Subject: **Coldwater Water Flow Data Collection Analysis and Recommendations**

Date: 26 November, 2012

SUMMARY RESULTS

While all methods can result in accurate water flow measurements, the *BUCKET FILL METHOD* offers several advantages which make it the best solution for our purposes:

- *Single-person data collection*
- *Higher precision of data*
    - *Lower compounded data error*
    - *Few mechanical steps – minimal human error*
- *Relatively short observation period*
- *Requires minimal observer training*

Based on the easy functionality of the Bucket Fill Method and the precision of the data extracted from the field trials, it is recommended that MNRRA use the ***BUCKET FILL METHOD***.

PURPOSE

To explain current and prospective water flow data collection techniques, their strengths and weaknesses, and provide recommendations for future collection methodologies based on empirically collected data.

METHODOLOGIES & TECHNIQUES

$$GPM = V_x * F_x \qquad \textit{Formula 1}$$

Where as:

GPM = Gallons per Minute

V_x = Volume of water collected

F_x = Water collection frequency period = $^{60\text{ seconds}}/_{\text{Time period in seconds}}$

3-Second Fill Method

This method involves utilizing a stopwatch and calibrated bucket to collect water over a three second period; mathematically the results can be represented as follows:

$$GPM = V_x * F_x \qquad \textit{Formula 1}$$

$$GPM = V_{3\text{-sec}} * {}^{60}/_{3}$$

$$= V_{3\text{-sec}} * 20 \qquad \textit{Formula 2}$$

This method was conducted three times in sequence and the values were averaged to calculate the gallons per minute observation. The averaging of the data is intended to reduce the amount of error which may occur during data collection. The method is typically accomplished with two personnel – one operating the stopwatch, the other collecting the water.

The precision of this collection method is inherently low due to two variables within the process. The first variable is attempting to collect water for precisely 3 seconds. This is inherently not possible and an error of 0.5 seconds will result in a variation of 10 GPM (0.5*20). The averaging of multiple collections attempts to minimize the error of this variable.

The second variable is the precision of the water volume measured. In order to measure the volume of water multiple buckets are used. A 5 gallon bucket is used for the initial water collection and additional smaller buckets are used for sub-gallon intervals. The volume recorded is dependent on calibration of the buckets and the method of transferring water to each bucket for smaller unit measurements. Errors will occur.

Bucket Fill Method

This method is conducted by placing a bucket of known volume into the water flow and measuring the time period it takes to fill the vessel. The method is conducted 3 times and the results are averaged. Mathematically, Formula 1 is still used but the variable changes from V_x to F_x as follows:

$$GPM = V_x * F_x \qquad \textit{Formula 1}$$

Where as:

GPM = Gallons per Minute

V_x = Volume of water collected

F_x = Water collection frequency period = $^{60 \text{ seconds}}/_{\text{Time period in seconds}}$

For the Bucket Fill Method, the equation is:

$$GPM = V_{5.75\text{ gallons}} * {}^{60}/_{T}$$ *Formula 3*

$$= {}^{5.75*60}/_{T}$$

$$= {}^{345}/_{T}$$

Where as:

$V_{5.75\text{ Gallons}}$ = the calibrated volume of the vessel (5.75 gallons)

T = the timed period it takes to fill the calibrated vessel

One person is capable of conducting this measurement. This actually minimizes errors associated with any time lag in communication (i.e. Ready… Start!). Since the method requires no movement of the vessel, no timing compensation is required to offset reaction times resulting in more precise measurements and lower inherent error. Additionally, since the volume being measured is increased the time period is also increased, resulting in reduced compound errors in calculations.

Digital Water Flow Meter

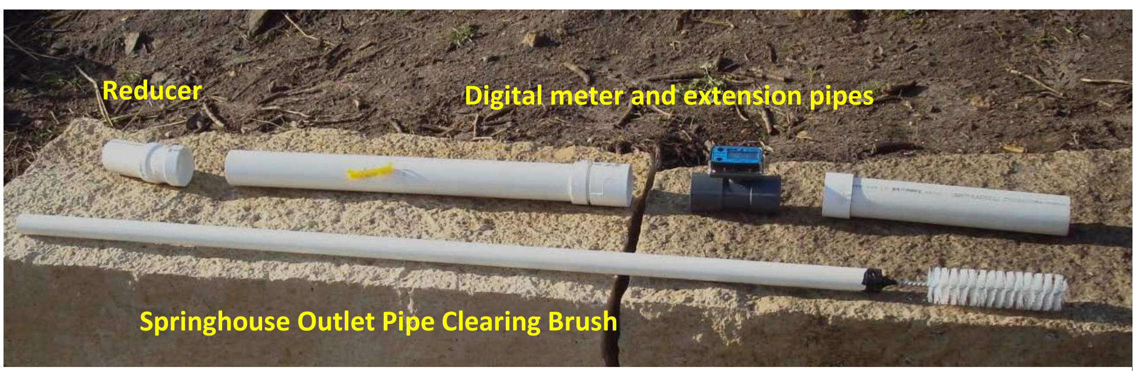

***Figure A* – Digital Water Meter**

This is an example of the water meter assembly torn-down for maintenance and laid out in order of assembly

The TM200 Electronic Water Meter from Great Plains Industries, Inc. was acquired in hopes of making data collection easier, more accurate, and more precise. The meter is modularly installed within a length of pipe as directed by the manufacturer and capable of being removed from the site when not in use; refer to *Figure A.*

Prior to water meter installation, the clearing brush is used to clear algae out of the outlet pipe as algae can have a significant impact of flow reading. The reducer is then installed with the meter/pipe assembly and water allowed to flow. This reducer increases the resistance of water flow and causes the water level to increase slightly within the Springhouse; the water level equalizes after roughly 3 minutes however in practice 5 minutes are allowed to pass before connecting the water meter/pipe assembly. The pipe assembly has alignment marks and levels to provide consistent placement of the assembly.

The meter displays two pieces of data that are useful to data observers. The first is FLOWRATE in Gallons per minute; an instantaneous reading which is most likely based in the meter's impeller RPM. The second is a resettable BATCH value in gallons that indicates the total number of gallons that have passed through the meter since the meter was last reset. After installation, the BATCH value is reset and started synchronously with a stopwatch, readings are recorded at one minute intervals which can provide insight into the validity of the data (increments between time steps should be linear if flow is accurate). After 5 minutes of data the meter is removed; total time for data collection is 10 to 11 minutes.

Data Collection Findings & Recommendations

Appendices A, B, and C contain all the data that was collected and their calculated values. While the Digital Meter was expected to meet the needs of the park, the method has proven difficult in yielding consistent GPM values that are quick, accurate, and precise. It is hypothesized that the modular nature of the meter lends itself to minor variations in the test system which result in meter readings that are amazingly precise within a single measurement collection (5-minute period) but vary significantly across multiple data collection sets. As such, the accurate calibration of the meter for our purposes is also difficult.

Data was collected on 9 November by Alan Robbins-Fenger, Rory Stierler, and Matthew Jorgenson; 14 November by Matthew Jorgenson and Kelsey Hans; and 19 November by Matthew Jorgenson.

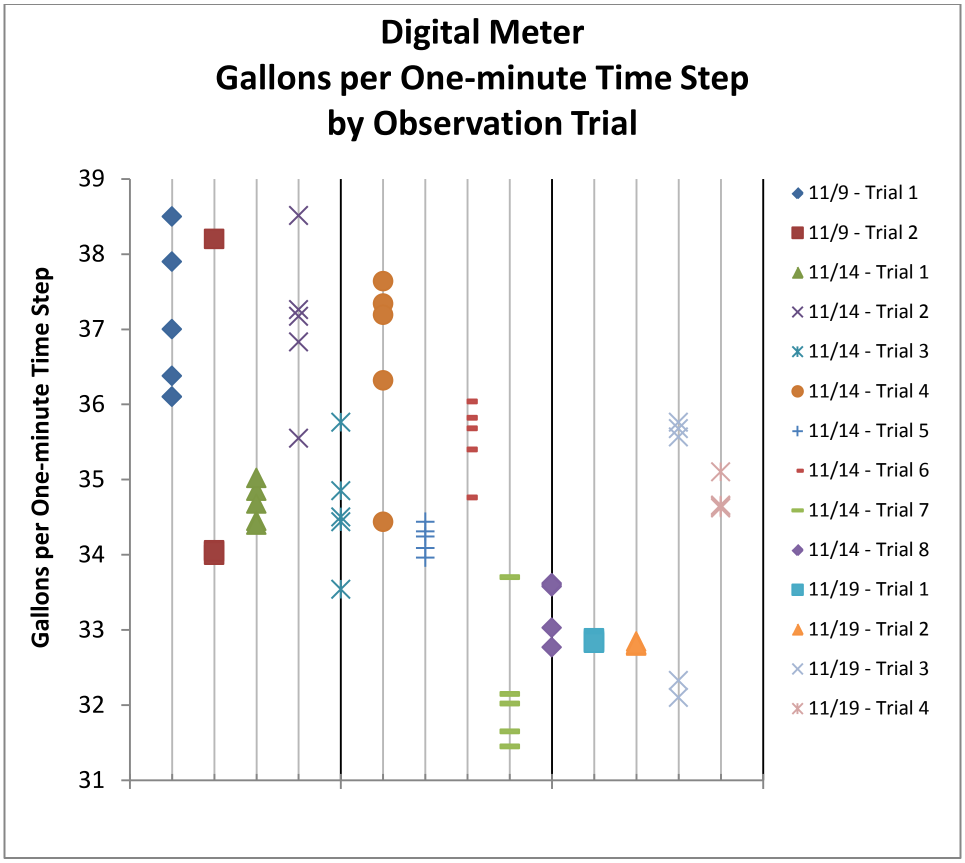

Figure B – Digital Meter Gallons per One Minute Time Step by Observation Trial

These values (97 data points) were calculated by taking the BATCH value at one minute increments and subtracting the previous observations value – essential showing gallon passing through the meter within the last minute. Each trial is then grouped together vertically to show variance across data sets (trials).

Figure B shows all of the calculated gallons per time step values recorded as well as the fluctuations across data sets (trials)

Figure C shows data points collected over the 9th,14th, and 19th of November in calculated GPM for the 3-second Fill, Bucket Fill, and Digital Meter – Gallons/Time Step (an aggregate of the data from Figure B).

The 3-second Fill has 26 data points, the Fill Bucket has 28 data points, and the Digital Meter has 97 data points. Additionally, The Digital Meter and 3-second Fill values were normalized to show relative variation compared to each other and the Bucket Fill method. The Bucket fill method has the narrowest range of data, and these numbers are even closer when looked a single day's recordings – the same cannot be said for the other methods investigated.

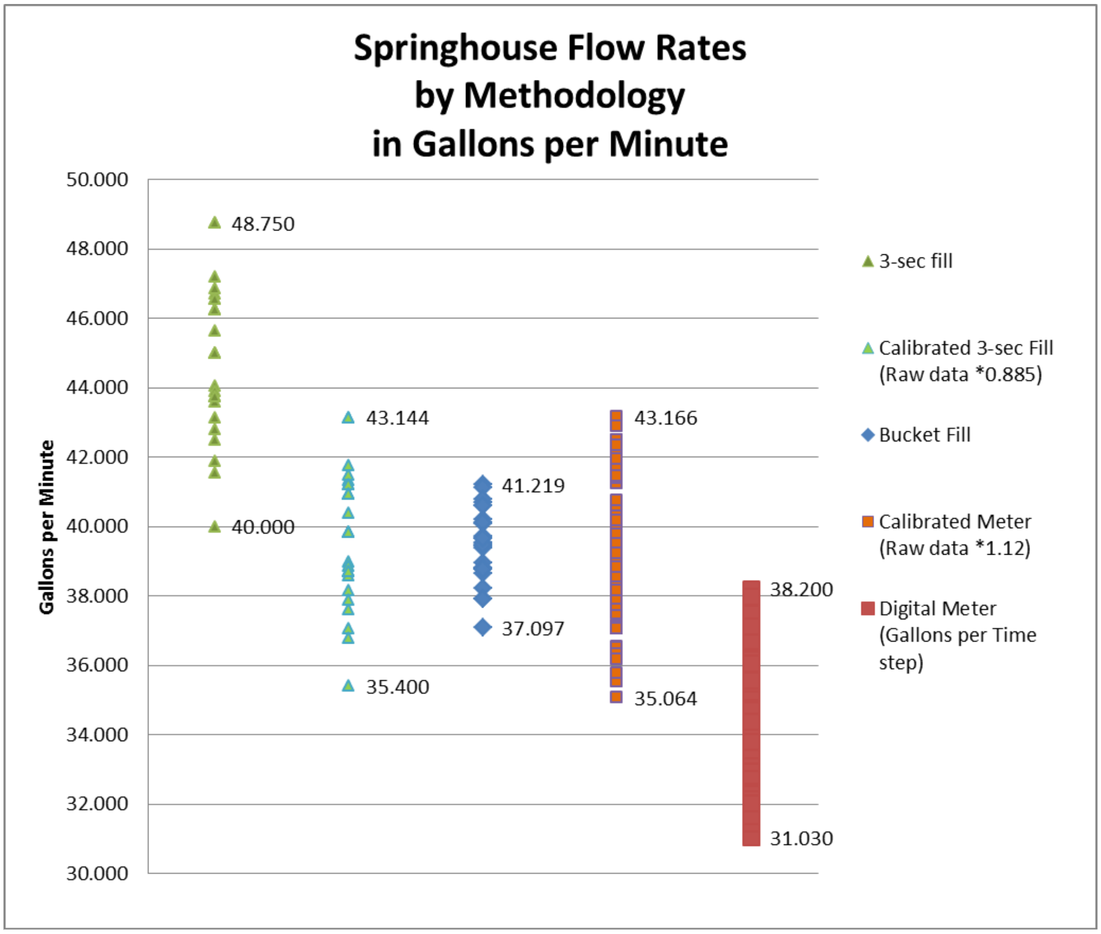

Figure C – Combined Springhouse Flow Rates by Methodology

Displays all data points collected over test period in gallons per minute and grouped by test methodology. Calibrated values are scalar adjustments to aid in visual representation of the relative precision of each method.

Note:* *the 3-second Fill values are higher than all historical MNRRA values because of how the data was measured.* *In order to remove the "eye-balling" variable, a 3-second timer was started when water entered the measurement bucket and the bucket was removed when the timer alarm sounded. This equates to a 0.5 second time lag, based on **Formula 1**, ***assuming that the Fill bucket is the most accurate method, which the data in Appendix C indicates. The lower values for the Digital Meter are believed to be the result of cavitation within the pipe assembly since the pipe is not completely filled with water during operation.***

While all methods can result in accurate water flow measurements, the Bucket FILL Method offers several advantages which make it the best solution for our purposes:

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- *Higher precision of data*
    - *Lower compounded data error*
    - *Few mechanical steps – minimal human error*
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Based on the easy functionality of the Bucket Fill Method and the precision of the data extracted from the field trials, it is recommended that MNRRA use the Bucket Fill METHOD.

Appendix A – Data Collected on 9 November, 2012

reduceer 1			
time	depth	dDepth	Instant GPM
0	2.250	0.000	
1	3.750	1.500	
2	3.875	1.625	
3	4.000	1.750	
4	4.000	1.750	
5	3.875	1.625	
6	3.875	1.625	
7	3.750	1.500	
8	3.688	1.438	
9	3.625	1.375	
10	3.688	1.438	
11	3.750	1.500	35.09
12	3.750	1.500	35.09
13	3.750	1.500	35.22
14	3.750	1.500	35.22
15			
Average			35.155
Std Dev			0.075056
Norm Max			35.23006
Norm Min			35.07994

reducer 2			
time	depth	dDepth	Instant GPM
0	2.250	0.000	
1	3.250	1.000	
2	3.250	1.000	
3	3.375	1.125	
4	3.375	1.125	
5	3.375	1.125	
6	4.125	1.875	34.1
7			
8			
9			
10			
11			
12			
13			
14			
15			
Average			34.1
Std Dev			
Norm Max			
Norm Min			

reducer 3			
time	depth	dDepth	Instant GPM
0			
1	3.000	0.000	
2	3.500	0.500	
3	3.500	0.500	
4	3.500	0.500	
5	3.625	0.625	
6	3.750	0.750	37
7	3.500	0.500	36.87
8	3.500	0.500	36.75
9	3.500	0.500	36.63
10	3.500	0.500	36.5
11	3.500	0.500	36.63
12	3.500	0.500	36.63
13	3.500	0.500	36.63
14			
15			
Average			36.705
Std Dev			0.160713
Norm Max			36.86571
Norm Min			36.54429

combined			
time	depth	dDepth	Instant GPM
0			
1	3.875	0.000	32.3
2	4.000	0.125	33.2
3	4.125	0.250	33.4
4	4.250	0.375	33.7
5	4.125	0.250	33.8
6	4.250	0.375	34.3
7	4.250	0.375	34.36
8	4.250	0.375	34.48
9	4.125	0.250	34.6
10	4.125	0.250	34.6
11	4.125	0.250	34.72
12	4.125	0.250	34.72
13	4.125	0.250	34.85
14	4.125	0.250	34.72
15	4.125	0.250	34.72
Average			34.16467
Std Dev			0.735788
Norm Max			34.90045
Norm Min			33.42888

Reducer +batch 1									
time	depth	dDepth	Instant GPM	Inst ant GP M A	Instant GPM B	Cum. Gallons (G)	G/T-step	G/T	11% CAL @T5
0									
1	3.063	0.000							
2	3.375	0.312							
3	3.375	0.312							
4	3.375	0.312							
5	3.375	0.312							
6	4.125	1.062	33.54	34					
7	4.250	1.187	34	34		31.62		31.62	
8	4.250	1.187	34.1	34		68	36.38	34	
9	4.250	1.187	34.36	34		106.5	38.5	35.5	
10	4.250	1.187	34.36	34		136.5	30	34.125	
11	4.000	0.937	37.6		37.6	172.6	36.1	34.52	38.3172
12	3.875	0.812	37.1		37.1	210.5	37.9	35.08333	38.9425
13	3.750	0.687	36.87		36.87	247.5	37	35.35714	39.246429
14	3.750	0.687	36.7		36.7	283.6	36.1	35.45	39.3495
15									
Average			35.40333	34	37.0675		35.99714	34.45693	
Std Dev			1.614528	0.3	0.391014		2.799534	1.289965	
Norm Max			37.01786	34	37.45851		38.79668	35.7469	
Norm Min			33.78881	34	36.67649		33.19761	33.16697	

Red numbers are possibly due to presenec of filementous algae on impeller blades

Reducer +batch 2						
time	depth	Instant GPM	Cum. Gallo ns (G)	G/T-step	G/T	11% CAL @T5
0						
1						
2						
3						
4						
5						
6		33.85	36		36	
7		34	74.2	38.2	37.1	
8		34	101.3	27.1	33.76667	
9		34	135.3	34	33.825	
10		34	169.4	34.06	33.872	37.59792
11		34	203.4	34.04	33.9	37.629
12						
13						
14						
15						
Average		33.975		33.48	34.74394	
Std Dev		0.061237		3.996974	1.442271	
Norm Max		34.03624		37.47697	36.18622	
Norm Min		33.91376		29.48303	33.30167	

Calibration Measurements			
Trial	Volume	Time	GPM (calc)
1	5.75	8.44	40.876777
2	5.75	8.27	41.71705
3	5.75	8.39	41.120381
Average			41.238069
Stdev			0.4323219

Appendix B – Data Collected on 14 November, 2012

trial 1		10:10 AM			
Time	Depth	dDepth	GPM	Gallons	dGallons
0	1.250	0			
1	2.500	1.25			
2	2.750	1.50			
3	2.875	1.63			
4	2.625	1.38			
5	2.630	1.38			
6	3.125	1.88			
7	3.250	2.00	35.4	34.85	34.85
8	3.500	2.25	34.97	69.87	35.02
9	3.375	2.13	34.48	104.55	34.68
10	3.500	2.25	34.36	139	34.45
11	3.380	2.13	34.48	173.4	34.4
12					
13					
14					
Average			34.738	34.68	34.68

trial 2		10:25			
Time	Depth	dDepth	GPM	Gallons	dGallons
0	1.250	0			
1	2.500	1.250			
2	2.625	1.375			
3	2.750	1.500			
4	3.250	2.000			
5	2.750	1.500			
6					
7					
8					
9				0	
10	3.125	1.875	38.2	35.55	35.55
11	3.000	1.750	37.6	74.06	38.51
12	3.000	1.750	37.36	110.89	36.83
13	2.750	1.500	37.2	148.15	37.26
14	2.750	1.500	37.12	185.32	37.17
Average			37.496	37.064	37.064

trial 5		11:17 AM			
Time	Depth	dDepth	GPM	Gallons	dGallons
0	1.750	0			
1	2.875	1.13			
2	3.250	1.50			
3	3.250	1.50			
4	3.250	1.50			
5	3.125	1.38			
6	3.438	1.69		0	
7	3.250	1.50	34	33.96	33.96
8	3.250	1.50	34.12	68.05	34.09
9	3.250	1.50	34.36	102.29	34.24
10	3.250	1.50	34.36	136.6	34.31
11	3.250	1.50	34.36	171.04	34.44
12					
13					
14					
Average			34.24	34.208	34.208

trial 3		10:45 AM			
Time	Depth	dDepth	GPM	Gallons	dGallons
0	1.250	0			
1	2.500	1.25			
2	2.875	1.63			
3	2.750	1.50			
4	2.500	1.25			
5	2.500	1.25			
6	3.125	1.88			
7	3.250	2.00	34.24	33.02	34.85
8	3.500	2.25	34.6	67.46	34.44
9	3.375	2.13	34.48	101.96	34.5
10	3.500	2.25	34.6	137.72	35.76
11	3.500	2.25	34.72	171.26	33.54
12					
13					
14					
Average			34.528	34.252	34.618

trial 4		11:00 AM			
Time	Depth	dDepth	GPM	Gallons	dGallons
0	1.375	0			
1	2.750	1.38			
2	2.750	1.38			
3	2.750	1.38			
4	2.500	1.13			
5	2.500	1.13			
6	3.125	1.75		0	
7	3.250	1.88	34.72	34.44	34.44
8	3.000	1.63	37.96	70.76	36.32
9	2.750	1.38	37.48	108.4	37.64
10	2.750	1.38	37.12	145.74	37.34
11	2.750	1.38	37.12	182.93	37.19
12					
13					
14					
Average			36.88	36.586	36.586

trial 6		11:32 AM			
Time	Depth	dDepth	GPM	Gallons	dGallons
0	1.625	0			
1	2.625	1.00			
2	2.625	1.00			
3	2.500	0.88			
4	2.500	0.88			
5	2.250	0.63			
6	2.250	0.63		0	
7	2.750	1.13	35.22	36.04	36.04
8	2.750	1.13	35.46	70.8	34.76
9	2.750	1.13	35.8	106.48	35.68
10	2.750	1.13	35.93	142.3	35.82
11	2.750	1.13	36.06	177.7	35.4
12					
13					
14					
Average			35.694	35.54	35.54

trial 7		11:48 AM			
Time	Depth	dDepth	GPM	Gallons	dGallons
0	1.250	0			
1	2.500	1.25			
2	2.500	1.25			
3	2.500	1.25			
4	2.250	1.00			
5	2.250	1.00			
6	2.250	1.00		0	
7	2.500	1.25	31.03	33.7	33.7
8	2.500	1.25	31.45	65.15	31.45
9	2.750	1.50	31.65	96.8	31.65
10	2.750	1.50	32.15	128.95	32.15
11	2.750	1.50	32.02	160.97	32.02
12					
13		PROB. ALGAE ON IMPELLER!!!			
14					
Average			31.66	32.194	32.194

trial 8		11:00 AM			
Time	Depth	dDepth	GPM	Gallons	dGallons
0	1.250	0			
1	2.500	1.25			
2	2.500	1.25			
3	2.500	1.25			
4	2.500	1.25			
5	2.250	1.00			
6					
7	3.250	2.00		0	
8	3.250	2.00	33.18	33.03	33.03
9	3.250	2.00	33.4	65.8	32.77
10	3.375	2.13	35.55	99.38	33.58
11	3.375	2.13	33.55	133	33.62
12	3.375	2.13	33.78	166.6	33.6
13					
14					
Average			33.892	33.32	33.32

Springhouse					
	Bucket Fill			3-sec Fill	
	Time	GPM		G/3 sec	GPM
	8.9	38.76404		2.188	43.75
	9.1	37.91209		2.313	46.25
	9.1	37.91209		2.313	46.25
	8.9	38.76404			
	8.7	39.65517			
Average	8.94	38.5906		2.271	45.4167

Wetland A					
	Bucket Fill			3-sec Fill	
	Time	GPM		G/3 sec	GPM
	16.3	21.16564		1.344	26.875
	16	21.5625		1.305	26.0938
	16.1	21.42857		1.180	23.5938
	15.8	21.83544			
	16	21.5625			
Average	16.04	21.50873		1.276	25.5208

Appendix C – Data Collected on 19 November, 2012

19-Novemeber-2012												
Time Observed	8:12						9:00					
	3 sec. (Gal)	3 sec GPM	Bucket Fill (T)	Bucket Fill (	Meter (Gal)	Gal/T-step	3 sec. (Gal)	3 sec GPM	Bucket Fill (T)	Bucket Fill GPM	Meter (Gal)	Gal/T-step
	2.438	48.750	8.370	41.219	32.889	32.889	2.141	42.813	8.760	39.384	32.844	32.844
	2.336	46.719	9.030	38.206	65.725	32.863	2.188	43.750	8.500	40.588	65.616	32.808
	2.000	40.000	8.890	38.808	98.533	32.844	2.250	45.000	8.600	40.116	98.406	32.802
	2.094	41.875	9.300	37.097	131.341	32.835	2.203	44.063	8.900	38.764	131.159	32.790
	2.188	43.750	8.480	40.684	164.149	32.830	2.250	45.000	8.890	38.808	164.040	32.808
	2.156	43.125	8.860	38.939								
	2.328	46.563	8.610	40.070								
	2.180	43.594	8.890	38.808								
	2.078	41.563	8.390	41.120								
	2.125	42.500	8.580	40.210								
Average	2.192		8.740				2.206		8.730			
GPM	43.844		39.474		32.830	32.852	44.125		39.519		32.808	32.810
	11:00						14:00					
	3 sec. (Gal)	3 sec GPM	Bucket Fill (T)	Bucket Fill (	Meter (Gal)	Gal/T-step	3 sec. (Gal)	3 sec GPM	Bucket Fill (T)	Bucket Fill GPM	Meter (Gal)	Gal/T-step
	2.313	46.250	8.690	39.701	32.100	32.100	2.281	45.625	8.700	39.655	35.100	35.100
	2.250	45.000	8.460	40.780	64.650	32.325	2.344	46.875	8.930	38.634	69.290	34.645
	2.438	48.750	8.730	39.519	106.700	35.567	2.328	46.563	8.500	40.588	103.860	34.620
					142.700	35.675	2.359	47.188	8.750	39.429	138.550	34.638
					178.800	35.760	2.195	43.906	8.740	39.474	173.300	34.660
Average	2.333		8.627				2.302		8.724			
GPM	46.667		39.992		35.760	34.285	46.031		39.546		34.660	34.733