UNIVERSITY OF MINNESOTA
ST. ANTHONY FALLS LABORATORY
Engineering, Environmental and Geophysical Fluid Dynamics

PROJECT REPORT 467

Testing an Underdrain System under Backwash Flow Conditions for the Chaparral Water Treatment Plant

By

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Prepared for
Johnsons Screens

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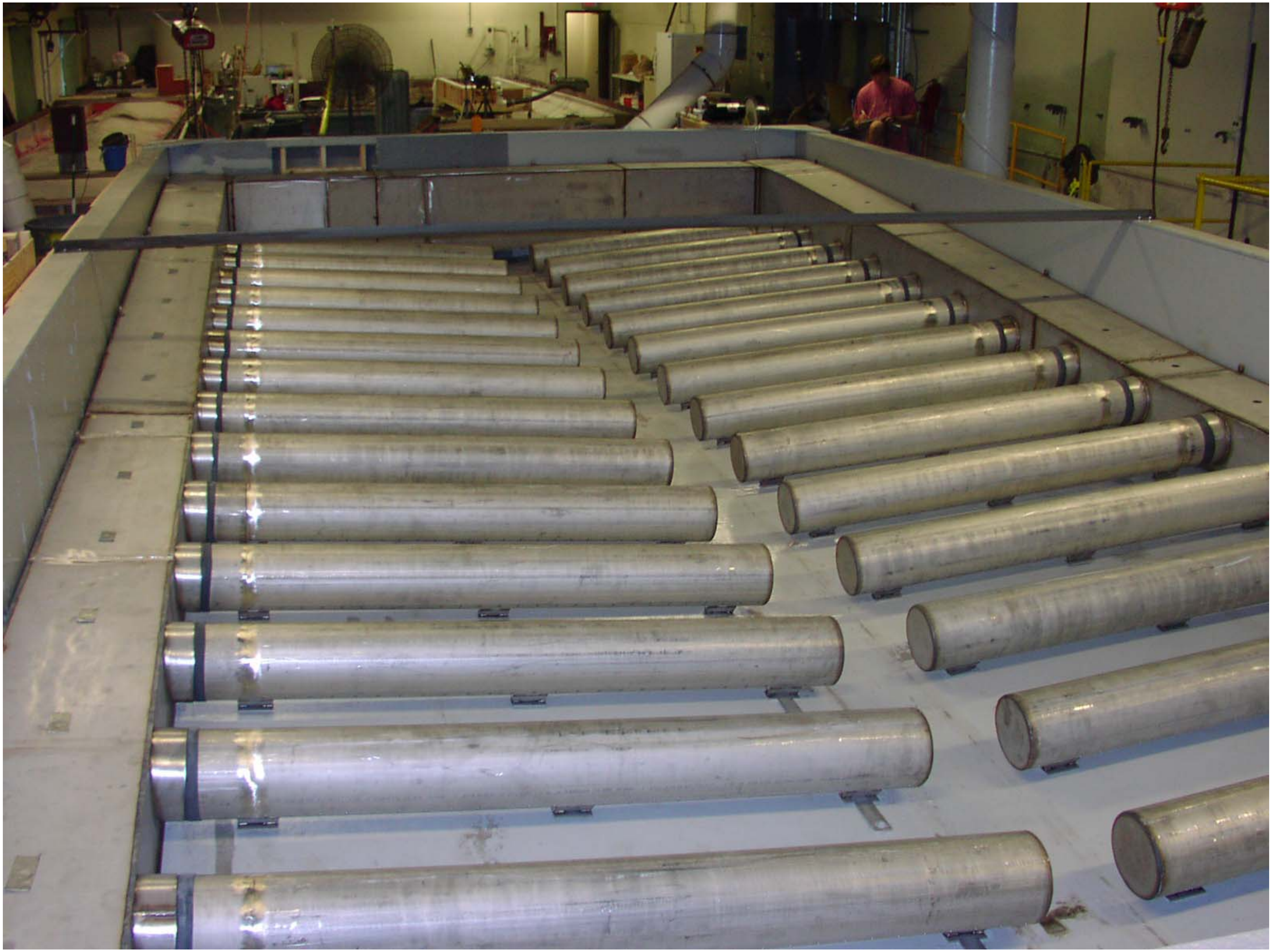

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Abstract

Johnsons Screens was required to test its underdrain system under backwash flow conditions to assess the uniformity of flow discharge throughout the manifold system. To test the system, a basin was built in St. Anthony Falls Laboratory and the underdrain system components were provided and installed by Johnsons Screens. To assess the uniformity of flow of the manifold system, a measurement technique was developed to determine the flow at a number of locations at design flows. The technique was a flow-capturing apparatus with an open-topped tank, two tubes, a hose and a pump. Using this apparatus, the flow was captured over a period of time and weighed to determine the flow rate from each triplet of orifices. The system error under high system flow rate (about 19 cfs) was less than 0.7%.

Six locations were determined by Johnsons Screens for the testing. At each location, a total of five measurements were taken and averaged under the high system flow rate (about 19 cfs) and an additional five measurements for the low system flow rate (about 4.4 cfs). The results of the measurements showed that the deviation of the flow measurements from the mean were within ±5% under high system flows and ±7% under low system flows.

Acknowledgements

The work reported herein was funded by Johnsons Screens, and Mr. Thomas Steinke from Johnsons Screen was the project officer. We would like to thank Mike Plante, Ben Erickson, Luke Carlson and Matthew Leuker of St. Anthony Falls Laboratory for their contribution to the model construction, video documentation and data collection.

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1. Introduction

Johnsons Screens was required to test its underdrain system, to be built for the City of Scottsdale, AZ, under backwash flow conditions to assess the uniformity of flow discharge throughout the manifold system. Uniform flow distribution is required for efficient and effective operation and backwash. It was expected that localized excess flow under any specified flow condition would not exceed ±5 of average flow per square foot of filter area. The system was to be tested under two different flow conditions, the maximum flow being 8700 gpm (19.4 cfs).

The underdrain system consists of a front manifold, two prismatic headers running down on each side of the basin, and thirty (30) 8-inch laterals (Figure 1). The headers cross-sectional areas vary along their lengths. During backwash, water enters the system through a 24-inch pipe, and is distributed between the two headers through a manifold header pipe.

The scope of this study was to build a basin with the same geometry as the underdrain system basin, to develop a flow velocity measurement technique with about 2% accuracy, and then to conduct full scale testing of the Johnsons Screens underdrain system. Testing would consist of operating the system at the design flows and measuring local discharge of the manifold system at a number of locations to assess discharge uniformity throughout the system.

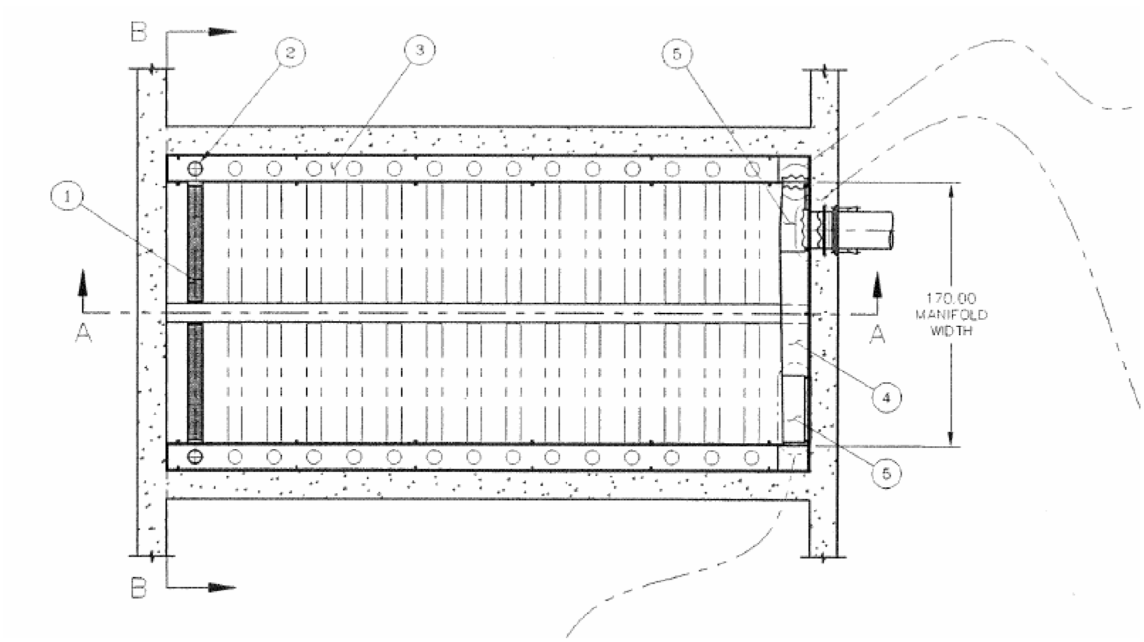

Figure 1. Plan view of the underdrain system.

2. Full Scale Facility Set-up

The facility included a basin, a sharp-crested weir at the downstream end of the basin, and the plumbing required to supply approximately 19 cfs. The basin was rectangular (17′×34′) with a 6.25% sloped floor built into the basin from the headers towards the middle of the basin, creating a 6-inch elevation difference between the wall base and the middle of the basin (Figure 2). The basin walls were 36 inches high, providing a total water depth of 39 inches in the middle of the basin and 3 inches of free board. The basin was constructed from lumber and plywood and was painted and sealed. All components of the underdrain system were provided and installed by Johnsons Screens (Figure 3). All plumbing outside of the basin, including the 24-inch inlet pipe and the drain system downstream of the weir, were done by SAFL and was designed to provide about 19 cfs flow through the system under backwash conditions.

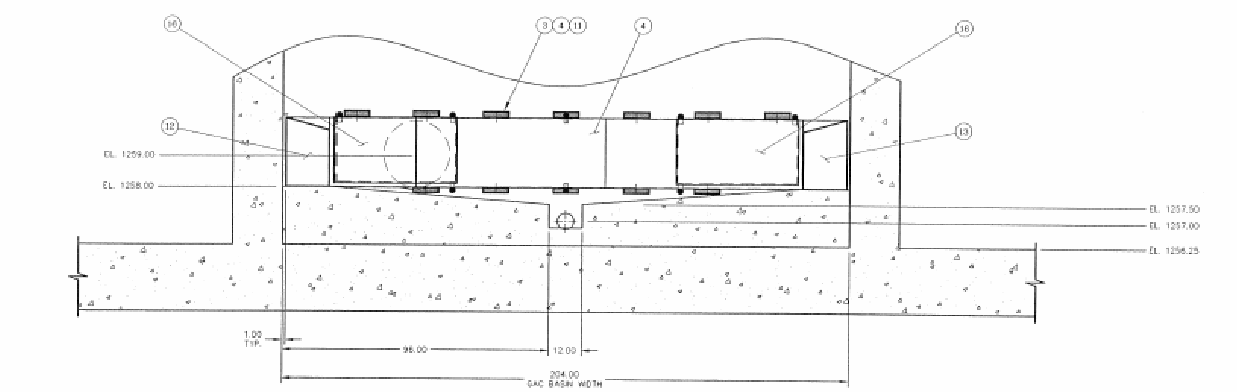

Figure 2. The basin cross-section provided by Johnsons Screens.

A sharp crested weir, with a maximum height of 36 inches was installed at the downstream end of the basin for system flow measurement. The flow was controlled using valves upstream of the inlet pipe.

Figure 3. The basin with Johnson Screens underdrain system installed.

2.1. Weir Calibration

To determine the total system flow through the basin, the sharp-crested weir was equipped with a wet well and a point gage having an accuracy of 0.001 feet. Initially, the wet well was connected to a pressure tap located 2 feet upstream of the weir in the basin floor. Due to the presence of local currents generated by nearby lateral discharge jets, pressures measured by this tap proved unstable and variable. Consequently, the location of this pressure tap was moved to an elevation somewhat below the elevation of the weir crest and oriented orthogonally to the flow direction as shown in Figure 4.

The weir was calibrated by routing the flow through the SAFL weighing tank facility. The SAFL weighing tanks were used to measure basin discharge with an accuracy of 0.2%. Under several flow conditions, discharge was measured using the weighing tanks, and the weir head (H in Figure 4) was measured using the wet well. Measured discharges were plotted versus heads and a power function was fitted to the data (Figure 5). The fitted function is slightly different from the classical sharp-crested weir equation due to flow contraction near the weir crest and the location of the wet well.

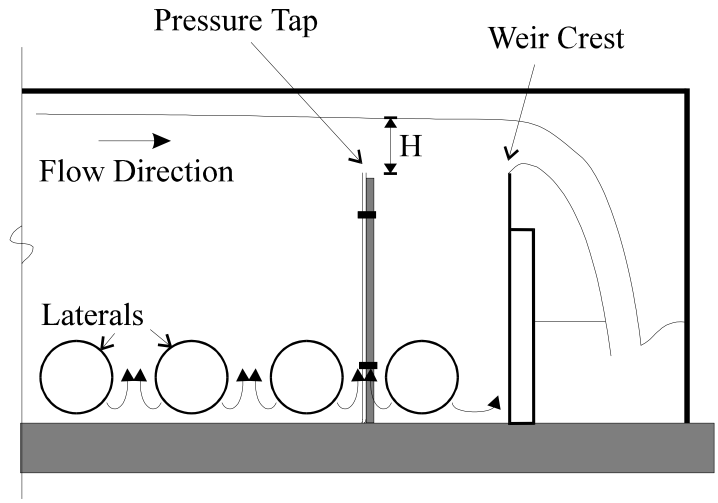

Figure 4. Schematic of the sharp-crested weir at the downstream end of the basin and the location of the pressure tap for measuring the static head upstream of the weir.

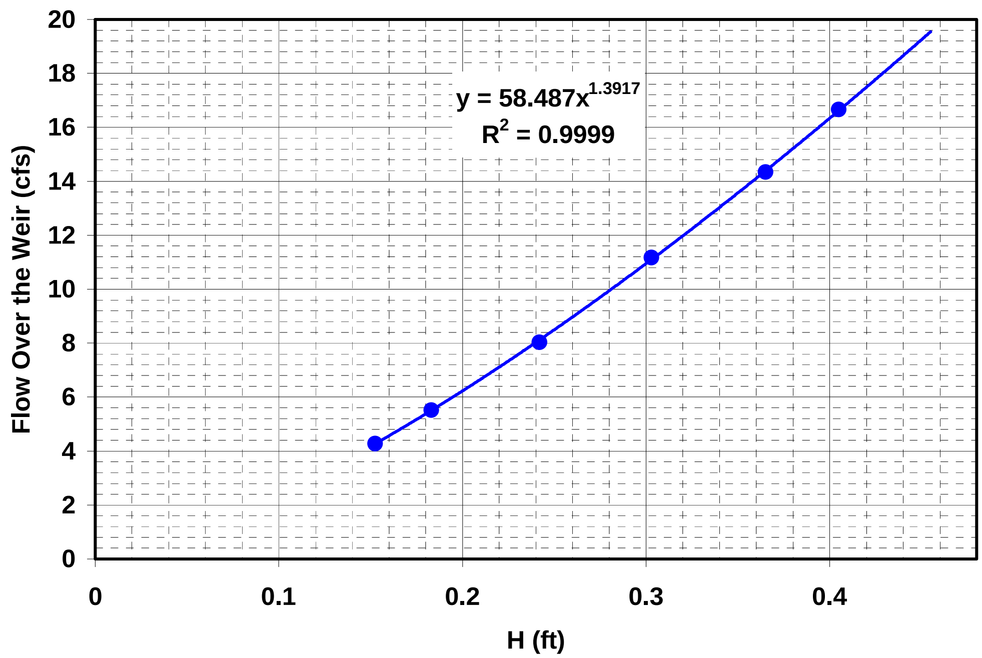

Figure 5. The discharge-head relationship of the sharp-crested weir

3. Instrumentation

The purpose of the test program was to assess the uniformity of the manifold system discharge. To do this, a measurement technique was needed that could determine local manifold discharge at a number of locations at design flows. There are 28 triplets of orifices on each lateral. At each triplet location, i.e. cross-section, one orifice was located on the bottom of the pipe and the other two were offset 45^{o} to either side (Figure 6). Two methods were proposed to measure the flow rate: (1) using a Sontek Acoustic Doppler Velocimeter (ADV) to measure the velocity of the jet leaving each orifice, and (2) capturing the flow out of each triplet of orifices and weighing it over a period of time to arrive at flowrate.

Due to logistics of making precise velocity measurements outside of the orifices, the possible use of this method was abandoned in favor of the discharge capture concept. The flow-capturing apparatus was comprised of an open-topped tank, two ¼" tubes, and a 1" flexible hose. The tank was made of Plexiglas with a width and length of 2.56"and 23", respectively, and could be split along the vertical centerline to allow repositioning along any lateral in the system.

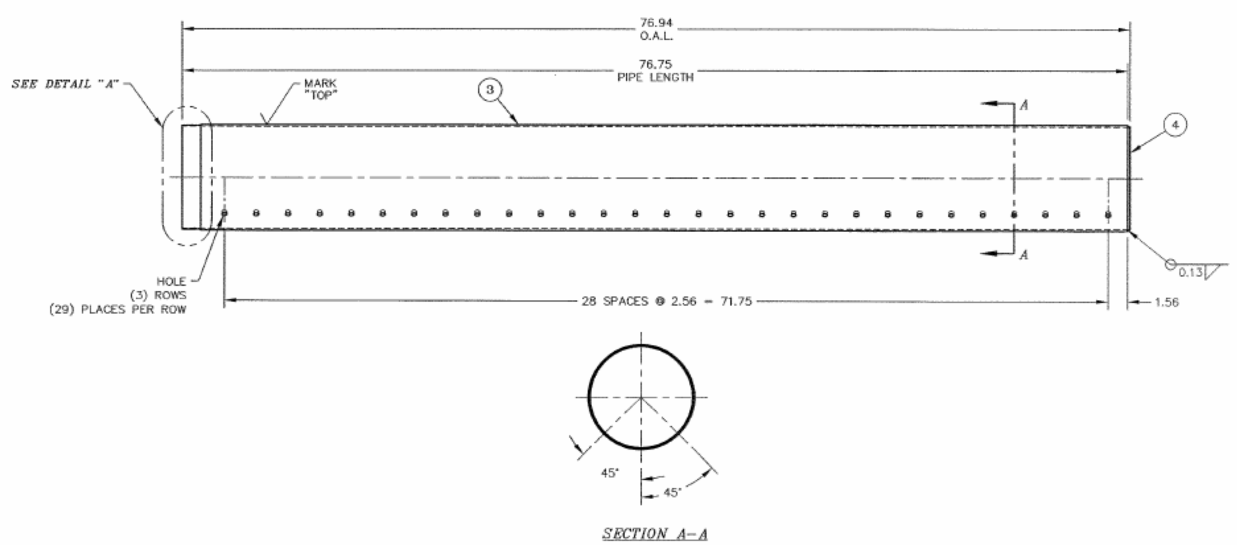

Figure 6. The positions of the orifices along and across the laterals.

The dimensions of the capturing tank were determined so as to take advantage of lines of symmetry in the manifold system. Thus, the width of the tank was equal to the distance between two adjacent triplets of orifices and the length of the tank was equal to the distance between the center points of two adjacent laterals. One of the ¼” tubes was connected to a pressure tap outside of the tank to provide the local basin water surface elevation (depth). The other ¼” tube was connected to a pressure tap to provide the water surface elevation (depth) inside the tank. The 1” hose was connected to a throttling valve and a pump and was used to extract water from the tank via a withdrawal manifold (Figure 7).

The two ¼” tubes were connected to a graduated manometer and would provide the water surface difference inside and outside of the tank. With the pump on, water was withdrawn from the tank, with the rate controlled by the valve. When the valve was adjusted such that the water surfaces inside and outside of the tank were the same and steady over time, the flow through the pump was equal to the orifice triplet discharge that would occur in the absence of the tank, i.e. in the normal operating condition.

The water discharged by the pump was collected in a thirty gallon container located outside of the basin and sitting on a scale. Filling of this container was initiated with the starting of a stopwatch and terminated after a precise time interval had elapsed. The accumulated weight and filling interval was then used to determine the discharge of the orifice triplet under test. For the high flow test, about 140 lbs of water was collected over 150 seconds. The system error is estimated from the following equation

$$dQ = dW \left| \frac{\partial Q}{\partial W} \right| + dt \left| \frac{\partial Q}{\partial t} \right|$$

where Q is discharge, W is the weight of water collected in the bucket, t is the time period for water to be collected in the bucket, dW is the error in measuring weight, dt is the error in measuring time, and dQ is the system error in measuring discharge. With 0.5 lbs error in measuring weight, and 0.5 seconds in measuring time, the error in flow rate becomes less than 0.7%. Measurement uncertainty was further reduced by averaging the results of 5 tests for each test point. The testing set-up is shown in Figure 8.

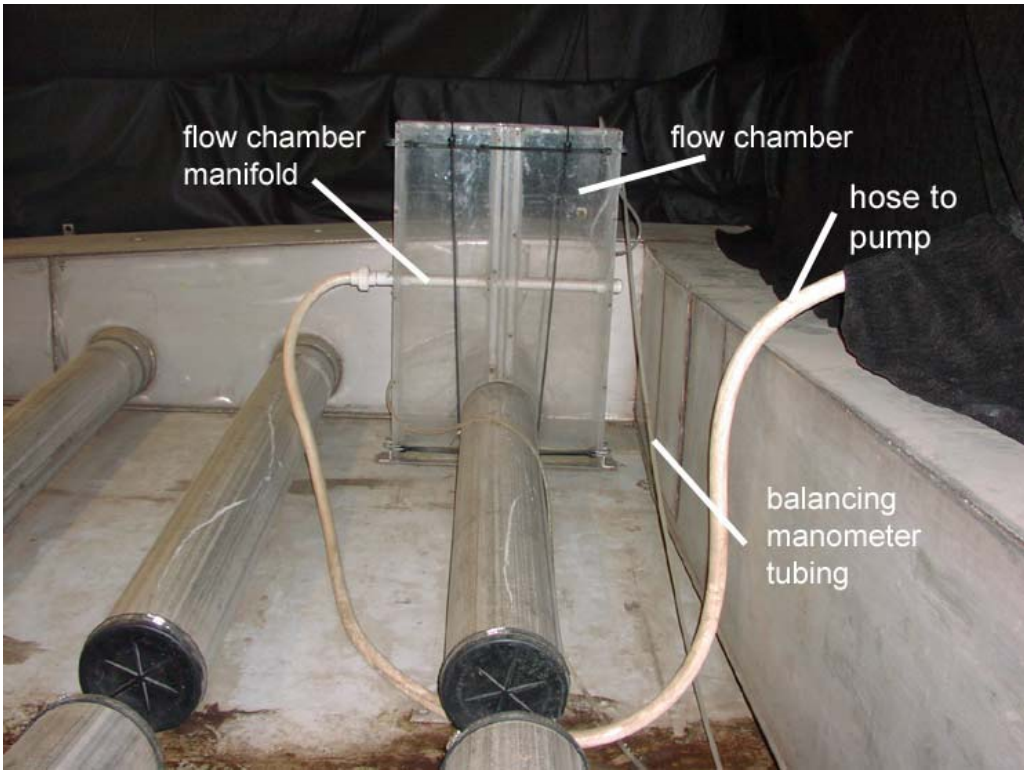

Figure 7. The flow capturing tank which was used to measure the flow rate through each row of orifices.

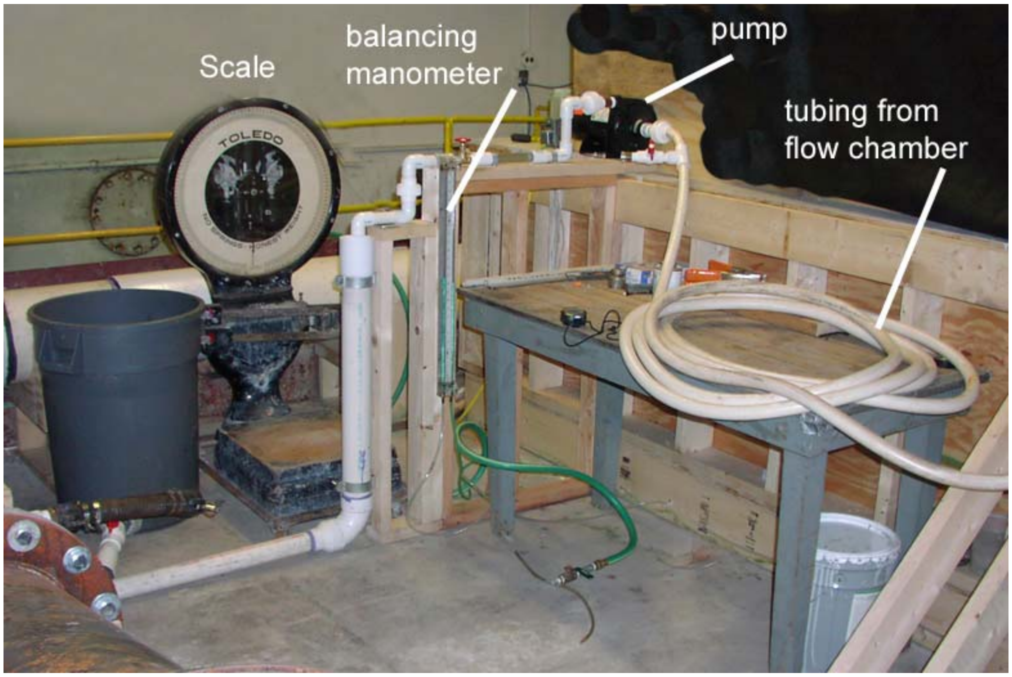

Figure 8. The test set-up for measuring flow rate

4. Test Results

The tests were initially done in autumn during an exceptionally long falling leaves season in Minneapolis. Since all tests were done using essentially unscreened Mississippi River water, a significant problem was caused by organic debris plugging the orifices and impacting the test results. Therefore, testing was postponed until the debris in the Mississippi River water decreased significantly.

4.1. Initial Tests

Per the request of Johnsons Screens, six locations were used to conduct flow measurement testing. The locations are shown in Appendix A (Figure A.1). At each location flow measurements were conducted for two system flow rates: 18.4 cfs and 4.4 cfs. Each measurement was repeated 5 times and the results averaged to reduce measurement uncertainty. Tables 1 and 2 give the results for high and low flow conditions. In addition to the original 60 tests, several tests were repeated to verify the repeatability of the test set-up. Therefore, five more tests were conducted under high flow conditions at point 1 (TP1), designated by TP1-2 in Table 1, and five more tests were conducted under low flow conditions at point 2 (TP2), designated by TP2-2 in Table 2.

Since the system flow varied somewhat from one test to another, a column was added to the tables to display the orifice triplet discharge adjusted for the system flow for that run in comparison to mean system flow. The adjusted flow was calculated as follows

$$Q = Q_m \frac{Q_s}{\overline{Q_s}}$$

Where Q is the adjusted flow, Q_m is the measured flow, Q_s is the system flow for that test, and $\overline{Q_s}$ is the average system flow.

Under high flow conditions, the standard deviation of each set of data collected at a point, i.e. of five tests at one test point, is less than 0.3% of the average of the set. In the last row of each set of tests for a given location, the average flow measured for that set was compared with the average flow of all tests. Under high flow conditions in the system, all measured flows are within ±5% of the average flow. The maximum deviation is 4.8%.

Under low flow conditions, the standard deviation of each set of data collected at a point is less than 1.5% of the average of the set. In addition, all measured flows are within ±7.1% of the average flow. This indicates that under low flow conditions there is more variability in the system.

Table 1 also gives the pressure difference in inches of water between the downstream point of the 24-inch inlet pipe and the basin. The average pressure differential was recorded to be 24.77 inches of water.

4.2. Final Tests

On October 27, 2005, a series of tests were conducted for TP6 in the presence of the Johnsons Screens representatives. After thorough inspection of the system, it became clear that flow was less than previous measurements due to clogging of one of the orifices at point TP6. The tests were repeated on November 22 under both high and low flow conditions. The test results are summarized in Table 3. The standard deviation of each set of data collected at TP6 is less than 0.5% of the average of the set. All measured flows were less than ±5% of the average flow. Figures 9 and 10 show the magnitude of flow measurements under high and low system flows, respectively. Figures 11 and 12 show the deviation from the mean of the flow measurements under high and low system flows, respectively.

The test results show that under high system flow conditions, flow through orifices varies less than ±5% when the underdrain system is in backwash mode. Under low system flow conditions, flow through orifices varies less than ±7%.

Table 1. Flow measurement data collected under high system flow conditions

Date	Location	Water Temperature	System Pressure Differential	Stilling Well	Net Weight	Measured Time	System Flow	System Flow	Lateral Flow	Lateral Flow Adjusted
		(^oF)	(in H_2O)	(ft)	(lbs)	(min.)	(CFS)	(gpm)	(gpm)	(gpm)
				0.7385	155.25	2.50	18.39	8255	7.44	7.45
				0.738	155.25	2.50	18.36	8242	7.44	7.44
				0.7375	155.75	2.50	18.33	8229	7.47	7.45
				0.738	155.25	2.50	18.36	8242	7.44	7.44
10/7/2004	TP1	60	23.75	0.738	155.75	2.50	18.36	8242	7.47	7.47
							Average	8242	7.45	7.45
							St. Dev.	9.323	0.013	0.010
							St.Dev./Avg.	0.1%	0.2%	0.1%
							Dev. From Avg		2.8%	2.7%
				0.738	155	2.50	18.36	8242	7.43	7.43
				0.738	155	2.50	18.36	8242	7.43	7.43
				0.7385	155.5	2.50	18.39	8255	7.46	7.47
				0.739	155	2.50	18.42	8268	7.43	7.45
10/7/2004	TP1-2	60	24.38	0.739	155.25	2.50	18.42	8268	7.44	7.47
							Average	8255	7.44	7.45
							St. Dev.	13.190	0.011	0.018
							St.Dev./Avg.	0.2%	0.1%	0.2%
							Dev. From Avg		2.6%	2.7%
				0.738	151.25	2.50	18.36	8242	7.25	7.25
				0.7375	151.25	2.50	18.33	8229	7.25	7.24
				0.7375	151.25	2.50	18.33	8229	7.25	7.24
				0.738	151.25	2.50	18.36	8242	7.25	7.25
10/11/2004	TP2	59	24.75	0.738	151	2.50	18.36	8242	7.24	7.24
							Average	8237	7.25	7.24
							St. Dev.	7.220	0.005	0.006
							St.Dev./Avg.	0.1%	0.1%	0.1%
							Dev. From Avg		0.0%	-0.1%
				0.738	158.75	2.50	18.36	8242	7.61	7.61
				0.7375	158.5	2.50	18.33	8229	7.60	7.59
				0.7375	158.75	2.50	18.33	8229	7.61	7.60
				0.738	158.25	2.50	18.36	8242	7.59	7.59
10/12/2004	TP3	58	25.5	0.738	158.5	2.50	18.36	8242	7.60	7.60
							Average	8237	7.60	7.60
							St. Dev.	7.220	0.010	0.010
							St.Dev./Avg.	0.1%	0.1%	0.1%
							Dev. From Avg		4.8%	4.7%
				0.738	150.75	2.50	18.36	8242	7.23	7.23
				0.7385	151.5	2.50	18.39	8255	7.26	7.27
				0.739	151	2.50	18.42	8268	7.24	7.26
				0.7385	150.5	2.50	18.39	8255	7.22	7.23
10/13/2004	TP4	58	25.25	0.738	151	2.50	18.36	8242	7.24	7.24
							Average	8252	7.24	7.24
							St. Dev.	11.035	0.018	0.022
							St.Dev./Avg.	0.1%	0.2%	0.3%
							Dev. From Avg		-0.2%	-0.1%
				0.7385	153	2.50	18.39	8255	7.34	7.35
				0.7385	153.5	2.50	18.39	8255	7.36	7.37
				0.738	153	2.50	18.36	8242	7.34	7.33
				0.738	153	2.50	18.36	8242	7.34	7.33
10/14/2004	TP5	58	25.00	0.738	153	2.50	18.36	8242	7.34	7.33
							Average	8247	7.34	7.34
							St. Dev.	7.223	0.011	0.016
							St.Dev./Avg.	0.1%	0.1%	0.2%
							Dev. From Avg		1.2%	1.2%
				0.7385	145.75	2.50	18.39	8255	6.99	7.00
				0.7385	145.75	2.50	18.39	8255	6.99	7.00
				0.738	145.75	2.50	18.36	8242	6.99	6.99
				0.738	145.5	2.50	18.36	8242	6.98	6.97
10/15/2004	TP6	56	24.75	0.7385	145.75	2.50	18.39	8255	6.99	7.00
							Average	8250	6.99	6.99
							St. Dev.	7.223	0.005	0.010
							St.Dev./Avg.	0.1%	0.1%	0.1%
							Dev. From Avg		-3.7%	-3.6%

Table 2. Flow measurement data collected under low system flow conditions

Date	Location	Water Temperature	Stilling Well	Net Weight	Measured Time	System Flow	System Flow	Lateral Flow	Lateral Flow Adjusted
		(^oF)	(ft)	(lbs)	(min.)	(CFS)	(gpm)	(gpm)	(gpm)
10/7/2004	TP1	60	0.458	44.25	3.00	4.37	1960	1.77	1.77
			0.458	44.5	3.00	4.37	1960	1.78	1.78
			0.458	44.75	3.00	4.37	1960	1.79	1.79
			0.458	44.5	3.00	4.37	1960	1.78	1.78
			0.458	44.25	3.00	4.37	1960	1.77	1.77
						Average	1960	1.78	1.78
						St. Dev.	0.000	0.008	0.008
						St.Dev./Avg.	0.0%	0.5%	0.5%
						Dev. From Avg		5.5%	5.6%
10/11/2004	TP2	59	0.458	40.25	3.00	4.37	1960	1.61	1.61
			0.458	39.75	3.00	4.37	1960	1.59	1.59
			0.458	41	3.00	4.37	1960	1.64	1.64
			0.458	40.5	3.00	4.37	1960	1.62	1.62
			0.458	40.75	3.00	4.37	1960	1.63	1.63
						Average	1960	1.62	1.62
						St. Dev.	0.000	0.019	0.019
						St.Dev./Avg.	0.0%	1.2%	1.2%
						Dev. From Avg		-4.0%	-3.9%
10/11/2004	TP2-2	59	0.458	40.75	3.00	4.37	1960	1.63	1.63
			0.458	41.25	3.00	4.37	1960	1.65	1.65
			0.458	41	3.00	4.37	1960	1.64	1.64
			0.458	40.25	3.00	4.37	1960	1.61	1.61
			0.458	40.5	3.00	4.37	1960	1.62	1.62
						Average	1960	1.63	1.63
						St. Dev.	0.000	0.016	0.016
						St.Dev./Avg.	0.0%	1.0%	1.0%
						Dev. From Avg		-3.3%	-3.2%
10/12/2004	TP3	58	0.457	44	3.0	4.33	1943	1.76	1.75
			0.457	45.5	3.0	4.33	1943	1.82	1.80
			0.457	44.75	3.0	4.33	1943	1.79	1.77
			0.457	44.25	3.0	4.33	1943	1.77	1.76
			0.457	44.25	3.0	4.33	1943	1.77	1.76
						Average	1943	1.78	1.77
						St. Dev.	0.000	0.024	0.024
						St.Dev./Avg.	0.0%	1.3%	1.3%
						Dev. From Avg		5.7%	4.9%
10/13/2004	TP4	58	0.458	41	3.0	4.37	1960	1.64	1.64
			0.4575	41.75	3.0	4.35	1952	1.67	1.66
			0.4575	42	3.0	4.35	1952	1.68	1.67
			0.458	41.75	3.0	4.37	1960	1.67	1.67
			0.458	42	3.0	4.37	1960	1.68	1.68
						Average	1957	1.67	1.67
						St. Dev.	4.817	0.016	0.015
						St.Dev./Avg.	0.2%	1.0%	0.9%
						Dev. From Avg		-1.0%	-1.1%
10/14/2004	TP5	58	0.458	41.5	3.00	4.37	1960	1.66	1.66
			0.458	41.5	3.00	4.37	1960	1.66	1.66
			0.458	42	3.00	4.37	1960	1.68	1.68
			0.458	42	3.00	4.37	1960	1.68	1.68
			0.458	42.25	3.00	4.37	1960	1.69	1.69
						Average	1960	1.67	1.67
						St. Dev.	0.000	0.013	0.013
						St.Dev./Avg.	0.0%	0.8%	0.8%
						Dev. From Avg		-0.7%	-0.5%
10/15/2004	TP6	56	0.458	38.5	3.00	4.37	1960	1.54	1.54
			0.458	39.75	3.00	4.37	1960	1.59	1.59
			0.458	39.5	3.00	4.37	1960	1.58	1.58
			0.458	38.5	3.00	4.37	1960	1.54	1.54
			0.458	39.5	3.00	4.37	1960	1.58	1.58
						Average	1960	1.56	1.57
						St. Dev.	0.000	0.024	0.024
						St.Dev./Avg.	0.0%	1.5%	1.5%
						Dev. From Avg		-7.1%	-7.0%

Table 3. Test results on 11/22/2004

Date	Location	Stilling Well	Net Weight	Measured Time	System Flow	System Flow	Lateral Flow	Lateral Flow Adjusted
		(ft)	(lbs)	(min.)	(CFS)	(gpm)	(gpm)	(gpm)
11/22/2004	TP6-H	0.738	143.50	2.50	18.36	8242	6.88	6.88
		0.738	143.75	2.50	18.36	8242	6.89	6.89
		0.738	144.50	2.50	18.36	8242	6.93	6.93
		0.7375	143.50	2.50	18.33	8229	6.88	6.87
		0.738	144.00	2.50	18.36	8242	6.91	6.90
					Average	8239	6.90	6.89
					St. Dev.	5.895	0.020	0.023
					St.Dev./Avg.	0.1%	0.3%	0.3%
					Dev. From Avg		-4.9%	-5.0%
11/22/2004	TP6-L	0.458	42.75	3.00	4.37	1960	1.71	1.71
		0.4585	42.75	3.00	4.39	1969	1.71	1.72
		0.458	42.75	3.00	4.37	1960	1.71	1.71
		0.459	43.00	3.00	4.41	1978	1.72	1.74
		0.458	42.75	3.00	4.37	1960	1.71	1.71
					Average	1966	1.71	1.72
					St. Dev.	7.881	0.004	0.011
					St.Dev./Avg.	0.4%	0.3%	0.6%
					Dev. From Avg		1.6%	2.0%
11/22/2004	TP6-check	0.4605	42.50	3.00	4.47	2004	1.70	1.74
		0.45825	42.25	3.00	4.38	1965	1.69	1.69
		0.4575	41.88	3.00	4.35	1952	1.67	1.67
		0.4575	42.00	3.00	4.35	1952	1.68	1.67
		0.457	42.25	3.00	4.33	1943	1.69	1.68
		0.457	42.00	3.00	4.33	1943	1.68	1.67
					Average	1963	1.68	1.69
					St. Dev.	24.473	0.009	0.028
					St.Dev./Avg.	1.2%	0.5%	1.7%
					Dev. From Avg		0.0%	0.1%

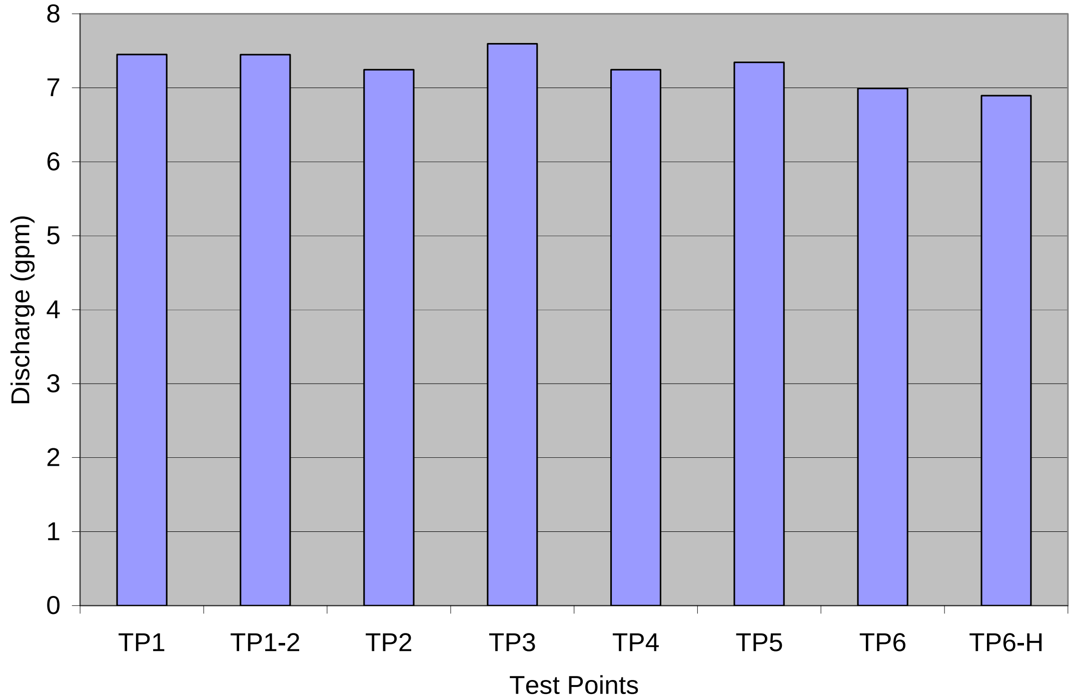

Figure 9. Average discharge measurements under high system flows

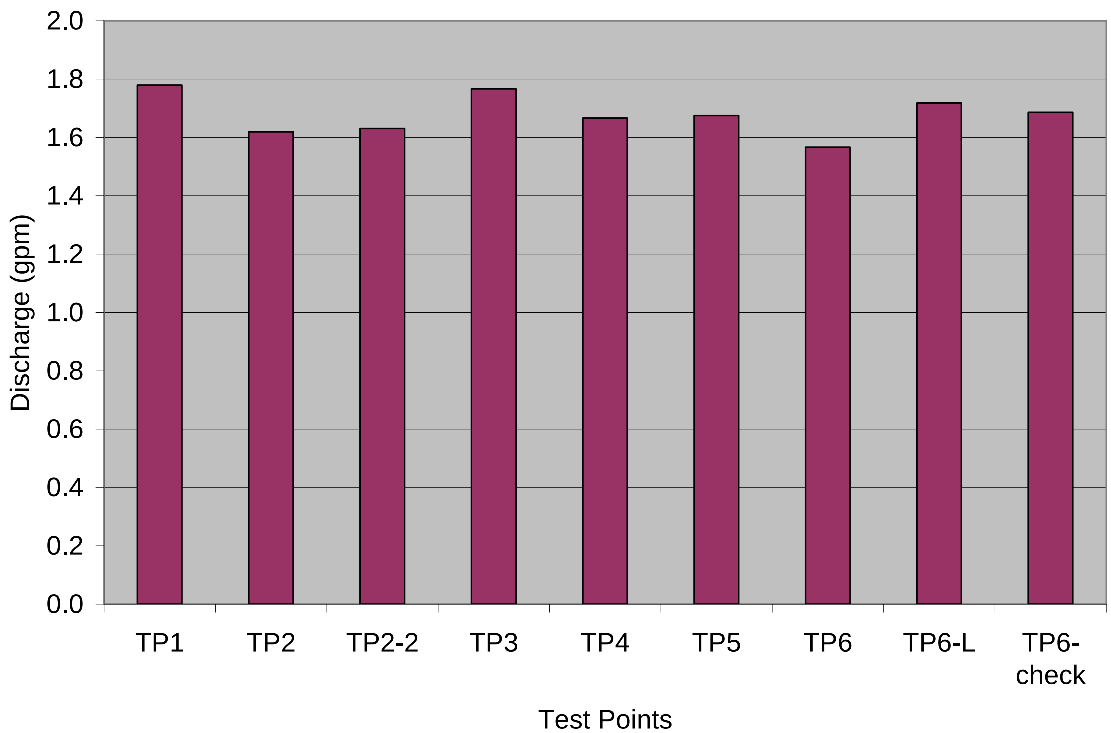

Figure 10. Average discharge measurements under low system flows

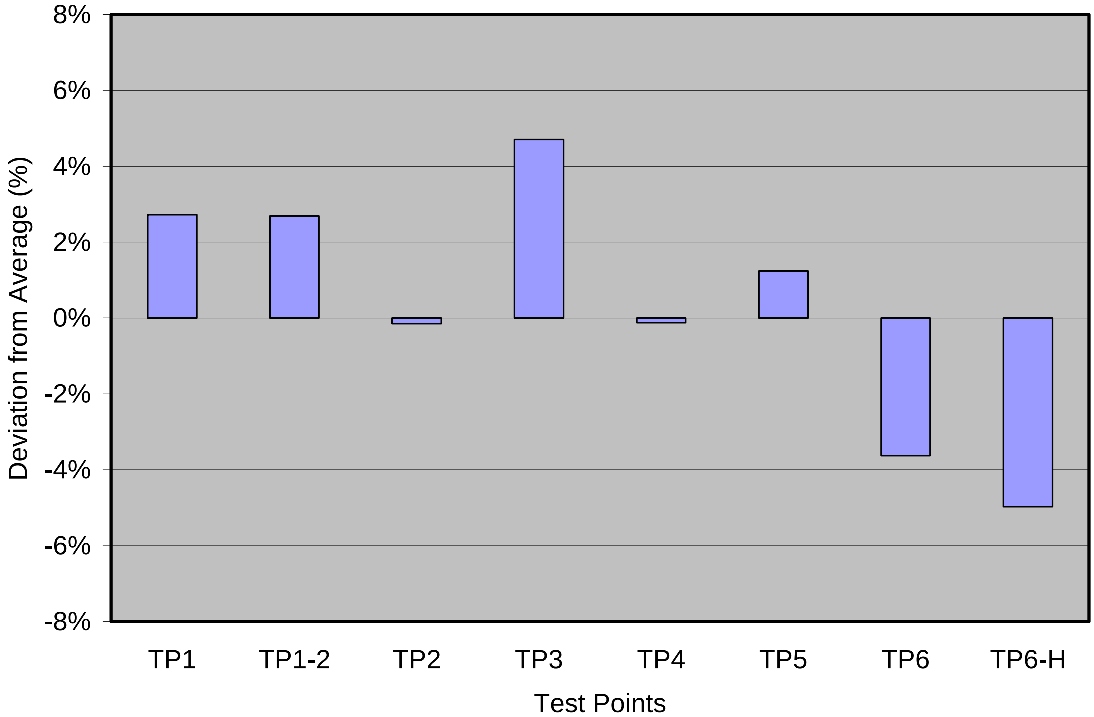

Figure 11. Deviation from the mean of discharge measurements under high system flows

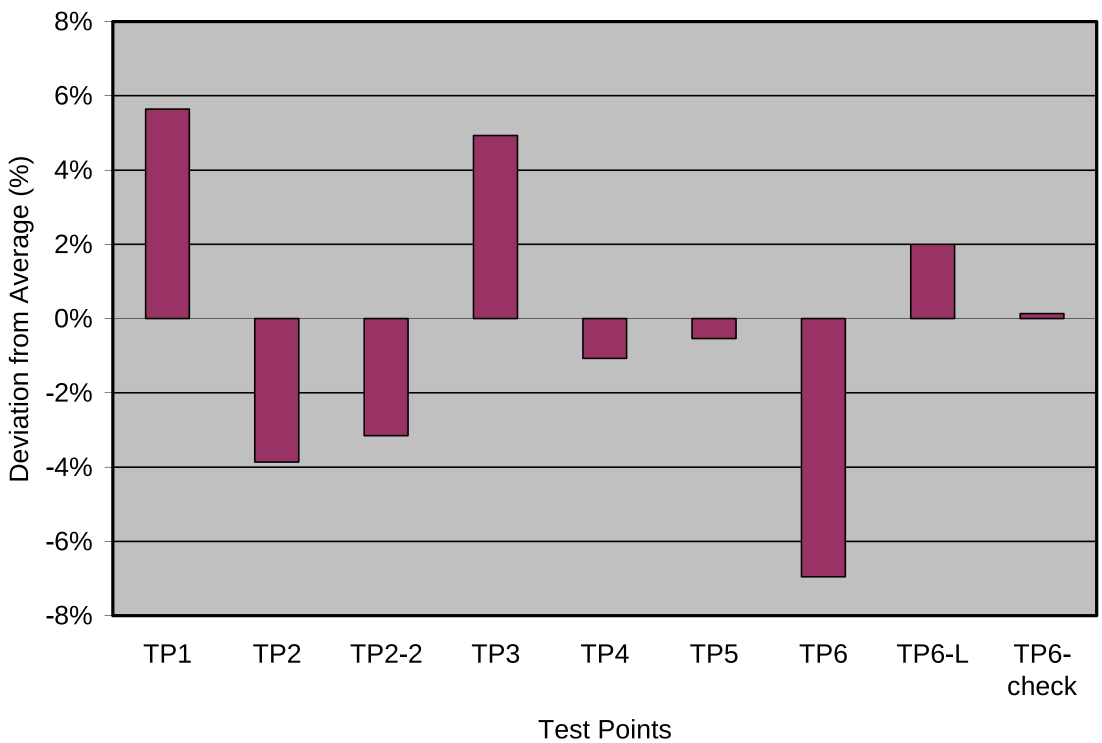

Figure 12. Deviation from the mean of discharge measurements under low system flows

5. Summary

Johnsons Screens was required to test its underdrain system for the City of Scottsdale, AZ, under backwash flow conditions. To test the system, a 17′×34′ basin was built in St. Anthony Falls Laboratory and the underdrain system components were provided and installed by Johnsons Screens. No screen was provided for the manifolds and headers for the laboratory testing. To assess the uniformity of flow of the manifold system, a measurement technique was developed to determine the flow at a number of locations at design flows. The technique was a flow-capturing apparatus with an open-topped tank, two tubes, a hose and a pump. Using this apparatus, the flow was captured over a period of time and weighed to determine the flow rate from each triplet of orifices. The system error under high system flow (about 19 cfs) was less than 0.7%.

Six locations were determined by Johnsons Screens for the testing. At each location, flow measurements were conducted for two system flow rates: 18.4 cfs and 4.4 cfs. Each measurement was repeated 5 times and the results averaged to reduce measurement uncertainty. Two tests were repeated to verify the repeatability of the test set-up. In addition, three more tests were conducted in the presence of the Johnsons Screens representatives to verify the test procedure and results.

The test results show that under high system flow conditions, flow through orifices varies less than ±5% when the underdrain system is in backwash mode. Under low system flow conditions, flow through orifices varies less than ±7%.

Appendix A. Locations of Flow Measurements

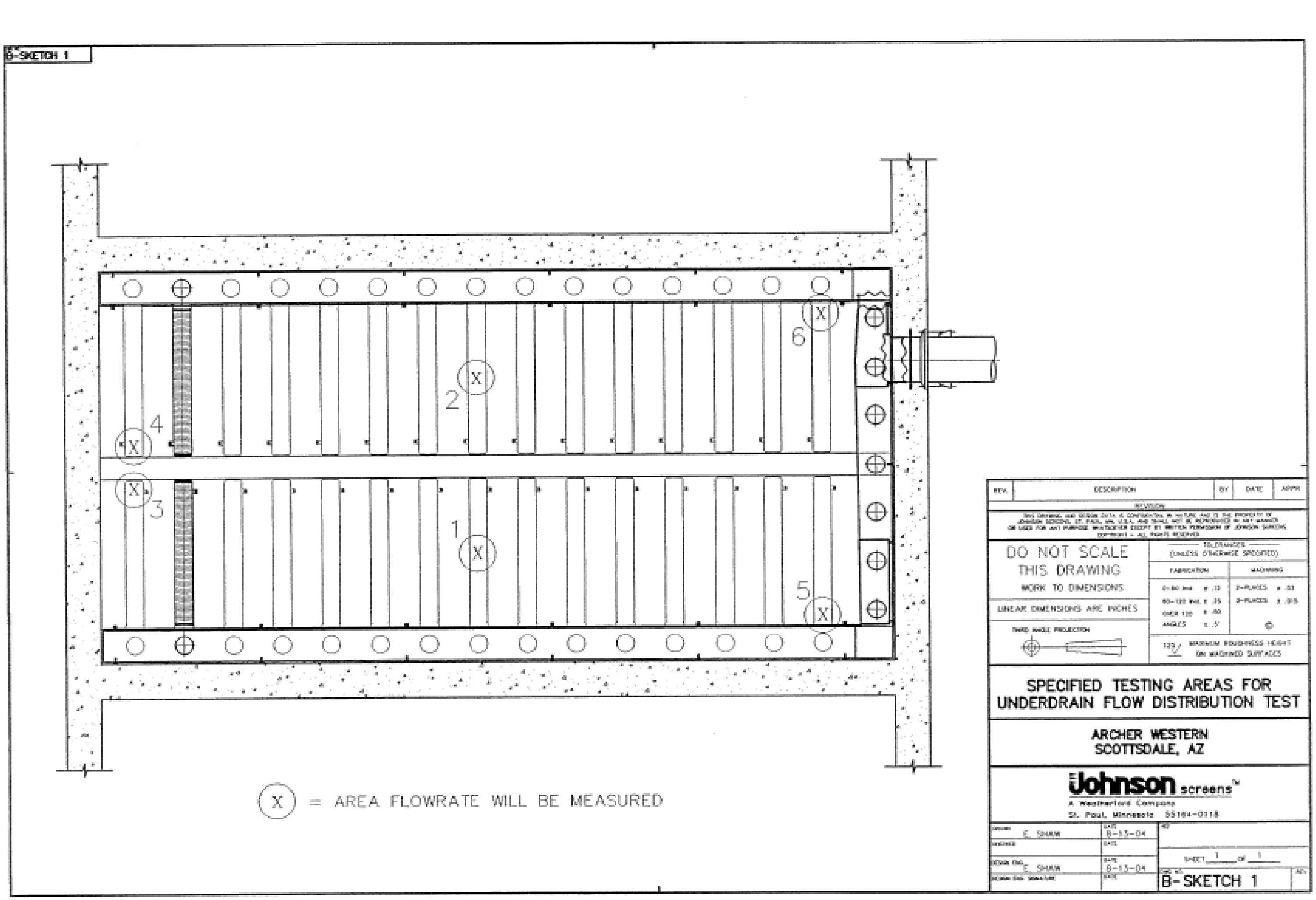

Figure A-1. Areas where flow measurements were conducted.