The attached document contains the results of tests of the
Marsh-McBirney 'Flo-Tote 3' Open Channel Flowmeter

as performed by:
Alden Research Laboratory, Inc.
Holden, Massachusetts USA
July 2003

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TESTS OF
OPEN CHANNEL FLOW METERS IN 36" PIPE
MARSH McBIRNEY, INC.
PURCHASE ORDER NUMBER QPO001299
JULY 2003 - ARL NO.160B-03/C780

CERTIFIED BY

James B. Nystrom

ALDEN RESEARCH LABORATORY, INC.
30 SHREWSBURY STREET
HOLDEN, MASSACHUSETTS 01520

INTRODUCTION

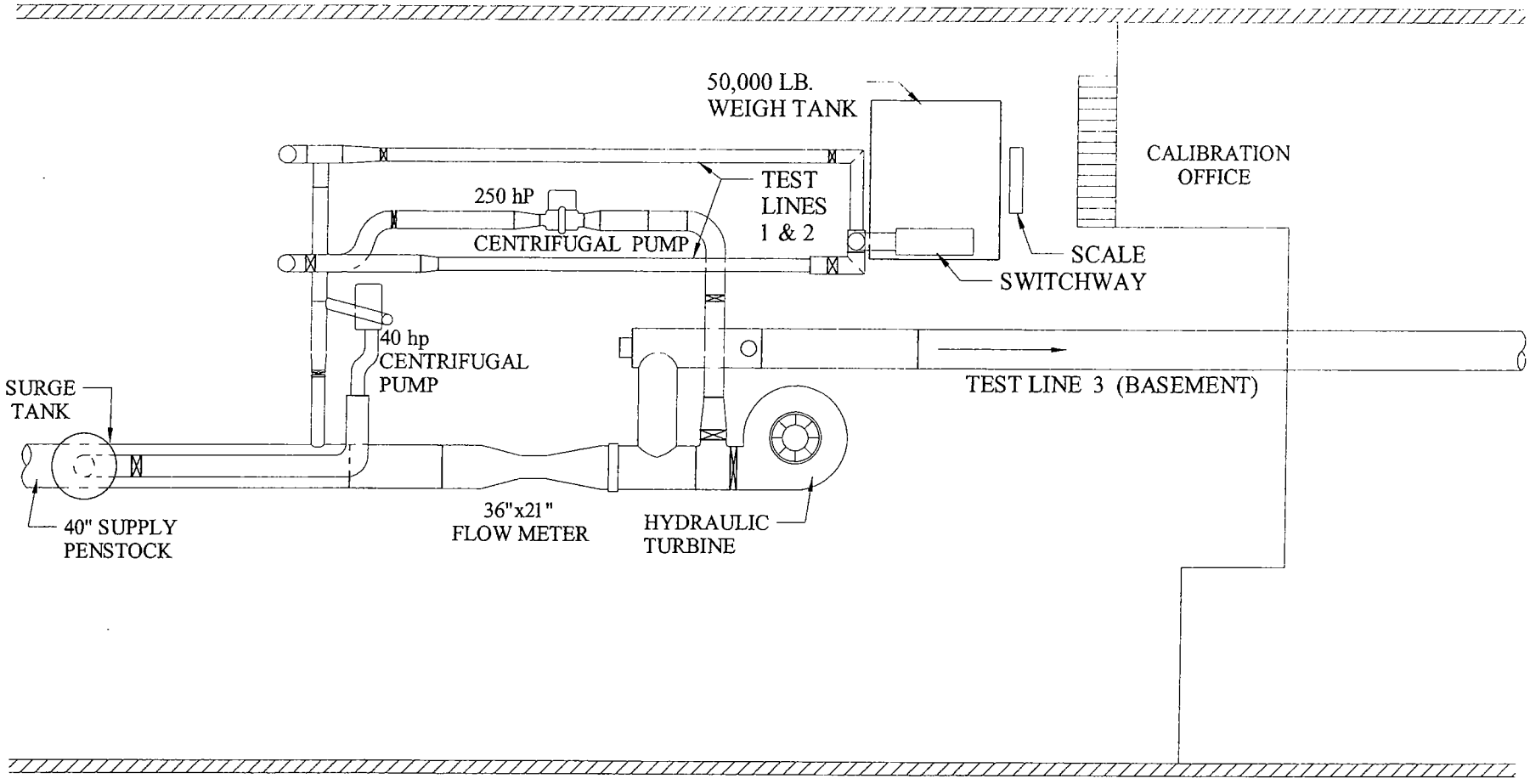
An open channel flow meter, Flo-Tote 3 Serial Number AC0101 , was tested in 36" pipe at Alden Research Laboratory, Inc. (Alden) for Marsh McBirney, Inc. under their Purchase Order Number QPO001299, using Alden's standard test procedures, QA-AGF-7-86 Revision 6. Flow meter performance is presented as deviation of meter output for flow from actual in percent of reading versus depth, in both tabular and graphical format.

FLOW METER INSTALLATION

The flow meter was installed in Test Line 3 in Building 2 shown in plan view on Figure 1. Water was provided through a 40" penstock from the main Laboratory pond resulting in a gross gravity head of approximately 28 feet. A calibrated 36" by 21" master Venturi measured flows greater than about 2,000 GPM and lower flows were measured with a 12" by 6" Venturi, which had been calibrated immediately before and after testing versus a 50,000 lb capacity weigh tank. The detailed piping arrangement, immediately upstream and downstream of the flow meter installation location, is shown in Figure 2 including all significant fittings and pipe lengths. A downstream butterfly valve, installed with the shaft vertical, was normally in the fully open position such that the flow control was the free discharge. An upstream control valve was used to set each flow. The 12" by 6" Venturi discharge was piped from test line 1 to Line 3 through a 12" line discharging vertically downward upstream of the flow straightener in Line 3. For some tests the valve was used as a control to obtain lower velocities.

A piezometer was installed 2 feet upstream of the entrance to the tee in which the meters were installed. A pressure transducer was used to read the water level at the piezometer.

Figure 1

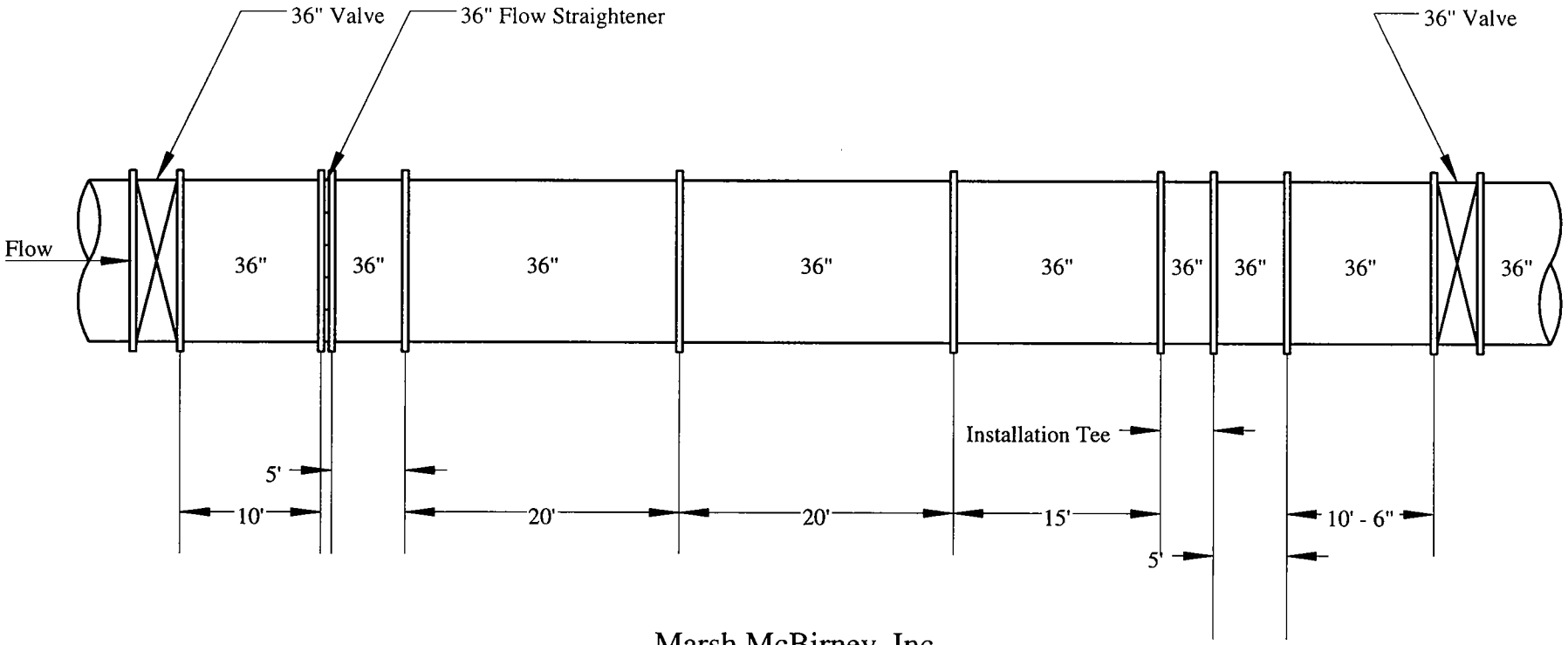


Hooper Low Reynolds Number Facility

Test Line 1, 2 & 3

ALDEN

Figure 2 Plan View Hooper Facility Line 3



Marsh McBirney, Inc.
Purchase Order Number: QPO001299
OPEN CHANNEL TEST

July 2003

FLOW MEASUREMENT METHOD

Flow was measured using Alden's 36" by 21" Master Venturi in the 40" supply penstock and a specially installed 12" by 8" Venturi in test line 1, both of which were calibrated using the gravimetric method (50,000 lb weigh tank) and a transfer standard venturi. The Master Venturi performance is characterized by plotting the discharge coefficient versus pipe Reynolds number. Flow is calculated by Equation (1).

$$q_a = C_{mV} K_m \sqrt{\Delta h_m} \qquad (1)$$

where q_a = actual flow, $\frac{ft^3}{sec}$

C_{mV} = Master Venturi discharge coefficient, dimensionless

K_{mV} = Master Venturi constant, $20.6091 \frac{ft^{2.5}}{sec}$

Δh_m = Master Venturi differential head, ft

The same equation with a different Venturi constant was used with a different meter coefficient, which was used to calculate flow for the 12" by 8" Venturi. The Venturi was calibrated in place versus the 50,000 lb capacity weigh tank in the Hooper Facility before and after testing.

TEST PROCEDURE

Marsh McBirney personnel installed their own equipment using the tee for access. A calibration flow was set up using about half full depth so that the equipment could be properly set up. That flow and level measured by Alden equipment was supplied to Marsh McBirney. Typically, the downstream control valve was left wide open and the upstream control valve was used to set the

water level. For accuracy testing after the system was allowed to stabilize, typically five average readings with a two minute duration were recorded by a computer based data acquisition system to determine flow and level for Alden data. The test equipment was set to log one minute of depth, flow, and velocity with a time stamp. The average Master Venturi flow, water level, and water temperature were recorded on a data sheet with the time of day. The control valve was then adjusted to the next flow and the procedure repeated.

FLOW METER SIGNAL RECORDING

The Master Venturi and 12" by 6" Venturi flow meter output was recorded by one of several "Smart" differential pressure transmitters having ranges of 25" W.C., 250" W.C., and 1000" W.C.. Each transmitter was calibrated with a pneumatic or a hydraulic dead weight tester having an accuracy of 0.02% of reading. Transmitter signals were recorded by a PC based data acquisition system having a 16 bit A to D board. Transmitter calibrations were conducted with the PC system such that an end to end calibration was achieved. Transmitter output was read simultaneously with the diversion of flow into the weigh tank at a rate of about 34 Hz for each test run (flow) and averaged to obtain a precise differential head. A similar transmitter with a range of 250" WC was used to measure the water level in the pipe using a pressure tap at the bottom of the pipe just upstream of the tee and a reference water level pot filled to the level of the invert. The level and Venturi meter outputs were measured and averaged simultaneously.

TEST RESULTS

The flow meter data logged outputs of level, velocity and flow over the entire test period and a data file was provided at the end of testing. The Appendix includes a printout of the data supplied. The raw data was averaged over the time period Alden averaged flow and depth and the averaged data is outlined by a box. Alden data, including the time of day, measured master meter flow, line temperature, and the water level at the piezometer are shown the table. For comparison to the test flow meter readings, the two Alden readings were averaged for each test depth. Initially, a setup

test at about half full pipe was recorded and flow and depth data was provided to Marsh McBirney personnel.

Test results are summarized for each test depth as a table of time of day, Alden flow and depth and the meter flow averaged over the same time period as the Alden average. The deviation the flow from the Alden average of two readings is shown as a percent of reading in a table. Deviation of flow is plotted versus depth with the average deviation shown.

Analysis indicates that the flow measurement uncertainty is within 0.50% of the true value for each test run. Calibrations of the test instrumentation (temperature, time, weight, and length measurements) are traceable to the National Institute of Standards and Technology (formerly the National Bureau of Standards) and Alden's Quality Assurance Program is designed to meet ANSI/NCSL Z540-1-1994 "Calibration Laboratories and Test Equipment-General Requirements" (supercedes MIL-STD-45662A).

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MARSH McBIRNEY, INC.

Purchase Order Number: QPO001299
OPEN CHANNEL TEST #1 FLO-TOTE 3
Serial Number: AC0101

CALIBRATION
DATE: July 17, 2003
PIPE DIAMETER = 35.307

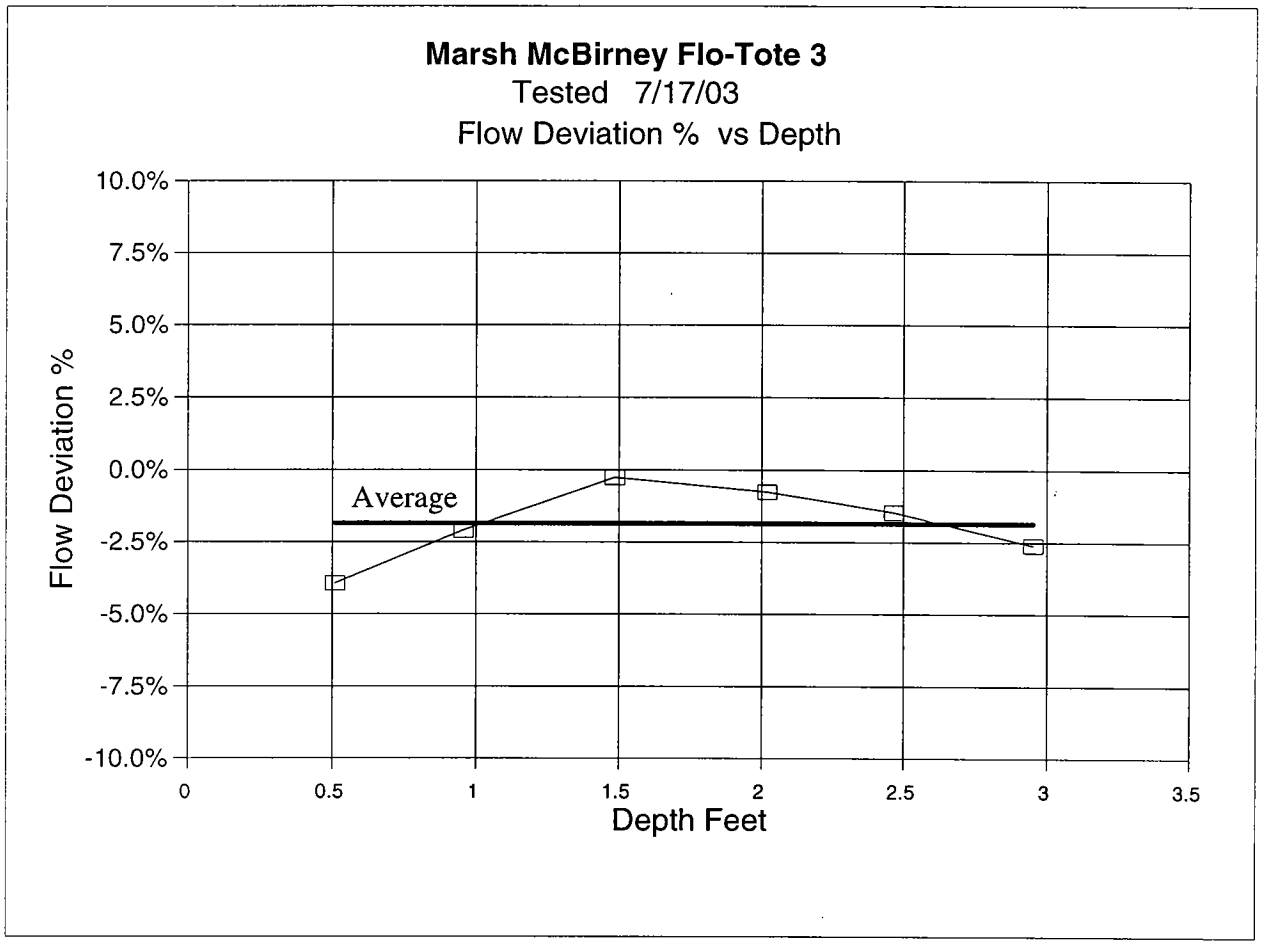
Run #	Time of Day	Line Temp Deg F	Air Temp Deg F	Output [see note]	Flow GPM	Level Feet	Flo-Tote 3 Reading GPM	Deviation Percent
1	09:25	73	65	2.600~	4797.3	1.559	4852	1.3
2	09:30	73	65	2.600~	4787.1	1.558		
3	09:47	73	65	2.197~	306.7	0.511	295	-3.9
4	09:52	73	65	2.196~	307.7	0.508		
5	10:10	73	65	2.369~	1544.3	0.957	1512	-2.1
6	10:15	73	65	2.369~	1545.4	0.957		
7	10:34	73	65	2.573~	4323.1	1.487	4310	-0.3
8	10:38	73	65	2.572~	4318.6	1.486		
9	10:49	74	67	2.778~	8188.6	2.021	8125	-0.8
10	10:53	74	67	2.778~	8186.4	2.021		
11	11:05	75	67	2.949~	12128.8	2.467	11946	-1.5
12	11:10	75	67	2.949~	12117.8	2.466		
13	11:20	75	67	3.136~	16748.9	2.952	16303	-2.6
14	11:24	75	67	3.136~	16732.0	2.952		

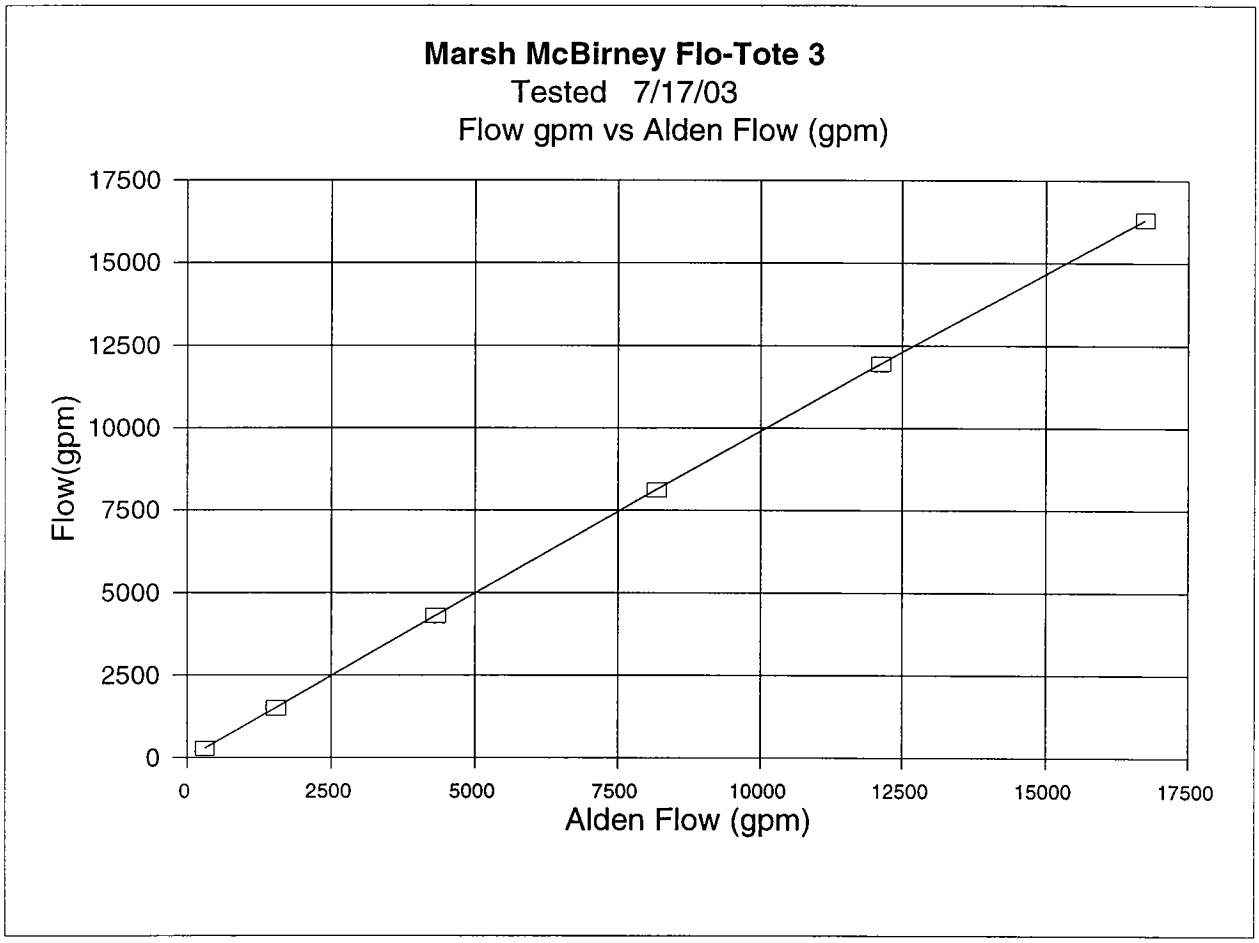
~ dp transmitter volts

The data reported on herein was obtained by measuring equipment the calibration of which is traceable to NIST , following the installation and test procedures referenced in this report, resulting in a flow measurement uncertainty of +/- 0.25% or less.

CALIBRATED BY: GRK

CERTIFIED BY:


Marsh McBirney Flo-Tote 3
Tested 7/17/03
Flow Deviation % vs Depth
10.0%
7.5%
5.0%
2.5%
0.0%
-2.5%
-5.0%
-7.5%
-10.0%
Flow Deviation %
Average
0
0.5
1
1.5
2
2.5
3
3.5
Depth Feet


Marsh McBirney Flo-Tote 3
Tested 7/17/03
Flow gpm vs Alden Flow (gpm)
Flow(gpm)
17500
15000
12500
10000
7500
5000
2500
0
0
2500
5000
7500
10000
12500
15000
17500
Alden Flow (gpm)

WATER DENSITY

Temperature Fahrenheit	Density lb_m / ft^3	Temperature Fahrenheit	Density lb_m / ft^3	Temperature Fahrenheit	Density lb_m / ft^3
32	62.4179	62	62.3549	92	62.0903
33	62.4201	63	62.3489	93	62.0788
34	62.4220	64	62.3427	94	62.0671
35	62.4235	65	62.3363	95	62.0552
36	62.4246	66	62.3296	96	62.0432
37	62.4255	67	62.3228	97	62.0311
38	62.4260	68	62.3157	98	62.0188
39	62.4262	69	62.3084	99	62.0063
40	62.4261	70	62.3010	100	61.9937
41	62.4257	71	62.2933	101	61.9810
42	62.4250	72	62.2855	102	61.9681
43	62.4240	73	62.2774	103	61.9551
44	62.4227	74	62.2692	104	61.9419
45	62.4211	75	62.2608	105	61.9286
46	62.4193	76	62.2522	106	61.9151
47	62.4171	77	62.2434	107	61.9015
48	62.4147	78	62.2344	108	61.8878
49	62.4121	79	62.2252	109	61.8739
50	62.4092	80	62.2159	110	61.8599
51	62.4060	81	62.2063	111	61.8458
52	62.4025	82	62.1966	112	61.8315
53	62.3988	83	62.1868	113	61.8172
54	62.3949	84	62.1767	114	61.8027
55	62.3907	85	62.1665	115	61.7880
56	62.3863	86	62.1561	116	61.7733
57	62.3816	87	62.1456	117	61.7584
58	62.3768	88	62.1348	118	61.7434
59	62.3716	89	62.1239	119	61.7284
60	62.3663	90	62.1129	120	61.7132
61	62.3607	91	62.1017	121	61.6978

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APPENDIX

DATA LOG FILE WITH AVERAGES

MMI Flo-Tote III Data ---July 17, 2003

Velocity	Level	Flow	Calc Time			
0.000	0.419	0	09:11:57 AM			
0.000	0.420	0	09:12:38 AM			
0.000	0.425	0	09:13:19 AM			
0.000	0.423	0	09:14:00 AM			
0.000	0.423	0	09:14:41 AM			
0.000	0.421	0	09:15:21 AM			
0.000	0.420	0	09:16:02 AM			
0.000	0.421	0	09:16:43 AM			
1.252	2.483	0.609	09:17:24 AM			
2.202	10.749	2.9	09:18:05 AM			
2.067	15.063	4.6	09:18:46 AM			
2.100	16.553	5.4	09:19:27 AM			
2.472	17.567	6.9	09:20:08 AM			
2.443	18.585	7.3	09:20:49 AM			
2.433	18.776	7.4	09:21:30 AM			
2.447	18.705	7.4	09:22:11 AM			
2.455	18.743	7.5	09:22:52 AM			
2.569	18.805	2309.7	09:23:47 AM			
2.617	18.759	5126.9	09:24:28 AM	2.475	18.772	4852.250
2.454	18.713	4790.0	09:25:09 AM	2.5	18.8	4852.2
2.397	18.769	4695.5	09:25:50 AM	2.5	18.8	4852.2
2.518	18.800	4947.7	09:26:31 AM	2.5	18.8	4852.2
2.466	18.722	4816.2	09:27:12 AM	2.5	18.8	4852.2
2.529	18.796	4967.5	09:27:53 AM	2.5	18.8	4852.2
2.449	18.812	4816.1	09:28:34 AM	2.5	18.8	4852.2
2.412	18.800	4737.5	09:29:15 AM	2.5	18.8	4852.2
2.519	18.725	4920.0	09:29:56 AM	2.5	18.8	4852.2
2.388	18.784	4686.6	09:30:37 AM	2.5	18.8	4852.2
2.477	18.809	4870.6	09:31:18 AM	2.5	18.8	4852.2
2.363	18.787	4638.9	09:31:59 AM			
2.417	18.838	4760.8	09:32:40 AM			
2.553	18.731	4991.4	09:33:23 AM			
2.503	18.682	4875.5	09:34:06 AM			
2.539	18.769	4979.8	09:34:50 AM			
2.447	18.824	4816.0	09:35:34 AM			
2.541	18.716	4963.9	09:36:17 AM			
2.348	18.788	4609.3	09:37:01 AM			
2.407	18.749	4711.0	09:37:43 AM			
2.431	18.743	4756.0	09:38:26 AM			
2.442	18.732	4772.4	09:39:10 AM			
2.372	18.775	4652.2	09:39:53 AM			
1.825	15.712	2864.0	09:40:37 AM			
1.160	10.235	940.5	09:41:18 AM			
0.933	8.180	532.5	09:42:00 AM			
0.895	7.337	430.2	09:42:40 AM			
0.859	6.924	375.8	09:43:22 AM			
0.767	6.664	316.5	09:44:03 AM			
0.795	6.499	315.3	09:44:44 AM			
0.799	6.406	309.4	09:45:25 AM	0.778	6.321	295.124
0.811	6.349	309.7	09:46:05 AM	0.8	6.3	295.1
0.793	6.329	301.5	09:46:46 AM	0.8	6.3	295.1
0.792	6.313	299.8	09:47:27 AM	0.8	6.3	295.1

0.774	6.308	292.5	09:48:11 AM	0.8	6.3	295.1
0.781	6.302	294.6	09:48:54 AM	0.8	6.3	295.1
0.756	6.309	285.8	09:49:36 AM	0.8	6.3	295.1
0.744	6.288	279.8	09:50:17 AM	0.8	6.3	295.1
0.739	6.309	279.6	09:50:58 AM	0.8	6.3	295.1
0.757	6.305	285.7	09:51:39 AM	0.8	6.3	295.1
0.815	6.309	307.9	09:52:20 AM	0.8	6.3	295.1
0.745	6.305	281.6	09:53:01 AM			
0.787	6.296	296.5	09:53:44 AM			
0.739	6.317	279.8	09:54:26 AM			
0.757	6.311	286.4	09:55:06 AM			
0.772	6.308	291.8	09:55:47 AM			
0.766	6.296	288.7	09:56:29 AM			
1.225	7.503	623.1	09:57:09 AM			
1.452	9.746	1083.3	09:57:50 AM			
1.438	10.723	1243.8	09:58:31 AM			
1.493	11.189	1376.1	09:59:12 AM			
1.455	11.463	1391.0	09:59:54 AM			
1.563	11.554	1513.4	10:00:35 AM			
1.587	11.611	1547.5	10:01:16 AM			
1.571	11.607	1530.6	10:01:57 AM			
1.614	11.615	1574.5	10:02:38 AM			
1.544	11.629	1509.0	10:03:19 AM			
1.558	11.625	1521.7	10:04:00 AM			
1.513	11.640	1480.1	10:04:40 AM			
1.598	11.617	1558.8	10:05:21 AM			
1.547	11.597	1505.9	10:06:02 AM			
1.551	11.637	1517.4	10:06:43 AM			
1.500	11.624	1464.9	10:07:24 AM			
1.577	11.607	1536.2	10:08:05 AM	1.550	11.617	1512.424
1.535	11.603	1494.6	10:08:46 AM	1.6	11.6	1512.4
1.572	11.657	1542.2	10:09:27 AM	1.6	11.6	1512.4
1.510	11.604	1470.2	10:10:08 AM	1.6	11.6	1512.4
1.579	11.607	1538.9	10:10:51 AM	1.6	11.6	1512.4
1.557	11.613	1518.2	10:11:34 AM	1.6	11.6	1512.4
1.622	11.623	1583.6	10:12:16 AM	1.6	11.6	1512.4
1.530	11.653	1499.7	10:12:57 AM	1.6	11.6	1512.4
1.536	11.615	1498.2	10:13:37 AM	1.6	11.6	1512.4
1.505	11.613	1467.6	10:14:18 AM	1.6	11.6	1512.4
1.528	11.597	1487.4	10:14:59 AM	1.6	11.6	1512.4
1.556	11.615	1517.5	10:15:40 AM			
1.558	11.569	1510.7	10:16:21 AM			
1.508	11.609	1469.4	10:17:02 AM			
1.509	11.625	1474.2	10:17:43 AM			
1.575	11.639	1541.1	10:18:24 AM			
1.600	11.601	1557.9	10:19:05 AM			
1.527	11.606	1487.8	10:19:46 AM			
1.567	11.621	1529.8	10:20:27 AM			
1.526	11.605	1487.1	10:21:08 AM			
1.031	9.878	828.5	10:21:49 AM			
2.399	14.054	3001.6	10:22:30 AM			
2.291	16.901	3879.5	10:23:11 AM			
2.316	17.470	4109.4	10:23:52 AM			
2.201	17.787	4003.0	10:24:33 AM			

2.354	17.803	4288.4	10:25:14 AM			
2.327	17.936	4282.0	10:25:55 AM			
2.237	17.889	4100.1	10:26:36 AM			
2.406	17.918	4421.0	10:27:17 AM			
2.288	17.911	4201.4	10:27:58 AM			
2.354	17.855	4303.9	10:28:39 AM			
2.381	17.837	4345.8	10:29:20 AM			
2.425	17.889	4444.9	10:30:01 AM			
2.319	17.869	4245.4	10:30:42 AM			
2.390	17.827	4361.8	10:31:23 AM			
2.338	17.834	4270.6	10:32:04 AM	2.354	17.873	4309.518
2.375	17.909	4361.8	10:32:46 AM	2.4	17.9	4309.5
2.353	17.865	4307.5	10:33:30 AM	2.4	17.9	4309.5
2.406	17.877	4406.4	10:34:13 AM	2.4	17.9	4309.5
2.290	17.902	4202.1	10:34:56 AM	2.4	17.9	4309.5
2.331	17.870	4265.8	10:35:40 AM	2.4	17.9	4309.5
2.332	17.889	4273.1	10:36:21 AM	2.4	17.9	4309.5
2.378	17.903	4364.2	10:37:02 AM	2.4	17.9	4309.5
2.351	17.827	4290.4	10:37:43 AM	2.4	17.9	4309.5
2.428	17.852	4438.0	10:38:24 AM	2.4	17.9	4309.5
2.307	17.876	4224.7	10:39:05 AM	2.4	17.9	4309.5
2.391	17.873	4378.9	10:39:46 AM			
2.265	17.877	4148.1	10:40:27 AM			
2.421	18.213	4580.1	10:41:08 AM			
2.842	22.777	7107.6	10:41:49 AM			
3.158	24.049	8425.1	10:42:30 AM			
3.045	24.063	8126.0	10:43:11 AM			
3.068	24.189	8237.3	10:43:52 AM			
2.977	24.113	7964.5	10:44:33 AM			
2.977	24.131	7972.0	10:45:14 AM			
3.010	24.111	8053.2	10:45:55 AM			
3.051	24.102	8157.4	10:46:37 AM			
3.008	24.173	8072.1	10:47:18 AM	3.034	24.137	8125.240
3.071	24.114	8217.5	10:47:58 AM	3.0	24.1	8125.2
2.997	24.144	8029.6	10:48:39 AM	3.0	24.1	8125.2
3.006	24.110	8041.4	10:49:20 AM	3.0	24.1	8125.2
2.938	24.134	7865.0	10:50:01 AM	3.0	24.1	8125.2
2.927	24.115	7832.0	10:50:42 AM	3.0	24.1	8125.2
3.033	24.093	8107.1	10:51:23 AM	3.0	24.1	8125.2
3.056	24.239	8225.7	10:52:04 AM	3.0	24.1	8125.2
3.179	24.135	8514.1	10:52:45 AM	3.0	24.1	8125.2
3.123	24.097	8348.2	10:53:26 AM	3.0	24.1	8125.2
3.031	24.149	8124.9	10:54:07 AM	3.0	24.1	8125.2
3.072	24.168	8241.1	10:54:48 AM			
2.963	24.161	7942.5	10:55:29 AM			
3.061	24.050	8162.3	10:56:10 AM			
3.395	26.135	9965.3	10:56:51 AM			
3.417	28.026	10754.9	10:57:32 AM			
3.633	28.730	11706.9	10:58:13 AM			
3.623	29.215	11849.7	10:58:54 AM			
3.599	29.266	11790.1	10:59:35 AM			
3.665	29.429	12061.3	11:00:16 AM			
3.655	29.469	12049.4	11:00:57 AM			
3.645	29.249	11933.4	11:01:39 AM			

3.688	29.456	12148.5	11:02:20 AM			
3.635	29.422	11965.9	11:03:00 AM	3.631	29.412	11945.451
3.490	29.439	11489.9	11:03:41 AM	3.6	29.4	11945.5
3.615	29.401	11890.8	11:04:25 AM	3.6	29.4	11945.5
3.454	29.337	11338.5	11:05:07 AM	3.6	29.4	11945.5
3.713	29.478	12237.2	11:05:51 AM	3.6	29.4	11945.5
3.795	29.425	12488.8	11:06:34 AM	3.6	29.4	11945.5
3.606	29.341	11838.6	11:07:18 AM	3.6	29.4	11945.5
3.650	29.434	12017.8	11:08:00 AM	3.6	29.4	11945.5
3.607	29.404	11862.2	11:08:41 AM	3.6	29.4	11945.5
3.626	29.426	11931.3	11:09:23 AM	3.6	29.4	11945.5
3.749	29.421	12338.9	11:10:06 AM	3.6	29.4	11945.5
3.713	29.403	12210.6	11:10:50 AM			
3.682	29.375	12102.1	11:11:33 AM			
3.655	29.338	11997.5	11:12:14 AM			
3.676	29.383	12087.3	11:12:57 AM			
4.736	34.817	16713.6	11:13:40 AM			
4.650	35.129	16359.5	11:14:23 AM			
4.803	35.223	16868.4	11:15:07 AM			
4.635	35.217	16273.7	11:15:50 AM			
4.832	35.100	17028.1	11:16:34 AM			
4.661	35.166	16391.8	11:17:17 AM			
4.560	35.075	16066.6	11:17:58 AM	4.639	35.175	16302.820
4.896	35.257	17166.8	11:18:39 AM	4.6	35.2	16302.8
4.612	35.137	16201.8	11:19:20 AM	4.6	35.2	16302.8
4.595	35.087	16158.5	11:20:02 AM	4.6	35.2	16302.8
4.677	35.028	16515.8	11:20:43 AM	4.6	35.2	16302.8
4.718	35.242	16555.5	11:21:24 AM	4.6	35.2	16302.8
4.714	35.347	16517.5	11:22:07 AM	4.6	35.2	16302.8
4.557	35.276	15979.0	11:22:48 AM	4.6	35.2	16302.8
4.461	35.129	15697.0	11:23:29 AM	4.6	35.2	16302.8
4.599	35.170	16169.8	11:24:10 AM	4.6	35.2	16302.8
4.673	35.109	16446.5	11:24:51 AM			
4.764	35.054	16794.3	11:25:33 AM			
4.570	35.126	16069.4	11:26:14 AM			
4.691	35.166	16494.3	11:26:55 AM			