WATER SCARCITY IN REMOTE COMMUNITIES

Novia C. Joshua C. Minh H. Joshua S. Marko S. Huanqing W. Yon Z.

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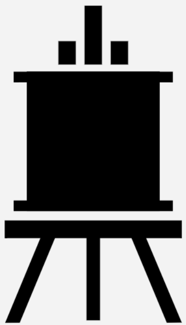
PROJECT CONTEXT

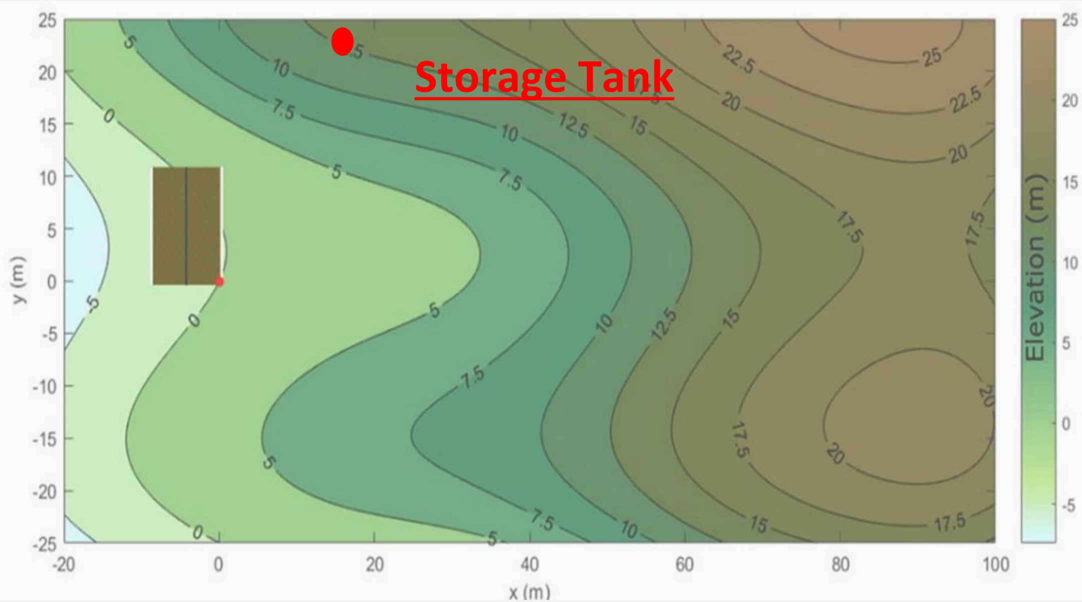
Developing a Rain Water Harvesting (RWH) system to provide adequate clean water to satisfy a pilot household of two people.

This RWH system will:

Capture water → Filter/Purify → Store excess → Supply back to user



DESIGN RECOMMENDATION



Comprised of the following components:

- **Two** solar panels
- **Three** filters (1µm, 5µm, and 200µm)
- **Chlorine** treatment system
- 50 watt **UV** system
- Pump
- Storage to house filter location
- Ground-level Storage tank
- Catchment tank

STAKEHOLDERS

- Members of RES’EAU WaterNET
- Remote communities
  of coastal British Columbia
- Equipment Manufacturers
- R2 Design Team
- Health Authorities
- Consultants

NEEDS

- Independent power system
- Sustainable
- Sufficient clean water
- Resilient system
- Cost-efficient
- Simple, easily maintained
- Compliant with regulations

KEY ASSUMPTIONS

Constants

- Gravitational acceleration: 9.81 m/s^2
- Density of water = 1000 kg/m^3
- Pipe Diameter: 20 mm
- Pipe friction factor (f) = 0.05
- Restriction Loss Coefficient (K)= 10

Model assumption

- Little rain deviation from rain harvesting data
- Pipe length => distance between home and storage tank

Measured values

- C_f = 8628.245

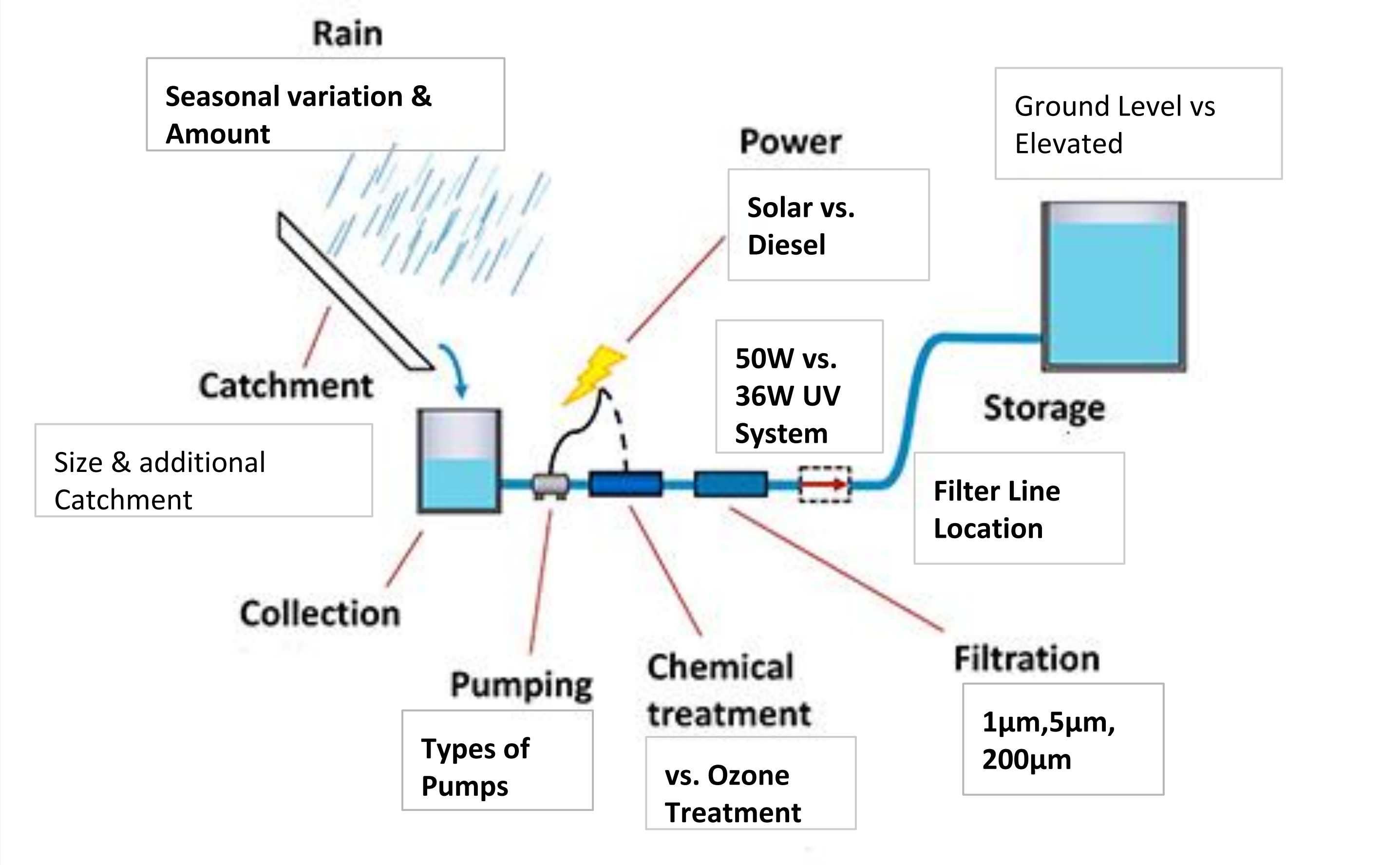
DECISION MAKING PROCESS

1. Analyzing main components in our design solution
- Rainwater collection
- Storage
- Pump
- Filtration
- Disinfection
- Power System

1. Prototyping:
   (physical and virtual)

1. Analyzing risk

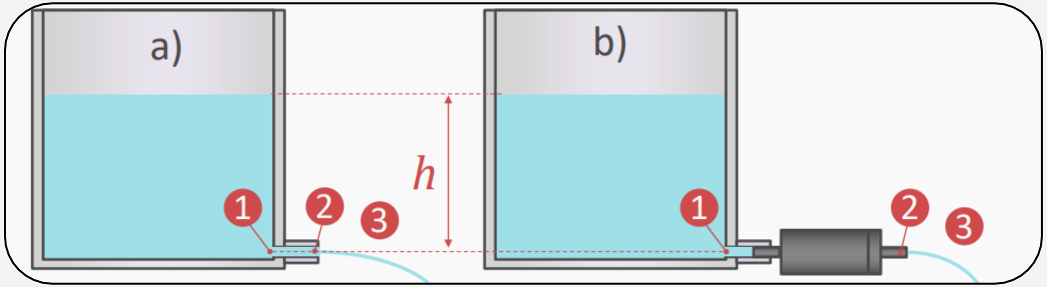
SOLUTIONS CONSIDERED

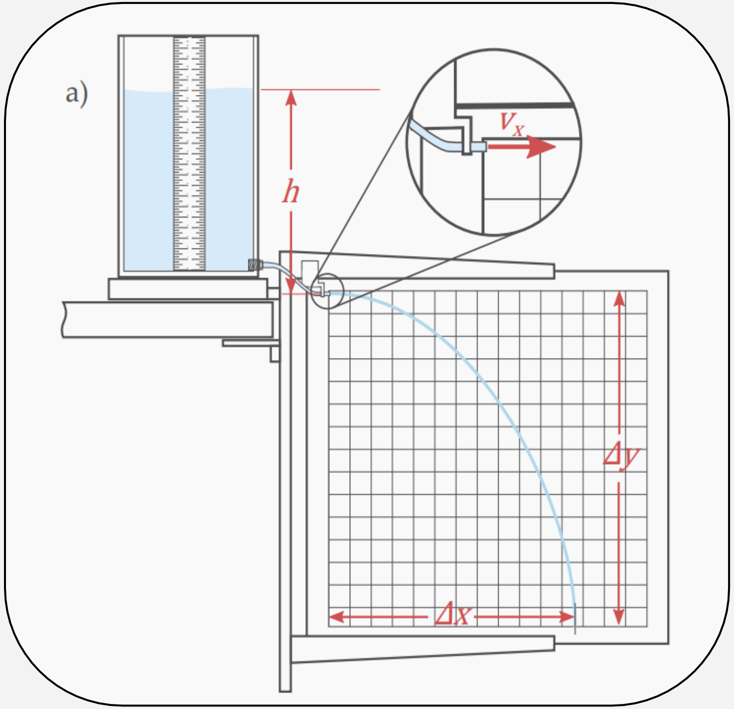


PHYSICAL PROTOTYPING

Using prototypes of RWH components to:

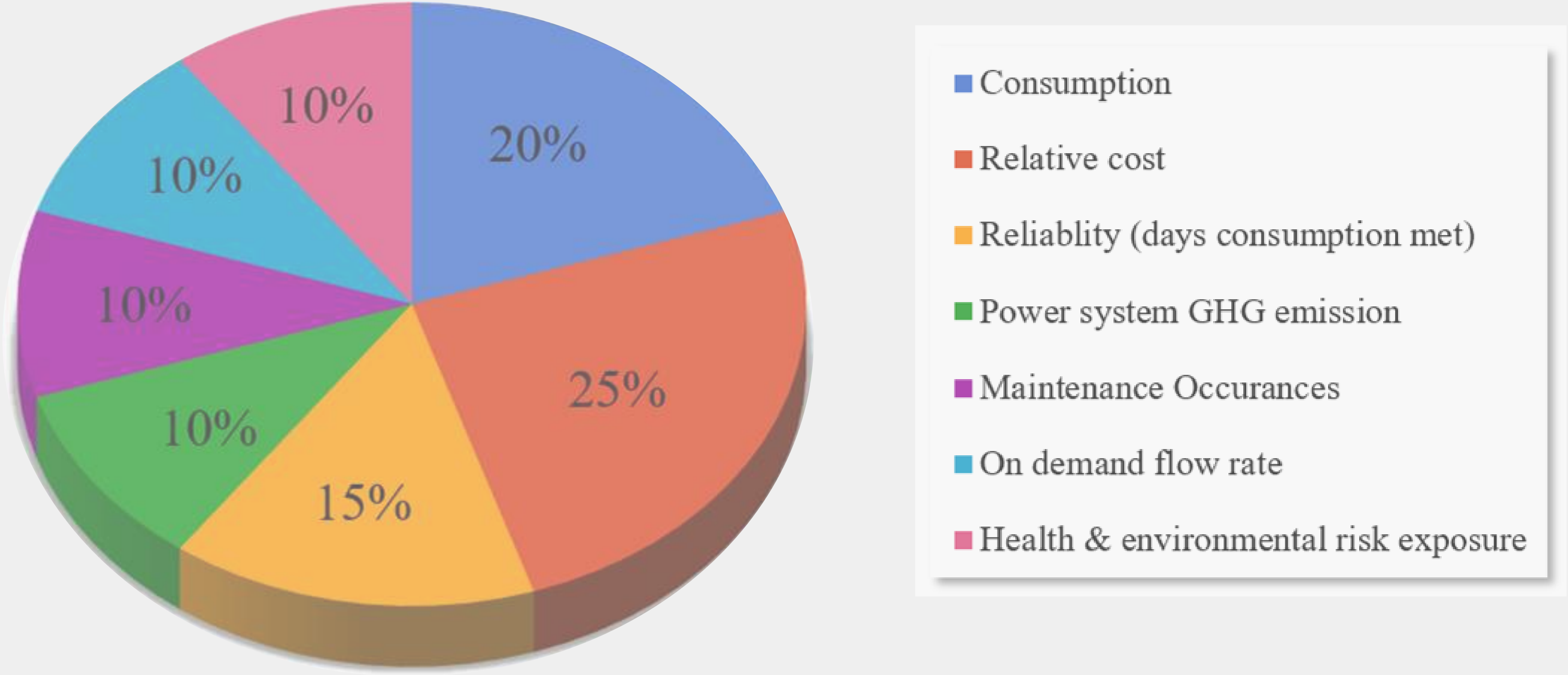
- Calculate C_f, K, f
- Observe flow rate behaviour through varying lengths of tubes





COMPREHENSIVE VIRTUAL PROTOTYPING

Optimizing Satisfaction for Satisfaction Criteria



DESIGN DECISIONS

Overall **Consumption**:
530 L/day

Cost

Maximize effectiveness over spending amount

Environmental Impact

Solar Panels

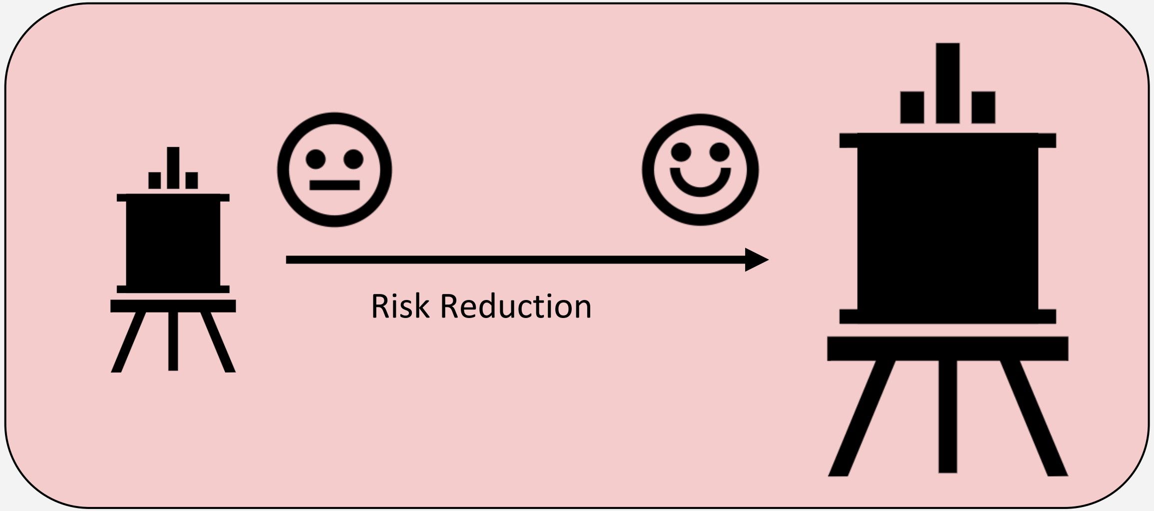
Reliability

Increasing Catchment Tank Size

Maintenance

Greatest number of filters for less maintenance

RISK



Identified Risk:

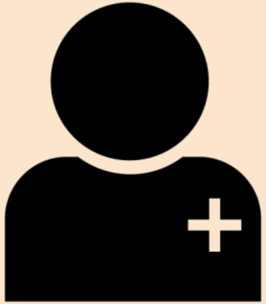
- Variations in future rainfall
- Amount of GHG Emissions

Reducing Risk:

- Larger storage tank
    - During times of low rainfall, the household can draw from the stored water reserves
    - Provides a safety net, ensuring that the household stays supplied with water even in periods of drought

- Solar instead of Diesel

SUSTAINABILITY



Societal:

- Provides clean water for the residents

- Lowers economic burden of shipping in water bottles, allowing residents to spend money on themselves and have a higher standard of living

Economic:

- Gives back economic agency to Van Anda

- Removes cost of shipping in water bottles

- Simple maintenance and low costs for effectiveness in perpetuity

Environmental:

- Solar powered, low GHG emissions

- Reusable system, low landfill production

DESIGN JUSTIFICATION

- Optimal solution for the project context
- Tested with real weather data
- Takes into account interloping factors and risks/tradeoffs
- Achieves high degree of stakeholder satisfaction

CONCLUSION

Environmentally Conscious

Impeccable Reliability

Minimal Maintenance

Optimized Costs

Overall Satisfaction

84.7%

APPENDIX

A. Upper and Lower Water Limits

A. Physical Prototyping

A. Physical Prototyping Results (2)

A. Virtual prototyping (2)

A. Pump vs. System Analysis

A. Preliminary Storage Tank Model

B. Final Satisfactions

C. Satisfaction Curves (2)

D. Health and Environmental Risk

Appendix A: Upper and Lower Water Limits

Lower Justification

Estimate for total litres/day:

122.0

Key Assumptions (per person):

- Washroom: once a day
- Showering once a week
- Wash dishes 2 times a week
- Drinking 946.353mL of water a day
- No other indoor uses

They would be satisfied. We took minimum usage as the definition for the lowest amount used for the two people. This would result in a high satisfaction level as they would be efficient, conservant and sustainable.

Upper Justification

Estimate for total litres/day:

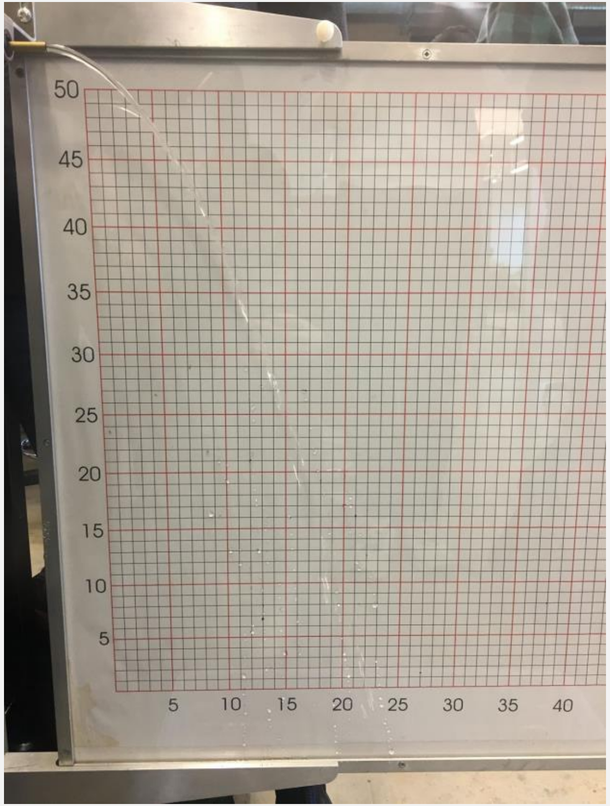
478.4

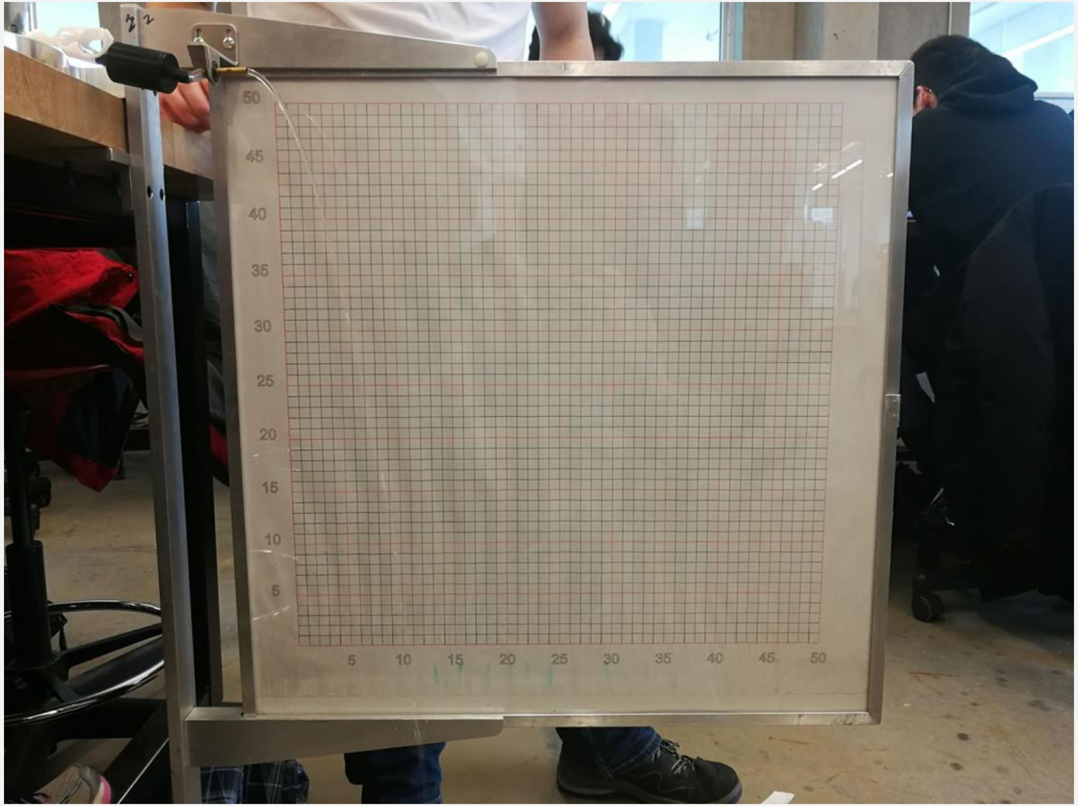
Key Assumptions (per person):

- Washroom seven times a day
- Drinking 1892.71ml of water
- Two showers per day
- Indoor uses of water occur, including watering potted plants, feeding pets, etc.

They would be satisfied. We took a very high maximum amount for usage. Some of these assumptions are unreasonable to expect a single person to use, which means that it would go above and beyond their usage.

Appendix B: Physical Prototyping





Appendix C: Physical Prototyping Results (1)

Lab A

Experiment	pgh	(1/2)pv^2	p (losses)	f	K	Cf
Base Case	2383.83	463.52	667.08		1.44	
	1716.75	406.53			1.64	
					1.54	
Piping Losses	2187.63	119.59	431.64	0.01	1.54	
	1755.99	78.95		0.01	1.54	
Clean Filter	2491.74	105.11	735.75		1.54	1251.67
	1755.99	46.71			1.54	2171.72
Fouled Filter	2491.74	112.23	755.37		1.54	1229.55
	1736.37	78.95			1.54	1595.00

Appendix C: Physical Prototyping Results (2)

Base Case - Nozzle Only → Piping Losses - 1 Metre Tubing → Clean Filter → Fouled Filter

Base Case - Nozzle Only

Friction and filter losses are negligible

H_1: $K = 1.439$

H_2: $K = 1.641$

$\mathbf{K_{avg}} = 1.54$ (constant for all other experiments)

Piping Losses - 1 Metre Tubing

Filter Losses are negligible

H_1: $f = 0.00985$

H_2: $f = 0.00985$

Clean Filter

Friction is negligible

H_1: $C_f = 1251.674272$

H_2: $C_f = 2171.7$

Fouled Filter

Friction is negligible

H_1: $C_f = 1229.553064$

H_2: $C_f = 1595.002909$

Loss Coefficient Calculations: since losses due to friction is negligible for the clean and fouled filter cases, the formula for pressure losses is:

$$p_{losses} \approx \bar{K}_1 \frac{\rho v^2}{2} + C_f v$$

H_1=When water tank is full

H_2=When water tank at 180mL

Hence, Filter loss coefficient C_f = (Pressure loss - Kρv^2/2)

The trend we noticed is the flow rate decreases as the stock water decreases in quantity. In addition, as the **length of tubing** the water needs to flow through is **increased**, the **flow rate is decreased**.

Appendix D: Virtual prototyping (1)

Model

File Edit View Insert Format Data Tools Add-ons Help All changes saved in Drive

SHARE

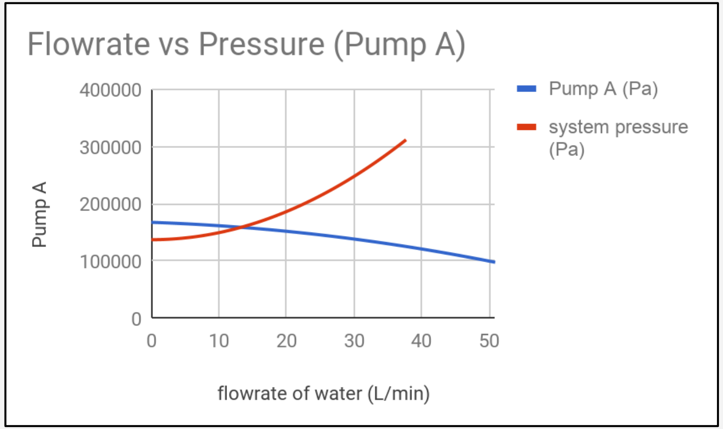
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
6	Date	Daily Rainfall	Qin	Qin rain	Qin to catchment	Qin to catchment	Storage Tank Volume	Energy for water	Energy required from Pump	Mass of ozone required	Energy of ozone required	Mass of chlorine	Mass of Solution	UV	Hours of Operation for Pump	Total Energy Required per day:
7		[mm]	[m^3/day]	[L/day]	[L/day]	[m^3/day]	[m^3]	[J]	[J]	[g/day]	[J]	[g/day]	[g/day]	[J/day]	[Hrs/day]	[J/day]
8	1/1/2014	18.8	1.88	1880.00	1880.00	1.88	1.88	460410.3231	639458.782	9.4	18800000	18.8	376	0	1.128010823	639458.782
9	1/2/2014	19.8	1.98	1980.00	1980.00	1.98	3.86	484900.2339	673472.5471	9.9	19800000	19.8	396	0	1.188011399	673472.5471
10	1/3/2014	0	0	0.00	0.00	0.00	3.86	0	0	0	0	0	0	0	0	0
11	1/4/2014	0	0	0.00	0.00	0.00	3.86	0	0	0	0	0	0	0	0	0
12	1/5/2014	0	0	0.00	0.00	0.00	3.86	0	0	0	0	0	0	0	0	0
13	1/6/2014	5	0.5	500.00	500.00	0.50	4.36	122449.554	170068.825	2.5	5000000	5	100	0	0.3000028785	170068.825
14	1/7/2014	20.4	2.04	2040.00	2040.00	2.04	6.40	499594.1804	693880.8061	10.2	20400000	20.4	408	0	1.224011744	693880.8061
15	1/8/2014	24.8	2.48	2480.00	2480.00	2.48	8.88	607349.7879	843541.3721	12.4	24800000	24.8	496	0	1.488014277	843541.3721
16	1/9/2014	34	3.4	3400.00	2500.00	2.50	11.38	612247.77	850344.1251	12.5	25000000	25	500	0	1.500014392	850344.1251
17	1/10/2014	44.6	4.46	4460.00	2500.00	2.50	13.88	612247.77	850344.1251	12.5	25000000	25	500	0	1.500014392	850344.1251
18	1/11/2014	14.4	1.44	1440.00	1440.00	1.44	15.32	352654.7155	489798.216	7.2	14400000	14.4	288	0	0.8640082901	489798.216
19	1/12/2014	50.2	5.02	5020.00	2500.00	2.50	17.82	612247.77	850344.1251	12.5	25000000	25	500	0	1.500014392	850344.1251
20	1/13/2014	9.6	0.96	960.00	960.00	0.96	18.78	235103.1437	326532.144	4.8	9600000	9.6	192	0	0.5760055267	326532.144
21	1/14/2014	5.8	0.58	580.00	580.00	0.58	19.36	142041.4827	197279.837	2.9	5800000	5.8	116	0	0.3480033391	197279.837
22	1/15/2014	1.6	0.16	160.00	160.00	0.16	19.52	39183.85728	54422.024	0.8	1600000	1.6	32	0	0.09600092112	54422.024
23	1/16/2014	0.8	0.08	80.00	80.00	0.08	19.60	19591.92864	27211.012	0.4	800000	0.8	16	0	0.04800046056	27211.012
24	1/17/2014	0	0	0.00	0.00	0.00	19.60	0	0	0	0	0	0	0	0	0
25	1/18/2014	2.6	0.26	260.00	260.00	0.26	19.86	63673.76808	88435.78901	1.3	2600000	2.6	52	0	0.1560014968	88435.78901
26	1/19/2014	1	0.1	100.00	100.00	0.10	19.96	24489.9108	34013.765	0.5	1000000	1	20	0	0.0600005757	34013.765
27	1/20/2014	0.6	0.06	60.00	60.00	0.06	20.02	14693.94648	20408.259	0.3	600000	0.6	12	0	0.03600034542	20408.259
28	1/21/2014	0.8	0.08	80.00	80.00	0.08	20.10	19591.92864	27211.012	0.4	800000	0.8	16	0	0.04800046056	27211.012
29	1/22/2014	0.6	0.06	60.00	60.00	0.06	20.16	14693.94648	20408.259	0.3	600000	0.6	12	0	0.03600034542	20408.259
30	1/23/2014	0	0	0.00	0.00	0.00	20.16	0	0	0	0	0	0	0	0	0

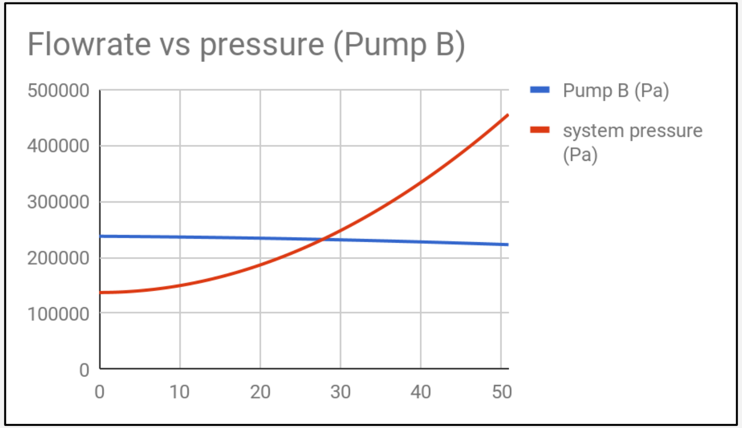
Satisfactions | Filtration | Collection/storage | MODEL | Flowrate | RIsk | Pump | Costs/ Maintenance | Disinfection | Power System | Health & Environment risk (Useless but colourful)

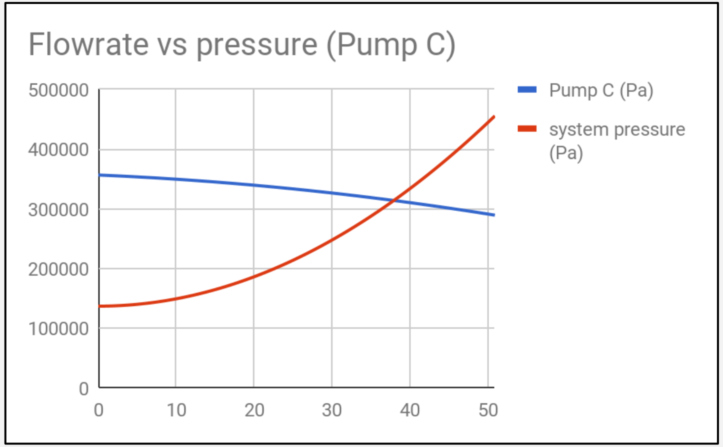
Appendix D: Virtual prototyping (2)

Total Cost:	39,385$	**Total Maintenance/year:**	29.0937649	
Rainwater Collection Cost	Catchment whole roof	Additional catchment	400L catchment tank	Piping cost
	350$	0$	900$	0.00$
Storage Cost	Storage Piping Cost(to and back):	Tower	Storage tank	
	2,785$	0$	13,750$	
Collection & Storage Total Cost:	**17784.55113**			
Pump Cost	Pump B			
	1,400$			
Filtration Cost	Bag Filter		Cartridge Filter	
	100$	50$ replacement	125$	75$ replacement
Filtration total cost(5 years)	**8550**			
Disinfection Costs	Chlorine Cost per year	**Maintenance:**		
	1540.733333	UV	1$	times/year
Disinfection Cost Total(5 years)	**7703.666667**	Chlorine	16	times/year
Power system cost(initial)	**3759**	Filtration	8	times/year
Cost to ship in water(5 years times average for one year):	**188$**	Pump	0$	times/year
		Solar Panel	4	times/year

Appendix E: Pump vs. System Analysis







Pump A is eliminated due to low flow rate.

Pump C is eliminated due to high initial cost.

Pump B is chosen due to highest efficiency and reasonable flow rate (27.8 L/min) and cost.

Appendix F: Preliminary Storage Tank Model

Tank Volume Recommendations:

	Volume of tank for **~1%** Satisfaction	Volume of tank for **~50%** Satisfaction	Volume of tank for **~100%** Satisfaction
Station 1 – 2014	**5.861** [m^3]	**16.624** [m^3]	**44.02** [m^3]
Station 1 – 2015	**7.523** [m^3]	**28.67** [m^3]	**55.35** [m^3]
Station 2 – 2015	**8.342** [m^3]	0 [m^3]	0 [m^3]
Station 3 – 2013	**5.012** [m^3]	0 [m^3]	0 [m^3]

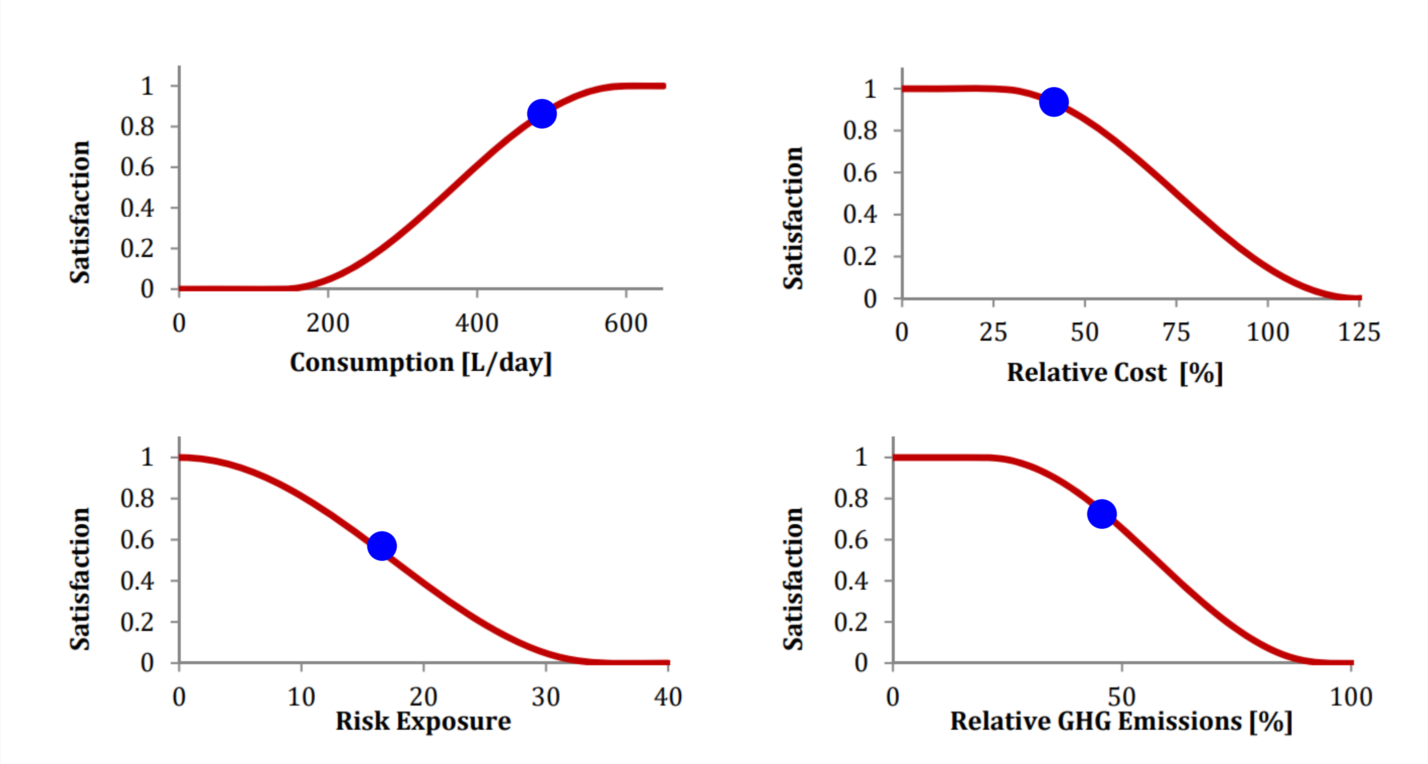
- Analysis shows that there will always be a day that the tank volume in station 2 and station 3 goes to 0 (rainfall cannot compensate the water consumption) for 50% and 100% satisfactions.

Appendix G: Final Satisfactions

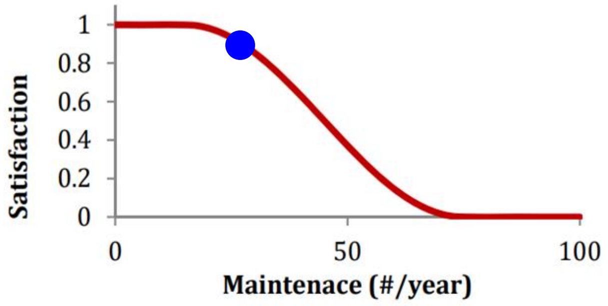
	Raw values	Weight	Min	Max	Satisfaction
Consumption	530.0	20%	135	600	94.5%
Relative cost	49.2	25%	25	125	86.2%
Health & environmental risk exposure	16.2	10%	0	35	55.9%
Power system GHG emission	43.5	10%	20	100	80.2%
Maintenance Occurrences	29.0	10%	15	75	87.2%
On demand flow rate	29.8	10%	15	35	84.1%
Reliability(days consumption met	331.8	15%	200	365	90.3%
				Total Satisfaction:	84.7%

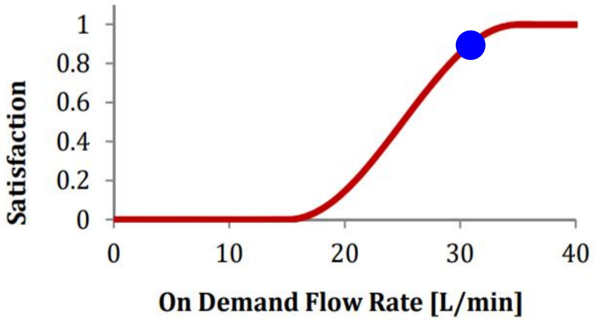
*based off reference cost of $80,000

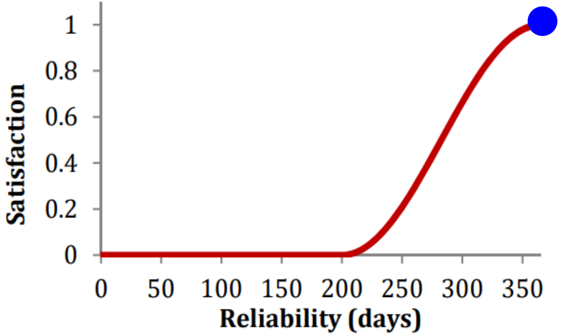
Appendix H: Satisfaction Curves (1)



Appendix H: Satisfaction Curves (2)







Appendix I: Health and Environmental Risk

		Irritation or Inconvenience	Minor injury- No medical Attention	Serious Injury - Medical Attention	Permanent injury or death
		1	2	3	4
Daily risk exposure	4	4	8	12	16
Weekly risk exposure	3	3	6	9	12
Monthly Risk exposure	2	2	4	6	8
Yearly risk exposure	1	1	2	3	4

		Begin Contamination	Trace Contamination	Long-term Environmental Damage	Widespread irreversible damage
		1	2	3	4
Daily risk exposure	4	4	8	12	16
Weekly risk exposure	3	3	6	9	12
Monthly Risk exposure	2	2	4	6	8
Yearly risk exposure	1	1	2	3	4