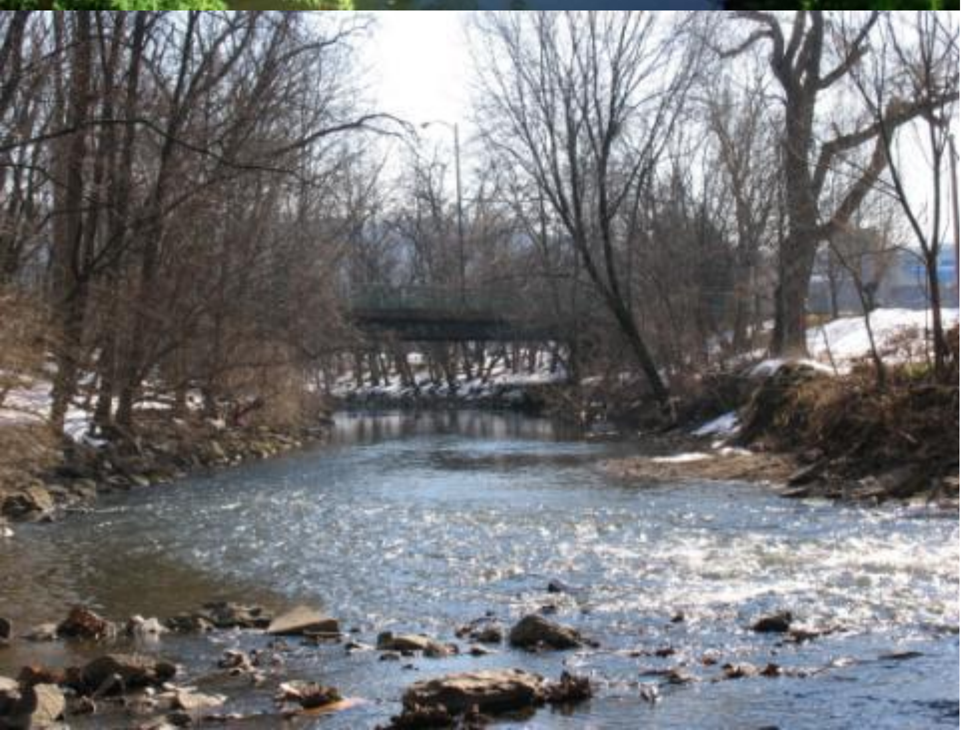



Optimizing the Biosand Filter

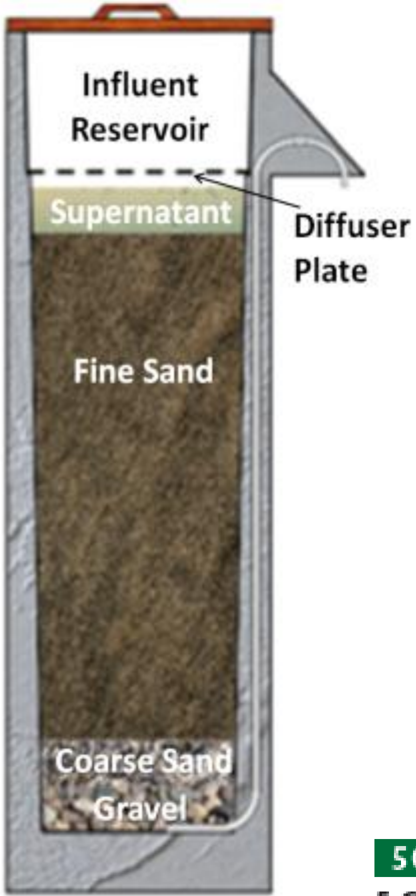
Julie Napotnik
Kristen Jellison, Ph.D.
Lehigh University

Disinfection 2011

Phase 1: Objectives

1. Test height of filtration sand bed
   – Three sizes of filters; 4 filters of each size
2. Test effects of turbidity
   – Alternated 5 and 50 NTU targets every 2 to 4 weeks
3. Test for effects of filter cleaning (swirl & dump)
   – Each filter was cleaned 4 to 9 times in the 275 days
   – A total of 72 cleanings were performed
4. Determine effect of moving filters (not planned!)
   – Supervised move of all filters to a new lab

1. Test height of filtration sand bed



Filtration Sand Heights:

Version 10 concrete = 55cm

5 Gallon Bucket = 16 cm

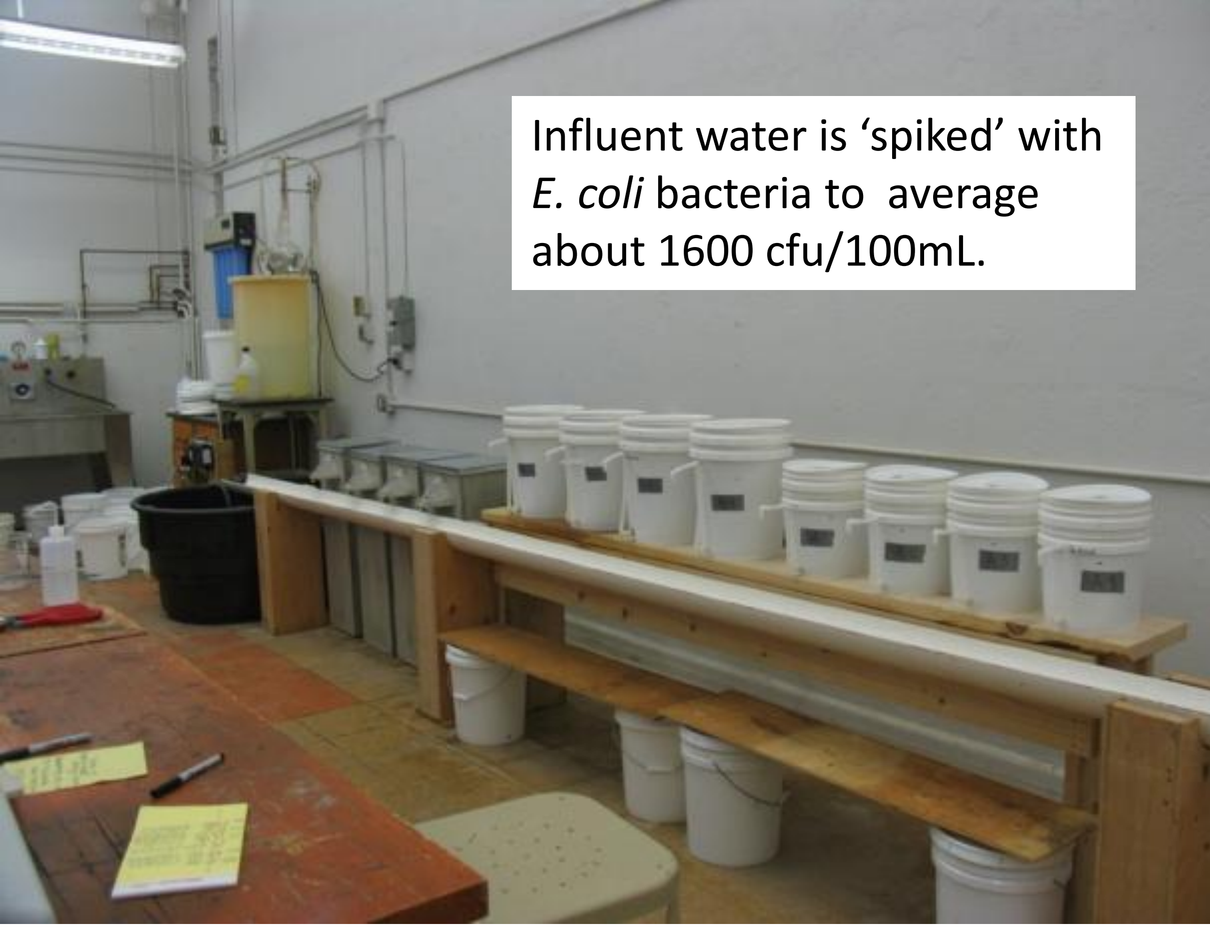
2 Gallon Bucket = 10 cm

Version 10 Concrete Biosand Filter

5 Gallon Bucket Biosand Filter

2 Gallon Bucket Biosand Filter

All filters were constructed at Lehigh University



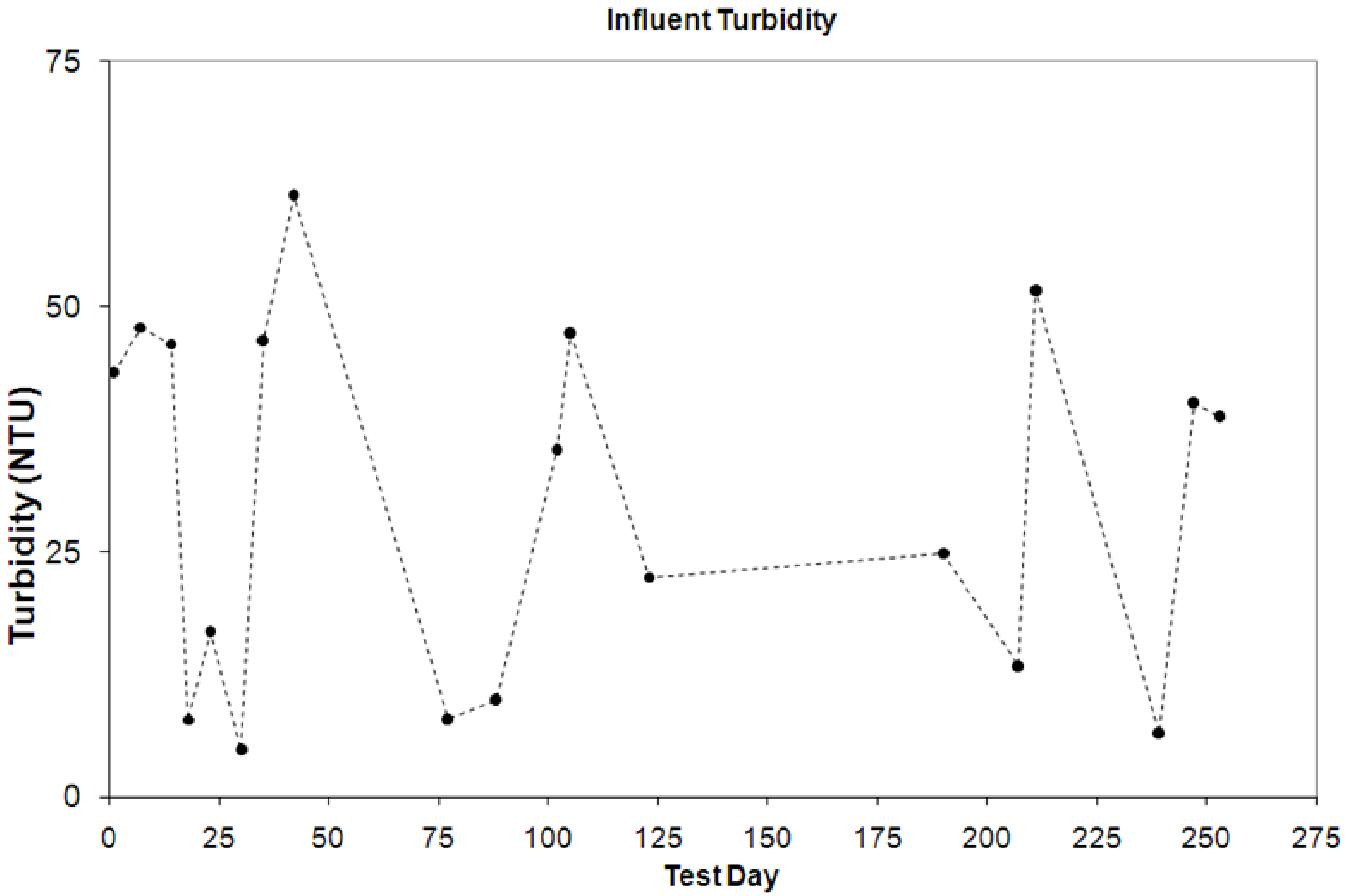
Influent water is ‘spiked’ with *E. coli* bacteria to average about 1600 cfu/100mL.

Pause period was kept constant at 3 hours between fillings.
Each filter was filled 3 times per day for nine months (275 days):

Concrete Ver. 10 =	12 L per fill x 3 = 36 L/day per filter x 4 filters	= 144	L/day
5-gallon bucket =	3.6 L per fill x 3 = 10.8 L/day per filter x 4 filters	= 43.2	L/day
2-gallon bucket =	1.5 L per fill x 3 = 4.5 L/day per filter x 4 filters	= 18	L/day
	Total:	205.2	L/day

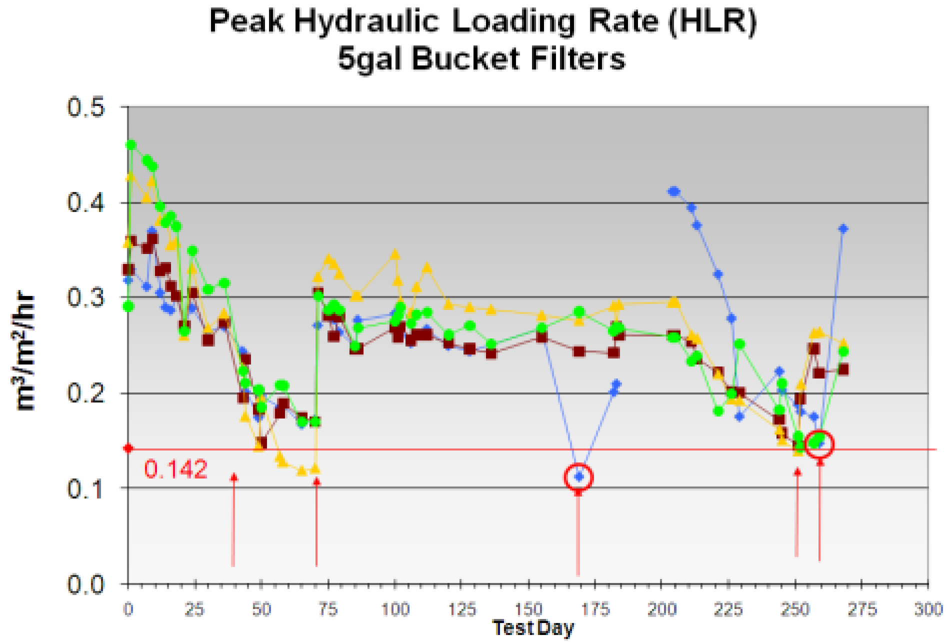
2. Test effects of turbidity

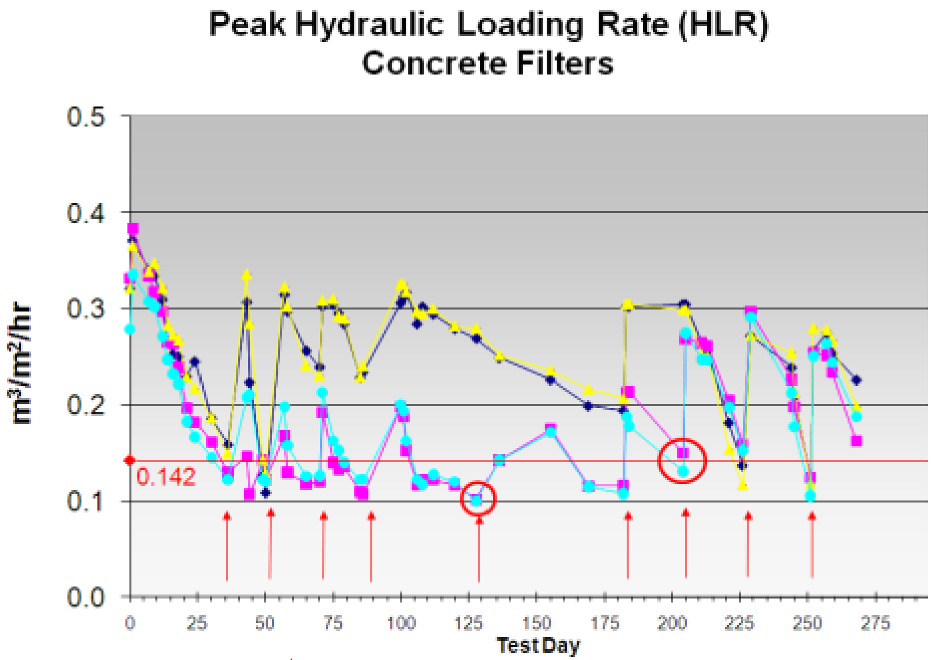
Influent turbidity was alternated; 5 and 50 NTU targets, using sediments from the water source (creek)

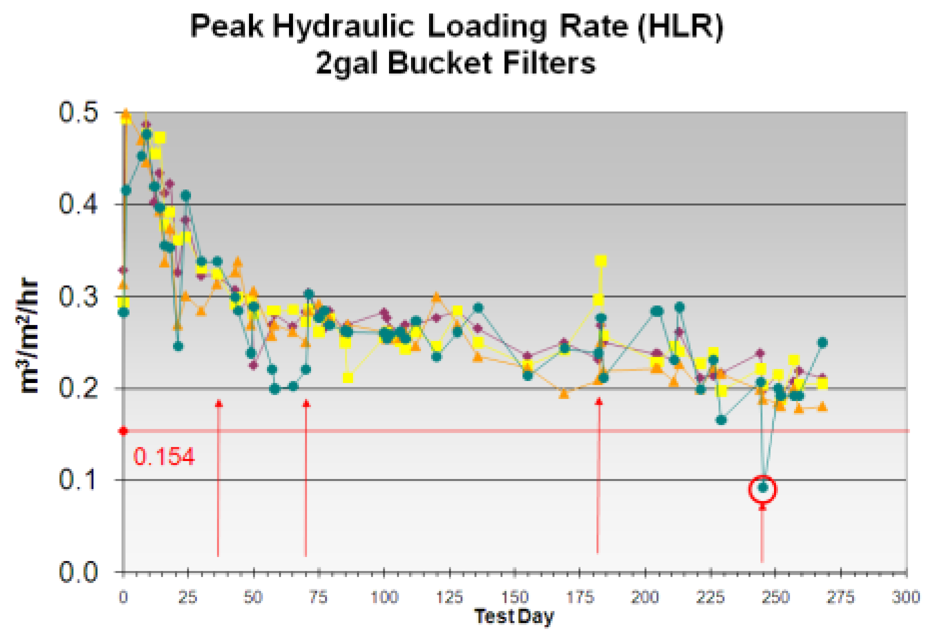


3. Test for effects of filter cleaning

Filter Type	Min Flow Rate (ml/min)	Avg Flow Rate (ml/min)
Concrete	140	250
5-gal Bucket	140	260
2-gal Bucket	100	180

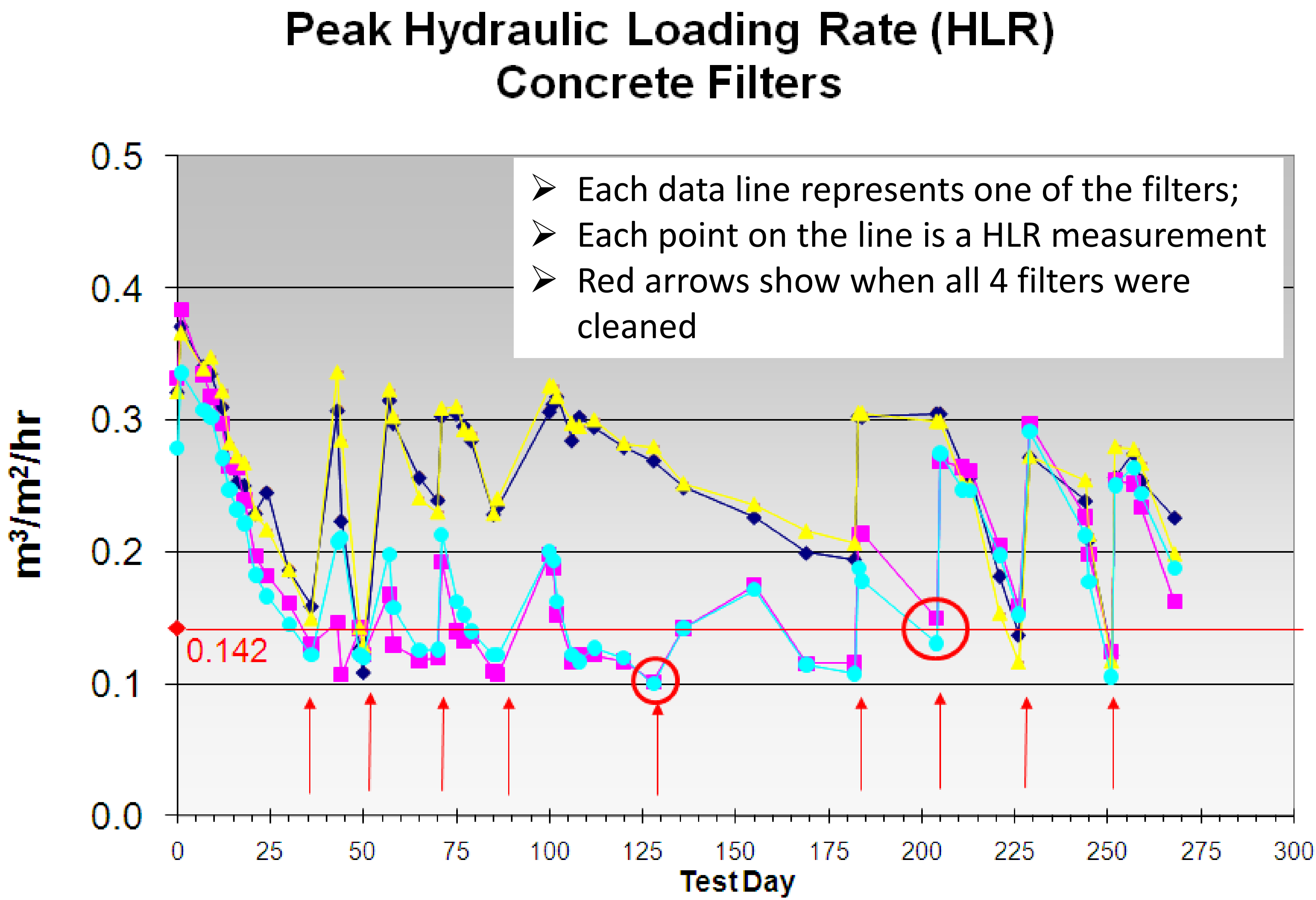




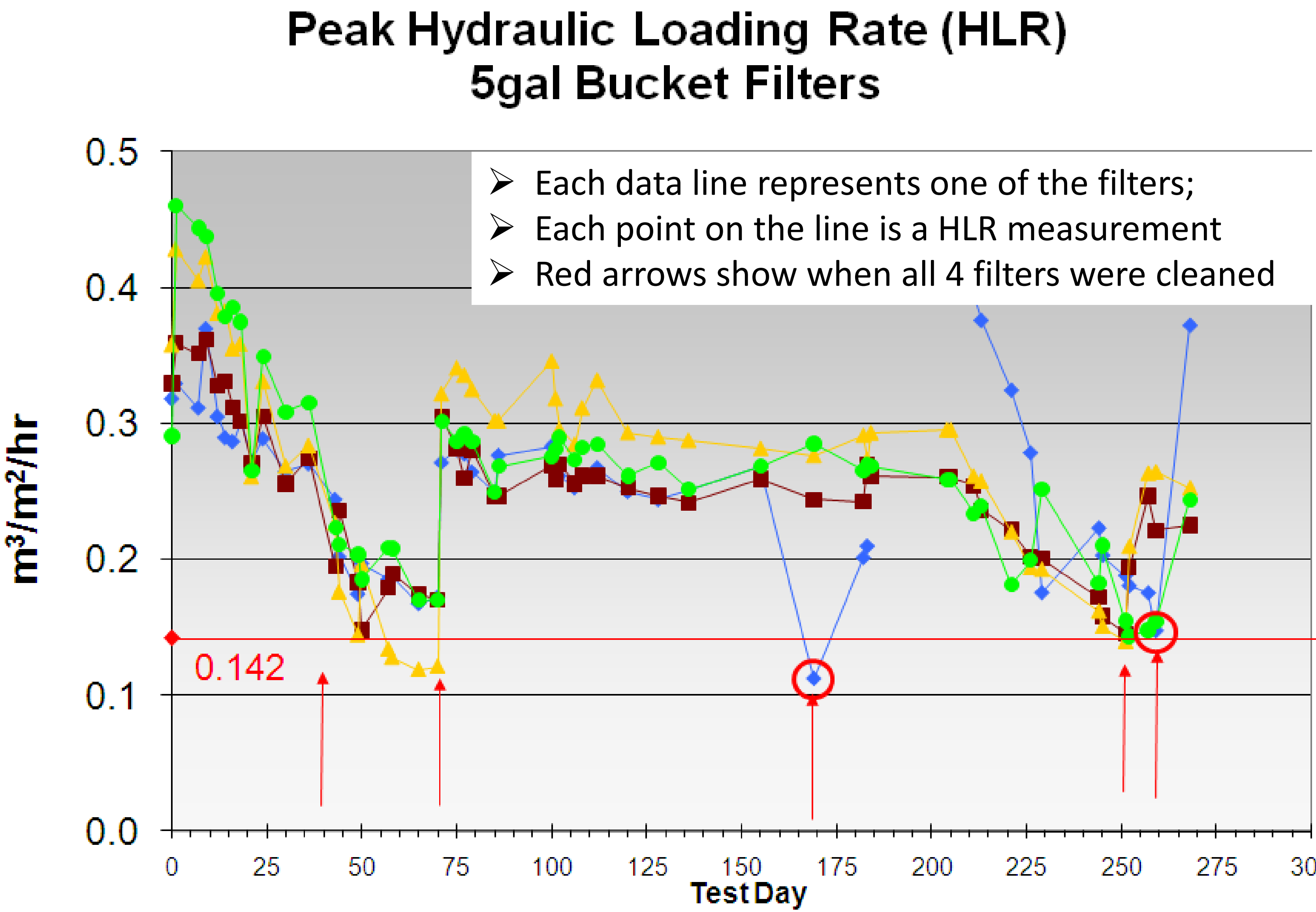


Red arrows indicate when all 4 filters of each size were cleaned

Cleaning frequency of concrete filters

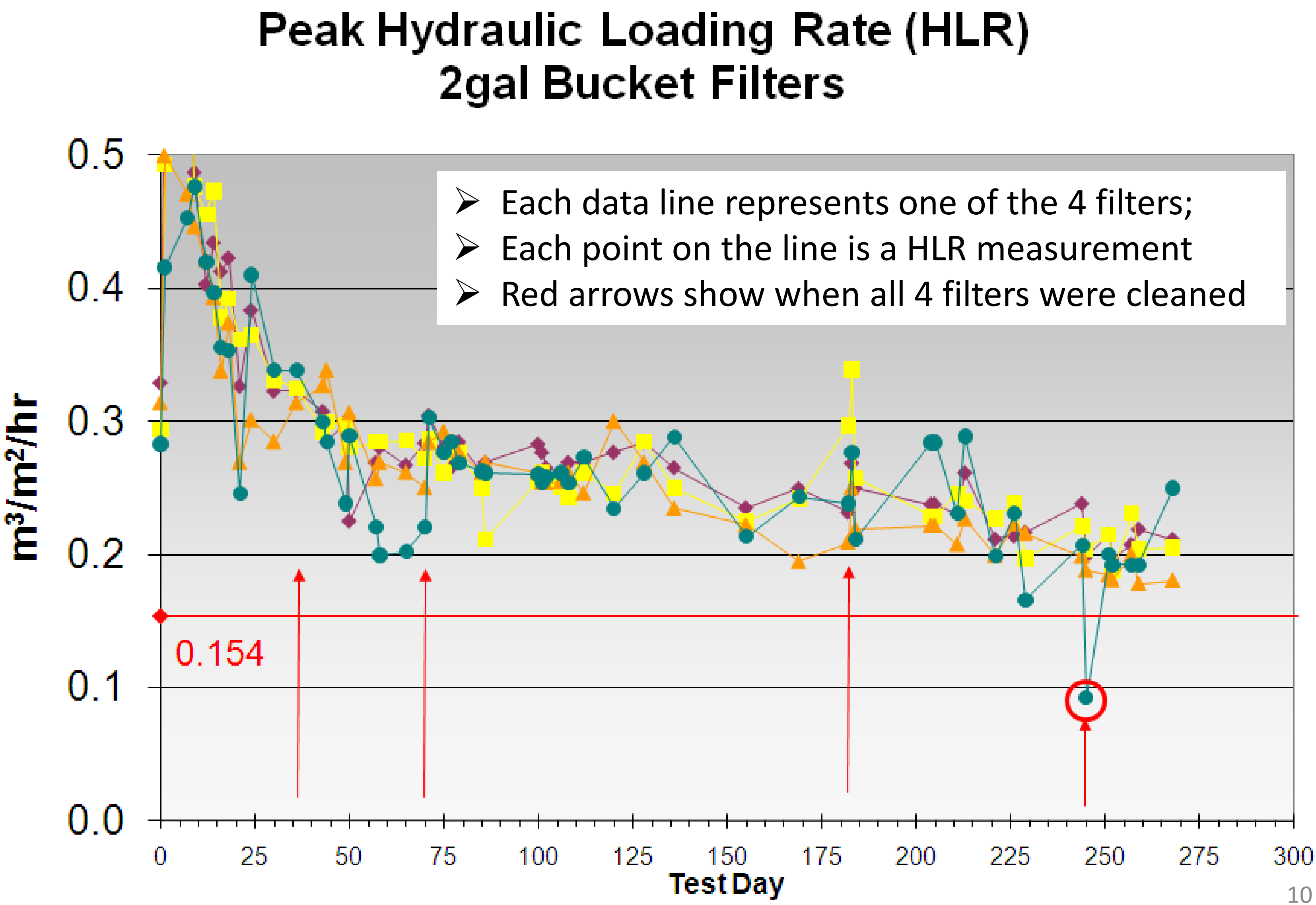


Cleaning frequency of 5-gallon filters



- Each data line represents one of the filters;
- Each point on the line is a HLR measurement
- Red arrows show when all 4 filters were cleaned

Cleaning frequency of 2-gallon filters

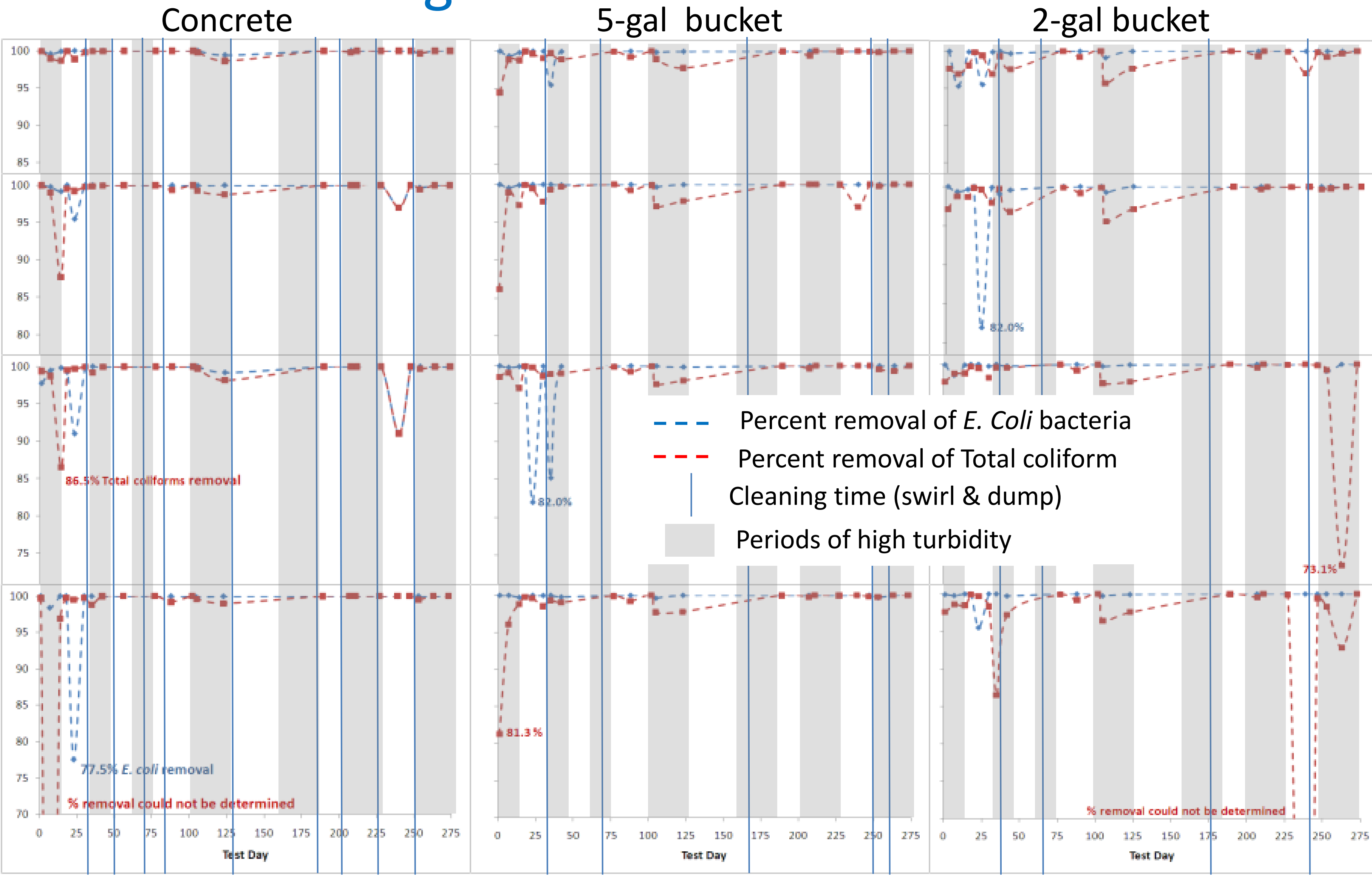


4. Determine effect of moving filters

All filters were moved to a new lab – the move was supervised…

Results

1. Test height of filtration sand bed



	Min	Max	Average	Std dev
E.coli	77.5	100.0	99.4	2.7
TC	0.0	100.0	98.2	10.6

	Min	Max	Average	Std dev
E.coli	82.0	100.0	99.5	2.5
TC	81.3	100.0	98.9	2.6

	Min	Max	Average	Std dev
E.coli	82.0	100.0	99.5	2.1
TC	0.0	100.0	97.4	11.0

Results:

Effectiveness vs. height of filtration sand bed

Concrete: **55 cm**

	Min	Max	Average	Std dev
E.coli	77.5	100.0	99.4	2.7
TC	0.0	100.0	98.2	10.6

5-Gallon Bucket: **16 cm**

	Min	Max	Average	Std dev
E.coli	82.0	100.0	99.5	2.5
TC	81.3	100.0	98.9	2.6

2-Gallon Bucket: **10 cm**

	Min	Max	Average	Std dev
E.coli	82.0	100.0	99.5	2.1
TC	0.0	100.0	97.4	11.0

Results:

Effectiveness vs. height of filtration sand bed

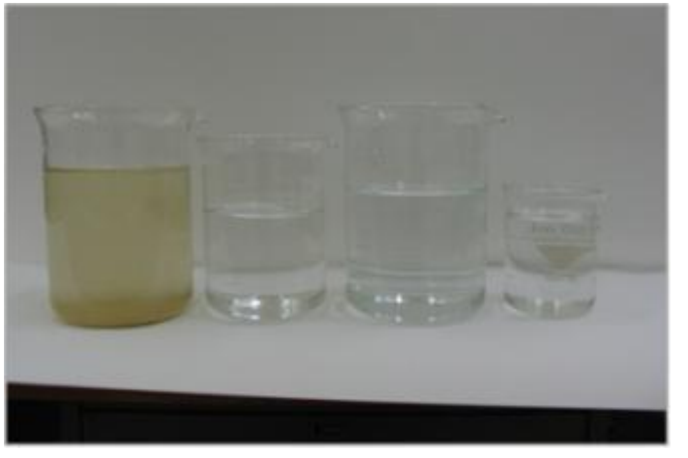
- The three filtration sand bed depths: 55 cm, 16 cm and 10 cm, all showed very similar bacteria removal effectiveness averaging 99.4% to 99.5% (log 2.2 to 2.3) for *E. coli*.
- The small bucket filters (5-gal & 2-gal) performed as well as the large concrete filters in removing *E.coli* and total coliform bacteria.
- These results support the understanding that bacteria is primarily removed in the top 10 cm of the sand bed including the top 1 – 2 cm where the biolayer is most active.
- Lower removals of *E. coli* (to a minimum 77%) were predominantly in the first month of filter operation when the biolayer may still be ripening.

2. Test effects of turbidity

	Min	Max	Avg	Std Dev
Influent	4.82	61.37	30.17	18.40
Concrete	0.15	1.61	0.43	0.29
5gal buckets	0.15	1.60	0.46	0.31
2gal buckets	0.23	1.41	0.53	0.28

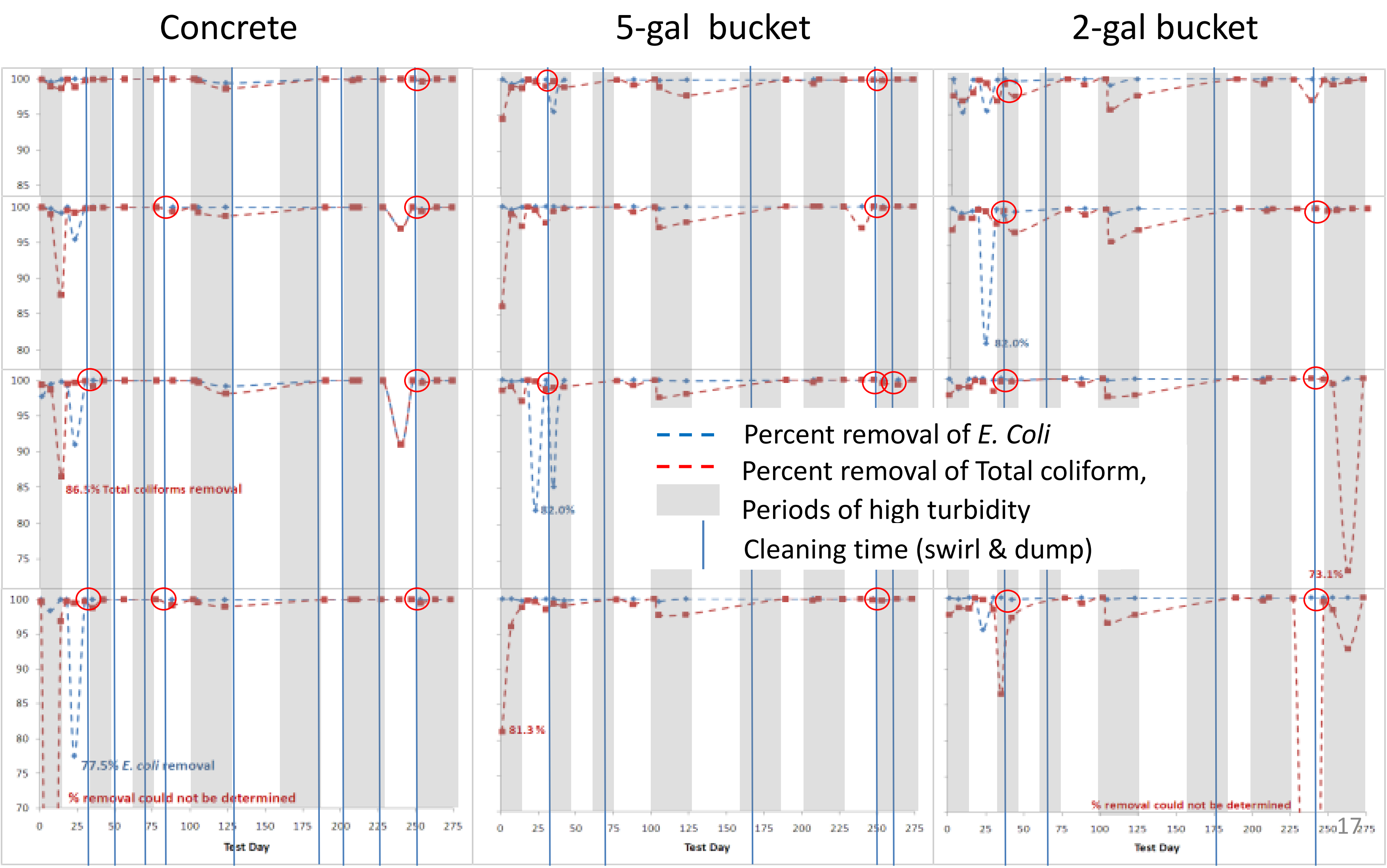
Results:

- All effluents consistently ≤1NTU
- Turbidity removal averages 98%
- No significant difference between the three filter sizes



3. Test for effects of filter cleaning

The filters were cleaned a total of 72 times – in 22 cases (31%) the removal effectiveness (*E. Coli* <u>or</u> TC) was lower in the next sample tested after the cleaning...see red circles



4. Determine effect of moving filters

Results:

- Although care was taken, when the filters were moved compaction of the sand reduced the flow rates.
- All filters experienced significantly reduced flow rate following the move ranging from 20% - 50%.
- The smaller filters were affected the most.
- This indicates that the small bucket filters are not transportable

	Flow rate (ml/min)				# of wks at least 1 filter required cleaning (out of 13)
	Requires Cleaning	Before Move Avg	After Move Avg	After Move Min	
Concrete	140	250	200	70	8
5-gal	140	260	185	85	8
2-gal	100	180	100	44	12

Reinstalled all filters

- required due to compaction when filters were moved

	Water ONLY	Media at 40% Porosity		After Rebuild	
	Max Flow Rate (ml/min)	Est Flow Rate (ml/min)	Est HLR ($m^3/m^2/hr$)	Avg Flow Rate (ml/min)	Avg HLR ($m^3/m^2/hr$)
Concrete	1000	400	0.41	420	0.43
5-gal bucket	230	90	0.10	140	0.15
2-gal bucket	210	80	0.13	130	0.20

Phase 2: Objectives

5. Test the effects of pause period
   - Filters to be filled at constant time intervals: 1, 3, 6, 12, 24 and 72 hours.
   - The actual 'pause period' will depend on the flow rate of the filter.
   - Each time period will be tested for 4 weeks
6. Determine removal effectiveness for virus (MS2) and protozoa (cryptosporidium) as well as bacteria (E. coli & TC) for the 3 biosand filter sizes
   - Target of 50 NTU turbidity for all influent water
7. Test the microbial removal using iron oxide
   - Small steel nails added to the diffuser basin of 2 filters of each size; total 6 of the 12 filters

5. Test the effects of pause period

Experiments recently started with 6 hour Pause Period

- 3 fills per day
- 6 hours between fills
- Turbidity ~50 NTU

Concrete = 12 L per fill
= 24 L per day

5-gal bucket = 3.6 L per fill
= 7.2 L per day

2-gal bucket = 1.5 L per fill
= 3.0 L per day

6. Determine removal effectiveness for virus (MS2) and protozoa (cryptosporidium) plus bacteria (E. coli & TC)

These experiments are underway now. They will take about 6 months to complete

7. Test the microbial removal using iron oxide

- Nails added
  - Concrete: 5 kg
  - 5-gal: 1.5 kg
  - 2-gal: 0.625 kg
- Microbial analyses
  - Bacteria (TC & *E. coli*)
  - *Cryptosporidium*
  - MS2 bacteriophage

Small common steel nails were added to the diffuser basins of 6 of the 12 filters.

Notes from Researcher:

- Spiking issues
  - Original target: 500cfu/100ml
  - Average: 1600cfu/100ml

Julie found that, at 500 cfu/100mL, the bacteria would stick to the sides of the container and 'disappear' so the target was raised to 1600

- Time requirements
  - Influent preparation
  - Sample processing

Creates practical constraints on the experiment plan

- Moving = compaction = decreased flow rate
- Long-term study (test day 615)

Ouch!

- Small-scale biosand filtration effective [for bacterial removal at least]
- Nails – improved microbial removal?

Acknowledgements

EPA P3 — People Prosperity Planet

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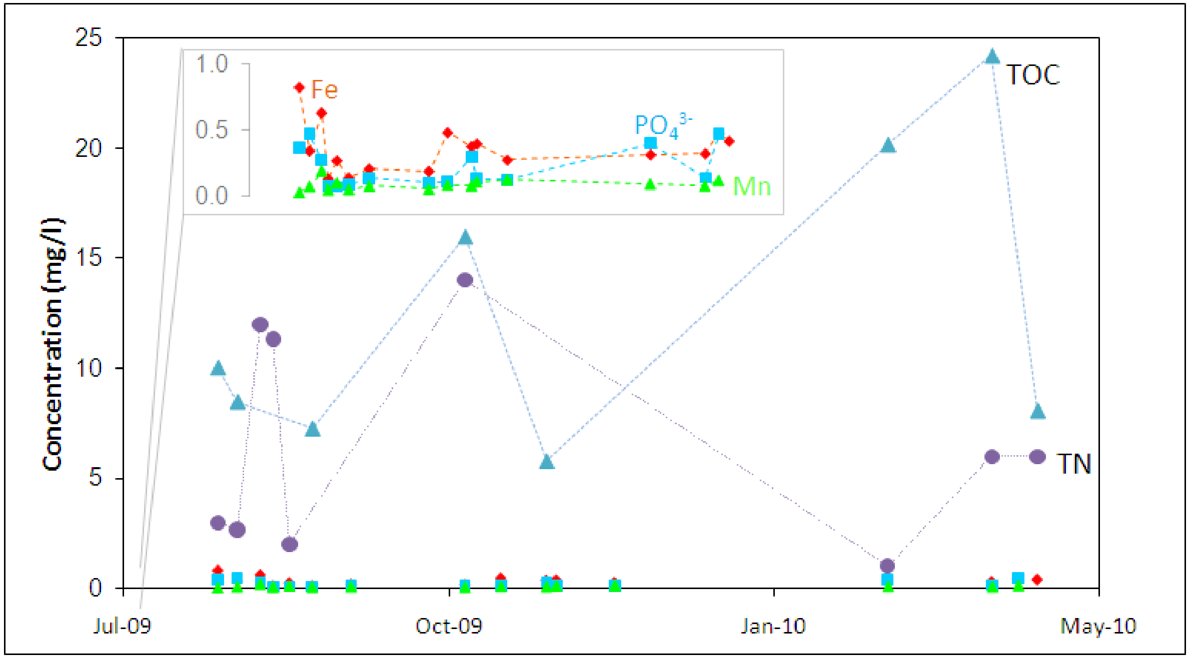
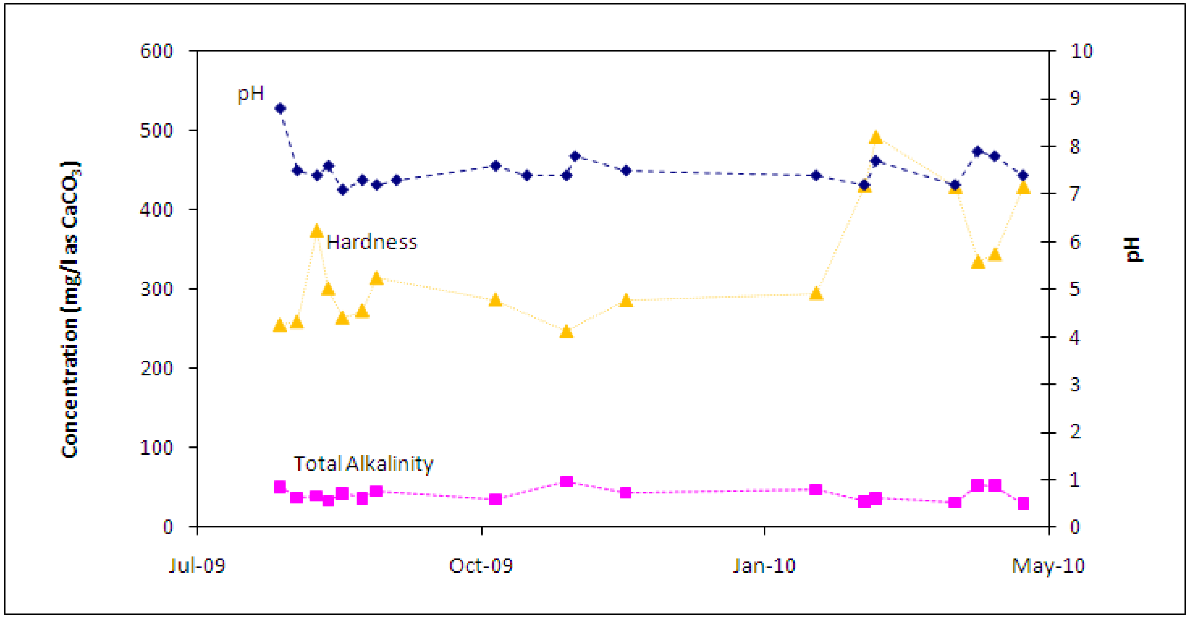
Influent Water Analysis





Influent Water Analysis

Hardness – as $CaCO_3$

The following is a measure of hardness (expressed in mg/l as CaCo3):

0 - 100	Soft
100 - 200	Moderate
200 - 300	Hard
300 - 500	Very hard
500 - 1,000	Extremely hard

Influent water = 240 – 500 mg/L – "very hard"

*From: www.idph.state.il.us/envhealth/pdf/**DrinkingWater**.pdf*

Influent Water Analysis

Iron - Fe

Fe – dissolved iron:

The following levels of iron (Fe) are expressed in mg/l:

0 - 0.3	Acceptable
0.3 - 1.0	Satisfactory (however, may cause staining & objectionable taste)
Over 1.0	Unsatisfactory

Influent water, Fe = 0.2 – 0.5 (max. 0.8) mg/L – "Satisfactory" for drinking water

*From: www.idph.state.il.us/envhealth/pdf/**DrinkingWater**.pdf*

Influent Water Analysis
pH

A measure of the acid or alkaline content of water…

The pH of drinking water normally ranges from 5.5 to 9.0.

Influent water: pH varies from 7 to 8 (max. pH 9 when filter first installed)

*From: www.idph.state.il.us/envhealth/pdf/**DrinkingWater**.pdf*

Influent Water Analysis
Alkalinity

Concentrations less than 100 ppm are desirable for domestic water supplies. The recommended range for drinking water is 30 to 400 ppm. A minimum level of alkalinity is desirable because it is considered a “buffer” that prevents large variations in pH.

Water with low alkalinity (less than 75 mg/l), especially some surface waters and rainfall, is subject to changes in pH due to dissolved gasses that may be corrosive to metallic fittings.

Influent water alkalinity is 30 to 50 mg/l – within recommended range for drinking water

Influent Water Analysis
Phosphate

The recommended level of total phosphorus in estuaries and coastal ecosystems to avoid algal blooms is 0.01 to .1 mg/l

Use the chart below to rate your water sample:

0.01 - 0.03 mg/L - the level in uncontaminated lakes

0.025 - 0.1 mg/L - level at which plant growth is stimulated

0.1 mg/L - maximum acceptable to avoid accelerated eutrophication

0.1 mg/L - accelerated growth and consequent problems

Influent water phosphate varies from ~ 0.1 to 0.5 mg/L this is above the acceptable range for eutrophication

Influent Water Analysis
Manganese - Mn

"The aesthetic objective for manganese in drinking water is ≤0.05 mg/L (≤50 µg/L). The presence of manganese in drinking water supplies may be objectionable for a number of reasons. At concentrations above 0.15 mg/L, manganese stains plumbing fixtures and laundry and produces undesirable tastes in beverages."

Influent water < 0.1 mg/L – acceptable

From: Health Canada www.hc-sc.gc.ca

Influent Water Analysis
Total Organic Carbon - TOC

TOC is mostly dissolved organic carbon compounds such as humic and fulvic acids…

The primary reasons for reducing organic carbon in drinking water are not related to the toxicity of the organic carbon compounds themselves but rather to the desire to reduce the formation of trihalomethanes (THMs) following chlorination, and avoid the objectionable colour that arises when humic and fulvic acids are present at high levels.

The water quality criteria for total organic carbon are 2 mg/L for treated water and 4 mg/L for source water.

Influent water TOC = 5 to 25 mg/L – high for drinking water source

Influent Water Analysis
Total Nitrogen - TN

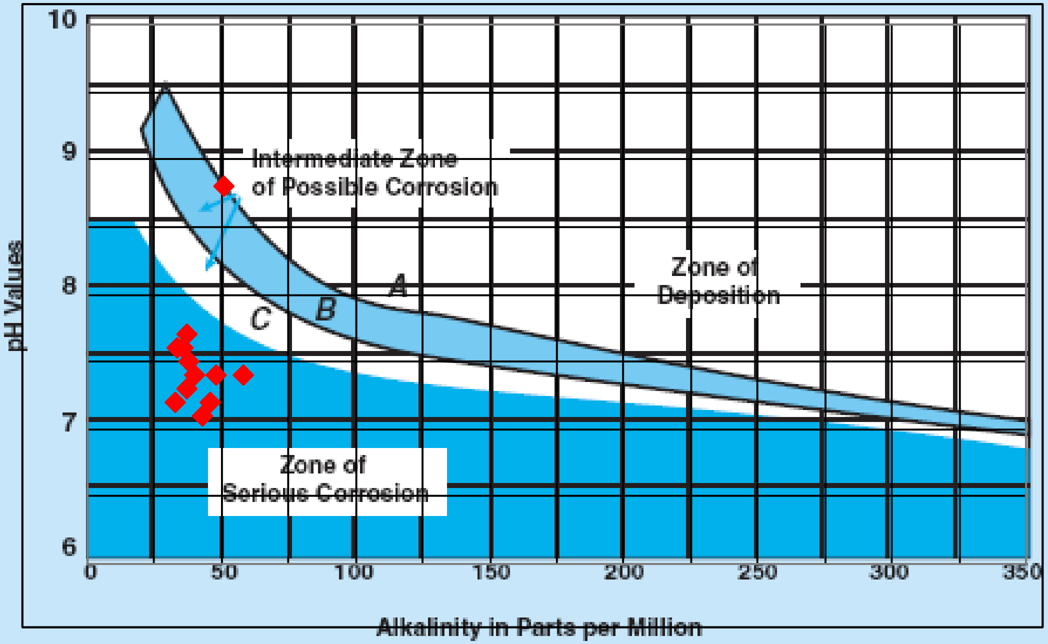
High levels of nitrites can oxidize hemoglobin to form methanoglobin which is unable to carry oxygen. Brain damage or death by suffocation can result from this condition known as methemoglobinemia or blue baby syndrome.
The allowable level of nitrogen in water for children six months or less is 10ppm (10 mg/1) as nitrate nitrogen or 45 ppm (45 mg/1) as nitrate.

Influent Water, TN = 1 to 15 mg/L – occasionally above allowable level for drinking water

http://www.dnr.state.md.us/forests/publications/exnit.html

Influent Water Analysis

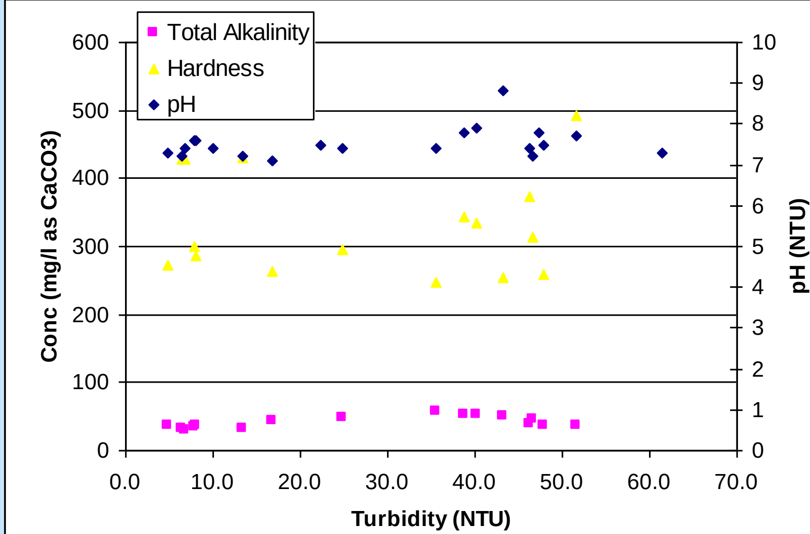
Figure 1. The Baylis curve.

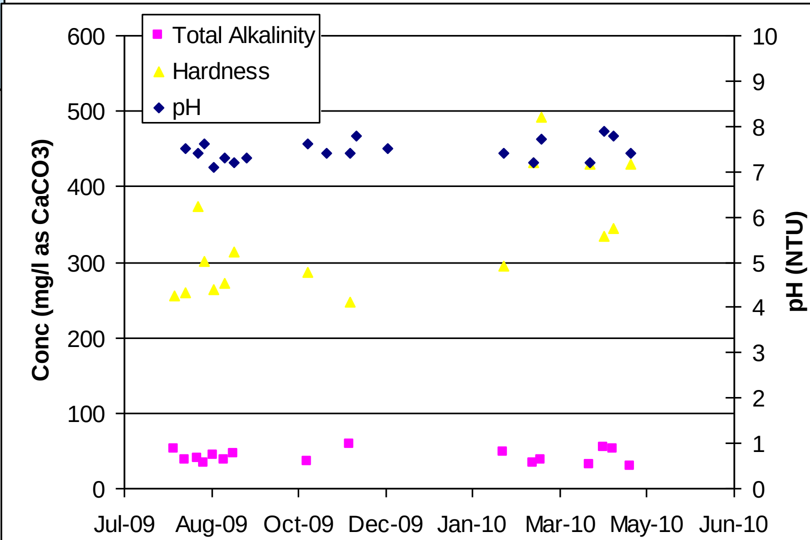


Note:
A = Curve of values necessary to produce a coating of calcium carbonate.
B = Curve of calcium carbonate equilibrium.
C = Curve of values necessary to prevent iron stains.

Source: Ripp 1991. Opflow

Lehigh BSF Study Data overlay.





Potential Impact

- Nails should rust / corrode easily to form iron oxides and possibly virus removal
- This issue was identified during field testing in Cambodia (Tom Mahin, MA DEP/CAWST)

Sieve Analysis

Filtration Sand

	Concrete				5-gal bucket				2-gal bucket			
d10 (mm)	0.18	0.18	0.18	0.17	0.18	0.18	0.18	0.19	0.16	0.17	0.16	0.17
d60 (mm)	0.33	0.3	0.42	0.32	0.32	0.33	0.32	0.43	0.29	0.34	0.31	0.3
U	1.83	1.67	2.33	1.88	1.78	1.83	1.78	2.26	1.81	2.00	1.94	1.76

*U = Uniformity Coefficient = d60/d10

All sieve analyses meet the specifications provided by CAWST for filtration sand in the biosand filter.

- Sand Bed: 3x washed all purpose sand
  - CBSF = 55cm
  - Lg bucket = 16cm
  - Sm bucket = 10cm
- Separating Layer:
  - Top layer: 1/8” <Delaware River Rx< 24mesh
  - Bottom layer: ¼” < Delaware River Rock < 1/8”
    - CBSF = 5cm; Lg bucket = 4cm; Sm bucket = 3cm
- Gravel Underdrain: ½” < Delaware River Rock < ¼”
    - CBSF = 5cm; Lg bucket = 4cm; Sm bucket = 3cm

Biosand Filter Designs: Concrete, 5-gal, 2-gal Bucket

Dimensions and Volumes

Concrete Biosand Filter - Volume Calculations

		Widths (internal) (mm)			Areas (m2)		Total (dry) Volumes		Porosity	Pore (void) Volumes	
	Depth (mm)	Top	Average	Bottom	Top	Average	(m^3)	litres	(%)	(m^3)	litres
Reservoir (Max. fill volume)	175	265	262	258		0.06848	0.01198	12.0	100%	0.011984	12.0
Supernatant (Standing Water)	50	245	244	243		0.05954	0.00298	3.0	100%	0.002977	3.0
Fine Sand (Filter Media)	546	243	234	225	0.059	0.05487	0.02996	30.0	40%	0.011983	12.0
Coarse Sand (Separating Layer)	50	225	224	224		0.05038	0.00252	2.5	33%	0.000831	0.8
Gravel (Underdrain)	50	224	223	222		0.04965	0.00248	2.5	42%	0.001043	1.0
Total Bucket	871						0.04992	49.9			28.8

Large Bucket Biosand Filter - Volume Calculations

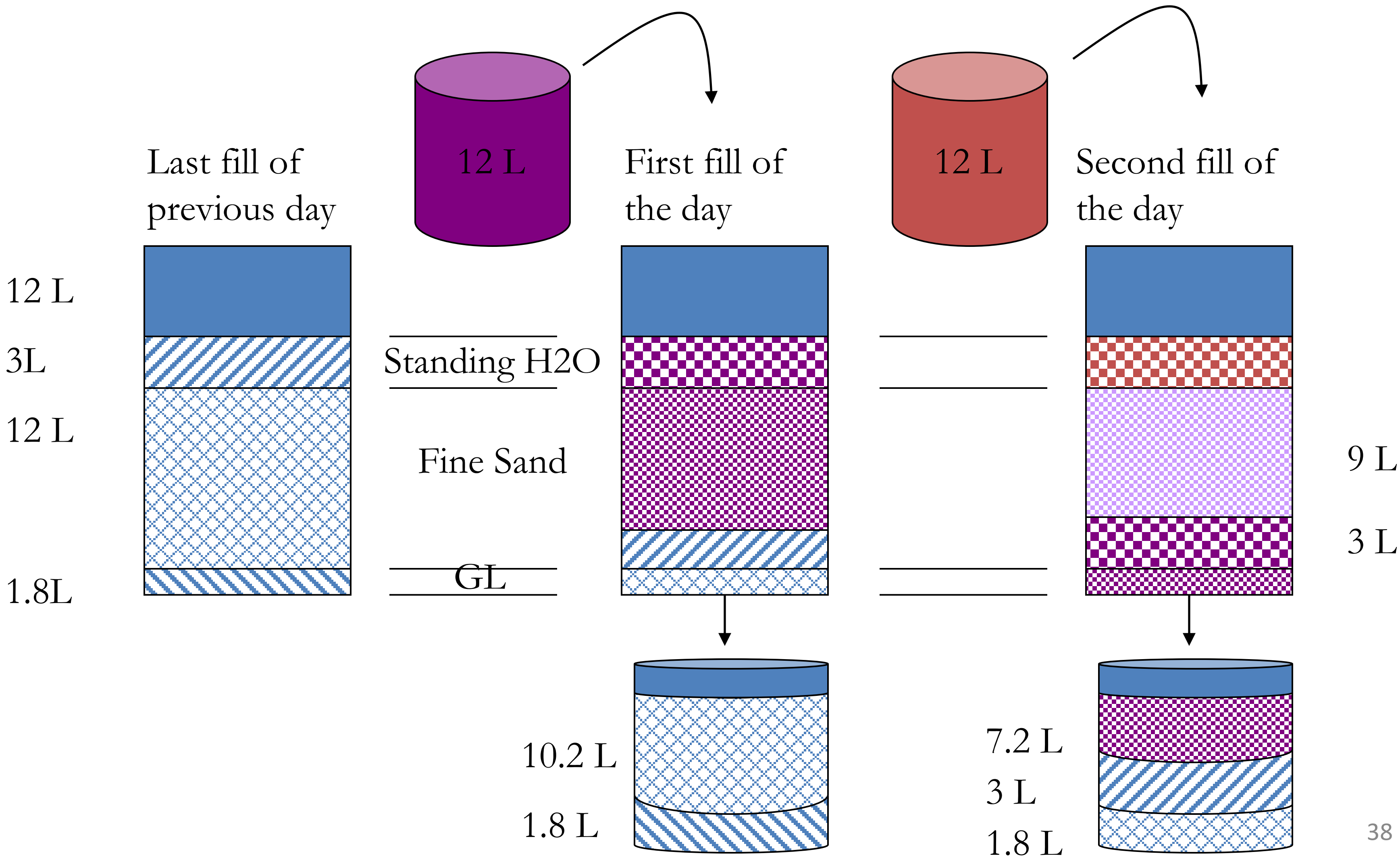
		Diameters (mm)			Areas (m2)		Total (dry) Volume		Porosity	Pore (void) Volume	
	Depth (mm)	Top	Average	Bottom	Top	Average	(m^3)	litres	(%)	(m^3)	litres
Reservoir (Max. fill volume)	57	285	282	278		0.06246	0.00356	3.56	100%	0.003560	3.6
Supernatant (Standing Water)	40	278	276	274		0.05983	0.00239	2.39	100%	0.002393	2.4
Fine Sand (Filter Media)	162	274	264	254	0.059	0.05474	0.00889	8.89	40%	0.003556	3.6
Coarse Sand (Separating Layer)	40	254	252	250		0.04988	0.00200	2.00	33%	0.000658	0.7
Gravel (Underdrain)	40	250	247	245		0.04792	0.00192	1.92	42%	0.000805	0.8
Total Bucket	339	285	265	245		0.05515	0.01872	18.72			11.0

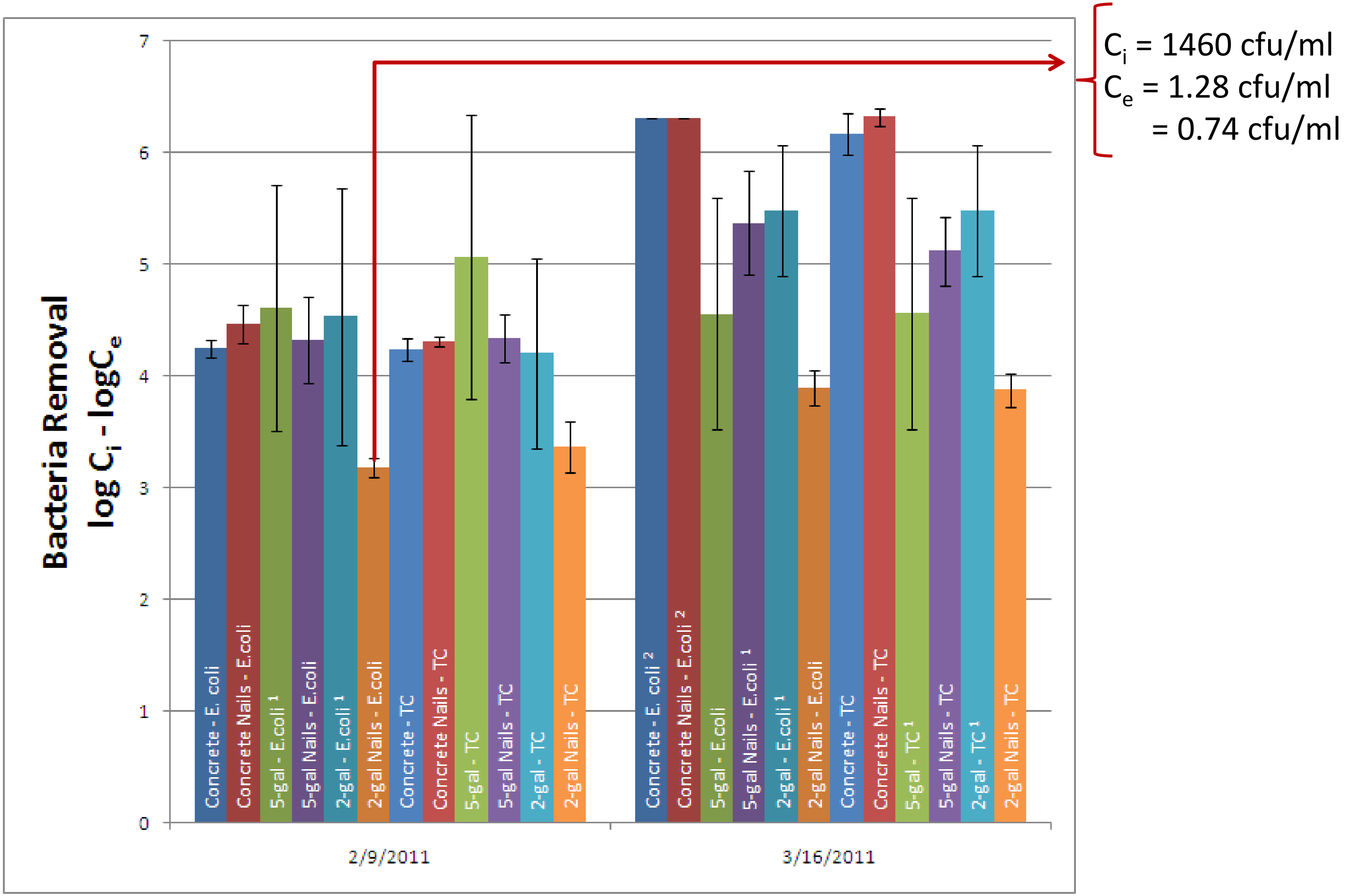
Small Bucket Biosand Filter - Volume Calculations

		Diameters (mm)			Areas (m2)		Total (dry) Volume		Porosity	Pore (void) Volume	
	Depth (mm)	Top	Average	Bottom	Top	Average	(m^3)	litres	(%)	(m^3)	litres
Reservoir (Max. fill volume)	38	230	228	225		0.04065	0.00154	1.54	100%	0.001545	1.5
Supernatant (Standing Water)	30	225	223	222		0.03918	0.00118	1.18	100%	0.001175	1.2
Fine Sand (Filter Media)	104	222	216	210	0.039	0.03659	0.00380	3.80	40%	0.001522	1.5
Coarse Sand (Separating Layer)	30	210	209	207		0.03431	0.00103	1.03	33%	0.00034	0.3
Gravel (Underdrain)	30	207	206	204		0.03333	0.00100	1.00	42%	0.00042	0.4
Total Bucket	232	285	265	245		0.05515	0.01280	12.80			5.0

Sample Collection

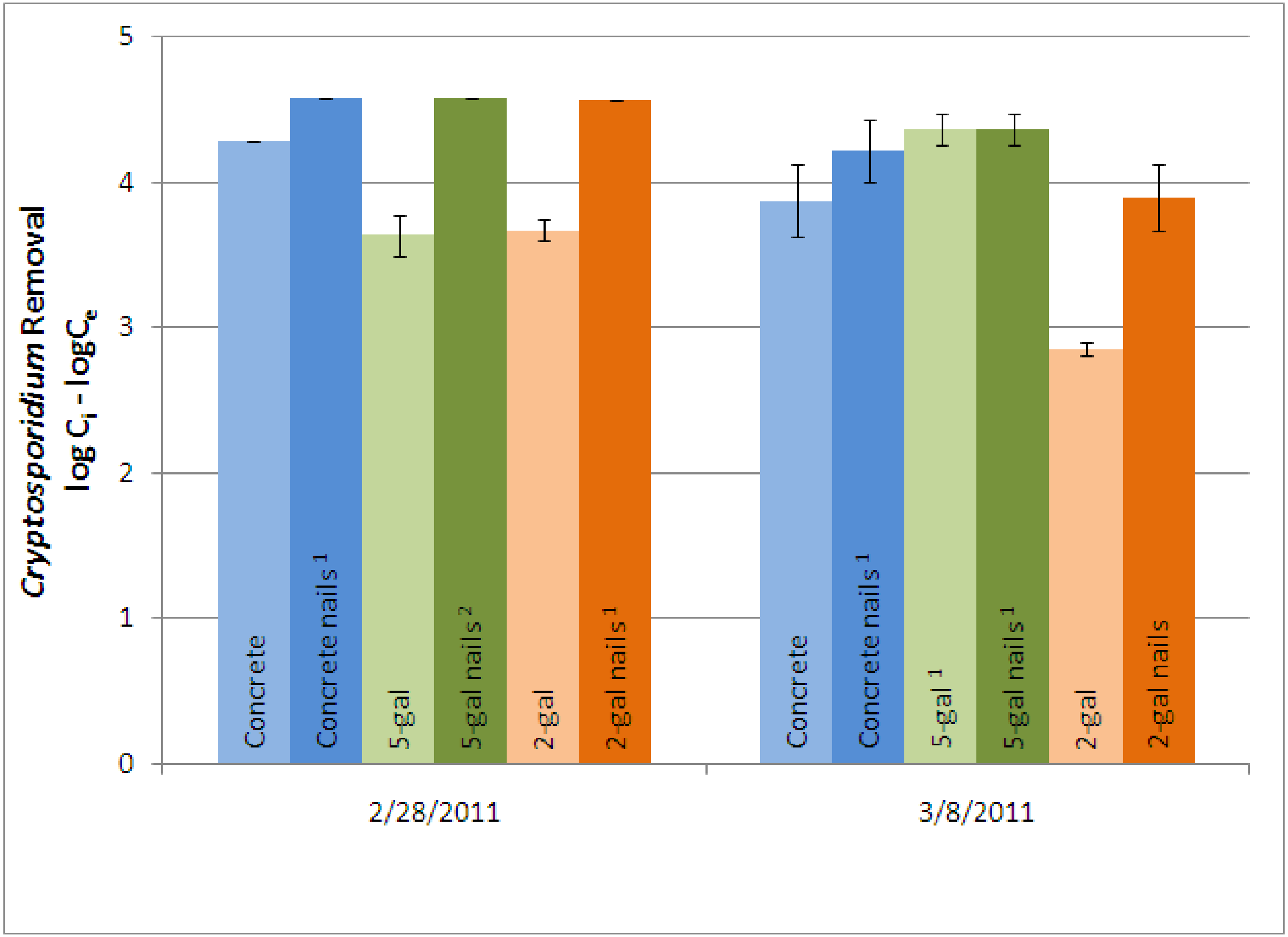
Samples are taken after the second fill to test the water that resided in the filter during the pause period (not overnight).





[1] one sample below detection limit, < 0.001 cfu/L.

[2] both samples below detection limit, < 0.001 cfu/L.



[1] one sample below detection limit, < 1 oocyst/L.

[2] both samples below detection limit, < 1 oocyst/L.

Virus Removal - MS2	
Influent (Ci)	8.E+06 pfu/ml
2-gal (Ce)	3.1 pfu/ml
LogCi - Log Ce	6.4