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

PROJECT REPORT 482

Testing a Single Lateral of an Underdrain System

By

Omid Mohseni and Richard Christopher

Prepared for
Johnson Screens
New Brighton, MN

October 2006
Minneapolis, Minnesota

Abstract

To evaluate the performance of the laterals of an underdrain system manufactured by Johnson Screens, a test-stand basin was built at St. Anthony Falls Laboratory. Two laterals were placed in the basin of which one was a blind lateral, i.e. with no orifice holes, for the leakage test. The laterals were 8-inch conduits with 9.25-inch diameter vee-wire wrap around them. Eleven series of tests were conducted on the laterals, of which five test series were to assess the hydraulic performance under the backwash mode, three test series to assess the hydraulic performance under the filter mode, and three test series to determine the amount of leakage.

Under the backwash mode, the flow rate from every two rings of orifices was measured using a flow-capturing apparatus. The flow rate varied from 53 GPM at the upstream point to 64 GPM at the downstream point. Two tests series were also conducted and flow velocities around the lateral were measured to determine the turbulence intensity along the lateral. The average turbulence intensities estimated at the upstream, downstream and the midpoint of the lateral were comparable.

Under the filter mode, the flow rate from the orifice rings could not be measured, therefore, only the approach flow velocities were measured. The average turbulence intensities estimated at the upstream, downstream and the midpoint of the lateral were again comparable.

For the leakage test, the amount of leakage exceeded the threshold during the first two series. Subsequently, the tested lateral was modified and improved by the Johnson Screens crew members. The final product was tested and the amount of leakage under 35 psi pressure with a duration of four minutes decreased to 5 GPM.

Acknowledgements

The work reported herein was funded by Johnson Screens, and Mr. Thomas Steinke from Johnson Screen was the project officer. We would like to thank Matthew Lueker and Ben Erickson of St. Anthony Falls Laboratory for their contributions to the project.

Table of Contents

List of Figures

List of Tables

1. Introduction

Johnson Screens was required to have its underdrain system (Figure 1.1) tested by an independent laboratory. The required shop tests comprised a hydraulic test and a leak test. The hydraulic test was to evaluate the performance of a single lateral under two conditions: (1) backwash mode, and (2) filter mode. The original scope of the tests was to determine the flow distribution along the lateral under both conditions. The backwash mode was expected to be tested under the maximum flow condition which was 390.6 GPM (gallons per minute) per lateral or 0.870 cfs, and the filter mode was expected to be tested under two flow conditions: (1) 20.8 GPM per lateral or 0.046 cfs, and (2) 127.6 GPM per lateral or 0.283 cfs. The leak test was expected to be conducted on a single blind lateral, i.e. with no orifice holes along the lateral, at an internal pressure of 35 pounds per square inch (psi).

The scope of this study was to build a basin for two laterals to conduct the hydraulic tests on a single lateral to determine the distribution efficiency at several flow rates under backwash and filtering modes, and to conduct a leakage test on a single lateral before the orifice holes were drilled.

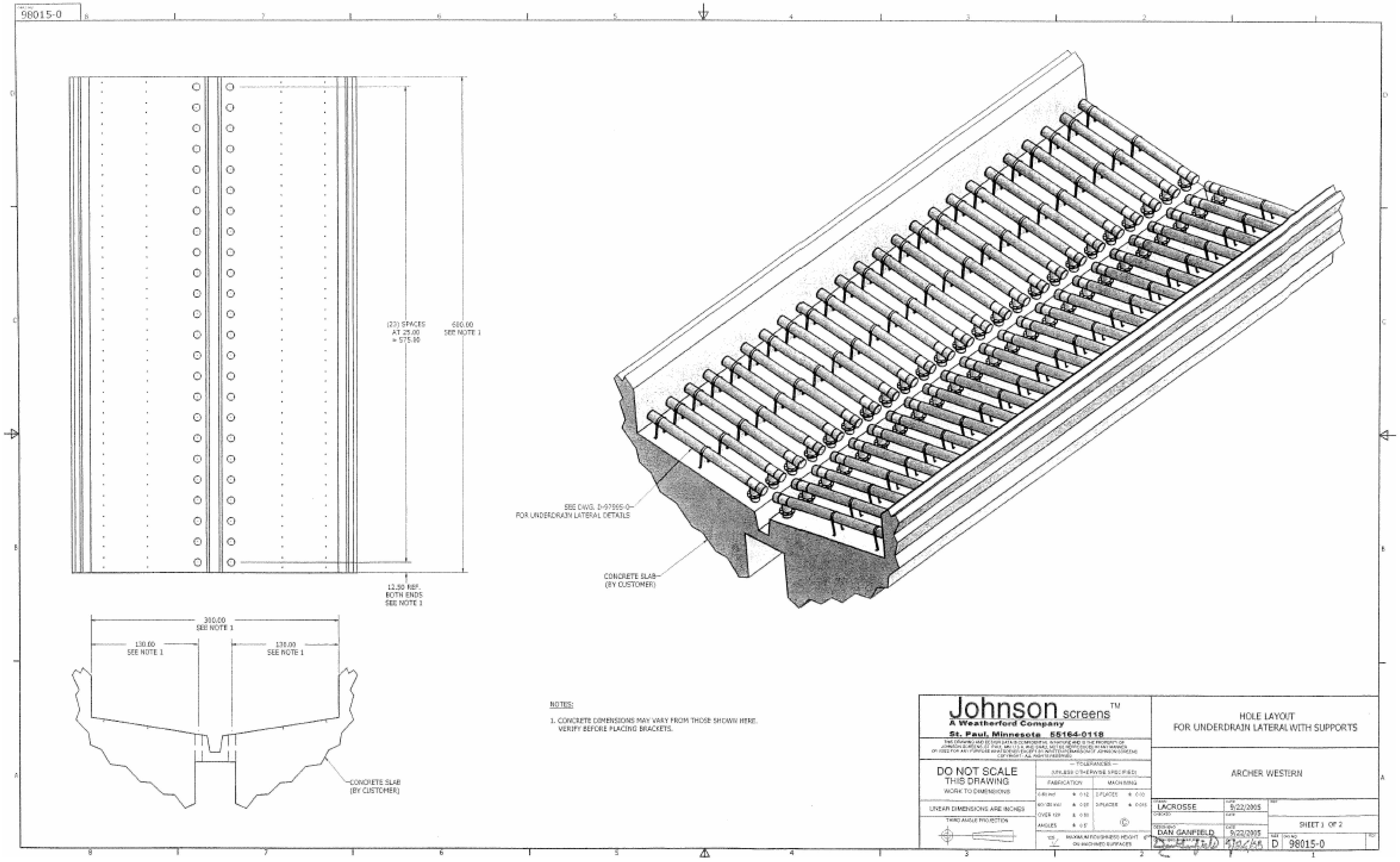


Figure 1.1. The layout of the underdrain system provided by Johnson Screens

2. Testing Facility Set-up

2.1. The Basin

The test set-up comprised a basin to withhold two laterals according to the drawing provided by Johnson Screens (Figure 2.1). The basin was a sloped 9'×4' rectangular wooden tank with a plumbing capable of supplying approximately one cfs (450 GPM). The height of the basin varied from 4' to 6 '. Along the length of the basin a 2'×9' tank was constructed to either supply water during the filter model or collect and reroute water during the backwash mode (Figure 2.2).

The laterals are approximately 8-inch conduits with 9.25-inch diameter vee-wire wrap around them (Figure 2.1). One of the laterals had no orifice drilled and was connected to the city water supply line. The other lateral was connected to a supply line which carried Mississippi River water. During backwash flow conditions, water was discharged out of the basin over a weir, and during the filter mode, water entered the basin over the same weir.

The basin was constructed from lumber and plywood (Figure 2.3). The laterals and a part of the drain pipes (vertical shafts) were supplied by Johnson Screens.

2.2. Instrumentation

To measure the flow rate through the system during the hydraulic tests, a standard orifice flow meter equipped with a differential pressure transducer was placed in the supply line. Two orifice plates were used for the tested range of flows. For high flow rates a 3-inch plate and for low flow rate a 1.5-inch plate. The orifice flow meter was also checked against the SAFL weighing tanks. For the 3-inch plate, at flows around 0.87 cfs, the standard flow values were slightly different from those measured by the weighing tanks (Figure 2.4). Since the difference was very small, it was decided to use standard flow values.

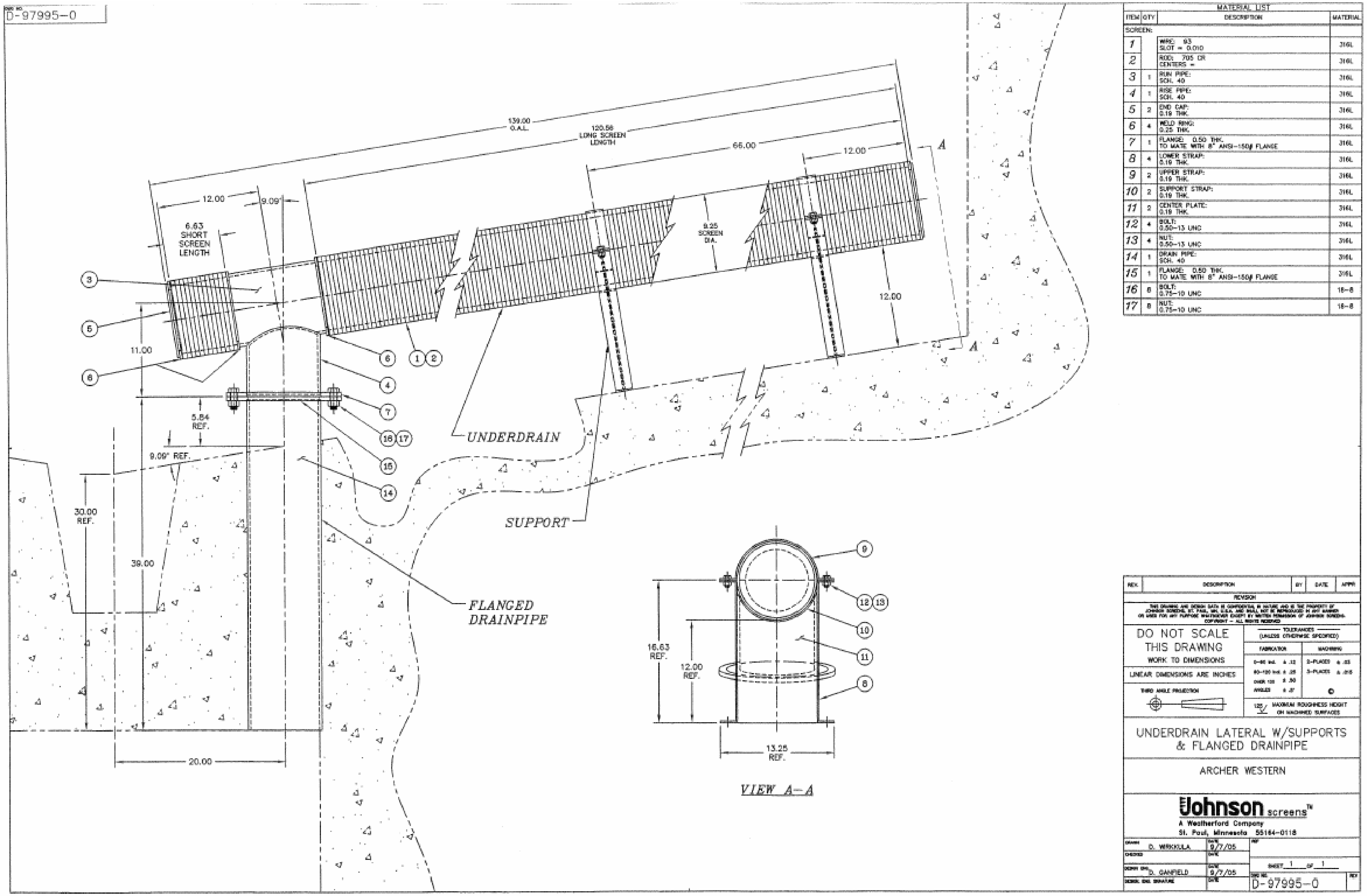
To determine the flow distribution along the lateral a flow chamber was built to capture the flow out of two rings of orifices over a period of time. The flow-capturing apparatus was comprised of a closed tank, two ¼” tubes, a manifold, and a 1.5” flexible hose (Figure 2.5). The tank was made of Plexiglas with a width and length of 12” and 25", respectively, and could be moved and positioned along the lateral.

The dimensions of the flow chamber were determined so as to take advantage of lines of symmetry in the manifold system. Thus, the internal width of the tank was equal to the distance between two adjacent rings of orifices and the internal 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 pressure inside the tank. The 1.5” hose was connected to a throttling valve and a pump and was used to extract water from the tank via a withdrawal manifold (Figure 2.6).

The two ¼” tubes were connected to a graduated manometer and would provide the water pressure difference inside and outside of the flow chamber. Under backwash conditions, with the pump on, water was withdrawn from the flow chamber, with the rate controlled by the valve. When the valve was adjusted such that the water pressure inside and outside of the flow chamber were the same and steady over time, the flow through the pump was equal to the orifice rings discharge that would occur in the absence of the flow chamber.

The water discharged by the pump was collected in a thirty gallon container located outside of the basin and sitting on a scale. The 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 were then used to determine the discharge of the rings of orifices being tested.

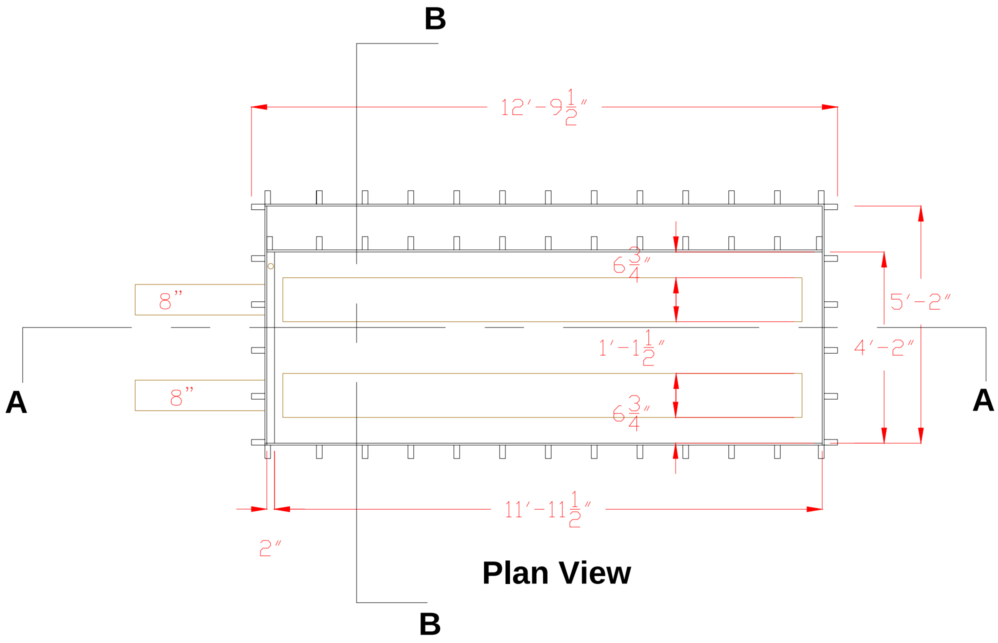
Initially a second pump was provided to use the flow chamber for the filter mode as well. Due to the presence of vee wire wrap around the lateral, it was impossible to balance the pressure inside and outside the flow chamber. Therefore, it was decided to use a 3-D Acoustic Doppler Velocimeter (ADV) and have it mounted on a towing carriage (Figure 2.7). The 3-D ADV provided the flow velocities around the lateral in three directions.



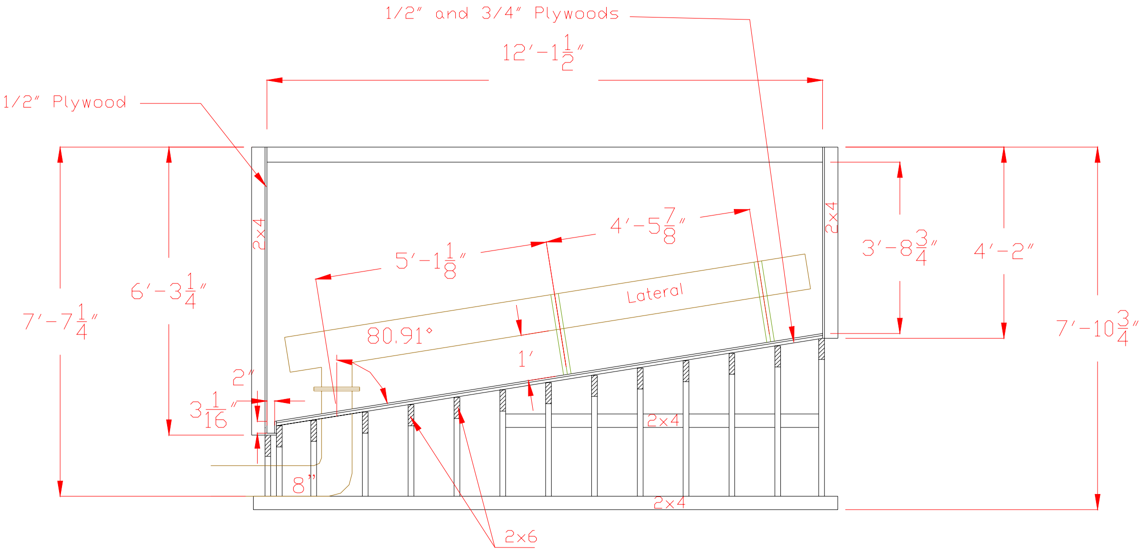
MATERIAL LIST

ITEM	QTY	DESCRIPTION	MATERIAL
SCREEN:			
1		WIRE: 93 SLOT = 0.010	316L
2		ROD: 705 CR CENTERS =	316L
3	1	RUN PIPE: SCH. 40	316L
4	1	RISE PIPE: SCH. 40	316L
5	2	END CAP: 0.19 THK.	316L
6	4	WELD RING: 0.25 THK.	316L
7	1	FLANGE: 0.50 THK. TO MATE WITH 8" ANSI-150# FLANGE	316L
8	4	LOWER STRAP: 0.19 THK.	316L
9	2	UPPER STRAP: 0.19 THK.	316L
10	2	SUPPORT STRAP: 0.19 THK.	316L
11	2	CENTER PLATE: 0.19 THK.	316L
12	4	BOLT: 0.50-13 UNC	316L
13	4	NUT: 0.50-13 UNC	316L
14	1	DRAIN PIPE: SCH. 40	316L
15	1	FLANGE: 0.50 THK. TO MATE WITH 8" ANSI-150# FLANGE	316L
16	8	BOLT: 0.75-10 UNC	18-8
17	8	NUT: 0.75-10 UNC	18-8

Figure 2.1. The position of the lateral and the drainpipe in the underdrain system.



Plan View



Cross-Section A - A

Figure 2.2. The layout of the basin test stand.

Figure 2.3. The basin test-stand made of lumber and plywood.

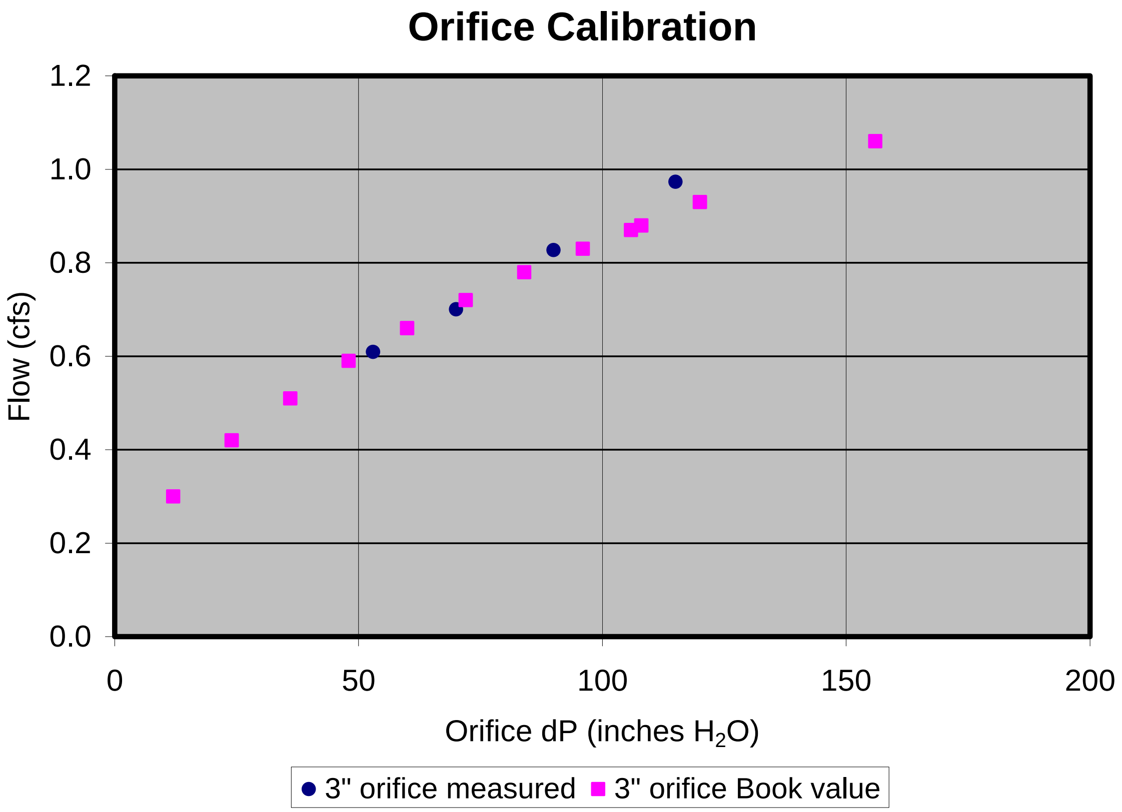


Figure 2.4. Verifying the standard values of the orifice flow meter against measured flows using the SAFL weighing tanks.

Figure 2.5. The flow-capturing apparatus to measure the flow rate out of two rings of orifices.

Figure 2.6. The pumps and plumbing used to measure the flow withdrawn from the flow chamber during the backwash mode.

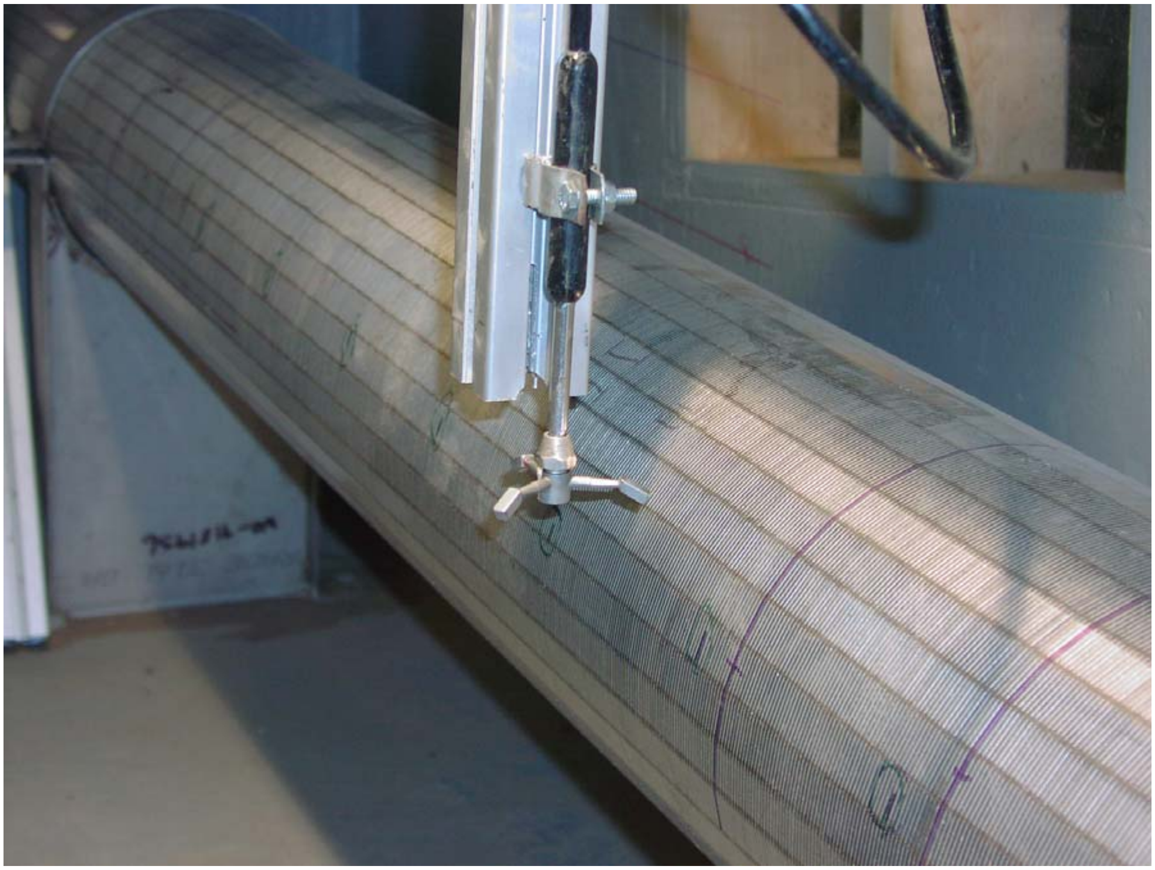


Figure 2.7. The 3-D Acoustic Doppler Velocimeter used to measure the flow velocity around the lateral.

3. Test Results

Eleven series of tests were conducted. Eight test series were conducted to determine the hydraulic performance as described in section 3.1 and three test series were conducted to determine the amount of leakage as described in section 3.2.

3.1. Hydraulic Tests

To measure the discharge through each ring of orifices of the underdrain system, a pressurized flow chamber was used. The flow chamber was one foot wide and was placed such that two rings of orifices would discharge into it. Two tubes conveyed water from inside and outside of the flow chamber to the edge of the basin. A third tube was connected to a pump to extract water from the flow chamber during the backwash mode or to pump water during the filter mode. By equalizing the pressure inside the flow chamber with the pressure in the basin, the water withdrawn during the backwash mode and the water discharged into the flow chamber during the filter mode would represent the flow through two rings of orifices.

During the filter mode, the pump did not perform well due to seepage underneath the screen, and the results were not conclusive. Therefore, an Acoustic Doppler Velocimeter (ADV) was used to estimate the flow rate under both conditions. The velocity measurements showed a highly turbulent flow condition under both backwash and filter modes, i.e. the standard deviation of measured velocities was about the same as the mean of the velocities. Therefore, no flow rate was inferred from the ADV measurements. Since the lateral was designed to uniformly wash off the debris along the screens under the backwash mode, and by creating a highly turbulent flow condition around the lateral to prevent any debris attaching to the screen under the filter mode, it was decided to estimate the kinetic energy of turbulence outside the lateral. The parameter which could well represent the quality of turbulence around the lateral was turbulent intensity which is estimated from the following equation.

$$Turbulent\ Intensity\,(TI) = \sqrt{\frac{\overline{u_x'^2} + \overline{u_y'^2} + \overline{u_z'^2}}{3}}$$

In the above equation, u' is the velocity fluctuation from the mean, x, y and z are the Cartesian coordinates, and u_x is the velocity component in the x direction.

In the following sections the results of the tests using the flow chamber and the ADV are summarized.

3.1.1. Backwash Mode

Three series of tests were conducted using the flow chamber. Each series of test comprised five tests at a single location. The locations are marked as F, C and L on Figure 3.1a. The results are given in Table 3.1. The flow rates at the upstream end (F) and the middle point (C) were very similar. However, the flow rate near the downstream end (L) of the lateral under the backwash mode was relatively different from the two locations. A very slight increasing trend in flow is evident in the three locations.

Table 3.1. Flow rates measured at three locations using the flow chamber under the backwash mode

Tests and Locations		System DP (inches H2O)	System Flow Rate (cfs)	Lateral pressure	Head pressure	Pressure Differential	Lateral	GPM	% Deviation
				inches Red Merriam	inches red Merriam		psi		
F	**test #1**	98.0	0.87	15.4	15.4	30.8	2.17	49.45	
	test #2	98.0	0.87	15.6	15.6	31.2	2.20	51.11	
	test #3	98.0	0.87	15.9	15.9	31.8	2.24	53.57	
	test #4	98.0	0.87	15.9	15.8	31.7	2.23	54.17	
	test #5	98.0	0.87	16.0	16.1	32.1	2.26	55.86	
							Average	**52.95**	**-7.3%**
L	**test #1**	98.0	0.87	15.2	15.3	30.5	2.15	62.48	
	test #2	98.0	0.87	15.4	16.0	31.4	2.21	65.24	
	test #3	98.0	0.87	15.0	15.3	30.3	2.13	64.18	
	test #4	98.0	0.87	15.0	15.3	30.3	2.13	64.75	
	test #5	98.0	0.87	15.4	15.6	31.0	2.18	64.35	
							Average	**64.20**	**12.4%**
C	**test #1**	98.0	0.87	15.1	15.1	30.2	2.13	54.54	
	test #2	98.0	0.87	15.4	15.6	31.0	2.18	54.54	
	test #3	98.0	0.87	15.5	15.7	31.2	2.20	53.95	
	test #4	98.0	0.87	15.6	15.6	31.2	2.20	54.40	
	test #5	98.0	0.87	16.0	16.1	32.1	2.26	53.81	
							Average	**54.25**	**-5.1%**

The first test series using ADV was conducted at 12 points: four points at F, four points at L and four points at C. The four points at each location were at 3, 6, 9 and 12 o'clock positions (Figure 3.1b). However, the results showed that not all points were aligned with the staggered orifices.

To avoid the problem with the location, the second test series was conducted at 10 locations, two inches apart from each other along locations F, C and L, i.e. 30 locations total (Figure 3.1a). All locations were at 3 o'clock position (see Figure 3.1b). Velocities were measured at a frequency of 2 Hz for a period of one minute. The point velocities were measured two inches away from the lateral. The noise-signal ratio showed that the measured velocities were not noise but actual velocities. However, no directional velocity was detected. The turbulent intensity estimated at each location is given in Table 3.2 and Figure 3.2. The average turbulent intensities were comparable as shown in Table 3.2.

Table 3.2. Turbulent intensities estimated (ft/sec) at 30 locations under the backwash mode

Position	Upstream	Center	Downstream
1	0.458	1.158	1.372
2	1.238	1.172	1.924
3	0.894	1.267	2.282
4	1.024	3.123	2.960
5	1.809	1.172	1.919
6	3.329	2.263	2.739
7	3.677	3.240	2.573
8	2.813	2.453	2.038
9	1.809	2.094	4.162
10	2.604	2.032	1.248
Average	**1.965**	**1.997**	**2.322**

3.1.2. Filter Mode

The first test series was conducted at 30 points, similar to the last backwash test series. Velocities were measured at a frequency of 2 Hz for a period of one minute. The point velocities were measured two inches away from the lateral. The flow rate was at 127.6 gpm (4.9 gpm/ft^2). The turbulent intensities are summarized in Table 3.3 and Figure 3.3. The average turbulent intensities at the three regions of the lateral were comparable.

Table 3.3. Turbulent intensities estimated (ft/sec) at 30 locations under the filter mode

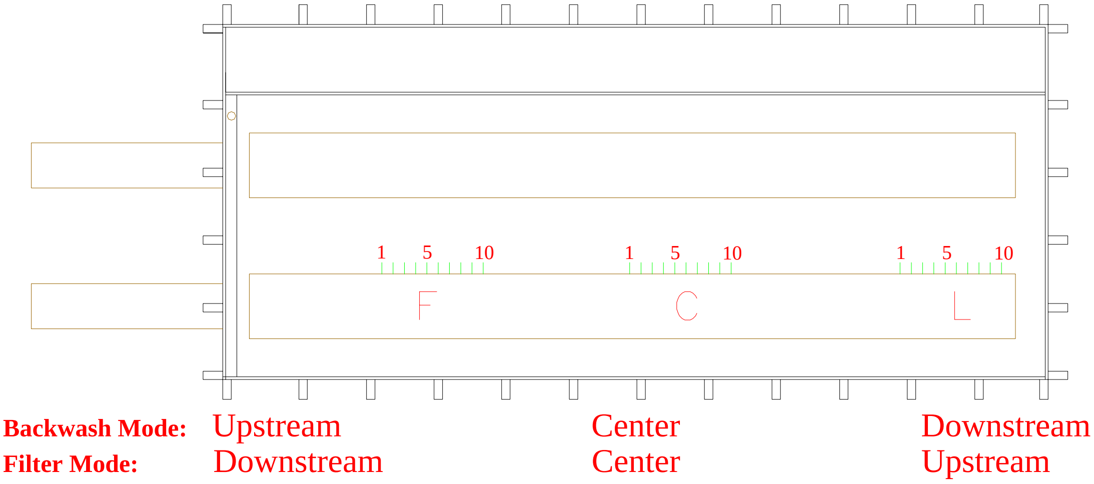
Position	Downstream	Center	Upstream
1	1.256	0.894	0.677
2	1.032	0.627	0.797
3	1.332	0.809	1.176
4	0.742	0.902	1.109
5	1.025	1.153	0.724
6	1.104	1.165	0.779
7	1.020	0.943	0.856
8	1.366	0.890	0.854
9	1.312	1.044	0.999
10	1.059	1.004	0.961
Average	**1.125**	**0.943**	**0.893**

The second test series was conducted for a period of 10 minutes to determine if a longer test duration would result in more meaningful average velocities. In this test series, the velocities were measured at a frequency of 25 Hz. The point velocities were all measured at L10 and two inches from the lateral. The ratio of the mean velocity to the standard deviation of measured velocities did not change. The turbulent intensity was estimated for ten durations as given in Table 3.4.

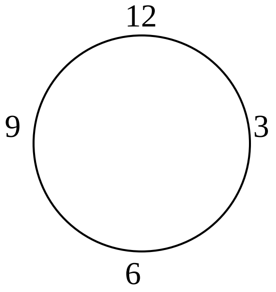
Table 3.4. Turbulent intensities estimated (ft/sec) for 10 different durations at one location

Time (min)	Turbulent Intensity
1	1.438
2	1.249
3	1.290
4	1.099
5	1.586
6	1.312
7	1.367
8	1.351
9	1.243
10	1.411

To obtain a better measure of directional velocities, the third test series was conducted to determine the velocities 1.5 inches from the lateral. The velocities were measured at three locations: F1, C2 and L1 (Appendix A). The three locations were selected such that they would align with three orifices. The velocities were measured at a frequency of 25 Hz and for a period of 10 minutes. The signal to noise ratios were admissible. No improvement in recording the directional velocity was detected which implied a highly turbulent flow conditions around the laterals. The turbulent intensities were estimated to be at 1.096, 1.387 and 1.054 fps which were comparable to those obtained in the first and second test series.



(a) Velocity Measurement Locations Along the Lateral



(b) Velocity Measurement Locations around the Lateral

Figure 3.1. The positions where velocities were measured (a) along the lateral and (b) around the lateral, and the associated identifiers for those locations. Identifier “3” in Figure b stands for 3 o’clock and is towards the blind lateral for the leak test, while the identifier “9” is towards the wall.

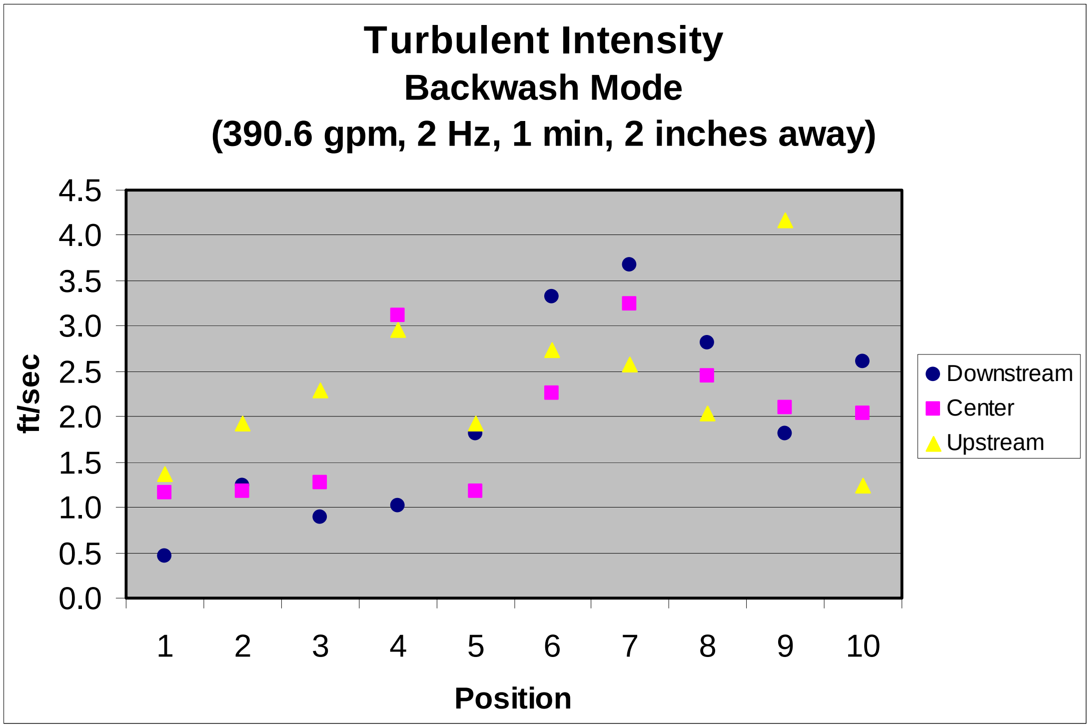


Figure 3.2. Turbulent intensities estimated at 10 locations along the lateral under the backwash mode.

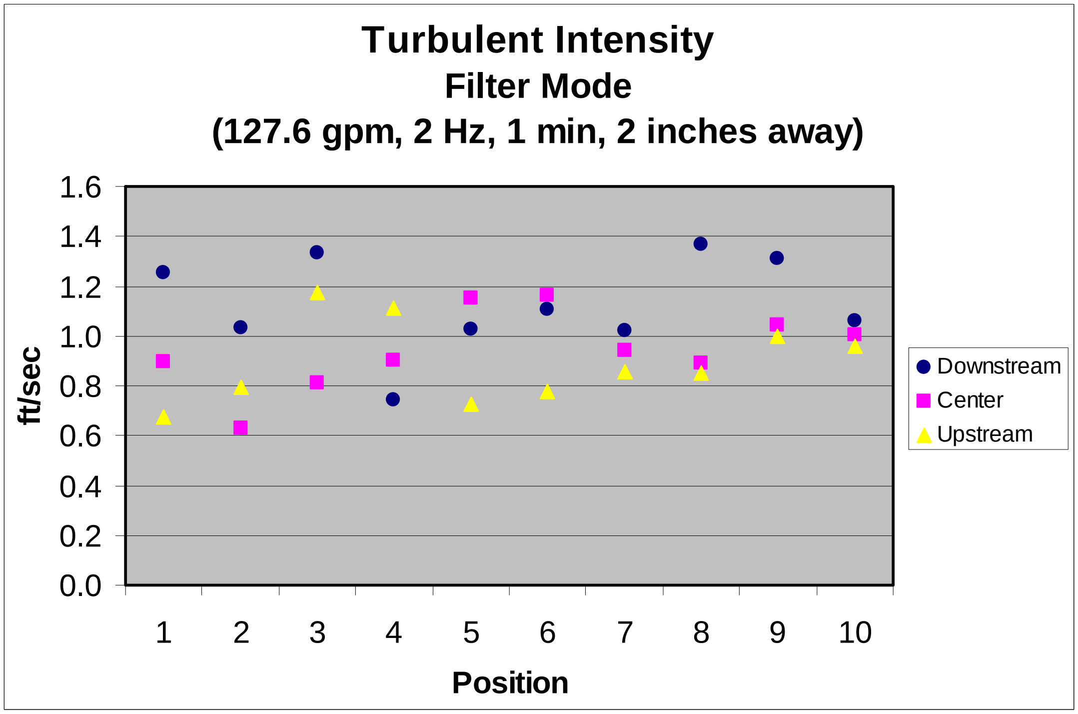


Figure 3.3. Turbulent intensities estimated at 10 locations along the lateral under the filter mode.

3.2. Leakage Test

For the leakage test, a 1 ¼ inch drain was installed in the wall of the basin and connected to the weighing set-up one floor below the basin level via a pipe. The drain was installed approximately six inches above the lowest point of the basin; therefore no section of the lateral was submerged during the leakage test. According to the assessment protocol, the leakage test needed to be conducted when the pressure in the lateral was at 35 psi. Therefore, upstream of the lateral, outside of the basin, a pressure gage was installed on the water supply line which was connected to the city water. The basin was filled with water up to the invert of the drain. Therefore, leaked water immediately flowed out of the basin.

During the first test, the leakage was so significant that the gage pressure never reached 35 psi while the leakage easily exceeded 6 gpm. Therefore, the lateral was removed and Johnson Screens modified the lateral.

The results of the second test series are given in Table 3.5. The water level in the basin did not fluctuate significantly. The amount of leaked water was measured at 2 minute, 15 minute and 30 minute intervals after the pressure reached 35 psi (first column of Table 3.5). The leakage was mostly from the welding at the two end enclosures and some from the channel rods. The cumulative effects of measurement errors (time and weight) were less than 0.1% assuming no error in the specific weight of water. The evident variability in the test results, i.e. 5.6 to 5.89 gpm, was due to the slight fluctuation of water level in the basin. Since the leakage exceeded the threshold limit of 4 gpm, the lateral was removed for additional improvements.

Table 3.5. Results of the second leakage test (May 30 2006)

Lapse Time	Water collected (lbs)	Add weight (lbs)	Tare (lbs)	Test duration (min.)	Total weight (lbs)	GPM	Potential error (GPM)
2 min.	125	75	11.25	4.0	188.75	5.66	0.00129
15 min	123	75	11.25	3.8	186.75	5.89	0.00138
30 min	123	75	11.25	4.0	186.75	5.60	0.00128

The results of the third test series are given in Table 3.6. The water level in the basin fluctuated less than in the second test series. The amount of leaked water was measured at 1 minute and 15 minute intervals after the pressure reached 35 psi. In the third test series, the performance of the lateral improved and the leakage decreased to 5.03 gpm.

Table 3.6. Results of the third leakage test (June 22 2006)

Lapse Time	Water collected (lbs)	Add weight (lbs)	Tare (lbs)	Test duration (min.)	Total weight (lbs)	GPM	Potential error (GPM)
1 min	105.25	75	11.25	4	169.00	5.06	0.00120
15 min	104	75	11.25	4	167.75	5.03	0.00120

4. Summary

To assess the hydraulic performance of an underdrain system designed and manufactured by Johnson Screens, two laterals of the system were tested at St. Anthony Falls Laboratory. One of the laterals was a blind lateral, i.e. with no orifice holes, for the leakage test.

A total of eleven test series were conducted, of which five test series were to assess the hydraulic performance under the backwash mode, three test series to assess the hydraulic performance under the filter mode, and three test series to determine the amount of leakage.

Under the backwash mode, three test series were conducted using a flow-capturing apparatus to measure the outflow from every two rings of orifices. The outflow at three locations along the lateral was measured to be 53 GPM at the upstream point, 54 GPM at the midpoint, and 64 GPM at the downstream point. In addition, two tests series were conducted to measure flow velocities around the lateral using a 3-D ADV. The discharge values estimated from the velocity measurements were inconclusive; therefore the average turbulence intensities were estimated at the upstream, downstream and the midpoint of the lateral, which were all comparable.

Under the filter mode, the flow-capturing apparatus was ineffective, therefore only the approach flow velocities were measured. Similarly, the average turbulence intensities estimated at the upstream, downstream and the midpoint of the lateral were comparable.

For the leakage test, the amount of leakage exceeded the threshold during the first two series. Subsequently, the tested lateral was modified and improved by the Johnson Screens crew members. The final product was tested and the amount of leakage under 35 psi pressure with a duration of four minutes decreased to 5 GPM.

Appendix A. Approach Velocities along the Lateral under the Filter Mode

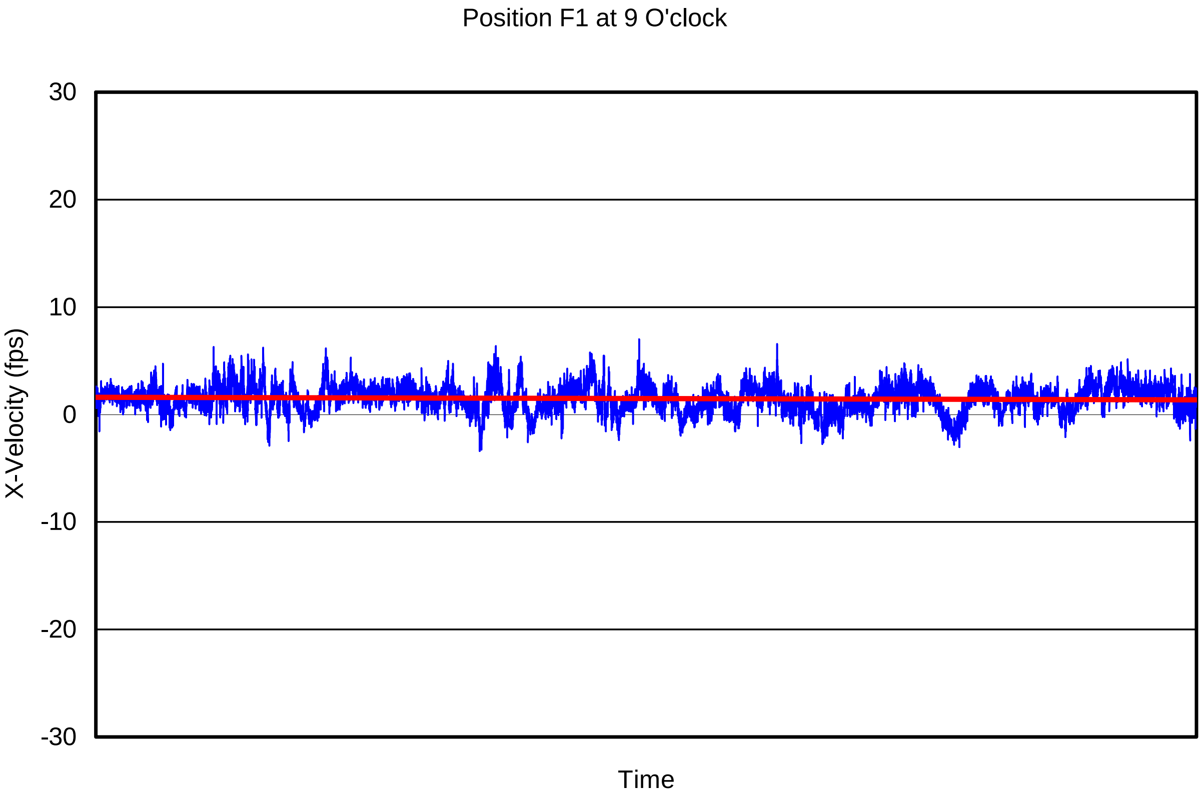


Figure A.1. Time series of the x-component of velocities measured at location F1 (Figure 3.1a) with the ADV measurement point at the 9 o’clock position. The measurement point was 1.5 inches away from the lateral and the frequency of measurements was set at 25 Hz for a period of 10 minutes, i.e. 15,000 measurements.

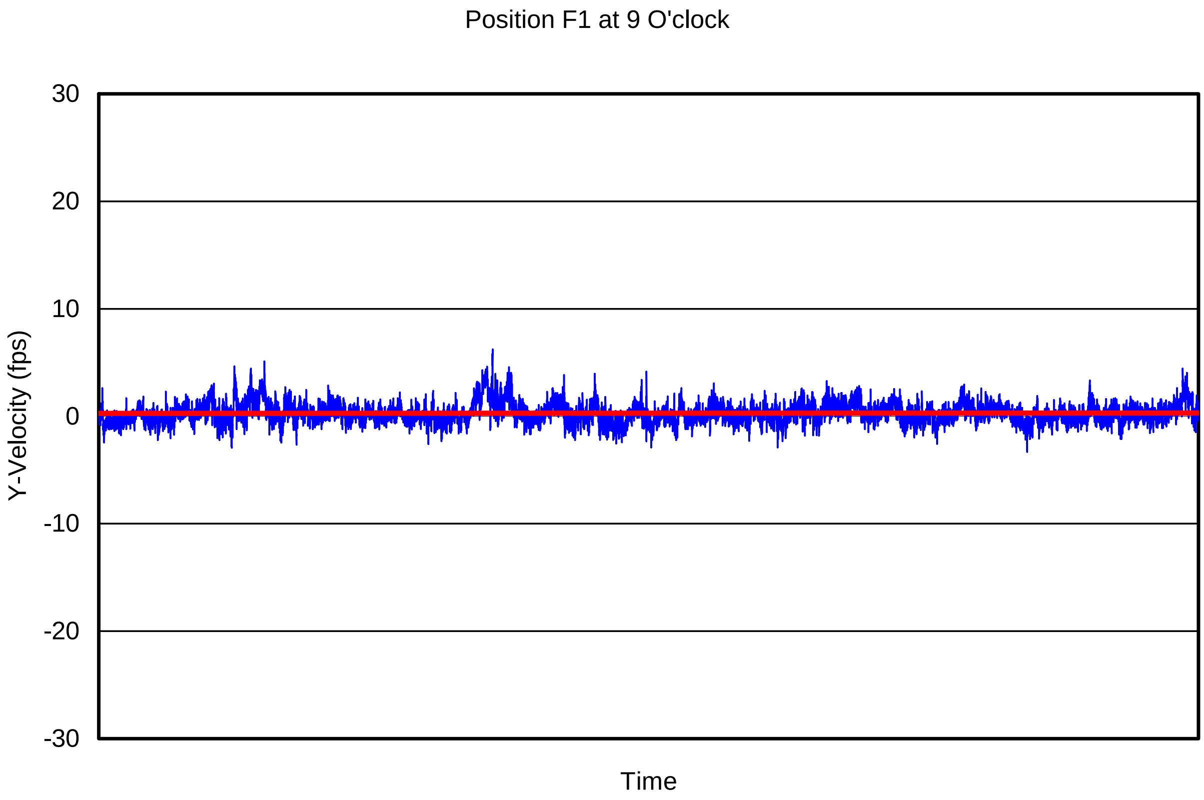


Figure A.2. Time series of the y-component of velocities measured at location F1 (Figure 3.1a) with the ADV measurement point at the 9 o’clock position. The measurement point was 1.5 inches away from the lateral and the frequency of measurements was set at 25 Hz for a period of 10 minutes, i.e. 15,000 measurements.

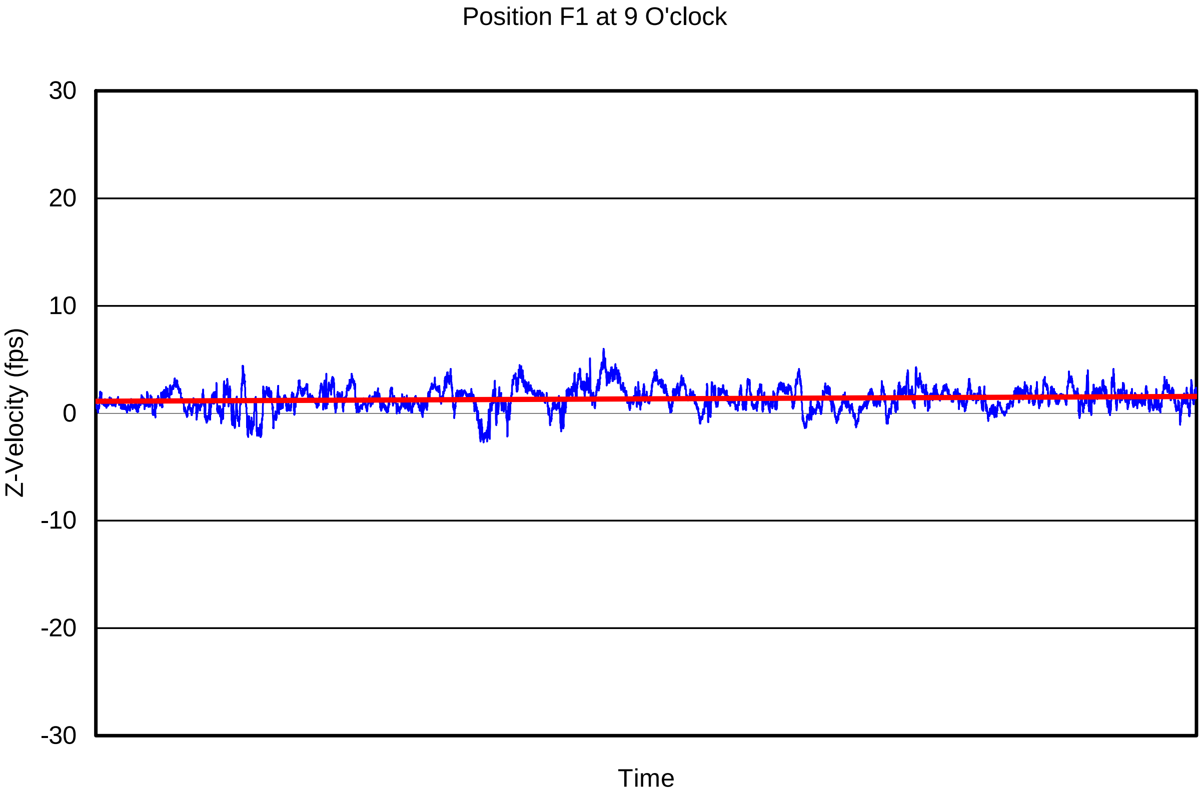


Figure A.3. Time series of the z-component of velocities measured at location F1 (Figure 3.1a) with the ADV measurement point at the 9 o’clock position. The measurement point was 1.5 inches away from the lateral and the frequency of measurements was set at 25 Hz for a period of 10 minutes, i.e. 15,000 measurements.

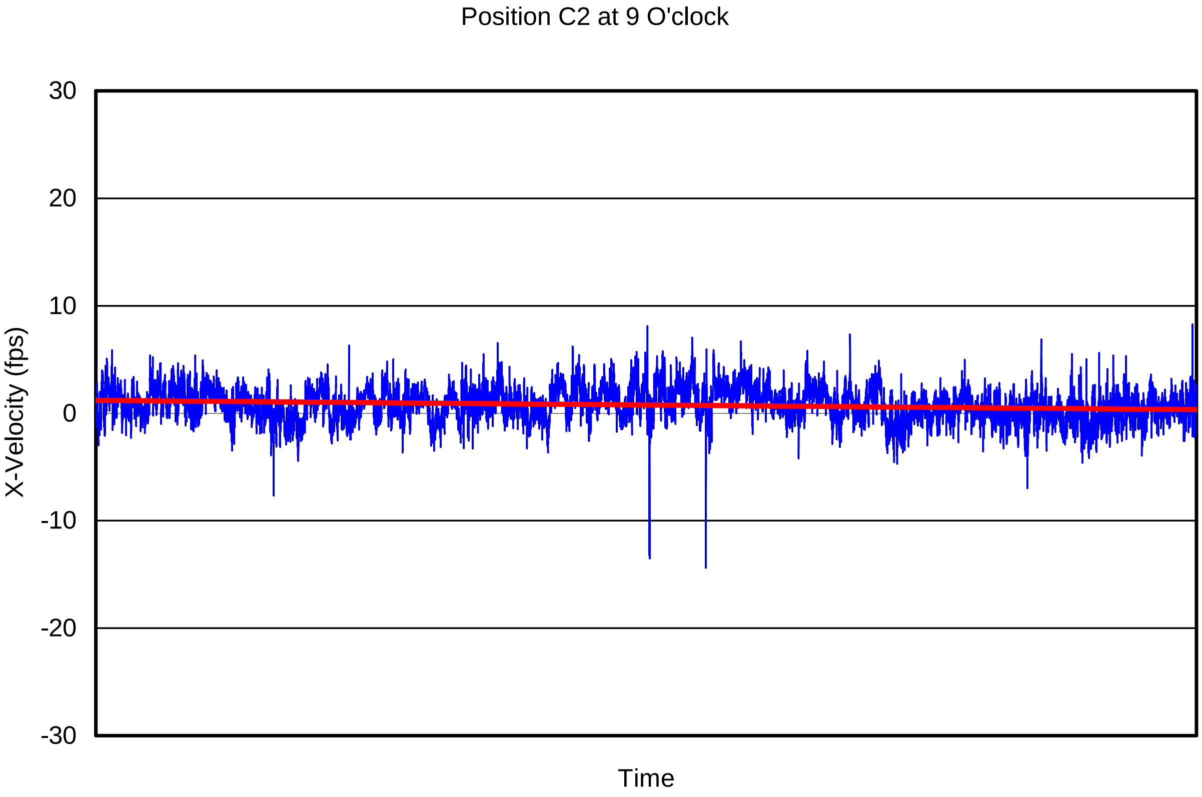


Figure A.4. Time series of the x-component of velocities measured at location C2 (Figure 3.1a) with the ADV measurement point at the 9 o’clock position. The measurement point was 1.5 inches away from the lateral and the frequency of measurements was set at 25 Hz for a period of 10 minutes, i.e. 15,000 measurements.

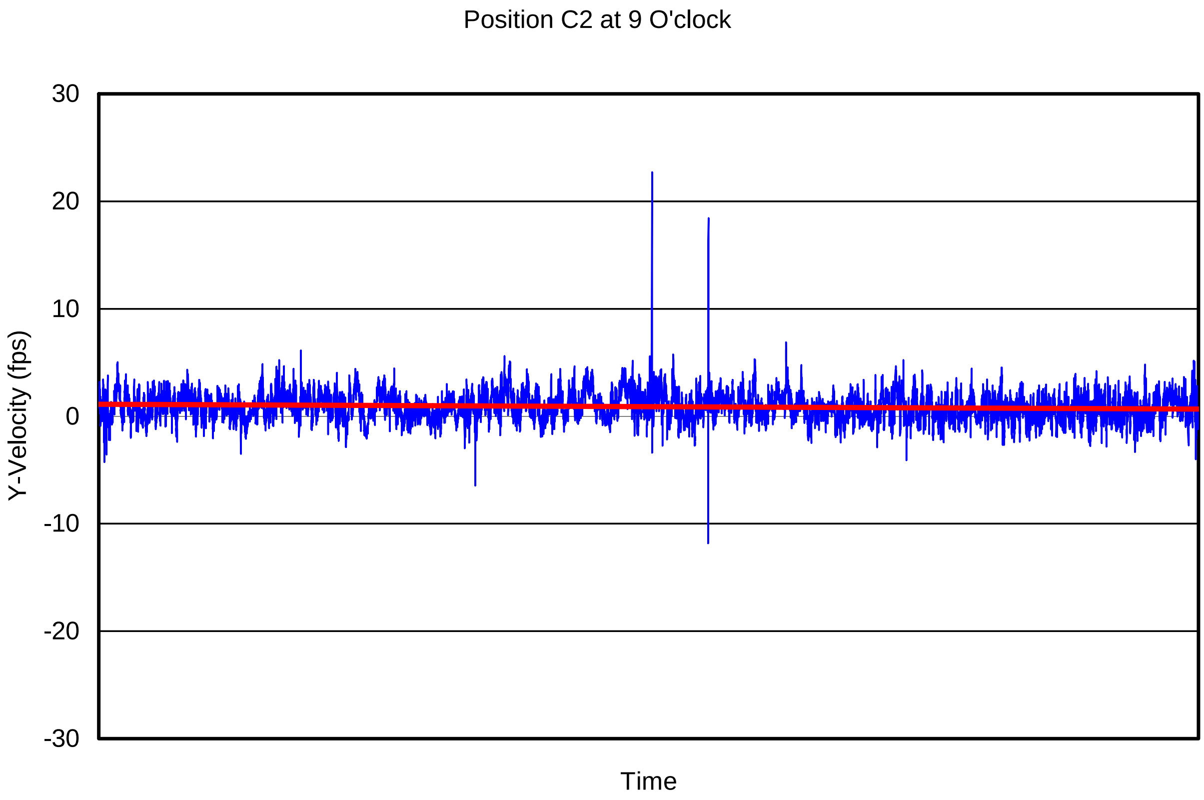


Figure A.5. Time series of the y-component of velocities measured at location C2 (Figure 3.1a) with the ADV measurement point at the 9 o'clock position. The measurement point was 1.5 inches away from the lateral and the frequency of measurements was set at 25 Hz for a period of 10 minutes, i.e. 15,000 measurements.

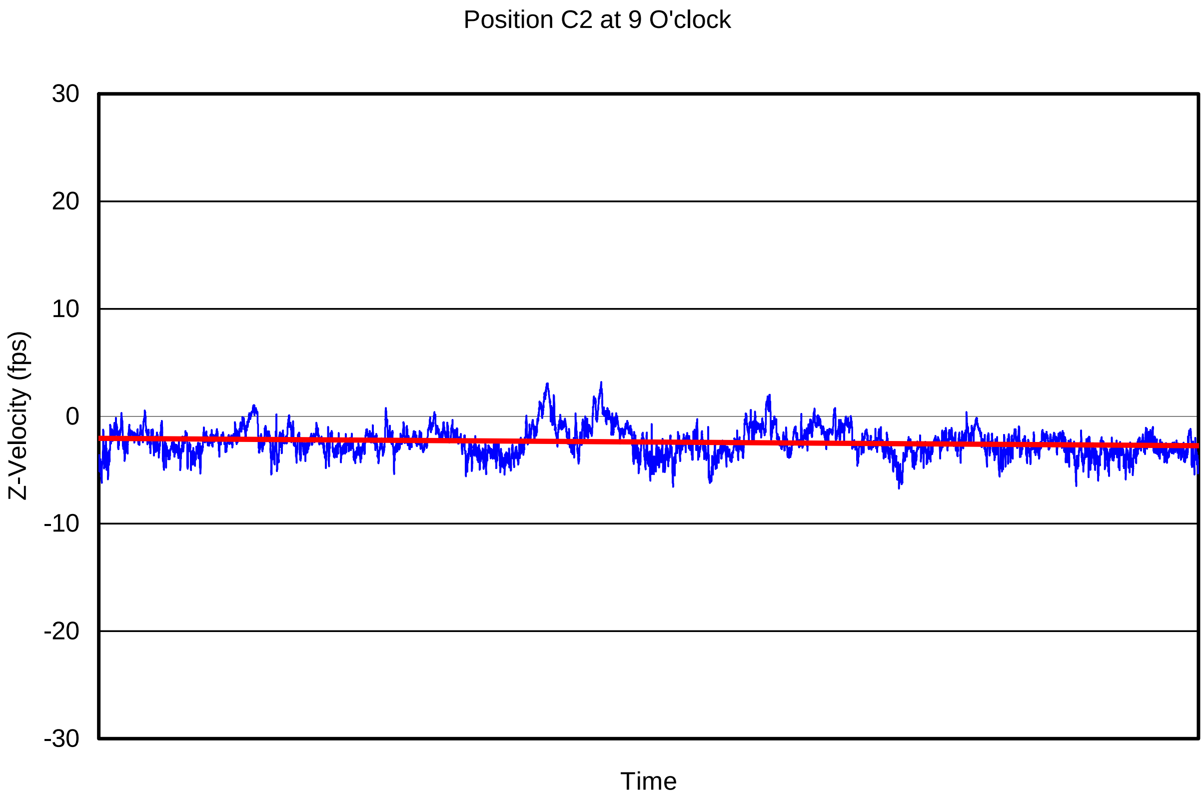


Figure A.6. Time series of the z-component of velocities measured at location C2 (Figure 3.1a) with the ADV measurement point at the 9 o’clock position. The measurement point was 1.5 inches away from the lateral and the frequency of measurements was set at 25 Hz for a period of 10 minutes, i.e. 15,000 measurements.

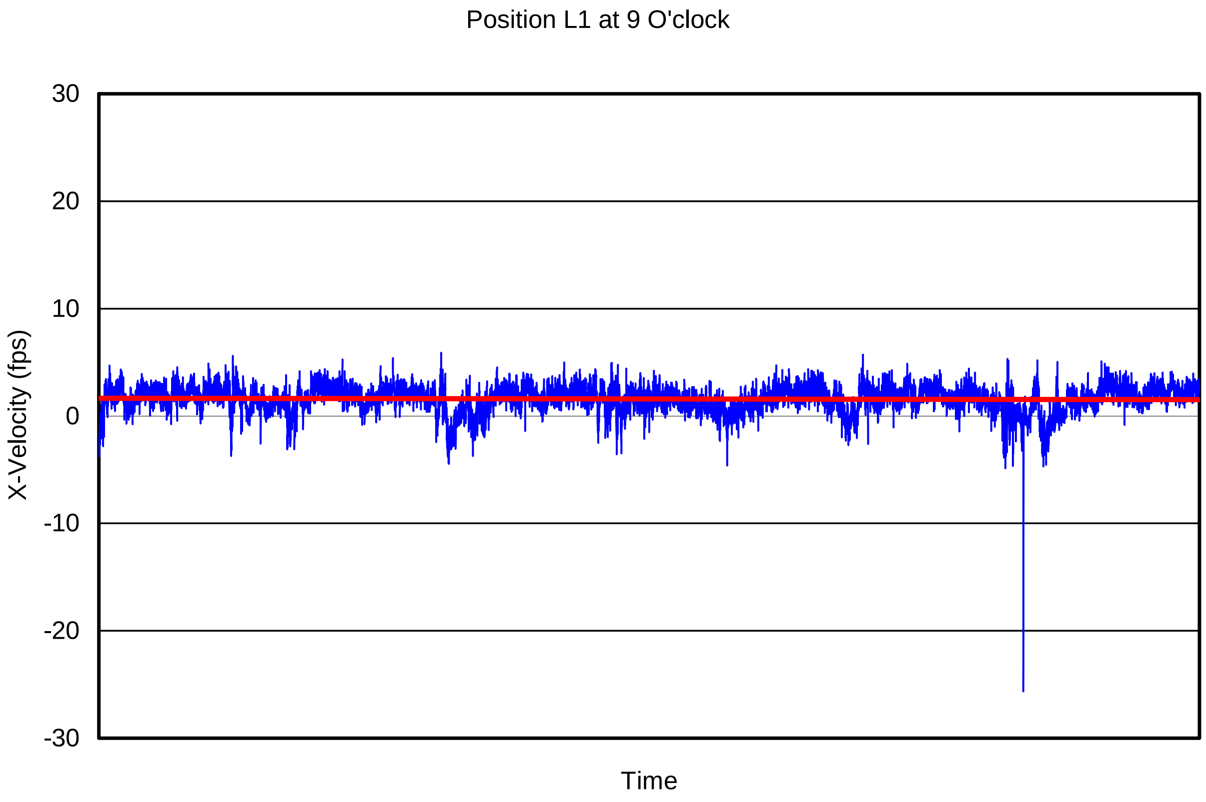


Figure A.7. Time series of the x-component of velocities measured at location L1 (Figure 3.1a) with the ADV measurement point at the 9 o'clock position. The measurement point was 1.5 inches away from the lateral and the frequency of measurements was set at 25 Hz for a period of 10 minutes, i.e. 15,000 measurements.

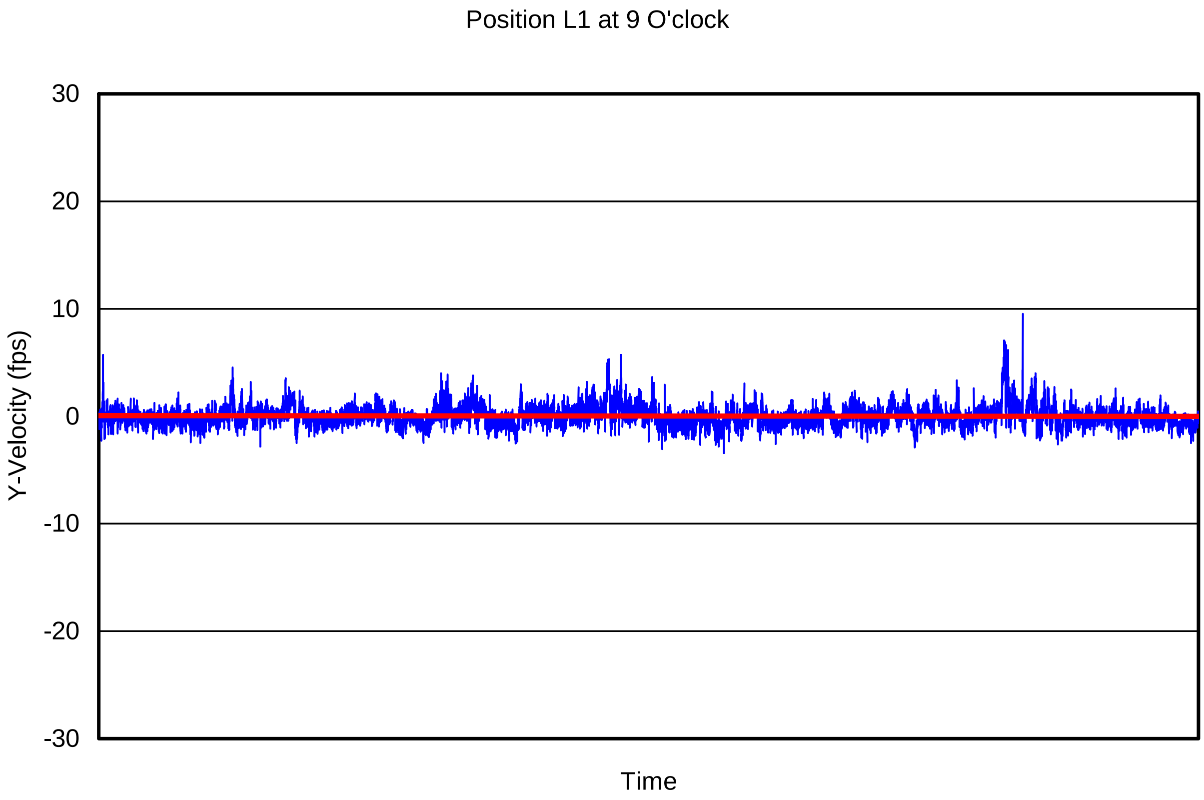


Figure A.8. Time series of the y-component of velocities measured at location L1 (Figure 3.1a) with the ADV measurement point at the 9 o'clock position. The measurement point was 1.5 inches away from the lateral and the frequency of measurements was set at 25 Hz for a period of 10 minutes, i.e. 15,000 measurements.

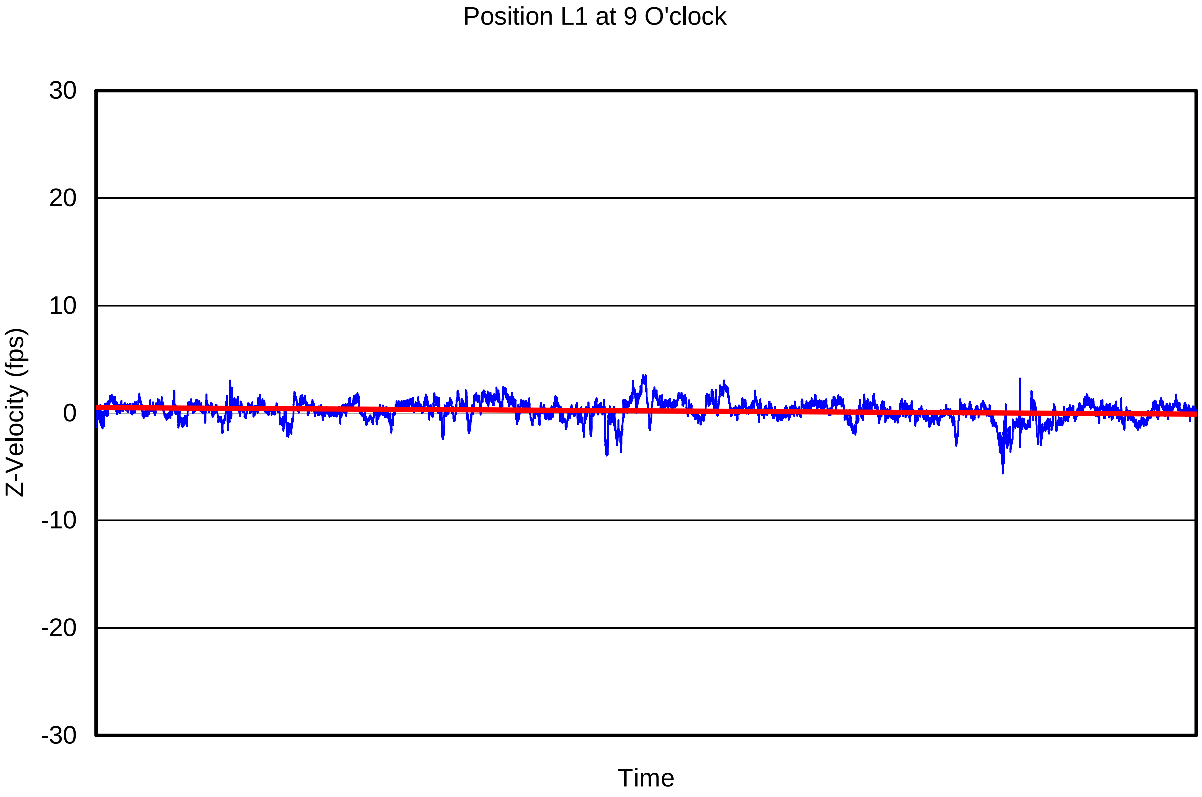


Figure A.9. Time series of the z-component of velocities measured at location L1 (Figure 3.1a) with the ADV measurement point at the 9 o’clock position. The measurement point was 1.5 inches away from the lateral and the frequency of measurements was set at 25 Hz for a period of 10 minutes, i.e. 15,000 measurements.