SYSTEMS MODELING

WATER SCARCITY CAPE TOWN, SOUTH AFRICA

Graywater and Rainwater to Enhance Local Supply

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Executive Summary

- Model:

  Community = 100 households

  Monthly demand and rainfall resolution

- High-dependency on municipal supply
- **Community Gray Water** is the most <u>cost-effective</u>
- We can reduce demand by 50% and save $60,000 in 5 years

- Individual household graywater is cost prohibited under most scenarios
- Scenarios where rain harvesting is selected have more contingencies
  - Increasing community size and payback period

Contents

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2. Model
3. Results
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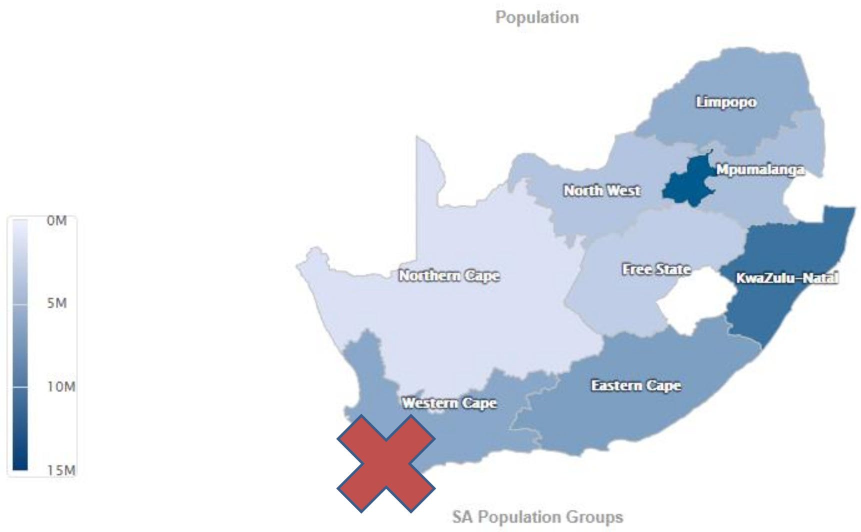
5. Conclusions

Statistical Overview

South Africa has recently faced challenges providing enough water for its residents

Population	Urban
58 MM (2019)	63%



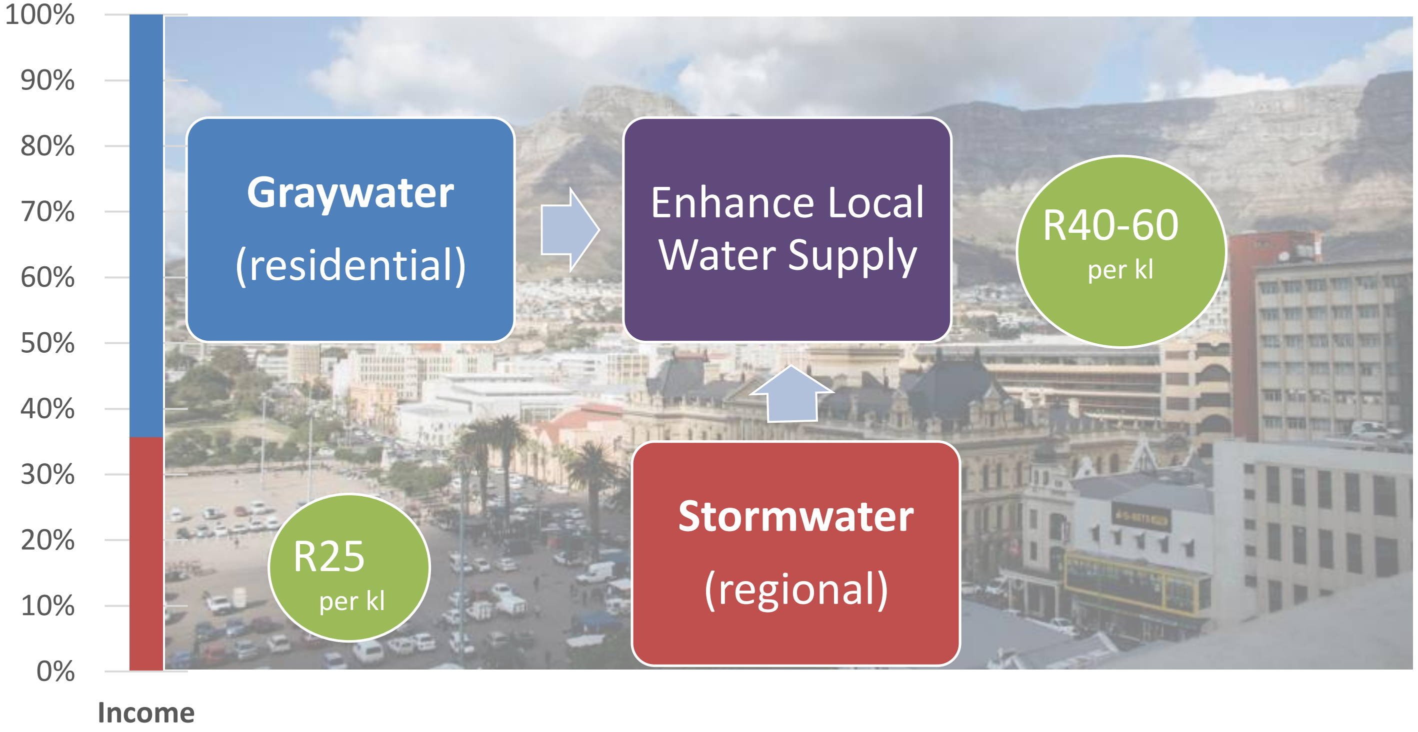
Cape Town's 1 MM households are almost entirely dependent on municipal supply

Source of water	Percentage
Regional/Local water scheme (operated by municipality or other water services provider)	97,3%
Borehole	0,5%
Spring	0,1%
Rain water tank	0,1%
Dam/Pool/Stagnant water	0,1%
River/Stream	0,1%
Water vendor	0,3%
Water tanker	0,4%
Other	1,1%

Sources: Stats SA, World Population Review

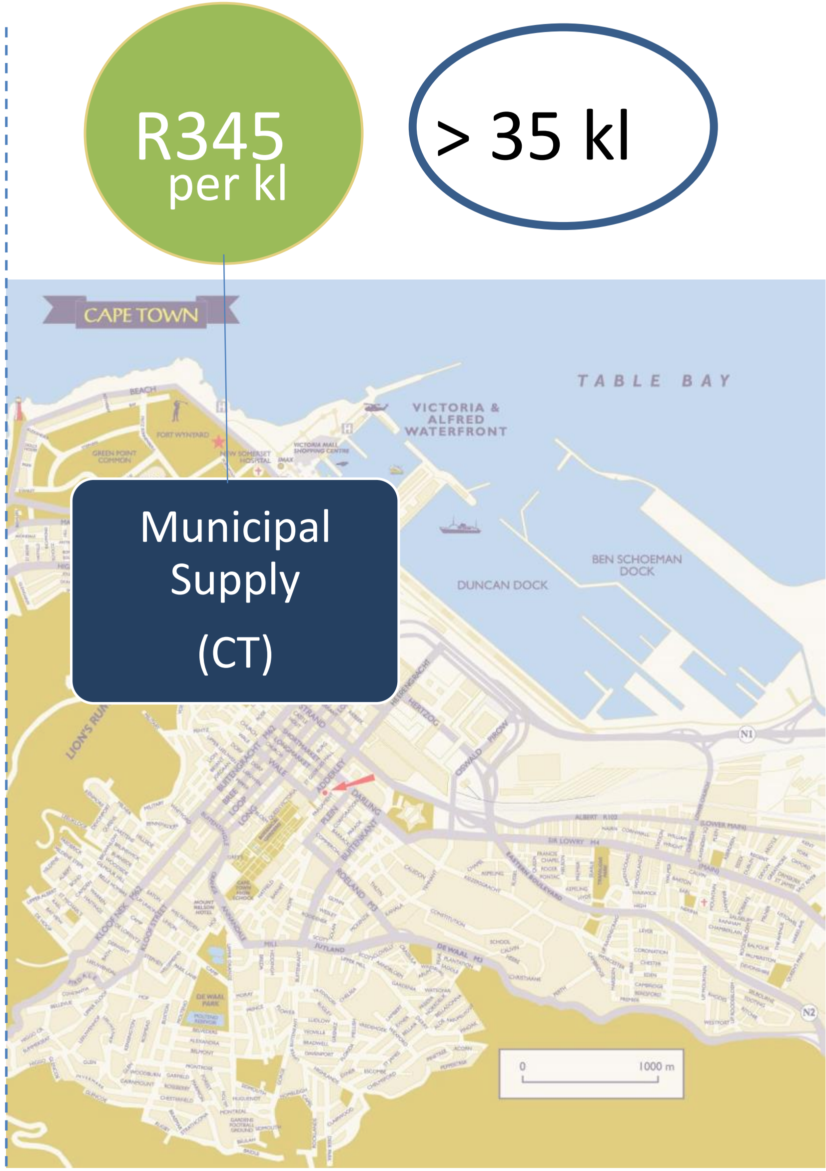
What We Want To Do…

Save water and **$X**



■ > R $3,500
■ < R $3,500

~ $250 USD per month



Water Tariff System

Monthly Residential Water Tariffs*

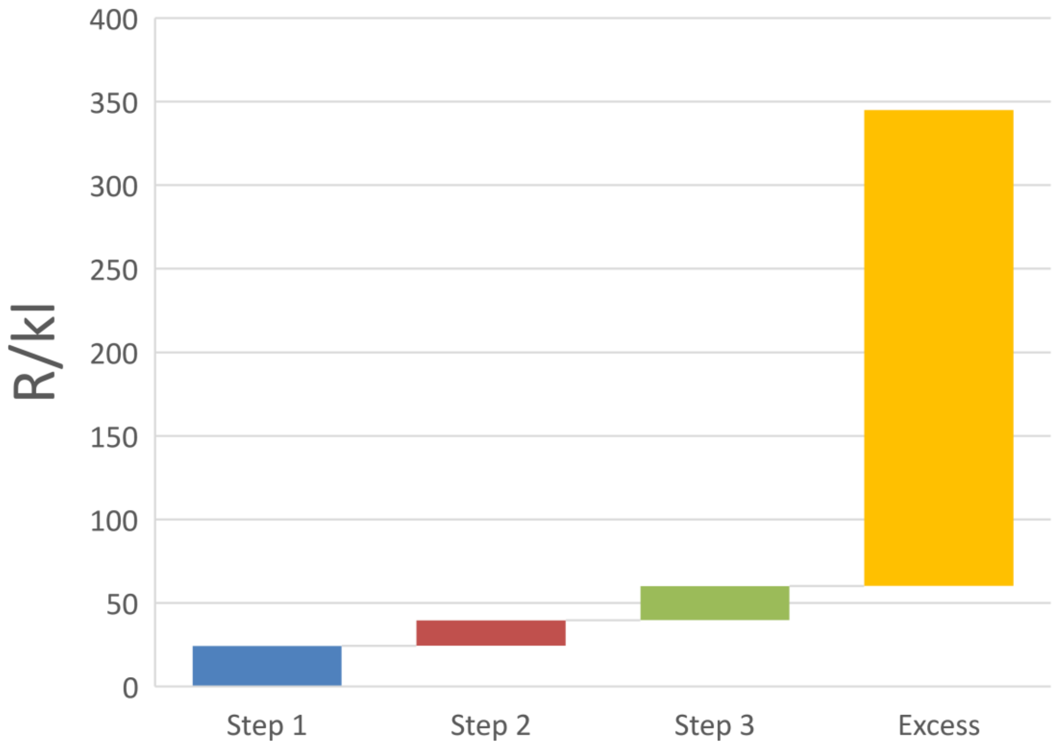
Step #	Volume [kl]	2018-2019 [R/kl]	Tariff Δ%
1	6	25	-
2	10.5	40	50
3	35	60	60
4	**35+**	**345**	**475**

Lower income levels have lower tariffs but they also follow step-wise increases

1 USD = 14.5 R

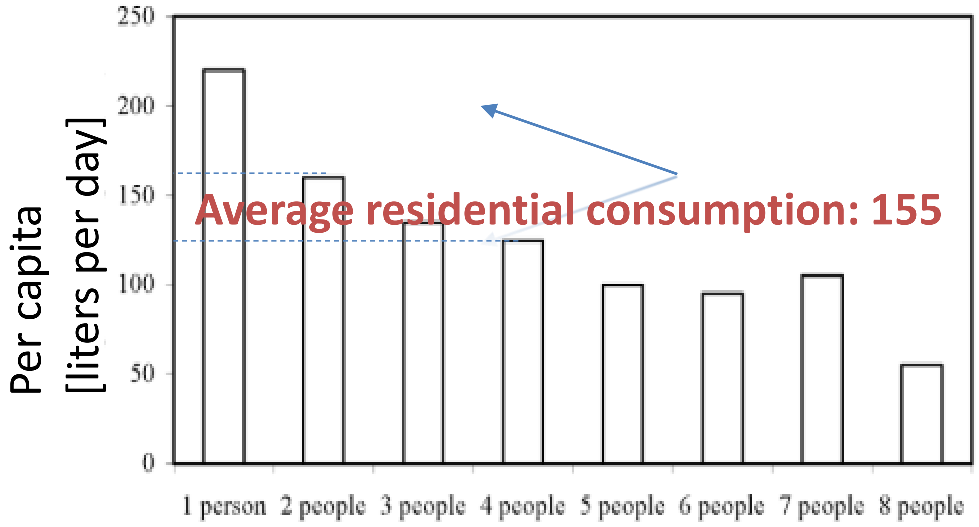
*Level 5: High Income (rounded)

Municipal supply **price signals** highlight need for sustainable water management



Western Cape: Urban and Climate Trends

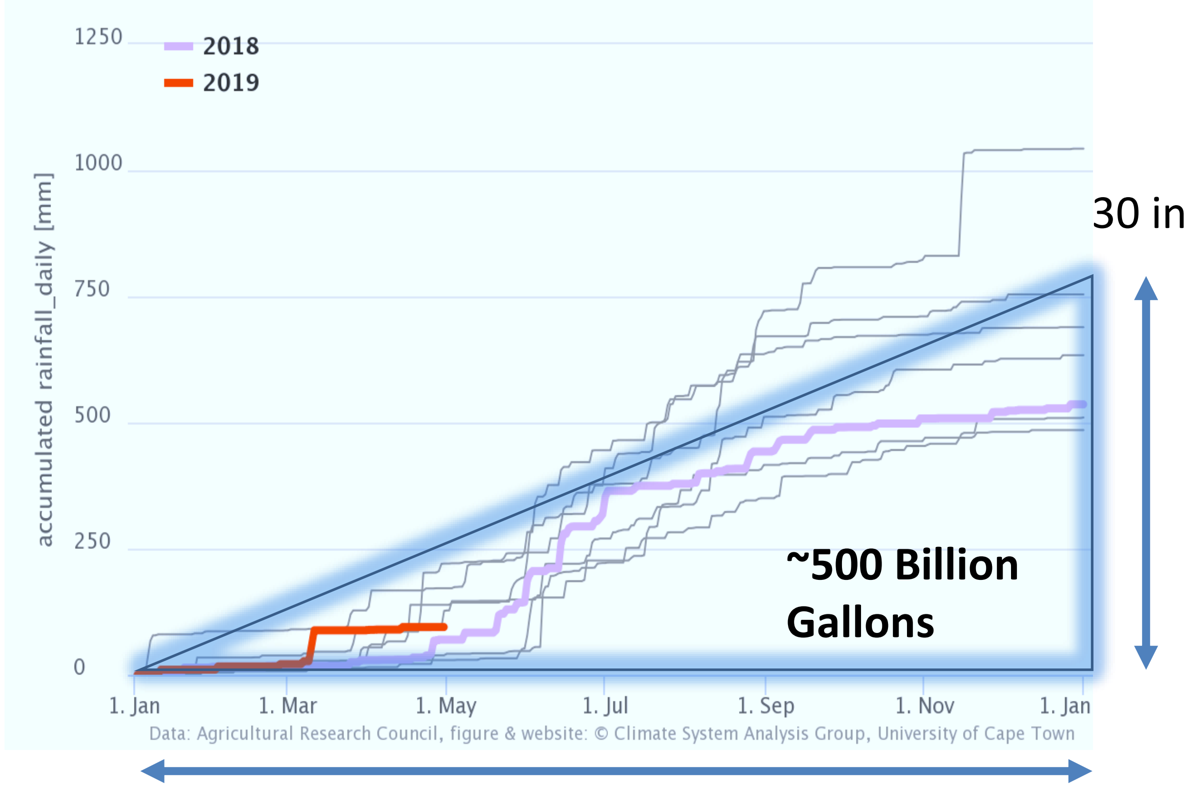
Greywater generation grows



→ 1 X 225	Per capita Δ	Net Δ
2 X 175	225-175 = 50	**100**
4 X 125	225-125 = 100	**400**

Figure 1.4 Impact of household size on per capita consumption (Edward and Martin, 1995).

Shrinking **stormwater** potential due to declining accumulated rainfall levels

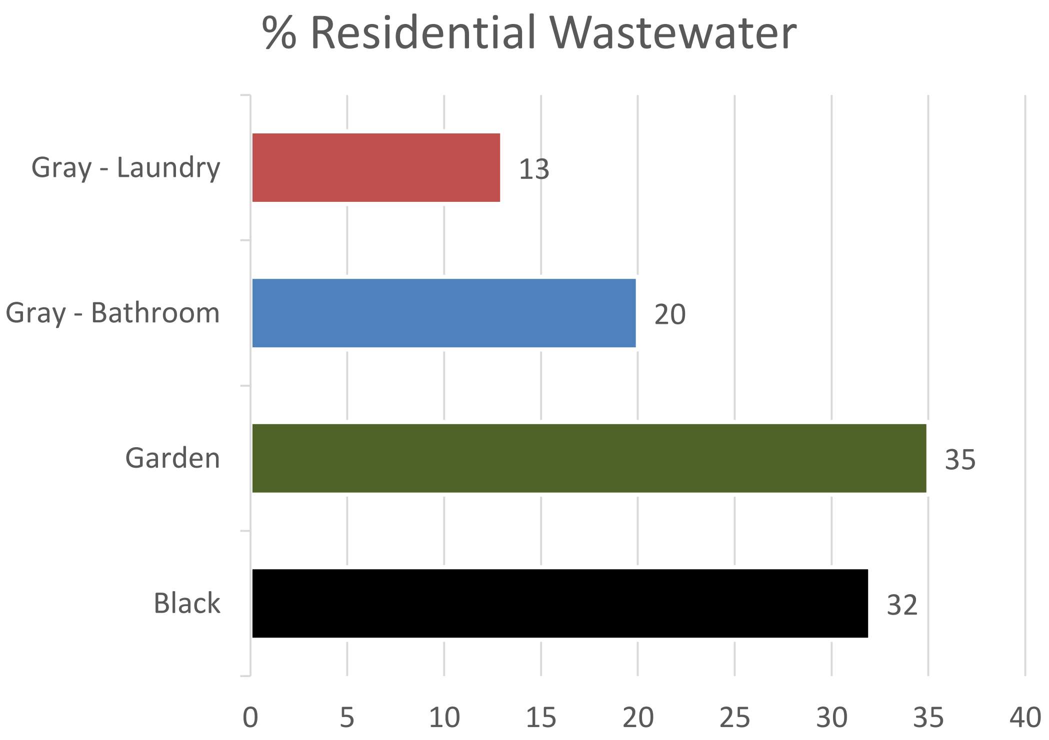


365 days

What is Gray Water?

No: Toilet, Kitchen

Yes: Sinks, Showers, Bathtubs, Washers



Outdoor	Indoor
Pumps	
Pipes	
Storage	
	Filters

$2,300 for a 5 person HH (Pumps, Pipes, Storage)

Filters: Up to $15,000

Average Annual Household Demand
[kl/year]

	Low	Base	High
Indoor	4.4	6.9	9.9
Outdoor	2.4	3.7	5.3
Total	**6.8**	**10.6**	**15.2**

People per household

Model Assumptions

1. Household Rainwater Harvesting (Outdoor Use only)
   - Like most systems
   - Note: Restricted the choice to a 1000 gallon tank only
2. Household Rainwater Harvesting (Indoor and Outdoor Use)
   - Like some systems in South Australia
   - Note: restricted tank size to 500 gallons; can add more later.
3. Household Greywater Recycling (Outdoor Use only)
   - Like systems in Australia
4. Community Scale Stormwater Recycling (Outdoor Use only)
   - Not done too many places
   - Assumed that the system can hold the average monthly rainfall
5. Community Scale Greywater Recycling (Indoor and Outdoor Use)
   - Like the Vitter paper also not done too many places.

Mathematical Formulation

Objective Function

$$\min\ c_{rho}x_{rho} + c_{rhi}x_{rhi} + c_{csw}x_{csw} + c_{cgw}x_{cgw} + c_{hgw}x_{hgw} + f_{rho}y_{rho} + f_{hgw}y_{hgw} + f_{cgw}y_{cgw} + f_{rhi}y_{rhi} + f_{csw}y_{csw} + c_e e_t$$

s.t.

$$\sum x_i \geq D_i$$

$$x_i \leq f_i(D_{cw} - l_{cw})$$

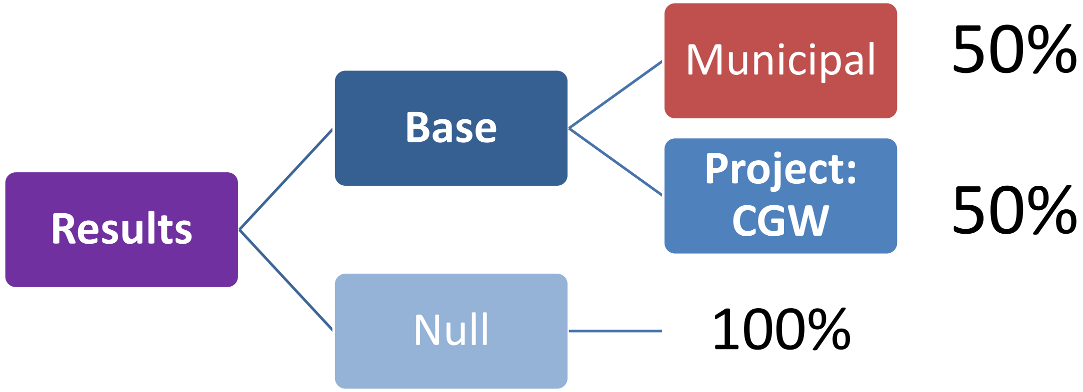
$$x_i \leq My_i$$

Constraints

Cost-Benefit Analysis

Benefits

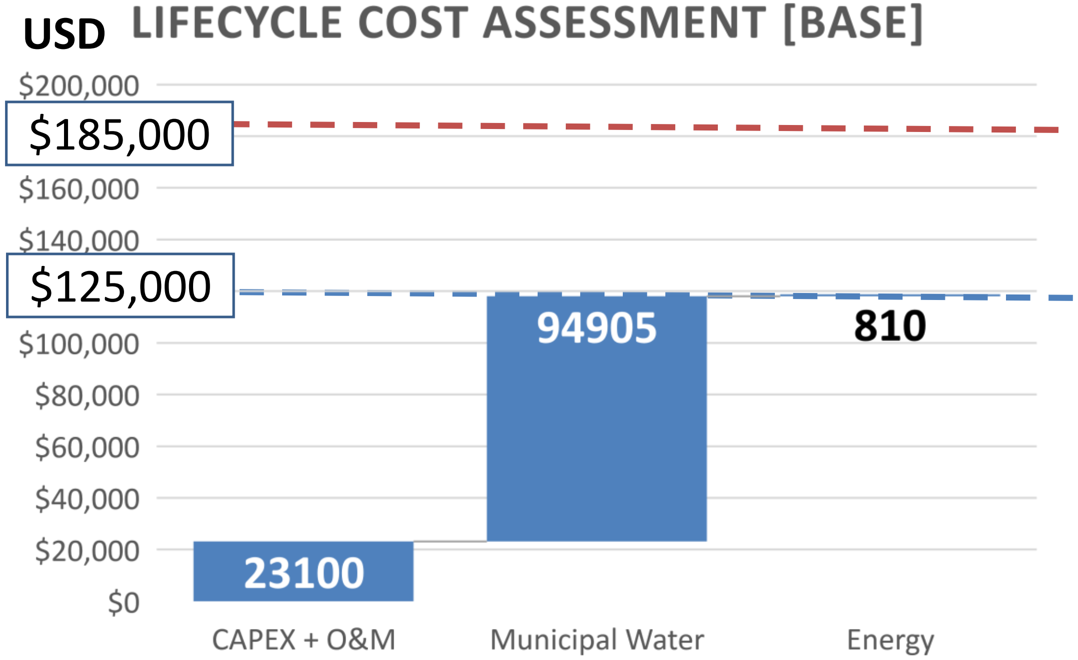
- Enhanced Local Water Supply
- Water and Financial Savings



Save: $60,000 per year

Costs

- Annual CAPEX required is <u>less</u> than **Municipal Water** or Energy



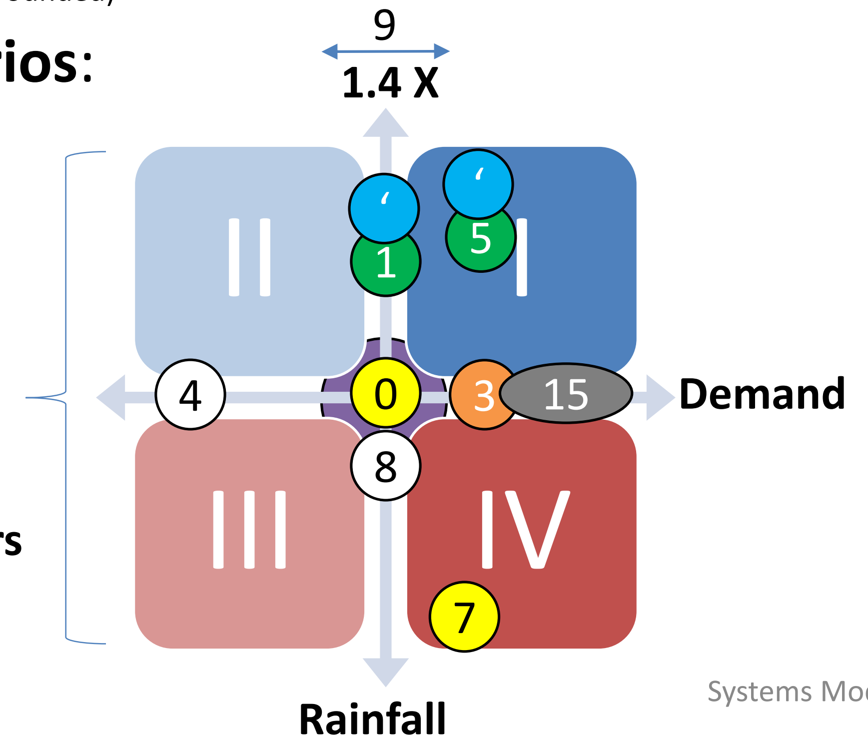
Technology Selection
Demand and Rain Water Scenarios

Base Case* [0]:

Cost [$,R] x 10^3	Energy [kWh]	% Technology
25, 350	1600	50

*:PER YEAR (rounded)

Scenarios:



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PP: 10 yrs

Cost

- 35% **HGW**: Household Gray Water
- 84% **CSW**: Community Storm Water
- 86% **RWI**: Rain Water Indoors
- 78% **RWO**: Rain Water Outdoors
- 49% **CGW**: Community Gray Water

PP: 5 years

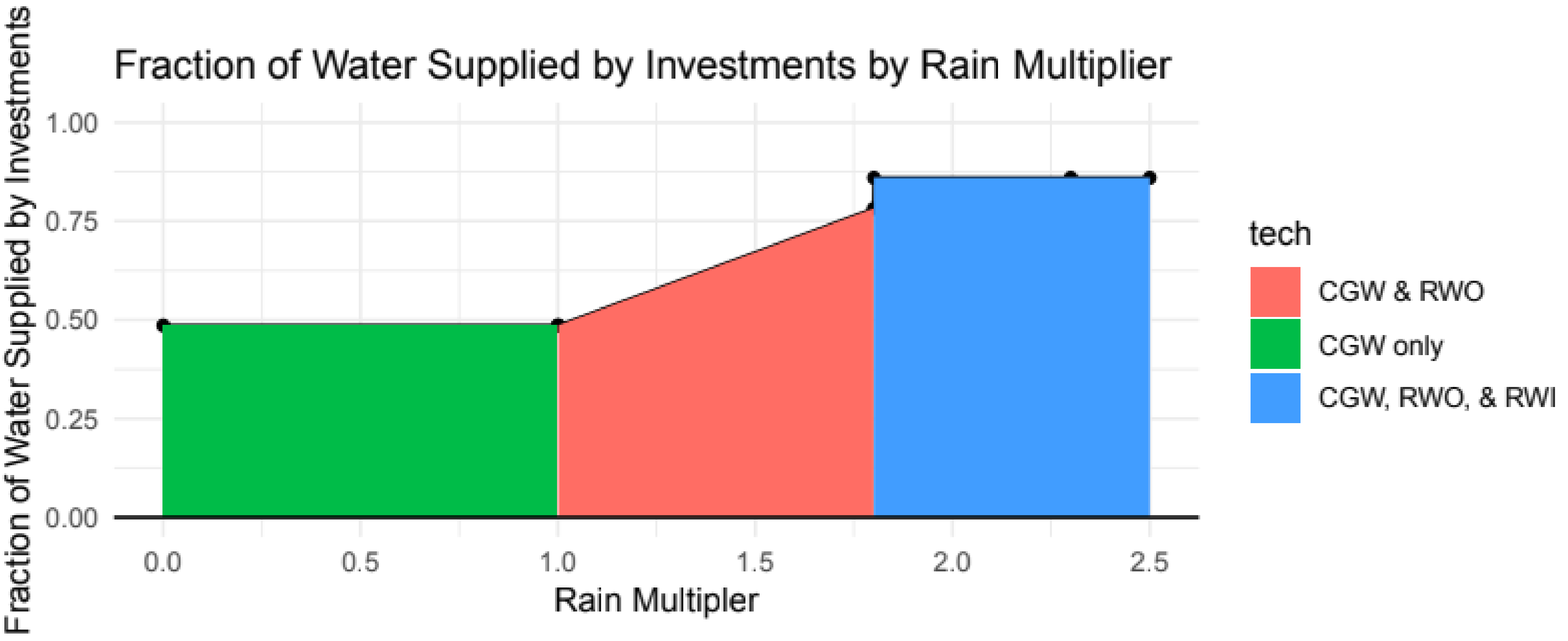
Conclusions

Discount Rate	5	%		1000	square foot roof
Payback Period	5	years		0.62	gallons/inch of water per sq ft
Yearly Water Demand	6660	kL		6200	gallons/inch of water (stormwater)
Yearly Rainfall	30.31	inches		75	% of indoor water available for greywater recycling

			Fraction of Capacity Installed							
Modification	Rain Multiplier	Demand Multiplier	Rainwater Harvesting Indoor Use	Rainwater Harvesting Outdoor Use	Community Stormwater System	Community Greywater System	Household Greywater	Annutized Cost	% of Water Supplied by Tech	kWh Used By Tech
Base Case	1	1	0	0	0	1	0	$23,763	48.6%	1620
Increased Rainwater (RW)	1.8	1	0	0.20	0	1	0	$23,313	78.2%	2701
Increased RW more	2.3	1	0.04	0.15	0	1	0	$20,693	86.0%	3276
Increased Demand	1	1.4	0	0	1	1	0	$30,594	83.8%	2595
Decreased Demand	1	0.2	0	0	0	0	0	$7,392	0.0%	0
Increased RW and Demand	1.9	1.4	0	0.27	0	1	0	$30,027	83.8%	3522
Increased RW and Demand	2.4	1.4	0.05682	0.21	0	1	0	$27,121	83.8%	3522
Decreased RW & Increased Demand	0	1.4	0	0	0	1	0	$31,420	86.0%	4586
Increased Discount Rate	86%	1	0	0	0	0	0	$36,963	0.0%	0
Increased # of Households	140 houses	1	0	0	1	1	0	$30,594	83.8%	2595

- Base case
- Change from anticipated value
- Parameter change
- New investment
- Deviation from base investment
- Favorable decrease or increase
- Unfavorable increase or decrease

Conclusions



Q&A

Dr. Leibowicz,

Thank you for a great semester!

Back-up slides

Rainwater: not internally plumbed	Dobrowksy et al. (2014); Mukheibir et al. (2014); Fisher-Jeffes et al. (2017)	Varies notably[2] Low summer yield in winter rainfall regions with $Y \approx 0$ in peak summer time	Non-potable	Outdoor use, hand washing of clothes, house cleaning (e.g. floors)	Yield is a function of rainfall, storage and roof size; potential mismatch between seasonal rainfall and highest demand; high capital cost; possible environmental impact (e.g., reduced urban streamflow impacts natural ecosystems)
Rainwater: Internally plumbed tanks	Beal et al. (2012)	Varies notably[2] Queensland Australia. Y varies from 54–260 $L{\cdot}hh^{-1}{\cdot}d^{-1}$, with ave. 137 $L{\cdot}hh^{-1}{\cdot}d^{-1}$	Non-potable	As above plus toilet flushing and clothes washing	
Greywater[4]	Christova-Boal et al. (1996); Eriksson et al. (2003); WHO (2006)	Reported Y varies from 218–346 $L{\cdot}hh^{-1}{\cdot}d^{-1}$; or about $\pm$ 100 $L{\cdot}c^{-1}{\cdot}d^{-1}$ (Jacobs and Van Staden, 2008)	Non-potable, relatively poor quality (Maimon et al., 2010)	Outdoor irrigation (Carden et al., 2017); toilet flush (Ilemobade et al., 2012)	Relatively constant yield; yield reduces in line with indoor water savings; relatively high community health risk and environmental risks; high capital and energy cost if treated

Cost Parameters

Graywater

Indoor		Outdoor	
MIT, Vitter, Book		Commercial	
Income			
Low	High	Low	High
Community	Residential		

Stormwater

Indoor	Outdoor

How much does it cost to install a rainwater collection system?

A rainwater collection system is a way to capture rainwater to save and distribute later. They can be simple or complex, but either way are a great way to save on your wat

If you live in an area that experiences drought or if you find
a rainwater storage and distribution system can help offset r

The true cost of any home improvement project will vary ba
tank system will cost about $2,500, including installation.

Comparing their improved model with the simple method used previously, they found that the energy use and carbon dioxide emissions predicted by the improved method were 60% higher than those predicted by the simple method. For instance, the simple method predicted energy use of 0.32kWh per m^3 of rainwater, versus 0.54kWh per m^3 from the improved method. Similarly, carbon dioxide emissions increased from 0.34kgCO_2e per m^3 of rainwater to 0.56 kgCO_2e per m^3. These results emphasised the importance of the amount of pump start-up energy consumption and efficiency and underlined the necessity to estimate the total energy consumption and CO_2 emissions.

1000 Gallon Poly-Mart Rain Harvesting Tank

The 1000 Gallon Rainwater Harvesting storage tank includes 3" overflow and 2" outlet with plug. Comes standard with 16" basket strainer.

Our Price	$679.95
List Price	~~$908.09~~
SKU	PM1000RH

Choose a color:

Select

Call 800-654-9283 for freight quote, input:

Poly-Mart Pallet

Select

Quantity 1 Order

Certain colors now in stock, ready to ship out the next business day! Please contact us for specific availability details.

Print Brochure

SHARE

Description | Cross Selling Products

Storage tank	Every rainwater system needs a storage tank This holds the water until you need to use it	**5,000-gallon *polyethylene*[3] tank: $2,000** **Steel tank: $4,000**
Tank top-up system	Not required A top-up system will open a valve if the water level gets too low Allow water to flow in from another source	**$100-$150**
Pump	Some systems may include a *pump*[4] Helps push water out of the storage tank and into an irrigation or sprinkler system Optional	**$100-$1,000**
Filters	Filters remove contaminants before the water goes into the storage tank Optional	**$100-$1,000**
Treatment system	If you intend to drink rainwater or use it for household use Optional	**$2,500-$3,000**
Tank gauge	Helps tell you how much water is in your storage tank Optional	**$30-$40**
Pipes	Connect your water storage system to your irrigation system or household pipes	Price will vary significantly Based on the pipe material, length and amount of digging required

5: Aqua2Use Greywater Recycling System

Features

Known as the GWDD system, Aqua2Use collects the water from your bath, shower, and laundry. The water gets filtered through a state-of-the-art system for progressive filtration. After that, the water automatically gets sent over to your irrigation system for a second use.

Because the Aqua2Use system uses full automation, it doesn't require any human intervention for operation. You'd feel surprised at what greywater looks like after you have filtered it. In the long run, this saves you extra cash.

Pros

- Employs a non-clog filter.
- Comes with a simple controller.
- It has an excellent overflow system.
- It is fairly easy to install.

Cons

- No indicator for on or off.
- Only one-year warranty.

Price: $789.95.

Uniqueness of Aqua2use Greywater Treatment System:

- Low power consumption: +/- 2kWh /KL produced
- No chemical & disinfectants added
- No new water needed for backwash
- Modern design easily integrates with the enviro
- User friendly : process is automatic & self-main
- Long lasting Matala filter media, no regular repl
- Progressive biofilter: copes with fluctuating flov pollution

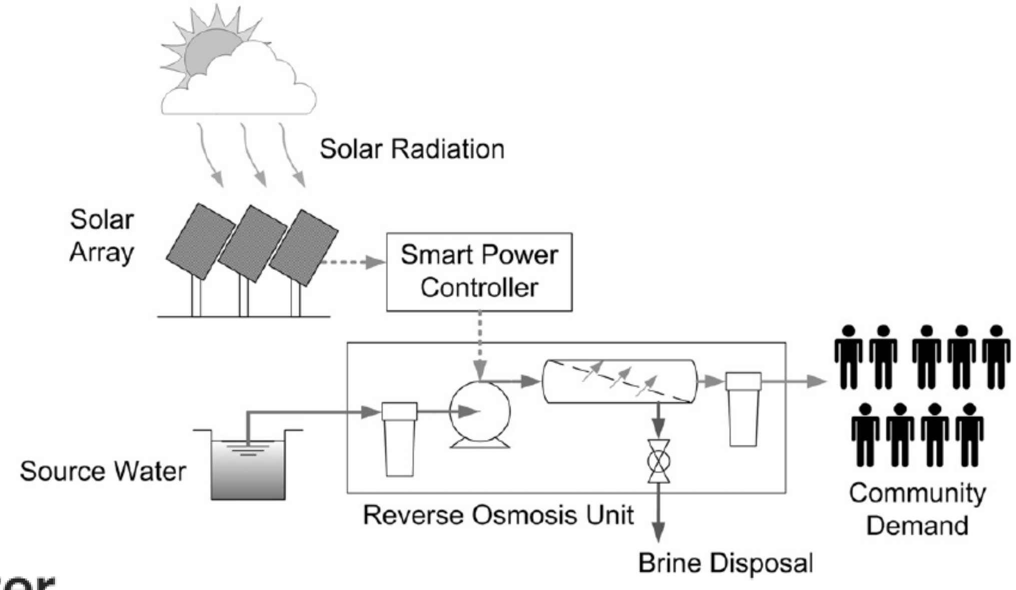


Fig. 2. Autonomous PVRO system.

4.3.1. Capital costs

The capital costs include the purchase price of components, shipping costs to the field site for assembly, and the labor for installation, approximately 10,000 USD (140,000 pesos) for this one-of-a-kind prototype system. Obviously, commercial prices would be substantially lower than these figures. The annualized capital cost is 1342 USD (18,184 pesos). The costs of individual subsystems, sensors, shipping and installation in percentages of total capital cost are presented in Table 3. Annu-

Stormwater

For Cost

Energy Assumption

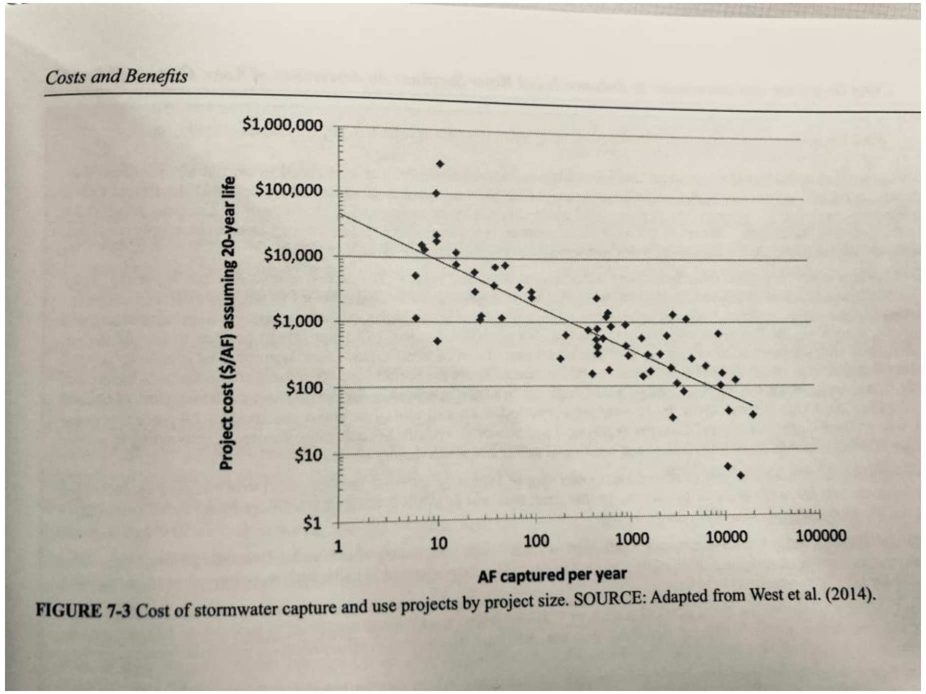


FIGURE 7-3 Cost of stormwater capture and use projects by project size. SOURCE: Adapted from West et al. (2014).

BASE

Min Sump Basin Size: 18 Inch

MOTOR

Horsepower: 1/2HP

Volt: 115

Phase: 1Ph

Hertz: 60Hz

Running Amps: 10.4

Operation: Automatic

RPM: 1750

Thermal Protection: YES

Power Cord Length: 10 Feet

Cord Type: UL listed, 3-wire neoprene cord and plug

Oil Free Motor: NO

Starting Amps: 43.6

PUMP

Housing Material: Cast Iron

Solids Handling Size: 2 inch

Float Type: Vertical Float

GPH @ 0 feet: 7680

GPH @ 5 feet: 7680

GPH @ 10 feet: 5340

GPH @ 15 feet: 3000

GPH @ 20 feet: 600

Max Head: 21.5 feet

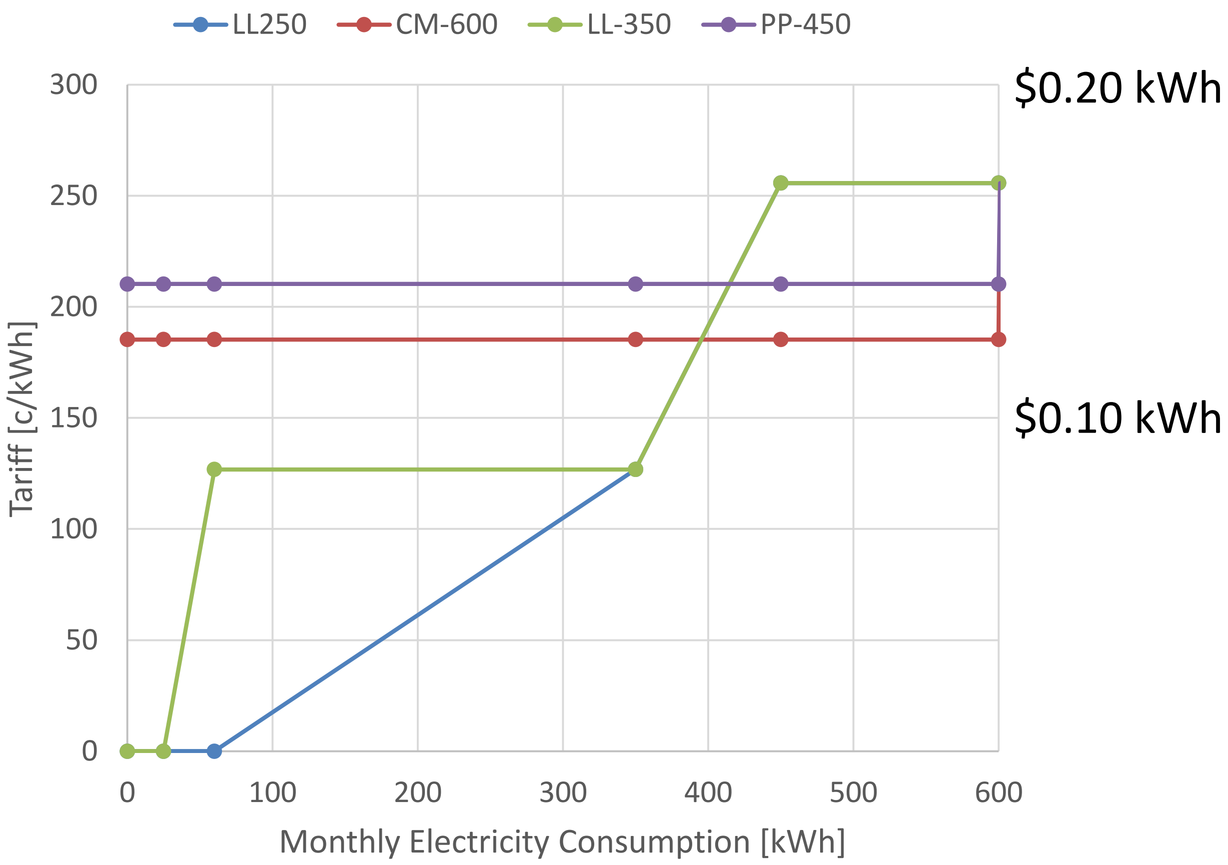
Max Flow Rate: 128 GPM

Electricity Cost

ID	LL-250	CM-600	LL-350	PP-450	PP-600
Tariff [c/kWh]	126.85	185.32	225.75	210.32	255.75
Max free [kWh]	25	0	60	0	0
Max block [kWh]	325	600	290	600	∞

1 c = 0.01 R = 0.00069 USD

LL: lifeline tariff
CM: credit meter
PP: prepayment meter



Back-up slides

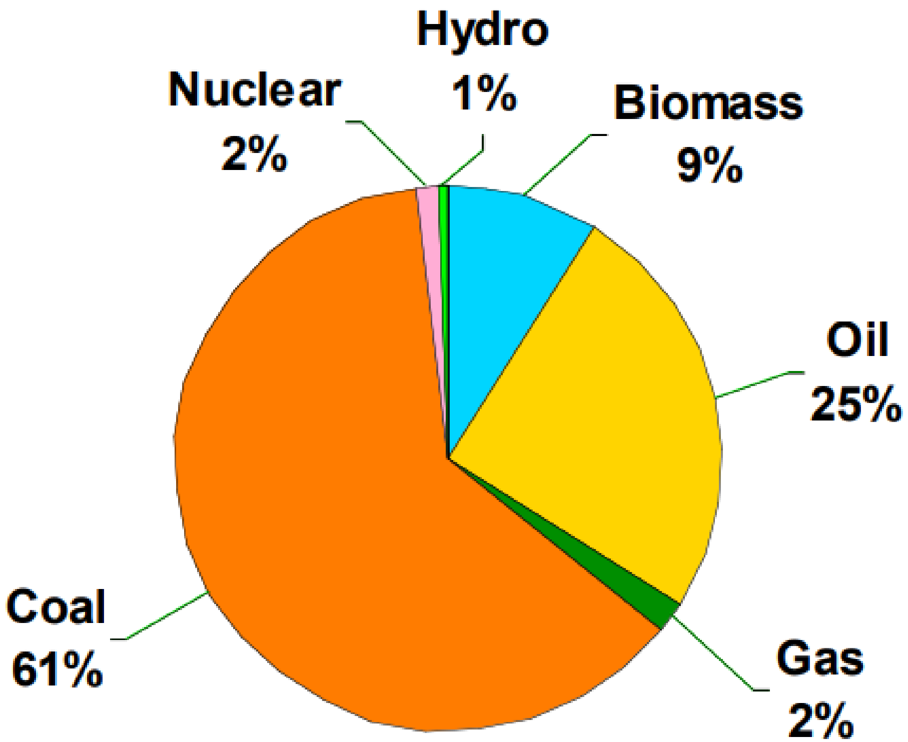


Figure 1. South African energy mix (Ward, 2008)

Back-up slides

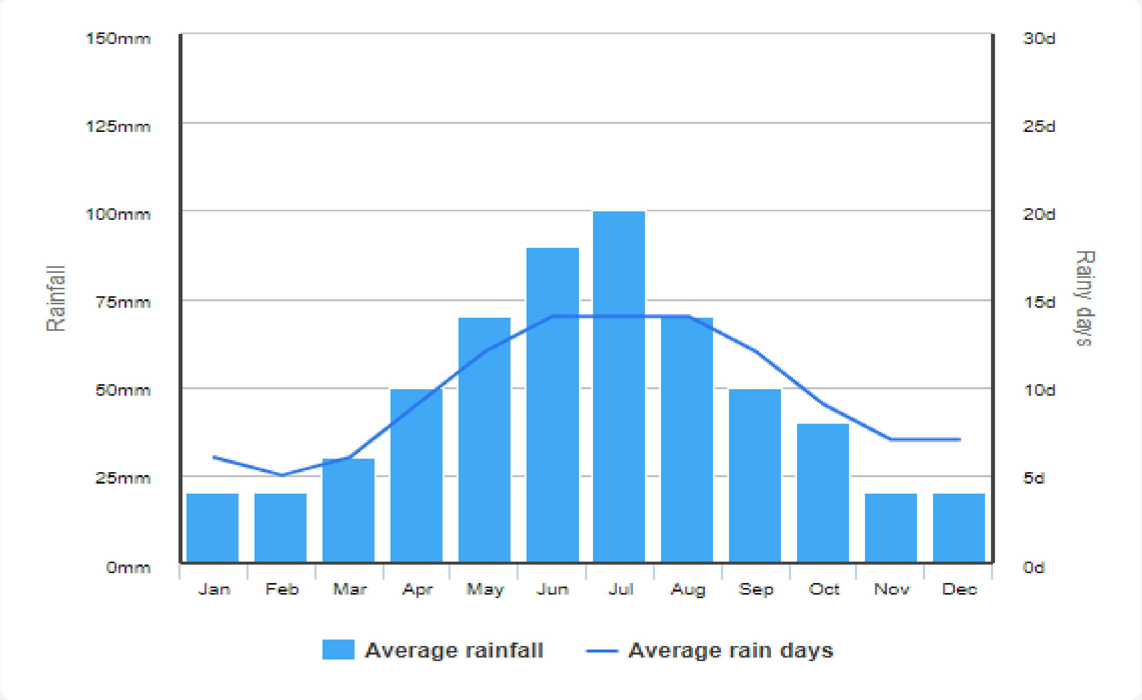
- Energy consumption per capita in 2004 was 44GJ/capita (SEA, 2006.) Much of Cape Town’s energy is consumed as electricity, see Figure 7.

44	GJ		1	year	277777.8	W h	1	kW	1019	kWh	0.1	$	102	$
	person	year	12	months	1	GJ	1000	W		month		kWh		month

- A low-income household could spend up to 25% of their monthly income on meeting their energy requirements, with most of the energy required for cooking. Mid to high income households typically spend 3-5% of their monthly income on energy, with the majority of the energy being used in water heating.

This is according to statements made by former Johannesburg mayor and president of the South African Local Government Association (SALGA) Parks Tau during a speech. Tau noted that the country's water consumption far exceeded international benchmarks and that the average water consumption in South Africa is 235 litres per capita per day compared to a world average of 185.

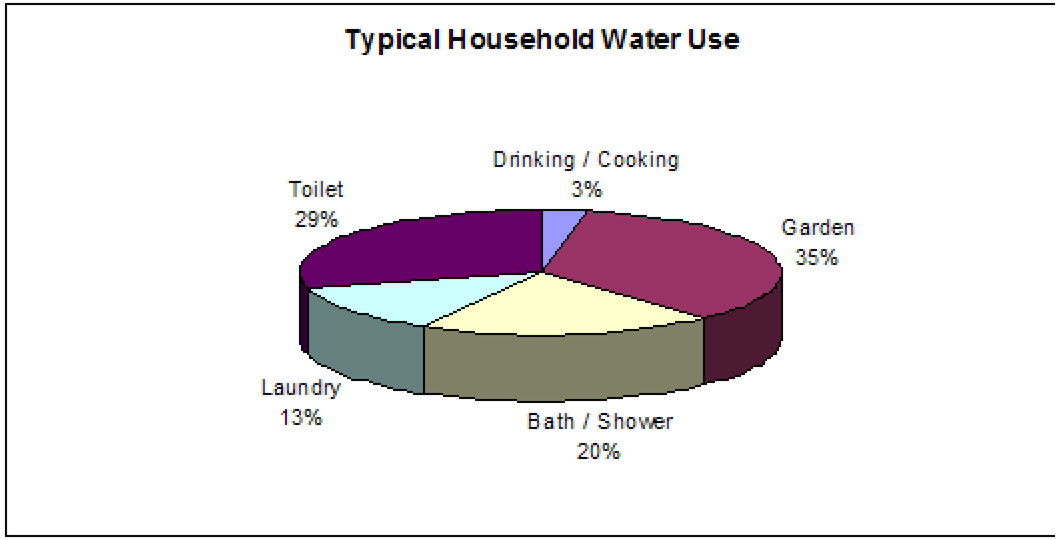
Average Rainfall: Cape Town



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
mm	20	20	30	50	70	90	100	70	50	40	20	20
Days	6	5	6	9	12	14	14	14	12	9	7	7

Here are the figures presented:

Province	Consumption (litres/person/day)
• Eastern Cape	200
• Free State	209
• Gauteng	305
• Limpopo	182
• KwaZulu Natal	225
• North West	186
• Northern Cape	238
• Western Cape	201
• Mpumalanga	205
• National	233

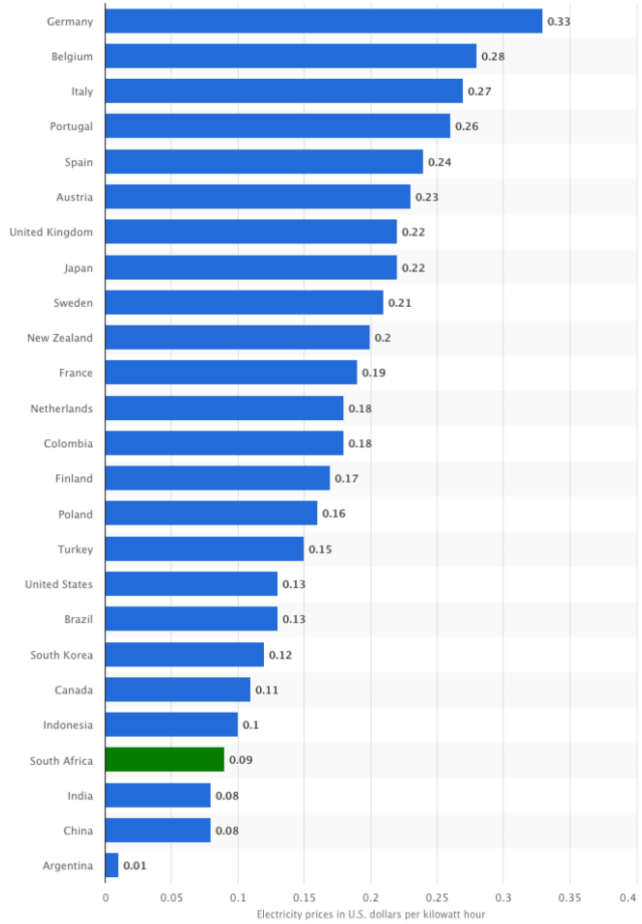


Residential Water Tariffs (Domestic Full and Domestic Cluster)		
Water Steps (1kl = 1000 litres)	**Level 5 (2018/19)** Until 30/11/2018 **Rands (incl VAT)**	**Level 3 (2018/19)** From 1/12/2018 **Rands (incl VAT)**
Step 1 (0 ≤ 6kl)	R24.37 (free for indigent households)	R15.73 (free for indigent households)
Step 2 (>6 ≤ 10.5kl)	R39.59 (free for indigent households)	R22.38 (free for indigent households)
Step 3 (>10.5 ≤ 35kl)	R60.25	R31.77
Step 4 (>35kl)	R345.00	R69.76

Residential Sanitation Tariffs (Domestic Full and Domestic Cluster)		
Water Steps (1kl = 1000 litres)	**Level 5 (2018/19)** Until 30/11/2018 **Rands (incl VAT)**	**Level 3 (2018/19)** From 1/12/2018 **Rands (incl VAT)**
Step 1 (0 ≤ 4.2kl)	R19.47 (free for indigent households)	R13.82 (free for indigent households)
Step 2 (>4.2 ≤ 7.35kl)	R34.79 (free for indigent households)	R19.67 (free for indigent households)
Step 3 (>7.35 ≤ 24.5kl)	R51.92	R29.43
Step 4 (>24.5 ≤ 35kl)	R124.30	R52.96

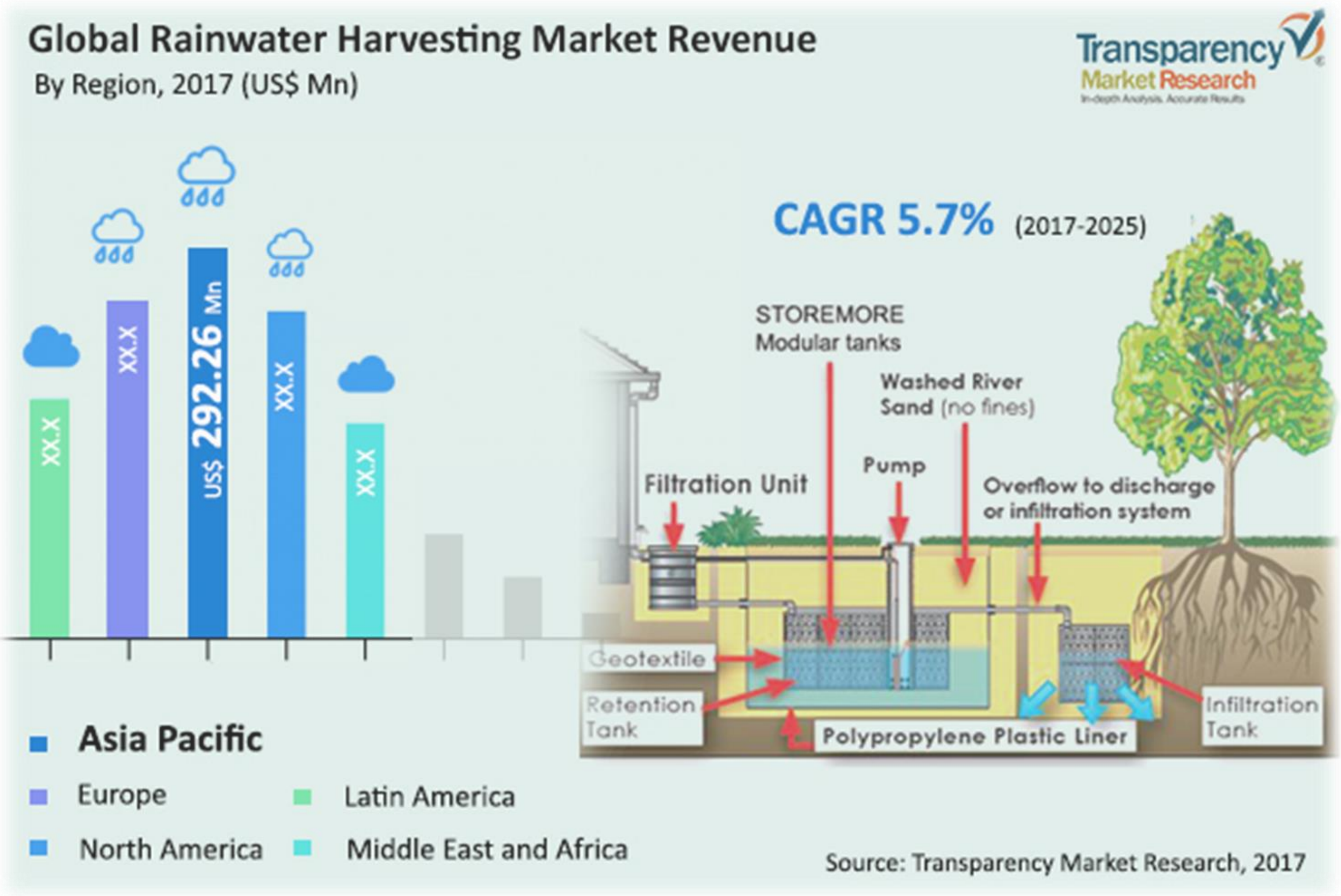
Fixed Basic Delivery Charge	
Size (mm)	**Monthly Charge** **Rands (incl VAT)**
15	R64.40 (free for indigent households)

Global electricity prices in 2018, by select country (in U.S. dollars per kilowatt hour)



What about stormwater?

Opportunity for **low-income** (36%) and **unemployed** (24%) residents



Sizing, distribution and connectivity matter

- <u>Harvesting Method</u>
  Optimize design to minimize total network costs
- <u>End-User Dispatch:</u>
  Shift timing of precipitation relative to water demand