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Civil Engineering Capstone Design Project

Design of a Water Treatment System for the Ryan Epps Home for Children in Haiti

Vol. 2 – Appendices (March 2015)

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Disclaimer

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List of Appendices

Appendix A

Water Quality Testing Data for Verrettes, Haiti

The following data tables were taken from the article: *Spring flow, bacterial contamination, and water resources in rural Haiti* by Peter J Wampler and Andrew J Sisson:

Table 1 Summary of spring locations and water quality measurements ($N = 25$)

Spring name	Latitude	Longitude	Elevation (m)	Spring type	Flow (L/min)	Conductivity (µs)	Dissolved O_2 (mg/L)	Salinity (ppt)	Temperature (°C)	Turbidity (NTU)
La Kreole	19.02292	−72.47763	214	Capped	43.52	471.3	1.6	0.2	27.6	0.9
Salo Spring Cap	19.02315	−72.47318	241	Capped	2.00	594	2.0	0.3	26.9	0.6
Kazo	18.98026	−72.47038	672	Capped	6.67	427	2.2	0.2	27.4	0.4
Payet	19.00808	−72.46442	392	Capped	0.49	442.4	2.1	0.2	26.8	0.2
Ravine Kafe (Savonet)	19.03771	−72.50525	274	Capped	258.45	498	2.0	0.2	27.1	1.1
Vyelo	19.03326	−72.49680	212	Capped	16.48	369.4	1.6	0.2	27.4	0.2
Kafa	19.01209	−72.45575	359	Capped	7.96	467	2.3	0.2	25.1	2.0
Ravine Mawo	19.00953	−72.44823	282	Capped	5.02	383.3	2.1	0.2	25.7	0.3
Mathurin	19.02031	−72.45103	275	Capped	3.93	426.1	2.7	0.2	27.9	0.4
Te rouge	19.03119	−72.45077	119	Capped	18.33	541	3.0	0.2	28.1	1.3
Kol min	19.04943	−72.53175	326	Capped	8.45	510	3.2	0.2	26.3	2.1
Rodinet	19.03108	−72.44561	94	Capped	47.42	524	4.0	0.2	27.9	1.3
La Koueen	19.03486	−72.45370	153	Capped	7.06	452	3.0	0.2	29.5	0.9
Ozys	19.00055	−72.50211	592	Capped	21.80	505	2.4	0.2	24.2	1.3
Trankite	19.00752	−72.50568	544	Capped	2.44	469	2.4	0.2	25.9	3.0
Kazo (uncapped)	18.98013	−72.47019	665	Uncapped	3.87	438.5	1.8	0.2	27.5	6.8
Ravine Mawo (uncapped)	19.00942	−72.44810	289	Uncapped	6.82	367.4	2.6	0.2	26.3	10.8
Tet Dlo	19.00706	−72.45192	326	Uncapped	13.63	327.5	3.1	0.2	25.6	1.1
Rochopye	19.02942	−72.44702	132	Uncapped	0.43	574	1.5	0.3	27.9	9.2
Ma Bef	19.00381	−72.49725	624	Uncapped	1.80	499	2.5	0.2	26.1	25.3
Paflip	19.00698	−72.50928	523	Uncapped	4.80	449.6	2.0	0.2	25.6	0.7
Font Rouge	18.99720	−72.47619	539	Uncapped	36.00	445.4	2.7	0.2	24.1	0.6
Kaywit (K-8)	18.99582	−72.47557	543	Uncapped	14.16	428.7	2.0	0.2	23.7	1.5
Dorfine	18.99895	−72.48326	531	Uncapped	90.00	387	2.3	0.2	ND	2.0
Simeon	19.00015	−72.48289	530	Uncapped	42.00	506	2.6	0.2	26.4	2.4
Average (all)						460.1	2.4	0.2	26.5	3.1
Average (capped)						472.0	2.4	0.2	26.9	1.1
Average (uncapped)						442.3	2.3	0.2	25.9	6.0

Spring name	pH	Chlorine (mg/L)	Iron (mg/L)	Phosphate (mg/L)	*E. coli* (CE)	Coliform (CE)	Total Coliform (CE)	*E. coli* (HAS)	Coliform (HAS)	Total Coliform (HAS)
La Kreole	7.6	ND	ND	ND	20	820	840	ND	ND	ND
Salo Spring Cap	7.5	ND	ND	ND	80	460	540	ND	ND	ND
Kazo	7.8	0	0.02	0.44	120	460	580	0	0	0
Payet	7.8	ND	ND	ND	440	300	740	ND	ND	ND
Ravine Kafe (Savonet)	7.3	0	0.03	0.23	200	140	340	0	2	2
Vyelo	7.7	0	0.03	0.43	160	320	480	0	0	0
Kafa	7.5	0	0.04	0.67	120	280	400	0	120	120
Ravine Mawo	7.5	0	0.01	0.86	100	140	240	0	0	0
Mathurin	7.4	0	0	1.52	20	200	220	0	0	0
Te rouge	7.4	0	0.03	1.1	40	260	300	6	0	6
Kol min	7.3	0	0	0.4	TNTC	60	TNTC	0	40	40
Rodinet	7.2	0.01	0.01	0.2	20	840	860	0	27	27
La Koueen	7.5	0.02	0.08	0.21	20	540	560	0	20	20
Ozys	7.2	0.02	0.06	0.19	0	TNTC	TNTC	4	60	64
Trankite	7.4	0.01	0.02	0.38	60	1,320	1,380	15	14	29
Kazo (uncapped)	7.9	ND	ND	ND	240	340	580	ND	ND	ND

Table 1 continued

Spring name	pH	Chlorine (mg/L)	Iron (mg/L)	Phosphate (mg/L)	*E. coli* (CE)	Coliform (CE)	Total Coliform (CE)	*E. coli* (HAS)	Coliform (HAS)	Total Coliform (HAS)
Ravine Mawo (uncapped)	7.6	0	0	0.62	0	880	880	33	40	73
Tet Dlo	7.8	0	0.02	1.33	20	160	180	4	0	4
Rochopye	7.2	0.01	0.02	0.42	180	380	560	200	27	227
Ma Bef	7.5	0.01	0.05	0.27	1,640	160	1,800	7	68	75
Paflip	7.3	0	0.05	0.38	2,000	780	2,780	0	TNTC	TNTC
Font Rouge	7.2	0.01	0.03	0.1	120	200	320	0	0	0
Kaywit (K-8)	7.3	0	0.02	0.28	60	320	380	0	0	0
Dorfine	7.1	0	0.04	0.73	100	220	320	0	28	28
Simeon	7.2	0.03	0.04	0.31	20	80	100	0	8	8
Average (all)	7.4	0.0	0.0	0.53	241	403	669	13	23	36
Average (Capped)	7.5	0.01	0.03	0.55	100	439	575	2	24	26
Average (Uncapped)	7.4	0.01	0.03	0.49	438	352	790	27	21	52

ND no data, *CE* Coliscan® Easygel® Kits (automated counting method), *HAS* Hospital Albert Schweitzer, *TNTC* Too numerous to count

Table 2 Percentage of springs deemed unsafe to drink based on WHO and HAS drinking water standards

Analysis method	*E. coli* only (%)		Total coliform (%)	
	WHO standard	HAS standard	WHO standard	HAS standard
HAS ($N = 21$)	33	14	71	52
Coliscan® Easygel® Kits (automated GIS) ($N = 25$)	92	92	100	100

REF: Sisson et Wampler, P. & A. (2010). Spring flow, bacterial contamination, and water resources in rural Haiti. Environmental Earth Sciences.

Appendix B

WHO Table 7.8: Log Removal Credits

The following Table 7.8 was taken from World Health Organization: *Guidelines for Drinking-water Quality Fourth Edition*:

Table 7.8 Reductions of bacteria, viruses and protozoa achieved by household water treatment technologies

Treatment process	Enteric pathogen group	Baseline removal (LRV)	Maximum removal (LRV)	Notes
Chemical disinfection				
Free chlorine disinfection	Bacteria	3	6	Turbidity and chlorine-demanding solutes inhibit this process; free chlorine × time product predicts efficacy; not effective against *Cryptosporidium* oocysts
	Viruses	3	6	
	Protozoa, non-*Cryptosporidium*	3	5	
	Cryptosporidium	0	1	
Membrane, porous ceramic or composite filtration				
Porous ceramic and carbon block filtration	Bacteria	2	6	Varies with pore size, flow rate, filter medium and inclusion of augmentation with silver or other chemical agents
	Viruses	1	4	
	Protozoa	4	6	
Membrane filtration (microfiltration, ultrafiltration, nanofiltration, reverse osmosis)	Bacteria	2 MF; 3 UF, NF or RO	4 MF; 6 UF, NF or RO	Varies with membrane pore size, integrity of filter medium and filter seals, and resistance to chemical and biological ("grow-through") degradation
	Viruses	0 MF; 3 UF, NF or RO	4 MF; 6 UF, NF or RO	
	Protozoa	2 MF; 3 UF, NF or RO	6 MF; 6 UF, NF or RO	
Fibre and fabric filtration (e.g. sari cloth filtration)	Bacteria	1	2	Particle or plankton association increases removal of microbes, notably copepod-associated guinea worm (*Dracunculus medinensis*) and plankton-associated *Vibrio cholerae*; larger protozoa (> 20 µm) may be removed; ineffective for viruses, dispersed bacteria and small protozoa (e.g. *Giardia intestinalis*, 8–12 µm, and *Cryptosporidium*, 4–6 µm)
	Viruses	0	0	
	Protozoa	0	1	
Granular media filtration				
Rapid granular, diatomaceous earth, biomass and fossil fuel–based (granular and powdered activated carbon, wood and charcoal ash, burnt rice hulls, etc.) filters	Bacteria	1	4+	Varies considerably with media size and properties, flow rate and operating conditions; some options are more practical than others for use in developing countries
	Viruses	1	4+	
	Protozoa	1	4+	
Household-level intermittently operated slow sand filtration	Bacteria	1	3	Varies with filter maturity, operating conditions, flow rate, grain size and filter bed contact time
	Viruses	0.5	2	
	Protozoa	2	4	

Table 7.8 (continued)

Treatment process	Enteric pathogen group	Baseline removal (LRV)	Maximum removal (LRV)	Notes
Solar disinfection				
Solar disinfection (solar UV radiation + thermal effects)	Bacteria	3	5+	Varies depending on oxygenation, sunlight intensity, exposure time, temperature, turbidity and size of water vessel (depth of water)
	Viruses	2	4+	
	Protozoa	2	4+	
UV light technologies using lamps				
UV irradiation	Bacteria	3	5+	Excessive turbidity and certain dissolved species inhibit process; effectiveness depends on fluence (dose), which varies with intensity, exposure time, UV wavelength
	Viruses	2	5+	
	Protozoa	3	5+	
Thermal (heat) technologies				
Thermal (e.g. boiling)	Bacteria	6	9+	Values are based on vegetative cells; spores are more resistant to thermal inactivation than are vegetative cells; treatment to reduce spores by boiling must ensure sufficient temperature and time
	Viruses	6	9+	
	Protozoa	6	9+	
Sedimentation				
Simple sedimentation	Bacteria	0	0.5	Effective due to settling of particle-associated and large (sedimentable) microbes; varies with storage time and particulates in the water
	Viruses	0	0.5	
	Protozoa	0	1	
Combination treatment approaches				
Flocculation plus disinfection systems (e.g. commercial powder sachets or tablets)	Bacteria	7	9	Some removal of *Cryptosporidium* possible by coagulation
	Viruses	4.5	6	
	Protozoa	3	5	

LRV, $\log_{10}$ reduction value; MF, microfilter; NF, nanofilter; RO, reverse osmosis; UF, ultrafilter

Estimated reductions of waterborne bacteria, viruses and protozoan parasites by several of the above-mentioned household water treatment technologies are summarized in Table 7.8. These reductions are based on the results of studies reported in scientific literature. Two categories of effectiveness are reported: baseline removals and maximum removals. Baseline removals are those typically expected in actual field practice when done by relatively unskilled persons who apply the treatment to raw waters of average and varying quality and where there are minimum facilities or supporting instruments to optimize treatment conditions and practices. Maximum removals are those possible when treatment is optimized by skilled operators who are supported with instrumentation and other tools to maintain the highest level of performance in waters of predictable and unchanging quality (e.g. a test water seeded with known concentrations of specific microbes).

REF: World Health Organization. (2011). *Guidelines for Drinking-water Quality 4th Edition.* Geneva: WHO. Retrieved from http://whqlibdoc.who.int/publications/2011/9789241548151_eng.pdf?ua=1

Appendix C

Water Quality Testing Data for Guichon Creek

Sample Date	Influent			Effluent		
	Turbidity (NTU)	E.coli per 100 mL	Total Coliform per 100 mL	Turbidity (NTU)	E.coli per 100 mL	Total Coliform per 100 mL
Testing Cycle #1 - Module A21						
23/01/2015		20-0-80	1000-0-TMC		0-0-0	0-0-0
26/01/2015	1.26	0-0-0	110-100-110	0.31	0-0-0	0-0-0
31/01/2015		0-0-0	40-30-0			
2015-05-02	1.02			0.27	0	0
19/02/2015	1.48			0.43		
Testing Cycle #2 - Module A42						
22/02/2015	3.32	0-20-80	410-450-TMC	0.24	0-0-0	0-0-0
28/02/2015	2.84			0.26		

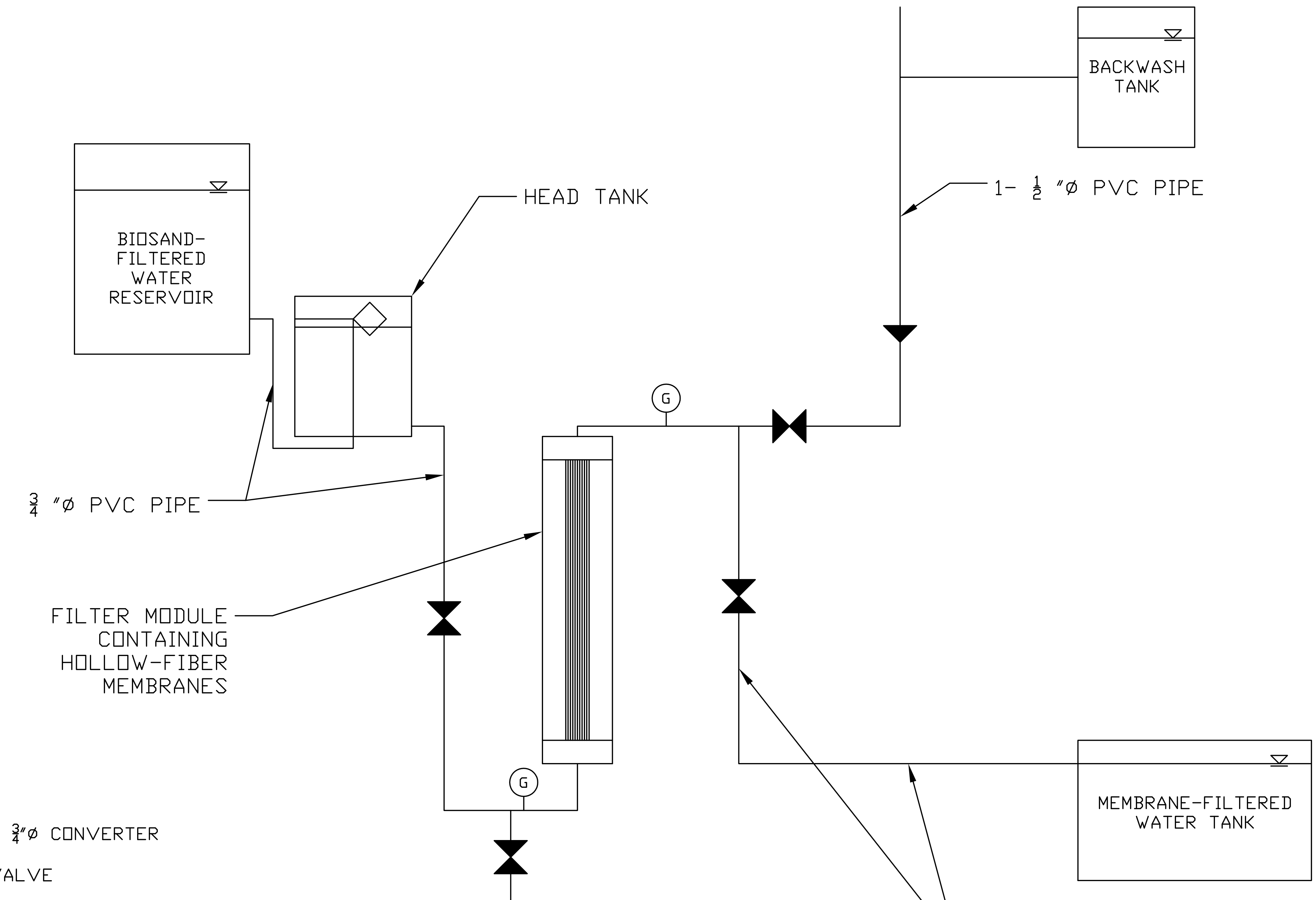
Note: All microbiological tests were done in accordance with the *CIVL 7062 Water Quality Engineering Lab 4 Microbiological Tests* handout. Colony forming units were counted after the samples had been incubated in inverted petri dishes for 24 hrs at 35°C. Turbidity tests were conducted using the HACH 2100Q turbidity meter provided in the BCIT laboratory.

Appendix D

Pilot Model System Schematic & Photos

OPTIMUS PILOT FILTRATION MODEL SCHEMATIC DIAGRAM

N.T.S.



LEGEND

- 1-½"ø TO ¾"ø CONVERTER
- FLOAT VALVE
- WATER TABLE
- PRESSURE GAUGES
- MANUAL VALVES

REVISIONS		
No.	DATE	DESCRIPTION

ISSUES		
No.	DATE	DESCRIPTION

ENGINEER'S SEAL

OPTIMUS ENGINEERING

PROJECT: OPTIMUS REHC TREATMENT SYSTEM

DWG. TITLE: SCHEMATIC DIAGRAM PILOT FILTRATION MODEL

DATE: 2015/MAR/04

DWG. No.: D-1

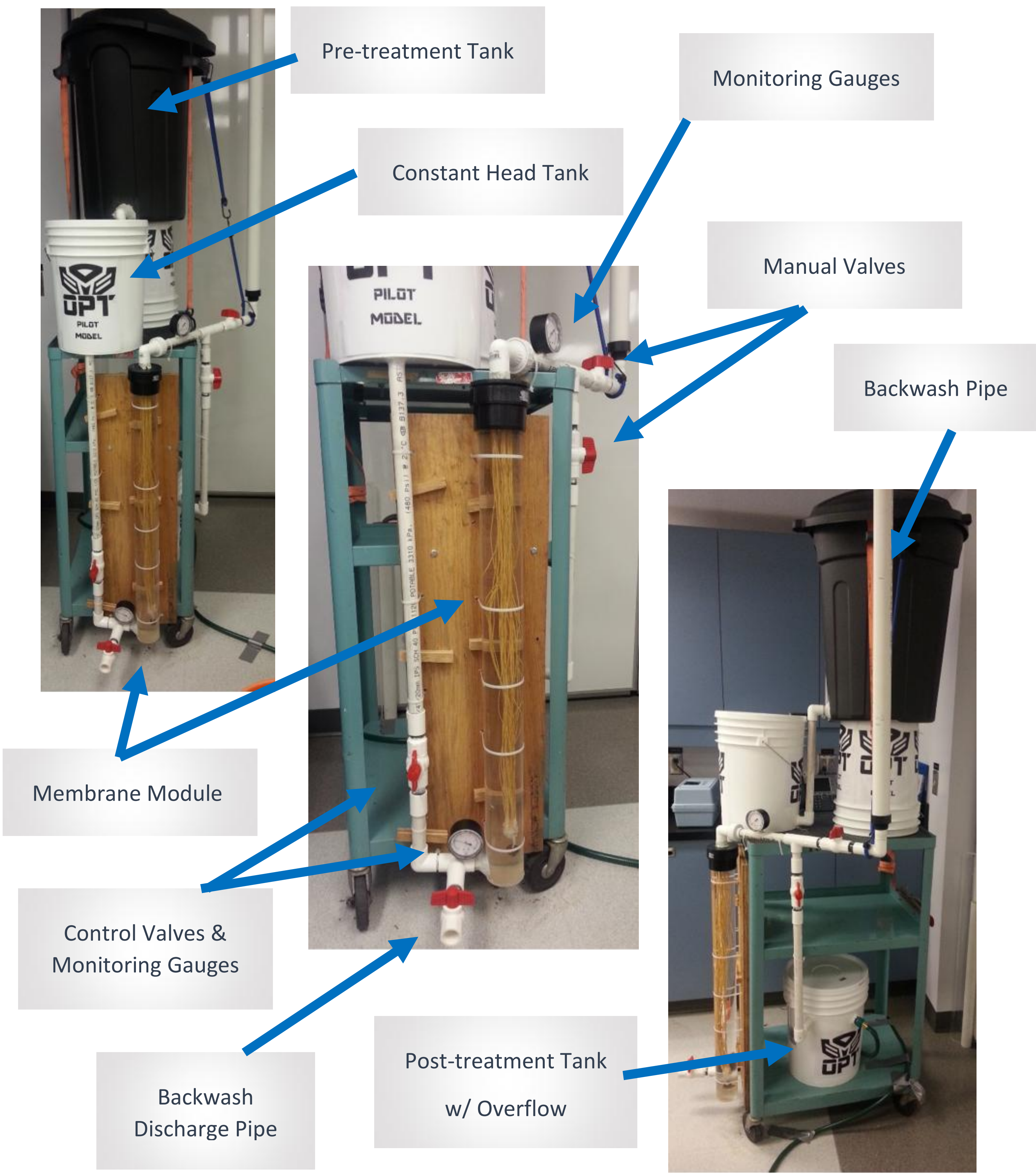
SCALE: _

NAME: MM

SET: _

ISSUE:

Optimus Pilot Model Photos



Appendix E

Pilot Model Design (Hand Calculations)

THE DESIGN OF A MEMRANE FILTRATION MODULE INVOLVES DETERMINING THE REQUIRED SURFACE AREA BASED ON THE FIBRE PROPERTIES & TRANS-MEMBRANE PRESSURE. SINCE WE WERE NOT PROVIDED THE FIBRE PROPERTIES FROM THE MANUFACTURER, WE WILL USE THE DATA OBTAINED FROM THE PILOT MODEL TO ESTIMATE THESE PROPERTIES FOR SCALING PURPOSES.

THE WATER FLUX DENSITY, $\mathring{j}_w$, IS A FLOW PER UNIT AREA. BASED ON THE CONTINUITY EQUATION

① $\mathring{j}_w = v(\text{pore}) \cdot a(\text{pore}) \cdot n(\text{pore})$

② $\mathring{j}_w = K(\text{membrane}) \cdot \left[\frac{\Delta P}{\mu}\right]$

③ $\mathring{j}_w = \frac{Q}{A}$

REF: Water Treatment Unit Processes
DAVID HENDRICKS

→ Combining ② & ③

$$\frac{Q}{A} = \left[\frac{\Delta P}{\mu}\right] K$$

→ $$K(\text{membrane}) = \frac{Q\mu}{A\Delta P}$$

THIS K VALUE IS A FUNCTION OF TIME SINCE FOULING WILL PREVENT FLOW THROUGH SOME PORES AS IT BUILDS UP.

INITIAL (CLEAN) → $Q = 440$ mL/hr

CURRENT → $Q = 310$ mL/hr

THE SURFACE AREA OF THE MEMRANES IN THE PILOT MODEL IS:

$D = 1.2$ mm (Unreinforced PVDF)
$\ell = 70$ cm (this length accounts for losses due to potting)

$A = \pi D \cdot \ell = \pi(0.0012\text{ m})(0.7\text{ m}) = 0.0026\text{ m}^2$ per fibre

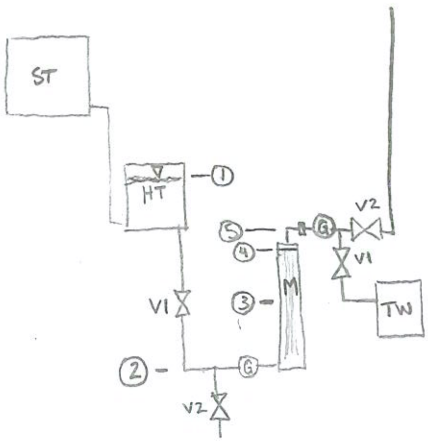
FIBRES = 21 − 4 = 17 (NOTE: 4 MEMBRANES ARE NOT FUNCTIONING)

$A_T = (0.0026\text{ m}^2/\text{fibre}) \cdot 17$ fibres

$A_T = 0.045\text{ m}^2$

$\mu_{@20°C} = 1.002 \times 10^{-3}$ Pa·s

ST - Storage tank (pretreated)
HT - Steady-head tank
V1 - BALL valve (open)
V2 - BALL valve (closed)
M - Membrane module
G - Pressure guage



Q (CLEAN) = 440 mL/hr ∴ h_L due to friction in pipes & through fittings is negligable

Influent

P_1 = Atmospheric

$P_2 = \rho g h = (9.81\, kN/m^3)(1.2\, m) = 11.8\, kPa$

$11.8\, kpa \left(\frac{1\, psi}{6.895\, kPa}\right) = 1.7\, psi$ (confirms reading on guage)

P_3 (@ membrane mid-height) $= 11.8\, kPa - (9.81\, kN/m^3)(0.45\, m)$

$= 7.4\, kPa \quad = 1.1\, psi$

Effluent

P_4 (@ TOP OF MEMBRANE FIBRES) $= (9.81\, kN/m^3)(0.05\, m)$

$= 0.5\, kPa \quad = 0.1\, psi$

P_5 = Atmospheric, the effluent pipes are not full @ this flow rate

∴ TMP = 6.9 kPa ≈ 7 kPa ≈ 1 psi

$$\mathring{j}_w = \frac{Q}{A} = \frac{0.31\ L/hr}{0.045\,m^2} = 6.9 \simeq 7\ Lmh$$

$$j_w = K_{(membrane)}\left[\frac{\Delta P}{\mu}\right]$$

$$\Rightarrow K_{(membrane)} = j_w \cdot \frac{\mu}{\Delta P} = \frac{(6.9\times10^{-3}\ m/hr)(1.002\times10^{-3}\ Pa\cdot s)}{7000\ Pa}\cdot\left(\frac{1hr}{3600s}\right)$$

$$\boxed{K_{(membrane)} = 2.75\times10^{-13}\ m}$$

This coefficient is usually determined through intensive testing by the manufacturer. For the purpose of designing a full-scale model, we will assume that the value determined through pilot model testing is representative of all of the membranes recieved from our supplier. In reality, the number and size of pores is variable which could effect our system flux under these operating conditions.

Appendix F

Pilot Model Membrane Flux Data

Module	Area	
A21	0.0449	m^2
A42	0.1108	m^2

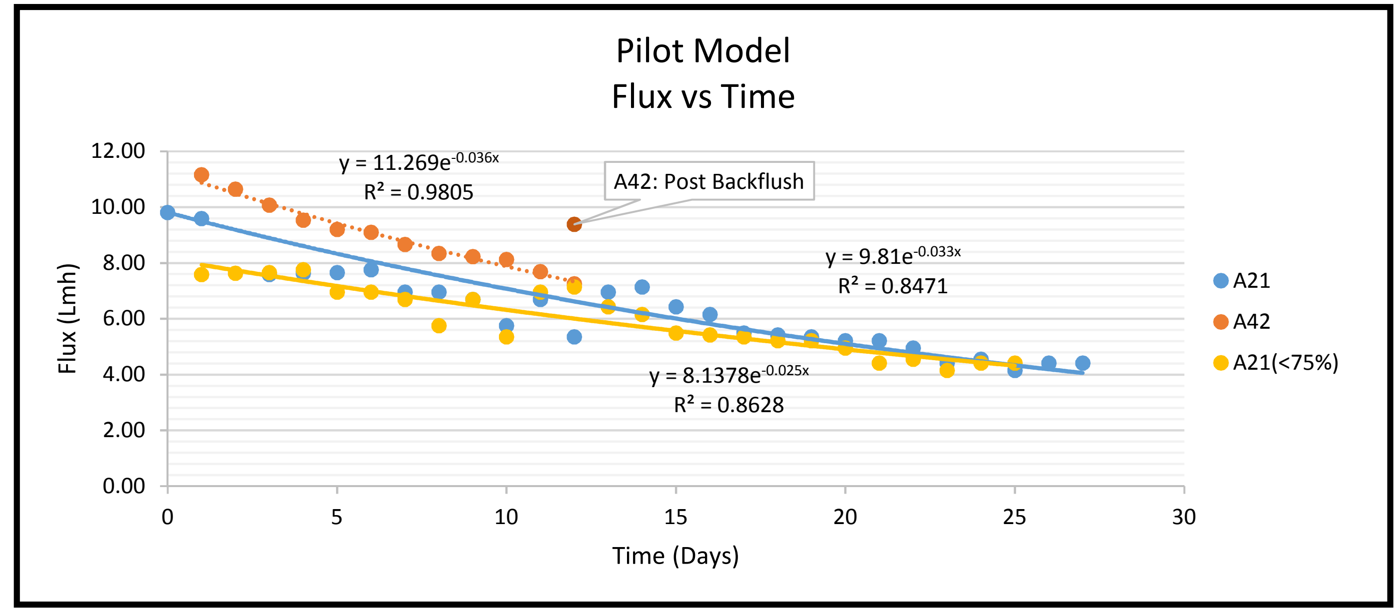
Membrane Flux						
Date	Time (days)	Q (mL/hr)	Flux	Flux drop	% Max. Flux	Q (L/day)
23/01/2015	0	440	9.81	-	100%	10.6
24/01/2015	1	430	9.58	2%	98%	10.3
26/01/2015	3	340	7.58	20%	77%	8.2
27/01/2015	4	342	7.62	0%	78%	8.2
28/01/2015	5	343	7.65	0%	78%	8.2
29/01/2015	6	348	7.76	-1%	79%	8.4
30/01/2015	7	312	6.95	8%	71%	7.5
31/01/2015	8	312	6.95	0%	71%	7.5
01/02/2015	9	300	6.69	3%	68%	7.2
02/02/2015	10	258	5.75	10%	59%	6.2
03/02/2015	11	300	6.69	-10%	68%	7.2
04/02/2015	12	240	5.35	14%	55%	5.8
05/02/2015	13	312	6.95	-16%	71%	7.5
06/02/2015	14	320	7.13	-2%	73%	7.7
07/02/2015	15	288	6.42	7%	65%	6.9
08/02/2015	16	276	6.15	3%	63%	6.6
09/02/2015	17	246	5.48	7%	56%	5.9
10/02/2015	18	243	5.42	1%	55%	5.8
11/02/2015	19	240	5.35	1%	55%	5.8
12/02/2015	20	234	5.22	1%	53%	5.6
13/02/2015	21	234	5.22	0%	53%	5.6
14/02/2015	22	222	4.95	3%	50%	5.3
15/02/2015	23	198	4.41	5%	45%	4.8
16/02/2015	24	204	4.55	-1%	46%	4.9
17/02/2015	25	186	4.15	4%	42%	4.5
18/02/2015	26	198	4.41	-3%	45%	4.8
19/02/2015	27	198	4.41	0%	45%	4.8

A21 module (17 working fibres)

22/02/2015	0	1236	11.15	-	100%	29.7
23/02/2015	1	1180	10.65	5%	95%	28.3
24/02/2015	2	1116	10.07	5%	90%	26.8
25/02/2015	3	1056	9.53	5%	85%	25.3
26/02/2015	4	1020	9.20	3%	83%	24.5
27/02/2015	5	1008	9.09	1%	82%	24.2
28/02/2015	6	960	8.66	4%	78%	23.0
01/03/2015	7	924	8.34	3%	75%	22.2
02/03/2015	8	912	8.23	1%	74%	21.9
03/03/2015	9	900	8.12	1%	73%	21.6
04/03/2015	10	852	7.69	4%	69%	20.4
05/03/2015	11	804	7.25	4%	65%	19.3
05/03/2015	12	1040	9.38	-	84%	25.0

A42 module

Post Backwash



Flux Vs. Time		
Data	Flux	Eqn #
A21 module	$J_1 = 9.81e^{-0.033t}$	Eqn 1
A21 module (not including first two data points)	$J_2 = 7.36e^{-0.025t}$	Eqn 2
A42 module	$J_3 = 11.27e^{-0.036t}$	Eqn 3

Notes:
The 7.36 in Eqn 2 is 75% of the initial flux in Eqn 1
The area for the A21 module represents only the 17 functional membrane fibres

Appendix G

REHC Treatment System Materials List

FULL-SCALE WATER FILTRATION SYSTEM MATERIALS LIST

Local Components

Component	Quantity Required
Pipe per 10'	90 ft
fittings (45/90), tees, gaskets	30 pcs
manual ball valves (bibcock valves)	25 pcs
head tanks/buckets	2 pcs
float valve	3 pcs
pipe glue	5 pcs
epoxy tubes (120 mL)	2 pcs
plumber's putty	5 pcs
ferro-cement tank (6000 gal = 7.07 m^3)	21.2 m^3 storage
bleach for chlorination	0.72 kg/month

Non-local Components

Component	Quantity Required
manual backwash pump	1 pc
membrane filter modules	6 pcs
solar panels	1 pc
solar pump	1 pc
pre-screen filter	30 m^2

Supplier Information:

Local Suppliers

MSC Trading		A & B Hardward S.A	
Address:	44 Boulevard do 15 Octobre, Tabarre, Haiti	**Address:**	32, Ange rue des Nimes et route de l'Aeroport
Phone:	(509) 3656-7777	**Phone:**	509 2513-0097
	(509) 3499-1616		509 2940-6003
	(509) 3462-1111		509 3701-3710
Email:	info@msctradinghaiti.com	**Email:**	patrick@abhardware.com
Website:	msctradinghaiti.com	**Website:**	n/a

Non-Local Suppliers

Grundfos Canada Inc.		Hinada Water Treatment Tech Co., Ltd	
Address:	2941 Brighton Road, Oakville, Ontario, L6H 6C9, Canada	**Address:**	A207, No.31 Kefeng Rd. Luoguang District, Guangzhou, Guangdong, China
Phone:	905-829-9533	**Phone:**	+86-20-82350103
Toll-Free-Phone:	1-800-644-9599	**Fax:**	+86-20-82350103
Fax:	905-829-9599	**Email:**	jeff@hinada.com
Toll-Free-Fax:	1-800-265-9862	**Website:**	www.hinada.com
Email:	canada@grundfos.ca		
Website:	ca.grundfos.com		

Note: Other non-local components can be outsourced in Alibaba.com. For details on Alibaba website, see www.alibaba.com

Appendix H

REHC Pure Water Business Plan

REHC Pure Water - Business Plan

Executive Summary

REHC Pure Water is a small business that will be set up through the Ryan Epps Home for Children (REHC) that will sell excess filtered water, from the water filtration system, to the community. The profits will then be used to cover maintenance and improvement costs associated with the water filtration system and also to raise funds for REHC. In addition, REHC Pure Water will aim to promote health in the community. A storefront, typical to those found in Haiti, will be set up and run by REHC to sell the water. The logo that Optimus has designed for REHC Pure Water is shown below in Figure 1.

Figure 1: REHC Pure Water Logo

Optimus anticipates there to be enough of a market within walking distance of REHC for the business to be sustainable, while having minimal impacts on existing water producers. Convenient business hours will be maintained so that it is easy for local residents to get the water they need with convenience.

1.0 Business Description

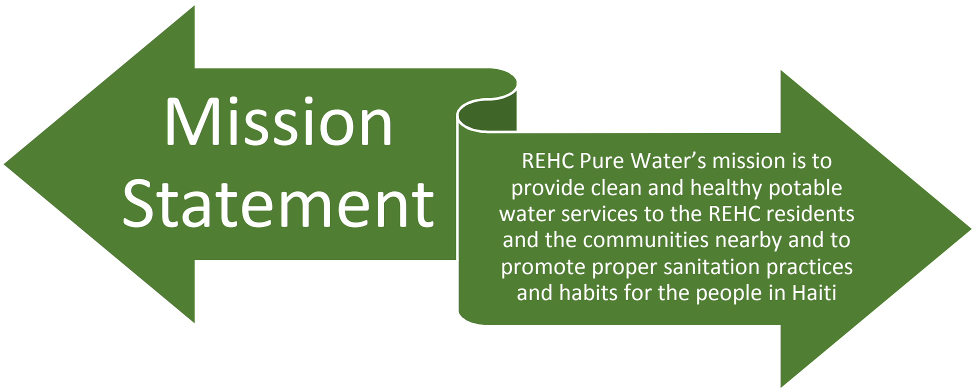
The Ryan Epps Home for Children (REHC) is a non-profit organization in Haiti which runs a school and orphanage in Croix de Bouquets, located near the capital city of Port au Prince. The REHC Pure Water store will consist of a storefront set up at the REHC site, and will sell treated water at a competitive price to local people in the area. Figure 2 below shows a typical store-front in Haiti, similar to what we envision for the storefront at the REHC.

Figure 2: Typical Storefront in Haiti (Compassion, 2015)

Profits from selling water will go towards paying for the initial costs of the system, the periodic costs of running the system. Any money generated beyond those costs will go towards maintenance and upgrades to the REHC. The business will be set up through the REHC.

2.0 Mission Statement

The following mission statement has been developed for REHC Pure Water:



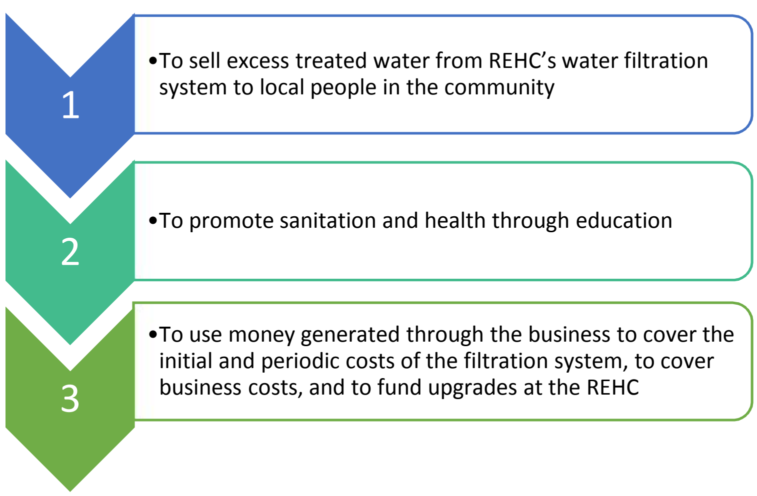
3.0 Vision Statement

REHC Pure Water's vision is to provide a local source of treated drinking water that is affordable, reliable, and sustainable to benefit people at the REHC and in the surrounding communities.

4.0 Goals and Objectives

The main goal for the water filtration system at the REHC is treat water for residents of the school and orphanage. Water produced in excess of the amounts required for the REHC will be available to be sold.

The REHC Pure Water business has three objectives which are listed as follows:



There will be up to 1800 L of treated water per day that is available for sale to the community.

5.0 Marketing Strategies

An analysis has been completed by Optimus on the expected number of potential customers for REHC Pure Water. A catchment zone radius of 1.25-km, as shown in Figure 3 below, was used to estimate the number of people who will be targeted for advertising. Based on the analysis, Optimus anticipates that 10% of the residents within the catchment area around REHC could be obtained as customers for REHC Pure Water. This results in a total 1800 potential customers.

Figure 3: Radius of Marketability (Google Maps, 2015)

To inform the local residents identified during the business analysis, flyers will be used for advertisement of the business. These flyers will contain information on the REHC's water products, as well as information on promoting healthy living and sanitation. These ads will be distributed around the community and among daily customers buying water from REHC Pure Water store. See Appendix O for the advertising flyer.

6.0 Competitive Analysis

The traditional business model for a drinking water distributor in Haiti is to have a large, centralized treatment system, and trucks to drive around and deliver the water. This model works as the businesses are able to treat large amounts of water, which can then be distributed to lots of people using the trucks (Healing Haiti). Figure 4 below shows people lining up behind a water truck in Haiti.

Figure 4: Water Truck in Haiti (Devitt)

The model that Optimus has developed for REHC is based off recent trends which are pushing for smaller, more local water treatment systems. While these systems produce less water for fewer people, they are generally more reliable, especially in disaster situations. This model suits REHC Pure Water as large profits are not needed, as costs are low. There are currently no small-scale local drinking water distributors in the area. As such REHC Pure Water should not impact any existing businesses, nor do existing businesses impact REHC Pure Water.

Because the customer base is so large for the centralized distributors, Optimus expects that some local customers will be diverted to REHC Pure Water. We feel that the reliability and convenience of our store front will appeal to local people in the area, and they will be drawn to REHC Pure Water to purchase drinking water.

7.0 Business Layout Plan

The business will consist of a storefront and a cleaning station, which will be located at the existing REHC site. The storefront will consist of a window located along the east side of the site and will be accessible from the street. The cleaning station, for sanitizing customer's water containers, will be located near the filtration system next to the taps. Figure 5 shows the proposed layout of the system.

Figure 5: Plan View of Layout Plan for REHC Site (Google, 2015)

The storefront will be located about 3 m southwest of the water filtration system just against the wall of the open lot. This way, the store is easy to find for the customers as well as easy access to the clean drinking water from the system for the store staff. The cleaning station will be installed just right on the top right corner of the filtration system, providing a close proximity from the water taps as well as the infiltration trench where wash water is to be directed.

8.0 Description of Products & Services

REHC Pure Water will sell treated water in one or five gallon amounts. We anticipate that customers will bring their own containers, but if not containers are available for purchase at an additional cost. A service will be provided by REHC Pure Water staff to clean and sanitize customer's containers for them, to ensure that it is done properly.

9.0 Operations & Management Plan

The business is to be run by the faculty and staff of REHC. As such, money raised from the sales will go directly to REHC. One staff member will run the till at the storefront, keep sales records daily, and sanitize containers for customers. We will ensure that at least two people are trained to run the storefront so that there is always an alternate. Table 1 below spells out the business hours for the storefront.

Table 1: REHC Pure Water Business Hours

Days	Hours
Monday - Friday	6:00 am to 6:00 pm
Saturday, Sunday, Holidays	6:00 am to 6:00 pm

Since the staff are also residents of REHC, the store will be available on weekends with less strict operating hours. The water will be priced at a rate of 4 HTG/gal. This is slightly cheaper than the average price of drinking water in Haiti, which is 5 HTG/gal (Numbeo, 2015).

10.0 Financial Factors

The initial cost of the filtration system will be funded through the REHC and its stakeholders. Money raised through the REHC Pure Water business will initially go to covering this investment. Based on Optimus's conservative cost projections, we anticipate that the system will be paid off within five years.

Money raised beyond this will go towards two things:

- Covering period costs of running the water filtration system
- Funding future upgrades and or maintenance to the school and home

The business will be set up through the REHC, who will be responsible for running the business and managing funds. With a projected lifespan of 25 years, we feel that the money raised through REHC Pure Water will be more than sufficient to initial system costs and periodic system costs, which is the main purpose of REHC Pure Water. See the attached excel printouts outlining financial aspects of the business plan including, material costs, construction costs, training costs, operating and maintenance costs, and break even analysis.

11.0 References

Compassion. (2015). *Storefront.* Retrieved March 01, 2015, from Rebuilding Haiti: http://www.compassion.com/press/fifth-anniversary-haiti-earthquake.htm

Devitt, T. (n.d.). *Cholera: Haiti's Latest Scourge.* Retrieved February 14, 2015, from The Why Files: http://whyfiles.org/2010/cholera-haitis-latest-scourge/

Google Maps. (2015). *Google Maps*. Retrieved February 16, 2015, from Haiti: https://www.google.ca/maps/place/Haiti/@18.5743383,-72.2083725,4782m/data=!3m1!1e3!4m2!3m1!1s0x8eb6c6f37fcbbb11:0xb51438b24c54f6d3

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Numbeo. (2015, March). *Food Prices in Haiti*. Retrieved March 04, 2015, from http://www.numbeo.com/food-prices/country_result.jsp?country=Haiti&displayCurrency=USD

BUSINESS PLAN FOR RYAN EPPS HOME FOR CHILDREN IN HAITI

Cost for Worker Wages

Component		Cost		Notes
Min. Rate =		300	HTG per 8-hr day	Production and piece rate workers
Min. Hourly Rate =		37.5	HTG/hr	
Min. Hourly Rate (CAD) =	$	0.98	CAD	
Min. Rate =		200	HTG per 8-hr day	Trainees, job transferees, and non-piece rate workers
Min. Hourly Rate =		25	HTG/hr	
Min. Hourly Rate (CAD) =	$	0.65	CAD	
# of Working Hours =		48	hrs/week	
Premium rate =		56.25	HTG/hr	

Reference

http://www.workersrights.org/freports/WRC%20Haiti%20Minimum%20Wage%20Report%2010%2015%2013.pdf

OPTIMUS ENGINEERING BUSINESS PLAN FOR RYAN EPPS HOME FOR CHILDREN IN HAITI

Cost for Local Components

Component	Cost, HTG	Cost, CAD	Units	Quantity Required	Units	Total Cost (CAD)
Pipe per 10'	134	$ 3.47	/10ft	90	ft	$ 31.25
fittings (45/90), tees, gaskets	57	$ 1.49	/pc	30	pc	$ 44.64
manual ball valves (bibcock valves)	95	$ 2.48	/pc	25	pcs	$ 62.00
head tanks/buckets	119	$ 3.10	/pc	2	pcs	$ 6.20
float valve	95	$ 2.48	/pc	3	pcs	$ 7.44
pipe glue	187	$ 4.87	/pc	5	pcs	$ 24.35
epoxy tubes (120 mL)	837	$ 21.77	/pc	2	pcs	$ 43.54
plumber's putty	208	$ 5.40	/pc	5	pcs	$ 27.00
ferro-cement tank (6000 L = 7.07 m^3)	2,385	$ 62.00	/m^3 storage	21.2	m^3 storage	$ 1,315.02
bleach for chlorination	8,585	$ 223.20	/50 kg	0.72	kg/month	$ 964.22
					Total:	**$ 2,525.66**

Cost for Non-local Components

Component	Cost, USD	Cost, CAD	Units	Quantity Required	Units	Total Cost (CAD)
pre-filter screen	$ 30.00	$ 20.00	/m^2	30	/m^2	$ 600.00
manual backwash pump	$ 50.00	$ 62.00	/pc	1	pc	$ 62.00
membrane filter modules	$ 200.00	$ 248.00	/pc	6	pcs	$ 1,488.00
solar pump	$ 1,200.00	$ 1,488.00	/pc	1	pc	$ 1,488.00
solar panels	$ 3,000.00	$ 3,720.00	/pc	1	pc	$ 3,720.00
					Total:	**$ 12,271.44**

OPTIMUS ENGINEERING BUSINESS PLAN FOR RYAN EPPS HOME FOR CHILDREN IN HAITI

Capital Costs for System Deployment

Item	Cost/hr, CAD	Hours	# of Workers	Total Cost, CAD
construction				
membranes assembly	$ 0.65	24	4	$ 62.40
ferrocement tanks and tower construction	$ 0.65	80	6	$ 312.00
well pump installation	$ 0.65	8	2	$ 10.40
other: pipes, connections	$ 0.65	8	2	$ 10.40
integrity tests	$ 0.65	8	2	$ 10.40
manual pump installation	$ 0.65	8	2	$ 10.40
training				
at construction and commissioning	$ 0.65	90	4	$ 234.00
after commissioning	$ 0.65	24	4	$ 62.40
after 3 months from initial startup	$ 0.65	24	4	$ 62.40
				Total: **$ 774.80**

Periodic Costs for System Operation

Item	Interval	Cost/unit, CAD	Unit	# of Workers	# of Hours	Total Cost, CAD
regular maintenance	monthly (2 hrs)	$ 0.65	/hr	2	2	$ 780.00
disinfection	monthly (4 hrs)	$ 0.65	/hr	2	4	$ 1,560.00
chemical cleaning	monthly (4 hrs)	$ 0.65	/hr	2	4	$ 1,560.00
monitoring	weekly (2 hrs)	$ 0.65	/hr	2	2	$ 780.00
testing for MB	bi-weekly (4 hrs)	$ 0.98	/hr	2	4	$ 2,340.00
testing for turbidity	bi-weekly (2 hrs)	$ 0.98	/hr	1	2	$ 585.00
power costs	monthly	$ 0.10	/kW-hr	-	6	$ 252.00
system backwash	weekly (4 hrs)	$ 0.98	/hr	2	4	$ 2,340.00
membrane module replacement	every 5 - 7 years	$ 4,464.00	/ye	4	-	$ 4,464.00
					Total:	**$ 14,661.00**
					Contingency:	$ 6,046.58
					Subtotal:	**$ 36,279.48**

BUSINESS PLAN FOR RYAN EPPS HOME FOR CHILDREN IN HAITI

Input Parameters and Conversions

Bokit =	5	-gal water jugs
Currency =	1	Hatian Gourde (HTG)
Haiti Conversion =	0.026	CAD/HTG
1 month =	30	days
chlorine =	4	ppm (mg/L)
HTG =	0.026	CAD
USD =	1.24	CAD
cost solar panel =	0.1	kW/hr
lifespan =	25	years
contingency fund =	20%	
1 year =	12	months = 52 weeks

Year Breakdown	
Description	**# of days**
school days	170
breaks	30
weekends	92
summer break	73
total	365

Input Data

School Days:

A.D.D. =	6	L/person/D	
Safety Factor =	3	(excess water for 3 days)	
F.A.D.D. =	18	L/person/D	
F.A.D.D. used =	20	L/person/D	
# of persons in REHC =	210		(200 children; 10 staff)
$V_{treated}$ =	4090	L/D	
V_{REHC} =	4200	L/D	
V_{net} =	787	L/D	(extra water for sale)
1 L =	0.264172	gal	
Cost of bokits =	20	HTG	
Cost per gallon =	4	HTG/gal	
Earnings per day =	831.45	HTG/day	
Earnings per school year =	141346.01	HTG	
Earnings per school year (USD) =	$ 3,675.00	CAD	

Weekends/Breaks/Summer Vacation Days:

A.D.D. =	6	L/person/D	
Safety Factor =	3	(excess water for 3 days)	
F.A.D.D. =	18	L/person/D	
F.A.D.D. used =	20	L/person/D	
# of persons in REHC =	40		(30 children; 10 staff)
$V_{treated}$ =	4090	L/D	
V_{REHC} =	800	L/D	
V_{net} =	787	L/D	(extra water for sale)
1 L =	0.264172	gal	
Cost of bokits =	20	HTG	
Cost per gallon =	4	HTG/gal	
Earnings per day =	831.45	HTG/day	
Earnings per school year =	162132.19	HTG	
Earnings per school year (USD) =	$ 4,215.44	CAD	

Total Potential Profit per year = $ 7,890.43

Overall Summary of System Costs		
Capital Cost	$	18,686.28
Periodic Cost (over 25 yrs)	$	17,593.20
Periodic Cost/yr	$	703.73
Overall Total Cost	$	36,279.48

System Deployment Costs		
Local Components	$	2,525.66
Non-local Components	$	12,271.44
Construction and Training	$	774.80

Breakeven = 4.60 yrs

Appendix I

WASH Program and Sanitation Recommendations

REHC WASH Program and Education on Sanitation

The Ryan Epps Home for Children (REHC) will require a Water and Sanitation Hygiene (WASH) program to accompany the Optimus water filtration system. This document consists of Optimus' guidelines and suggestions for incorporating proper and adequate sanitation services to the school and to the people in the community.

1.0 Background

Since the earthquake that occurred in Haiti in 2010, there have been numerous outbreaks of cholera and other diseases. Clean water has become a precious commodity for the local people as it is not readily available. Children would often miss school either to collect water or due to illness resulting from inadequate hygiene. By implementing a water filtration system for the REHC, we are providing a clean drinking water source for the residents and locals. Clean drinking water is essential to healthy living, but it does not on its own lead to improved health. In addition, proper sanitation is needed along with clean water to promote good health. The relationship between hygiene practices, sanitation, polluted water sources and diseases needs to be understood in order to mitigate health risks and prevent the further spread of diseases.

2.0 Sanitation and Hygiene Promotion

To promote the need for improved sanitation and hygiene, Optimus has developed the following sets of recommendations. The first set is targeted towards the general public, and the second set is specific for teachers and staff at REHC. These procedures are intended to help promote proper hygienic practices and prevent the spread of diseases.

2.1 Tips for Everyone:

- Wash hands with soap and water before preparing and eating food.
- Wash hands with soap and water right after defecating.
- Wash hands with soap and water after cleaning a child's bottom.
- Wash hands with soap and water right after using the toilet, urinal, or latrine.
- Alternatives for soap, such as ash, can be used for washing and cleaning.
- Provide a consistent source of clean water near the toilets for washing.
- Separate latrine facilities for girls and boys.
- Cover cooked and uncooked food to protect from disease carrying agents.
- Get enough rest and sleep.
- Ensure to have adequate exercise regularly.

2.2 Tips Specifically for REHC Teachers and Staff:

- Function as role models / initiators for proper hygiene practices in the school and community
- Incorporate good hygiene education into school curriculum
- Have access to teaching methodologies and materials regarding health and prevention of diseases
- Provide adequate supervision and monitoring of sanitation for students and residents
- Ensure access to clean water and sanitation facilities
- Identify and correct improper sanitary practices, and encourage good hygiene by using practical demonstrations, repetition of messages on sanitary habits during prayer sessions, sport events and other social, cultural, and religious events
- Hygiene promotion must be made culturally appropriate.
- Do not overburden one group within the population (e.g. women) with the responsibility of hygiene promotion activities and management of these activities.
- Keep latrines and wash stations clean at all times

These recommendations, prepared by Optimus Engineering, have been interpreted from the WASH guidelines as provided by the United Nations Children's Fund (Unicef, 2013) and the Sphere Project Handbook (The Sphere Project) to suit the needs of REHC and its surrounding communities

3.0 Wash Program Implementation

There are four major components for the implementation of the WASH program:

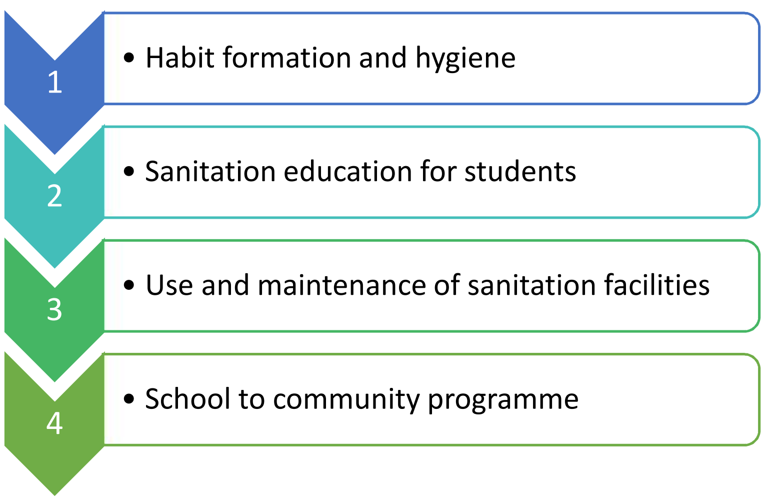

Figure 1: Components of WASH implementation program (Unicef, 2013)

All four of these items need to be introduced to residents at REHC and incorporated with the implementation of Optimus' water treatment system.

4.0 WASH and Women

In Haiti, women and girls bear the responsibility of doing household chores. This includes collecting water, cleaning latrines, and executing garbage disposal. Lack of sanitation and hygiene facilities in schools has a greater negative impact on girls than on boys. This can be attributed to the higher exposure to poor sanitary conditions and the greater need for these types of facilities due to bodily functions. Sanitation facilities must also be considered private and secure as women and girls are more vulnerable to assault or abuse. (Unicef, 2013)

5.0 Water Supply

REHC has a relatively clean well water source existing on-site. With Optimus' water filtration system, the school will have a safe source of drinking water capable of producing sufficient supply for the school and surrounding community. Figure 2 below shows a typical well source in Haiti.

Figure 2: Typical Well Source in Haiti (Wickenhauser, 2012)

The well pictured in Figure 2 above is a fairly clean water source which is common for groundwater sources. As such, concern will be focused on water supply for washing, cleaning, and sanitation purposes.

6.0 Excreta Disposal

One of the primary causes of the outbreak of cholera in the country is the lack of sanitary sewers in Haiti. Sanitary sewers essentially separate human excretion from clean water in a more organized manner (Unicef, 2013). Figure 3 shows a latrine over water in Haiti.

Figure 3: Latrine in Haiti (Stauffer, 2007)

Latrines like the one pictured in Figure 3 are hazardous as they directly contaminate surface waters. Without separation, excretion becomes mixed with the clean water and contaminates it, causing further spread of diseases to people who drink it.

REHC has its own toilets for proper excrete disposal. However, it is still important to implement a plan that would guide the staff, students, and residents of REHC, to develop habits on proper management of excrete disposal that could benefit the community as a whole. Appropriate anal cleansing material for use must also be available in these toilets as well as in other conventional latrines around. Toilet facilities must be safe, private and internally lockable, easy to keep clean, and provide adequate washing and drying materials for users (Unicef, 2013).

7.0 Vector Control

Vector control is the process of controlling, minimizing, preventing, and potentially eliminating diseases caused by disease-carrying agents called vectors. Examples of vectors include mosquitoes, flies, bedbugs, fleas, ticks, lice, rats and mice. Vectors, like the one in Figure 4, can cause a wide variety of sickness such as malaria, dengue, yellow fever, diarrhoeal diseases, scabies, leptospirosis and salmonellosis, and many other diseases and infections.

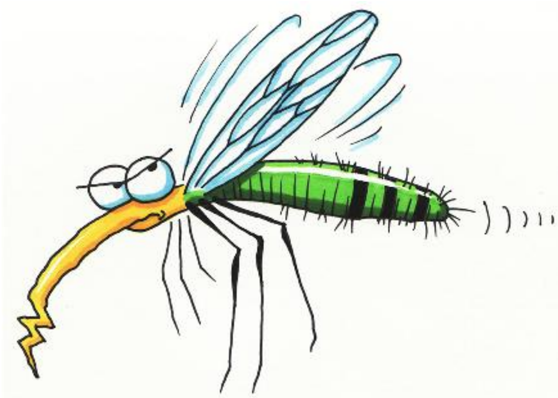

Figure 4: Mosquito (Meyer, 2014)

Diseases like these can be controlled in a variety of ways. In the context of REHC, methods of prevention may include proper water supply, proper excreta disposal, proper water drainage, and provision of health services. Optimus has made the following recommendations:

- Raise awareness for affected people who are at risk from vector-borne diseases by providing knowledge on causes of these diseases, how they can be transmitted, and what are possible ways can be undertaken to prevent them
- Make sure that all beddings and clothing are washed and cleaned on a regular basis.
- Protect against mosquito exposure by using bed nets, repellents, long-sleeved clothing, burning coils
- Regular washing of clothes and beddings are very effective in keeping body lice.
- Good waste disposal and food storage deters rats, rodents and other nuisances
- Proper disposal of excreta and proper disposal of refuse must be implemented to control population of flies and rodents from growing.
- Drain stagnant water and clear unwanted plants from open canals and ponds to reduce habitat of mosquitoes and control their population from growing.
- Seek advice from locals with regards to local disease patterns, breeding sites, seasonal variations in vector numbers, and incidence of diseases (The Sphere Project).

8.0 References

Meyer, D. O. (2014, December). How to Avoid Getting Bit by Mosquitoes. Retrieved March 04, 2015, from https://www.dr-olivier-clinic.com/how-to-avoid-getting-bit-by-mosquitos/

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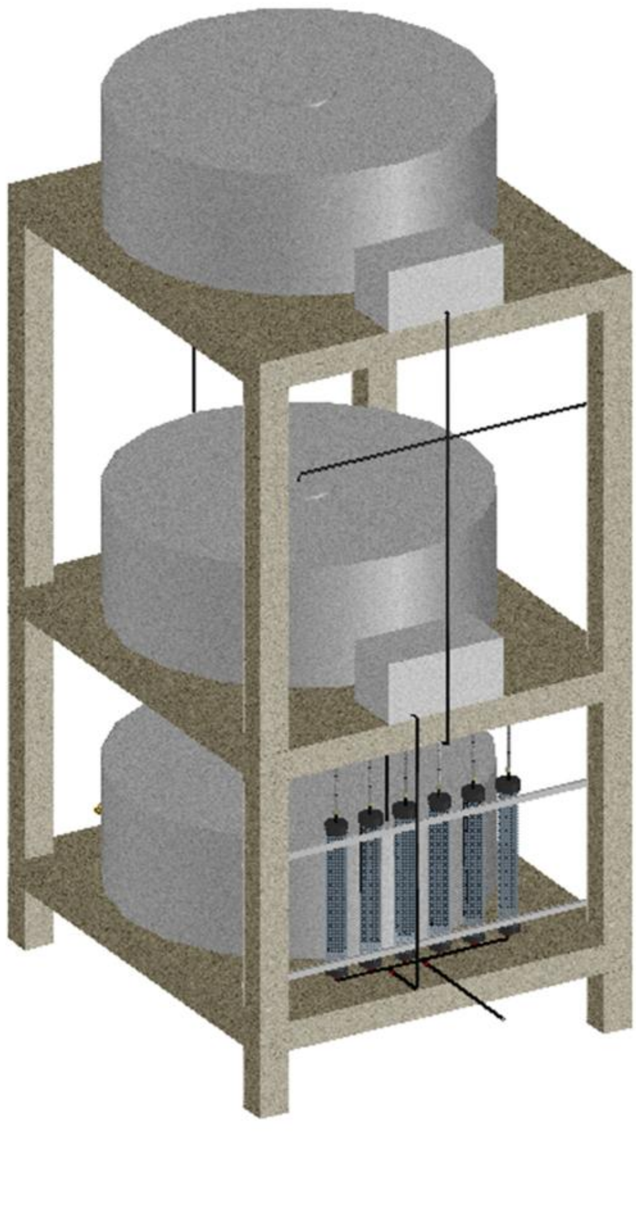
Appendix J

Operation and Maintenance Manual

REHC Water Filtration System: Operation and Maintenance Manual



Optimus Engineering - March 2015

1.0 Introduction and Guidance

The Optimus water filtration system for the Ryan Epps Home for Children (REHC) is a gravity fed membrane filtration unit capable of producing high quality potable water. Proper training, operating procedure, and maintenance is necessary to ensure the system performs as intended. This manual has been developed to provide instructions for system operators, identify safety concerns, outline ongoing testing procedures, and detail system materials.

1.1 How to Use This Guide

This guide is intended as an educational and reference document for the operators of the REHC water filtration system. It is designed to be the main training document for all system operators. As well, it is also meant to act as a reference guide that operators utilize during system operation for troubleshooting purposes. Any questions that are outside the scope of this document can be brought to Optimus Engineering, which has been designed to provide technical support for the system. This document is a supplementary component of the REHC water filtration system, and is meant to compliment Optimus' implementation plan and design report.

1.2 Operator Training Considerations

It is intended that operator training during initial project construction will be provided by members of Optimus Engineering. A minimum of two operators will be selected to run the system, who will be appointed by staff at REHC. Training for these operators will consist of an overview of the system, monitoring and support during the construction stage, and additional comprehensive training upon system initiation. Considerations should be made to select operators who are most likely to be present during the length of the project.

1.2.1 System Overview

This will be the first stage in operator training. This stage involves a brief introduction to the water filtration system, to inform the operators of how it functions. This section will be short, and will encompass material that is presented in Section 3 of this manual.

1.2.2 Construction

As part of the training, operators will be involved in construction monitoring and support for the filtration system. This is intended to give the operators a better sense of how the system functions, and will help them later on when maintenance is required.

1.2.3 Comprehensive Training

The last stage of operator training will consist of more comprehensive education on the operation of the system, monitoring activities required, and maintenance requirements. This section will encompass material that is presented in Sections 2 through 7 of this manual.

2.0 Health and Safety

The primary objective of the Optimus REHC water treatment system is to provide safe clean water for residents in Haiti. It is intended that the system adhere to all relevant regulations with regard to water quality and as such, it has been designed based on existing standards. Ongoing assessment of effluent quality and proper disposal of backwash water is vital to ensure the health of the systems consumers.

2.1 Guidance and Relevant Regulations

This water filtration system is intended to provide clean drinking water to the residents and customers of REHC. Clean water refers to water that passes all parameters set out in the World Health Organisation's (WHO) Guidelines for drinking water (4th Edition). Based on these guidelines, the following criteria need to be met for the water to be drinkable (World Health Organization, 2011):

- 4-log removal for bacteria and viruses
- turbidity of less than 0.3 NTU
- zero E.coli per 100mL sample

This system has been designed to standards as laid out in the United States Environmental Protection Agency (EPA) Membrane Filtration Guidelines (United States Environmental Protection Agency, 2005).

2.2 Health Risk Assessment

Risks associated with this system are related to potential breaches which are not detected, which could result in someone consuming contaminated water and becoming ill. To mitigate this risk, routine monitoring will be undertaken in ensure proper system operation The system will be checked for integrity upon implementation, and treated water will be tested on a monthly basis to ensure that the water remains clean.

2.3 Disposal Information

While contaminated water is not safe for human consumption, it poses minimal risk to the environment. Contaminated water is to be disposed of in the designated infiltration trench. Excess chlorine can either be taken to relevant disposal area, or can be diluted with waste water and emptied into the infiltration trench.

LARGE AMOUNTS OF CHLORINE CAN BE EXTREMELY HAZARDOUS / FATAL. PLEASE CONSULT MANUFACTURER'S INFORMATION WHILE USING.

3.0 System Description

This Optimus water filtration system has been developed specifically for REHC. The system has been designed to treat groundwater from the well on-site at REHC. The system has been tailored to address the expected water quality conditions at REHC as described in Optimus' design report.

3.1 System Operation

The Optimus system is a direct water filtration system, which uses membrane filtration technology. This system is a gravity feed system, and relies on solely on gravity for the filtration process. Additional power is required only for the solar pump to extract well water. There are four steps to the filtration process, which is shown in Figure 1.

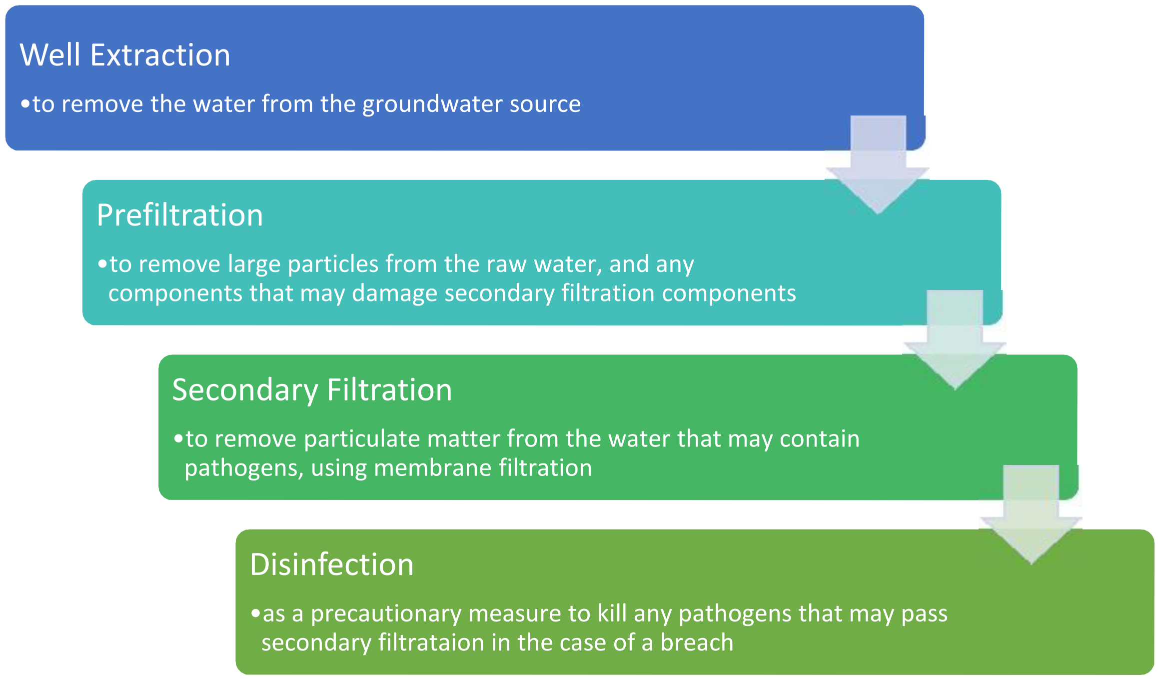


Figure 1: system operation process chart steps

To achieve these four steps, there are six major system components required: well pump, pre-treatment storage tank, pre filtration, membrane filter modules, post treatment storage tank, and backwash system. See Section 8 for process diagram, system schematics, and system component diagrams.

3.2 Design Parameters

This filtration system design was based on EPA membrane filtration guidelines. Table 1 contains design parameters and assumptions which are unique to this water filtration system (United States Environmental Protection Agency, 2005).

Table 1: Design Parameters for the Optimus Water Treatment System

Design Parameter / Assumption	Value
Water requirement per person	15 L / Person / Day
Population using water	200 people
Flux through membranes	7.0 L / m^2 / hour

The values set out in Table 1 were used to design the filtration system, and are unique to this project.

3.3 Filtration System Schematic

Figure 2 below depicts an overview of the major components of the filtration system. See Section 8 for complete drawings.

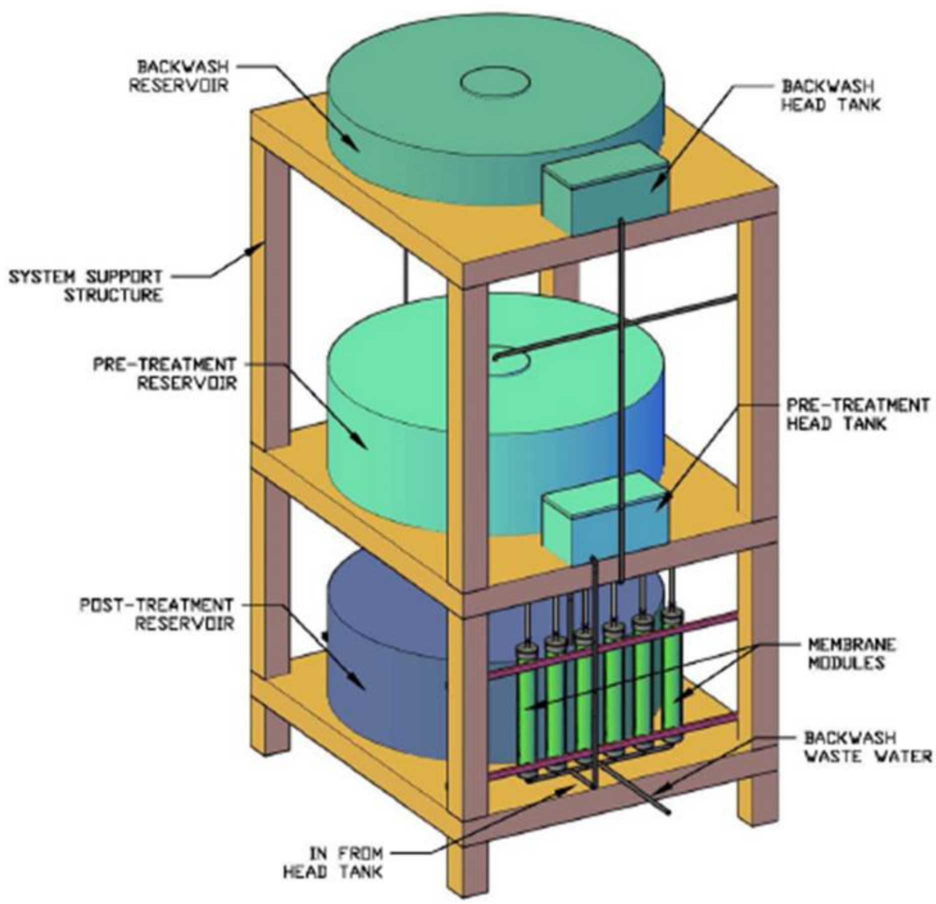


Figure 2: Filtration system components

With the exception of the well pump and the backwash pump, the system will be run by gravity. For general operation of the whole scale filtration system, see Section 4.1.

4.0 Operation Procedures

This section outlines the general operation of the filtration system, system start-up, backwashing procedures, chemical cleaning of the membranes, membrane inspection, water quality testing, and measures for troubleshooting the system.

4.1 General Operation

This system is designed to operate on its own, with input only needed during backwashing. Human inputs are also necessary for system monitoring and periodic water quality testing. Power is required for the well pump to extract the raw water from the well, but the rest of the filtration process is controlled by gravity. From the well the water is pumped to a pre-treatment storage tank, which flows to a constant-head tank, then through the pre-filtration system, secondary treatment system, and into the post-treatment water storage, where disinfection occurs and water is extracted from.

4.2 System Start-up

The following steps lay out what needs to be done in order to start filtering water:

1. Switch well pump to on, and fill pre-treatment reservoir and head tank. The well pump should be set to turn off when pre-treatment reservoir is full, and turn on when pre-treatment reservoir is at 25% full.
2. Ensure **Backwash Wastewater Outlet Valve** and **Backwash Water Inlet Valve** are both CLOSED (see backwashing procedure below)
3. OPEN **Filtered Water Outlet Valve** and **Head Tank Inlet Valve** (see backwashing procedure below)
4. Water should begin to filter out into the post-treatment reservoir

4.3 Backwashing Procedure

To mitigate the effects of fouling on the outside of the filtration membrane fibres, backwashing need to be performed periodically. This process reverses the flow through the membranes to push the fouling off of the outside of the membranes. The waste water is then collected and disposed of.

The backwashing steps are listed below. Refer to Figure 3.

1. Pump up water to backwashing reservoir, ensure water level is sufficient
2. CLOSE **Filtered Water Outlet Valve** and **Head Tank Inlet Valve**
3. OPEN **Backwash Wastewater Outlet Valve** and **Backwash Water Inlet Valve**
4. Let backwash cycle run
5. Reverse Step 2 to end backwashing
6. Reverse Step 3 to return to normal operation

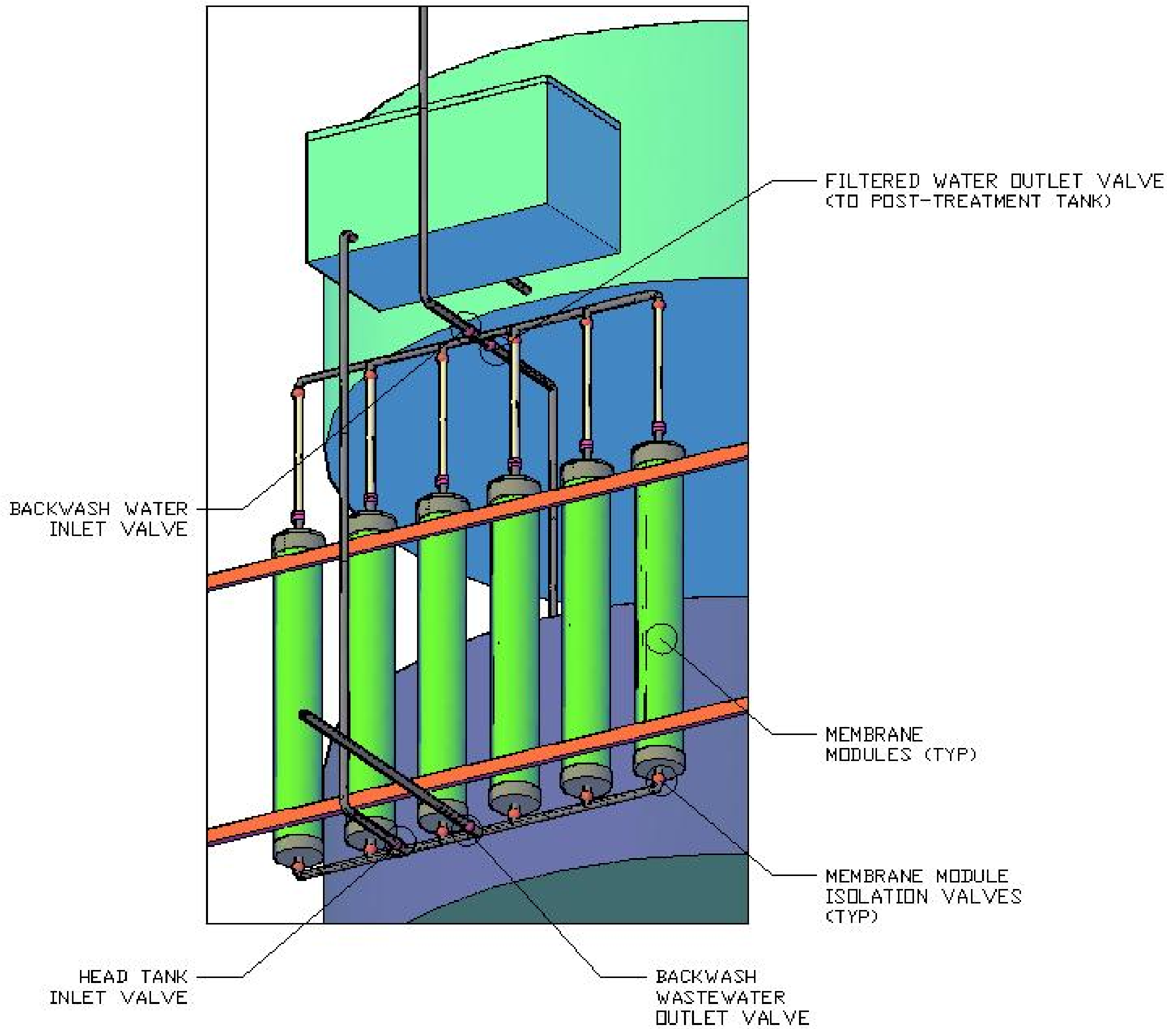


Figure 3: Backwashing system valves

Figure 3 shows components of the backwash system. The anticipated fouling rate for the Optimus system is relatively low due to the low pressures within the system, so the need for backwashing is fairly infrequent. Table 2 below outlines the requirements for backwashing and backwash monitoring.

Table 2: Backwashing Procedure Monitoring

Item	Interval	Description	Duration
Regular Backwash	Every 19 days	Close regular operation valves (x2), open backwashing valves (x2), see steps above.	60 min
Backwash Monitoring	Every backwash cycle	Observe membrane cleaning during backwash to ensure desired operation as described above.	60 min

4.4 Membrane Chemical Cleaning

Chemical cleaning of the membranes is required at intervals of **every three months**. This process involves the following steps:

1. Shut down the filtration system and empty the membrane module.
2. Remove the modules from racks and isolate the module for cleaning.
3. Carefully remove the membrane fibers from the module. Wrap the membranes with a clean wet cloth to keep it from drying.
4. Soak the fibers in a chlorine solution with 750 ppm chlorine for 24 hours.
5. Soak and rinse fibers with clean water for 30 min to remove residual chlorine.
6. Visually inspect the membrane fibers for any irregularities.
7. Carefully reinstall the membrane fibres into module.
8. Carefully reinstall the module into the system and start up the system again.

See Figures 4 to 6 for visual instructions outlining the chemical cleaning process.

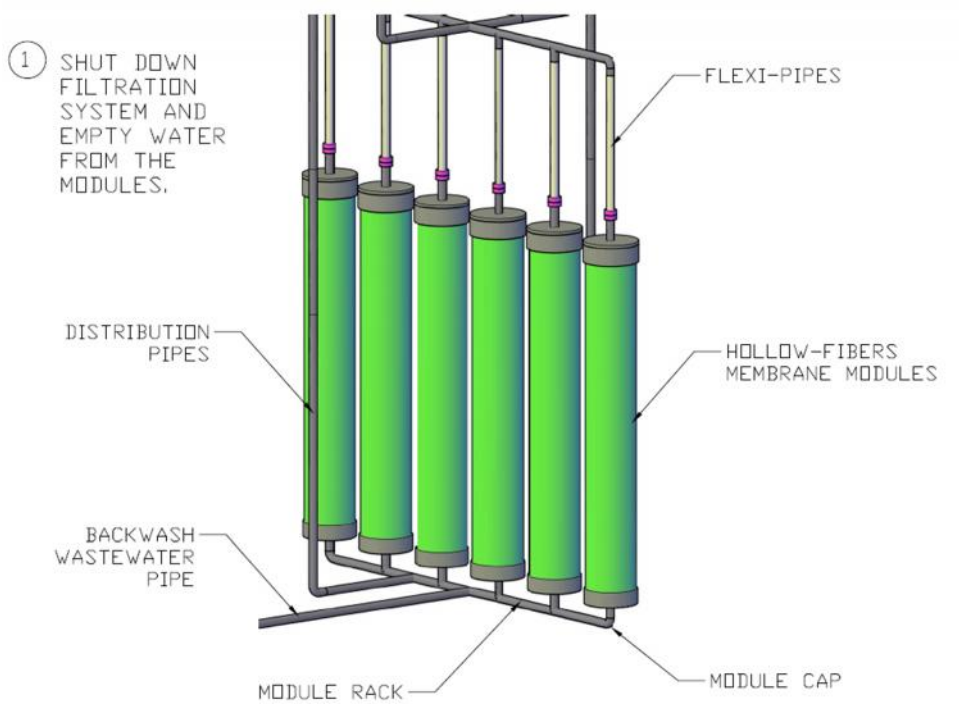


Figure 4: Chemical Cleaning Step 1

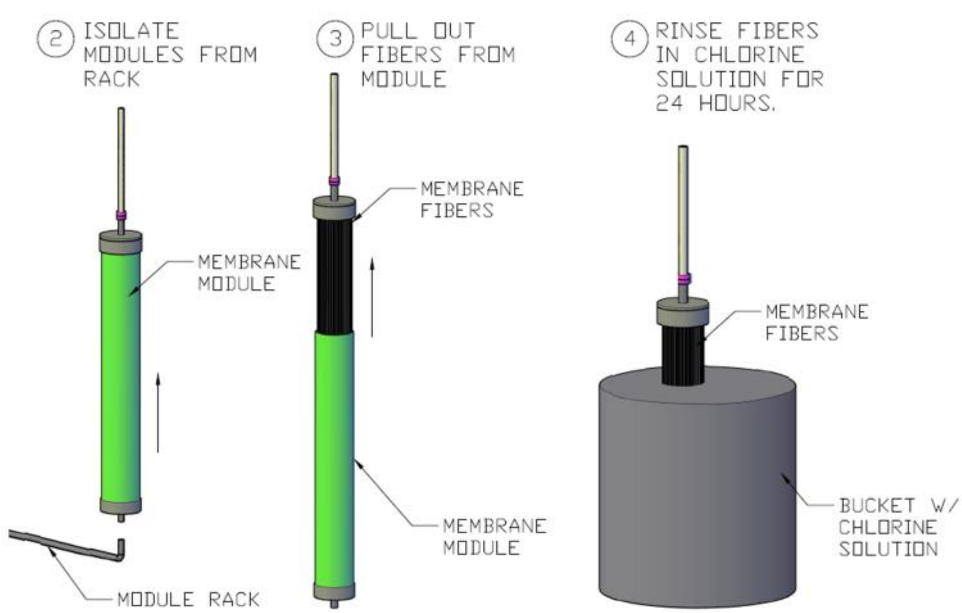


Figure 5: Chemical Cleaning Steps 2 to 4

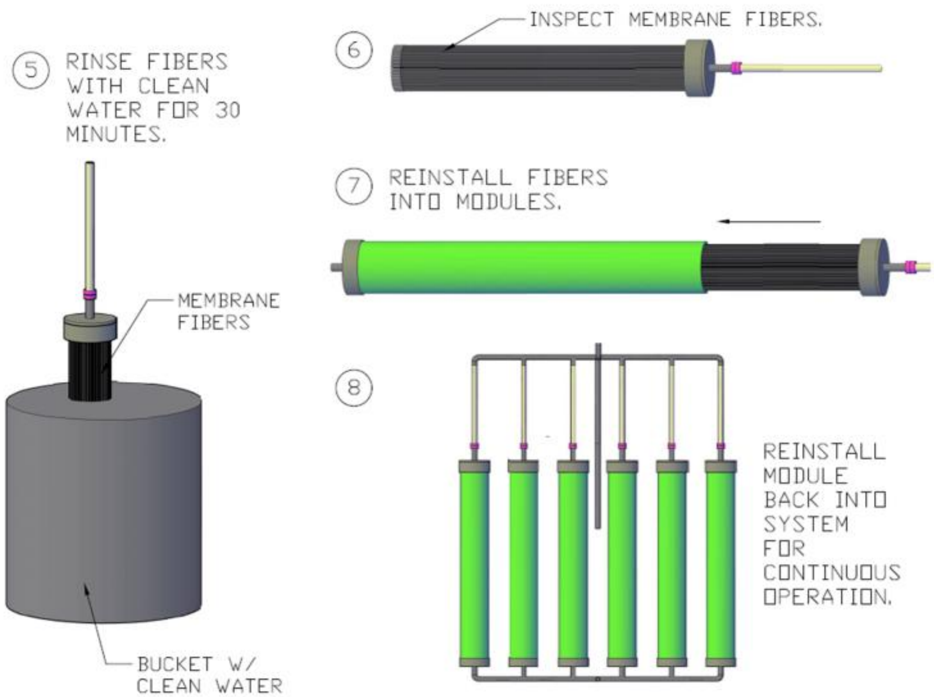


Figure 6: Chemical Cleaning Steps 5 to 8

4.5 Monitoring / Fault Inspection

Regular monitoring of the system will be done to make sure the system is working correctly and determine when membranes need to be replaced. Table 3 below lays out the monitoring requirements of the system.

Table 3: Monitoring Requirements

Monitoring Item	Interval	Description	Time Required (estimate)
Correct System Operation	Daily	Ensure water flowing in to post-treatment tank, pressure head maintained, pressure across modules is normal, treated water is not cloudy	10 min
Flow Measurement	Daily	Flow measured going into the post treatment tank. To be done by measuring the volume filtered per time	10 min

Table 3 summarizes monitoring requirements for the system. Flow through the system will be monitored to determine flux drop in the membranes. Flux is a flow rate per unit area, which in this case is treatment flow through the combined surface area of the membranes. While fouling of the membranes decreases the overall flux, the backwashing and chemical cleaning processes will help recover these losses. If the system flux reaches a critical level, where the required flow rate is not being met, then the membranes fibres will need to be replaced.

4.6 Routine Water Quality Testing

To ensure there are not any breaches in the membranes and maintain water quality, regular testing of treated water will be done. Microbiological and turbidity tests should be performed on treated water to ensure that the water is drinkable. Chlorine monitoring for disinfection process should also be completed daily as an insurance that any remaining pathogens resulting from membrane breach or system contamination become deactivated. Table 4 below summarizes the testing intervals.

Table 4: Microbiological and Turbidity Testing Intervals

Item	Interval	Description	Time Required (estimate)
Microbiological Test	Monthly	Microbiological test will be performed on two treated water samples. See section 7 for testing procedure. A positive test result indicates a breach, the system should be shut down in the case of a breach.	30 min
Turbidity Test	Weekly	Visual turbidity tests to be undertaken weekly, see section 7 for procedure. In this case a microbiological test should be performed, and an actual turbidity test as per the procedure in section 7.	5 min (visual) 20 min(full test)
Chlorine Monitoring	Daily	Chlorine levels should be monitored inside the post treatment tank. Chlorine tablets to be added as necessary to achieve desired concentration.	20 min

Testing intervals for microbiological and turbidity testing as outlined in Table 4 have been based on water quality standards and testing procedures are outlined in Section 7. Guidelines and testing procedures for chlorine levels will need to be confirmed with local authorities upon implementation of the Optimus system. However, Optimus recommends that a level of 4 ppm not be exceeded to prevent adverse health effects.

4.7 Troubleshooting

Troubleshooting is generally a very difficult task, as no two problems may be alike, and unique solutions may be needed for each problem. Incorporated in the filtration system design are manual valves at either end of any major component. This gives the ability to isolate components to determine where a problem exists. Figure 7 below breaks down the process that should be undertaken when troubleshooting, to help narrow down the problem

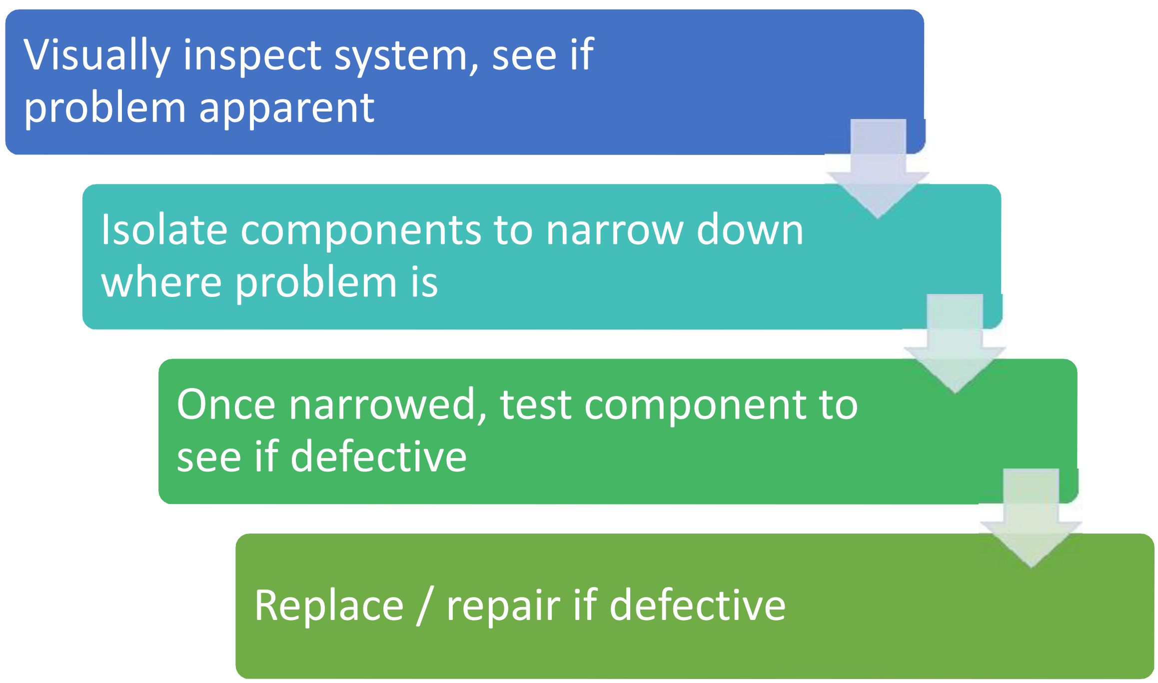


Figure 7: Problem Solving Flow Chart

The process laid out in Figure 7 above can be applied to most trouble shooting situations, such as determining where a breach is or detecting a leak.

5.0 Maintenance Procedures

Listed in Table 5 below are several maintenance procedures that may be required, and their estimated interval.

Table 5: Summary of Maintenance Procedures

Task	Interval	Description
Replace pre-filtration filter unit	Yearly or as needed	Filter units to be replaced or cleaned at interval specified by manufacturer.
Replace membrane module	Every 5-7 years or as needed	Membrane modules to be replaced when flux has dropped below critical value. See section 4 for details.
Leak repair	As needed	Leaks can be fixed in place by using products such as epoxy putty, which is a cost effective solution and can be done without shutting down the system.

These maintenance procedures are outlined to serve anticipated time intervals of the system components during the life expectancy of the system. In case of any unforeseen events, breakdowns, and stoppages on the system not listed in detail in this section, consult a trained staff member or Optimus.

6.0 Parts Information

For a complete list of Optimus filtration system materials and parts, see Appendix G in the Optimus design report. Included in this appendix is supplier/manufacture information and contacts, in case spare parts need to be ordered.

7.0 Water Quality Testing

Water quality testing of the filtered water coming out of the filtration system is necessary to ensure that the system is performing as expected. Table 6 below summarizes the water quality targets for turbidity and microbiological parameters (World Health Organization, 2011).

Table 6: Microbiological and turbidity monitoring parameters and frequencies

Parameter	Water Quality Targets	Frequency	Method
Turbidity	Never greater than 1 NTU; 95% of samples less than 0.3 NTU	once per week	permeate water will be tested
Indicator Organisms	• Zero E.coli • No more than one sample for total coliform can test positive per month	once per month	Pre-filtered samples will be tested to confirm absence of contaminants per 100 mL.

7.1 Microbiological Tests Available

Typically microbiological tests are done in the laboratory and require sterile equipment, and a 24 hour incubation period and oven. This is difficult to get in Haiti, but there are several testing procedures for applications such as this where access to a lab is difficult. One such kit that is available is the Coliscan EasyGel kit, which is a field based test for testing for E.coli. As well, the WHO is developing another field testing procedure in conjunction with MIT, which is another option when it is fully developed. Listed below are the two field microbiological tests.

- Coliscan EasyGel test (Micrology Laboratories)
- WHO / MIT test (World Health Organization, 2011)

7.2 Turbidity Tests Available

Turbidity is an important parameter to test for as many harmful pathogens that are in water cling to suspended material that is in water. As such, turbidity testing can be an indication that there has been a filter breach. Turbidity can be estimated by comparing samples to standard samples visually. This will give the operator a good indication if there is a problem. Visual tests include doing a visual inspection of a sample. If the sample appears to be cloudy, this may indicate a breach.

As well, there are fairly reasonable (under $100 US) testing kits available for measuring turbidity. Optimus recommends that a visual test be done prior to the actual test, to determine whether the actual test is calibrated properly. For an actual turbidity test, a LaMotte Turbidity Test Kit (LaMotte) is available which could take in-field turbidity measurements.

8.0 Drawings and Schematics

For drawings and schematics of the system, please refer to Appendix M of the Optimus report.

9.0 References

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Appendix K

Grundfos SQFlex Solar Pump Specifications

1. Product data

Introduction

The SQFlex system is a reliable water supply system based on renewable energy sources, such as solar and wind energy. The SQFlex system incorporates an SQF submersible pump.

Very flexible as to its energy supply and performance, the SQFlex system can be combined and adapted to any need according to the conditions on the installation site.

The system components are

- SQF submersible pump
- CU 200 SQFlex control unit
- IO 50 SQFlex switch box
- IO 101 SQFlex switch box
- IO 102 SQFlex breaker box
- charge controller
- energy supply:
  - solar panels
  - wind turbine
  - generator
  - batteries.

SQF submersible pump

The SQF pump range comprises two pump technologies:

- the helical rotor pump (3") for high heads and small flows.
- the centrifugal pump (4") for low heads and large flows.

The performance curves in fig. 1 illustrates the pump performance for the two pump models.

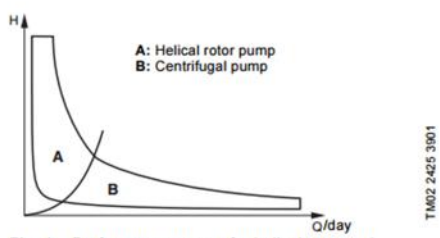


Fig. 1 Performance ranges for helical rotor and centrifugal pumps

The SQF pump is available as a complete unit only.

The SQF pump complete comprises:

- motor
- 6 ft (1.8 m) cable with water level electrode and socket
- cable guard.

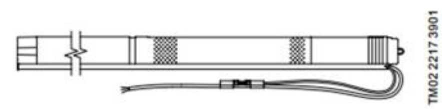


Fig. 2 SQF pump

Pump type	Pump size	Product number
3 SQF 2	3"	95027332
3 SQF 3	3"	95027333
6 SQF 2	3"	95027334
6 SFQ 3	3"	96834840
11 SQF 2	3"	95027335
16 SQF 10	4"	95027350
25 SQF 3	4"	95027351
25 SQF 7	4"	95027353
40 SQF 3	4"	95027354
40 SQF 5	4"	95027355
60 SQF 3	4"	95027443

Currently the complete range consists of six centrifugal pumps and five helical rotor pumps. The centrifugal pumps are adapted from Grundfos' present 4" SP range (16S, 25S, 40S, and 60S). These pumps are used when lower heads and higher flow rates are required.

The positive displacement helical pump ends are 3" in diameter and available in five models ranging from 3 to 11 gpm (0.68 to 2.50 m^3/h). These are designed for higher head and lower flow requirements. The pump rotor is a single-twisted helix (spiral) made of hard-chromium plated stainless steel. During operation, the rotor rotates eccentrically in a double helical elastic stator.

Motor

The motor has been developed specifically for the SQFlex system and is designed according to the permanent-magnet principle with built-in electronic unit and is available in only two sizes.

The motor speed range is 500-3600 rpm, depending on power input and load.

The motor is constructed in 304 stainless steel.

Max. ratings are as follows:

- Maximum power input (P_1) of 1400 W
- maximum current of 8.4 A
- maximum speed of 3600 rpm

The pump delivers its maximum performance when one of the above parameters is reached.

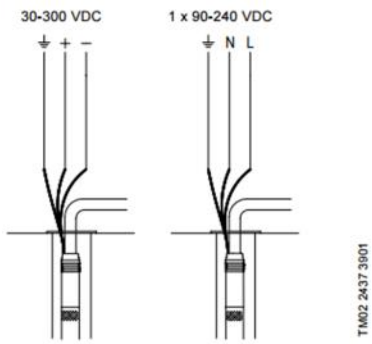


Fig. 3 Wiring diagram

The motor is to be connected to the power supply as shown in fig. 3.

As the integrated electronic unit enables the motor to handle both DC and AC supply voltages, it makes no difference how the wires "+" and "–" or "N" and "L" are connected.

Supply voltage

Flexible as regards power supply and power range, the motor can be supplied with either DC or AC voltage:

- 30-300 VDC, PE
- 1 x 90-240 V –10 % / +6 %, 50/60 Hz, PE.

CU 200 SQFlex control unit

The CU 200 is a combined status and control unit for the SQFlex pump system. Moreover, the CU 200 enables connection of a level switch placed in a water reservoir or tank.

IO 50 SQFlex switch box

The IO 50 is an on/off switch box designed for opening and closing the system power supply.

IO 101 SQFlex switch box

The IO 101 is an on/off switch box designed for opening and closing the system power supply and is used in solar-powered SQFlex systems with a back-up generator.

IO 102 SQFlex breaker box

The IO 102 is an on/off breaker box designed for opening and closing the system power supply and is used in wind-powered SQFlex systems or wind- and solar-powered SQFlex systems.

The IO 102 makes it possible to slow down or stop the wind turbine.

Charge controller

The charge controller is used when a battery backup system is installed with an SQFlex pumping system.

Solar modules

Grundfos' solar modules have been developed specifically for the SQFlex system. The solar modules are equipped with plugs and sockets enabling easy connection in series or parallel.

For further information on solar modules, please contact your local Grundfos company.

Generator

In case the power supply from its primary source of energy is temporarily insufficient or unavailable, the SQFlex system can be powered by a generator.

Batteries

The SQFlex system can be powered by batteries with a voltage supply of 30-300 VDC, maximum current 8.4 A.

Applications

Being designed for continuous as well as intermittent operation, the SQFlex system is especially suitable for water supply applications in remote locations, such as

- villages, schools, hospitals, single-family houses, etc.
- farms
  - watering of cattle
  - irrigation of fields and greenhouses
- game parks and game farms
  - watering applications
- conservation areas
  - surface water pumping
  - floating pump installations for pumping of water from ponds and lakes.

Pumped liquids

SQF pumps are applicable in thin, clean, non-aggressive, non-explosive liquids, not containing solid or long-fibered particles larger than sand grains.

pH value: 5 to 9.

Liquid temperature: +32 °F to +104 °F (0 °C to +40 °C)

The pump can run at free convection (~ 0 ft/s) at maximum 104 °F (+40 °C).

Sand content

Maximum sand content: 50 ppm.

A higher sand content will reduce the pump life considerably due to wear.

Salt content (chloride ions Cl^-)

The table below shows the resistance of stainless steel to Cl^-. The figures in the table are based on a pumped liquid with a pH value of 5 to 9.

Stainless steel AISI	Cl^- content [ppm]	Liquid temperature [°F (°C)]
304	0-300	< 104 (40)
	300-500	< 86 (30)

Features and benefits

Dry-running protection

The SQF pump is protected against dry running in order to prevent damage to the pump. The dry-running protection is activated by a water level electrode placed on the motor cable 12-24 in. (.3 to .6 m) above the pump, depending on pump type.

The water level electrode measures the contact resistance to the motor sleeve through the water. When the water level falls below the water level electrode, the pump will be cut out. The pump will automatically cut in again 5 minutes after the water level is above the water level electrode.

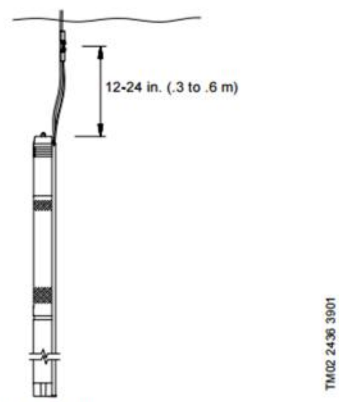


Fig. 4 Vertical installation

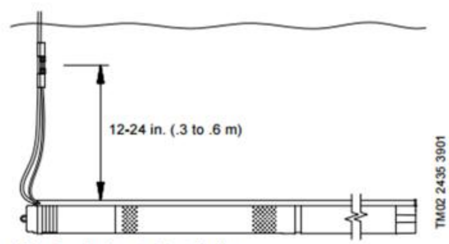


Fig. 5 Horizontal installation

High efficiency

The MSF 3 motor is a permanent-magnet motor (PM motor) featuring a higher efficiency within the power range compared to a conventional asynchronous motor.

In addition to this, the segmented motor stator contributes considerably to the high efficiency.

The MSF 3 motor is furthermore characterized by a high locked-rotor torque even at low power supply.

Overvoltage and undervoltage protection

Overvoltage and undervoltage may occur in case of unstable power supply or a faulty installation.

The pump will be cut out if the voltage falls outside the permissible voltage range. The motor is automatically cut in when the voltage is again within the permissible voltage range. Therefore no extra protection relay is needed.

Note: The MSF 3 motor is protected against transients from the power supply according to IEC 60664-1 "overvoltage category III" (4 kV). In areas with high lightning intensity, external lightning protection is recommended.

Overload protection

In case the upper load limit is exceeded, the motor will automatically compensate for this by reducing the speed. If the speed falls below 500 rpm, the motor will be cut out automatically.

The motor will remain cut out for 10 seconds after which period the pump will automatically attempt to restart.

The overload protection prevents burnout of the motor. Consequently, no extra motor protection is required.

Overtemperature protection

A permanent-magnet motor gives off very little heat to its surroundings. In combination with an efficient internal circulation system leading the heat away from the rotor, stator and bearings, this fact ensures optimum operating conditions for the motor.

As an extra protection, the electronic unit has a built-in temperature sensor. When the temperature rises above 185 °F (85°C), the motor is automatically cut out. When the temperature has dropped to 165 °F (73 °C), the motor is automatically cut in again.

Maximum Power Point Tracking (MPPT)

The built-in electronic unit gives the SQFlex system a number of advantages compared to conventional products. One of these advantages is the built-in microprocessor with MPPT (MPPT = **M**aximum **P**ower **P**oint **T**racking).

Thanks to the MPPT-function, the pump duty point is continuously optimized according to the input power available. MPPT is only available for pumps connected to DC supply.

Wide voltage range

The wide voltage range enables the motor to operate at any voltage from 30-300 VDC or 90-240 VAC. This makes installation and sizing especially easy.

Built-in sand shield

The built-in sand shield prevents sand damage to the pump and motor by slinging it out through the oval slots located at the base of the pump end.

Reliability

The MSF 3 motor has been developed with a view to high reliability achieved through the following features:

- carbon/ceramic bearings
- excellent starting capabilities
- various protection facilities.

Simple installation

The following features ensure simple installation of the SQF pump:

- low weight ensuring user-friendly handling
- installation in 3", 4" or larger boreholes
- only an on/off switch is needed, which means that no extra motor starter / starter box is necessary.

Note: Horizontal installation requires the water level electrode to be placed above the pump to ensure the dry-running protection.

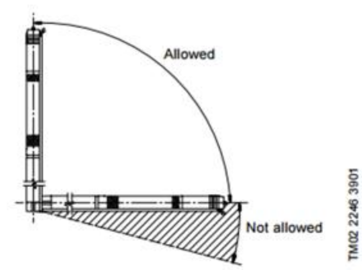


Fig. 6 Installation of SQF pumps

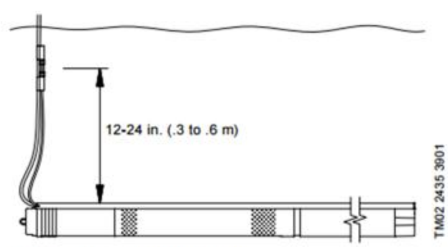


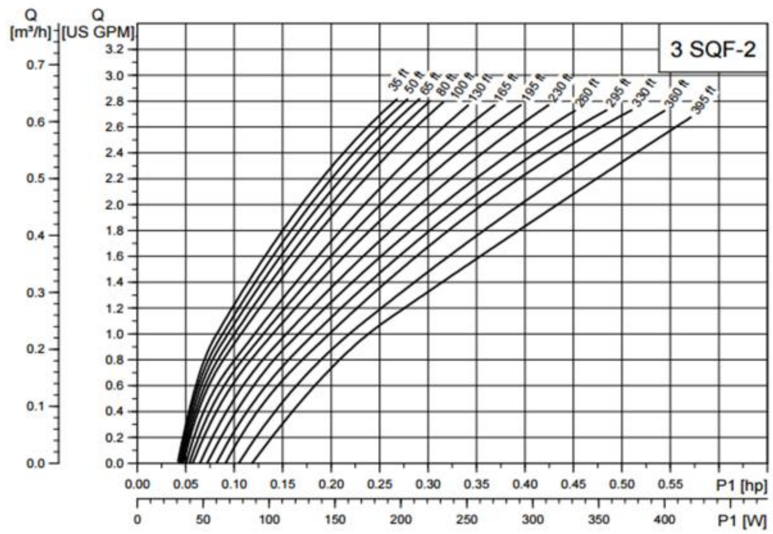
Fig. 7 Horizontal installation

Ease of service

The modular pump and motor design facilitates installation and service. The cable and the end cover with socket are fitted to the pump with screws which enable replacement.

Curve charts

3 SQF-2



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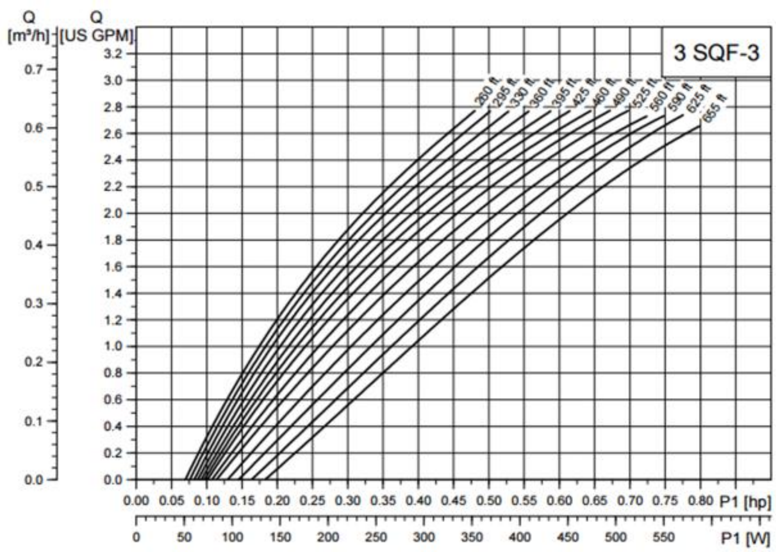
3 SQF-3



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Note: Max. P1 (W) shown on curve represents max. motor RPM.

Appendix L

Full-Scale Design and Backwash Optimization Calculator and Supporting Hand Calculations

Optimus A1 UF Module

Membrane Specifications		
K_m	1.92E-13	m
Flux	4.83	Lmh
L	1	m
O.D.	1.2	mm

Module Specifications		
L	1.2	m
I.D.	152.4	mm
# of fibres	1553	
A	5.85	m^2

REHC Design Parameters		
Q	167	L/hr
μ (20°C)	0.001002	Pa·s
TMP	7	kPa

System Requirements		
A_{min}	34.6	m^2
# Fibres	9171	
# Modules	6	

System Output		
Q =	170	L/hr
Q =	4072	L/day

Note: The design flux and K constant are from the optimization calculator on Pg. 3 or the Optimization tab of the MS Excel workbook. To use the calculator, input the design parameters in the blue-highlighted cells.

Optimus A1 Membrane Potting Configuration

Row	Bundles	Membranes
1	1	7
2	6	42
3	12	84
4	20	140
5	20	140
6	20	140
7	20	140
8	40	280
9	40	280
10	40	280
	SUM	1533

Note: See design drawing for potting details

Optimization

To use this calculator the user must input values for the blue-highlighted cells. Next, the user presses the Backwash Timer button. Finally, the data can be plotted by pressing the Plot square. The user is able to determine the optimal backwash frequency by comparing the total output for each. Based on the testing data obtained by Team Optimus, the optimal BW frequency was found to be 19 days. This is based on 365 days of operation and 90 day chemical cleaning frequency. The backwas volume was assumed to be the constant including 1 extra litre for lost revenue. It should be noted that this is based on the source water and testing parameters that were used in the hydraulics lab at BCIT and is subject to change for different locations such as the REHC location in Haiti. Please refer to hand calculations for

Data Assumptions:
1) The first backwash is only 75% efficient due to high initial fouling.
2) The remaining backwash procedures are 95% efficient (10% permanent fouling per cycle)
3) Chemical cleaning restores membranes to 90% efficiency

Calculator Limitations:
1) The total output does not account for the 1 day downtime per chemical clean
2) Much more data required to produce accurate estimates of long term performance

Total Output	**1898.3**	**L**
Average Flux	4.83	Lmh
Duration	365	days
BW frequency	19	days
BW volume	14	L
Chemical Cleaning Freq.	90	days

$$J_1 = 9.81e^{-0.033t}$$

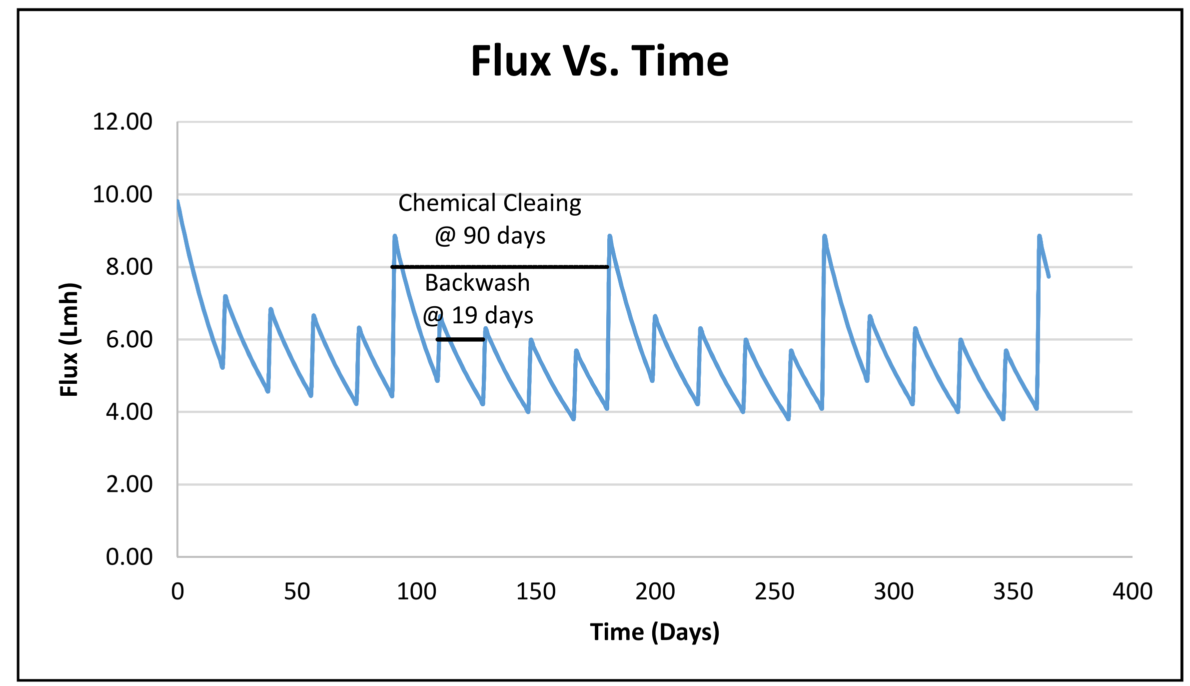
$$J_2 = (0.95)^{(n-1)}(0.75)9.81e^{-0.025t}$$

For Plotting Black Lines			
90	8	109	6
180	8	128	6

Backwash Timer

Plot Flux vs. Time

Plotting Data					
Flux vs. Time		Output Volume			
Day	Flux	Flux	BW Cycle (n)	Time (days)	Volume (L)
0	9.81	J_1	0	19	135.2
1	9.49	J_2	1	38	105.9
2	9.18	J_2 Cont.	2	57	99.9
3	8.89		3	76	94.2
4	8.60		4	95	120.3
5	8.32		5	114	93.9
6	8.05		6	133	88.5
7	7.79		7	152	83.4
8	7.53		8	171	78.5
9	7.29		9	190	120.3
10	7.05		10	209	93.9
11	6.82		11	228	88.5
12	6.60		12	247	83.4
13	6.39		13	266	78.5
14	6.18		14	285	120.3
15	5.98		15	304	93.9
16	5.79		16	323	88.5
17	5.60		17	342	83.4
18	5.42		18	361	120.3
19	5.24		19	365	27.2
20	7.18				
21	7.00				
22	6.83				
23	6.66				
24	6.50				
25	6.33				



Data continued to 365 days. See Excel Spreadsheet

BACKWASH OPTIMIZATION

☆ ASSUMPTIONS

1) The first BW is only 75% efficient due to high initial fouling rate following chemical cleaning (or membrane replacement)
2) Subsequent BW procedures are 95% efficient (5% permanent fouling) with reduced initial fouling rate.
3) Chemical cleaning restores membranes to 90% capacity

A21 module (17 functional membranes)

n = Backwash cycle since last chemical clean (or new)

→ for n = 0,

$J(\text{Lmh}) = 9.81e^{-0.033t} = Q/A_{21}$ where A21 = Surface area of 17 membranes $= 0.0449\ m^2$

→ $Q\ (\text{L/day}) = J \cdot A_{21} \cdot 24\ \text{hrs/day}$

$$Q = 10.57\,e^{-0.033t}$$

$$V = \int_0^t Q\,dt$$

$$V\ (L) = \frac{10.57}{-0.033}\,e^{-0.033t}\Big|_{t=0}^{t=\text{BW freq.}} \qquad \int e^{ax}\,dx = \frac{1}{a}e^{ax}$$

$$V_1 = -320.3\,e^{-0.033t}\Big|_{t=0}^{t=\text{BW freq.}} \qquad V = [L],\ t = [\text{days}]$$

→ for n = 1,

$J\ (\text{Lmh}) = (0.75 \times 9.81)e^{-0.025t}$ where 0.75 = efficiency of 1st BW

$$Q\ (\text{L/day}) = (0.75 \times 9.81)\,e^{-0.025t} \cdot A_{21} \cdot 24\ \text{hrs/day}$$

$$Q = 7.93\,e^{-0.025t}$$

$$V = \frac{7.93}{-0.025}\,e^{-0.025t}\Big|_{t=0}^{t=\text{BW frequency}}$$

$$V_2 = -317.1\,e^{-0.025t}\Big|_{t=0}^{t=\text{BW freq.}} \qquad V = [L],\ t = [\text{days}]$$

→ for $n > 1$

$$J = (0.95)^{n-1} \cdot (0.75 \times 9.81) e^{-0.025t}$$ where 0.95 = BW efficiency

$$Q\,(L/day) = (0.95)^{n-1} \cdot 7.93 e^{-0.025t}$$

$$V_3(L) = (0.95)^{n-1} \cdot -317.1 e^{-0.025t} \Big|_{t=0}^{t=\text{BW freq}}$$

@ $n = 11$ (3 months time) chemical cleaning occurs

⇒ Total Output for first cycle

$$V_T = V_1 + V_2 + \sum_{n=2}^{11} V_3$$

Now, Chemical cleaning = 90% efficiency

→ Total output per subsequent cycles

$$V_T = (0.90) V_1 + (0.90) V_2 + \sum_{n=2}^{11} (0.90) V_3$$

An excel spread sheet has been developed to optimize the BW frequency. It should be noted that the design is based on the 3 assumptions on Pg. 1. The validity of these assumptions is highly dependant on the source water quality and duration of cleaning cycles.

⇒ The BW efficiency is based on a 1 hour duration BW with a total of 14.0L of clean water required for each flush.

APPENDIX L

WATER DEMAND: 20 L/day (full-time children)
15 L/day (part-time children & adults)

OF PEOPLE: 30 full-time children
170 school-time children
5 full-time adults

REQ'D OUTPUT = 30 × 20 L/day = 600 L/day
170 × 15 L/day = 2550 L/day
5 × 15 L/day = 75 L/day
ECONOMIC SALES = 790 L/day

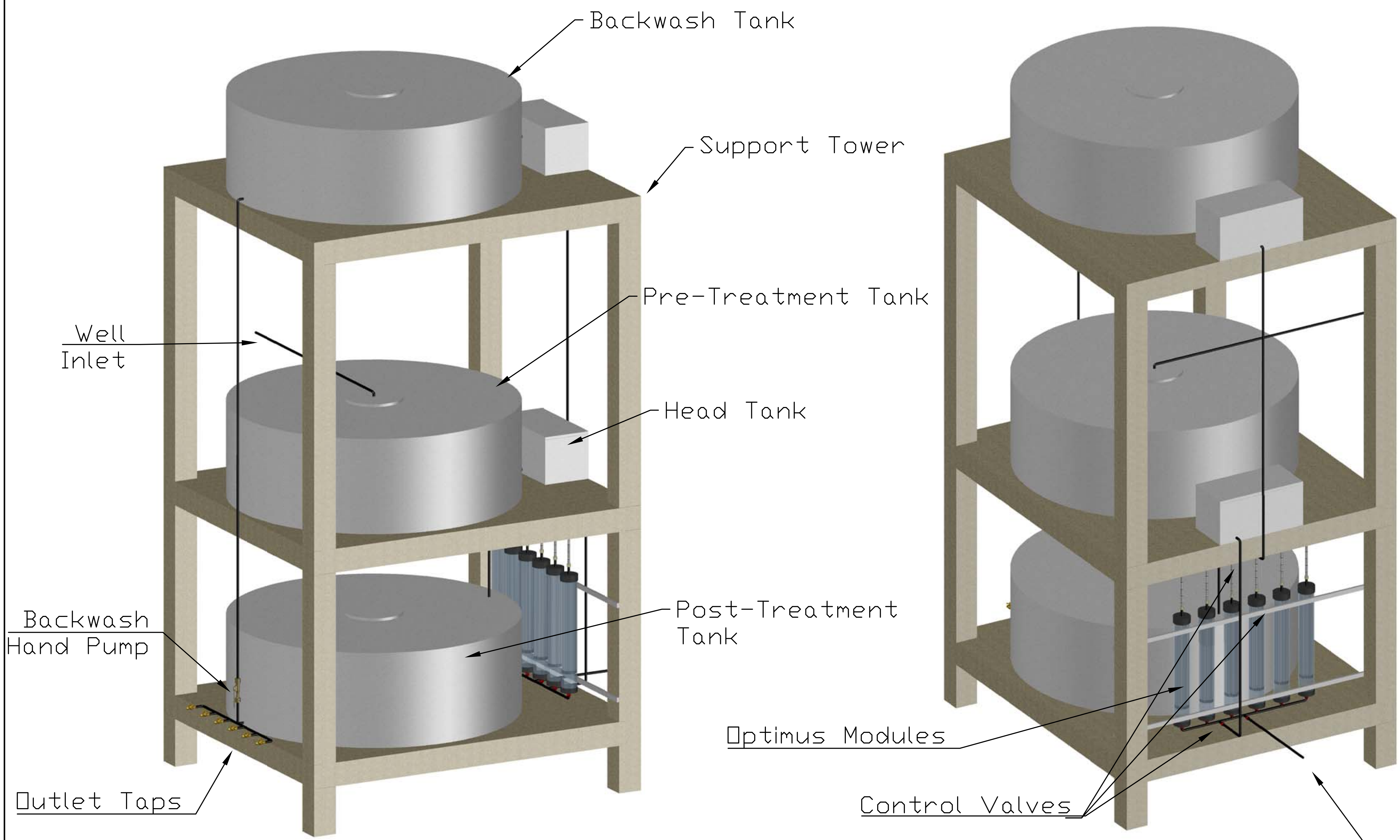
TOTAL OUTPUT REQ'D = 4015 L/day

→ Using MS Excel calculator,

TOTAL NUMBER OF MODULES = 6

Appendix M

Design Drawings of REHC Treatment System



ISOMETRIC VIEW

NTS

REVISIONS

No.	DATE	DESCRIPTION

No.	DATE	DESCRIPTION

ISSUES

BCIT BRITISH COLUMBIA INSTITUTE OF TECHNOLOGY A POLYTECHNIC INSTITUTION

PROJECT: OPTIMUS REHC TREATMENT SYSTEM

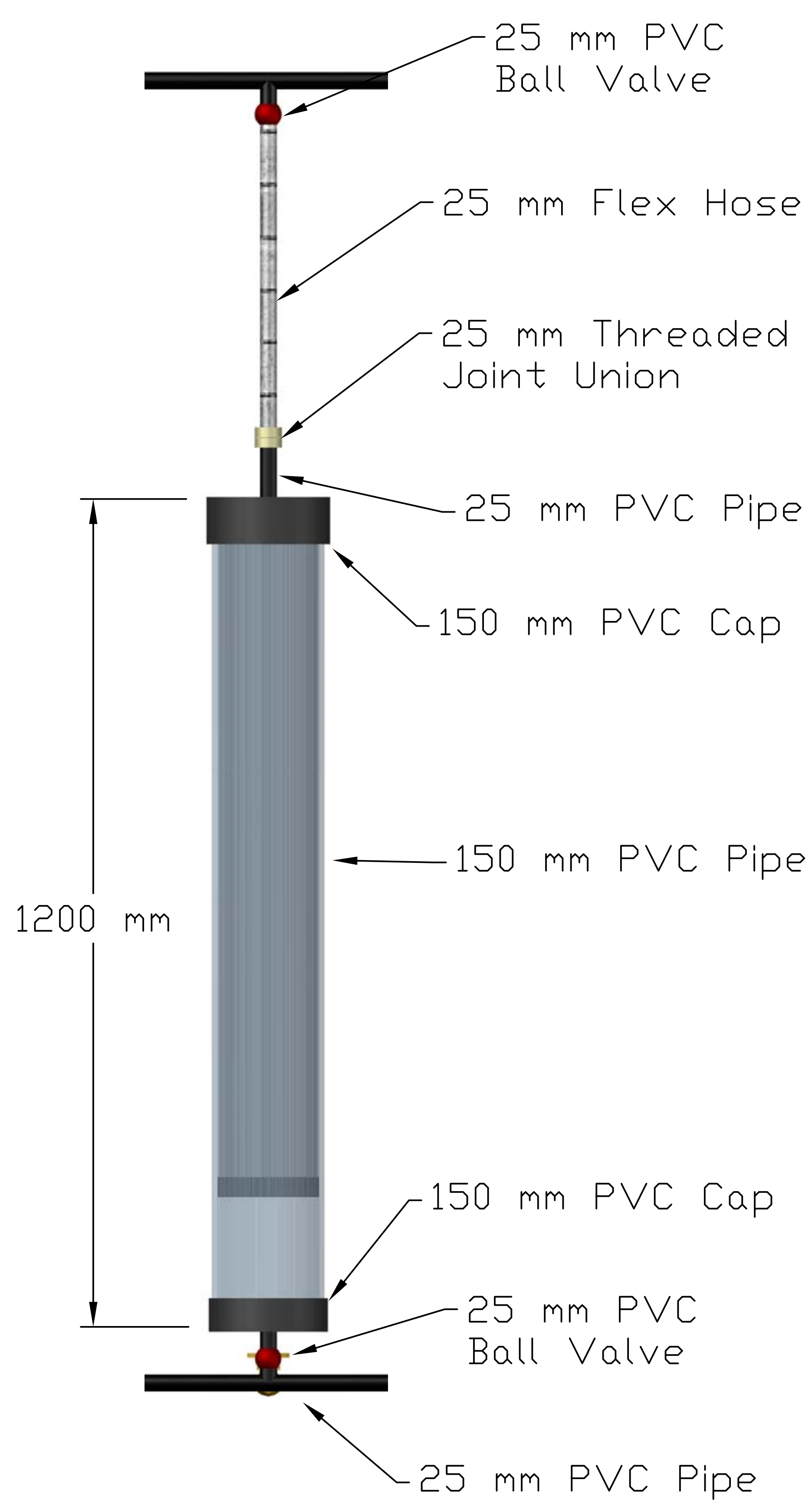
DWG. TITLE: 3D MODEL

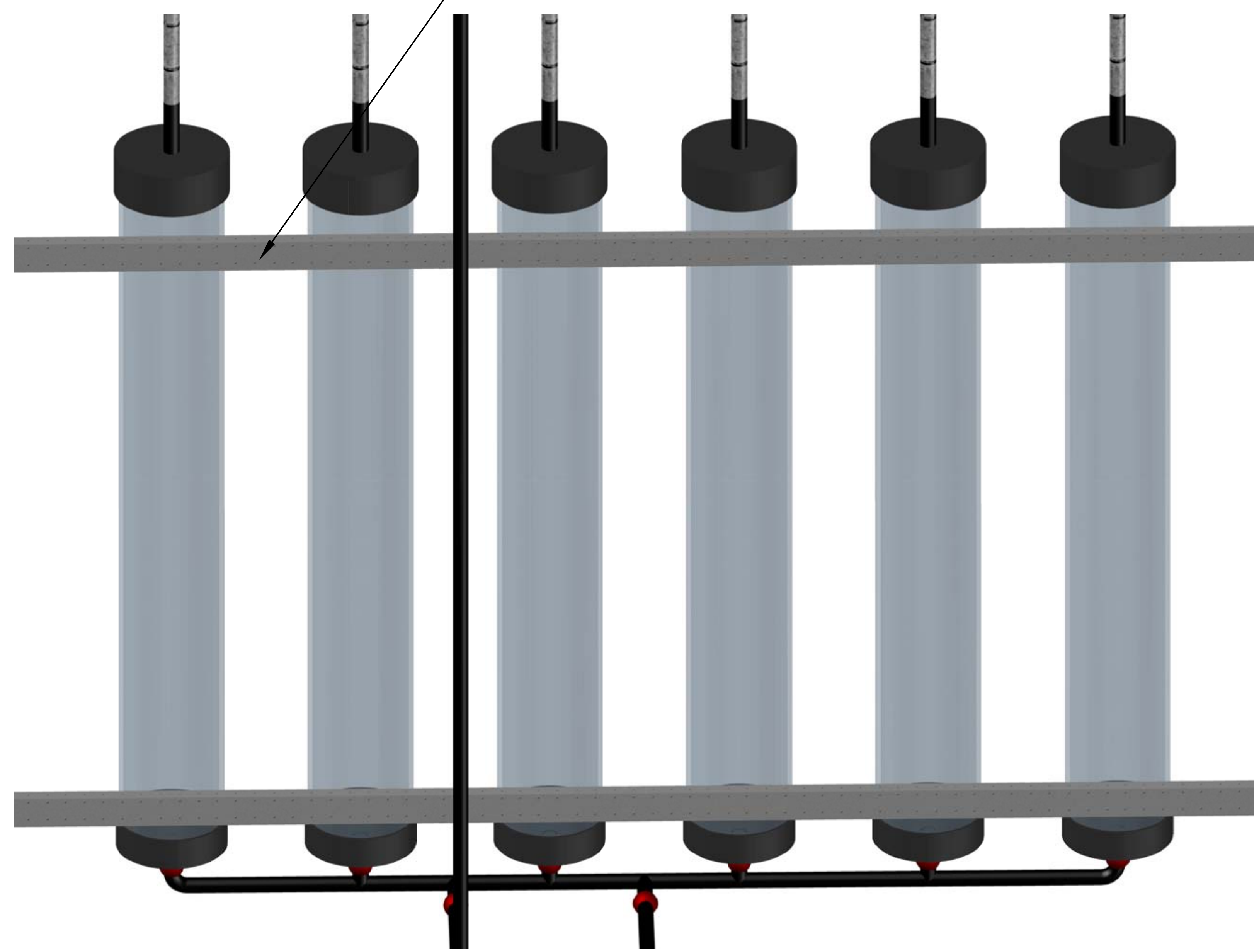
DATE: 2015/MAR/04

SCALE: NTS

NAME: DL

DWG. No.: M-01





6 - OPTIMUS MODULES

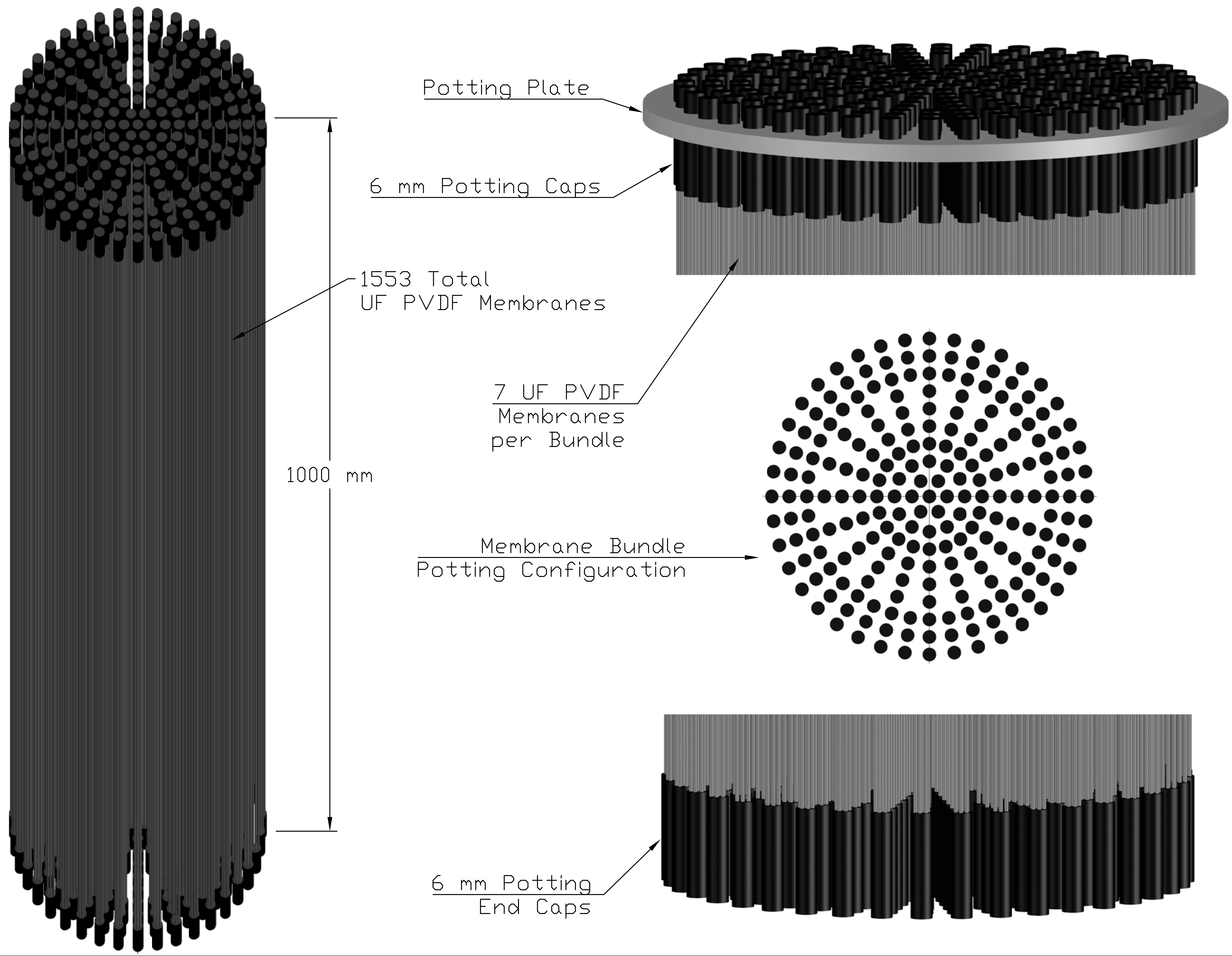
REVISIONS		
No.	DATE	DESCRIPTION

No.	DATE	DESCRIPTION

ISSUES

BRITISH COLUMBIA INSTITUTE OF TECHNOLOGY
A POLYTECHNIC INSTITUTION

PROJECT	OPTIMUS REHC TREATMENT SYSTEM
DWG. TITLE	MODULES
DATE	2015/MAR/04
SCALE	NTS
NAME	DL
DWG. No.	M-02



REVISIONS

No.	DATE	DESCRIPTION

No.	DATE	DESCRIPTION

ISSUES

BRITISH COLUMBIA INSTITUTE OF TECHNOLOGY
A POLYTECHNIC INSTITUTION

PROJECT: OPTIMUS REHC TREATMENT SYSTEM

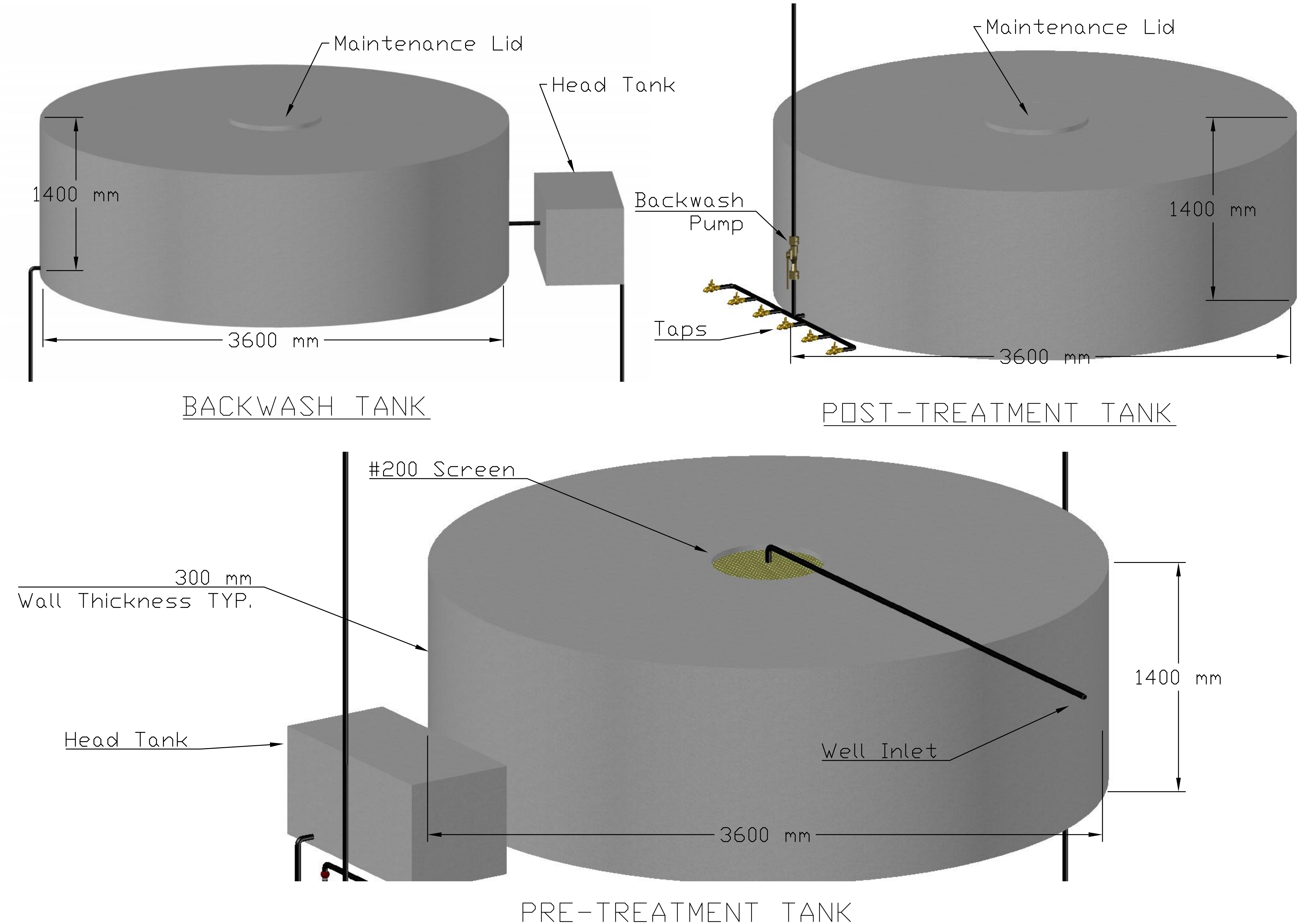
DWG. TITLE: UF MEMBRANES

DATE: 2015/MAR/04

SCALE: NTS

NAME: DL

DWG. No.: M-03



REVISIONS

No.	DATE	DESCRIPTION

ISSUES

No.	DATE	DESCRIPTION

OPT

BCIT® BRITISH COLUMBIA INSTITUTE OF TECHNOLOGY A POLYTECHNIC INSTITUTION

PROJECT: OPTIMUS REHC TREATMENT SYSTEM

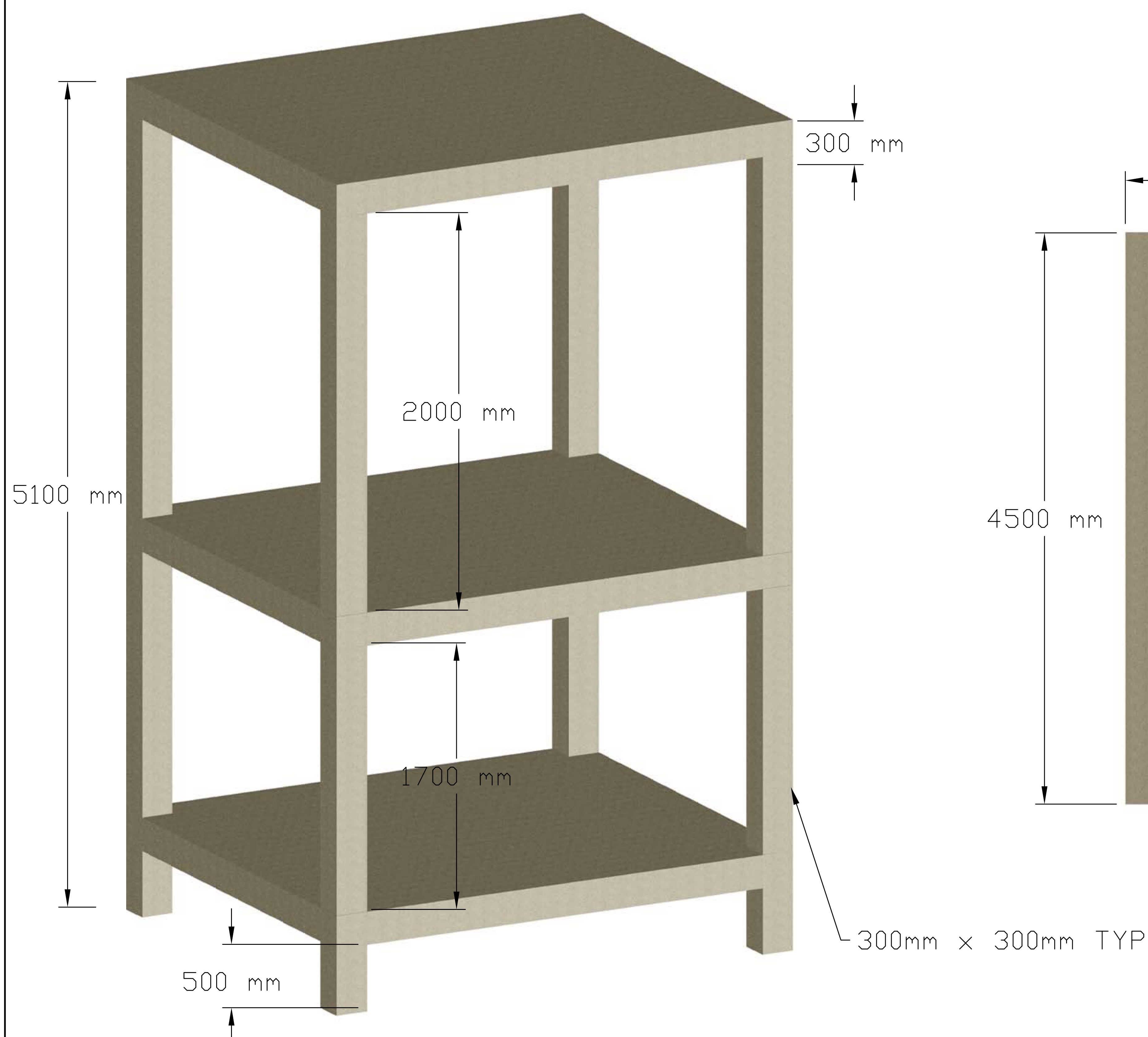
DWG. TITLE: WATER TANKS

DATE: 2015/MAR/04

SCALE: NTS

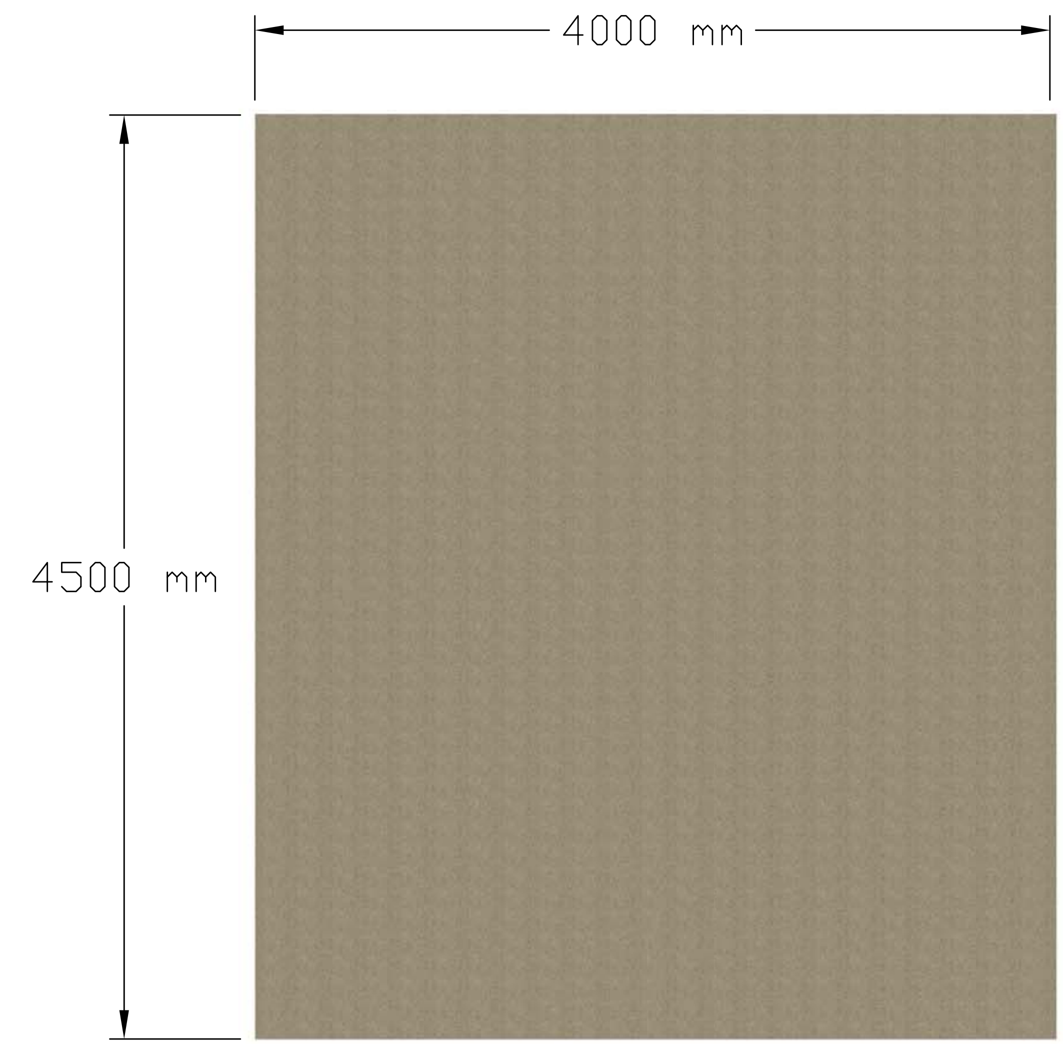
NAME: DL

DWG. No.: M-04



ISOMETRIC VIEW

NTS



PLAN VIEW

NTS

REVISIONS

No.	DATE	DESCRIPTION

No.	DATE	DESCRIPTION

ISSUES

BRITISH COLUMBIA INSTITUTE OF TECHNOLOGY
A POLYTECHNIC INSTITUTION

PROJECT	OPTIMUS REHC TREATMENT SYSTEM
DWG. TITLE	SUPPORT TOWER
DATE	2015/MAR/04
SCALE	NTS
NAME	DL
DWG. No.	M-05

Appendix N

Site Plan and Infiltration Trench Details

REVISIONS		
No.	DATE	DESCRIPTION

No.	DATE	DESCRIPTION
ISSUES		

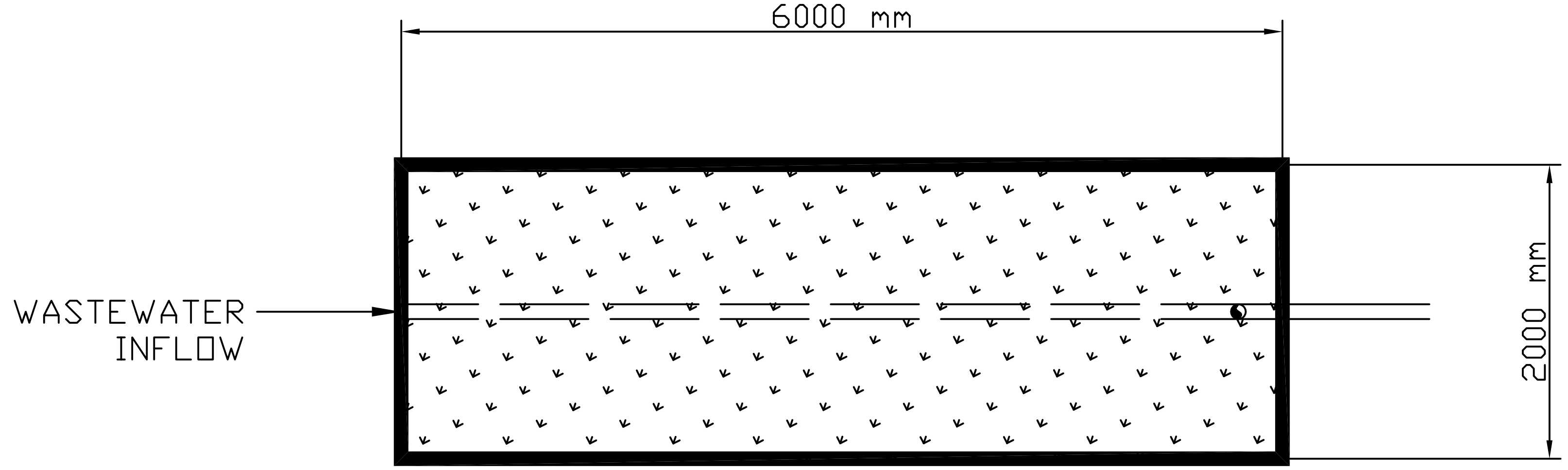
ENGINEER'S SEAL

OPTIMUS ENGINEERING

PROJECT
OPTIMUS REHC TREATMENT SYSTEM

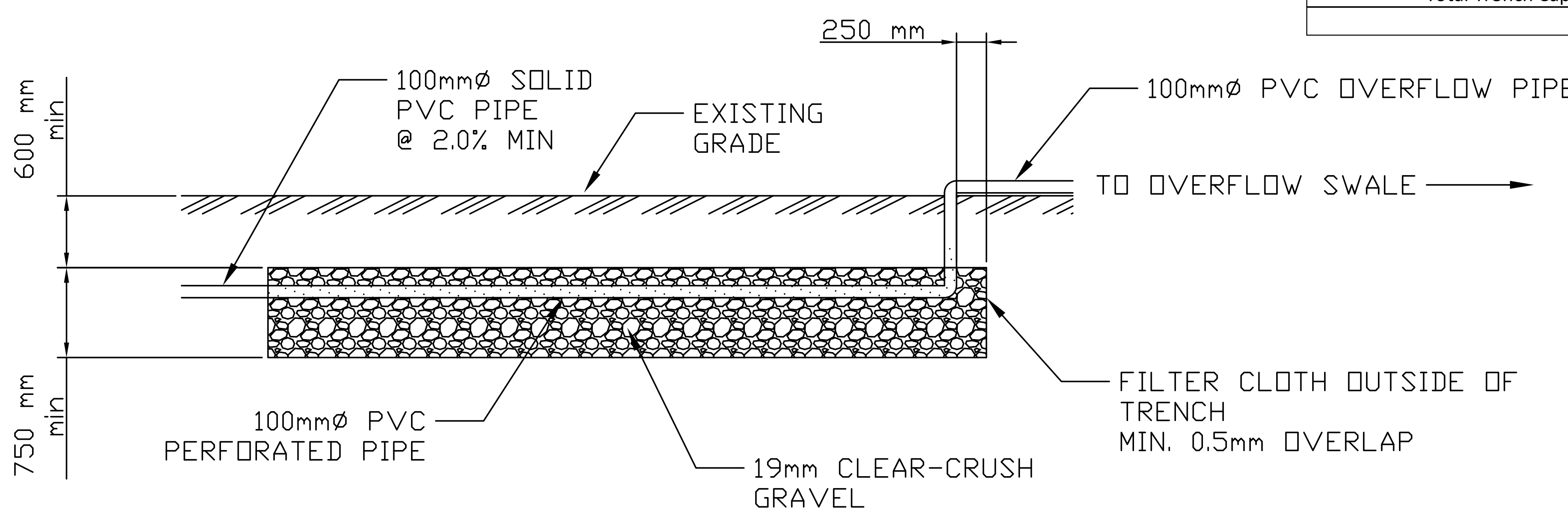
DWG. TITLE
RYAN EPPS HOME
SITE PLAN LAYOUT

DATE 2015/MAR/04	DWG. No. N - 1
SCALE 1:150	
NAME MM	
SET –	ISSUE



INFILTRATION TRENCH PLAN VIEW
SCALE = 1:50

Optimus Engineering	Capstone Design Project 2015	
Infiltration Trench Sizing		
Backwash Flow =	3000.0	L/hr
Backwash Flow Rate =	50.0	L/min
Backwash Cycle Time =	60.0	min
Backwash Frequency =	0.053	Times / day
Backwash Volume =	3000.0	L/hr
Expected Bottle-wash station Vol =	100.0	L/Day
Total Flow into Trench =	3100.0	L/Day
Ave Alluvium Infiltration Rate =	0.00840	m/hr
	0.00014	m/min
Gravel Porosity =	0.35	
Infil Trench Height =	0.75	m
Infil Trench Width =	2.00	m
Infil Trench Length =	6.00	m
Trench Storage =	3150.0	L
Expected Infiltration (Alluvium) =	100.8	L/hr
Total Trench Capacity =	3250.8	L
Trench Size OK		



PROFILE VIEW
SCALE = 1:50

REVISIONS		
No.	DATE	DESCRIPTION

ISSUES		
No.	DATE	DESCRIPTION

ENGINEER'S SEAL

OPTIMUS ENGINEERING

PROJECT: OPTIMUS REHC TREATMENT SYSTEM

DWG. TITLE: INFILTRATION TRENCH

DATE: 2015/MAR/04

SCALE: 1:50

NAME: MM

SET: _

DWG. No.: N - 2

ISSUE:

Appendix O

REHC Pure Water Flyer

Ryan Epps Home for Children's Pure Water

REHC PURE WATER

- Clean and Safe Drinking Water !
- Very Low Price! 4 HTG/gal!
- Support the Kids!
- Support the Community!

Ryan Epps Home for Children's Pure Water

Clean Drinking for Healthy Living! Every gourde earned goes to the benefit of the children in Ryan Epps Home for Children.

Available 7 days a week!

6:00am—6:00pm

Appendix P

WASH Educational Pamphlet

REHC's Quick Guide to Proper Water, Sanitation, and Hygiene Practices

Putting Sanitation and Hygiene First

Ryan Epps Home for Children
Your business tag line here.

- Ensure clean, safe and secure latrines and restrooms, especially for girls and women.

Source: US Scouting Service Project

Source: Animal-kid.com

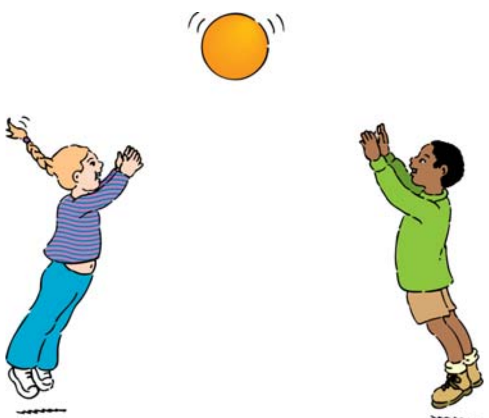
- Cover food and water from disease carrying-agents.

- Dispose of waste and garbage properly.

Source: Junk Removal Vancvouer

Source: fitnessandfreebies.com

Get plenty of rest and sleep. Aim for at least 8 hours of sleep every night.



Source: funcentrate.com

Wash hands with soap and water

- Before eating
- Before preparing food
- After using the toilet.

Source: Cliparts.co

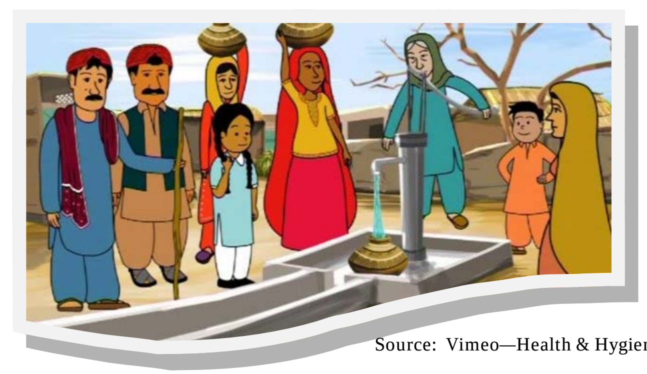
Have enough exercise regularly.

Source: Dondrup.com

- Keep latrines and sanitation facilities clean and green.

Source: Hesperian Health Guides

- Ensure adequate access to clean water and sanitation facilities



Source: Vimeo—Health & Hygiene Animation

- Act as role models for proper hygiene habits and practices.

Appendix Q

Implementation Plan

Implementation Plan

1.0 Introduction

To ensure the long term sustainability for Optimus' proposed water treatment system, a detailed understanding of the proposed system and its components is required. Often, new treatment systems in developing countries become inoperable within a short time frame due to poor maintenance and lack of operating guidelines. To prevent misuse and to ensure long term operation, Optimus has developed the following implementation plan.

1.1 Purpose

The purpose of this plan is to establish a water filtration system at the Ryan Epps Home for Children (REHC) to provide clean water in the long term for the school and community. Optimus also aims to convince local people through education that they need to be drinking clean water in order to stay healthy.

1.2 System Overview

The following goals need to be met for successful implementation of the water filtration system:

- build the water filtration system at the REHC
- train people at the REHC how to operate and maintain the system
- set up a business to sell water to locals
- teach people at the REHC about disease transmission and prevention
- sell REHC people and locals on the need for filtered water to be healthy
- follow up in the long term to ensure that the system is still operating well

This implementation plan is intended to ensure that these goals are achieved.

2.0 Management Overview

Management of the system will be divided into initial and long term project operation. Several tasks will need to do be completed during these phases by key personnel. Optimus intends to create various levels of involvement for the project, with the overall goal of enabling the project to be sustainable without long term external support.

2.1 Implementation Description

The time allotted for system deployment is three months, which will be the time that team Optimus will spend in Haiti. This includes going to Haiti, getting the materials, talking with officials in the community, building the system, training individuals, getting the system operational, and training people on sanitation and education. The implementation process is shown in Figure 1 below.

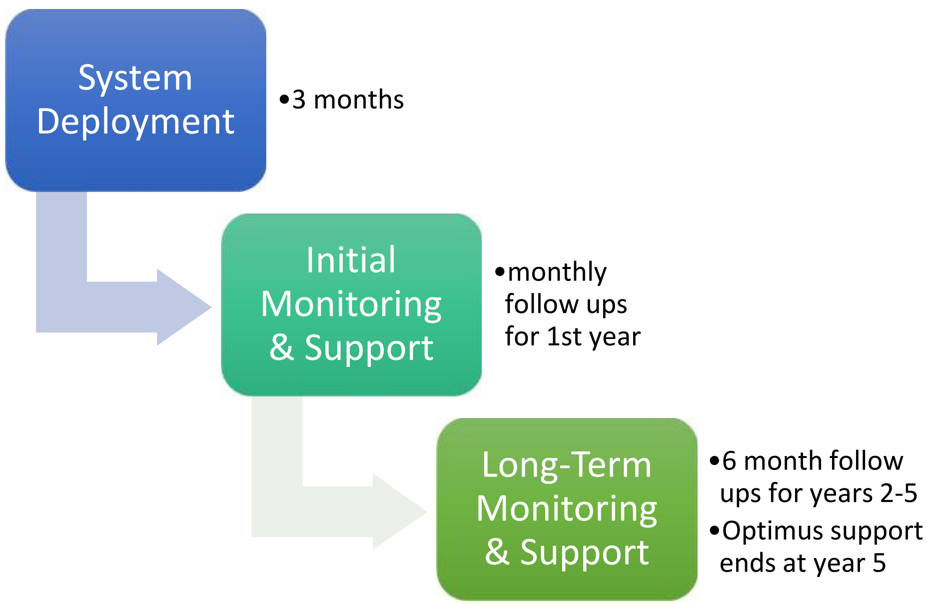


Figure 1: Implementation plan process chart

As shown in the figure above, support from Optimus Engineering will end after five years. It is assumed that after five years the system will be making enough money to support itself, and operators will be experienced enough to maintain the system themselves. REHC is an established registered non-profit organization in Haiti, therefore we will apply for a business license through REHC for the Pure Water business.

2.2 Key People Involved

People to be consulted before the project will include community leaders of Croix de Bouquets and REHC board of directors. The Community of Croix-de-Bouquets, the area's municipal government, will also be consulted. Along with these people, involvement will include the following:

- two individuals, chosen with the REHC, to help construct the system and learn how it operates
- additional workers to help construct the system as required
- staff to run the water selling business

2.3 Major Tasks

The major tasks to be completed over the course of implementation are listed as follows:

- consult community leaders and REHC regarding business
- select people who will be involved with building system/business
- construct the filtration system
- challenge test the system and troubleshooting if needed
- train individuals on operation of system, and oversee to ensure proper operation
- set up business and hire staff to run it (or use REHC people)
- provide support and do check-ups for next few months/years to ensure performance

2.4 Schedule / Flow Chart

The following flow chart outline the estimated implementation

1
- Planning and system design
- (4 months)

2
- Consulting with locals and REHC directors
- (1 week)

3
- Compiling materials (not available in Haiti)
- (2 weeks)

4
- Go to Haiti with materials
- (1 week)

5
- Selecting operators for system with REHC
- (1 week)

6
- Get materials in Haiti
- (2 weeks)

7
- Construct system
- (3 weeks)

8
- Set up business and staff
- (1 week)

9
- Test system and troubleshoot
- (2 weeks)

10
- Leave Haiti

11
- Provide Support and follow-ups
- (5 years)

3.0 System Construction

The water filtration system will be constructed in stages. Key individuals selected in conjunction with REHC staff will be included in the construction. These individuals will be hired to help construct the system in order to get a deeper understanding of how the system works. Specialty construction people will be hired to deal with the ferrocement tanks.

The stages of construction are as follows:

1. clear site area
2. prepare foundations for support structure
3. construct upper tank, supports and lower tank (and wait to cure)
4. waterproof tanks
5. install membrane modules and pre-treatment system in utility area
6. install piping and valves to membranes and tanks
7. install infiltration trench
8. construct storefront and install wash station

4.0 Implementation Support

Implementation of the system requires considerations with regards to who needs to be involved and what impact the system will have to REHC and other stakeholders. Most materials will be purchased in Haiti at local hardware stores. See Appendix G of the Optimus design report for the REHC system materials list. System components not available in Haiti will be shipped from outside sources. Supplier information for these non-local materials is also included in Appendix G.

4.1 Personnel Required

Operating personnel will be chosen by representatives of REHC, who are the system owners and primary water consumers. Two people will be chosen, and training will be provided as part of the system implementation. Only one person is required to oversee the system, except for backwashing where two people are required. Having two people trained will ensure that there is always one alternate. Another person will be required to staff the storefront for selling water. This person will be required to run the till, keep sales records, and sanitize containers for customers. The selection of this person will be the responsibility of the REHC.

4.2 Impact of Implementation

The system is intended to provide water for children and staff at the REHC, as well as water available for purchase to local people in the community. Implementation of this system will have a positive impact on these groups, by providing them with clean local water. This may add increased competition to existing water producers, but because most water producers in Haiti use delivery trucks to drive around and distribute the water, Optimus feels that the proposed system will have a minimal impact on these producers.

5.0 Performance Monitoring

Once constructed, the water treatment system will require ongoing testing to ensure that the membranes are working properly. There is a period between successful challenge tests, which is to be determined upon deployment. Once this is past, microbiological tests will be performed on treated water. As well, flow measurements and pressure readings will be recorded periodically to determine how flux in the system is dropping and when membranes need to be replaced. In the first year follow ups will occur frequently to ensure that the system is running as expected with few surprises. See the operations manual in Appendix J in the Optimus design report for more details about periodic monitoring requirements.

5.1 Support, Monitoring & Follow Up

Long term monitoring, support and follow ups will be broken up into three stages which are listed as follows:

- initial implementation
- first year support
- successive support

Upon initial implementation the system will be checked to ensure that it is operating as expected without any issues. After this, Optimus will follow up for the first year, corresponding with the monthly microbiological samples. Phone and email support will be provided for any small issues or questions that arise during operation. After the first year, support will be maintained, and system performance will be checked every six months. This will continue for the remaining four years of the system operation.

5.2 Exit Strategy

After the system is up and running Optimus will terminate on-site support in Haiti with the exception of periodic inspections. However, five years of external support will be provided for the system. After this time, full control of the water treatment system operation will be given to the REHC, including the responsibility to maintain and operate it. We will include options for the REHC to continue system support either through Optimus or another outfit. Contact information from Optimus will also be provided to REHC in case any further assistance is needed after the five-year period. As well, there will be a continuous open communication between team Optimus and REHC throughout the lifespan of the system.

6.0 Site Requirements

Implementation of the system requires a portion of the unused land owned by the REHC, materials brought to Haiti from other places, materials purchased in Haiti, and local people to operate and maintain the system. The area that has been allotted to place the system is large enough to easily accommodate all of the treatment system components, and no additional area will be needed. See Figure 2 for site layout and land allotment.

Figure 2: Plan view of water filtration system component layout on site (Google, 2015)

7.0 Risks and Contingencies

Table 1 lists some of the potential risks that have been identified in the implementation of this system, and the contingency that has been allocated to the risk.

Table 1: Risks and Contingencies

Risk	Contingency
Increased system costs	A 20% contingency has been added to the system cost estimate in order to account for unforeseen issues
Well pump issues	Pump designed to work within constraints of a solar power system. If issues with pump, a pump replacement can be ordered. Alternative is to use a hand pump as a temporary solution if the electric pump is not working.
Water quality differences between assumed and actual conditions in Haiti	Differences that could be encountered are increased turbidity or increased water hardness. The pre-filtration system will deal with turbidity prior to secondary filtration. Increased turbidity will only affect the frequency of cleaning the pre-filters. If increased hardness is encountered, a hardness filter can be added before secondary filtration. This would take care of increased hardness in the groundwater

Difference in estimated water production	The number of filter modules can be changed to accommodate the amount of water desired. System is scaled based off of available surface area of the membranes. If less water is being produced, additional modules can be added to the system, and vice versa.
Solar system problems	The solar panel system assumes that there is six hours of good sunlight per day, which is a conservative estimate for typical conditions in Haiti. There are options to use grid power or a generator, which could be explored if the solar system is not performing
Backwashing system problems	If backwashing is not cleaning the membranes adequately, potential investigation into further backwashing cycle optimization including more frequent washing or increased pressure will be considered
Not enough water sold to cover periodic costs	If not enough water is sold to cover periodic costs of the filtration system, the costs will have to funded by the REHC. Periodic costs are fairly low and would not be much of a financial burden to the REHC.
Optimus not able to provide support	Optimus will identify an alternative support provider in the upon system deployment who could be used if Optimus is unable to provide technical support for the filtration system

8.0 Implementation Validation and Acceptance

The implementation of the water filtration system will be validated if it can achieve all of the following:

- Provide treated water for all children and staff at the school
- Provide enough treated water to be sold back to the community
- establish a business that can sell enough water back to cover periodic running costs of the system
- remains running for a period of five years (we anticipate membrane replacement after about 5 - 7 years)

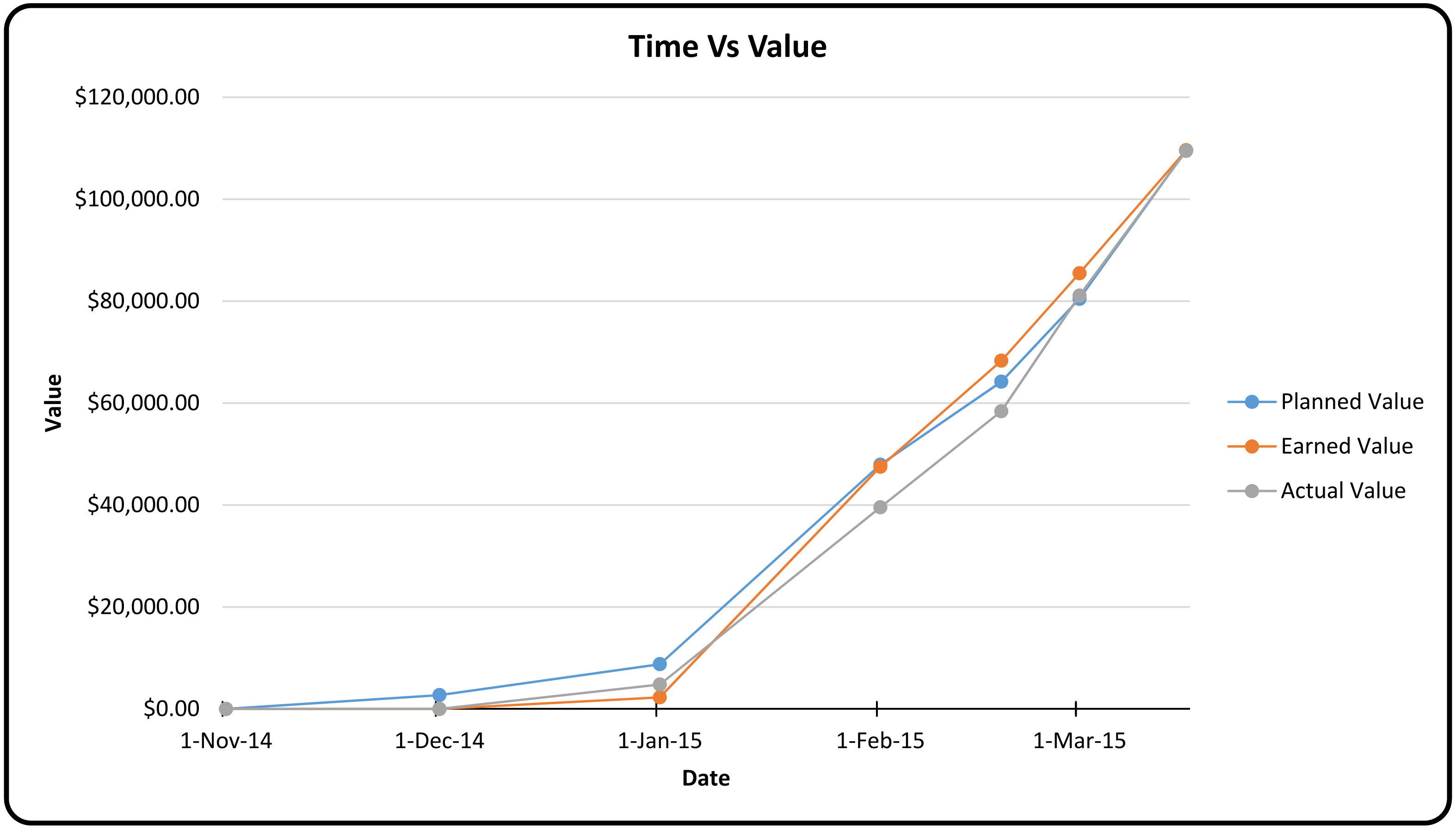
The system will be accepted if it can produce sufficient amounts of clean, treated water.

9.0 References

Google. (2015). *REHC Site*. Retrieved March 02, 2015, from Google Maps: https://www.google.ca/maps/place/Haiti/@18.5733306,-72.2069291,77m/data=!3m1!1e3!4m2!3m1!1s0x8eb6c6f37fcbbb11:0xb51438b24c54f6d3

Appendix R

Optimus Engineering Associates Consulting Hours and Fees



Plotting Data

Earned	$0.00	$0.00	$2,270.50	$47,512.40	$68,303.60	$85,481.30	$109,602.00
Actual	$0.00	$0.00	$4,783.92	$39,557.88	$58,396.00	$81,081.44	$109,468.00
Planned	$0.00	$2,709.48	$8,771.43	$47,919.58	$64,185.85	$80,452.13	$109,602.00
Monthly	$0.00	$2,709.48	$6,061.95	$39,148.15	-	$32,532.55	$29,149.87
Date	11/1/2014	12/1/2014	1/1/2015	2/1/2015	2/18/2015	3/1/2015	3/16/2015

Optimus Consulting Hours and Fee Breakdown

Optimus Engineering Associates

REHC Water Treatment Project

	Total Project Hours						Optimus Team Hours & Cost					Earned Value	Completion			
	Nov	Dec	Jan	Feb	Mar	TOTAL	David	Lindsey	Shane	Meghan	TOTAL		Dec	JAN	FEB	MAR
RESEARCH PHASE																
Identify Standards & Criteria	0.0	10.0	6.5	6.5	0.0	**23.0**	9.0	2.0	7.0	5.0	**23.0**	**28.0**	20%	70%	100%	100%
Develop Conceptual Drawings	0.0	0.0	3.0	4.5	0.0	**7.5**	1.5	3.0	0.0	3.0	**7.5**	**20.0**	0%	100%	100%	100%
Order membranes	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	**0.0**	**4.0**	0%	100%	100%	100%
Total Hours	**0.0**	**10.0**	**9.5**	**11.0**	**0.0**	**30.5**	**10.5**	**5.0**	**7.0**	**8.0**	**30.5**	**52.0**	11%	84%	100%	100%
Burden Rate							$191.00	$153.00	$138.00	$138.00						
TOTAL COST	$0.00	$1,587.05	$1,507.70	$1,745.75	$0.00	**$4,840.50**	**$2,005.50**	**$765.00**	**$966.00**	**$1,104.00**	**$4,840.50**	**$8,060.00**	$868.00	$6,758.00	$8,060.00	$8,060.00
DESIGN PHASE																
Design of Primary Components																
Support Structure	0.0	0.0	0.0	4.0	0.0	**4.0**	4.0	0.0	0.0	0.0	**4.0**	**8.0**	0%	0%	90%	100%
Pretreatment Screen	0.0	0.0	1.0	1.5	0.0	**2.5**	1.5	1.0	0.0	0.0	**2.5**	**8.0**	0%	25%	75%	100%
Filtration Modules	0.0	0.0	7.0	11.0	0.0	**18.0**	2.5	15.5	0.0	0.0	**18.0**	**24.0**	0%	0%	80%	100%
Power & Pump Systems	0.0	0.0	0.0	4.5	0.0	**4.5**	4.5	0.0	0.0	0.0	**4.5**	**16.0**	0%	0%	70%	100%
Design Drawings	0.0	0.0	0.0	18.5	3.0	**21.5**	15.5	6.0	0.0	0.0	**21.5**	**22.0**	0%	0%	80%	100%
Design of Secondary Components																
Storage Tanks	0.0	0.0	0.0	4.5	0.0	**4.5**	4.5	0.0	0.0	0.0	**4.5**	**12.0**	0%	0%	75%	100%
Disinfection System	0.0	0.0	0.0	4.0	0.0	**4.0**	0.0	4.0	0.0	0.0	**4.0**	**12.0**	0%	0%	100%	100%
Waste Removal Plan	0.0	0.0	0.0	1.0	4.0	**5.0**	0.0	0.0	0.0	5.0	**5.0**	**12.0**	0%	0%	90%	100%
Design Drawings	0.0	0.0	0.0	7.5	6.0	**13.5**	8.5	0.0	0.0	5.0	**13.5**	**20.0**	0%	0%	75%	100%
Total Hours	**0.0**	**0.0**	**8.0**	**56.5**	**13.0**	**77.5**	**32.5**	**26.5**	**0.0**	**10.0**	**77.5**	**102.0**	0%	5%	75%	100%
Burden Rate							$191.00	$153.00	$138.00	$138.00						
TOTAL COST	$0.00	$0.00	$1,201.75	$8,487.39	$1,952.85	**$11,642.00**	**$6,207.50**	**$4,054.50**	**$0.00**	**$1,380.00**	**$11,642.00**	**$17,418.00**	0	$870.90	$13,063.50	$17,418.00
CONSTRUCTION PHASE																
Fabricate Components	0.0	0.0	50.5	15.0	0.0	**65.5**	14.0	23.0	14.0	14.5	**65.5**	**80.0**	0%	100%	100%	100%
Assemble Components	0.0	0.0	84.5	9.0	0.0	**93.5**	29.5	25.0	17.0	22.0	**93.5**	**80.0**	0%	100%	100%	100%
Total Hours	**0.0**	**0.0**	**135.0**	**24.0**	**0.0**	**159.0**	**43.5**	**48.0**	**31.0**	**36.5**	**159.0**	**160.0**	0%	100%	100%	100%
Burden Rate							$191.00	$153.00	$138.00	$138.00						
TOTAL COST	$0.00	$0.00	$21,198.82	$3,768.68	$0.00	**$24,967.50**	**$8,308.50**	**$7,344.00**	**$4,278.00**	**$5,037.00**	**$24,967.50**	**$25,178.00**	0	$25,178.00	$25,178.00	$25,178.00
TESTING & OPTIMIZATION PHASE																
Turbidity Testing	0.0	0.0	3.5	5.0	0.0	**8.5**	3.5	2.0	2.0	1.0	**8.5**	**12.0**	0%	25%	75%	100%
Microbiological Testing	0.0	0.0	25.0	6.5	0.0	**31.5**	1.0	9.0	8.0	13.5	**31.5**	**32.0**	0%	80%	90%	100%
Testing System Flux	0.0	0.0	7.0	28.5	4.0	**39.5**	15.0	8.0	7.0	9.5	**39.5**	**46.0**	0%	15%	60%	100%
Optimization	0.0	0.0	1.0	12.0	2.0	**15.0**	3.0	12.0	0.0	0.0	**15.0**	**30.0**	0%	3%	70%	100%
Total Hours	**0.0**	**0.0**	**36.5**	**52.0**	**6.0**	**94.5**	**22.5**	**31.0**	**17.0**	**24.0**	**94.5**	**120.0**	0	50%	80%	100%
Burden Rate							$191.00	$153.00	$138.00	$138.00						
TOTAL COST	$0.00	$0.00	$5,677.20	$8,088.06	$933.24	**$14,698.50**	**$4,297.50**	**$4,743.00**	**$2,346.00**	**$3,312.00**	**$14,698.50**	**$18,056.00**	0	$9,028.00	$14,444.80	$18,056.00

Optimus Consulting Hours and Fee Breakdown

Optimus Engineering Associates

REHC Water Treatment Project

	Total Project Hours						Optimus Team Hours & Cost					Earned Value				
	Nov	Dec	Jan	Feb	Mar	TOTAL	David	Lindsey	Shane	Meghan	TOTAL	Completion				
SUSTAINABILITY PHASE																
Development of User Manual	0.0	0.0	0.0	21.0	17.0	38.0	0.0	0.0	26.0	12.0	38.0	30.0	0%	0%	70%	100%
Development of Business Plan	0.0	0.0	0.0	32.5	10.5	43.0	0.0	0.0	16.0	27.0	43.0	30.0	0%	0%	90%	100%
Educational Reccomendation	0.0	0.0	0.0	7.0	17.0	24.0	0.0	0.0	12.0	12.0	24.0	18.0	0%	0%	40%	100%
Total Hours	**0.0**	**0.0**	**0.0**	**60.5**	**44.5**	**105.0**	**0.0**	**0.0**	**54.0**	**51.0**	**105.0**	**78.0**	0%	0%	60%	100%
Burden Rate							$191.00	$153.00	$138.00	$138.00						
TOTAL COST	$0.00	$0.00	$0.00	$8,349.00	$6,141.00	**$14,490.00**	**$0.00**	**$0.00**	**$7,452.00**	**$7,038.00**	**$14,490.00**	**$11,700.00**	0	0	$7,020.00	$11,700.00
REPORTING PHASE																
Report Writing	0.0	0.0	12.5	45.5	56.0	114.0	36.5	30.0	30.5	17.0	114.0	100.0	0%	13%	65%	100%
Editing	0.0	0.0	0.0	2.0	51.5	53.5	17.0	11.0	13.5	12.0	53.5	20.0	0%	0%	5%	100%
Printing & Binding	0.0	0.0	0.0	0.0	12.0	12.0	6.0	4.0	2.0	0.0	12.0	8.0	0%	150%	0%	100%
Total Hours	**0.0**	**0.0**	**12.5**	**47.5**	**119.5**	**179.5**	**59.5**	**45.0**	**46.0**	**29.0**	**179.5**	**128.0**	0%	10%	47%	100%
Burden Rate							$191.00	$153.00	$138.00	$138.00						
TOTAL COST	$0.00	$0.00	$1,991.61	$7,568.11	$19,039.78	**$28,599.50**	**$11,364.50**	**$6,885.00**	**$6,348.00**	**$4,002.00**	**$28,599.50**	**$19,840.00**	0	$1,937.50	$9,300.00	$19,840.00
PROJECT MANAGEMENT																
Meetings	0.0	16.0	18.5	8.5	2.0	45.0	15.0	13.0	7.5	9.5	45.0	40.0	40%	86%	100%	100%
Project Coordination	0.0	4.0	1.5	13.5	0.0	19.0	6.0	6.0	5.0	2.0	19.0	18.0	22%	31%	80%	100%
Total Hours	**0.0**	**20.0**	**20.0**	**22.0**	**2.0**	**64.0**	**21.0**	**19.0**	**12.5**	**11.5**	**64.0**	**58.0**	15%	40%	90%	100%
Burden Rate							$191.00	$153.00	$138.00	$138.00						
TOTAL COST	$0.00	$3,196.88	$3,196.88	$3,516.56	$319.69	**$10,230.00**	**$4,011.00**	**$2,907.00**	**$1,725.00**	**$1,587.00**	**$10,230.00**	**$9,350.00**	$1,402.50	$3,740.00	$8,415.00	$9,350.00
Monthly Cost Breakdown		$4,783.92	$34,773.95	$41,523.57	$28,386.56						**Earned Value Breakdown**	$109,602.00	$2,270.50	$47,512.40	$85,481.30	$109,602.00

COST SUMMARY

	Nov	Dec	Jan	Feb	Mar	TOTAL	David	Lindsey	Shane	Meghan	TOTAL
Research	0.0	10.0	9.5	11.0	0.0	$4,840.50	10.5	5.0	7.0	8.0	$4,840.50
Design	0.0	0.0	8.0	56.5	13.0	$11,642.00	32.5	26.5	0.0	10.0	$11,642.00
Construction	0.0	0.0	135.0	24.0	0.0	$24,967.50	43.5	48.0	31.0	36.5	$24,967.50
Testing & Optimization	0.0	0.0	36.5	52.0	6.0	$14,698.50	22.5	31.0	17.0	24.0	$14,698.50
Sustainability	0.0	0.0	0.0	60.5	44.5	$14,490.00	0.0	0.0	54.0	51.0	$14,490.00
Report	0.0	0.0	12.5	47.5	119.5	$28,599.50	59.5	45.0	46.0	29.0	$28,599.50
Project Management	0.0	20.0	20.0	22.0	2.0	$10,230.00	21.0	19.0	12.5	11.5	$10,230.00
TOTAL	**0.0**	**30.0**	**221.5**	**273.5**	**185.0**	**$109,468.00**	**189.5**	**174.5**	**167.5**	**170.0**	**$109,468.00**

Optimus Engineering Burden Rates

Optimus Engineering Associates

REHC Water Treatment Project

Burden Rates per hour

Engineer Level 7	$293.00	Technologist Level 7	$192.00
Engineer Level 6	$266.00	Technologist Level 6	$187.00
Engineer Level 5	$214.00	Technologist Level 5	$170.00
Engineer Level 4	$191.00	Technologist Level 4	$141.00
Engineer Level 3	$153.00	Technologist Level 3	$129.00
Engineer Level 2	$138.00	Technologist Level 2	$109.00
Engineer Level 1	$119.00	Technologist Level 1	$99.00