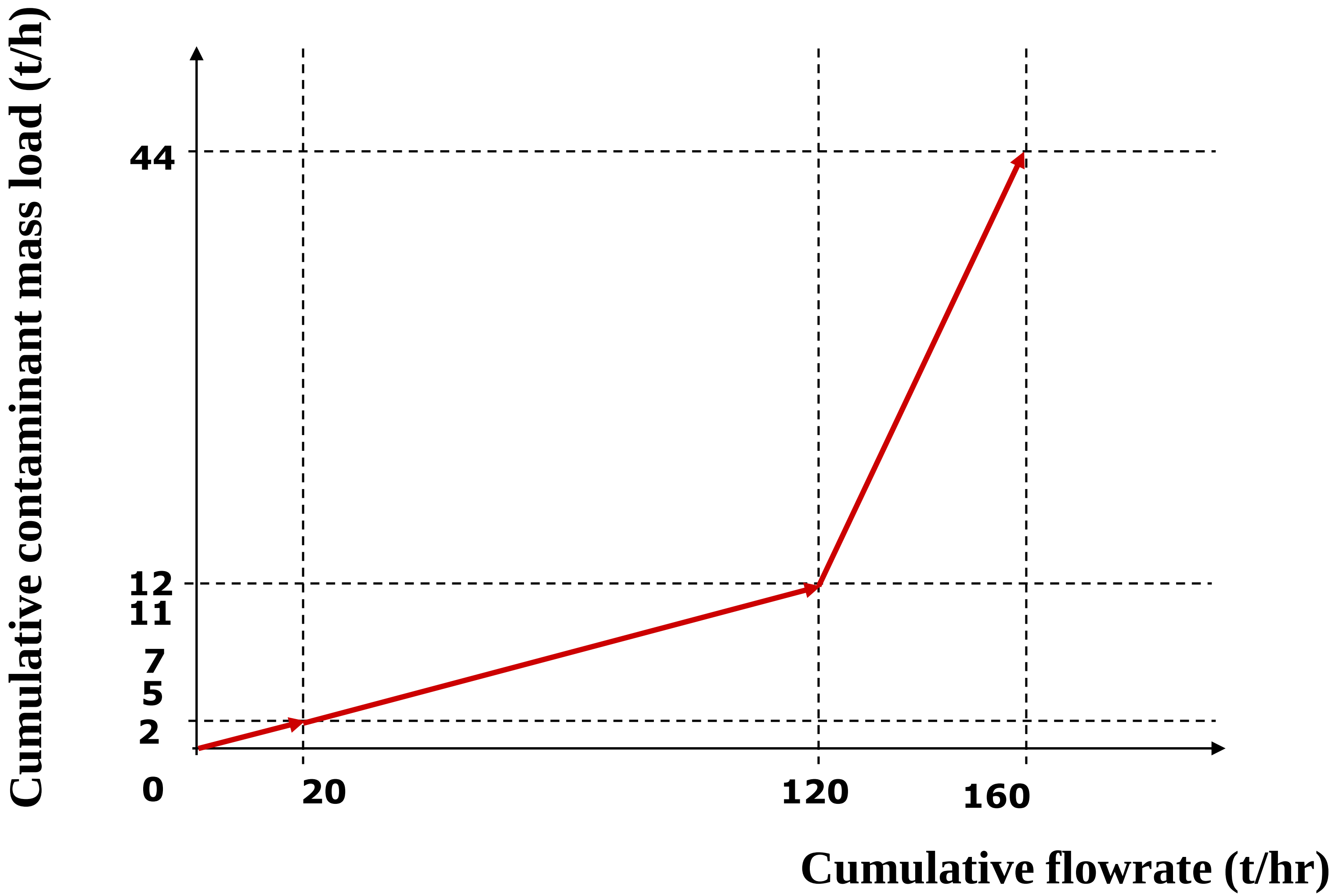
Source Process Number	Cum F	Cum m
	0	0
Abultion	20	2
Bathing	120	12
Washing car	160	44



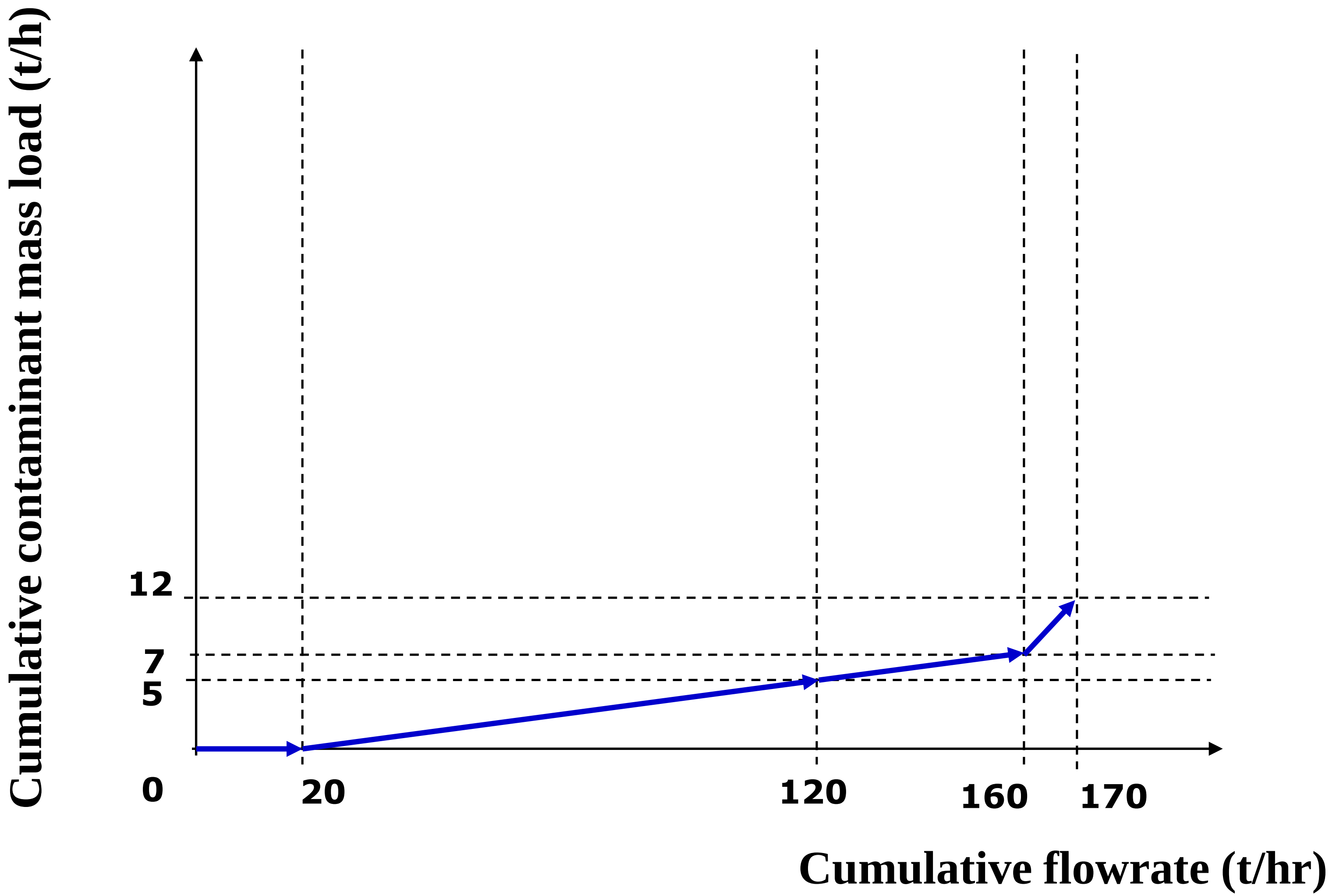
Water source and demand composite curves

Minimum utility (water) targeting

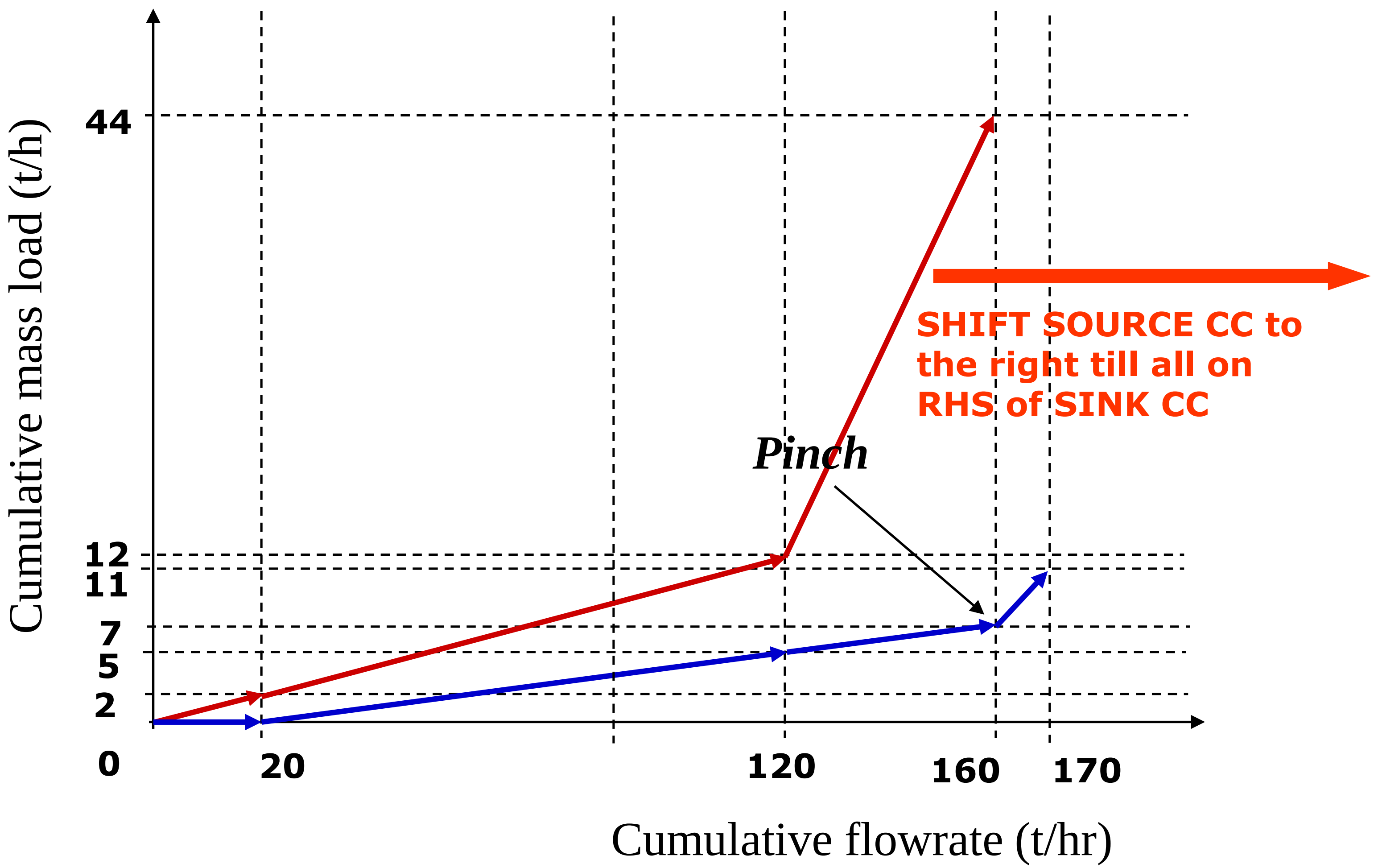
The Water Source Composite Curves



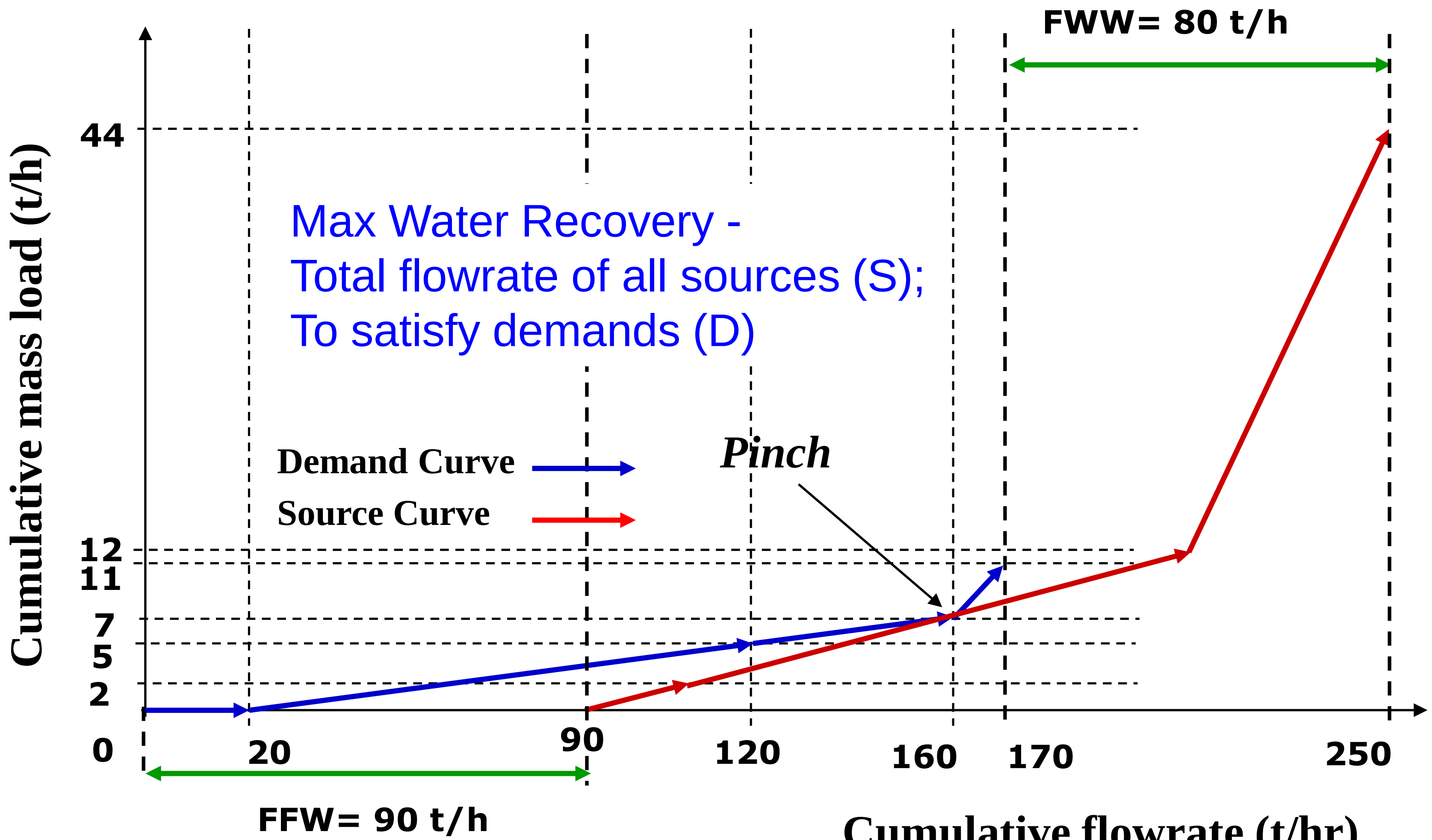
The Water Sink Composite Curves



The Water Sources and Demand Curves



Source and Demand Curves, The Minimum Water Targets



Better, (greener) ways?

1. Not to use water,
2. Use less water

Change Process/Streams!

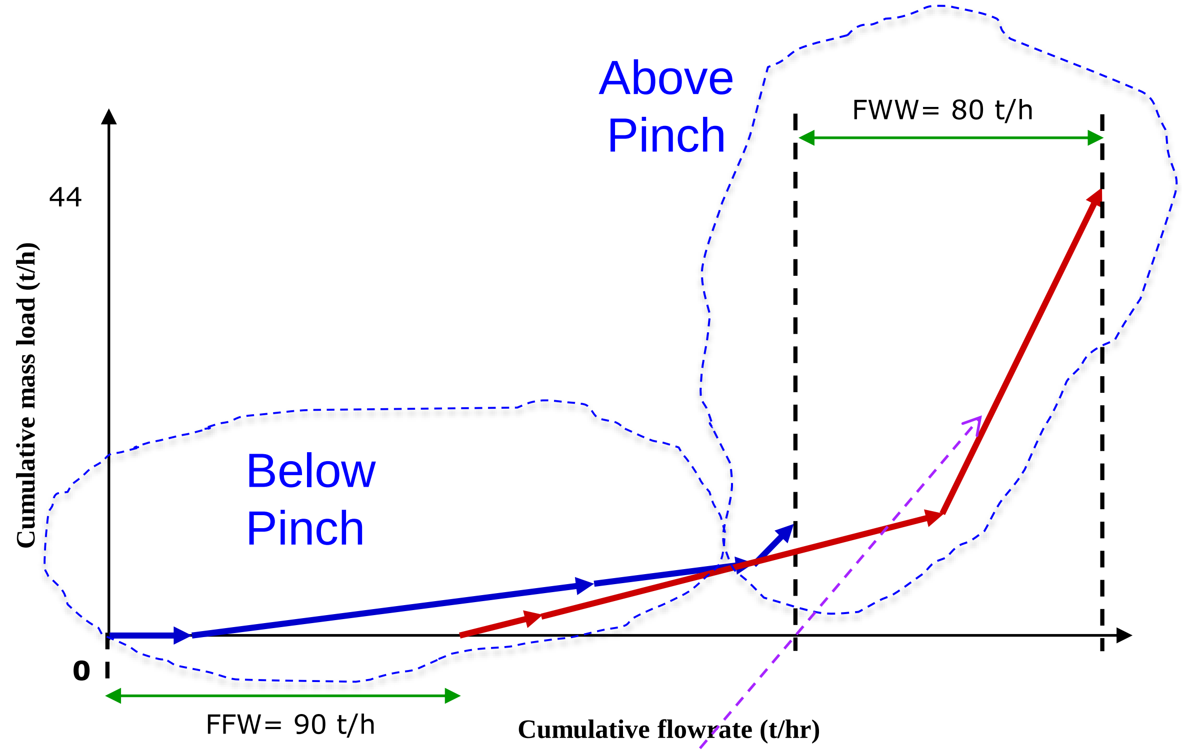
Lets Have Fun!

Better, (greener) ways?

1. Not to use?
2. Use less?
3. "Best-mix" options?

Apply W3E!

Site Water Reduction



1. Direct Reuse

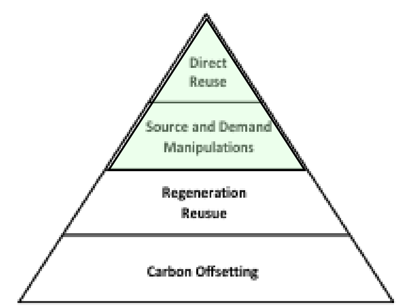
Use of various water sources to satisfy water demands

2. Source & Demand Manipulation

Source Elimination or Reduction

– *Eliminate/reduce water source streams above the pinch*

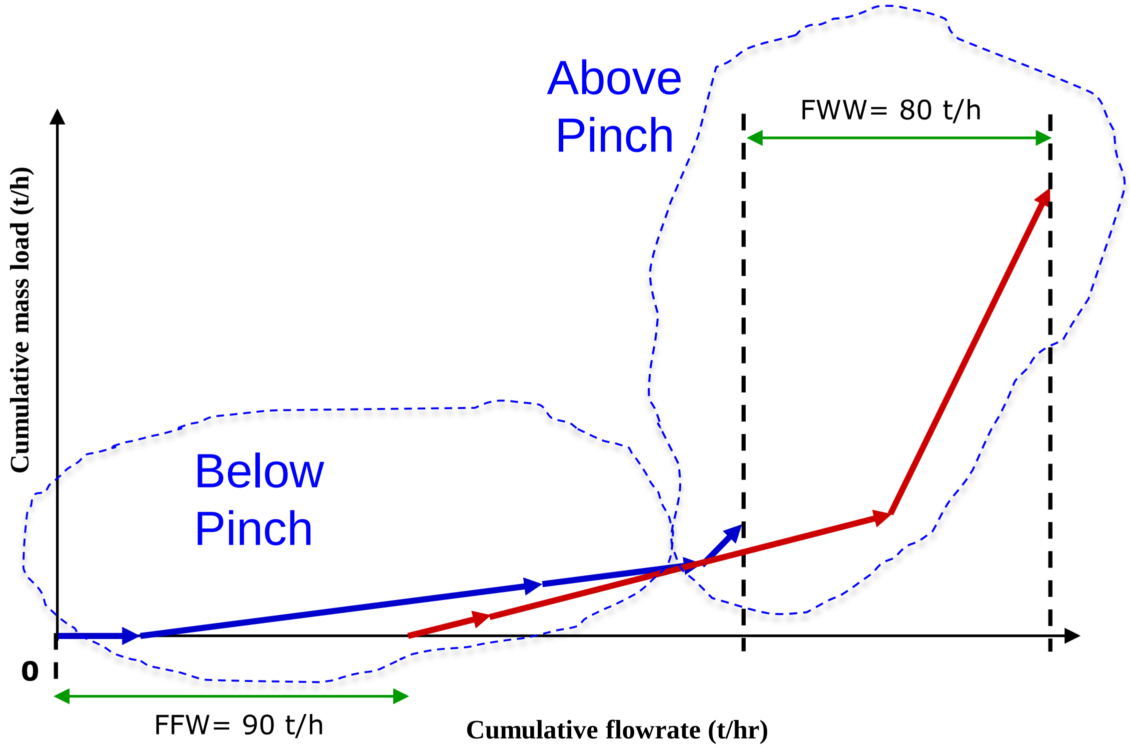
- E.g. Source switching
- Parameter changes, equipment modifications, reaction chemistry (reduce)



Site Water Reduction

2. Source & Demand Manipulation

Demand Manipulation

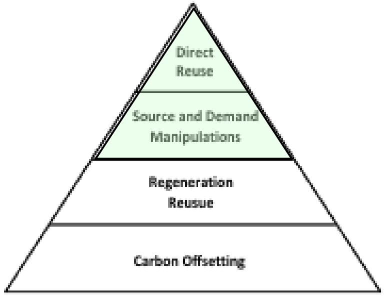


Above Pinch:

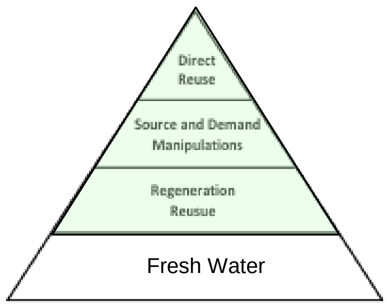
- Increase demand flowrates
- add new demands

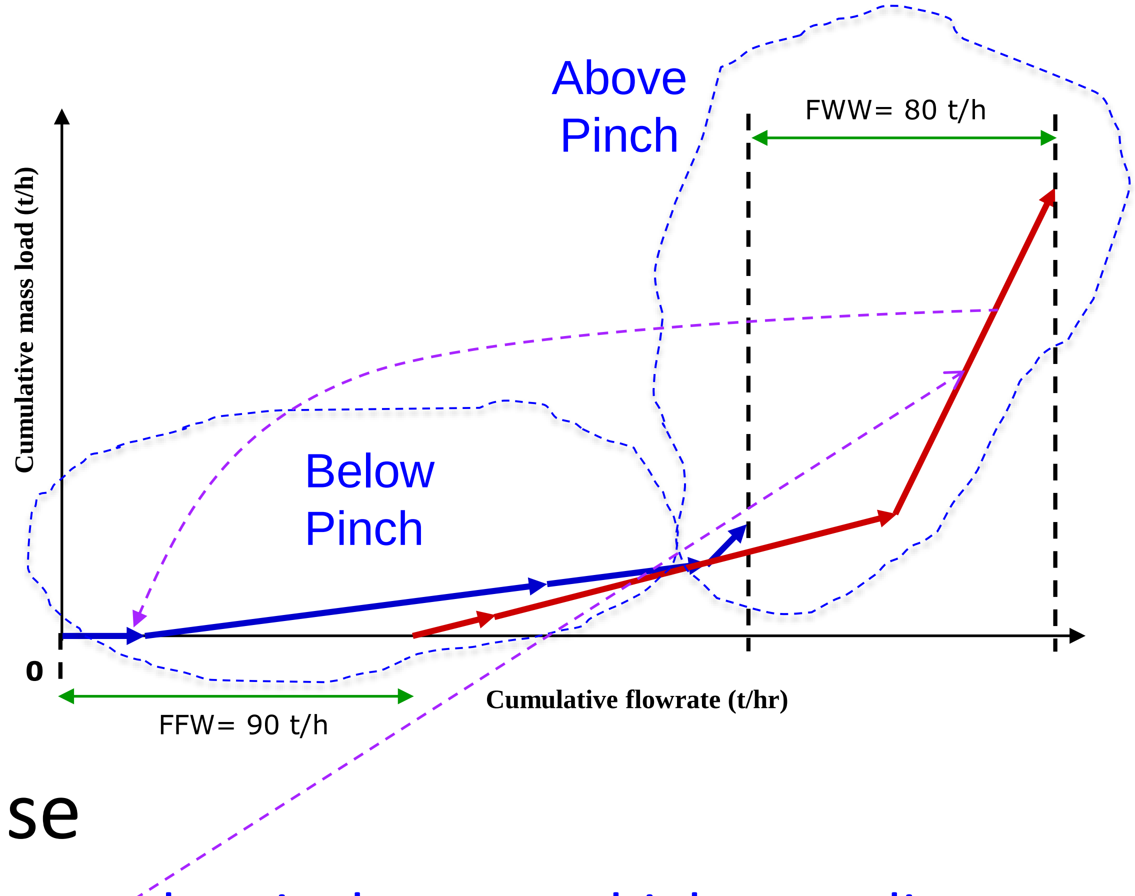
Below Pinch:

- Reduce demand flowrates
- eliminate demands



Site Water Reduction





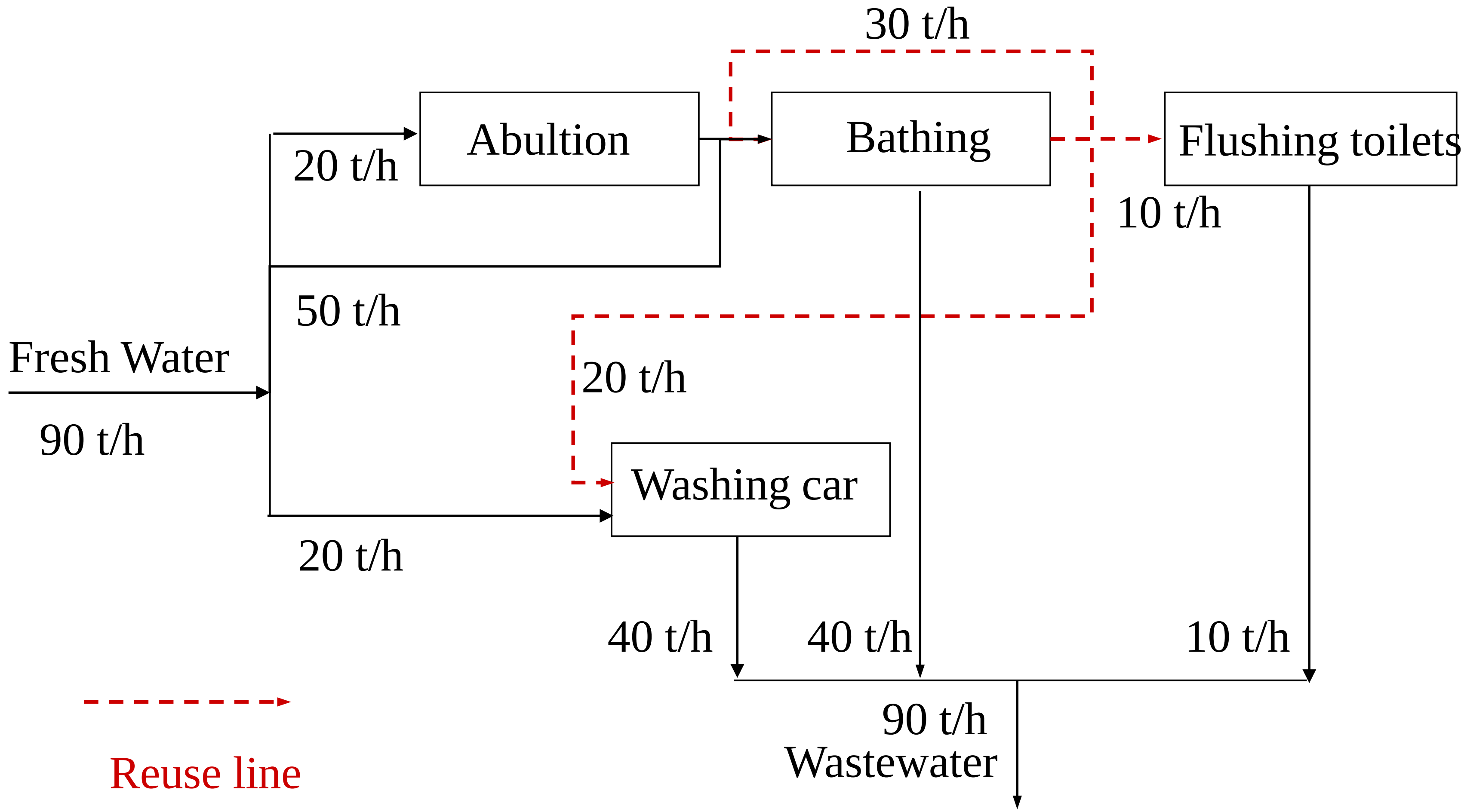
3. Regeneration – Reuse

Regenerate source streams across the pinch to get a higher quality source

Integrate with demands below pinch

- ✓ Reduce waste water
- ✓ Reduce fresh water

Network Design after WPA

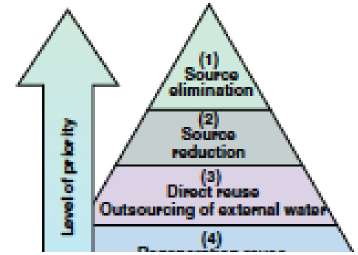


It is not 80 t/h since FT WW was excluded from WPA analysis

Showcase Project

Assess Your Plant's True Water-Savings Potential

Using the minimum water network involves detailed analysis of plant configuration and design, material and energy balances, design and thermodynamic constraints



A CASE STUDY: SETTING TARGETS FOR MINIMUM WATER NETWORK IN A SEMICONDUCTOR FABRICATION PLANT

Water is a major utility for many sectors of the chemical process industries, but for semiconductor manufacturers, it is also a precious commodity. The extreme water demands of a semiconductor fabrication plant — from the ultrapure water required for chipmaking processes to potable water and, increasingly, recycled water for plant operations and maintenance — provide an ideal case study for the application of MWN benchmarking techniques.

In this case, the facility is MySem, **a semiconductor fabrication** plan in Malaysia. ; While the facility's primary activity is research and development (R&D), **it produces 6-in. and 8-in. wafers.** Figures 3 and 4 show the fab's water distribution network. Water demands include deionized (DI) process water for **solvent processes**, acid processes, wet cleaning and tools cleaning; the rest is for **plant operations such as abatement, scrubber, cooling tower** and wet bench cooling, and maintenance such as toilet flushing, office cleaning, wash basin, toilet pipes and ablution, as shown in **Figure 5**.

Total water consumption varied throughout the year, depending on wafer production and equipment conditions. During the month of the benchmarking study, the fab's estimated total freshwater consumption was 42.6 m^3/h. Of this value, 31.78 m^3/h was used for DI water production and the rest for plant operations and maintenance.

Step 1. Specify the limiting water data

This step involved detailed process survey and line tracing, establishing process stream material balances and conducting water quality tests. Stream flowrates were extracted from data collected by either the plant's distributed control system (DCS) or ultrasonic flowmeters. Depending on the stream audited, tests for total suspended solids (TSS), biological oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS) were conducted onsite. For processes that only used ultrapure water, TSS levels were negligible. BOD was absent since no biological contaminants were present. COD was a component of TDS. TDS

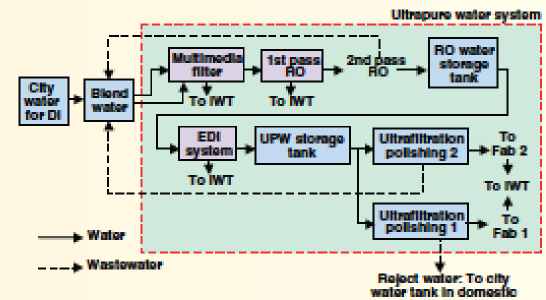


FIGURE 3. Process flow diagram for the ultrapure water system

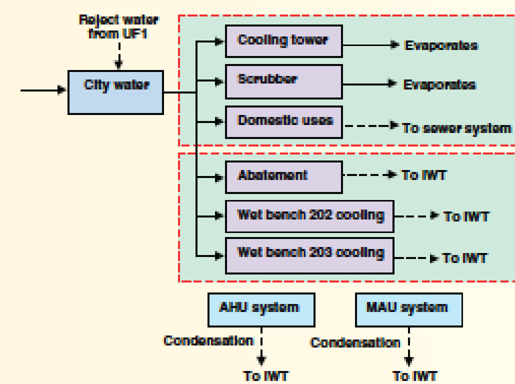
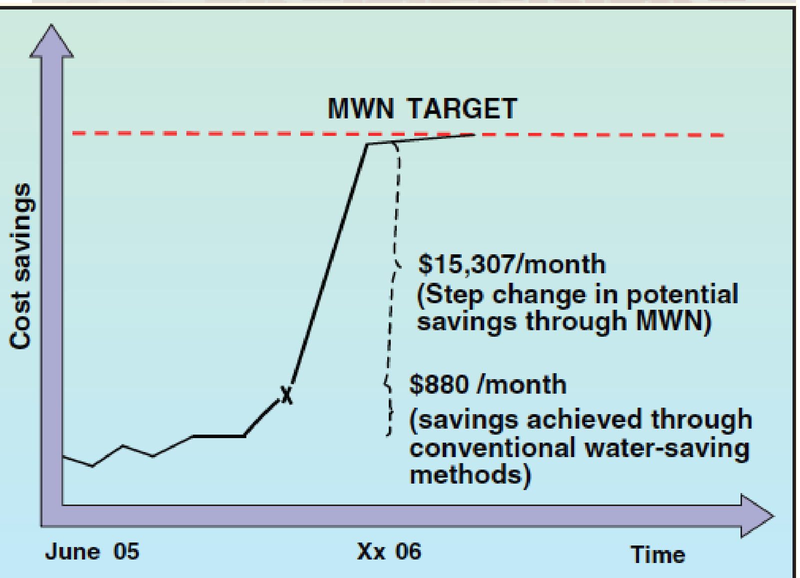


FIGURE 4. Water uses for plant operations and maintenance



Industrial Case Study

Wan Alwi, S. R. and **Z. A. Manan,** (2006). *A Holistic Framework For Design Of Cost Effective Minimum Water Utilisation Networks*. Journal of Environmental Management. 88 (2008) 219–252.

Z. A. Manan, S. R. Wan Alwi, M. H. Samingin and N. Misran, *Assess Your Plant's True Water-Saving Potential*, *Chemical Engineering*, December 2006.

Industrial Water Sources & Demands

Water Sources

Sources	F, t/h	C, ppm x10^3	m, kg/h x10^3	Cum F, t/h	Cum m, kg/h x10^3
Source 1 (S_1)	300	250	75	300	75
Source 2 (S_2)	55	800	44	355	119
Source 3 (S_3)	70	850	59.5	425	178.5
Source 4 (S_4)	130	880	114.4	555	292.9
Source 5 (S_5)	200	900	180	755	472.9
Source 6 (S_6)	90	920	82.8	845	555.7

Total Cumulative waste water

Demand Processes

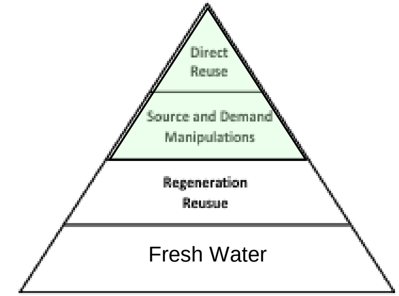
Demands	F, t/h	C, ppm x10^3	m, kg/h x10^3	Cum F, t/h	Cum m, kg/h x10^3
Demand 1 (D1)	50	1	0.05	50	0.05
Demand 2 (D2)	208.3	200	41.66	258.3	41.71
Demand 3 (D3)	83.3	500	41.65	341.6	83.36
Demand 4 (D4)	220	900	198	561.6	281.36

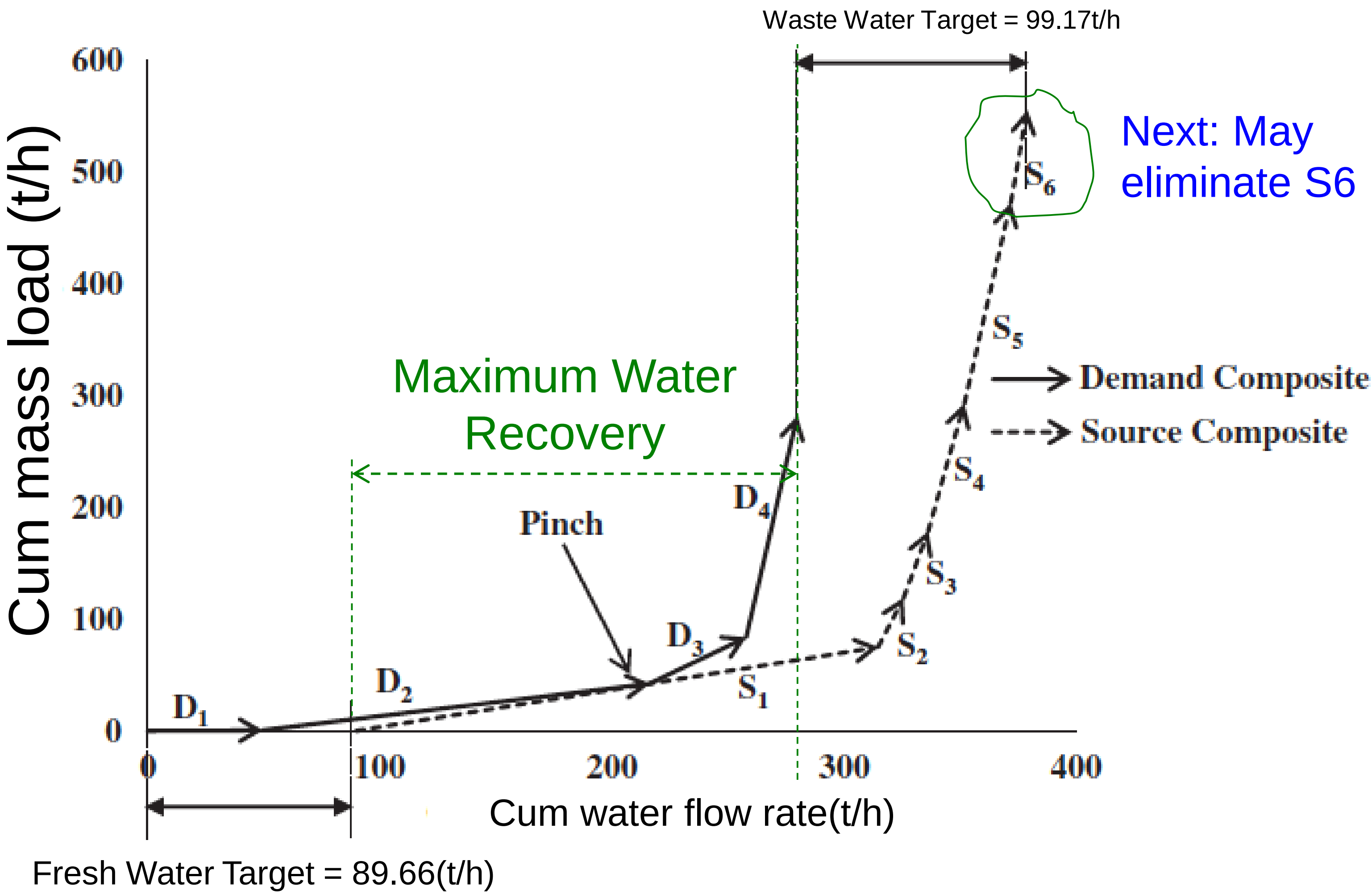
75

Targeting;

Implementing Top Priority Water Minimisation Options

Direct Reuse, Source Elimination





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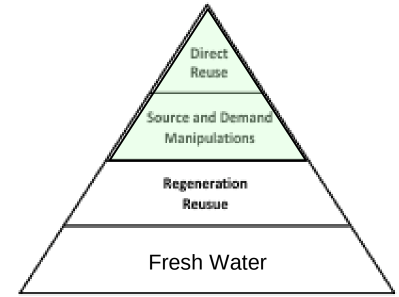
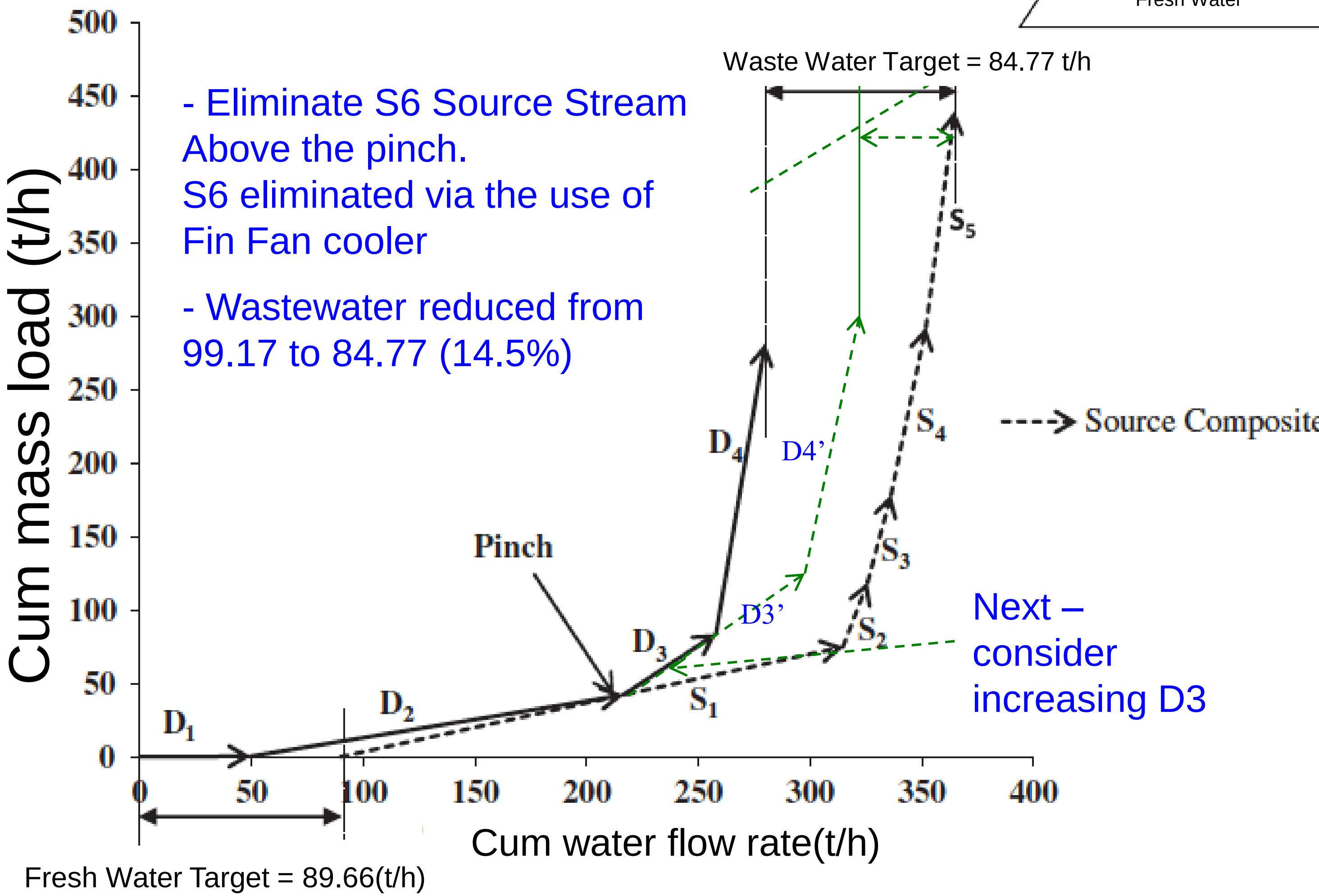
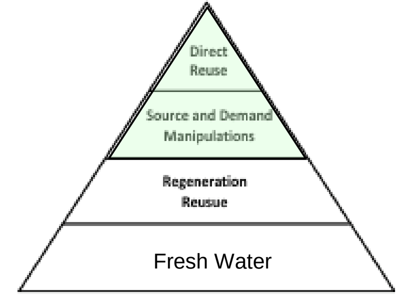
Source Elimination





Demand Increase

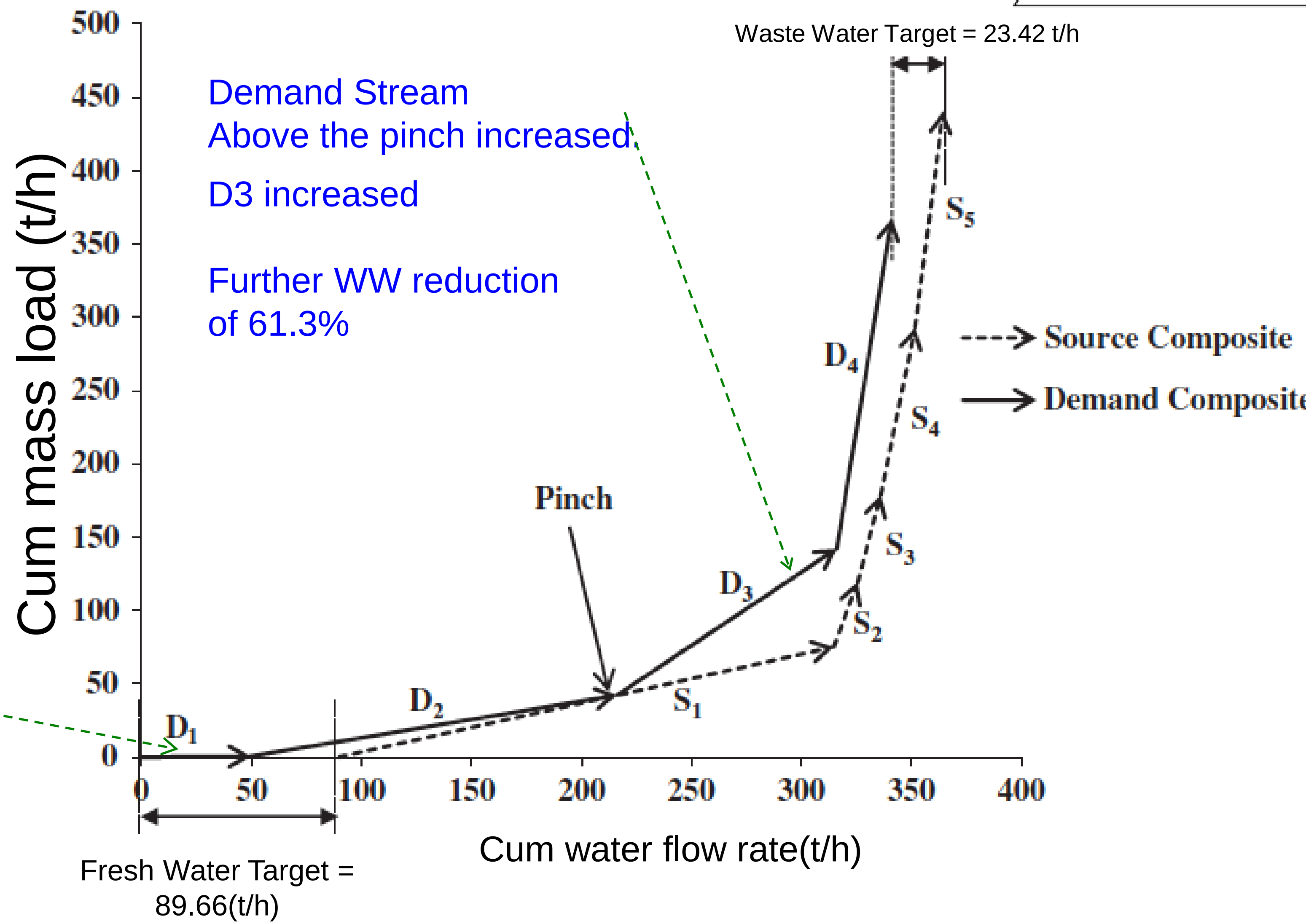


Demand Stream
Above the pinch increased.

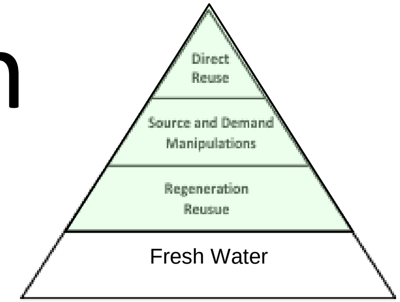
D3 increased

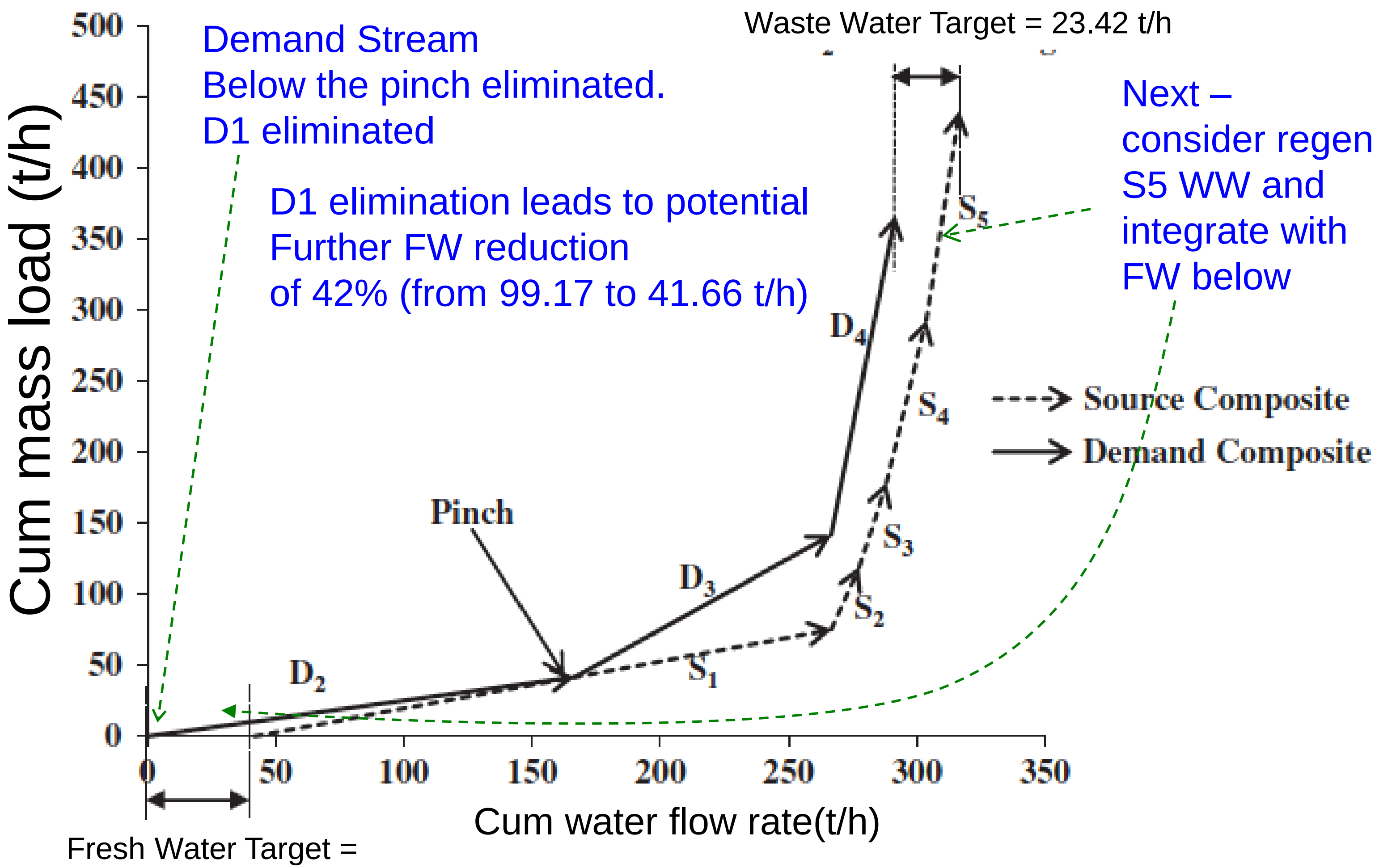
Further WW reduction of 61.3%

Next – consider eliminating D1 to reduce FW_2



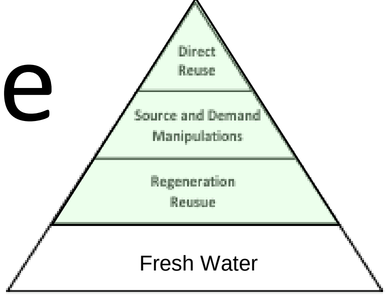
Demand elimination

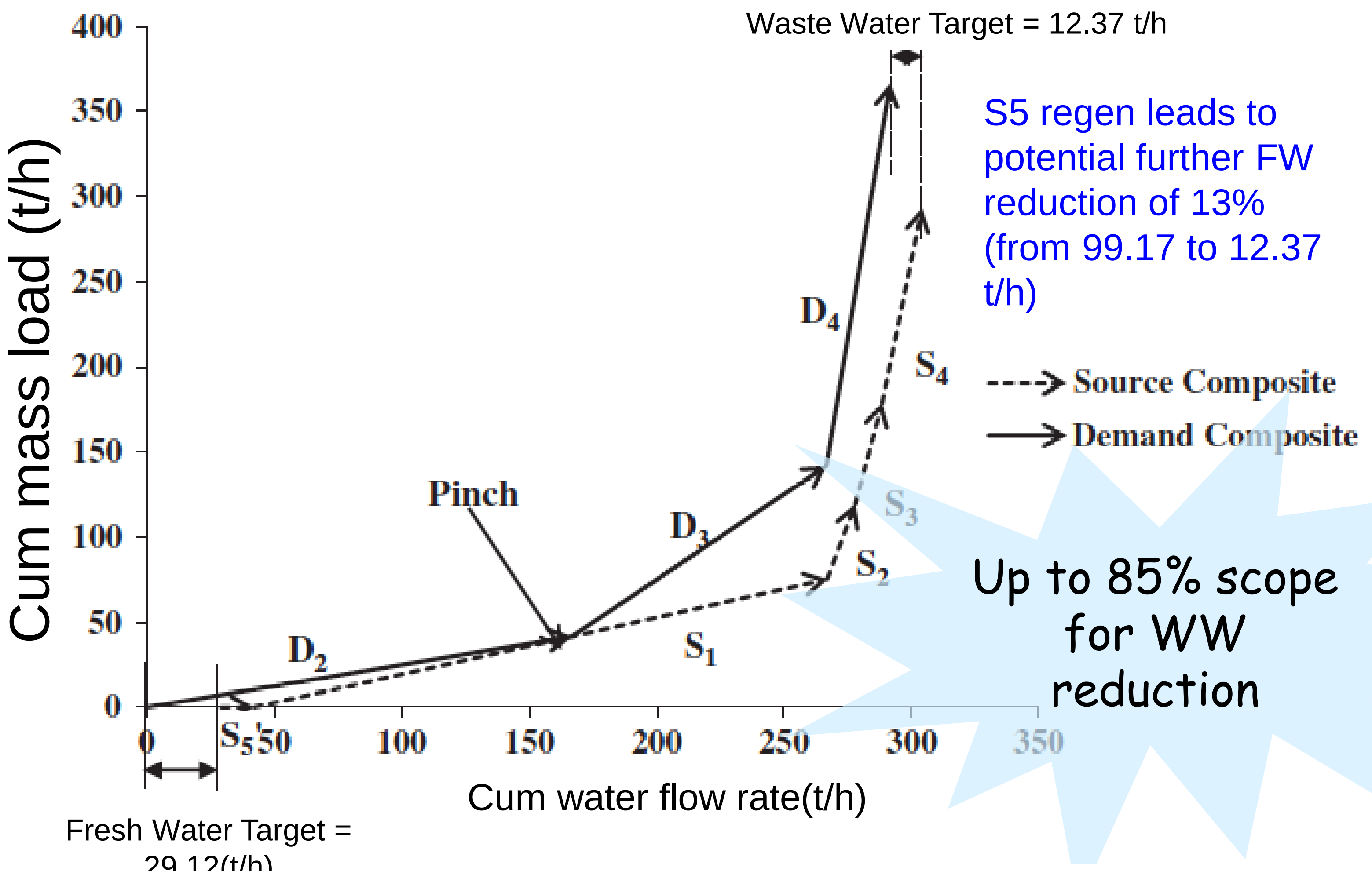




Yinling Tan and **Manan, Z. A.**, Retrofit of Water Networks with Optimization of Existing Regeneration Units, *Ind. Eng. Chem. Res.* 2006, 45, 7592-7602.

Regeneration - Reuse





S5 regen leads to potential further FW reduction of 13% (from 99.17 to 12.37 t/h)

The Minimum Water Targets

	Specific process changes considered	Fresh Water Target t/h	Waste Water Target t/h	
Initial	None	None	289.3	None
Direct Reuse	Sources and Demand Integration	89.66	99.17	216.14
+ Source & Demand Manipulation	Source Switching (S3) Equipment Change (S_6)	89.66	84.77	216.14
	Increase D above pinch	89.66	23.42	216.14
	Eliminate D below pinch	41.66	24.92	166.64
+ Regeneration Reuse	Regenerate S_5	29.12	12.37	166.64
+ Water Upgrading	Water Upgrading	29.12	0	166.64
= Holistic Minimum Water Network		**29.12**	**0**	**166.64**

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Water Allocation; Network Design

Water Allocation Network

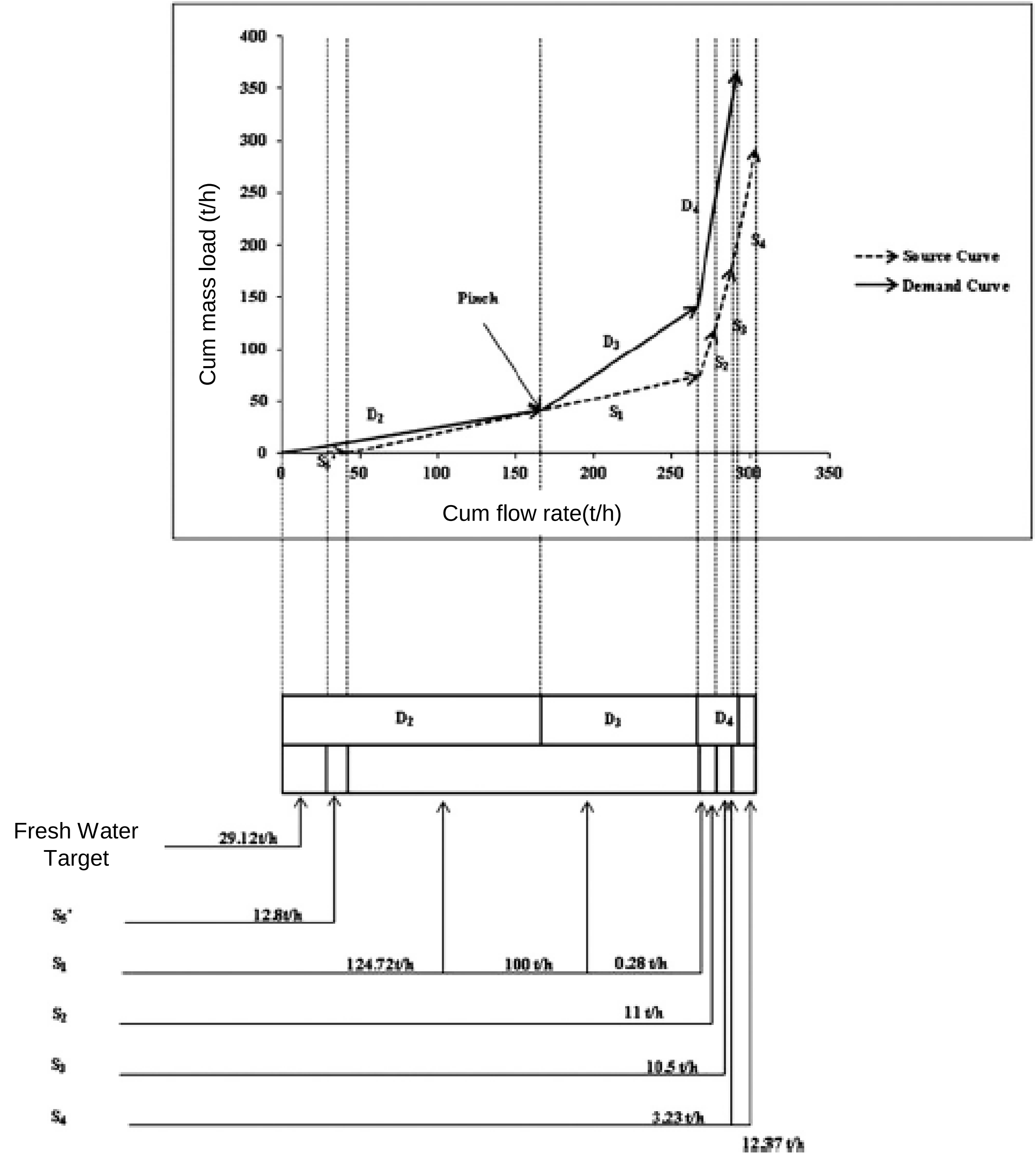

Fig. 10. The final Network Allocation Diagram (NAD) for the refinery.

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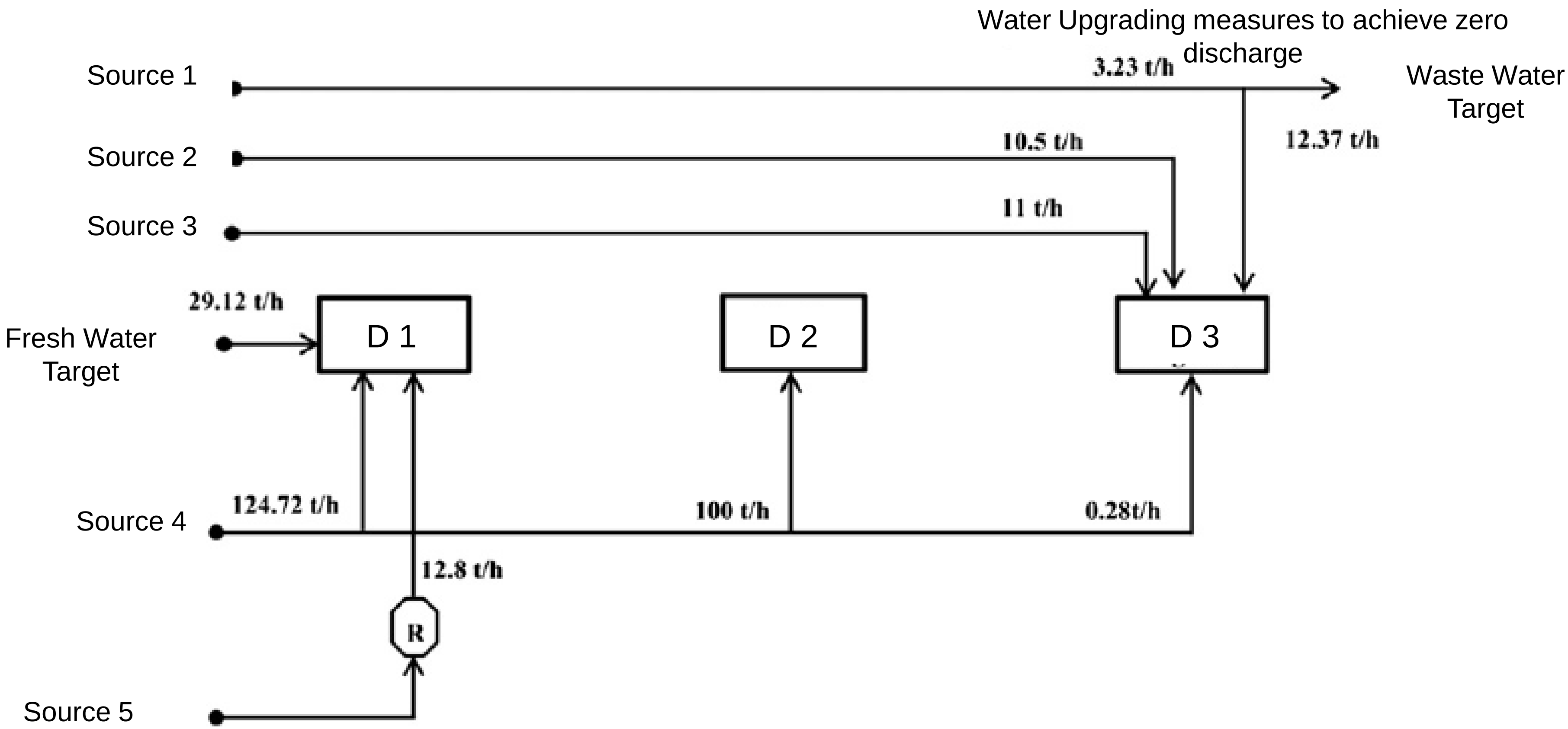
Final Industrial Site Water Allocation Network



WMH-guided process changes

WMH levels	Specific process changes considered	New FW target, t/hr	New IWT+WW [based on limiting data] target, t/hr	New pinch point concentration, ppm	New total IWT (all IWT considered) target, t/hr
Initial	None	39.94	34.85	22360	34.4500
Reuse	Base case (MWR)	11.0400	0.0190	22 360	5.7090
+ Elimination	Eliminate WB cooling 202 (D13) and 203 (D12)	8.3525	0.0215	22 360	3.0215
+ Reduction	WB reduction in Fab 1 and Fab 2	6.7518	0.0258	4608	1.4216
+	Heater WB201 reduction	6.7314	0.0264	4608	1.4454
	Fab 1 return reduction	6.6094	0.0354	4608	1.3109
	Option 1: EDI decommissioning	6.3038	0.0378	4608	1.0112
	Increase RO rate of recovery	6.2110	0.0380	4608	0.9132
	Reduce multimedia filter backwash and rinsing time	6.0857	0.0387	4608	0.7879
	Option 4: Reduce abatement pollution system (D3 = 0.57 t/hr and S17 = 0.57 t/hr).	6.0831	0.0361	4608	0.7853
	Cooling tower reduction (D2 = 5.86 t/hr)	5.9452	0.0382	4608	0.7874
Outsourcing	Add a source, S25=0.11 t/hr of C = 16 ppm by harvesting rainwater	5.8349	0.0379	4608	0.7871
+ Regeneration	Regenerate remaining IWT to the maximum flowrate for a source from to C=52 ppm.	5.7970	0	4608	0.7492
= Minimum water network (MWN) targets		5.7970	0	4608	0.7492

Before analysis

After MWR

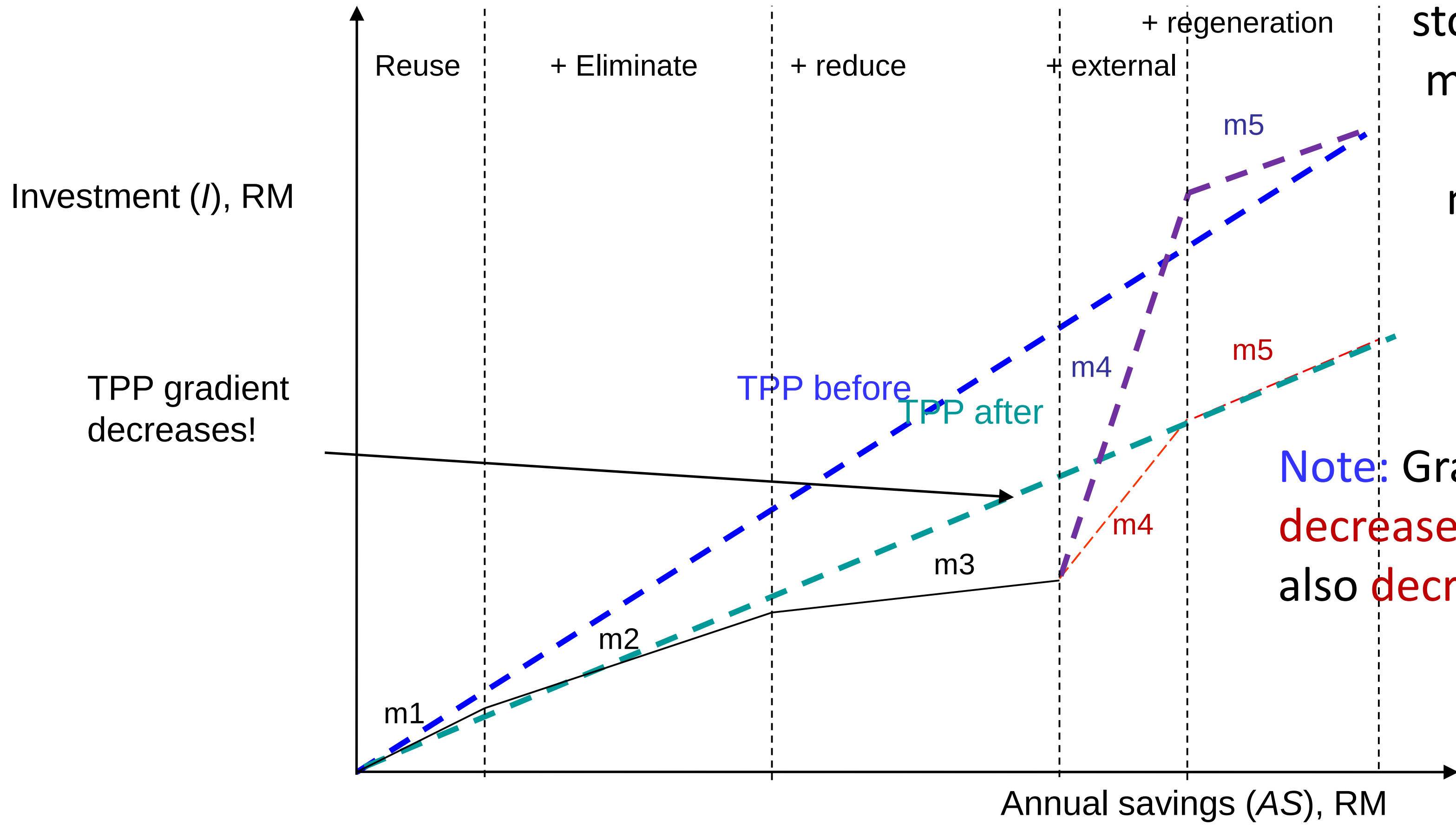
After MWN

Water Wise?

$$$ Wise?

Systematic Hierarchical Approach for Resilient Process Screening (SHARPS) technique

- Strategy 1: Substitution

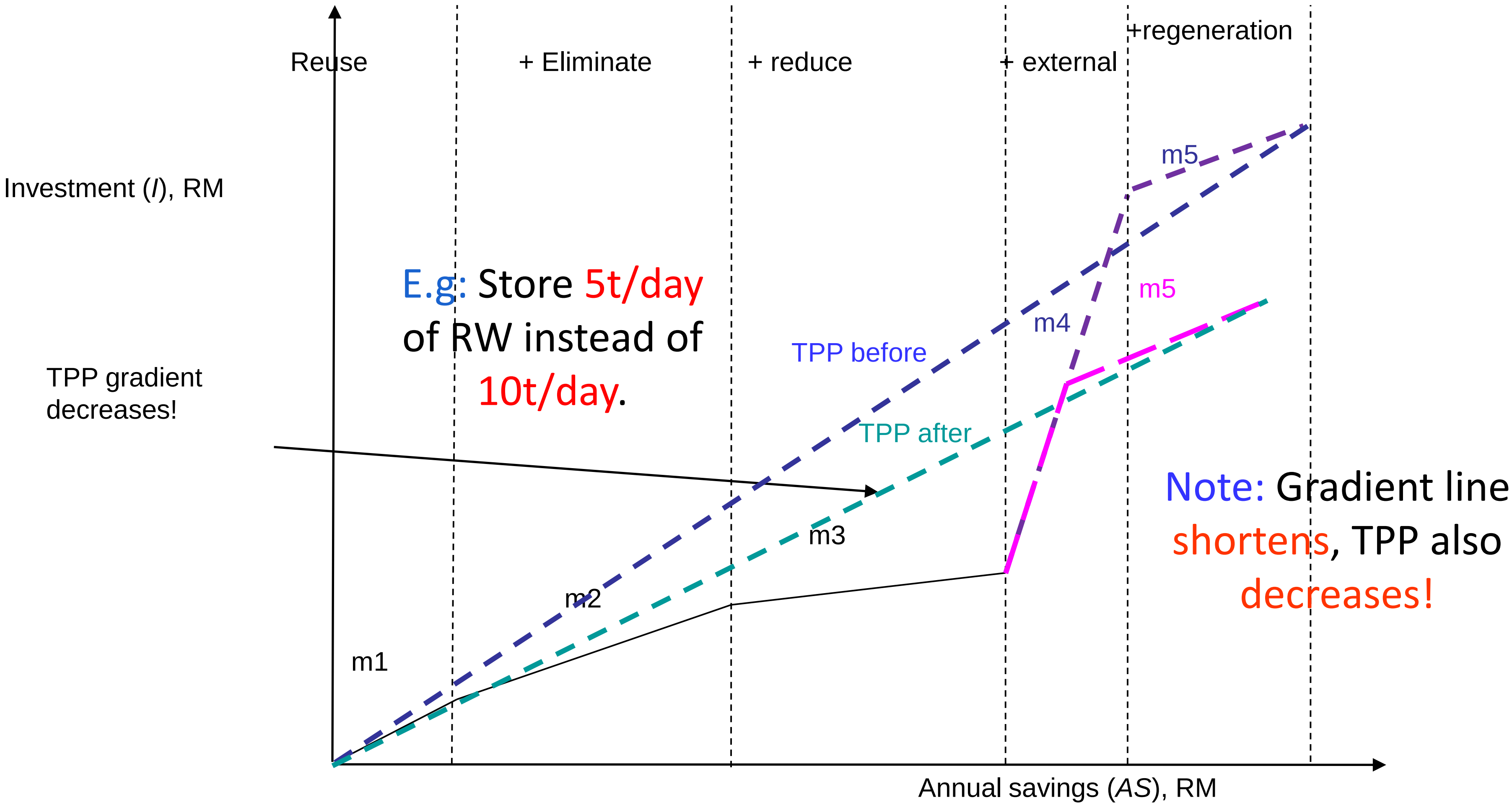


E.g: Use storage tank made from cheaper material.

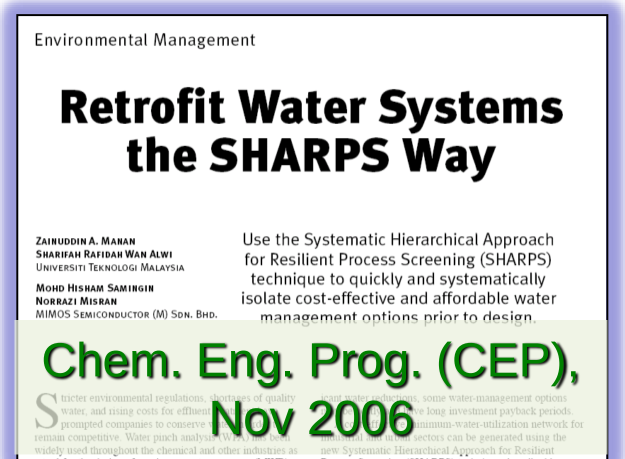
Note: Gradient decreases, TPP also decreases!

Systematic Hierarchical Approach for Resilient Process Screening (SHARPS) technique

- Strategy 2: Intensification



SHARPS technique

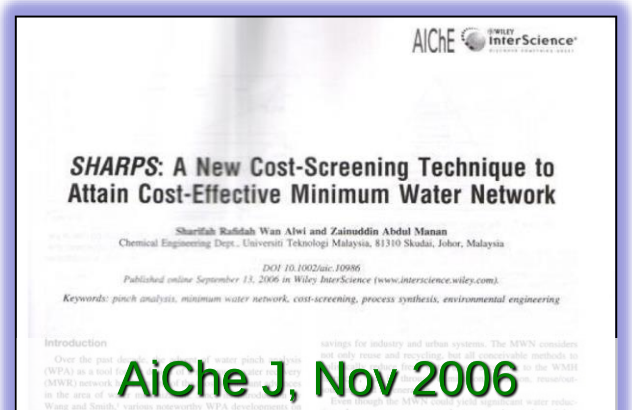

Environmental Management

Retrofit Water Systems the SHARPS Way

Zainuddin A. Manan
Sharifah Rafidah Wan Alwi
Universiti Teknologi Malaysia
Mohd Hisham Samingin
Norrazi Misran
MIMOS Semiconductor (M) Sdn. Bhd.

Use the Systematic Hierarchical Approach for Resilient Process Screening (SHARPS) technique to quickly and systematically isolate cost-effective and affordable water management options prior to design.

Chem. Eng. Prog. (CEP), Nov 2006


AIChE InterScience

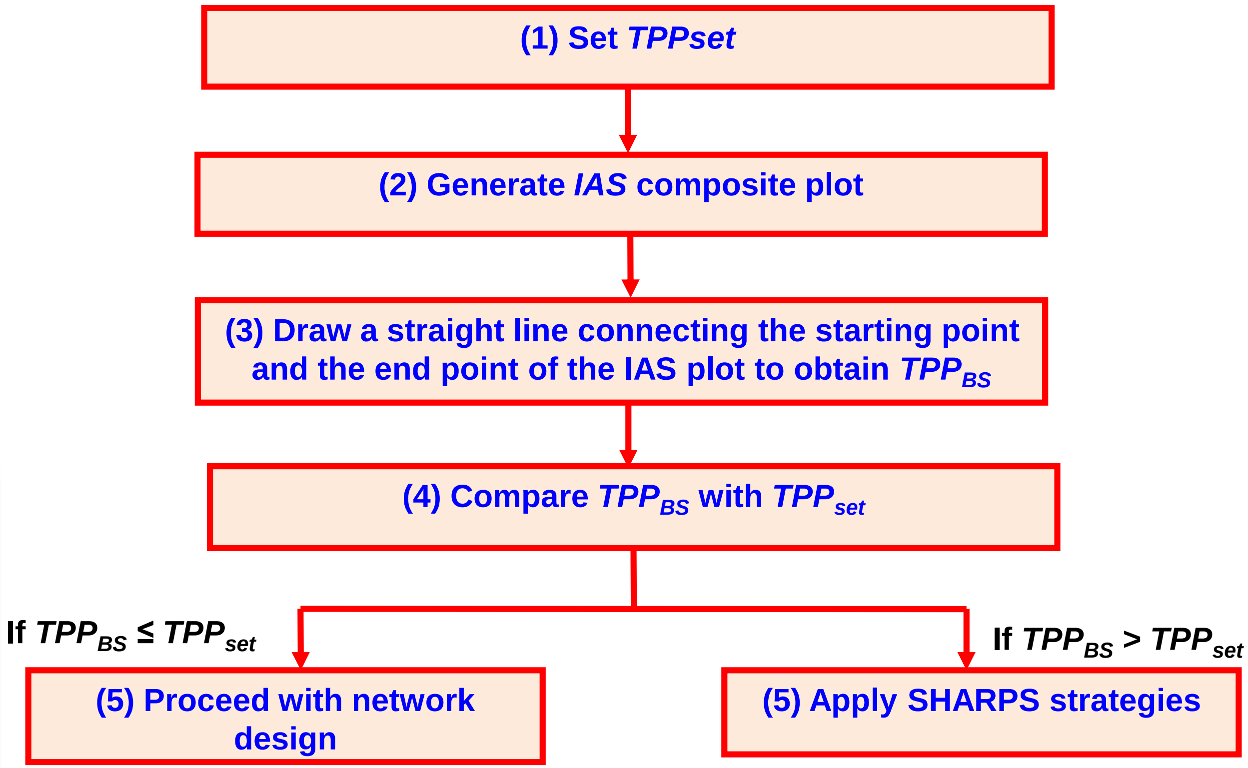
***SHARPS*: A New Cost-Screening Technique to Attain Cost-Effective Minimum Water Network**

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

AiChe J, Nov 2006



S. R. Wan Alwi and **Z. A. Manan**. (2005) *SHARPS – A New Cost Screening Technique to Attain Cost-effective Minimum Water Network*. AiChe Journal, Vol 52, No. 11, November, 2006.

Pitfalls

Multiple Contaminants

Localised Integration

Localised Integration

Pitfalls

Multiple Contaminants

Address with

Localised Integration

Reconcile & iterate with other contaminants

Back to Rigorous Solution

Handandi, Z.B., Wan Alwi, S.R., Hashim, H., ***Z.A. Manan****, Holistic Approach For Design Of Minimum Water Networks Using The Mixed Integer Linear Programming (MILP) Technique, Industrial and Engineering Chemistry Research, Volume 49, Issue 12, 16 June 2010, Pages 5742-5751.*

Stage 2: E-Mode ~ Mixed Integer Nonlinear Programming (MINLP)

Objective function: MAXIMISE NET ANNUAL SAVINGS

Freshwater savings

Wastewater savings

Chemical savings

$$
\text{Max NAS} = \left[
\begin{array}{l}
\sum_{j}\left(FW_{j}^{initial} - FW_{j}\right) CostFW + \sum_{i}\left(WW_{i}^{initial} - WW_{i}\right) CostWW \\
+\sum_{i}\sum_{r}\left(F_{i,r}^{initial} - F_{i,r}\right) CostChemReg \\
+\sum_{i}\left(WW_{i}^{initial} - WW_{i}\right) CostElecPOPump \\
+\sum_{j}\left(FW_{j}^{initial} - FW_{j}\right) CostElecPOPump \\
+\sum_{i}\sum_{j}\left(F_{i,j}^{initial} - F_{i,j}\right) CostElecPOPump \\
+\sum_{j}\left(Fos_{os,j}^{initial} - Fos_{os,j}\right) CostElecPOPump \\
+\sum_{i}\sum_{r}\left(F_{i,r}^{initial} - F_{i,r}\right) CostElecPOPump \\
+\sum_{r}\sum_{j}\left(F_{r,j}^{initial} - F_{r,j}\right) CostElecPOPump
\end{array}
\right] * AOT
$$

Energy savings

AOT: Annual operating time

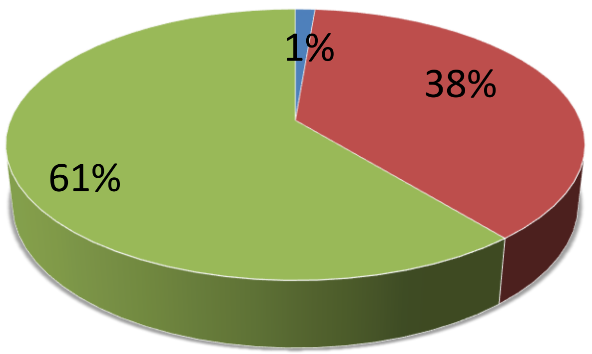
Industry;

Public & Commercial Facilities;

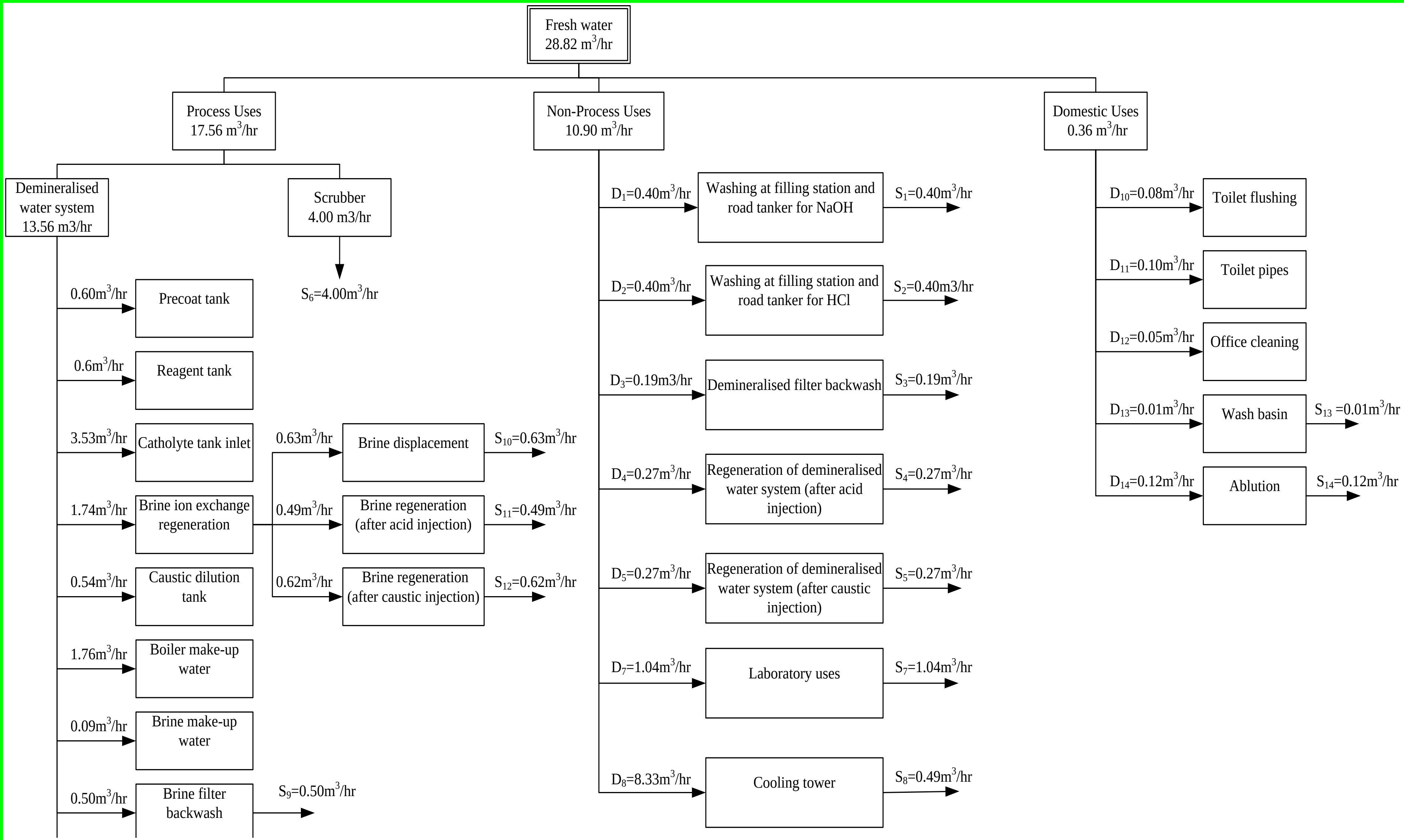
Domestic & Individuals

Industrial Case Study: A chlor-alkali plant (CCMC)

- 2 chlor-alkali plants (PGW1 and PGW2) and one coagulant plant (PGW3)
- Produced liquid chlorine, caustic soda, hydrochloric acid, sodium hypochlorite, hydrogen, ferric chloride, and polyaluminium chloride
- Applied the membrane cell process; one of the latest technologies to produce chlorine and caustic soda, has more economic value and environmental friendly.
- PGW1 uses an average of 680 m^3 raw water (industrial and domestic) daily.
- 3 types water uses: process, non-process, and domestic uses

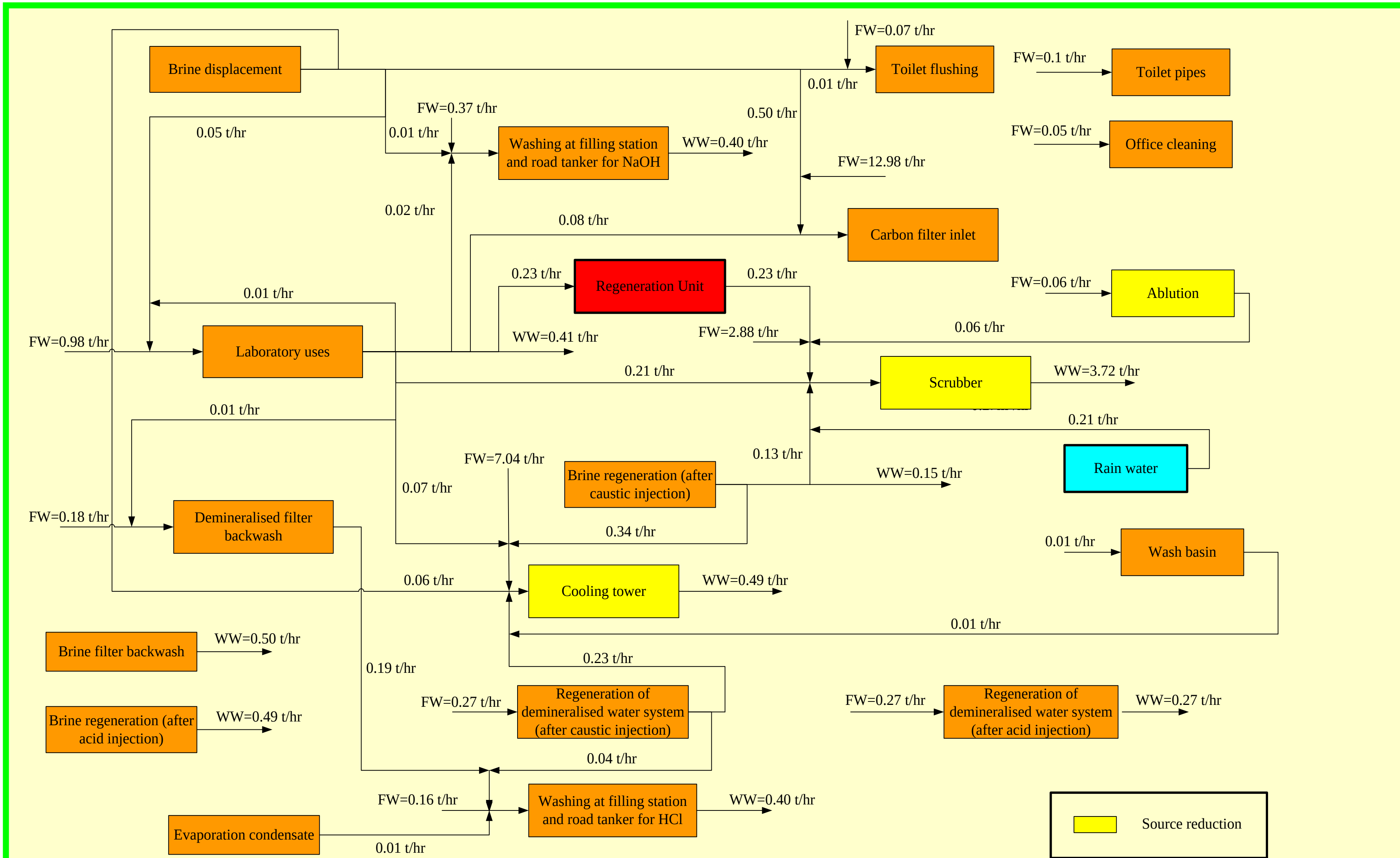


Water distribution of the chlor-alkali plant

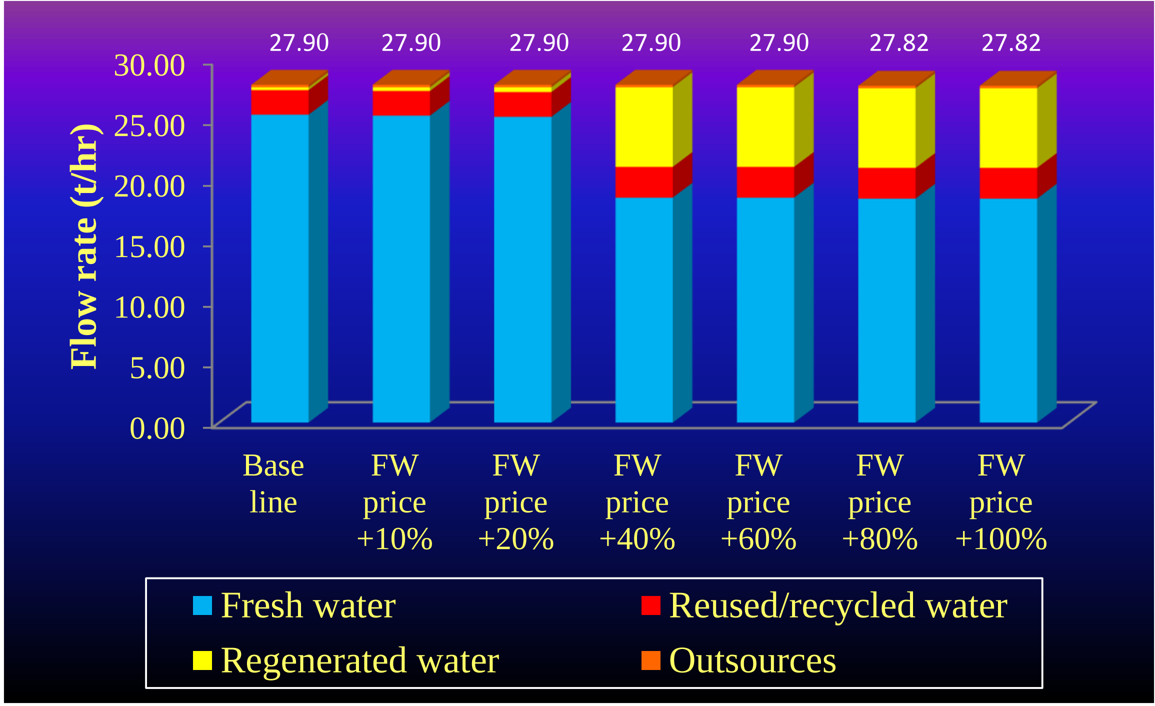


Foo, D. C. Y., **Manan, Z. A.** and El-Halwagi, M. M. (2005). *Correct Identification of Limiting Water Data for Water Network Synthesis*, Clean Technology and Environmental Policy, No. 8, 96-104).

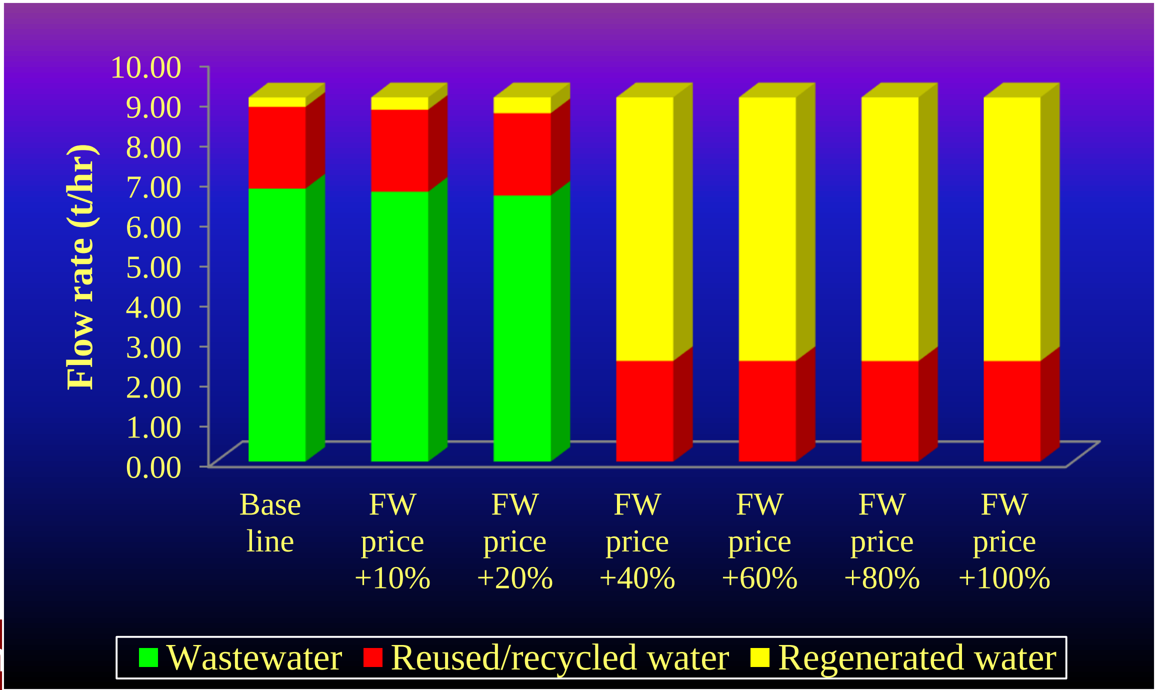
Optimal Water Network Design



SENSITIVITY ANALYSIS



Effects of Fresh Water Prices on Total Water Demand Flow Rates and Water Minimisation Schemes

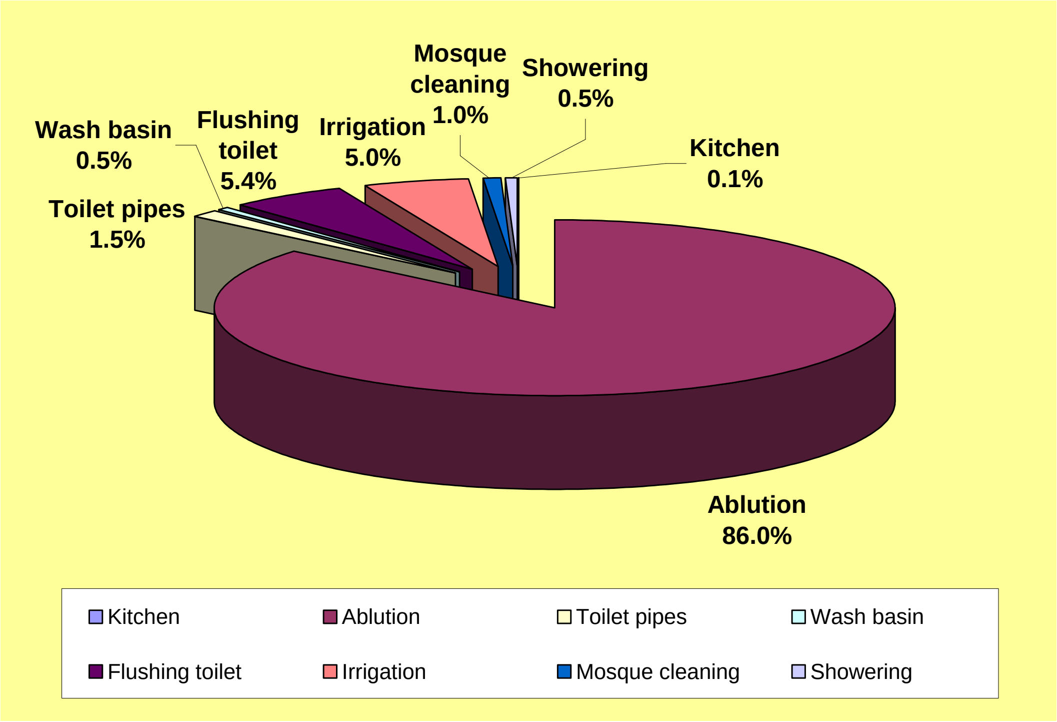


Effects of Fresh Water Prices on Total Water Source Flow Rates and Water Minimisation Schemes

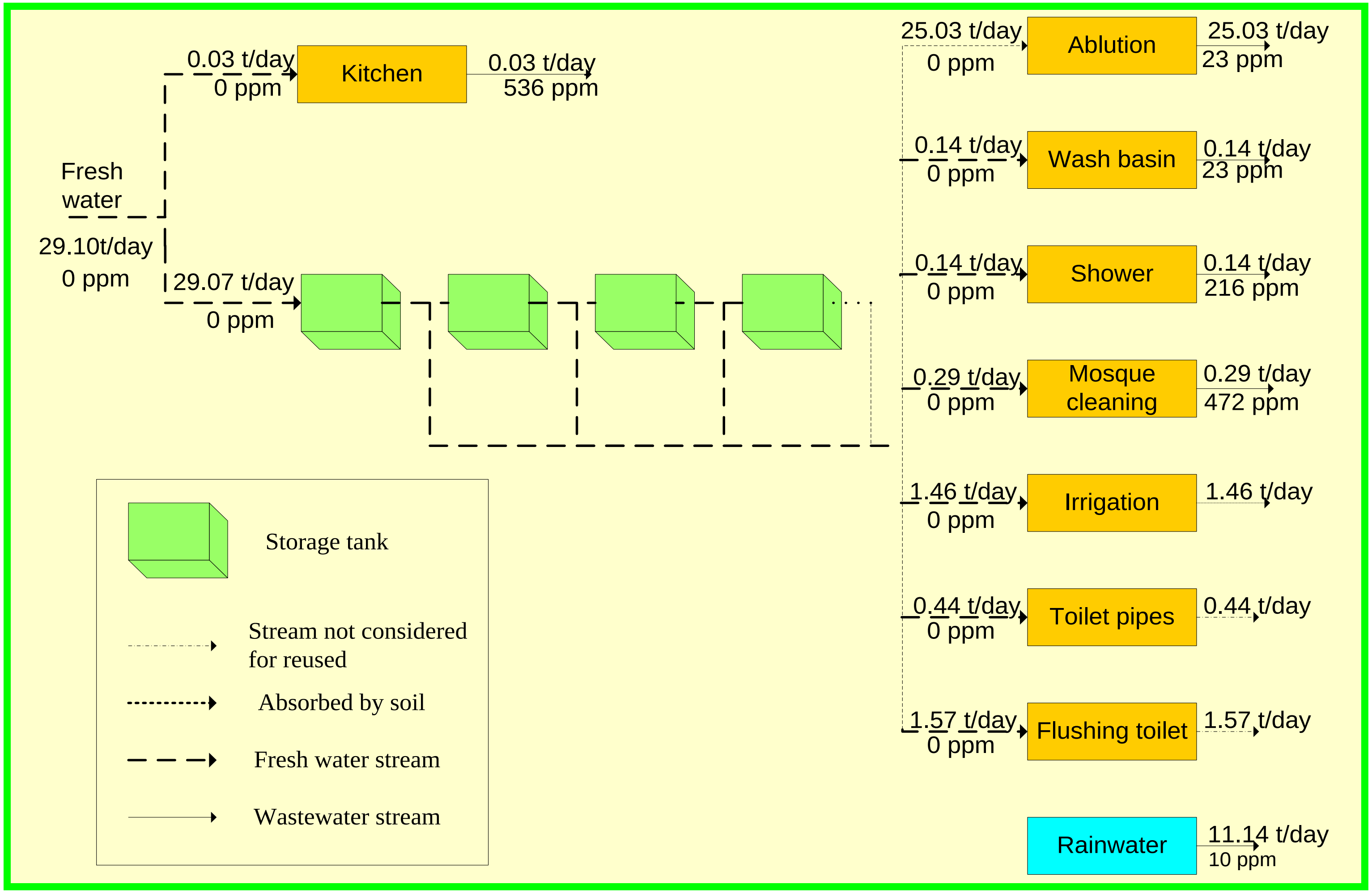
Industry;
Public & Commercial Facilities;
Domestic & Individuals

Urban Case Study: Sultan Ismail Mosque (SIM)

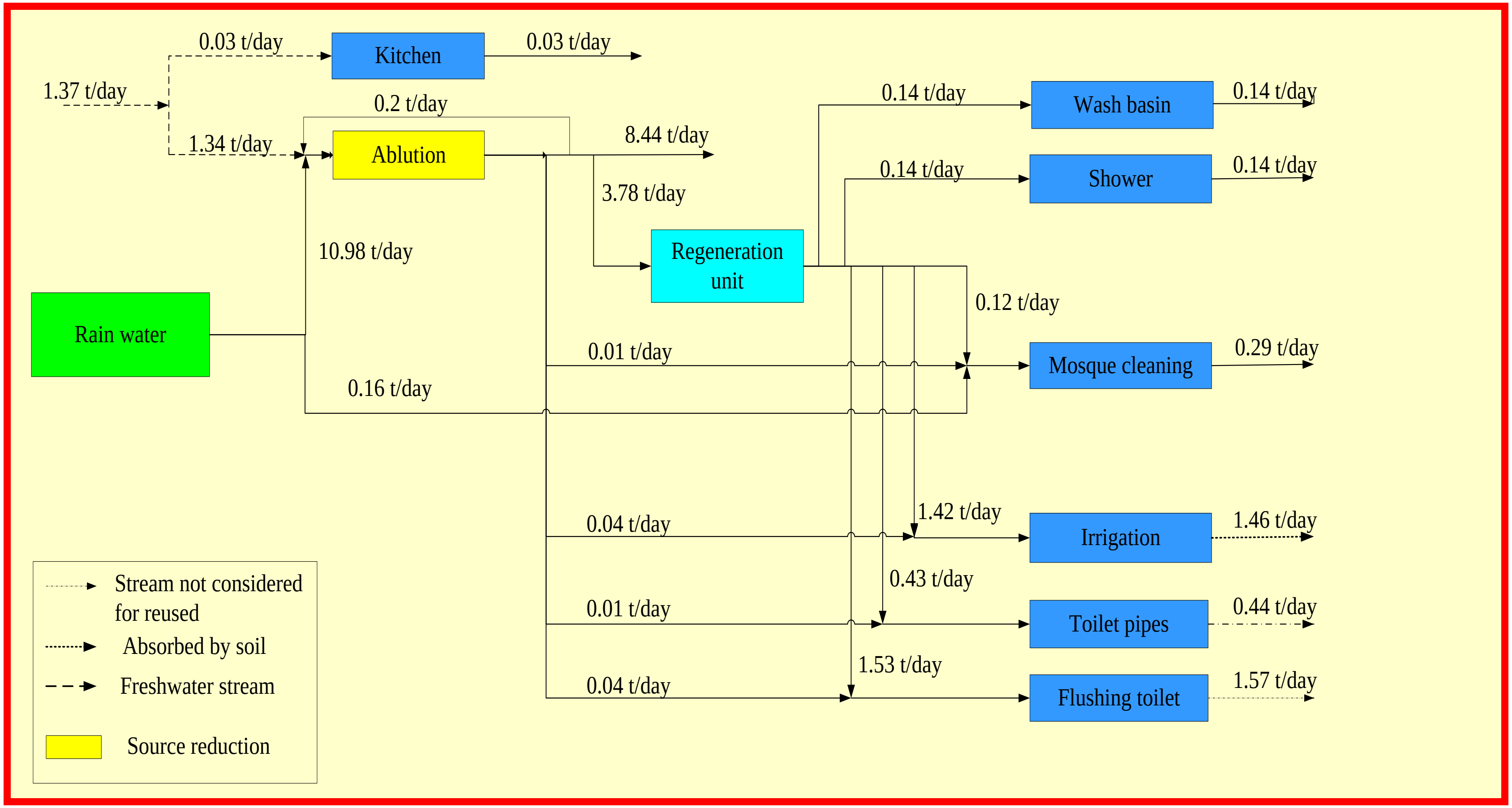
- Mainly used by the Muslim students and staff of UTM for prayer and educational activities
- Used for ablution, irrigation, shower, kitchen and toilet services as well as mosque cleaning (Wan Alwi, 2007)
- FW is supplied by SAJ and stored in four interconnected distribution tank
- The estimated fresh water usage for SIM is 11, 550 m^3/yr (Ujang and Larsen, 2000).



Water distribution for SIM



Optimal Water Network Design for SIM



Results

	Initial	MWR (Base-Case)	MODWN	
			Without setting payback period limit	Set payback period limit at 15 months
Water elimination (t/hr)	-	-	$D_{10} = 0$	-
Water reduction (t/hr)	-	-	$\alpha_{6,1}D_6 = 3.72$ $\alpha_{8,1}D_8 = 7.75$ $\alpha_{14,1}D_{14} = 0.16$	$\alpha_{6,1}D_6 = 3.72$ $\alpha_{8,1}D_8 = 7.75$ $\alpha_{14,1}D_{14} = 0.16$
Total reused/recycled water (t/hr)	-	2.13	2.53	2.03
Total external water sources (t/hr)	-	-	0.21	0.21
Total regenerated water (t/hr)	-	-	6.57	0.23
Total fresh water consumption (t/hr)	28.82	26.69	18.51	25.42
Total wastewater generation (t/hr)	9.44	7.31	0	6.83
Net annual savings (USD/yr)	-	-	105,383	33,589
Net capital investment (USD)	-	-	197,183	41,986
Total payback period (yr)	-	-	1.87	1.25

Highlights of other results

Handandi, Z.B., Wan Alwi, S.R., Hashim, H., ***Z.A. Manan****, Holistic Approach For Design Of Minimum Water Networks Using The Mixed Integer Linear Programming (MILP) Technique, Industrial and Engineering Chemistry Research, Volume 49, Issue 12, 16 June 2010, Pages 5742-5751.*

Industry & Urban Cases

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FW reduction: 95.3 %
WW reduction: 64.7 %
Net annual savings = USD 5, 400 /year
Payback period = 5 years

SEMI-CONDUCTOR PLANT
FW reduction: 85.1%
WW reduction: 97.7%
Net annual savings = RM 190, 000 /year
Payback period = 4 months

CHLOR ALKALI PLANT
FW reduction: 35.8%
WW reduction: 100%
Net annual savings = USD 105, 000 /year
Payback period = 1.87 years

MALAYSIAN NEWSPRINT INDUSTRIES

PAPER MILL PLANT
FW reduction: 14%
WW reduction: 14%
Net annual savings = USD 150, 000 /year
Payback period = 1.5 years

Optimal Water – Tool for Holistic Water Minimisation

OPTIMAL WATER

Economic analysis – Payback period, NPV, ROI

Rainwater harvesting potential calculator

Water regeneration potential calculator

Target the maximum water reuse potential

Design Water Network System

Explore Various WM Options using WM Hierarchy

Advantages-Disadvantages of MODWN & CEMWN

MODWN		CEMWN	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
Can handle multiple contaminants problem	Not providing good insight to designer during network synthesis	Provides an interactive, quick and efficient guide to screen design options involving process changes	Only applicable for single contaminant system
Considers simultaneously all factors that contributes to overall network cost effectiveness	Very dependent on good starting points and do not always guarantee global optimum	Help in getting physical insight of the problem through graphical procedures	Tedious graphical step and manual heuristic procedures
Decision tool to decide an appropriate water management schemes to be implemented			Only suitable for simple systems with simple constraints
Minimum water targets and design an optimal water network is generated simultaneously			

WATER SUSTAINABILITY via *HOLISTIC* WATER MINIMISATION

Safeguard company's license to operate

Reduce purchasing, treatment and discharge cost

Avoid production disruption

Protects the environment

UTM
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PROSPECT
PROCESS SYSTEMS ENGINEERING CENTRE
engineering sustainability

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Industry;

Public & Commercial Facilities;

Domestic & Individuals

Holistic Water Minimisation

The Good & The Bad in UTM

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Key Take Home Messages

- ❑ **Water shortage – one of the world's biggest risk**
- ❑ **Engineer water sustainability via Holistic WM [subject to W3E nexus impact]**
- ❑ **Apply the winning strategy of blending power with Insights**

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Ministry of Higher Education (MOHE) MALAYSIA

A Huge Thank You, and Congratulations to…

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