Design of a water reuse network in an industrial site in Kenya

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Technical University of Denmark

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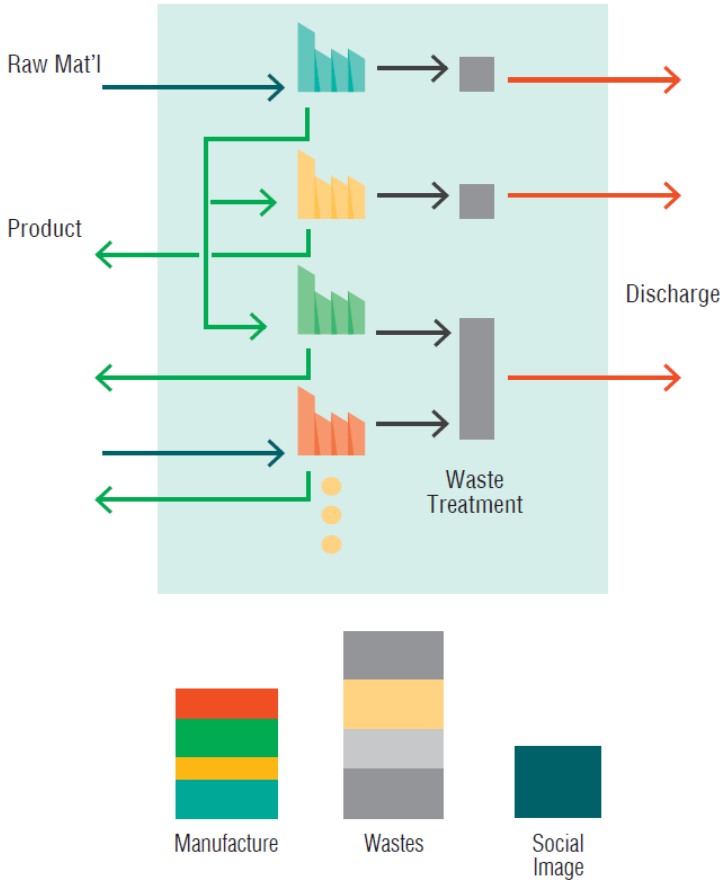
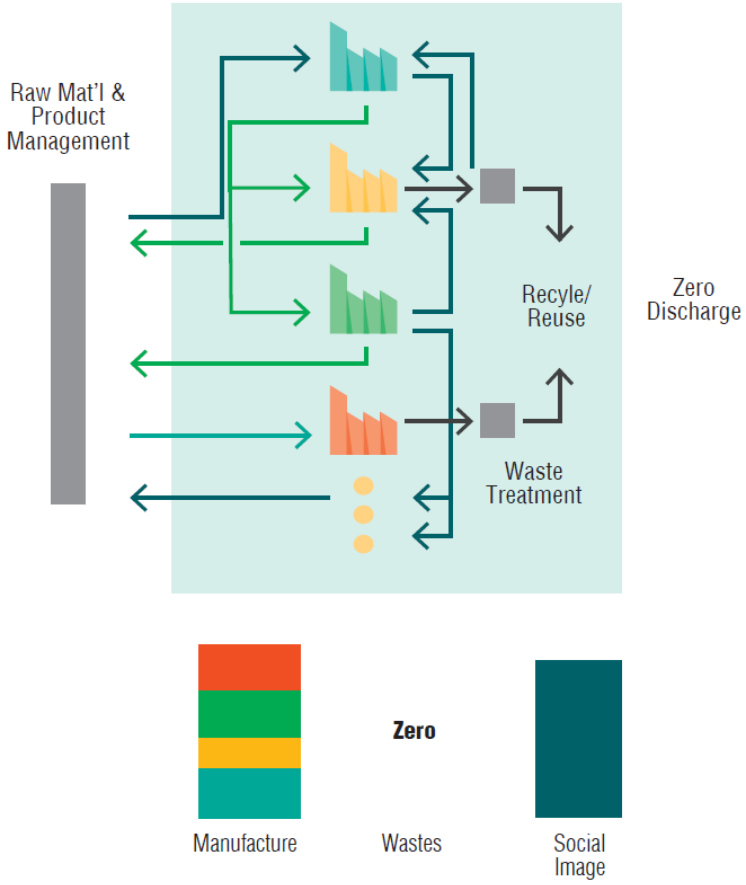
Eco-industrial Park



Present Industrial Park

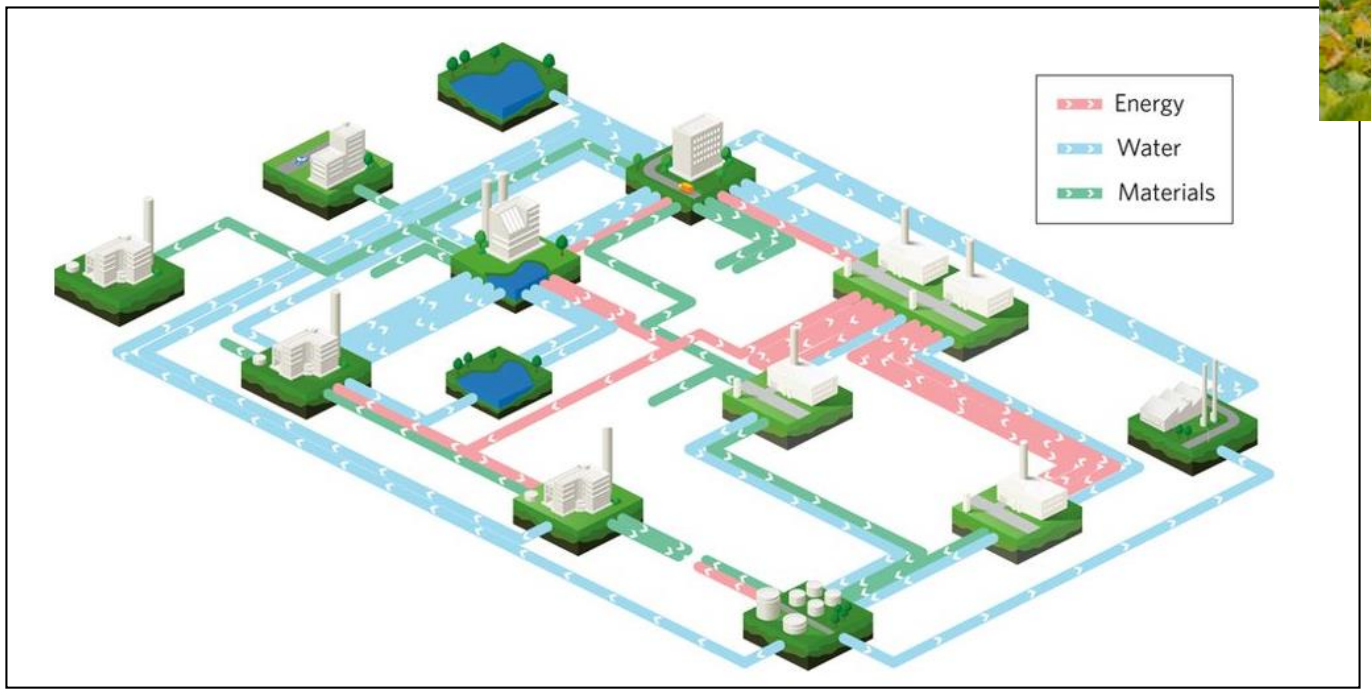


Eco- Industrial Park

Source: Lee in Chiu 2015

Example – Kalundborg (DK)

Source: Symbiosis Center Denmark



Source: Ibrahim, Nadine. "Mitigation: Decarbonization unique to cities." Nature Climate Change 7.10 (2017): 690.

GECKO Project

Maj Munch Andersen

Krist V. Gernaey

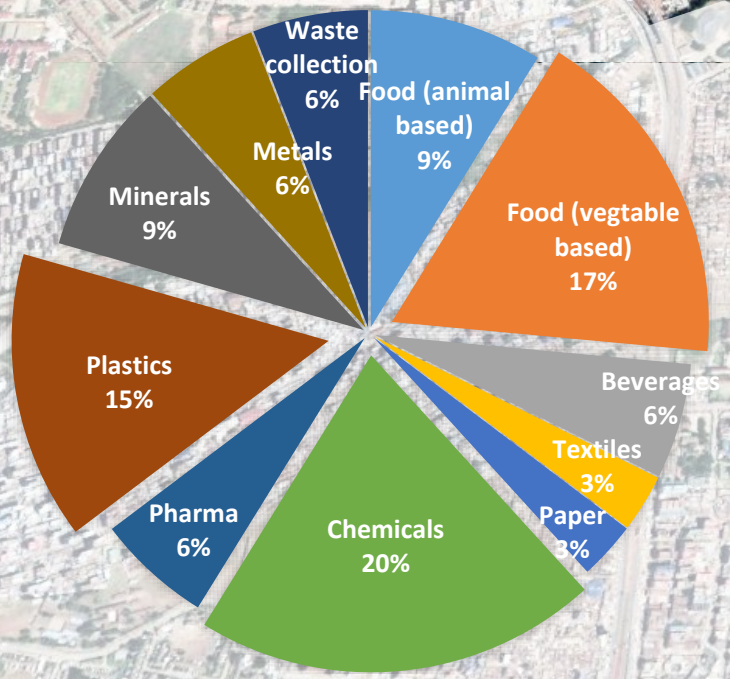
Kelvin Khisa, KIRDI

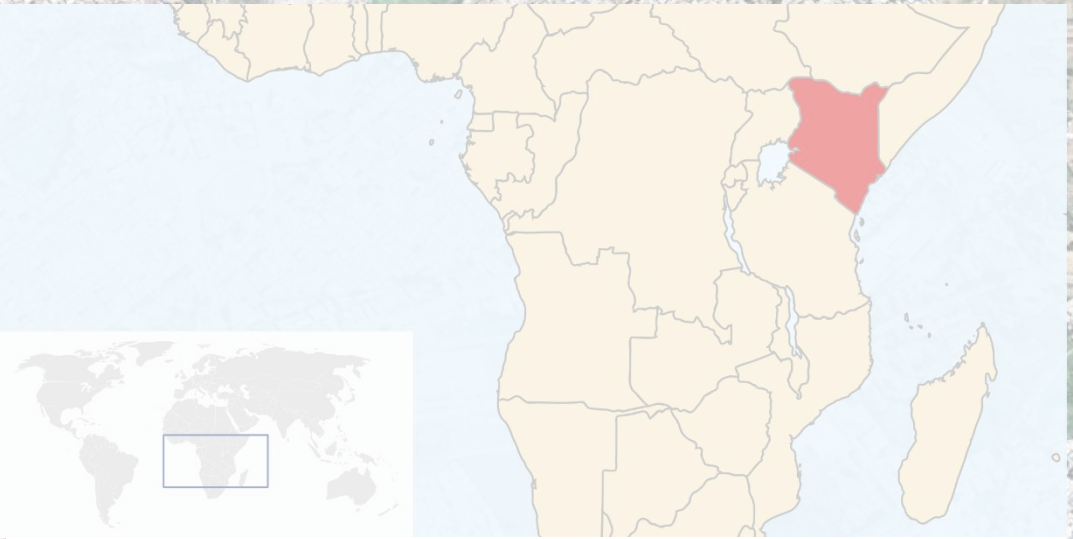
- Danida funded 2-year pilot research project
- Duration: April 2018- March 2020
- Aims to provide the scientific knowledge base to develop a national strategy for designing and projecting high-circular eco-industrial parks (industrial symbiosis) in Kenya

<u>Objectives:</u>

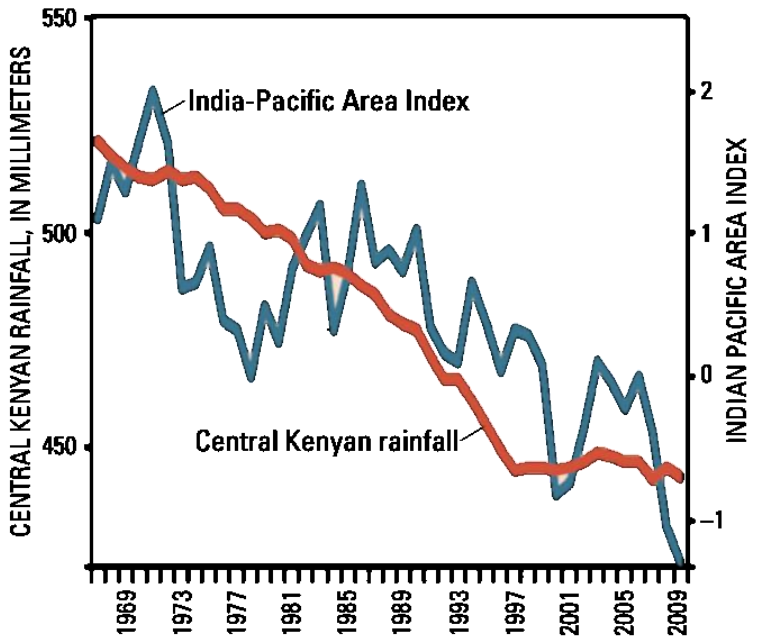
- Business research (WP2)
- Governance research (WP3)
- Technical feasibility studies of selected symbiosis solutions (WP4)
- **System modeling of symbiosis solutions** (WP5)

Ruaraka industrial park



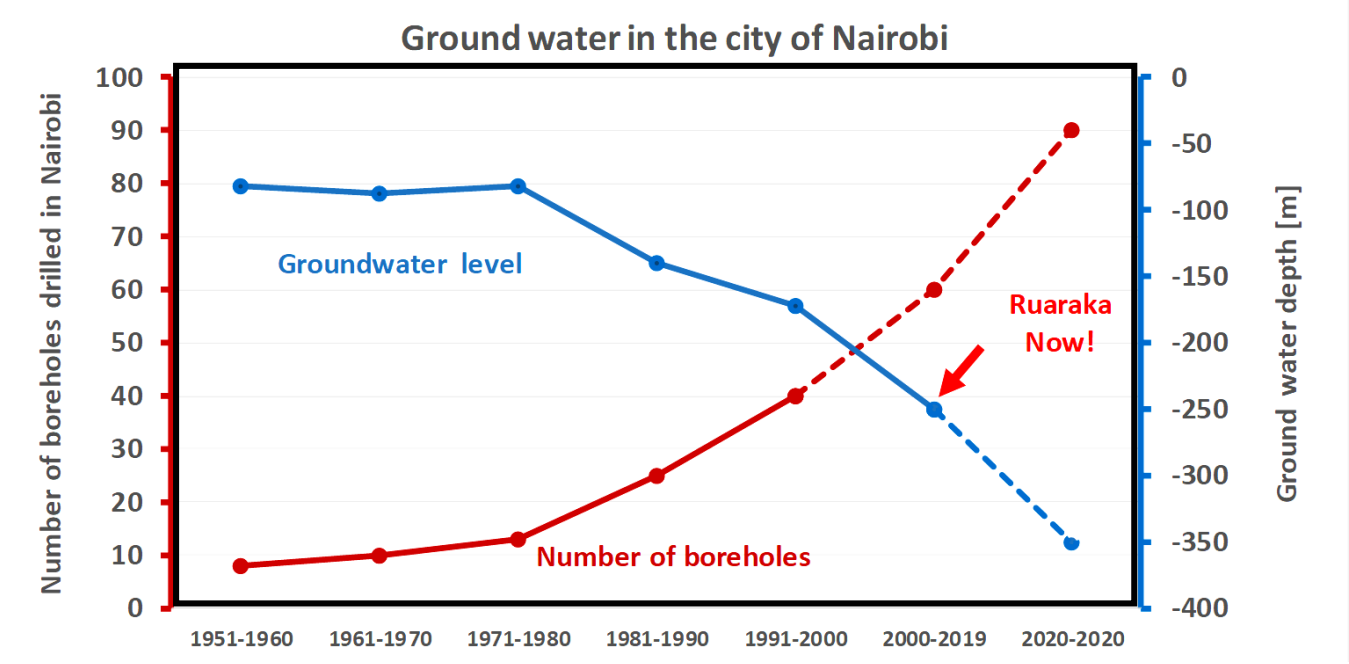


Rainfall in Kenya



(Source: UNEP-NET)

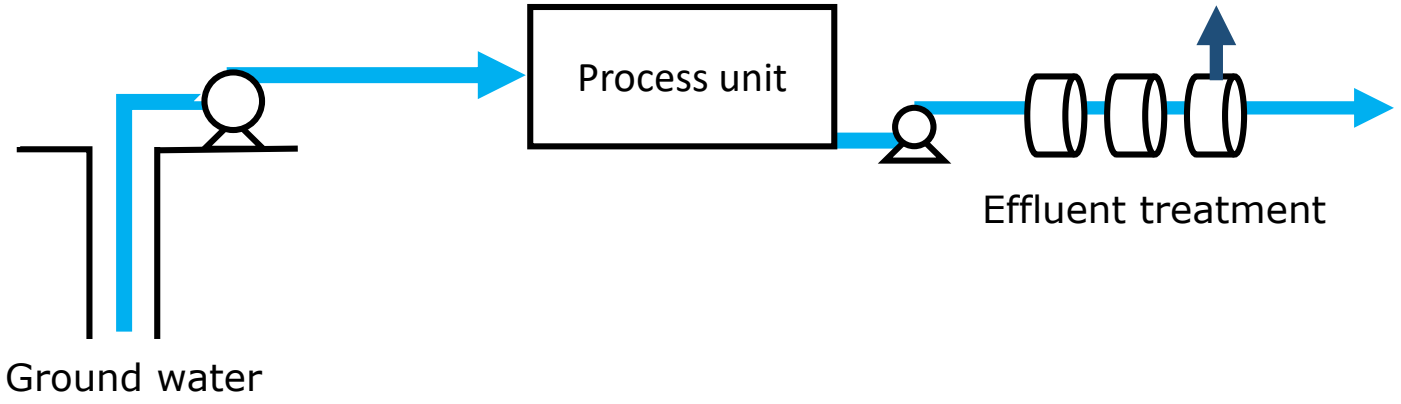
Groundwater level in Nairobi

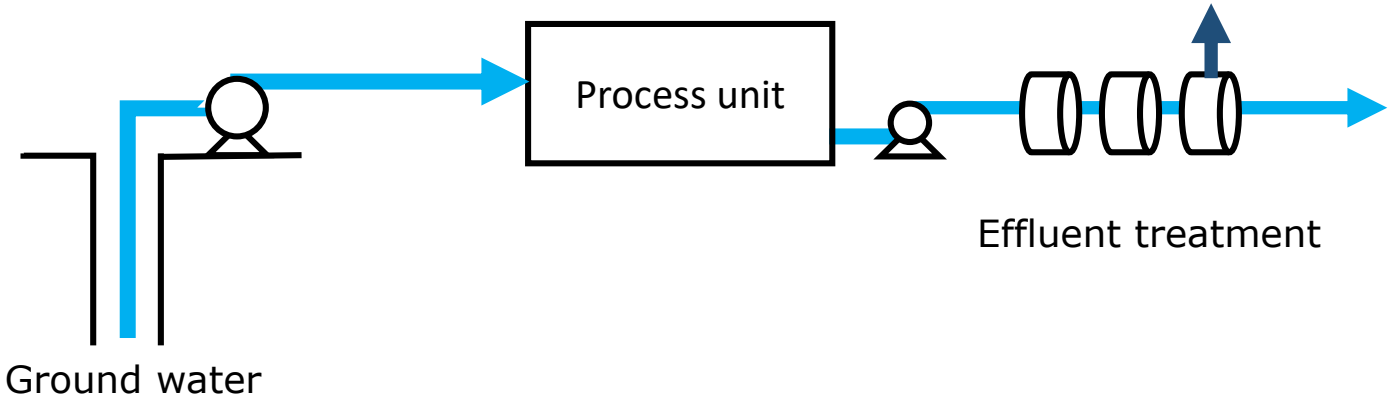


Case Study

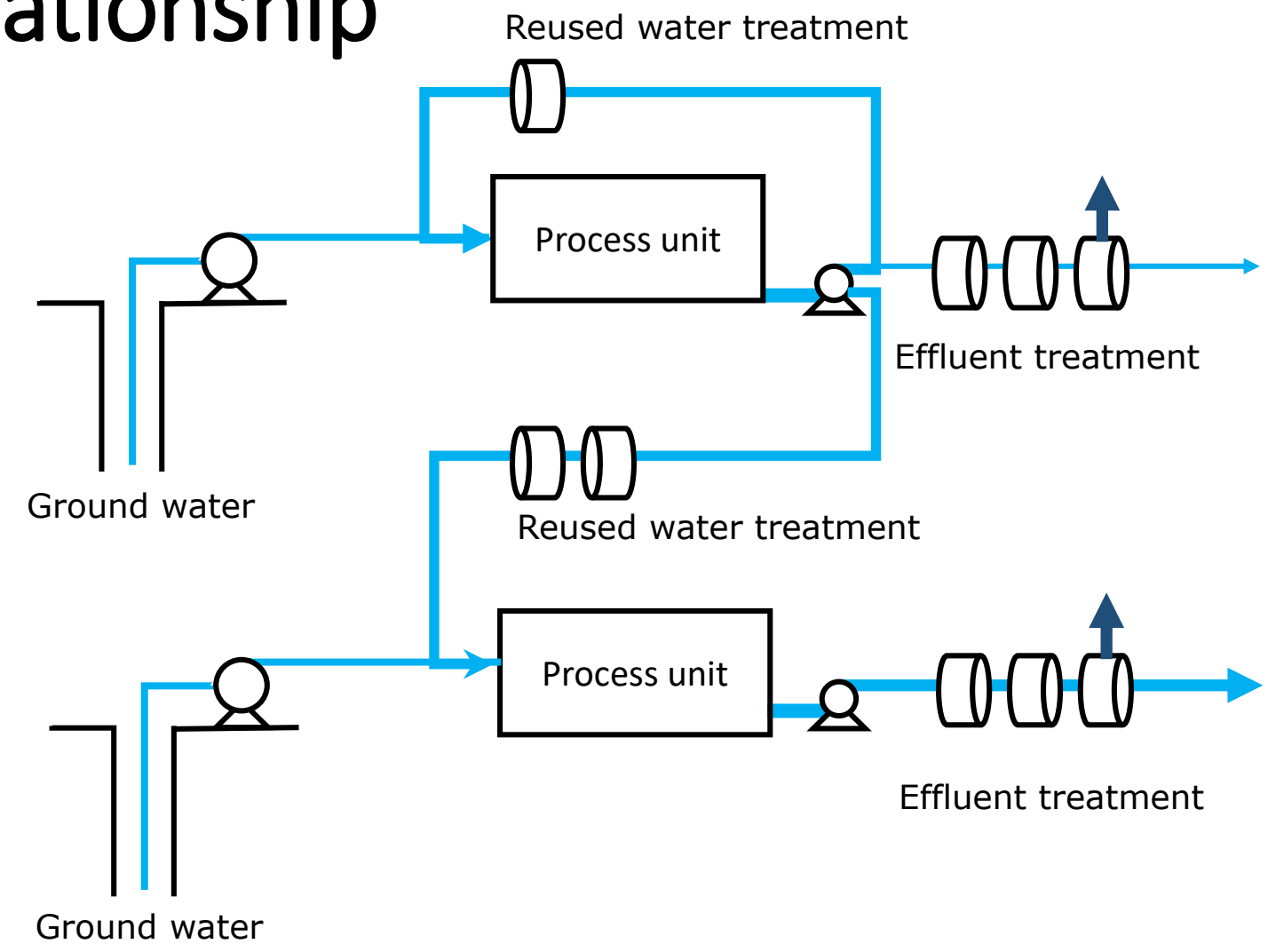
Companies	Units	Water use m^3/d
A	Cooling Boiler	1000 500
B	Washing	126
C	Boiler	150
D	Process	550
E	Process Boiler	420 200

Existing Situation





Symbiotic Relationship



Water Treatment for Reuse

	Chemical Treatment	Ultra Filtration	Forward Osmosis
COD removal	80%	50%	90%
TSS removal	50%	80%	90%
TDS removal	10%	20%	95%
Unit cost	0.1 $/m^3	0.2 $/m^3	0.4 $/m^3

Cost Functions

Total cost = Annualized capital cost + yearly operating cost

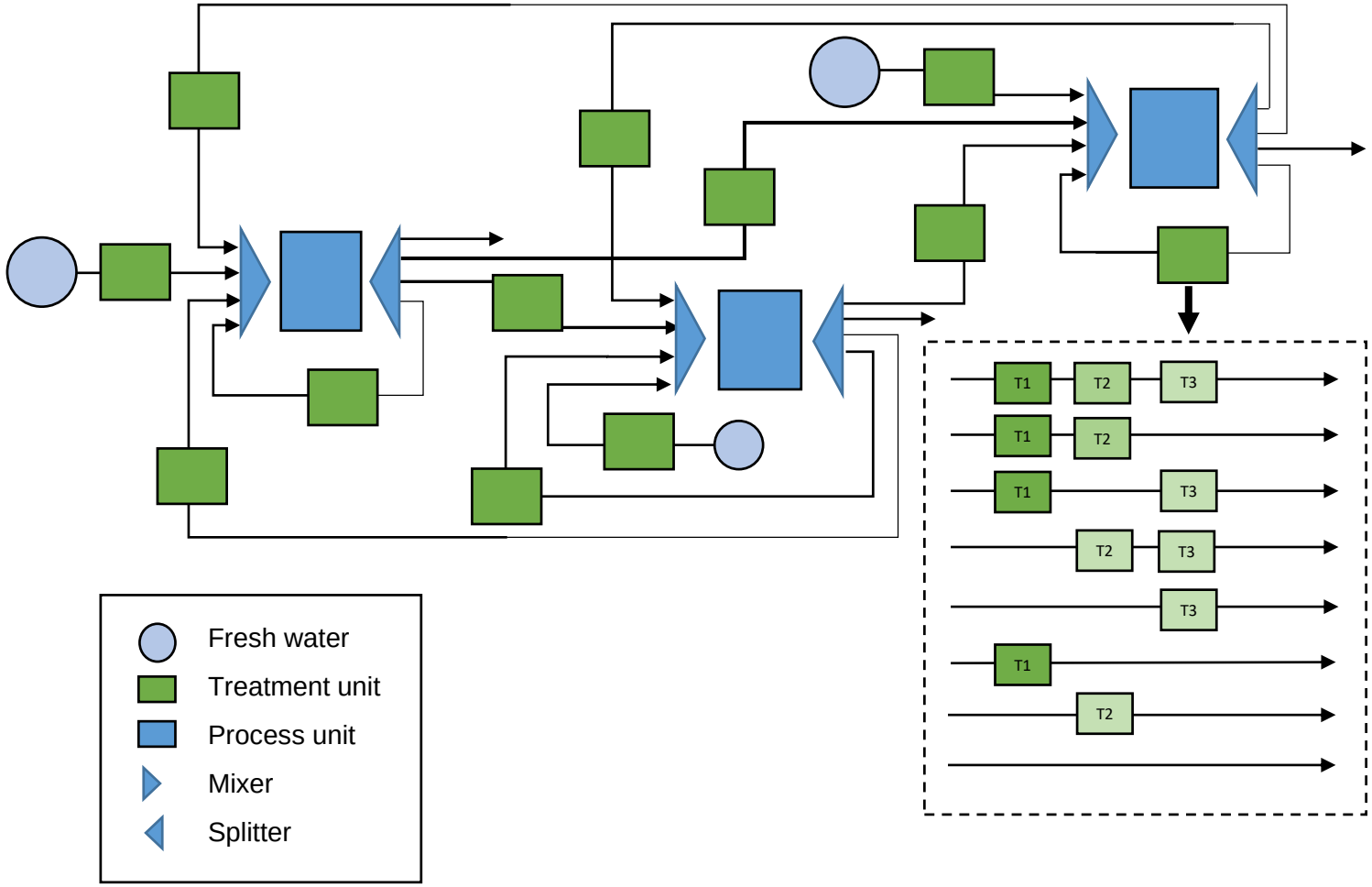
1. Water supply: Borehole drilling + Equipment + Pumping
2. Network = Pipes + Pumps + Treatment Units

    12% discount rate

    20-year life time

- Maintenance: 5% of capital cost

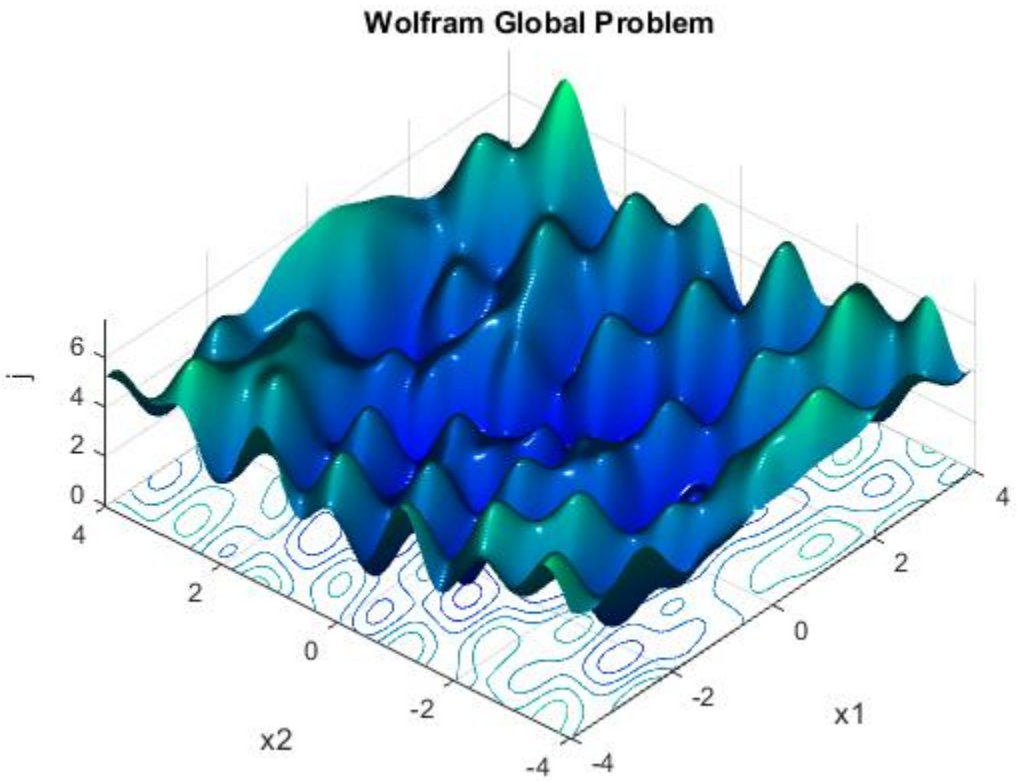
Optimization – Model Superstructure



Optimization – Deterministic Approach

Non-Convex Mixed Integer Nonlinear Program (MINLP)

$$
\begin{aligned}
\min_{\mathbf{x}} \; & f(\mathbf{x}) \\
\text{subject to: } & \mathbf{A}\mathbf{x} \leq \mathbf{b} \\
& \mathbf{A}_{\text{eq}}\mathbf{x} = \mathbf{b}_{\text{eq}} \\
& \mathbf{l}_{\text{b}} \leq \mathbf{x} \leq \mathbf{u}_{\text{b}} \\
& \mathbf{c}(\mathbf{x}) \leq \mathbf{d} \\
& \mathbf{c}_{\text{eq}}(\mathbf{x}) = \mathbf{d}_{\text{eq}} \\
& x_i \in \mathbb{Z} \\
& x_j \in \{0, 1\}
\end{aligned}
$$



Optimization – Metaheuristic Approach

Non-dominated sorting genetic algorithm – NSGA II (Deb et al, 2002)

Advantages

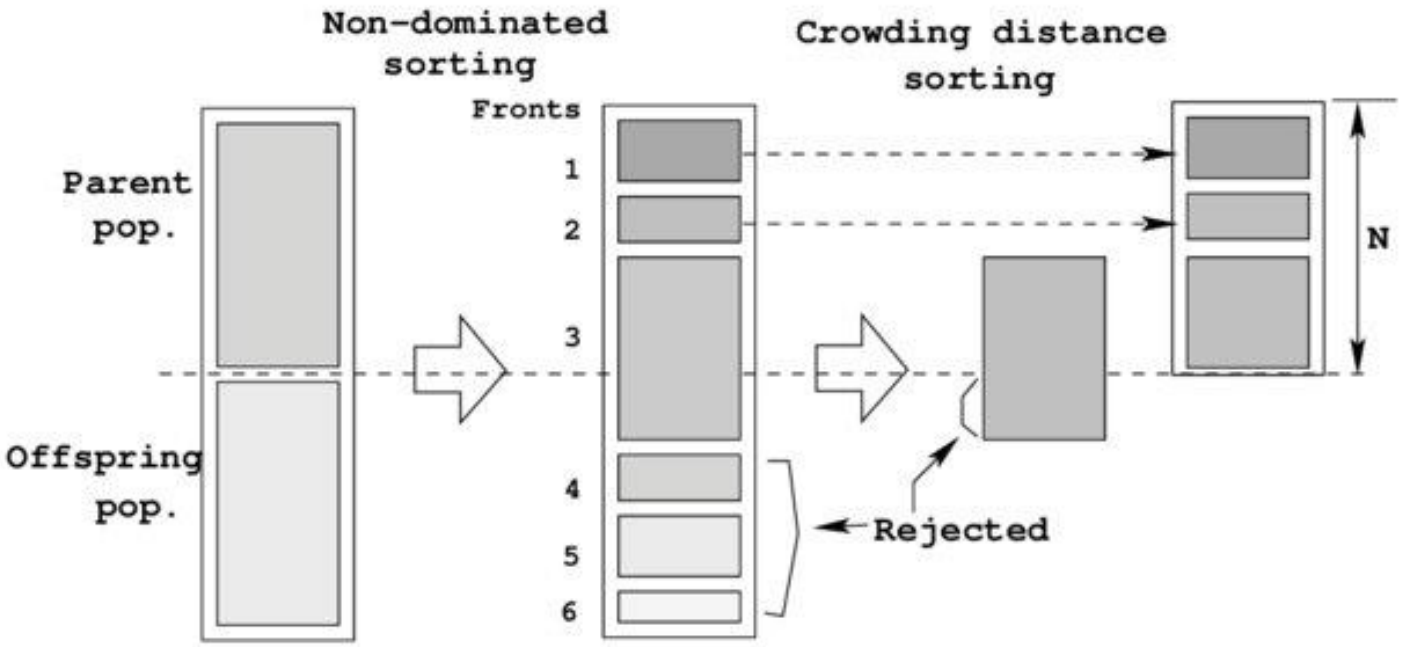
- Not problem specific
- “Hill climbing” method
- Higher stability

Disadvantage

- Premature convergence
- Near optimum solution

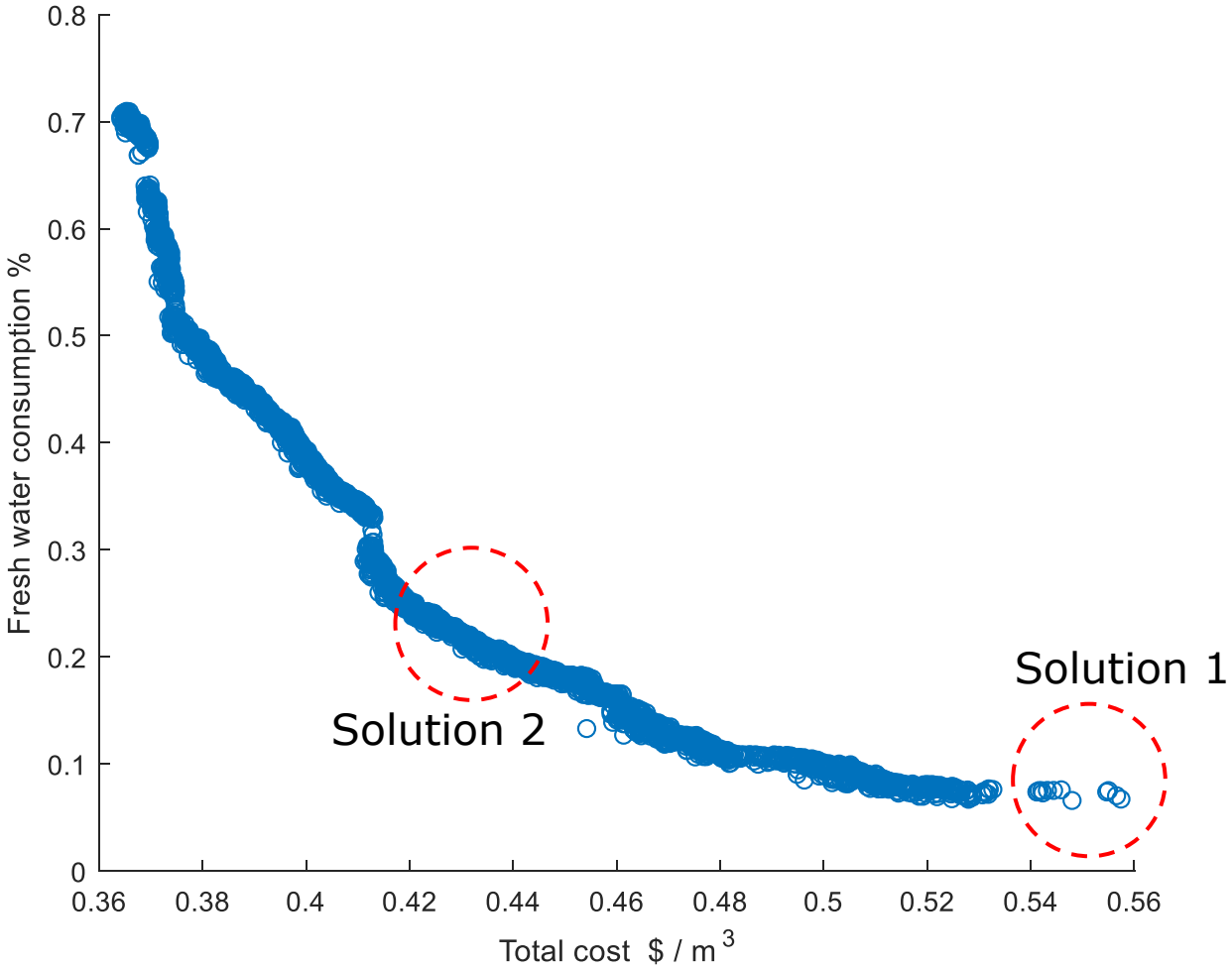
Further improvements

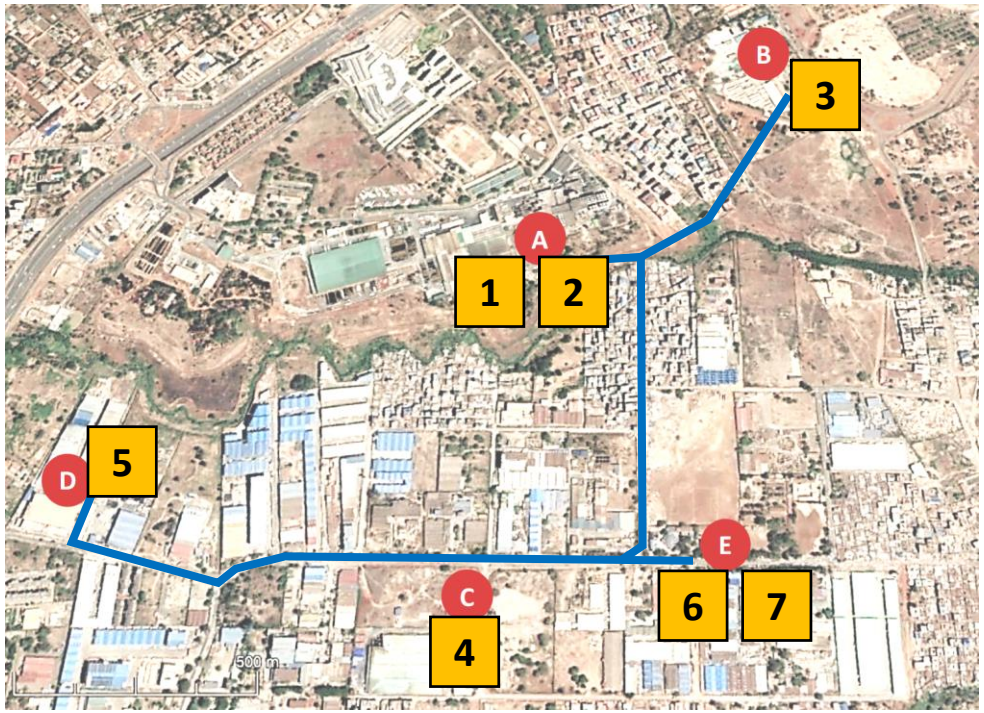
- Initialization of population
- Adjusting GA parameters



Deb, Kalyanmoy, et al. "A fast and elitist multiobjective genetic algorithm: NSGA-II." *IEEE transactions on evolutionary computation* 6.2 (2002): 182-197.

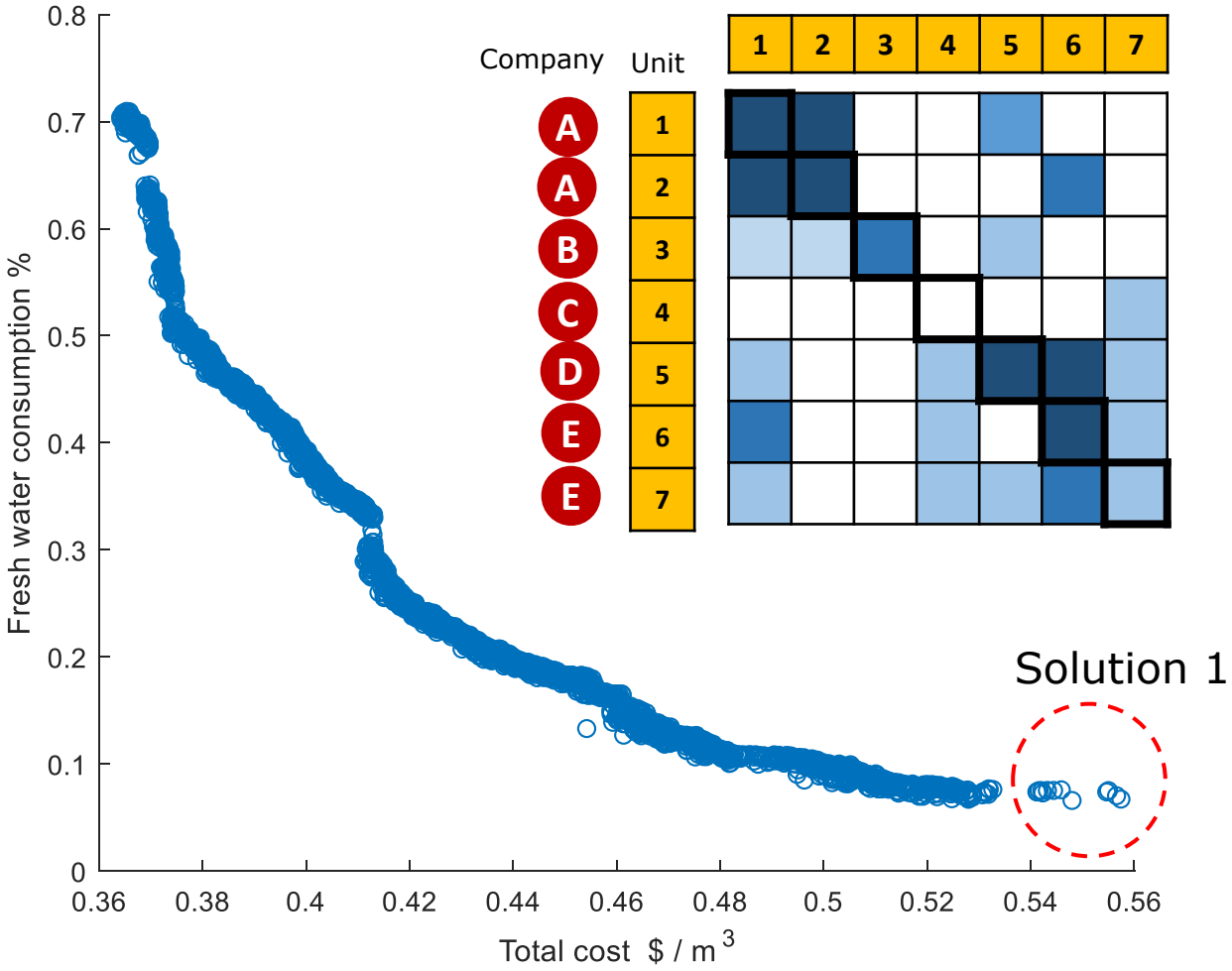
Solutions – Pareto Front

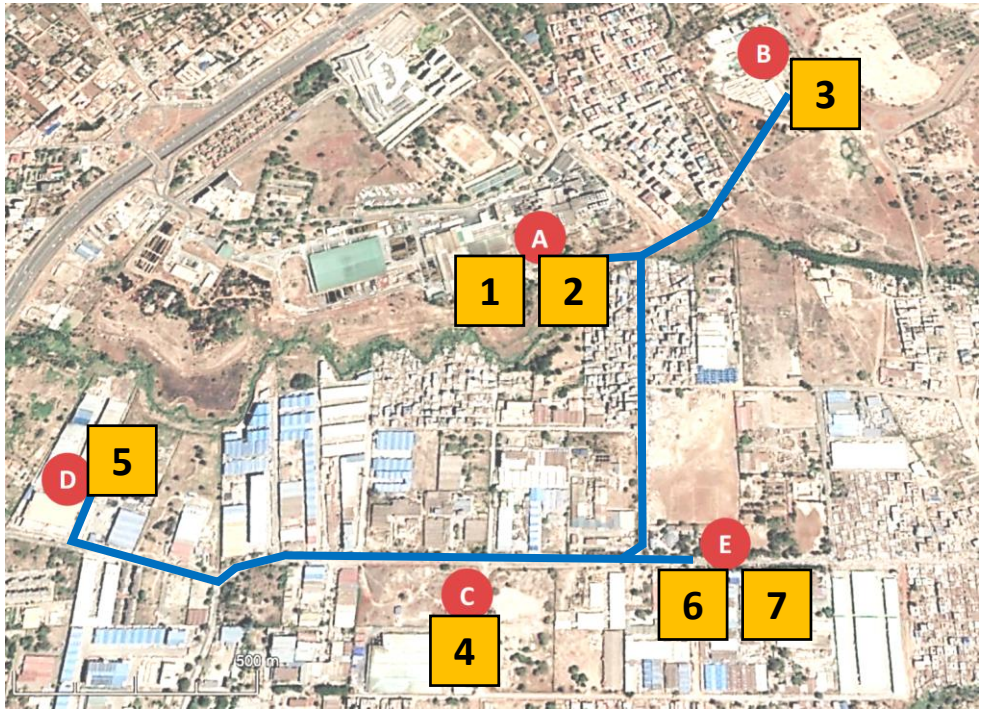




Solution 1

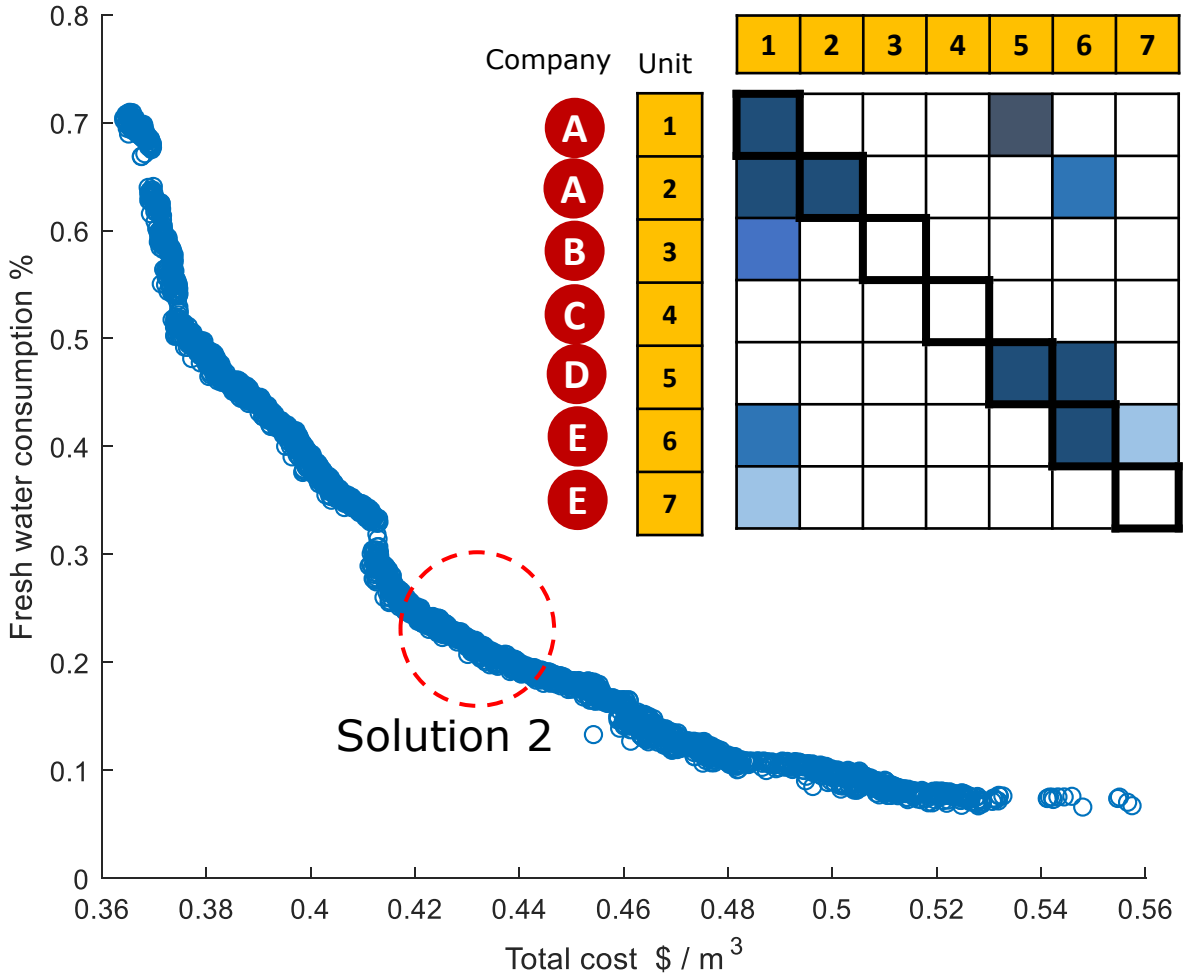
	Flow	Pipe diameter
	> 100 m^3/d	90 – 160 mm
	50 – 100 m^3/d	50 – 75 mm
	< 50 m^3/d	< 40 mm

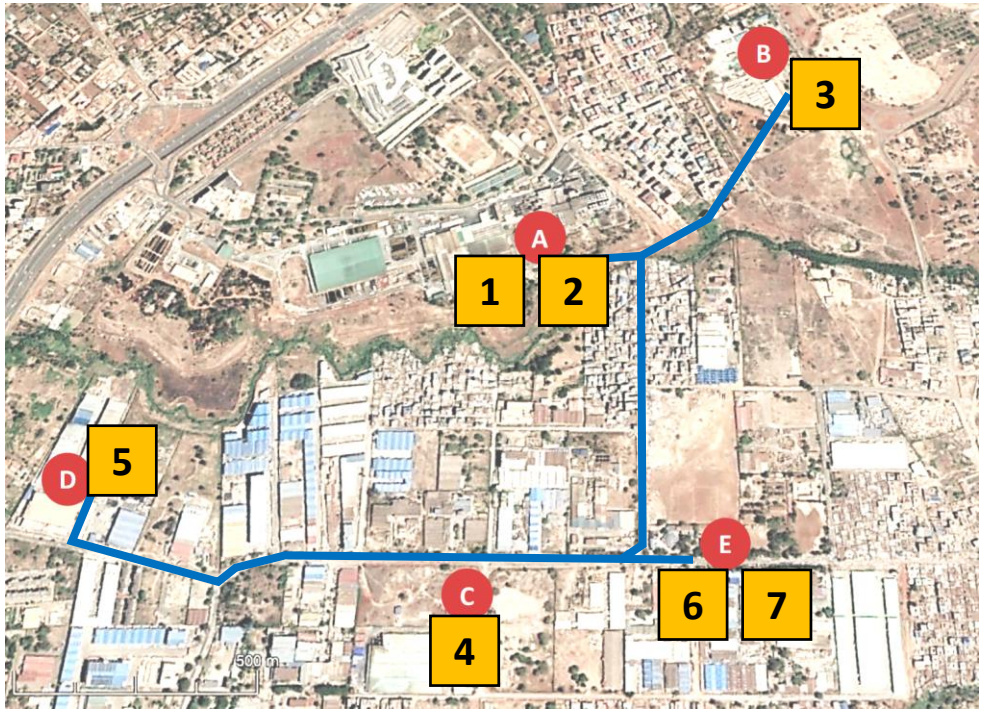




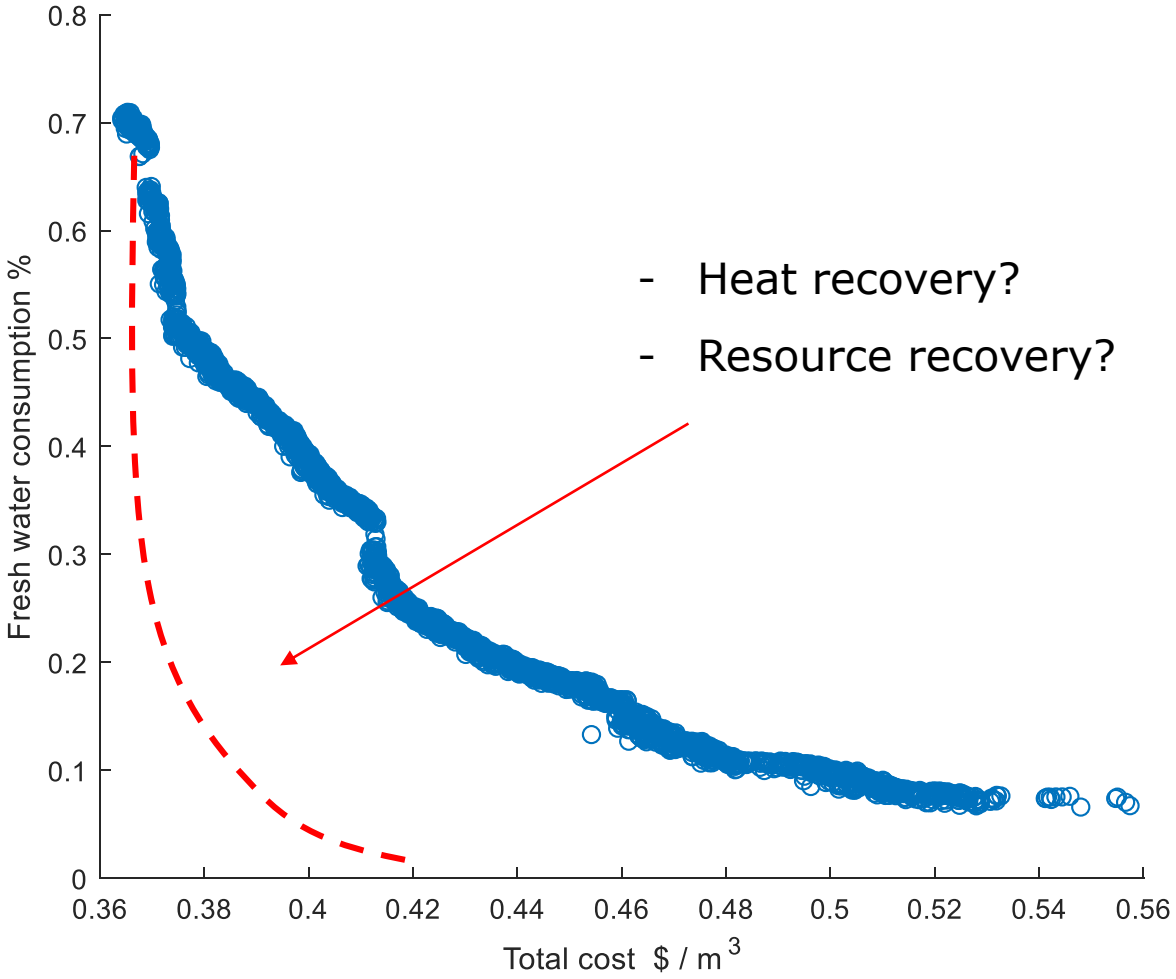
Solution 2

	Flow	Pipe diameter
	> 100 m³/d	90 – 160 mm
	50 – 100 m³/d	50 – 75 mm
	< 50 m³/d	< 40 mm





Improving Economic Viability



- Heat recovery?
- Resource recovery?

Challenges

Data quality

Static versus dynamic

The resilience measure

Flexibility

Denmark

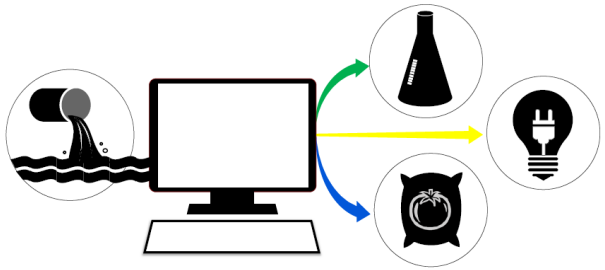
Symbiosis Center Denmark

Kenya

Google image

Conclusions

- Metaheuristic optimization approach shows high potential in water saving using water reuse network in an existing Kenyan industrial site
- The economic burden of water reuse can be decreased by recovering heat and valuable components from water (resource recovery)
- The metaheuristic approach can be used to perform uncertainty and flexibility assessments of water reuse networks



A New Danida project in South Africa:

Evaluation of Resource recovery Alternatives in South African water **(ERASE)**

Thank you for your attention!

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