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Verification Testing of the Lane Enterprises SK75 Stormkeeper Chamber Sediment Strip and Prinsco Hydrostor HS75 Sediment Row In Accordance with the NJDEP Laboratory Protocol to Assess Total Suspended Solids Removal by a Filtration Manufactured Treatment Device, 2013

Technical Evaluation Report

Alden Report No. : 1162LESSCSVT

Submitted to:

Lane Enterprises

Camp Hill, PA

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1.0 INTRODUCTION

Under a contract from Lane Enterprises (Lane), verification testing was conducted on the Lane Enterprises SK75 Stormkeeper Chamber Sediment Strip and Prinsco Hydrostor HS75 Sediment Row treatment system, at Alden Research Laboratory, Inc. (Alden), Holden, Massachusetts.

The purpose of the testing was to define the performance characteristics of the sediment strip chamber under controlled laboratory conditions, utilizing established standard testing methodologies. The testing was conducted in accordance with "New Jersey Department of Environmental Protection Laboratory Protocol to Assess Total Suspended Solids Removal by a Filtration Manufactured Treatment Device", 2013, to establish the following parameters:

a) **Hydraulic Characteristic Curves:**

b) **Sediment Removal Efficiency at Maximum Treatment Flow Rate (MTFR)**

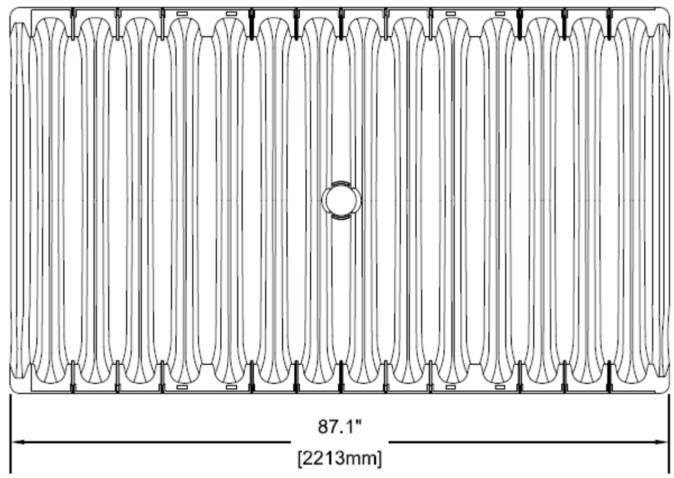
c) **Filter Blinding (Occlusion) or maintenance statement.**

d) **At a minimum, the particle size distribution of the influent material for sediment test conditions.**

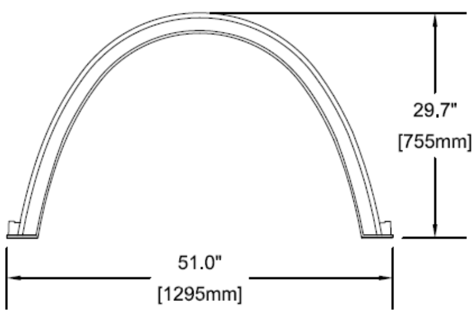
2.0 TEST UNIT DESCRIPTION

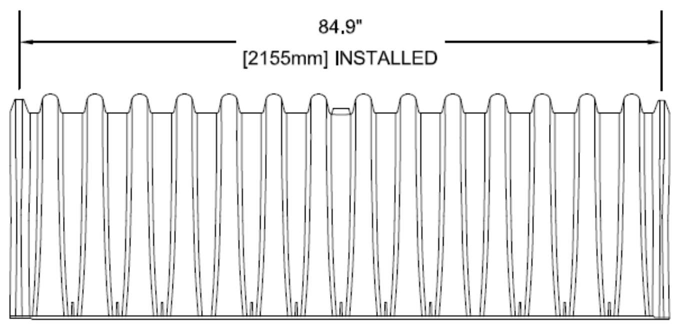
The tested treatment chamber was an arched stormwater detention/retention sediment collection and filtering device, measuring approximately 51" wide x 30" high x 7 ft long. Both ends of the chamber were sealed with the use of end caps. A water-tight tank was used to house the test chamber system. The chamber was installed on top of a 1-ft base of ¾"-2" double-washed stone containing a 6" underdrain pipe, which penetrated the downstream tank wall. Two layers of woven Geotextile fabric were placed between the stone base and chamber to collect particulate contaminants, as well as protect the stone base from scouring. The fabric had an open-area of 1% and opening size of 425 microns. The top fabric layer was used to fully wrap the chamber and end caps. The chamber floor filtration area was approximately 30 ft^2. Water was conveyed into the chamber by means of a 12" inlet pipe, which penetrated the upstream end cap. The junction was wrapped in non-woven fabric. The invert of the pipe was approximately flush with the chamber floor. Additional stone was installed around the outside of the chamber until fully buried. A 4-inch x 2-ft tall PVC standpipe was installed into the crown of the chamber. In a typical installation, water passing through the base fabric seeps into the stone base and is either re-infiltrated into the surrounding soil, enter the underdrain and is conveyed into an outlet control structure, or is distributed into other chambers in the stormwater management system. Although the primary function of the sediment strip chamber is to capture and retain sediment particles, the Geotextile membrane possesses filtering characteristics and therefore, was tested as such. On-line scour testing was not conducted, as the system is designed for an off-line application with the inclusion of an upstream bypass weir. The weir was not included in the laboratory set-up.

Drawings of the SK75 test unit are shown on **Figure 1**. A Photograph showing the wrapped unit installed in the test tank is shown on **Figure 2.** The final installation is shown on **Figure 3**. A photograph of the test loop is shown on **Figure 4**.



Chamber Specifications	
Chamber Size (L x W x H)	87.1" x 51.0" x 29.7" (2,212 x 1295 x 754 mm)
Installed Length	84.9" (2,156 mm)
Chamber Storage	46.4 ft^3 (1.31 m^3)
Min. Installed Storage*	74.9 ft^3 (2.12m^3)
Weight / Chamber	70 lbs (32 kg)
Chambers / Pallet	33
Approx. Weight / Pallet	2,500 lbs (1,134 kg)





End Cap Specifications	
End Cap Size (L x W x H)	11.6" x 48.1" x 29.4" (295 x 1,222 x 747 mm)
Installed Length	8.0" (203 mm)
End Cap Storage	2.75 ft^3 (0.08 m^3)
Min. Installed Storage*	12.02 ft^3 (0.34 m^3)
Weight	12 lbs (5.44 kg)

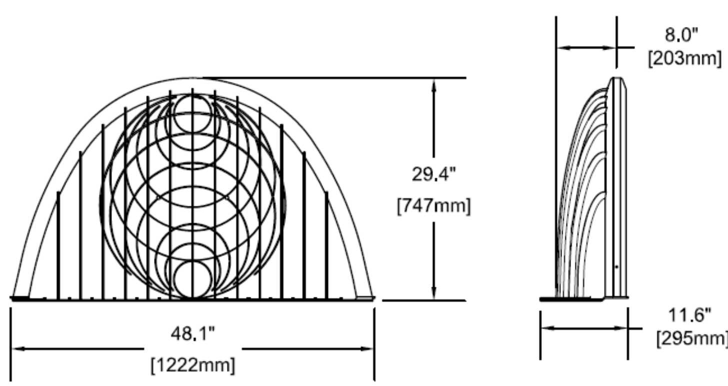


Figure 1: Drawing of the SK75 Treatment Unit

Figure 2: Lane SK75 Test Unit Installed in the Test Tank Prior to Backfilling

Figure 3: Lane SK75 Test Unit Fully Installed in the Test Tank

Figure 4: Photograph of the Test Set Up

3.0 MATERIALS AND METHODS

3.1 EXPERIMENTAL DESIGN

The SK75 test unit was installed in the Alden test loop, shown on **Figure 5,** which is set up as a recirculation system. The loop is designed to provide metered flow up to approximately 17 cfs. Flow was supplied to the unit with one or two selected laboratory pumps (20HP, 50HP), drawing water from a 50,000-gallon supply sump. The test flow was set and measured using one of five differential-pressure meters and corresponding control valves. A Differential Pressure (DP) cell and computer Data Acquisition (DA) program was used to record the test flow. 25 feet of straight 12-inch PVC influent pipe conveyed the metered flow to the unit. 2 feet of 6-inch PVC pipe free-discharged the effluent flows to a receiving tank, which contained a calibrated V-notch weir at the downstream end for measuring drawdown flow. The influent and effluent pipes were set at 1% slopes. A 12-inch tee was located 4 pipe-diameters (4 ft) upstream of the test unit for injecting sediment into the crown of the influent pipe using a variable-speed auger feeder.

Filtration of the supply sump, to reduce background concentration, was performed with an in-situ filter wall containing 1-micron bag filters.

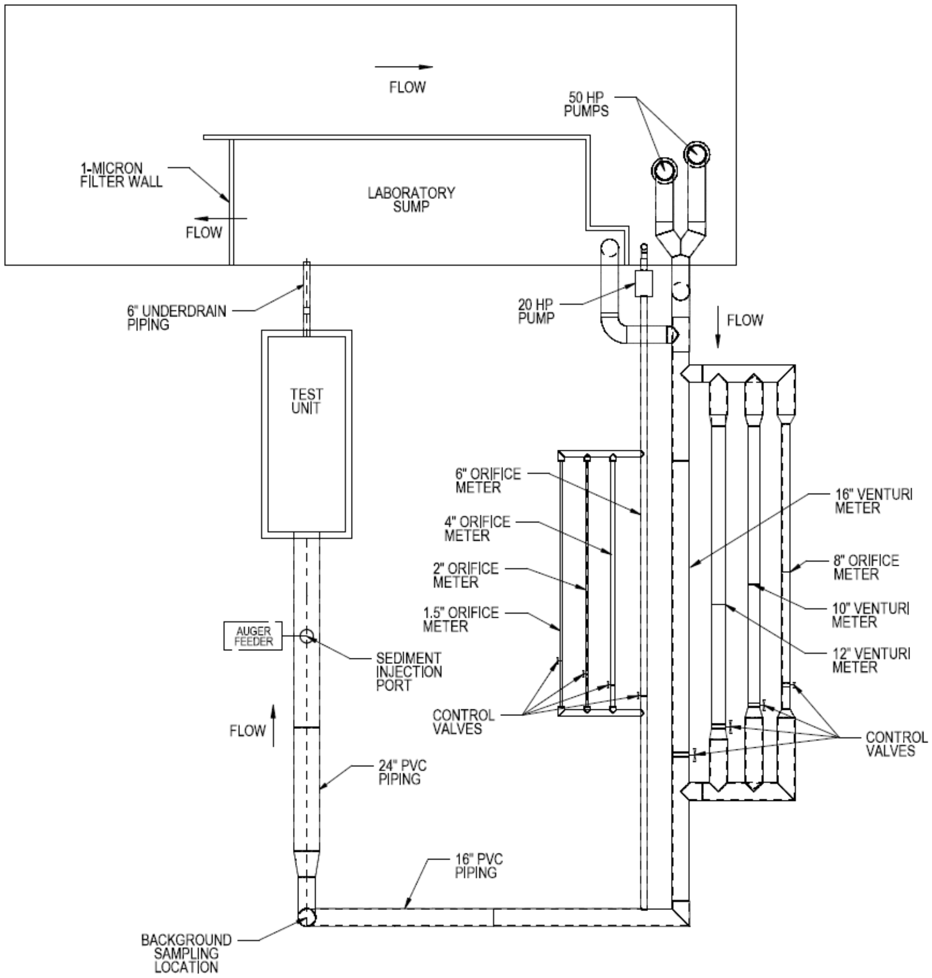


Figure 5: Plan View of Alden Flow Loop

3.1.1 Hydraulic Testing

The SK75 unit was tested with clean water to determine its hydraulic characteristic curves, including loss coefficients (Cd's) and/or K factors. Flow and water level measurements were recorded during steady-state flow conditions using a computerized Data-Acquisition (DA) system, which included a data collect program, 0-250" Rosemount Differential Pressure (DP) cell (flow), and Omegadyne PX419 0-2.5 psi Single-ended Pressure (SP) cell (water elevations). Flows were set and measured using the calibrated flow meters and control valves. Each test flow was set and operated at steady state for approximately 10 minutes, after which time a minimum of 30 seconds of flow and pressure data were averaged and recorded for each pressure tap location. Water elevations were measured above and below the fabric layer outside of the chamber. Measurements within the influent and effluent pipes were taken one pipe-diameter upstream and downstream of the unit.

3.1.2 Removal Efficiency Testing

Sediment testing was conducted to determine the removal efficiency, as well as sediment mass loading capacity.

The sediment testing was conducted on an initially clean system at the 100% MTFR of 120 gpm (as selected by Lane). A minimum of ten 30-minute test runs were required to be conducted. The captured sediment was not removed from the chamber between tests.

The total mass injected into the system was quantified at the conclusion of the 10 runs. This data was used for determination of the required maintenance frequency.

The test sediment was prepared by Alden to meet the PSD gradation of 1-1000 microns in accordance with the distribution shown in column 2 of **Table 1**. The sediment is silica based, with a specific gravity of 2.65. Three random PSD samples of the test sediment were analyzed by an independent certified analytical laboratory using ASTM D 422-63 (Reapproved 2007) "Standard Test Method for Particle Size Analysis of Soils". The average of the three samples was used for compliance with the protocol. Additional discussion of the sediment is presented in Section 3.4.

Table 1: Test Sediment Particle Size Distribution

Table 1: Test Sediment Particle Size Distribution[1]

Particle Size (Microns)	Target Minimum % Less Than[2]
1,000	100
500	95
250	90
150	75
100	60
75	50
50	45
20	35
8	20
5	10
2	5

1. The material shall be hard, firm, and inorganic with a specific gravity of 2.65. The various particle sizes shall be uniformly distributed throughout the material prior to use.
2. A measured value may be lower than a target minimum % less than value by up to two percentage points, A measured value may be lower than a target minimum % less than value by up to two percentage points (e.g., at least 3% of the particles must be less than 2 microns in size [target is 5%]), provided the measured d50 value does not exceed 75 microns..

The target influent sediment concentration was 200 mg/L (+/-20 mg/L) for all tests. The concentration was verified by collecting a minimum of three timed dry samples at the injector and correlating the data with the measured average flow to produce the resulting influent concentration values for each test. The allowed Coefficient of Variance (COV) for the measured samples is 0.10. The moisture content of the test sediment was determined using ASTM D4959-07 for each test conducted and was utilized in the final removal calculation.

The protocol requires the temperature of the supply water to be below 80 degrees F.

Five (5) time-stamped effluent samples were collected from the end of the pipe during each run. A minimum of three detention times were allowed to pass before collecting the sample when the sediment feed was interrupted for measurements. Three (3) background samples of the supply water were collected with each odd-numbered effluent sample (1, 3 & 5). Collected samples were analyzed for Suspended Solids Concentration (SSC) using the ASTM D3977-97 (2013).

At the conclusion of a run, the injection feed was stopped and time-stamped. The flow was stopped after one (1) detention time had passed. The drawdown flow was measured at the V-notch weir every five (5) seconds until the effluent was reduced to 1% of the test flow. Two (2) evenly-spaced effluent samples were collected from the pipe during drawdown.

3.2 INSTRUMENTATION AND MEASURING TECHNIQUES

Instrument calibrations are presented in **Appendix B**.

3.2.1 Influent Flow

The inflow to the test unit was measured using one of six (6) calibrated differential-pressure flow meters (2", 4", 6", 8", 10" or 12"). Each meter is fabricated per ASME guidelines and calibrated in Alden's Calibration Department prior to the start of testing. The high and low pressure lines from each meter were connected to manifolds containing isolation valves. Flows were set with a butterfly valve and the differential head from the meter was measured using a Rosemount® 0 to 250-inch Differential Pressure (DP) cell, also calibrated at Alden prior to testing. All pressure lines and cells were purged of air (bled) prior to the start of each test. The test flow was averaged and recorded every 5 seconds throughout the duration of the test using an in-house computerized data acquisition (DA) program. The accuracy of the flow measurement is ±2%. A photograph of the flow meters is shown on **Figure 6** and the pumps on **Figure 7.**

Figure 6: Photograph Showing Laboratory Flow Meters

Figure 7: Photograph Showing Laboratory Pumps

3.2.2 Drawdown Flow

The drawdown flow was measured with the use of a V-notch weir installed at the end of the effluent tank. The weir was fabricated in accordance with the Bureau of Reclamation Water Measurement Manual guidelines. The weir was calibrated through the full range of flows prior to initiating the removal testing. The calculated and measured weir curves are shown on **Figure 8**.

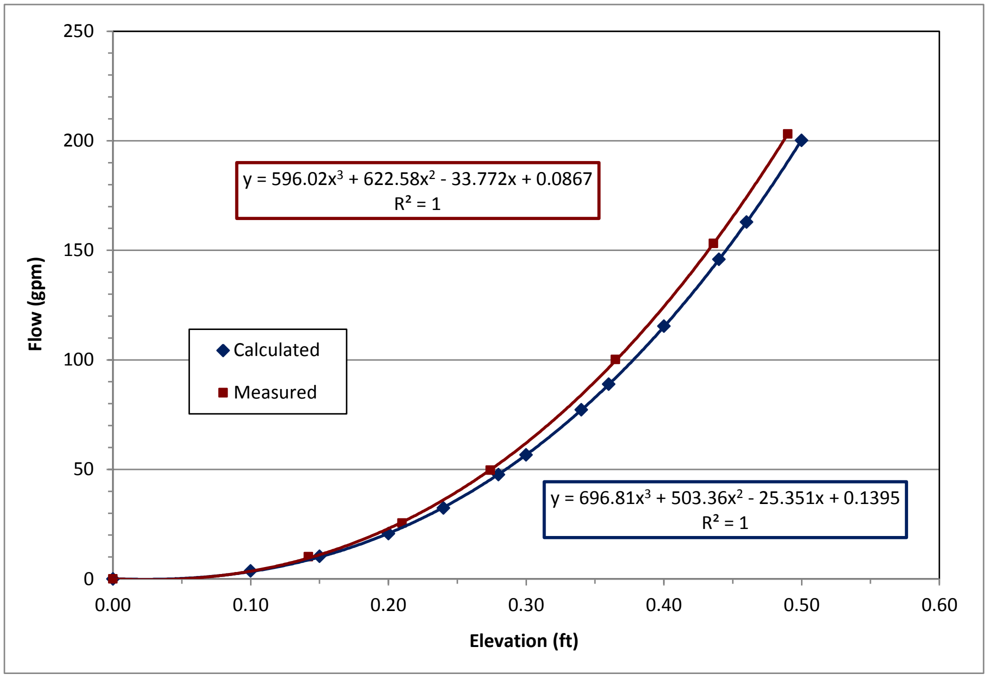


Figure 8: Drawdown V-notch Weir Flow vs Head Curves

3.2.3 Temperature

Water temperature measurements within the supply sump were obtained using a calibrated Omega® DP25 temperature probe and readout device. The calibration was performed at the laboratory prior to testing. The temperature reading was documented at the start and end of each test, to assure an acceptable testing temperature of less than 80 degrees F.

3.2.4 Pressure Head

Pressure head measurements were recorded at multiple locations using piezometer taps and a Omegadyne PX419, 0 - 2.5 psi cell. The pressure cell was calibrated at Alden prior to testing. Accuracy of the readings is ± 0.001 ft. The cell was installed at a known datum in relation to the tank floor, allowing for elevation readings through the full range of flows. A minimum of 30 seconds of pressure data was averaged and recorded for each pressure tap during hydraulic testing, under steady-state flow conditions, using the computerized DA program. Driving head and effluent weir measurements were averaged and recorded every 5-seconds during removal efficiency testing. A photograph of the pressure instrumentation is shown on **Figure 9**.

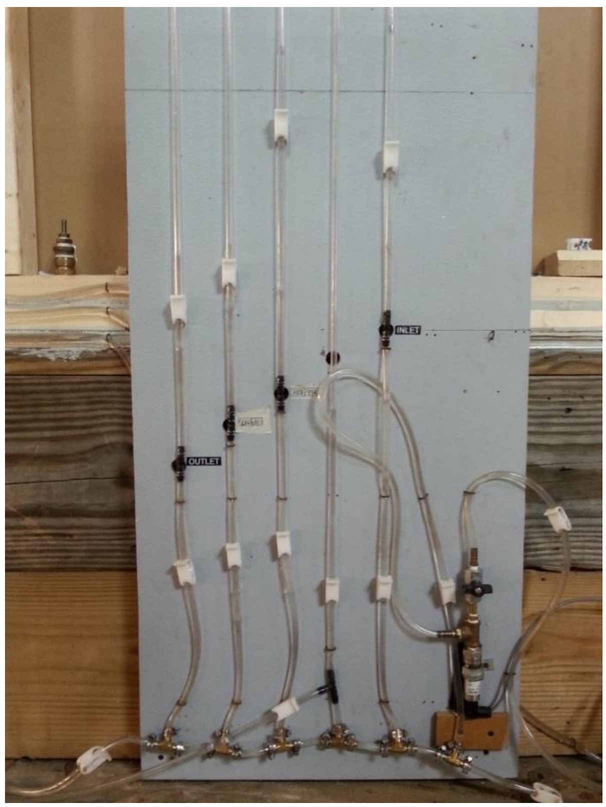


Figure 9: Pressure Measurement Instrumentation

3.2.5 Sediment Injection

The test sediment was injected into the crown of the influent pipe using an Auger® volumetric screw feeder, model VF-1, shown on **Figure 10**. The auger feed screw, driven with a variable-speed drive, was calibrated with the test sediment prior to testing, to establish a relationship between the auger speed (0-100%) and feed rate in grams/minute. The calibration, as well as test verification of the sediment feed was accomplished by collecting timed dry samples of 0.1-liter, up to a maximum of 1-minute, and weighing them on an Ohaus® 4000g x 0.1g, model SCD-010 digital scale. The feeder has a hopper at the upper end of the auger to provide a constant supply of dry test sand. The allowable Coefficient of Variance (COV) for the injection is 0.10.

Figure 10: Photograph Showing Variable-speed Auger Feeder

3.2.6 Sample Collection

Effluent samples were collected in 2-liter containers from the end of the 6-inch effluent pipe. Background concentration samples were collected from the center of the vertical pipe upstream of the test unit with the use of a calibrated isokinetic sampler, shown on **Figure 11**.

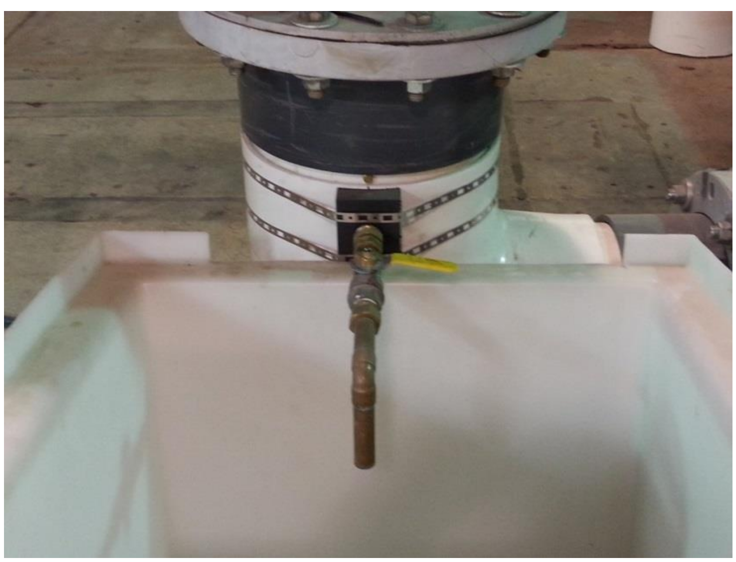


Figure 11: Photograph Showing the Background Isokinetic Sampler

3.2.7 Sample Concentration Analyses

Effluent and background concentration samples were analyzed by Alden in accordance with Method B, as described in ASTM Designation: D 3977-97 (Re-approved 2013), “Standard Test Methods for Determining Sediment Concentration in Water Samples”. The required silica sand used in the sediment testing did not result in any dissolved solids in the samples and therefore, simplified the ASTM testing methods for determining sediment concentration. Associated instrumentation included:

- 2-Liter collection beakers
- Ohaus® 4000g x 0.1g digital scale, model SCD-010
- Oakton® StableTemp gravity convection oven, model 05015-59
- Sanplatec Dry Keeper® desiccator, model H42056-0001
- AND® 0.0001-gram analytical balance, model ER-182A
- Advantec 3-way filtration manifold
- Whatman® 934-AH, 47-mm, 1.5-micron, glass microfiber filter paper

Samples were collected in graduated 2-Liter beakers which were cleaned, dried and weighed to the nearest 0.1-gram, using an Ohaus® 4000g x 0.1g digital scale, model SCD-010, prior to sampling. Collected samples were also weighed to the nearest 0.1-gram using the Ohaus® digital scale. Each collected sample was filtered through a pre-rinsed Whatman® 934-AH, 47-mm, 1.5-micron, glass microfiber filter paper, using a laboratory vacuum-filtering system. Prior to processing, each filter was rinsed with distilled water and placed in a designated dish and dried in an Oakton® StableTemp gravity convection oven, model 05015-59, at 225 degrees F for a minimum of 2.5 hours. Each dried filter was placed in a Sanplatec Dry Keeper® desiccator, model H42056-0001, to cool and then weighed to the nearest 0.0001-gram to determine the tare weight, using an AND® analytical balance, model ER-182A. Once filtered, each sample and dish was dried at a temperature between 175 and 210 degrees F (below boiling) for 20 to 30 minutes until visually dry. The oven temperature was increased to 225 degrees F and the samples were dried for an additional 2.5 hours. The dry samples and dishes were then cooled in the desiccator and weighed to the nearest 0.0001-gram, using the AND® balance. Net sediment weight (mg) was determined by subtracting the dried filter weight (tare) from the dried sample weight and multiplying the result by 1,000. The net sample volume, in liters, was determined by subtracting the beaker and net sediment weight from the overall sample weight and dividing by 1,000. Each sample sediment concentration, in mg/liter, was determined by dividing the net sediment weight by the net sample volume.

Photographs of the utilized laboratory instrumentation are shown on **Figure 12** and **Figure 13**.

Figure 12: Laboratory Sample Filtration Equipment and Scale

Figure 13: Sample Analysis Laboratory Equipment

3.3 DATA MANAGEMENT AND ACQUISITION

A designated Laboratory Records Book was used to document the conditions and pertinent data entries for each test run conducted. All entries are initialed and dated.

A personal computer running an Alden in-house Labview® Data Acquisition (DA) program was used to record all data related to instrument calibration and testing. A 16-bit National Instruments® NI6212 Analog to Digital (A/D) board was used to convert the signal from the pressure cells. Alden's in-house data collection software, by default, collects one second averages of data collected at a raw rate of 250 Hz. The system allows very long contiguous data collection by continuously writing the collected 1-second averages and their RMS values to disk. The data output from the program is in tab delimited text format with a user-defined number of significant figures.

Test flow and pressure data was continuously collected at a frequency of 250 Hz. The flow data was averaged and recorded to file every 5 seconds. Steady-state pressure data was averaged and recorded over a duration of 30 seconds for each point. The recorded data files were imported into a spreadsheet for further analysis and plotting.

Excel based data sheets were used to record all sediment related data used for quantifying injection rate, effluent and background sample concentrations. The data was input to the designated spreadsheet for final processing.

3.4 PREPARATION OF TEST SEDIMENT

The sediment particle size distribution (PSD) used for removal efficiency testing was comprised of 1-1000 micron silica particles, as shown in **Table 1**. The Specific Gravity (SG) of the sediment mixes was 2.65. A commercially-available blend of each mix was provided by AGSCO Corp., a QAS International ISO-9001 certified company, and adjusted by Alden as required. Samples were collected from random bags and analyzed in accordance with ASTM D422-63 (2007), by GeoTesting Express, an ISO/IEC 17025 accredited independent laboratory. The average %-finer values of the stock material were found to be outside of the NJDEP acceptance criteria of 2% for particle sizes ≤ 20 microns. The test mix was adjusted to within the NJDEP acceptance criteria with the addition of commercially-available US-Silica Min-U-Sil 10, with a PSD of approximately 1-25 microns. Test batches of approximately 30 lbs each, were prepared in individual 5-gallon buckets, which were arbitrarily selected for the removal testing. A well-mixed random sample was collected from three random test batches and analyzed for PSD by GeoTesting Express. The average of the samples was used for compliance to the protocol specifications listed in Column 2 of **Table 1**. The D_{50} of the samples ranged from 61 to 63 microns, with an average of 62 microns. The PSD data of the samples are shown in **Table 2** and the corresponding curves are shown on **Figure 14**.

Table 2: PSD Analyses of Alden NJDEP 1-1000 Mix

Particle size (µm)	NJDEP	Sample 1	Sample 2	Sample 3	Average
1000	100%	100%	100%	100%	100%
500	95%	96%	95%	96%	96%
250	90%	92%	91%	92%	92%
150	75%	79%	79%	79%	79%
110	60%	65%	65%	65%	65%
75	50%	53%	53%	53%	53%
53	45%	48%	47%	47%	47%
20	35%	34%	32%	36%	34%
8	20%	20%	19%	19%	19%
5	10%	14%	13%	13%	13%
2	5%	4%	4%	4%	4%
75	D_{50}	61	63	63	62

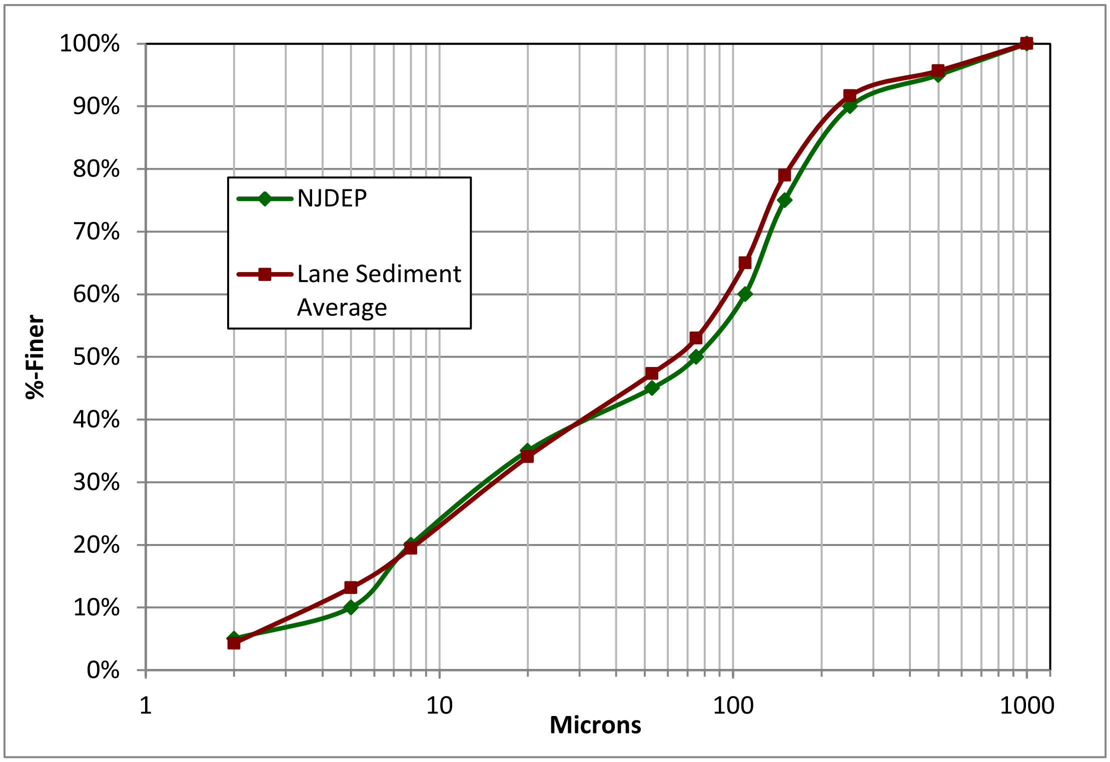


Figure 14: PSD Curves of 1-1000 micron Test Sediment and NJDEP Specifications

3.5 DATA ANALYSIS

The following equations and procedures were used in analyzing the data collected on the Lane SK75 test unit:

3.5.1 Hydraulics

The pressure cell was mounted at a height of 4.942 ft above the floor of the test unit. This datum value was added to all recorded measurements to correct the water height above the unit floor. The system energy loss across the unit was determined by adding the velocity head to the piezometric measurements taken in the inlet and outlet pipes.

The velocity head is defined by:

$$\mathbf{H = V^2/2g} \qquad (1)$$

where,

H = velocity head (ft), V = velocity (ft/sec), and g = gravity (32.17 ft/sec^2).

The velocity is defined by:

$$\mathbf{V = Q/A} \qquad (2)$$

where,

V = velocity (ft/sec), Q = flow (ft^3/sec), and A = wetted area (ft^2).

The area in the partial pipe flow was calculated using:

$$A = 0.125(\theta - Sin\theta)D^2 \tag{3}$$

where,

A = wetted area (ft^2), θ = angle of inclusion (radians), and D = pipe diameter (ft).

The angle of inclusion of the water surface (θ) was calculated using:

$$\theta = 2\pi - 2\left(ACos\left(\frac{y-\frac{D}{2}}{\frac{D}{2}}\right)\right) \tag{4}$$

where,

Y = measured water depth (ft), and D = pipe diameter (ft).

3.5.2 Removal Efficiency

The injected mass of each run was calculated by:

$$\mathbf{M_{inj} = \Delta M - (\Delta M \times w)} \tag{5}$$

where,

M_{inj} = final mass of injected sediment (grams), ΔM = measured mass of injected sediment (grams), w = moisture content of sediment (%).

The injected concentration was calculated by:

$$\mathbf{C_{inj} = M_{inj} / Vol} \tag{6}$$

where,

C_{inj} = injected concentration (mg/L), M_{inj} = final mass of injected sediment (grams), Vol = total volume of water during sediment dosing (L).

The sediment removal efficiency was calculated by:

$$\mathbf{\%\ Removal = (((M_{inf})-(M_{eff})-(M_{dd}))\ /\ M_{inf}) \times 100} \tag{7}$$

where,

M_{inf} = Influent Mass: Average Influent TSS Concentration x Total Volume of water flowing through the filtration MTD during the addition of test sediment or Total Mass Added.
M_{eff} = Effluent Mass: Adjusted (for background TSS concentration) Effluent TSS Concentration x Total Effluent Volume of water flowing through the filtration MTD during the addition of test sediment.

M_{dd} = Drawdown Mass: Average Drawdown TSS Concentration x Total Volume of water flowing from the filtration MTD during drawdown

The effluent and background sample concentrations were calculated as follows:

$$\textbf{Concentration (mg/L) = Sediment Wt (mg) / Sample Volume (L)} \quad (8)$$

The auger injector verification concentrations were determined by the following:

$$C_i = M_f / Q_{avg} \quad (9)$$

where,

C_i = influent concentration (mg/L), M_f = sediment mass feed (mg/min),
Q_{avg} = average flow (lpm)

3.6 LABORATORY ANALYSIS

The following Test Methods were used to analyze the various dry and aqueous sediment samples:

- Sediment Concentration

  ASTM Designation: D 3977-97 (Re-approved 2013), "Standard Test Methods for Determining Sediment Concentration in Water Samples"

- Sediment Moisture Content

  ASTM Designation: D4959-07, "Standard Test Method for Determination of Water (Moisture) Content of Soil by Direct Heating"

- Dry Sediment Particle Size Distribution

  ASTM D422-63 (2007), "Standard Test Method for Particle Size Analysis of Soils"

3.7 QUALITY ASSURANCE AND CONTROL

All instruments were calibrated prior to testing and periodically checked throughout the test program. The instrumentation calibrations are shown in Appendix B.

3.7.1 Flow

The flow meters and pressure cells were calibrated in Alden's Calibration Laboratory, which is ISO 17025 accredited. All pressure lines were purged of air prior to initiating each test. A standard water manometer board and Engineers Rule were used to measure the differential pressure and verify the computer measurement of the selected flow meter.

3.5.1 Sediment Injection

The sediment feed (g/min) was verified with the use of a digital stop watch and 4000g calibrated digital scale. The tare weight of the sample container was recorded prior to collection of each sample. The samples were a minimum of 0.1 liters in size, with a maximum collection time of 1-minute.

3.7.2 Sediment Concentration Analysis

All sediment concentration samples were processed in accordance with the ASTM D3977-97 (2013) analytical method. Gross sample weights were measured using a 4000g x 0.1g calibrated digital scale. The dried sample weights were measured with a calibrated 0.0001g analytical balance. Any change in filter weight due to processing was accounted for by including three control filters with each test set. The average of the three values, which was +/- 0.1-0.5 mg, was used in the final concentration calculations.

Analytical accuracy was verified by preparing two blind control samples and processing using the ASTM method. The final calculated values were within 0.26% and 0.87% of the theoretical sample concentrations, with an average of 0.57% accuracy. This value was not corrected for particles smaller than the filter designation of 1.5 microns and therefore, is considered conservative.

4.0 RESULTS AND DISCUSSION

4.1 SEDIMENT REMOVAL PERFORMANCE

Ten (10) removal efficiency test runs were conducted at a target flow of 120 gpm, corresponding to a normalized flow of 4 gpm/ft^2. The minimum duration of each run was 30 minutes, with a target influent sediment concentration of 200 mg/l. All test runs met or exceeded the protocol testing criteria.

The measured flow for the 10 runs ranged from 119.5 gpm to 120.8 gpm, with an average flow of 119.9 gpm. The calculated COVs ranged from 0.001 to 0.004. The maximum recorded temperature for each run ranged from 67.2 to 78.4 degrees F. The calculated mass/volume influent concentrations ranged from 189 to 207 mg/L, with an average concentration of 201 mg/L. The measured injected influent concentrations ranged from 198 to 201 mg/L, with an average concentration of 200 mg/L. The injection COVs ranged from 0.001 to 0.003. The average adjusted effluent concentrations ranged from 29.2 to 41.5 mg/L and the average drawdown concentrations ranged from 5.0 to 25.7 mg/L. The drawdown duration for the ten (10) runs increased sequentially from 29 minutes to 74 minutes. The calculated removal efficiencies utilizing the mass/volume concentration ranged from 85.5% to 82.7%, with an average removal of 84.0%. The removal efficiency utilizing the injected concentration ranged from 85.5% to 82.8%, with an average removal of 83.9%. The maximum recording driving head was 3.26 ft, which correlates to 0.76 ft above the crown of the chamber.

The removal efficiencies were calculated using both the mass/volume and injected influent concentrations, and are shown in **Table 3.** The measured and calculated data for the ten runs is shown in **Table 4** and **Table 5**. The influent concentration and removal curves are shown on **Figure 15**.

Table 3: Removal Efficiency Summary

Run #	Removal Efficiency	
	mass/volume	Injection Rate
1	**85.5%**	85.5%
2	**85.4%**	85.0%
3	**82.7%**	83.6%
4	**83.8%**	83.5%
5	**84.2%**	83.9%
6	**84.1%**	83.9%
7	**83.6%**	83.3%
8	**82.9%**	83.2%
9	**83.2%**	82.8%
10	**84.5%**	84.2%
Average	**84.0%**	**83.9%**

Table 4: Measured Influent Parameters

Run #	Measured Flow		Max Temp	Influent Concentration (mg/L)		
	gpm	COV	Deg. F	mass/volume	Injection Rate	Injection COV
1	120.8	0.004	78.4	198	198	0.002
2	119.6	0.001	78.1	207	201	0.002
3	119.7	0.002	74.8	189	200	0.003
4	119.7	0.001	74.6	203	200	0.001
5	119.5	0.001	74.8	204	201	0.001
6	120.2	0.001	70.5	202	200	0.001
7	119.7	0.001	70.7	204	200	0.002
8	120.1	0.001	69.7	196	199	0.002
9	119.8	0.001	68.6	204	200	0.002
10	119.9	0.001	67.2	203	200	0.001
Average	**119.9**			**201**	**200**	

Table 5: Measured Sample Concentrations

Run #	Maximum Background	Adjusted Effluent Concentrations (mg/L)						Drawdown Concentrations (mg/L)		
	mg/L	#1	#2	#3	#4	#5	Average	#1	#2	Average
1	1.7	21.39	19.71	19.94	43.56	41.30	**29.18**	12.33	39.14	**25.73**
2	3.0	19.75	23.25	25.22	63.47	44.35	**35.21**	9.19	5.51	**7.35**
3	4.3	38.33	35.94	39.79	40.91	39.69	**38.93**	9.39	4.76	**7.07**
4	0.9	37.31	40.21	41.01	41.24	41.60	**40.28**	7.32	3.43	**5.37**
5	1.0	36.04	37.24	41.02	40.58	41.34	**39.24**	7.86	3.11	**5.48**
6	0.2	37.81	37.48	41.27	40.86	40.02	**39.49**	7.60	3.28	**5.44**
7	0.6	37.44	39.24	40.07	42.90	43.45	**40.62**	7.69	3.77	**5.73**
8	1.0	39.21	39.05	41.13	42.64	40.48	**40.50**	6.50	3.39	**4.95**
9	0.9	38.24	41.77	42.78	41.84	42.91	**41.51**	9.69	4.58	**7.14**
10	6.6	32.24	35.76	46.27	39.88	36.87	**38.20**	12.14	5.56	**8.85**

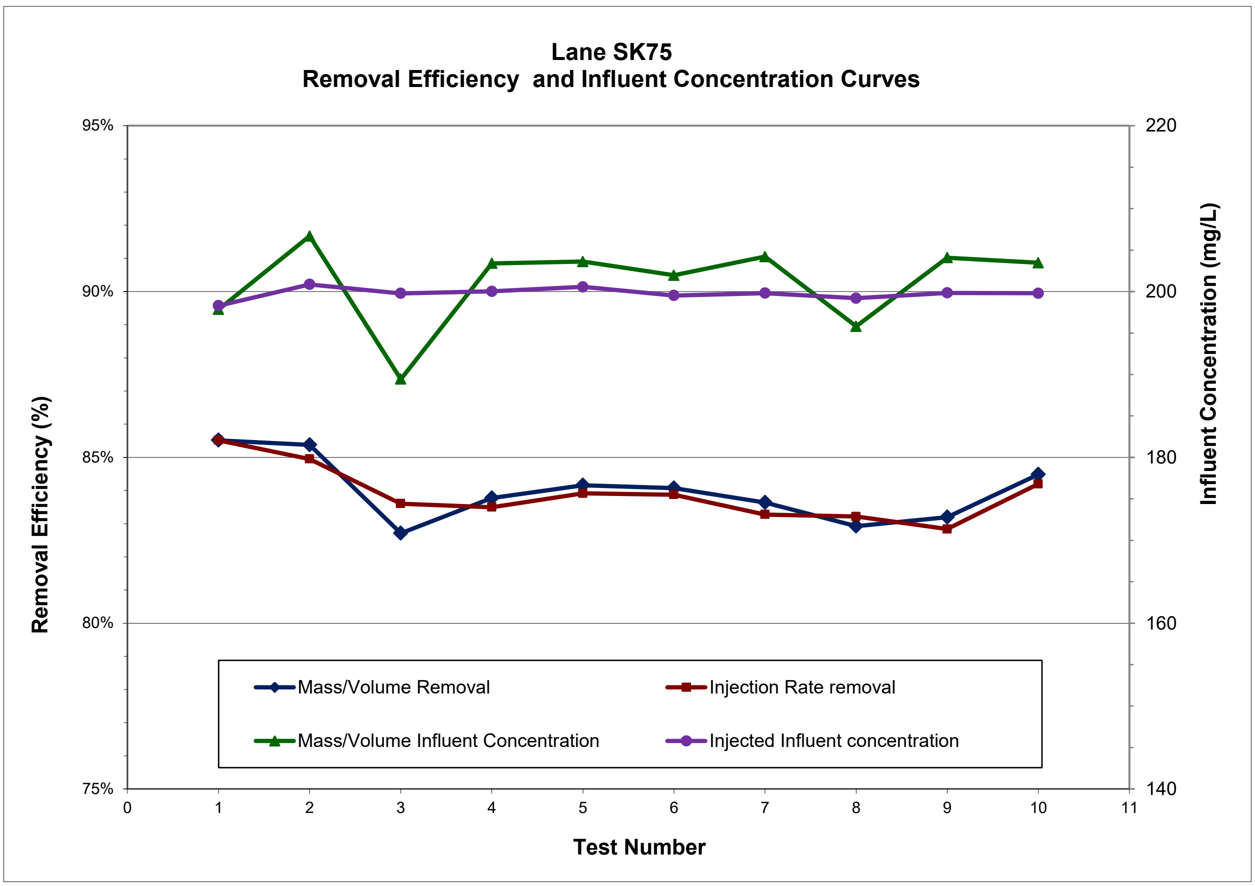


Figure 15: Lane SK75 Removal Efficiency and Influent Concentration Curves

4.2 Hydraulic Measurements

Steady-state pressure measurements were recorded on the clean chamber to establish the hydraulic characteristic curves. Recorded flows ranged from 10 to 353 gpm (0.33 to 11.75 gpm/ft^2). The recorded data is shown in **Table 6** and corresponding curves on **Figure 16**.

Table 6: Measured Hydraulic Data

Flow			Inlet El. (A')	Outlet El. (D')	System Energy Loss
gpm	cfs	gpm/sq-ft	Corrected for Energy ft	Corrected for Energy ft	A'-D'
0	0				
10.1	0.02	0.34	**1.281**	**0.389**	**0.892**
25.4	0.06	0.85	**1.331**	**0.446**	**0.886**
49.6	0.11	1.65	**1.385**	**0.513**	**0.873**
100.1	0.22	3.34	**1.494**	**0.619**	**0.875**
153.1	0.34	5.10	**1.578**	**0.708**	**0.870**
203.1	0.45	6.77	**1.832**	**0.787**	**1.046**
246.1	0.55	8.20	**2.112**	**0.855**	**1.257**
305.5	0.68	10.18	**2.583**	**0.939**	**1.644**
352.5	0.79	11.75	**2.984**	**1.010**	**1.975**

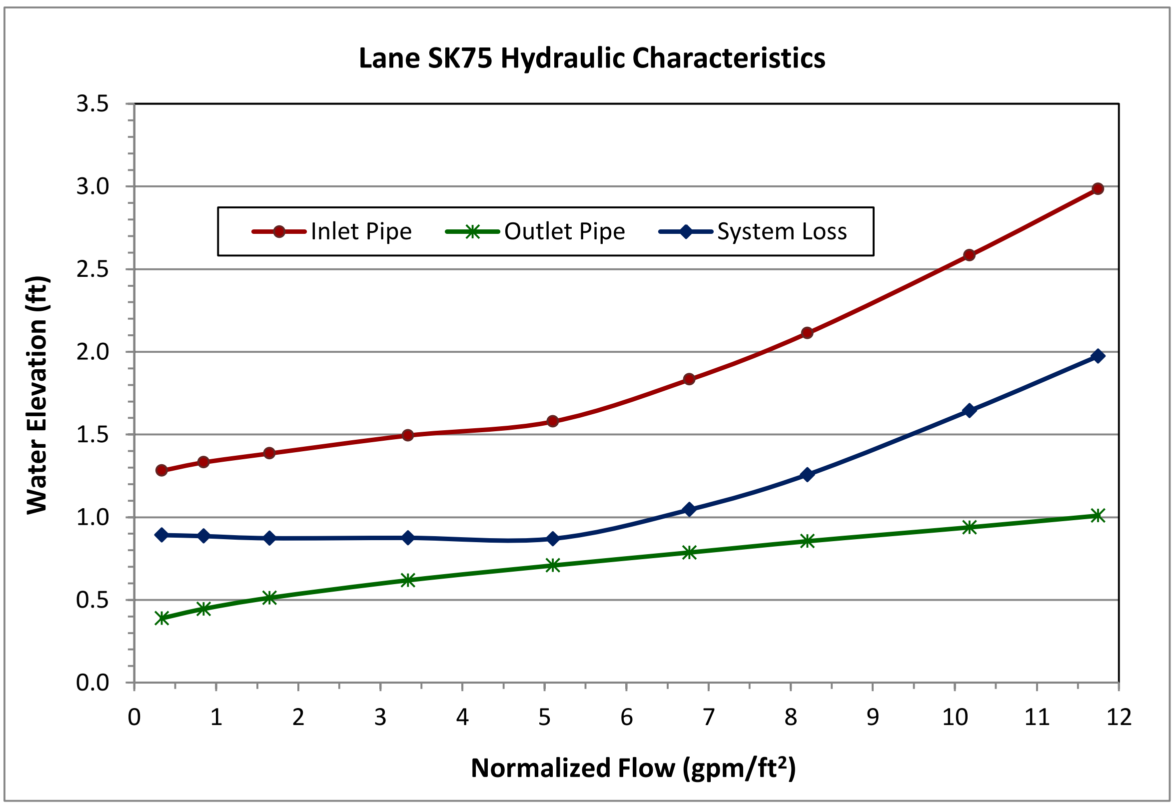


Figure 16: Lane SK75 Hydraulic Characteristic Curves

5.0 CONCLUSIONS

The Lane SK75 Stormwater Treatment Unit achieved a sediment removal efficiency of 84.0% for the ten (10) runs conducted at 120 gpm (4 gpm/ft^2), using 1-1000 micron NJDEP sediment, meeting the NJDEP filtration testing protocol criteria.

All testing conducted on the Lane SK75 Stormwater Treatment System met or exceeded the requirements as set forth in the 2013 NJDEP Testing Protocol.

James T. Mailloux

Senior Engineer
Alden Research Laboratory
Holden, MA 01520

NOMENCLATURE AND ABBREVIATIONS

A	= area	(L^2)
Cd	= coefficient of discharge	
Ci	= influent sediment concentration	(M/L^3)
Cfs	cubic feet per second	(L^3/T)
COV	= coefficient of variance	
D	= diameter	(L)
D_{50}	= median particle size	(L)
DA	= data acquisition	
DP	= differential pressure	(ΔL)
°F	= degree Fahrenheit	(T)
Ft	= feet	(L)
Ft/s	= feet per second	(L/T)
g	= grams	(M)
g	= gravity	(L/T^2)
gpm	gallons per minute	(L^3/T)
H	= head	(L)
Hz	= hertz	(T)
L	= liters	(L^3)
Lbs	= pounds	(M)
mg/L	= milligram per liter	(M/L^3)
min	= minute	(T)
PSD	= particle size distribution	
Q	= flow	(L^3/T)
sec	= seconds	(T)
SLR	= surface loading rate	($L^3/T/L^2$)
SSC	= suspended solids concentration	
V	= velocity	(L/T)
w	moisture content (%)	

REFERENCES

ASTM (2013), "Standard Test Methods for Determining Sediment Concentration in Water Samples", Annual Book of ASTM Standards, D3977-97, Vol. 11.02.

ASTM (2007), "Standard Test Method for Particle Size Analysis of Soils", Annual Book of ASTM Standards, D422-63, Vol. 04.08.

ASTM (2007), "Standard Test Methods for Determination of Water (Moisture) Content of Soil by Direct Heating", Annual Book of ASTM Standards, D4959-07, Vol. 04.08.

ASME (1971), "Fluid Meters Their Theory and Application- Sixth Edition".

NJDEP (2013), "Laboratory Protocol to Assess Total Suspended Solids Removal by a Hydrodynamic sedimentation Manufactured Treatment Device".

U.S. Department of the Interior, Bureau of Reclamation "Water Measurement Manual", 3rd edition (2001)

Appendix A ALDEN QUALIFICATIONS

Founded in 1894, Alden is the oldest continuously operating hydraulic laboratory in the United States and one of the oldest in the world. From the early days of hydropower development and aviation, through World Wars I and II, and into the modern world defined by environmental needs, Alden has been a recognized leader in the field of fluid dynamics consulting, research and development. In the 21st Century, Alden is a vibrant, growing organization consisting of engineers, scientists, biologists, and support staff in five specialty areas. Much of our work supports the power generating, environmental, manufacturing, and process industries.

Alden offers a scope of specialized services including: conceptual design, detailed design, verification testing, analytical modeling, Computational Fluid Dynamics (CFD), field measurements, physical modeling, precision flow meter and instrumentation calibrations (ISO 17025 certified), and field testing. Decades of combined experience in numerical simulation techniques, physical modeling, and field studies provide the broad knowledge that is essential for recognizing which method is best suited to solving a problem.

Unusually large facilities (more than 125,000 square feet of enclosed space) and sophisticated data acquisition systems are available for each study. Approximately twenty buildings, located on thirty acres at our headquarters in Holden, MA are equipped with flow supplies and control systems for conducting hydraulic modeling, verification and equipment testing, fish testing, air/gas flow modeling, and numerous other types of flow testing. Fixed facilities providing air and water flow and an inventory of movable flow related equipment such as pumps, valves, meter devices, fish screens, etc. are located on the premises at our Massachusetts laboratory. Fully equipped and staffed carpentry, machine, and instrumentation shops provide rapid and efficient project support.

Alden has performed verification testing on approximately twenty Hydrodynamic Separator and Filtration Manufactured Treatment Devices (MTDs) for multiple manufacturers under various state and federal testing protocols. Alden’s senior stormwater engineer, James Mailloux, has served on the ASTM and SWEMA Stormwater Technical committees, providing guidance in the area of testing methodologies. He has a Master’s Degree in Environmental Engineering from Worcester Polytechnic Institute and has been conducting testing at Alden for more than 25 years. Mr. Mailloux has contributed to articles related to laboratory testing in Stormwater Magazine, as well as presented on multiple testing and regulatory topics at various conferences, including StormCon, WefTec and National Precast Concrete Association training seminars.

Appendix B INSTRUMENTATION CALIBRATIONS

CALIBRATION OF:

4" ORIFICE PLATE METER, SN 1

250" DP CELL, CELL NO. 812

FOR:

ALDEN RESEARCH LABORATORY

INTERNAL PURCHASE ORDER NUMBER 66124

JUNE 2015 - REPORT NO. 2151ARL004-R1

CERTIFIED BY

Philip S. Stacy

ALDEN RESEARCH LABORATORY, INC.

30 SHREWSBURY STREET

HOLDEN, MASSACHUSETTS 01520

All Client supplied information and calibration results are considered proprietary and confidential to the Client. If a third party is a witness during calibrations or if the Client requests transmittal of data to a third party, Alden considers that the Client has waived confidentiality for the Witness.

In the event the Client distributes any report issued by Alden outside its own organization, such report shall be used in its entirety, unless Alden approves a summary or abridgment for distribution.

No advertising or publicity containing any reference to Alden or any employee, either directly or by implication, shall be made use of by Client without Alden's written approval.

INTRODUCTION

One 4" Orifice Plate Meter and a DP Cell were calibrated at the Alden Research Laboratory, Inc. (Alden) for Alden Research Laboratory, under Alden Internal PO Number 66124, Job 1142AS3SVT. Alden's standard test procedures, in QMSM-01 Revision 5, were used for testing. Flow element performance is presented in both tabular and graphical format.

FLOW ELEMENT INSTALLATION

The meter under test was installed in Test Line 4 in the Hooper Low Reynolds Number Facility, shown in plan view on Figure 1. Water is provided through a 40" penstock from the laboratory head pond at a head of about 18 feet. Electrically driven centrifugal pumps provide a maximum head of about 170 ft and a maximum flow of 1,200 gpm. The Gravimetric Method is used to measure flow.

The detailed piping arrangement immediately upstream and downstream of the meter under test, including all significant fittings and pipe lengths, is shown in Figure 2. Careful attention was given to align the meter under test with the test line piping, and to assure no gaskets between flanged sections protruded into the flow. Vents were provided at critical locations of the test line to purge the system of air.

TEST PROCEDURE

The test technician verified proper installation of the meter under test in the test line prior to introducing water into the system to equalize test line piping and primary element temperature to water temperature.

Prior to the test run, the control valve was set to produce the desired flow, while the flow was directed to waste. Sufficient time was allowed to stabilize both the flow and the instrument readings, after which the weigh tank discharge valve was closed and the weigh tank scale indicator and the electric timer were both zeroed. To begin the test run, flow was diverted into the weigh tank, which automatically started the timer.

At the start of the water collection a computer based data acquisition system was activated to read the meter output, such that the meter output was averaged while the weigh tank was filling. At the end of the run, flow was diverted away from the weigh tank and the timer and data acquisition system were stopped to terminate the test run. The weight of water in the tank, elapsed time, water temperature, and average meter output were recorded on a data sheet. The data were entered into the computer to determine the flow and the results were plotted so that each test run was evaluated before the next run began. The control valve was then adjusted to the next flow and the procedure repeated.

FLOW MEASUREMENT METHOD

Flow was measured by the gravimetric method using a tank mounted on a scale having a capacity of 45,000 pounds with resolution of 0.5 lb. Alden's flow meter calibrations using the gravimetric flow measurement method comply with ASME/ANSI MFC-9M-1988 Measurement of Liquid Flow in Closed Conduits by Weighing Method. Water passing through the flow element was diverted into the tank with a hydraulically operated knife edge passing through a rectangular jet produced by a diverter head box. A Hewlett-Packard 10 MHz Frequency Counter with a resolution 0.001 sec was started upon flow diversion into the tank by an optical switch, which is positioned at the center of the jet. The timer was stopped upon flow diversion back to waste and the elapsed diversion time was recorded. An RTD thermometer measured water temperature to allow calculation of water density. Volumetric flow was calculated by Equation (1).

$$q_a = \frac{W}{T\rho_w B_c} \tag{1}$$

where

	q_a	=	actual flow, ft^3/sec
	W	=	mass of water collected, lb_m
	T	=	time, sec
	ρ_w	=	water density, lb_m/ft^3
	B_c	=	buoyancy correction, $1-\rho_a/\rho_w$

The buoyancy correction includes air density calculated by perfect gas laws with the standard barometric pressure, a relative humidity of 75%, and measured air temperature. The weigh tank is periodically calibrated to full scale using 10,000 lbm of cast iron weights, whose calibration is traceable to NIST. Flow calculations are computerized to assure consistency. Weigh tank calibration data and water density as a function of temperature, are stored on disk file. Data were recorded manually and on disk file for later review and reporting.

DISCHARGE COEFFICIENT CALCULATIONS

Discharge coefficient, C, is defined by Equation (2) and plotted versus pipe or throat Reynolds number. Calculations of the discharge coefficient of differential producing flow meters are in accordance with ASME/ANSI MFC-3M-2004 Measurement of Fluid Flow in Pipes Using Orifice, Nozzle and Venturi, and ASME 19.5-2004 Flow Measurement. The discharge coefficient relates the theoretical flow to the actual flow.

$$C = \frac{q_a}{q_{th}} = \frac{q_a}{F_a K_M \sqrt{\Delta h}} \qquad (2)$$

where	C	=	discharge coefficient, dimensionless
	q_{th}	=	theoretical flow, ft^3/sec
	F_a	=	thermal expansion factor, dimensionless
	Δh	=	differential head, ft at line temperature
	K_M	=	meter constant, $ft^{2.5}/sec$

The theoretical proportionality constant, K_M, between flow and square root of differential head is a function of the meter throat area, the ratio of throat to pipe diameter, and the local gravitational constant, as defined by Equation (3).

$$K_M = \frac{a_t\sqrt{2g_l}}{\sqrt{1-\beta^4}} \qquad (3)$$

where	a_t	=	throat area, $\pi d^2/4$, ft^2
	d	=	throat diameter, ft
	g_l	=	local gravitational constant, 32.1625 ft/sec^2 at Alden
	β	=	ratio of throat to pipe diameter, d/D, dimensionless
	D	=	pipe diameter, ft

The effect of fluid properties, viscosity and density, on the discharge coefficient is determined by Reynolds number, the ratio of inertia to viscous forces. Pipe Reynolds number, R_D, is determined by Equation (4).

$$R_D = \frac{q_a D}{a_p \gamma} \tag{4}$$

where a_p = pipe area, $\pi D^2/4$, ft^2

γ = kinematic viscosity, ft^2/sec

FLOW METER SIGNAL RECORDING

The secondary element, which converts the primary element signal into engineering units, was one of several "Smart" differential pressure transmitters having a range of 250" and 1,000" Water Column. 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. Average transmitter reading was converted to feet of flowing water using a linear regression analysis of the calibration data and line water temperatures to calculate appropriate specific weight.

TEST RESULTS

The results are presented in tabular and graphical format. The calculated flow, meter signal and meter performance are listed in the tables in the following pages.

Analysis indicates that the flow measurement uncertainty is within 0.25% 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).

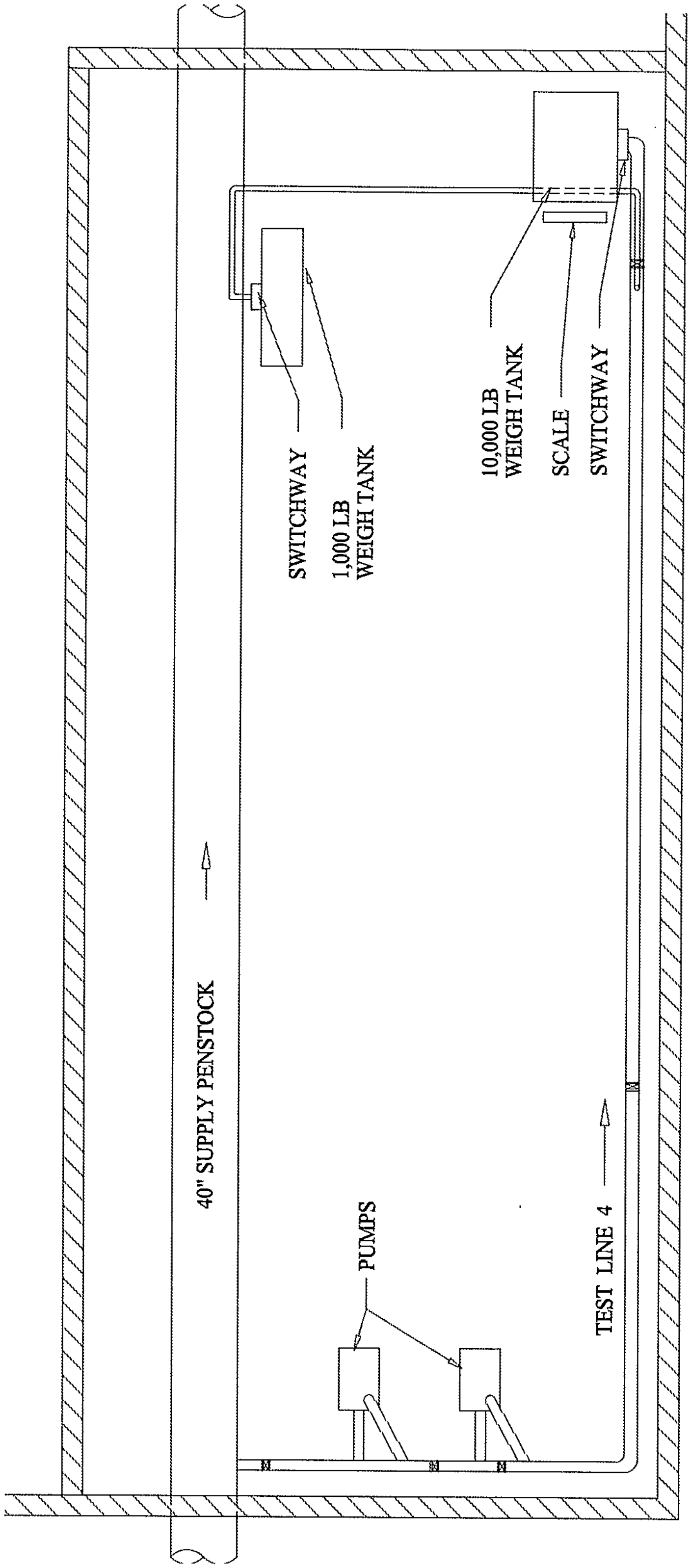


Figure 1
Hooper Low Reynolds Facility Test Line 4

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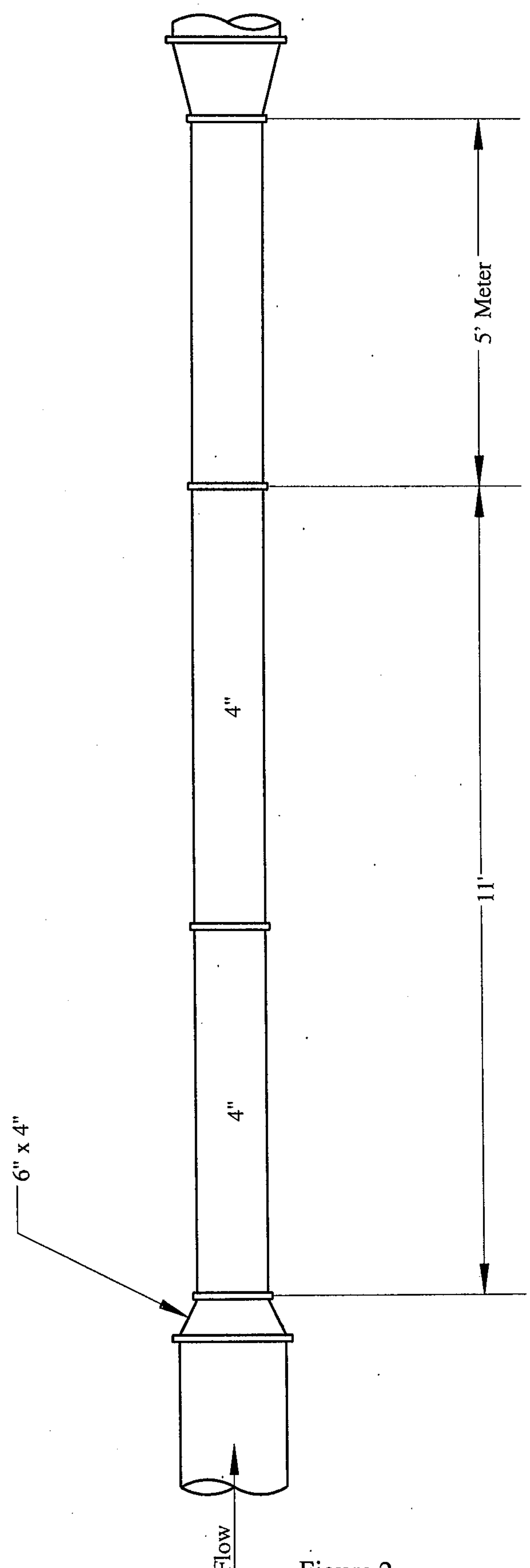
Plan View Hooper Facility Line 4



ALDEN RESEARCH LAB

4" ORIFICE PLATE METER
Serial Number: 1
June 1, 2015

Figure 2

ALDEN RESEARCH LAB

4" ORIFICE PLATE METER
Serial Number: 1

CALIBRATION
DATE: June 1, 2015
PIPE DIAMETER = 4.0260
THROAT DIAMETER = 2.6170

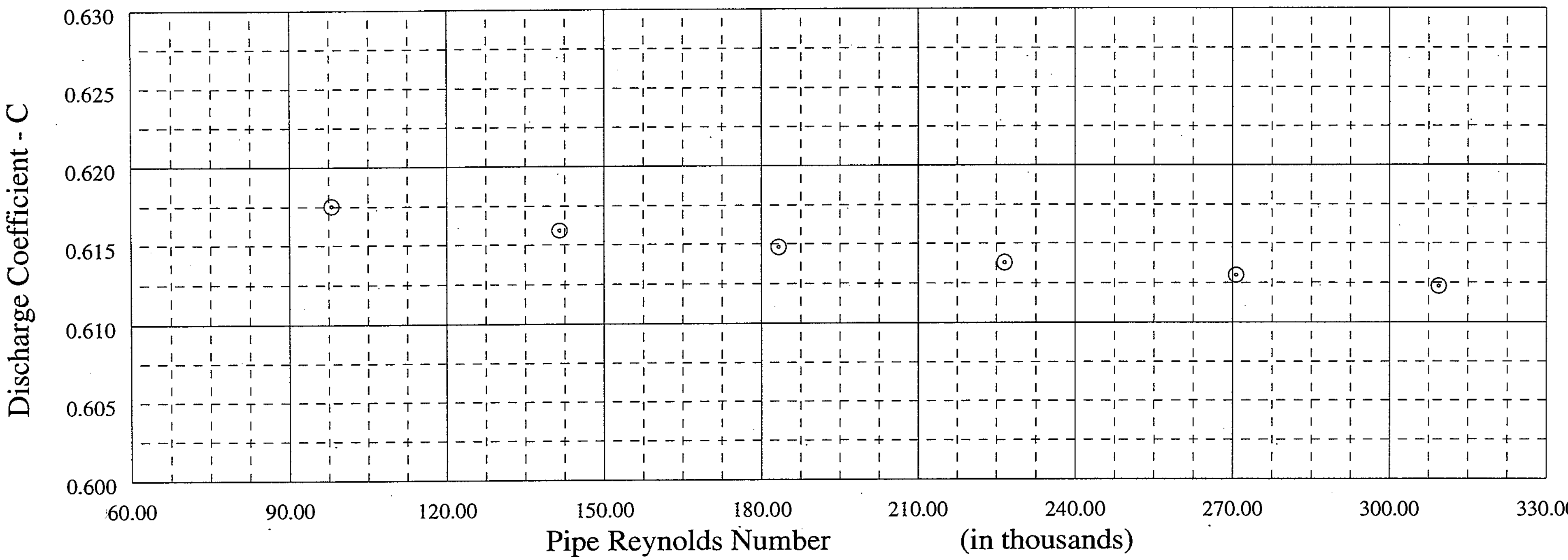
Run #	Line Temp Deg F	Air Temp Deg F	Net Weight lb.	Run Duration secs.	Output [see note]	Flow GPM	H Line FT H20	Pipe Rey. # x 10^5	Coef
1	67	66	9605	171.655	9.586~	403.4	19.725	3.0942	0.6123
2	67	66	8568	176.461	7.698~	350.0	14.820	2.7068	0.6130
3	68	67	7564	186.594	5.960~	292.2	10.303	2.2660	0.6138
4	68	67	6060	184.800	4.581~	236.4	6.720	1.8331	0.6148
5	68	67	4536	178.904	3.535~	182.8	4.002	1.4154	0.6159
6	68	67	3539	201.568	2.730~	126.5	1.910	0.9802	0.6175

~ 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: THL

CERTIFIED BY:



$$q_a = C\,F_a\,K_M\,\sqrt{\Delta h}$$

q_a =	Actual Flow (ft^3/sec)		
C =	Discharge Coefficient (Dimensionless)		
Δh =	Pressure Differential (Feet of Water at Run Temperature)		
K_M =	Meter Constant = $\dfrac{a\sqrt{2g}}{\sqrt{1-\beta^4}}$	=	0.3305
F_a =	Average Thermal Expansion Factor	=	1.0000
a =	Throat Area (ft^2)	=	0.0374
g =	Local Acceleration of Gravity (ft/sec^2)	=	32.1625
ß =	Ratio of Throat to Pipe Diameter (Dimensionless)	=	0.6500
	Pipe Diameter (Inches)	=	4.0260
	Throat Diameter (Inches)	=	2.6170

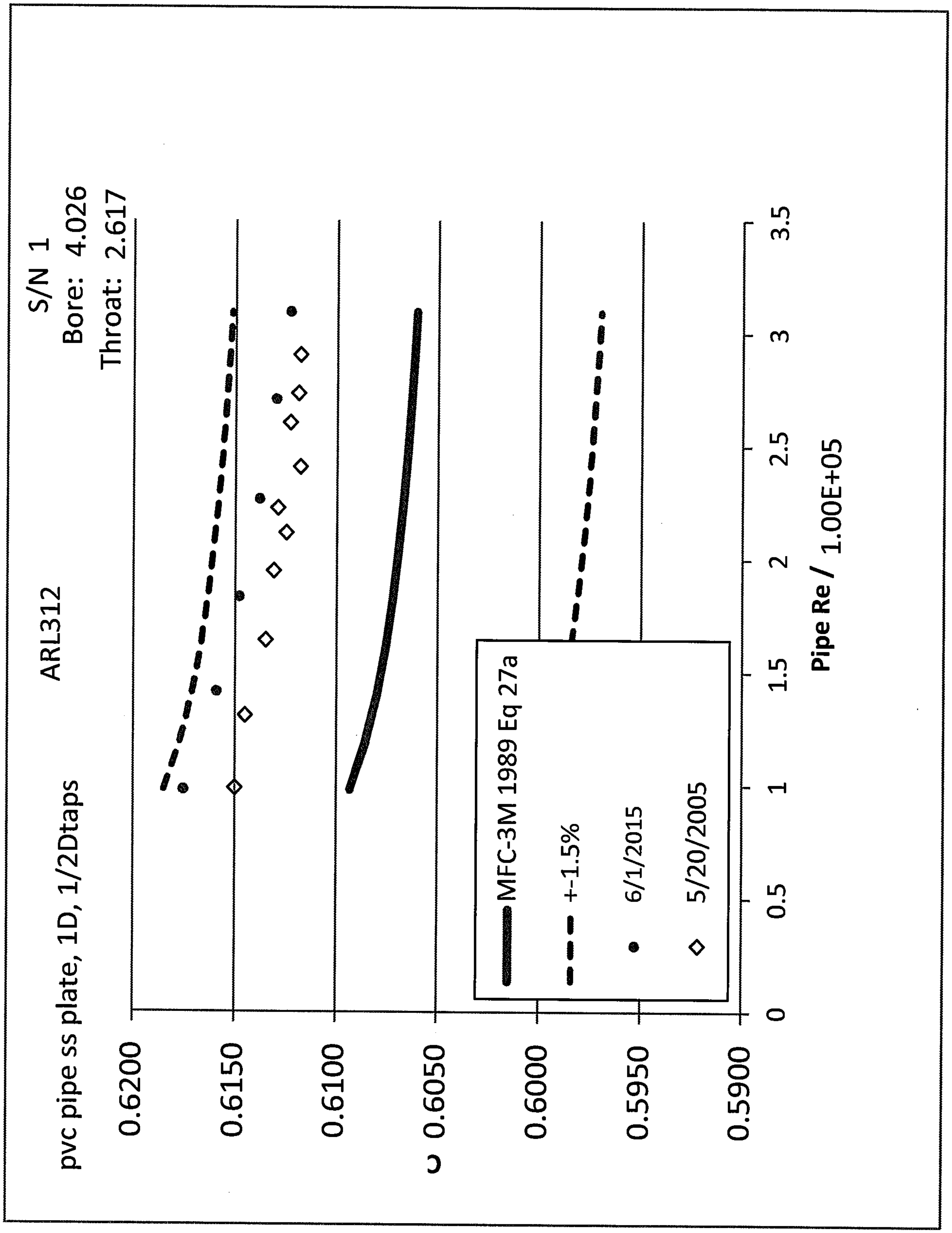
Dimensions By: ALDEN RESEARCH LAB

ALDEN RESEARCH LAB

4" ORIFICE PLATE METER
Serial Number: 1
June 1, 2015

Certified By:

ARL



V:\Data\PTCData\Alden Meters\arl312 (sn 1).xlsx

Calibrated By:	THL
Cell No.:	812
Date:	2-Jun-15
Temp.:	62
A-D Board No.:	swdaq1/ni212
Using Pneumatic DWT No.:	1055

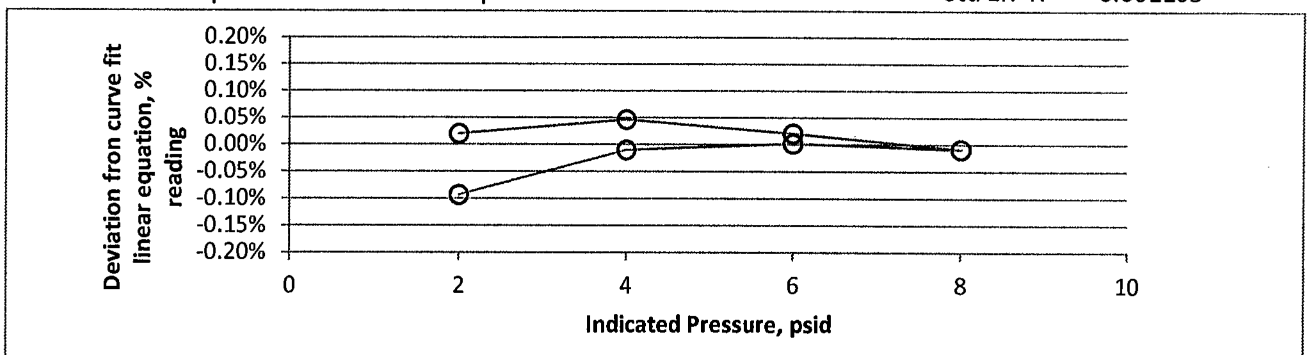
250" cell

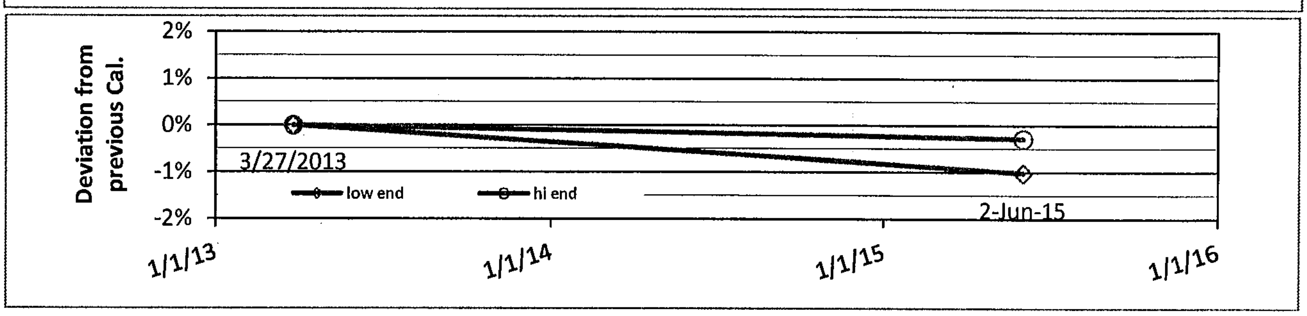
---Weight Identification---

	8	7	6	5	4	3	2	1	Tester PSI	Reading Volts	Calculated PSI	curve fit Error	mA
1									0	**2.030**			4.076925
3	1								1.999608	**3.796**	1.9977445	-0.093%	7.626303
5	1	1							3.999269	**5.565**	3.9988662	-0.010%	11.18171
7				1					5.998745	**7.333**	5.9988567	0.002%	14.73511
9		1		1					7.998406	**9.100**	7.997716	-0.009%	18.28649
10		1		1					7.998406	**9.100**	7.997716	-0.009%	18.28649
12				1					5.998745	**7.334**	5.999988	0.021%	14.73712
14	1	1							3.999269	**5.567**	4.0011287	0.047%	11.18573
16	1								1.999608	**3.798**	2.000007	0.020%	7.630322
20									0	**2.030**			4.076925

Note: Zeroes not included in regression.
Note: Pressures correct only for
temperature indicated at top.

Slope: 1.131216 ZERO>
Intercept: -2.296353
Std Err Y: 0.001105





Thermal Expansion Factor

The dimensions of a differential producing flow meter are affected by the operating temperature, requiring a Thermal Expansion Factor (F_a) to be included in the calculations. The calculation requires the temperature at which the meter dimensions were measured be known. If this information is not available, an ambient temperature of 68° F is assumed. The Thermal Expansion Factor is calculated according to the American Society of Mechanical Engineers Standard ASME MFC-3M-1989, Equation 17 (pg 11).

$$F_a = 1 + \frac{2}{1-\beta^4}\left(\alpha_{PE} - \beta^4{}_{meas} \propto_p\right)(t - t_{meas})$$

where

where	β	=	ratio of throat diameter to pipe diameter, dimensionless
	α_{PE}	=	thermal expansion factor of primary element, (in./in./°F)
	$\propto_p$	=	thermal expansion factor of pipe, (in./in./°F)
	t	=	temperature of flowing fluid, °F
	t_{meas}	=	temperature of measurements, °F

Thermal expansion factors, α, excerpted from MFC-3M-1989, are listed in the Table below for six typically used materials at three temperatures. Linear interpolation is used to determine the coefficients at flowing temperature.

Mean Coefficient of Thermal Expansion $= \frac{A}{10^6}$ (in./in./°F)

Material	Coef.	-50 °F	70 °F	200 °F
Bronze 4-10	A	9.15	9.57	10.03
300 Series Stainless Steel	A	8.90	9.11	9.34
Monel	A	7.15	7.48	7.84
.2 to 1.1% C Steel	A	5.80	6.07	6.38
5% Chrome Moly	A	5.45	5.73	6.04
410 to 430 Stainless Steel	A	5.00	5.24	5.50

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

* Distilled water values used in all calculations

BLDG 2 TRACEABILITY

ARL NUMBER	MODEL	SERIAL NUMBER	DESCRIPTION	Notes	Location	LAST CAL DATE	NEXT CAL DUE
00484	1823	22101115	B&K PRECISION TIMER/COUNTER - BACKUP	FREQUENCY CHECKED DAILY - HOOPER LINE 4	BLDG 2		
00489	1823	2210206	B&K PRECISION TIMER/COUNTER - PRIMARY	FREQUENCY CHECKED DAILY - HOOPER LINE 4	BLDG 2		
00565	KCC300S	2539467	50,000# WEIGH TANK SCALE W/ JAG EXTREME READOUT	READOUT: JAG EXTREME S/N 5309718-5HD - HOOPER LINE 1 & 2 50,000 # SCALE	BLDG 2	2/10/2015	8/11/2015
00584	DP41-RTD	6240653	LINE TEMPERATURE THERMOMETER READOUT	STUDENT LAB	BLDG 2	5/26/2015	11/24/2015
00596	DP41-RTD	7091746	AMBIENT TEMPERATURE THERMOMETER READOUT	STUDENT LAB	BLDG 2	5/26/2015	11/24/2015
00825	3051SCD2A2001A	0481273	DP TRANSMITTER 0-250"		BLDG 2	6/1/2015	6/22/2015

June 10, 2015

CERTIFICATE OF CALIBRATION

To Whom It May Concern:

This is to certify work performed under Internal Purchase Order Number 66124, *Job Number* issued by Alden Research laboratory, Inc., for the calibration of (1) 4" Orifice Plate Meter, Serial Number 1, and (1) 250" DP Cell, Cell Number 812.

The meter was calibrated in Alden's Hooper Low Reynolds Number Facility and the test instrumentation used was calibrated with Transfer Standards traceable to the National Institute of Standards & Technology (NIST).

Testing was conducted on June 1 - 2, 2015, in accordance with Alden's Quality Management System Manual; QMSM-01 Revision 5, October 17, 2014.

Philip S. Stacy
Director, Calibration Services

PSS/cmk

ALDEN Research Laboratory, Inc.
30 Shrewsbury Street, Holden, Massachusetts 01520-1843
508-829-6000/phone • 508-829-5939/fax
info@aldenlab.com • www.aldenlab.com

CALIBRATION OF:
6" ORIFICE METER
SERIAL NUMBER 977

FOR:
ALDEN RESEARCH LABORATORY, INC.
PURCHASE ORDER NUMBER 63372
MARCH 2013 - REPORT NO. 2131ARL004-R1

CERTIFIED BY
Philip S. Stacy

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

All Client supplied information and calibration results are considered proprietary and confidential to the Client. If a third party is a witness during calibrations or if the Client requests transmittal of data to a third party, Alden considers that the Client has waived confidentiality for the Witness.

In the event the Client distributes any report issued by Alden outside its own organization, such report shall be used in its entirety, unless Alden approves a summary or abridgment for distribution.

No advertising or publicity containing any reference to Alden or any employee, either directly or by implication, shall be made use of by Client without Alden's written approval.

INTRODUCTION

One 6" Orifice Meter was calibrated at the Alden Research Laboratory, Inc. (Alden) for Alden's Hydraulic Department under their internal purchase order number 63372. Alden's standard test procedures, in QMSM-01 Revision 4, were used for calibration. Flow element performance is presented as coefficient C versus pipe Reynolds number, in both tabular and graphical format.

FLOW ELEMENT INSTALLATION

The meter under test was installed in Test Line 4 in the Hooper Low Reynolds Number Facility, which is shown in plan view on Figure 1. Water was provided from a 40" penstock from the Laboratory head pond at a head of about 18 feet. An electrically driven centrifugal pump provided a maximum head of about 170 ft and a maximum flow of 1,200 gpm.

The detailed piping arrangement, immediately upstream and downstream of the meter, including all significant fittings and pipe lengths, is shown in Figure 2. Careful attention was given to align the meter with the test line piping, and to assure no gaskets between flanged sections protruded into the flow. Vents were provided at critical locations of the test line to purge the system of air.

TEST PROCEDURE

The test technician verified proper installation of the meter under test in the test line prior to introducing water into the system to equalize test line piping and primary element temperature to water temperature.

Prior to the test run, the control valve was set to produce the desired flow, while the flow was directed to waste. Sufficient time was allowed to stabilize both the flow and the instrument readings, after which the weigh tank discharge valve was closed and the weigh tank scale indicator and the electric timer were both zeroed. To begin the test run, flow was diverted into the weigh tank, which automatically started the timer.

At the start of the water collection a computer based data acquisition system was activated to read the meter output, such that the meter output was averaged while the weigh tank was filling. At the end of the run, flow was diverted away from the weigh tank and the timer and data acquisition system were stopped to terminate the test run. The weight of water in the tank, elapsed time, water temperature, and average meter output were recorded on a data sheet. The data were entered into the computer to determine the flow and the results were plotted so that each test run was evaluated before the next run began. The control valve was then adjusted to the next flow and the procedure repeated.

FLOW MEASUREMENT METHOD

Flow was measured by the gravimetric method using a tank mounted on a scale having a capacity of 1,000 pounds with a resolution of 0.1 lbs. Alden's flow meter calibrations using the gravimetric flow measurement method comply with ASME/ANSI MFC-9M-1988 Measurement of Liquid Flow in Closed Conduits by Weighing Method. Water passing through the flow element was diverted into the tank with a hydraulically operated knife edge passing through a rectangular jet produced by a diverter head box. A Hewlett-Packard 10 MHz Frequency Counter with a resolution 0.001 sec was started upon flow diversion into the tank by an optical switch, which is positioned at the center of the jet. The timer was stopped upon flow diversion back to waste and the elapsed diversion time was recorded. A thermistor thermometer measured water temperature to allow calculation of water density. Volumetric flow was calculated by Equation (1).

$$q_a = \frac{W}{T\rho_w B_c} \qquad (1)$$

where	q_a	=	actual flow, ft^3/sec
	W	=	mass of water collected, lb_m
	T	=	time, sec
	ρ_w	=	water density, lb_m/ft^3
	B_c	=	buoyancy correction, $1-\rho_a/\rho_w$

The buoyancy correction includes air density calculated by perfect gas laws with the standard barometric pressure, a relative humidity of 75%, and measured air temperature. The weigh tank is periodically calibrated to full scale using 10,000 lbm of cast iron weights, whose calibration is traceable to NIST. Flow calculations are computerized to assure consistency. Weigh tank calibration data and water density as a function of temperature, are stored on disk file. Data were recorded manually and on disk file for later review and reporting.

DISCHARGE COEFFICIENT CALCULATIONS

Discharge coefficient, C, is defined by Equation (2) and plotted versus pipe or throat Reynolds number. Calculations of the discharge coefficient of differential producing flow meters are in accordance with ASME/ANSI MFC-3M-2004 Measurement of Fluid Flow in Pipes Using Orifice, Nozzle and Venturi, and ASME 19.5-2004 Flow Measurement. The discharge coefficient relates the theoretical flow to the actual flow.

$$C = \frac{q_a}{q_{th}} = \frac{q_a}{F_a K_M \sqrt{\Delta h}} \tag{2}$$

where	C	=	discharge coefficient, dimensionless
	q_{th}	=	theoretical flow, ft^3/sec
	F_a	=	thermal expansion factor, dimensionless
	Δh	=	differential head, ft at line temperature
	K_M	=	meter constant, $ft^{2.5}/sec$

The theoretical proportionality constant, K_M, between flow and square root of differential head is a function of the meter throat area, the ratio of throat to pipe diameter, and the local gravitational constant, as defined by Equation (3).

$$K_M = \frac{a_t\sqrt{2g_l}}{\sqrt{1-\beta^4}} \tag{3}$$

where	a_t	=	throat area, $\pi d^2/4$, ft^2
	d	=	throat diameter, ft
	g_l	=	local gravitational constant, 32.1625 ft/sec^2 at Alden
	β	=	ratio of throat to pipe diameter, d/D, dimensionless
	D	=	pipe diameter, ft

The effect of fluid properties, viscosity and density, on the discharge coefficient is determined by Reynolds number, the ratio of inertia to viscous forces. Pipe Reynolds number, R_D, is determined by Equation (4).

$$R_D = \frac{q_a D}{a_p \gamma} \tag{4}$$

where a_p = pipe area, $\pi D^2/4$, ft^2

γ = kinematic viscosity, ft^2/sec

FLOW METER SIGNAL RECORDING

The secondary element, which converts the primary element signal into engineering units, was one of several "Smart" differential pressure transmitters having a range of 250" and 1,000" Water Column. 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. Average transmitter reading was converted to feet of flowing water using a linear regression analysis of the calibration data and line water temperatures to calculate appropriate specific weight.

TEST RESULTS

The results are presented in tabular and graphical format. The calculated flow, meter signal and meter performance are listed in the table(s) in the following pages.

Analysis indicates that the flow measurement uncertainty is within 0.25% 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).

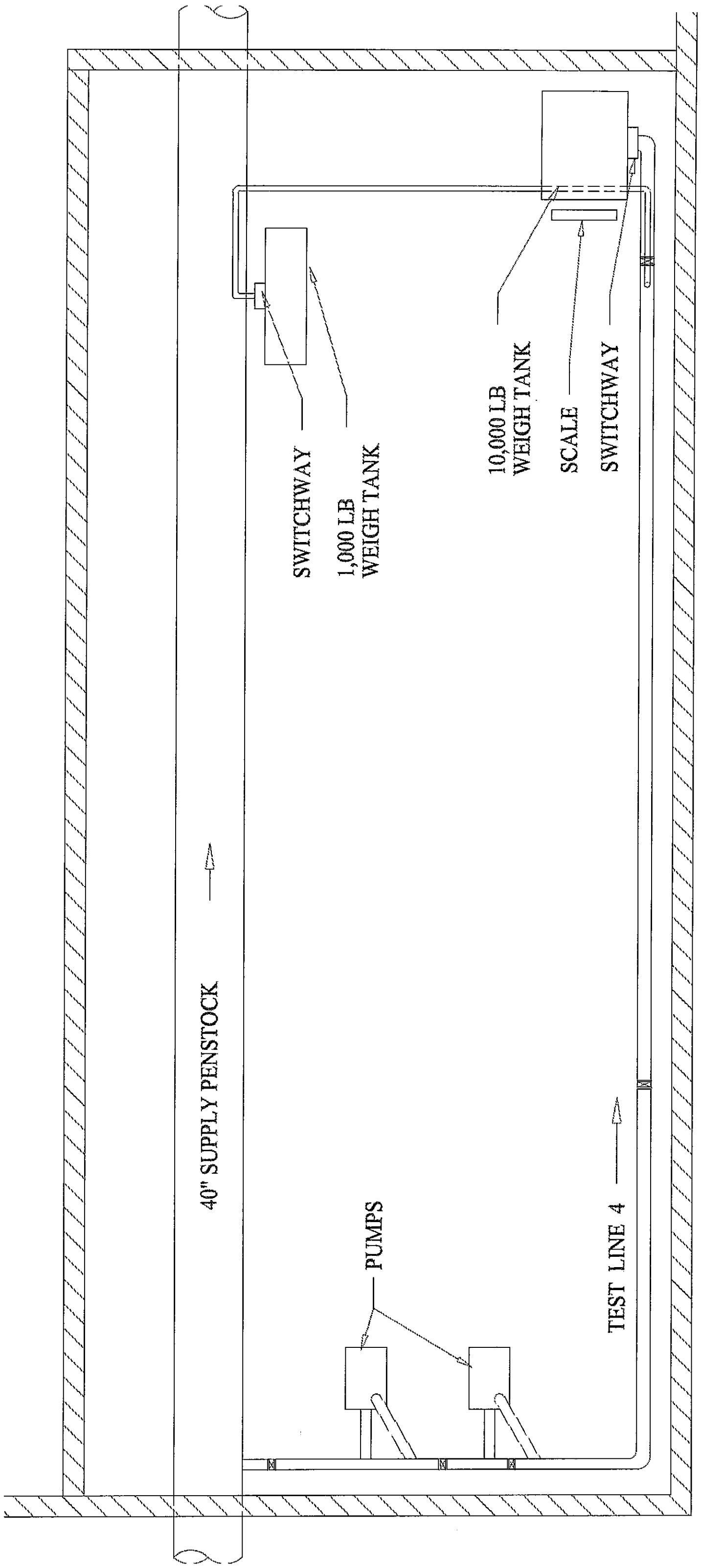


Figure 1
Hooper Low Reynolds Number Facility Test Line 4

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Plan View Hooper Facility Line 4

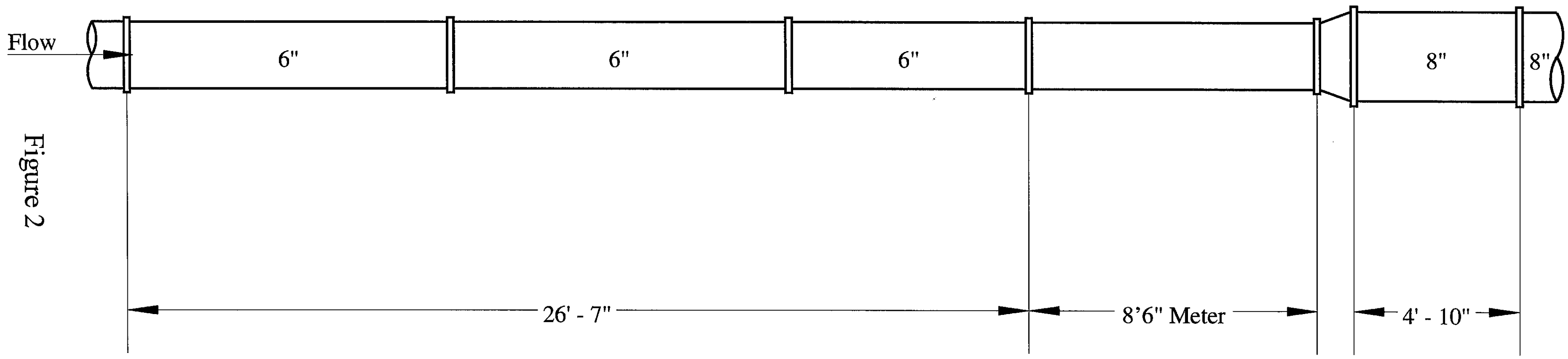


Figure 2

ALDEN RESEARCH LAB
Purchase Order Number: 63372
6" ORIFICE METER
Serial Number: 977
March 19, 2013

ALDEN RESEARCH LAB

Purchase Order Number: 63372
6" ORIFICE METER
Serial Number: 977

CALIBRATION
DATE: March 19, 2013
PIPE DIAMETER = 6.0650
THROAT DIAMETER = 4.2000

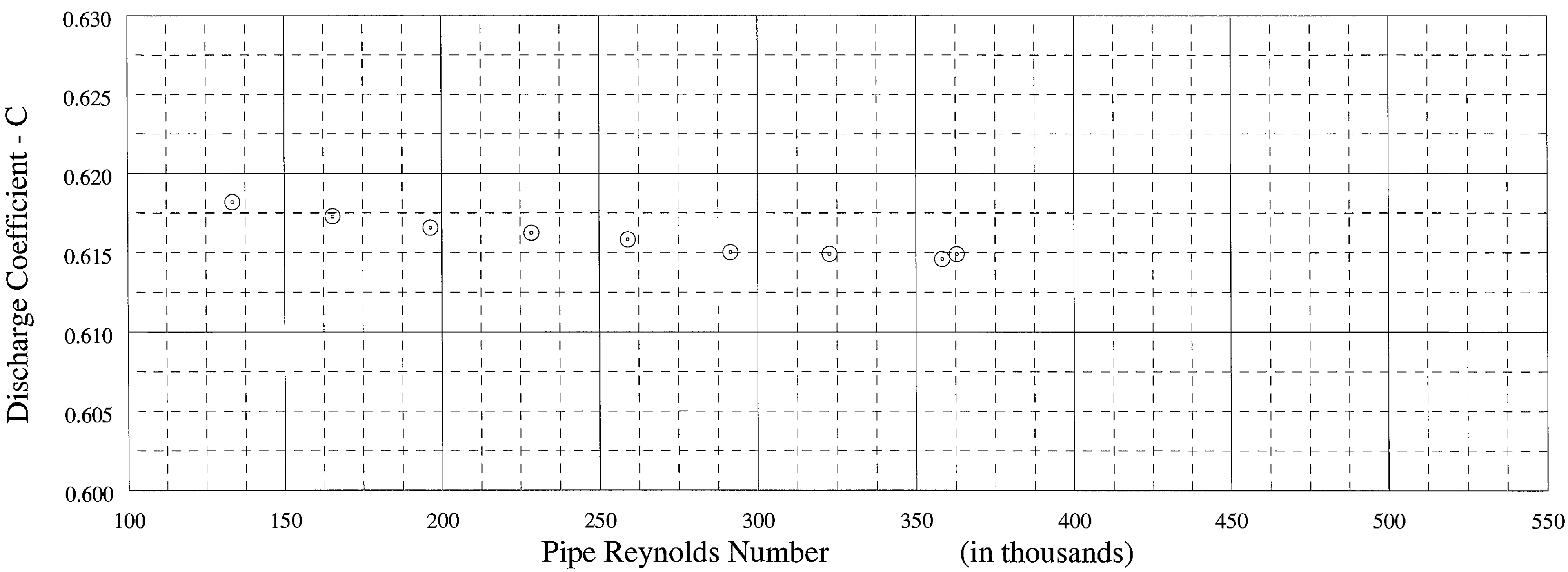
Run #	Line Temp Deg F	Air Temp Deg F	Net Weight lb.	Run Duration secs.	Output [see note]	Flow GPM	H Line FT H20	Pipe Rey. # x 10^5	Coef
1	41	60	9574	66.414	9.040~	1037.	18.321	3.5828	0.6146
2	40	61	9571	64.570	9.435~	1066.	19.350	3.6287	0.6149
3	39	57	9577	70.732	8.203~	974.6	16.146	3.2263	0.6149
4	39	56	9565	78.217	7.057~	880.2	13.165	2.9138	0.6150
5	39	56	9566	88.001	5.984~	782.4	10.375	2.5901	0.6158
6	39	57	9563	99.712	5.097~	690.4	8.067	2.2854	0.6163
7	39	57	9558	115.951	4.284~	593.3	5.953	1.9643	0.6166
8	39	57	9554	137.621	3.614~	499.7	4.212	1.6543	0.6173
9	39	57	9552	170.537	3.046~	403.1	2.734	1.3347	0.6182

~ 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: THL

CERTIFIED BY:



$$q_a = C\,F_a\,K_M\sqrt{\Delta h}$$

q_a = Actual Flow (ft^3/sec)		
C = Discharge Coefficient (Dimensionless)		
Δh = Pressure Differential (Feet of Water at Run Temperature)		
K_M = Meter Constant = $\dfrac{a\sqrt{2g}}{\sqrt{1-\beta^4}}$	=	0.8794
F_a = Average Thermal Expansion Factor	=	0.9994
a = Throat Area (ft^2)	=	0.0962
g = Local Acceleration of Gravity (ft/sec^2)	=	32.1625
β = Ratio of Throat to Pipe Diameter (Dimensionless)	=	0.6925
Pipe Diameter (Inches)	=	6.0650
Throat Diameter (Inches)	=	4.2000
Dimensions By: ALDEN RESEARCH LAB		

ALDEN RESEARCH LAB
Purchase Order Number: 63372
6" ORIFICE METER
Serial Number: 977
March 19, 2013

Certified By:

Thermal Expansion Factor

The dimensions of a differential producing flow meter are affected by the operating temperature, requiring a Thermal Expansion Factor (F_a) to be included in the calculations. The calculation requires the temperature at which the meter dimensions were measured be known. If this information is not available, an ambient temperature of 68° F is assumed. The Thermal Expansion Factor is calculated according to the American Society of Mechanical Engineers Standard ASME MFC-3M-1989, Equation 17 (pg 11).

$$F_a = 1 + \frac{2}{1-\beta^4}\left(\alpha_{PE} - \beta^4{}_{meas} \propto_p\right)(t - t_{meas})$$

where

	β	=	ratio of throat diameter to pipe diameter, dimensionless
	α_{PE}	=	thermal expansion factor of primary element, (in./in./°F)
	$\propto_p$	=	thermal expansion factor of pipe, (in./in./°F)
	t	=	temperature of flowing fluid, °F
	t_{meas}	=	temperature of measurements, °F

Thermal expansion factors, α, excerpted from MFC-3M-1989, are listed in the Table below for six typically used materials at three temperatures. Linear interpolation is used to determine the coefficients at flowing temperature.

Mean Coefficient of Thermal Expansion = $\frac{A}{10^6}$ (in./in./°F)

Material	Coef.	-50 °F	70 °F	200 °F
Bronze 4-10	A	9.15	9.57	10.03
300 Series Stainless Steel	A	8.90	9.11	9.34
Monel	A	7.15	7.48	7.84
.2 to 1.1% C Steel	A	5.80	6.07	6.38
5% Chrome Moly	A	5.45	5.73	6.04
410 to 430 Stainless Steel	A	5.00	5.24	5.50

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

* Distilled water values used in all calculations

BLDG 2 TRACEABILITY

ARL NUMBER	MODEL	SERIAL NUMBER	DESCRIPTION	Notes	Location	LAST CAL DATE	NEXT CAL DUE
00484	1823	22101115	B&K PRECISION TIMER/COUNTER - BACKUP	FREQUENCY CHECKED DAILY - HOOPER LINE 4	BLDG 2		
00489	1823	2210206	B&K PRECISION TIMER/COUNTER - PRIMARY	FREQUENCY CHECKED DAILY - HOOPER LINE 4	BLDG 2		
00584	DP41-RTD	6240653	LINE TEMPERATURE THERMOMETER READOUT	STUDENT LAB	BLDG 2	11/28/201	5/29/2013
00596	DP41-RTD	7091746	AMBIENT TEMPERATURE THERMOMETER	STUDENT LAB	BLDG 2	11/28/201	5/29/2013
00825	3051SCD2A20 01A	0481273	DP TRANSMITTER 0-		BLDG 2	3/19/2013	4/9/2013
01018	6286	1005 FCB	10,000# WEIGH TANK SCALE WITH LOAD CELL 1048	10,000# CAPACITY THURMAN SCALE - HOOPER FACILITY LINE 4	BLDG 2	12/20/201	6/20/2013

CALIBRATION OF:

10" VENTURI

SERIAL NUMBER 10x5

8" ORIFICE METER

SERIAL NUMBER 8x5.25

FOR

ALDEN RESEARCH LABORATORY, INC.

PURCHASE ORDER NUMBER 67374

AUGUST 2015 - REPORT NO. 2151ARL014-R1

CERTIFIED BY

Philip S. Stacy

ALDEN RESEARCH LABORATORY, INC.

30 SHREWSBURY STREET

HOLDEN, MASSACHUSETTS 01520

All Client supplied information and calibration results are considered proprietary and confidential to the Client. If a third party is a witness during calibrations or if the Client requests transmittal of data to a third party, Alden considers that the Client has waived confidentiality for the Witness.

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INTRODUCTION

Two flow meters were calibrated at the Alden Research Laboratory, Inc. (Alden). Alden's standard test procedures, in QMSM-01 Revision 5, were used for testing. The performance of the meter under test is presented in both tabular and graphical format.

FLOW ELEMENT INSTALLATION

The meter under test was installed in test line 1, 2, 3 or 4 of the Hooper Facility, depending on flow requirements and pipe size. In the Hooper Facility, water is provided from a 40" penstock from the laboratory head pond at a head of about 18 feet. Electrically driven centrifugal pumps provide a maximum head of about 140 ft and a maximum flow of 6,000 gpm in Lines 1 and 2, and a maximum head of about 170 ft and a maximum flow of 1,200 gpm in Line 4. In Line 3, water is provided through a 40" penstock from the main laboratory pond resulting in a gross gravity head of approximately 28 feet and a maximum flow of 35,000 gpm. A calibrated master Venturi is used to measure flow in Line 3 and the Gravimetric Method is used to measure flow in Lines 1, 2 and 4.

The detailed piping arrangements, including all significant fittings and pipe lengths, immediately upstream and downstream of the flow sections, are shown in the included figures. Careful attention was given to align the meter under test with the test line piping, and to assure no gaskets between flanged sections protruded into the flow. Vents were provided at critical locations of the test line to purge the system of air.

TEST PROCEDURE

The test technician verified proper installation of the meter under test in the test line prior to introducing water into the system to equalize test line piping and primary element temperature to water temperature.

Prior to the test run, the control valve was set to produce the desired flow, while the flow was directed to waste. Sufficient time was allowed to stabilize both the flow and the instrument readings, after which the weigh tank discharge valve was closed and the weigh tank scale indicator and the electric timer were both zeroed. To begin the test run, flow was diverted into the weigh tank, which automatically started the timer.

At the start of the water collection a computer based data acquisition system was activated to read the meter output, such that the meter output was averaged while the weigh tank was filling. At the end of the run, flow was diverted away from the weigh tank and the timer and data acquisition system were stopped to terminate the test run. The weight of water in the tank, elapsed time, water temperature, and average meter output were recorded on a data sheet. The data were entered into the computer to determine the flow and the results were plotted so that each test run was evaluated before the next run began. The control valve was then adjusted to the next flow and the procedure repeated.

FLOW MEASUREMENT METHOD

Flow was measured by the gravimetric method using tanks mounted on a scale having a capacity of 100,000 pounds, with resolution of 1.0 lb. Alden's flow meter calibrations using the gravimetric flow measurement method comply with ASME/ANSI MFC-9M-1988 Measurement of Liquid Flow in Closed Conduits by Weighing Method. Water passing through the meter under test was diverted into the tank with a hydraulically operated knife edge passing through a rectangular jet produced by a diverter head box. A Hewlett-Packard 10 MHz Frequency Counter with a resolution 0.001 sec was started upon flow diversion into the tank by an optical switch, which is positioned at the center of the jet. The timer was stopped upon flow diversion back to waste and the elapsed diversion time was recorded. An RTD thermometer measured water temperature to allow calculation of water density. Volumetric flow was calculated by Equation (1).

$$q_a = \frac{W}{T\rho_w B_c} \tag{1}$$

where	q_a	=	actual flow, ft^3/sec
	W	=	mass of water collected, lb_m
	T	=	time, sec
	ρ_w	=	water density, lb_m/ft^3
	B_c	=	buoyancy correction, $1-\rho_a/\rho_w$

The buoyancy correction includes air density calculated by perfect gas laws with the standard barometric pressure, a relative humidity of 75%, and measured air temperature. The weigh tank is periodically calibrated to full scale using 10,000 lbm of cast iron weights, whose calibration is traceable to NIST. Flow calculations are computerized to assure consistency. Weigh tank calibration data and water density as a function of temperature, are stored on disk file. Data were recorded manually and on disk file for later review and reporting.

DISCHARGE COEFFICIENT CALCULATIONS

Discharge coefficient, C, is defined by Equation (2) and plotted versus pipe or throat Reynolds number. Calculations of the discharge coefficient of differential producing flow meters are in accordance with ASME/ANSI MFC-3M-2004 Measurement of Fluid Flow in Pipes Using Orifice, Nozzle and Venturi, and ASME 19.5-2004 Flow Measurement. The discharge coefficient relates the theoretical flow to the actual flow.

$$C = \frac{q_a}{q_{th}} = \frac{q_a}{F_a K_M \sqrt{\Delta h}} \tag{2}$$

where

	C	=	discharge coefficient, dimensionless
	q_{th}	=	theoretical flow, ft^3/sec
	F_a	=	thermal expansion factor, dimensionless
	Δh	=	differential head, ft at line temperature
	K_M	=	meter constant, $ft^{2.5}/sec$

The theoretical proportionality constant, K_M, between flow and square root of differential head is a function of the meter throat area, the ratio of throat to pipe diameter, and the local gravitational constant, as defined by Equation (3).

$$K_M = \frac{a_t \sqrt{2g_l}}{\sqrt{1-\beta^4}} \tag{3}$$

where

	a_t	=	throat area, $\pi d^2/4$, ft^2
	d	=	throat diameter, ft
	g_l	=	local gravitational constant, 32.1625 ft/sec^2 at Alden
	β	=	ratio of throat to pipe diameter, d/D, dimensionless
	D	=	pipe diameter, ft

The effect of fluid properties, viscosity and density, on the discharge coefficient is determined by Reynolds number, the ratio of inertia to viscous forces. Throat Reynolds number, R_d, (or pipe; R_D) is determined by Equation (4).

$$R_d = \frac{q_a d}{a_t \gamma} \qquad (R_D = \frac{q_a D}{a_D \gamma}) \tag{4}$$

where a_t = throat area, $\pi d^2/4$, ft^2 ($a_D = \pi D^2/4$)

γ = kinematic viscosity, ft^2/sec

FLOW METER SIGNAL RECORDING

The secondary element, which converts the primary element signal into engineering units, was one of several "Smart" differential pressure transmitters having a range of 250" and 1,000" Water Column. 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. Average transmitter reading was converted to feet of flowing water using a linear regression analysis of the calibration data and line water temperatures to calculate appropriate specific weight.

TEST RESULTS

The results are presented in tabular and graphical format. The calculated flow, meter signal and meter performance are listed in the table(s) in the following pages.

Analysis indicates that the flow measurement uncertainty is within 0.25% 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).

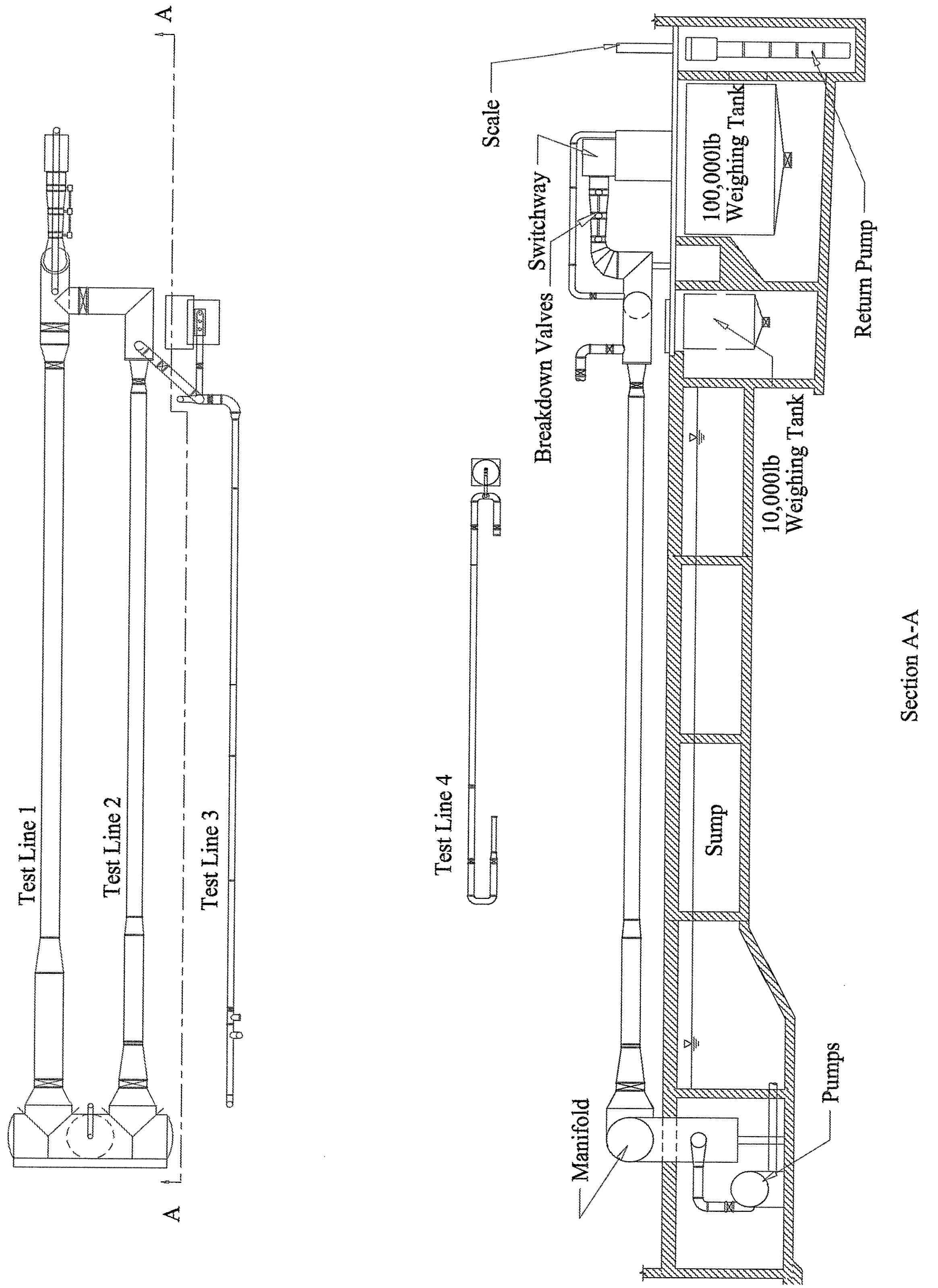

Figure 1
Allen High Reynolds Facility Test Lines 1, 2, 3 and 4

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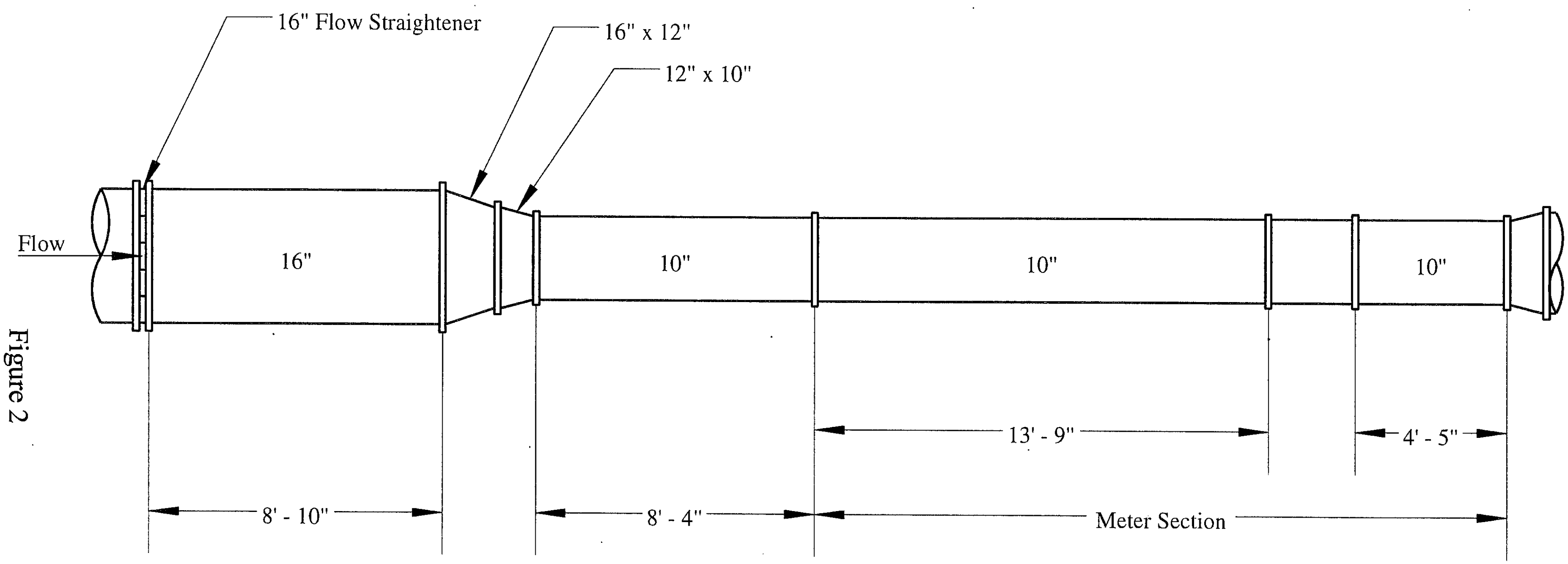
Plan View Hooper Facility Line 1



ALDEN RESEARCH LAB
Purchase Order Number: 67374
10" VENTURI METER
Serial Number: 10x5
Tag Number: #3
August 31, 2015

Figure 2

ALDEN RESEARCH LAB

Purchase Order Number: 67374
10" VENTURI METER
Serial Number: 10x5
Tag Number: #3

CALIBRATION
DATE: August 31, 2015
PIPE DIAMETER = 10.0000
THROAT DIAMETER = 5.0000

As found is as left data

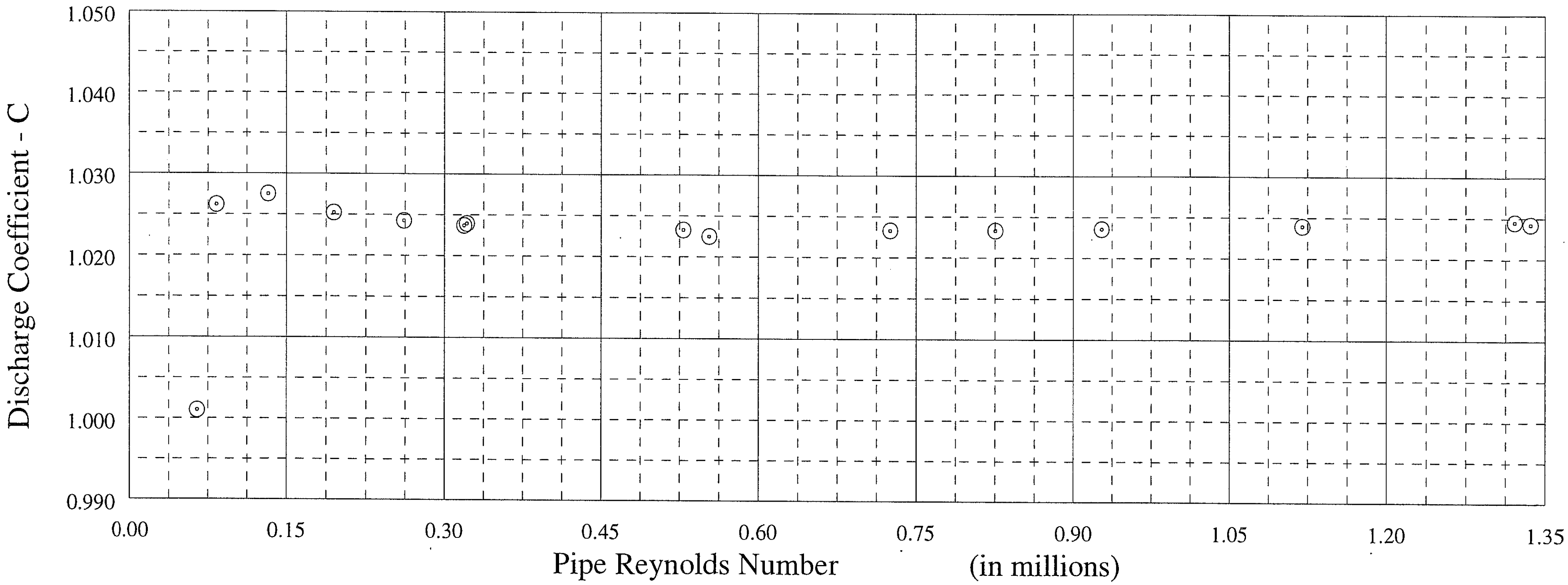
Run #	Line Temp Deg F	Air Temp Deg F	Net Weight lb.	Run Duration secs.	Output [see note]	Flow GPM	H Line FT H20	Pipe Rey. # x 10^6	Coef
1	71	76	42714	181.415	6.123~	1698.	10.735	0.5534	1.0225
2	71	77	45874	82.011	7.809~	4034.	60.354	1.3214	1.0245
3	72	77	45938	97.637	6.116~	3394.	42.754	1.1201	1.0240
4	72	77	46036	118.652	4.803~	2799.	29.098	0.9273	1.0236
5	72	78	45774	150.565	8.868~	2193.	17.874	0.7256	1.0233
6	72	78	43154	194.344	5.661~	1601.	9.536	0.5286	1.0233
7	72	78	30273	225.089	3.338~	970.2	3.495	0.3190	1.0237
8	72	74	46084	81.778	7.899~	4065.	61.294	1.3364	1.0243
9	72	74	45676	131.383	4.252~	2507.	23.371	0.8255	1.0233
10	72	74	24814	182.929	3.360~	978.5	3.554	0.3217	1.0239
11	72	73	24254	219.962	2.896~	795.4	2.347	0.2615	1.0243
12	71	72	18258	222.270	7.011~	592.5	1.300	0.1946	1.0253
13	71	72	12473	222.355	4.332~	404.6	0.604	0.1329	1.0275
14	71	72	6753	192.605	2.919~	252.9	0.236	0.0830	1.0262
15	71	72	6557	240.524	2.588~	196.6	0.150	0.0646	1.0011

~ 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: THL

CERTIFIED BY:



As found is as left data

ALDEN RESEARCH LAB
Purchase Order Number: 67374
10" VENTURI METER
Serial Number: 10x5
Tag Number: #3
August 31, 2015

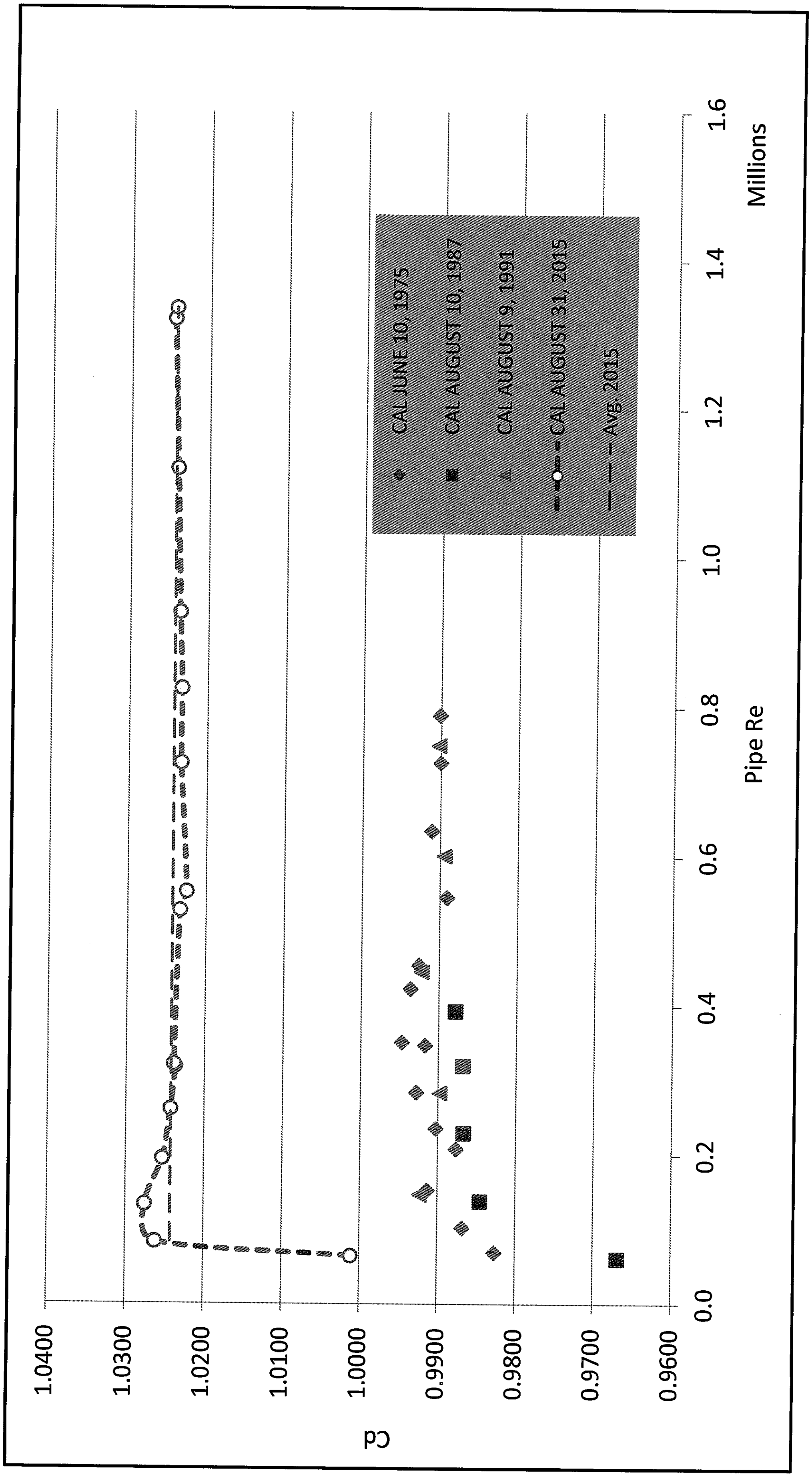
$$q_a = C F_a K_M \sqrt{\Delta h}$$

q_a = Actual Flow (ft^3/sec)
C = Discharge Coefficient (Dimensionless)
Δh = Pressure Differential (Feet of Water at Run Temperature)

K_M =	Meter Constant = $\dfrac{a\sqrt{2g}}{\sqrt{1-\beta^4}}$	=	1.1295
F_a =	Average Thermal Expansion Factor	=	1.0000
a =	Throat Area (ft^2)	=	0.1364
g =	Local Acceleration of Gravity (ft/sec^2)	=	32.1625
ß =	Ratio of Throat to Pipe Diameter (Dimensionless)	=	0.5000
	Pipe Diameter (Inches)	=	10.0000
	Throat Diameter (Inches)	=	5.0000

Dimensions By: ALDEN RESEARCH LAB

Certified By:



Cd
1.0400
1.0300
1.0200
1.0100
1.0000
0.9900
0.9800
0.9700
0.9600
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
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Millions
Pipe Re
CAL JUNE 10, 1975
CAL AUGUST 10, 1987
CAL AUGUST 9, 1991
CAL AUGUST 31, 2015
Avg. 2015

Plan View Hooper Facility Line 1

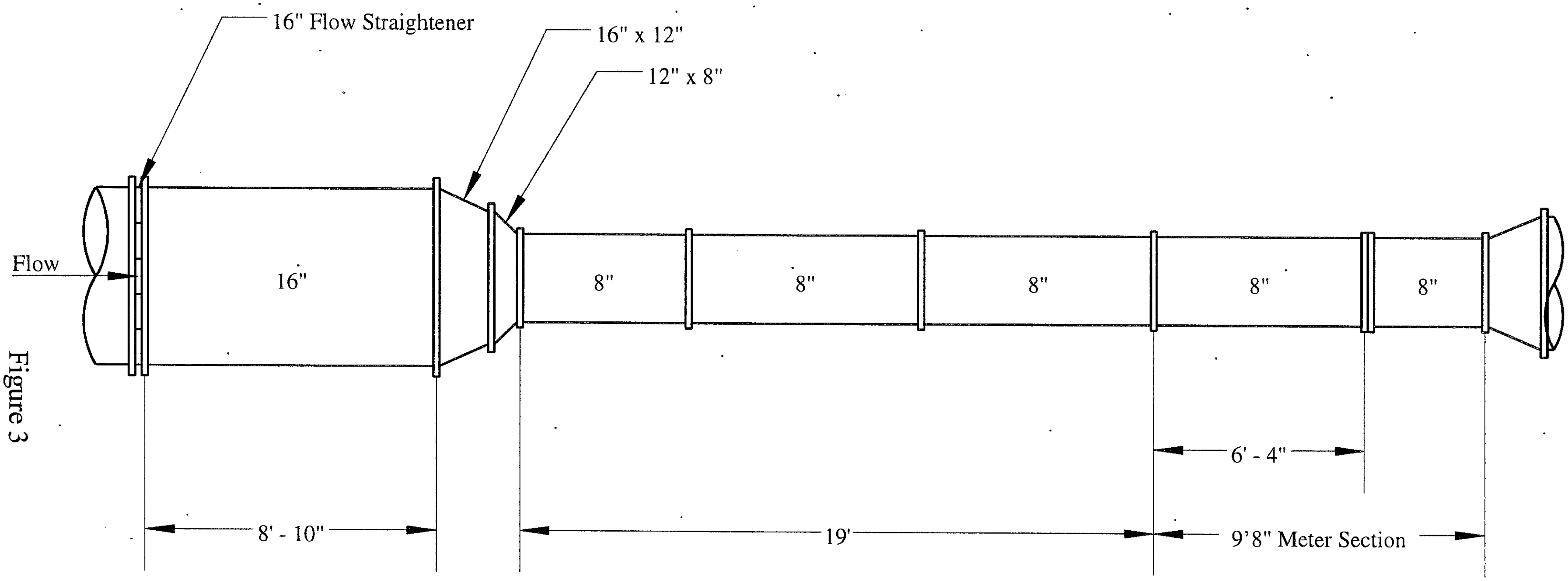


Figure 3

ALDEN RESEARCH LAB
Purchase Order Number: 67374
8" ORIFICE PLATE
Serial Number: 8x5.25
September 1, 2015

ALDEN RESEARCH LAB

Purchase Order Number: 67374
8" ORIFICE PLATE
Serial Number: 8x5.25

CALIBRATION
DATE: September 1, 2015
PIPE DIAMETER = 8.0000
THROAT DIAMETER = 5.2510

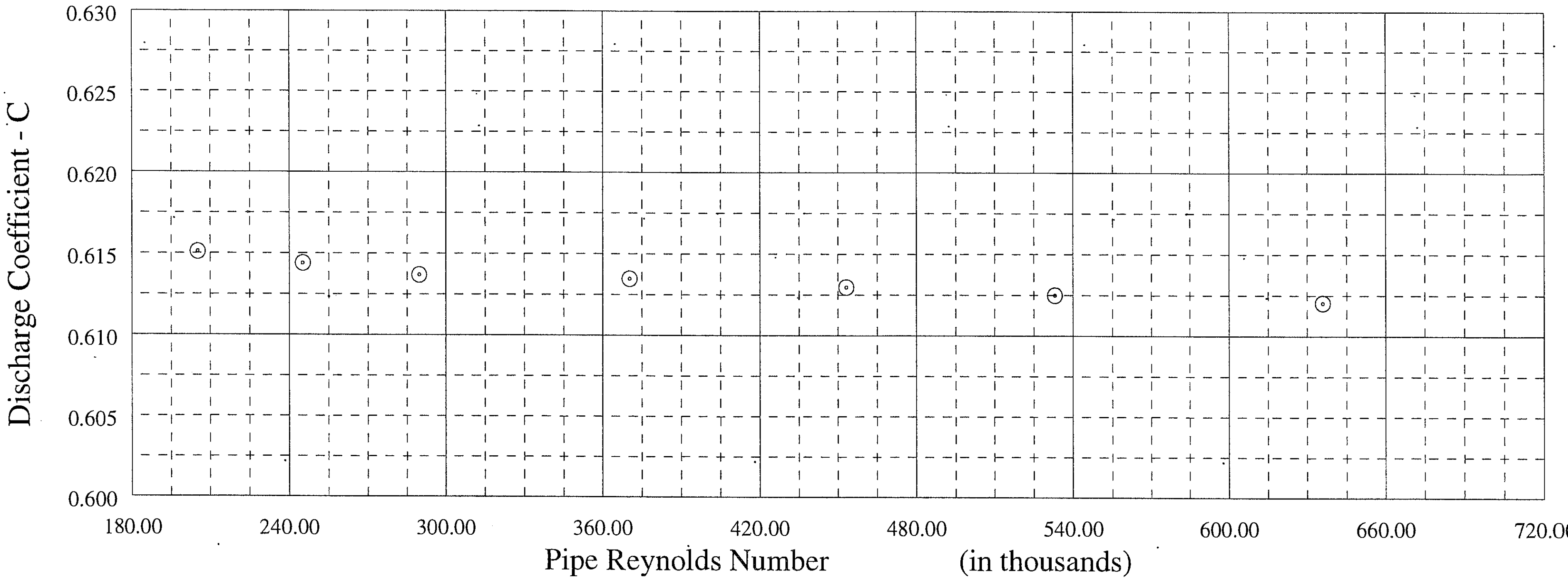
Run #	Line Temp Deg F	Air Temp Deg F	Net Weight lb.	Run Duration secs.	Output [see note]	Flow GPM	H Line FT H20	Pipe Rey. # x 10^5	Coef
1	71	72	36527	169.405	8.896~	1555.	17.946	6.3592	0.6120
2	71	72	36509	202.484	6.813~	1300.	12.531	5.3313	0.6125
3	71	72	30587	199.534	5.472~	1105.	9.043	4.5326	0.6130
4	71	72	24506	195.660	4.311~	903.4	6.027	3.7033	0.6135
5	71	72	18663	190.467	3.411~	706.8	3.686	2.8972	0.6137
6	71	72	18231	262.642	9.094~	500.7	1.841	2.0525	0.6151
7	71	72	18255	220.333	3.005~	597.6	2.629	2.4497	0.6144

~ 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: THL

CERTIFIED BY:



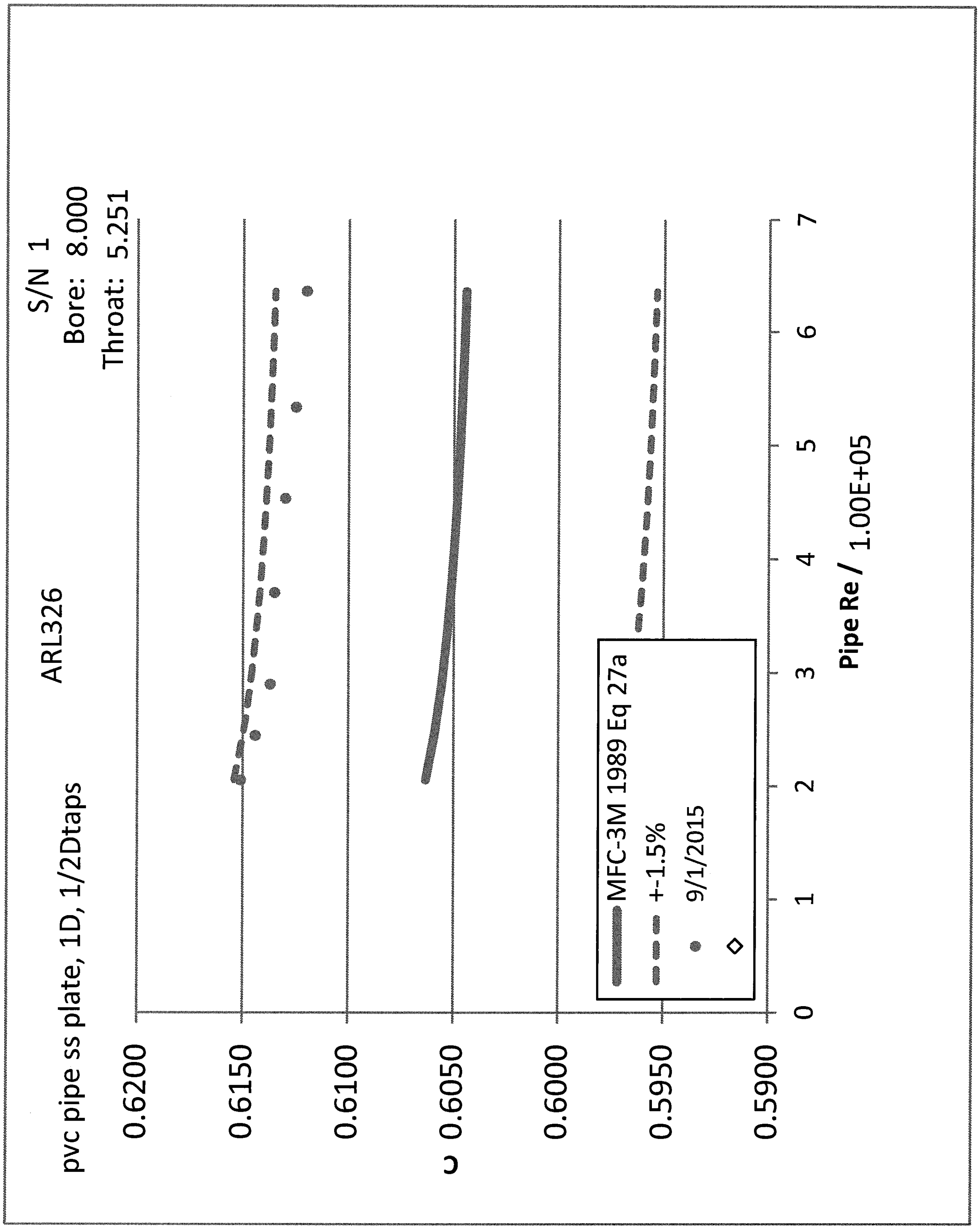
$$q_a = C\,F_a\,K_M\,\sqrt{\Delta h}$$

q_a =	Actual Flow (ft^3/sec)		
C =	Discharge Coefficient (Dimensionless)		
Δh =	Pressure Differential (Feet of Water at Run Temperature)		
K_M =	Meter Constant = $\dfrac{a\sqrt{2g}}{\sqrt{1-\beta^4}}$	=	1.3366
F_a =	Average Thermal Expansion Factor	=	1.0000
a =	Throat Area (ft^2)	=	0.1504
g =	Local Acceleration of Gravity (ft/sec^2)	=	32.1625
ß =	Ratio of Throat to Pipe Diameter (Dimensionless)	=	0.6564
	Pipe Diameter (Inches)	=	8.0000
	Throat Diameter (Inches)	=	5.2510

Dimensions By: ALDEN RESEARCH LAB

ALDEN RESEARCH LAB
Purchase Order Number: 67374
8" ORIFICE PLATE
Serial Number: 8x5.25
September 1, 2015

Certified By:



V:\Data\PTCData\Alden Meters\arl326 (sn8x5.25).xlsx

THERMAL EXPANSION FACTOR

The dimensions of a differential producing flow meter are affected by the operating temperature, requiring a Thermal Expansion Factor (F_a) to be included in the calculations. The calculation requires the temperature at which the meter dimensions were measured be known. If this information is not available, an ambient temperature of 68° F is assumed. The Thermal Expansion Factor is calculated according to the American Society of Mechanical Engineers Standard ASME MFC-3M-1989, Equation 17 (pg 11).

$$F_a = 1 + \frac{2}{1-\beta^4}\left(\alpha_{PE} - \beta^4{}_{meas} \propto_p\right)(t - t_{meas})$$

where

	β	=	ratio of throat diameter to pipe diameter, dimensionless
	α_{PE}	=	thermal expansion factor of primary element, (in./in./°F)
	$\propto_p$	=	thermal expansion factor of pipe, (in./in./°F)
	t	=	temperature of flowing fluid, °F
	t_{meas}	=	temperature of measurements, °F

Thermal expansion factors, α, excerpted from MFC-3M-1989, are listed in the Table below for six typically used materials at three temperatures. Linear interpolation is used to determine the coefficients at flowing temperature.

Mean Coefficient of Thermal Expansion = $\frac{A}{10^6}$ (in./in./°F)

Material	Coef.	-50 °F	70 °F	200 °F
Bronze 4-10	A	9.15	9.57	10.03
300 Series Stainless Steel	A	8.90	9.11	9.34
Monel	A	7.15	7.48	7.84
.2 to 1.1% C Steel	A	5.80	6.07	6.38
5% Chrome Moly	A	5.45	5.73	6.04
410 to 430 Stainless Steel	A	5.00	5.24	5.50

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

* Distilled water values used in all calculations

ARL

12X8 VENTURI METER #6

CALIBRATION
DATE: October 26, 2007
PIPE DIAMETER = 12.0000
THROAT DIAMETER = 8.0000

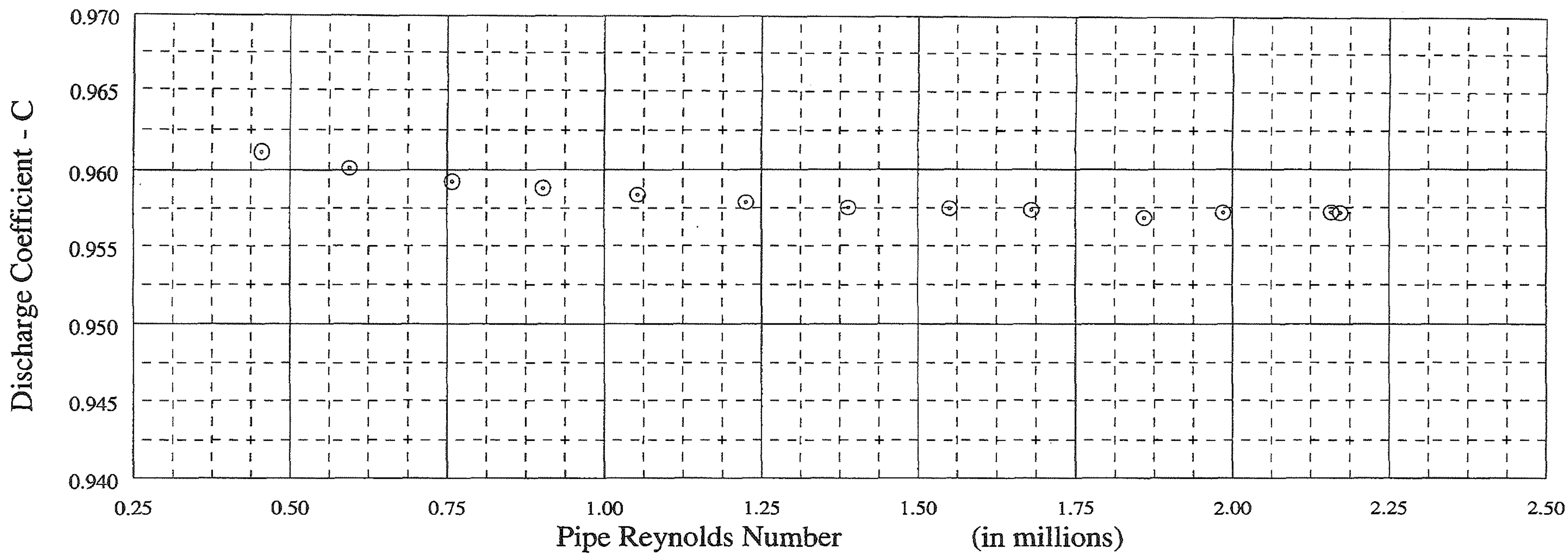
Run #	Line Temp Deg F	Air Temp Deg F	Net Weight lb.	Run Duration secs.	Output [see note]	Flow GPM	H Line FT H20	Pipe Rey. # x 10^6	Coef
2	94	70	95258	113.301	9.819~	6086.	20.539	2.1724	0.9572
3	93	70	95330	123.785	8.560~	5574.	17.232	1.9853	0.9572
4	93	70	95355	132.042	7.771~	5227.	15.162	1.8595	0.9568
5	93	70	95340	146.093	6.707~	4724.	12.368	1.6804	0.9574
6	93	70	95152	157.832	6.016~	4363.	10.553	1.5506	0.9574
7	93	70	95191	176.317	5.220~	3908.	8.462	1.3886	0.9575
8	93	70	95122	199.660	4.504~	3448.	6.584	1.2253	0.9579
9	93	70	95136	232.159	3.850~	2966.	4.866	1.0528	0.9584
10	93	70	95069	270.713	3.357~	2542.	3.570	0.9022	0.9589
11	93	70	95007	322.214	2.955~	2134.	2.515	0.7575	0.9593
12	93	70	95055	410.403	2.587~	1676.	1.549	0.5943	0.9601
13	93	70	94972	535.373	2.342~	1284.	0.906	0.4547	0.9612
14	93	70	95339	113.245	9.838~	6093.	20.588	2.1580	0.9572

~ 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: S.V.K.

CERTIFIED BY:



$$q_a = C F_a K_M \sqrt{\Delta h}$$

q_a = Actual Flow (ft^3/sec)		
C = Discharge Coefficient (Dimensionless)		
Δh = Pressure Differential (Feet of Water at Run Temperature)		
K_M = Meter Constant = $\dfrac{a\sqrt{2g}}{\sqrt{1 - \beta^4}}$	=	3.1252
F_a = Average Thermal Expansion Factor	=	1.0003
a = Throat Area (ft^2)	=	0.3491
g = Local Acceleration of Gravity (ft/sec^2)	=	32.1625
ß = Ratio of Throat to Pipe Diameter (Dimensionless)	=	0.6667
Pipe Diameter (Inches)	=	12.0000
Throat Diameter (Inches)	=	8.0000
Dimensions By: ARL		

ARL

12x8 VENTURI METER #6
October 26, 2007

Certified By:

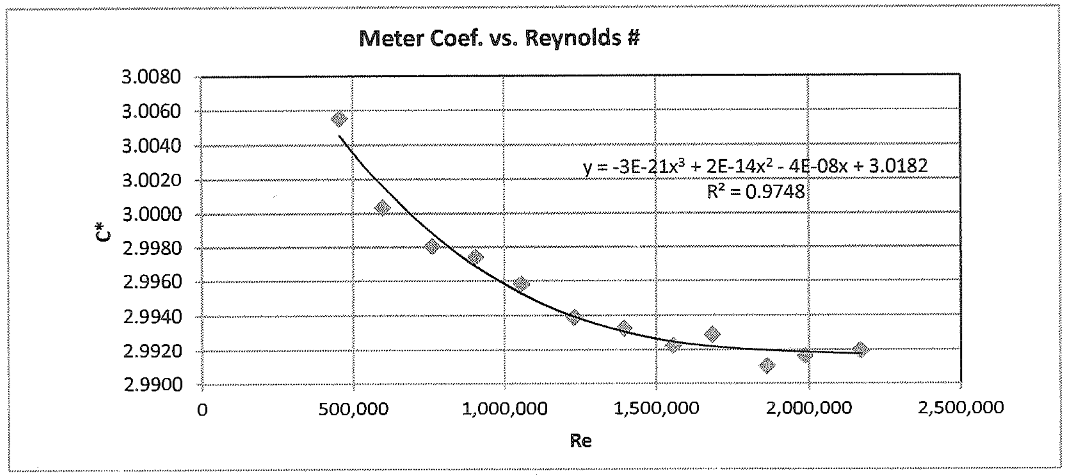
ARL

12 x 8 Venturi Meter No. 6

10/26/07 calibration

C*=C * K

Re	C	K	C*
2,171,392	0.9263	3.230	2.9919
2,168,897	0.9263	3.230	2.9919
1,986,433	0.9262	3.230	2.9916
1,862,771	0.9260	3.230	2.9910
1,683,515	0.9266	3.230	2.9929
1,554,863	0.9264	3.230	2.9923
1,392,713	0.9267	3.230	2.9932
1,228,780	0.9269	3.230	2.9939
1,057,008	0.9275	3.230	2.9958
905,905	0.9280	3.230	2.9974
760,504	0.9282	3.230	2.9981
597,284	0.9289	3.230	3.0003
457,585	0.9305	3.230	3.0055
average=	**0.9273**	average=	**2.9951**



	A	B	C	D	C* (avg)	K
old	-8.00E-05	0.0011	-0.0057	1.3962	3.0765	3.230
new	-3.00E-21	2.00E-14	-4.00E-08	3.018	2.9951	3.230

CHECK

X	Y
500000	3.00262500000000000E+00

C=Q/(K*SQRT(H))

H (ft)	Q (cfs)
5	6.6972
10	9.4713
15	11.5999
20	13.3944

4.531997
13.55928
6085.813

12 x 8 #6

CAL October 26, 2007

nu: 7.96E-06

K=3.230 C=Q/K*SQRT(H)

RUN	Q	DEL H	C	PIPE REN #
2	6086	20.539	0.9263	2,168,897
3	5574	17.232	0.9262	1,986,433
4	5227	15.162	0.9260	1,862,771
5	4724	12.368	0.9266	1,683,515
6	4363	10.553	0.9264	1,554,863
7	3908	8.462	0.9267	1,392,713
8	3448	6.584	0.9269	1,228,780
9	2966	4.866	0.9275	1,057,008
10	2542	3.57	0.9280	905,905
11	2134	2.515	0.9282	760,504
12	1676	1.549	0.9289	597,284
13	1284	0.906	0.9305	457,585
14	6093	20.588	0.9263	2,171,392

ARL

16X12.5 VENTURI
MANIFOLDED TAPS

CALIBRATION
DATE: November 9, 2007
PIPE DIAMETER = 16.0000
THROAT DIAMETER = 12.5000

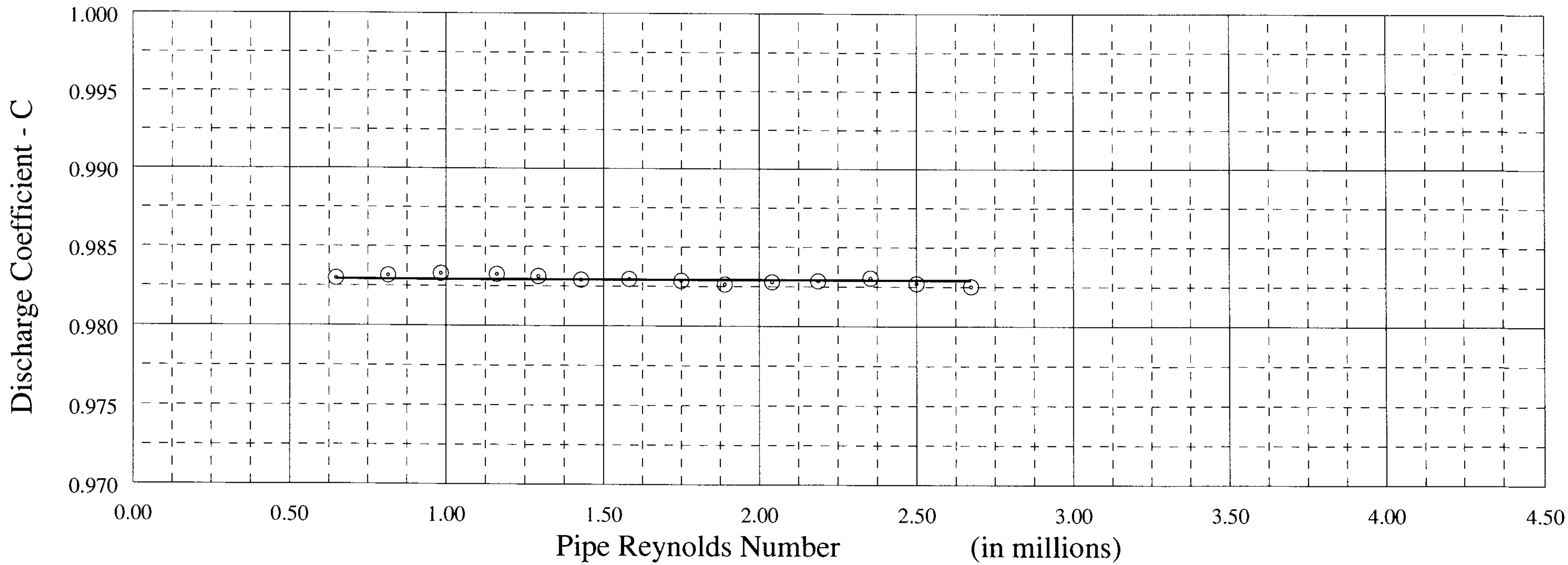
Run #	Line Temp Deg F	Air Temp Deg F	Net Weight lb.	Run Duration secs.	Output [see note]	Flow GPM	H Line FT H20	Pipe Rey. # x 10^6	Coef
1	93	73	95821	73.871	4.313~	9389.5	6.082	2.4993	0.9827
2	93	73	95821	78.379	4.053~	8849.2	5.398	2.3529	0.9830
3	93	73	95675	84.231	3.772~	8221.9	4.662	2.1861	0.9828
4	93	73	95437	89.924	3.547~	7682.1	4.070	2.0403	0.9828
5	93	73	95513	97.235	3.325~	7110.2	3.488	1.8884	0.9826
6	93	73	95398	104.869	3.136~	6584.6	2.990	1.7488	0.9828
7	93	73	95303	115.751	2.930~	5959.6	2.449	1.5810	0.9829
8	93	73	95251	127.847	2.761~	5392.5	2.005	1.4274	0.9829
9	93	73	95078	140.965	2.623~	4881.8	1.643	1.2922	0.9831
10	93	73	95140	157.095	2.501~	4383.4	1.324	1.1603	0.9832
11	92	73	95080	185.182	2.360~	3716.1	0.952	0.9826	0.9833
12	92	73	95172	223.427	2.247~	3083.0	0.655	0.8143	0.9832
13	92	73	95118	281.180	2.155~	2448.3	0.413	0.6467	0.9830
14	92	73	95810	68.512	4.689~	10121.4	7.070	2.6733	0.9825

~ dp transmitter volts

For Pipe Rey. #s above 0.64 x 10^6 Avg Coef = 0.9829 With Standard Deviation = 0.0002
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: S.V.K.

CERTIFIED BY:



$q_a = C\,F_a\,K_M \sqrt{\Delta h}$	
q_a = Actual Flow (ft^3/sec)	
C = Discharge Coefficient (Dimensionless)	
Δh = Pressure Differential (Feet of Water at Run Temperature)	
K_M = Meter Constant = $\dfrac{a\sqrt{2g}}{\sqrt{1-\beta^4}}$ =	8.6286
F_a = Average Thermal Expansion Factor =	1.0004
a = Throat Area (ft^2) =	0.8522
g = Local Acceleration of Gravity (ft/sec^2) =	32.1625
β = Ratio of Throat to Pipe Diameter (Dimensionless) =	0.7812
Pipe Diameter (Inches) =	16.0000
Throat Diameter (Inches) =	12.5000
For Pipe Reynolds Number > 0.64 x 10^6 avg coefficient =	0.9829
Dimensions By: ARL	

MANIFOLDED TAPS

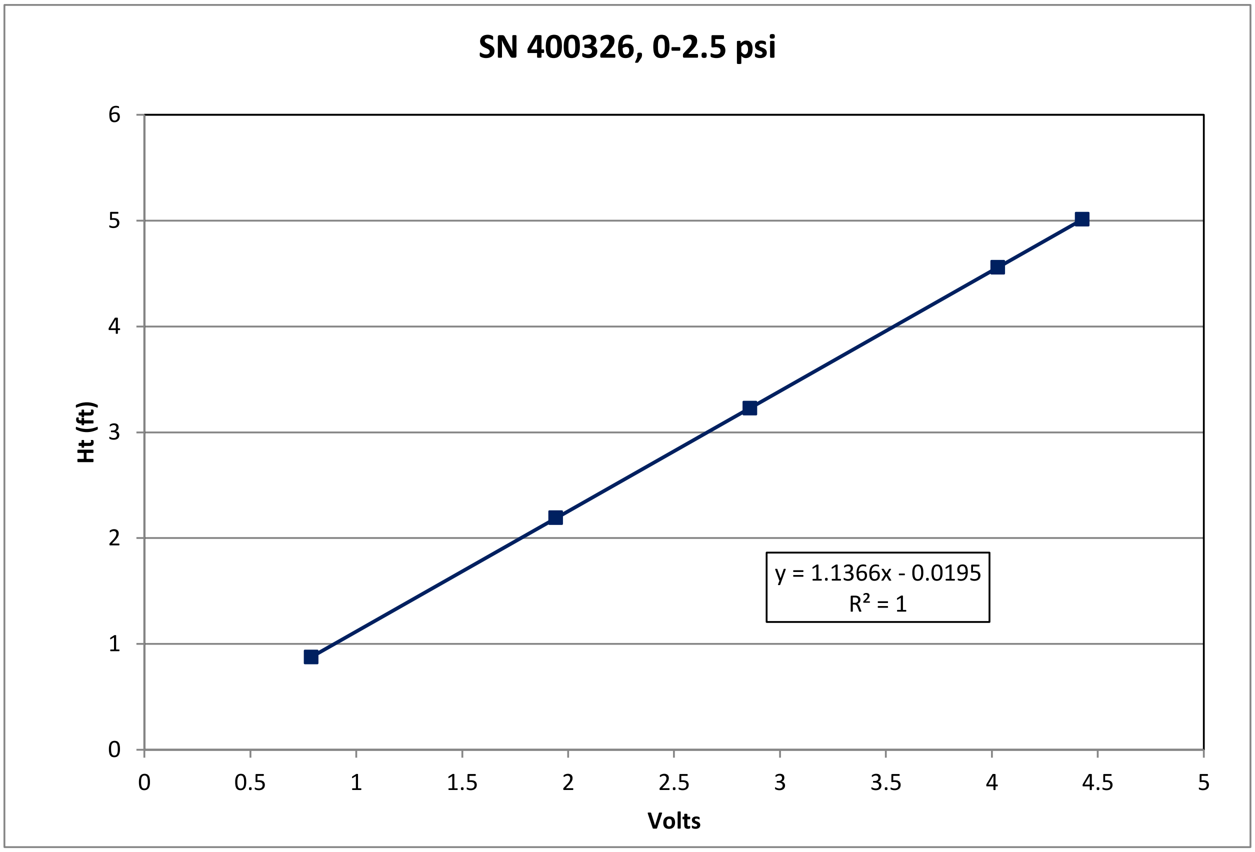
ARL

16X12.5 VENTURI
November 9, 2007

Certified By:

ARL

SN 400326 8/12/2016		
H	H	Volts
(inch)	(ft)	
10.512	0.876	0.7883
26.292	2.191	1.942
38.712	3.226	2.859
54.696	4.558	4.028
60.168	5.014	4.427



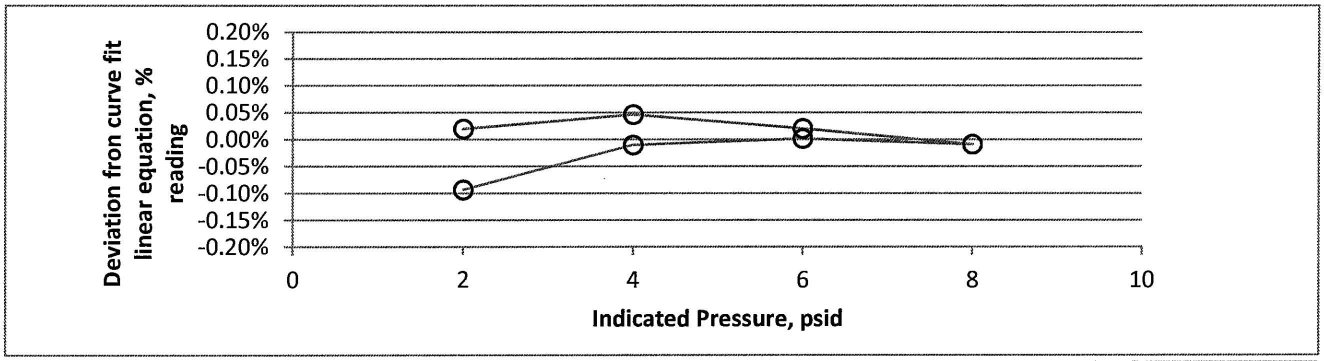
Calibrated By:	**THL**
Cell No.:	**812**
Date:	**2-Jun-15**
Temp.:	**62**
A-D Board No.:	**swdaq1/ni212**
Using Pneumatic DWT No.:	**1055**

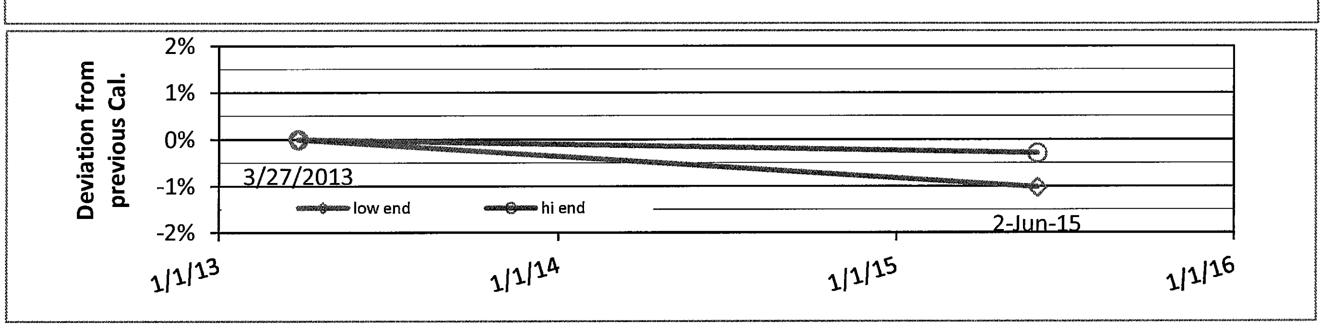
250" cell

---Weight Identification---	8	7	6	5	4	3	2	1	Tester PSI	Reading Volts	Calculated PSI	curve fit Error	mA
1									0	**2.030**			4.076925
3	1								1.999608	**3.796**	1.9977445	-0.093%	7.626303
5	1	1							3.999269	**5.565**	3.9988662	-0.010%	11.18171
7				1					5.998745	**7.333**	5.9988567	0.002%	14.73511
9		1		1					7.998406	**9.100**	7.997716	-0.009%	18.28649
10		1		1					7.998406	**9.100**	7.997716	-0.009%	18.28649
12				1					5.998745	**7.334**	5.999988	0.021%	14.73712
14	1	1							3.999269	**5.567**	4.0011287	0.047%	11.18573
16	1								1.999608	**3.798**	2.000007	0.020%	7.630322
20									0	**2.030**			4.076925

Note: Zeroes not included in regression.
Note: Pressures correct only for temperature indicated at top.

Slope: 1.131216 ZERO>
Intercept: -2.296353
Std Err Y: 0.001105





Printed: 6/4/2015

V:\M&TE\Model Studies\Mailloux 250in Cell SN 0812.xls

Reviewed:_______________

ESSCO CALIBRATION LABORATORY

DIVISION OF WALSH ENGINEERING SERVICES, INC.

CALIBRATION/REPAIR OF ALL TYPES OF ELECTRONIC / MECHANICAL TEST EQUIPMENT

27 INDUSTRIAL AVE, CHELMSFORD, MA 01824-3618

TEL: (800) 325-2201 (978) 250-0880 www.esscolab.com

NVLAP LAB CODE 200972-0

CERTIFICATE OF CALIBRATION

ISSUE DATE: 11/10/2015 **Certificate #: 1244842**

CUSTOMER / LOCATION

ALDEN RESEARCH LABORATORY INC
30 SHREWSBURY STREET
HOLDEN, MA 01520

PURCHASE ORDER:

EQUIPMENT INFORMATION

MANUFACTURER:AND
MODEL NO:ER182A
SERIAL NO:4704083
CONTROL NO:1502
TYPE: ANALYTICAL BALANCE

AS FOUND IN TOLERANCE

AS LEFT IN TOLERANCE

Remarks:
ON SITE

METHOD / ENVIRONMENT

PERFORMED: ON SITE TEMPERATURE (deg C): 23

METHOD:ECP NO. 1.5.16 Rev. 5 2/25/2010 REL HUMIDITY (%RH): 63

CALIBRATION

CALIBRATION DATE:11/6/2015 METROLOGIST: Jose Galindez Jr

CALIBRATION DUE: 11/6/2016

Standards Used To Calibrate Equipment

I.D.	Template	Type Equipment	Report No.	Last Cal. Date	Cal. Due Date
E3285	@ TROEMNER 7212-1W	6110X1G CLASS 1 WEIGHT SET	1191723	06/30/2014	06/30/2016

The ESSCO Quality System is accredited to ISO 17025:2005

The results above relate only to the item(s) calibrated. Expanded uncertainties were calculated per ISO "Guide to the Expression of Uncertainty Measurement", (GUM) with 95% confidence level and a coverage factor of $k=2$. This certificate shall not be reproduced, except in full, without written approval of ESSCO. The user should consider the measurement uncertainty when assessing the metrological status of the equipment.

This document certifies that the unit conformed to applicable specifications upon successful completion of the calibration. Any number of factors may cause the calibration item to drift out of calibration before the recommended interval has expired. The standards used are traceable to NIST or a National Measurement Institute.

This calibration was performed in compliance with the ESSCO Quality System manual, ECL1 Rev 35, dtd 20 Mar 2015, ISO 9001:2008, ANSI/NCSL Z540.1, ISO 10012:2003, ISO 13485, TS 16949, and when required contractually, 10CFR21 and 10CFR50 App. B.

This report must not be used to claim product certification, approval, or endorsement by NVLAP, NIST, or any agency of the Federal Government.

Richard A. Berry Jr.

RICK BERRY
Releasing Authority

Internal Use Only: 11/06/2015 DATA MDY ALD100 146688

Test Points

Seq.	Description	Nominal	Tolerance	Unit Measure	As Found	As Left	Uncertainty
1	REPEATABLE 20G	0.000000	0.000020 0.000000	g	0.000000	0.000000	0.0000037g
2	REPEATABLE 100G	0.00000	0.00010 0.00000	g	0.00000	0.00000	0.000037g
3	LIN TARE 0+10G=REF	10.00000	99.99999 0.00000	g	9.99999	9.99999	0.000024g
4	LIN TARE 10+10G-REF	0.00000	0.00003 -0.00003	g	-0.00001	-0.00001	0.000024g
5	LIN TARE 20+10G-REF	0.00000	0.00003 -0.00003	g	-0.00001	-0.00001	0.000024g
6	LIN TARE 0+30G=REF	30.0000	99.9999 0.0000	g	0.0000	0.0000	0.00013g
7	LIN TARE 30+30G-REF	0.0000	0.0002 -0.0002	g	0.0001	0.0001	0.00013g
8	LIN TARE 60+30G-REF	0.0000	0.0002 -0.0002	g	0.0001	0.0001	0.00013g
9	LIN TARE 90+30G-REF	0.0000	0.0002 -0.0002	g	0.0001	0.0001	0.00013g
10	LIN TARE 120+30G-REF	0.0000	0.0002 -0.0002	g	0.0000	0.0000	0.00013g
11	LIN TARE 150+30G-REF	0.0000	0.0002 -0.0002	g	0.0000	0.0000	0.00013g
12	SPAN ACCY	100.0000	100.0003 99.9997	g	100.0000	100.0000	0.00015g
13	100G LOADSHIFT L	0.0000	0.0003 -0.0003	g	-0.0001	-0.0001	0.00013g
14	100G LOADSHIFT R	0.0000	0.0003 -0.0003	g	-0.0001	-0.0001	0.00013g
15	100G LOADSHIFT C	0.0000	0.0003 -0.0003	g	0.0000	0.0000	0.00013g
16	100G LOADSHIFT F	0.0000	0.0003 -0.0003	g	0.0000	0.0000	0.00013g
17	100G LOADSHIFT B	0.0000	0.0003 -0.0003	g	0.0000	0.0000	0.00013g

Test Points

Seq.	Description	Nominal	Tolerance	Unit Measure	As Found	As Left	Uncertainty

End of Data

Note: A = Adjusted F = Failed L = Limited ** = Outside Scope of Accreditation

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TEL: (800) 325-2201 (978) 250-0880 www.esscolab.com

NVLAP LAB CODE 200972-0

CERTIFICATE OF CALIBRATION

ISSUE DATE: 11/10/2015 **Certificate #: 1244832**

CUSTOMER / LOCATION	EQUIPMENT INFORMATION
ALDEN RESEARCH LABORATORY INC 30 SHREWSBURY STREET HOLDEN, MA 01520	MANUFACTURER:ADAM MODEL NO:GBK-35A SERIAL NO:AE948423 CONTROL NO:AE948423
PURCHASE ORDER:	TYPE: 16X0.0005KG DIGITAL COUNTING SCALE

AS FOUND	**IN TOLERANCE**
AS LEFT	**IN TOLERANCE**

Remarks:
ON SITE

METHOD / ENVIRONMENT

PERFORMED: ON SITE   TEMPERATURE (deg C): 23
METHOD:ECP NO. 1.5.16 Rev.5 2/25/2010 REL HUMIDITY (%RH): 63

CALIBRATION

CALIBRATION DATE:11/6/2015   METROLOGIST: Jose Galindez Jr
CALIBRATION DUE: 11/6/2016

Standards Used To Calibrate Equipment

I.D.	Template	Type Equipment	Report No.	Last Cal. Date	Cal. Due Date
E2850	@ TROEMNER 7212-1T	6110X1G CLASS 1 WEIGHT SET	1117492	07/17/2014	07/17/2016
E3285	@ TROEMNER 7212-1W	6110X1G CLASS 1 WEIGHT SET	1191723	06/30/2014	06/30/2016
E3287	@ TROEMNER 10 KG	WEIGHT	1191758	06/30/2014	06/30/2016

The ESSCO Quality System is accredited to ISO 17025:2005

The results above relate only to the item(s) calibrated. Expanded uncertainties were calculated per ISO "Guide to the Expression of Uncertainty Measurement", (GUM) with 95% confidence level and a coverage factor of $k=2$. This certificate shall not be reproduced, except in full, without written approval of ESSCO. The user should consider the measurement uncertainty when assessing the metrological status of the equipment.

This document certifies that the unit conformed to applicable specifications upon successful completion of the calibration. Any number of factors may cause the calibration item to drift out of calibration before the recommended interval has expired. The standards used are traceable to NIST or a National Measurement Institute.

This calibration was performed in compliance with the ESSCO Quality System manual, ECL1 Rev 35, dtd 20 Mar 2015, ISO 9001:2008, ANSI/NCSL Z540.1, ISO 10012:2003, ISO 13485, TS 16949, and when required contractually, 10CFR21 and 10CFR50 App. B.

This report must not be used to claim product certification, approval, or endorsement by NVLAP, NIST, or any agency of the Federal Government.

Richard A. Berry
RICK BERRY
Releasing Authority

Internal Use Only: 11/06/2015 DATA MDY ALD100 146688

Test Points

Seq.	Description	Nominal	Tolerance	Unit Measure	As Found	As Left	Uncertainty
1	REPEAT STDEV 5KG	0.00	1.00 -1.00	g	0.00	0.00	0.18 g
2	LINEARITY & ACCY	0.0	1.5 -1.5	g	0.0	0.0	0.29 g
3	LINEARITY & ACCY	2000.0	2001.5 1998.5	g	2000.0	2000.0	0.29 g
4	LINEARITY & ACCY	4000.0	4001.5 3998.5	g	4000.0	4000.0	0.29 g
5	LINEARITY & ACCY	8000.0	8001.5 7998.5	g	8000.0	8000.0	0.29 g
6	LINEARITY & ACCY	12000.0	12001.5 11998.5	g	11999.5	11999.5	0.29 g
7	LINEARITY & ACCY	16000.0	16001.5 15998.5	g	16000.0	16000.0	0.29 g
8	LINEARITY & ACCY	8000.0	8001.5 7998.5	g	8000.0	8000.0	0.29 g
9	LINEARITY & ACCY	4000.0	4001.5 3998.5	g	4000.0	4000.0	0.29 g
10	LINEARITY & ACCY	2000.0	2001.5 1998.5	g	2000.0	2000.0	0.29 g
11	LINEARITY & ACCY	0.0	1.5 -1.5	g	0.0	0.0	0.29 g
12	5KG LOAD-SHIFT L	0.0	1.5 -1.5	g	0.0	0.0	0.29 g
13	5KG LOAD-SHIFT R	0.0	1.5 -1.5	g	0.0	0.0	0.29 g
14	5KG LOAD-SHIFT F	0.0	1.5 -1.5	g	0.0	0.0	0.29 g
15	5KG LOAD-SHIFT B	0.0	1.5 -1.5	g	0.0	0.0	0.29 g

End of Data

Note: A = Adjusted F = Failed L = Limited ** = Outside Scope of Accreditation

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NVLAP LAB CODE 200972-0

CERTIFICATE OF CALIBRATION

ISSUE DATE: 11/10/2015 **Certificate #: 1244839**

CUSTOMER / LOCATION
ALDEN RESEARCH LABORATORY INC
30 SHREWSBURY STREET
HOLDEN, MA 01520

PURCHASE ORDER:

EQUIPMENT INFORMATION
MANUFACTURER: OHAUS
MODEL NO: SP4001
SERIAL NO: 7126070017
CONTROL NO: 0742
TYPE: DIGITAL BALANCE

AS FOUND	**IN TOLERANCE**
AS LEFT	**IN TOLERANCE**

Remarks:
ON SITE

METHOD / ENVIRONMENT

PERFORMED: ON SITE TEMPERATURE (deg C): 23
METHOD: ECP NO. 1.5.16 Rev. 5 2/25/2010 REL HUMIDITY (%RH): 63

CALIBRATION

CALIBRATION DATE: 11/6/2015 METROLOGIST: Jose Galindez Jr
CALIBRATION DUE: 11/6/2016

Standards Used To Calibrate Equipment

I.D.	Template	Type Equipment	Report No.	Last Cal. Date	Cal. Due Date
E3285	@ TROEMNER 7212-1W	6110X1G CLASS 1 WEIGHT SET	1191723	06/30/2014	06/30/2016

The ESSCO Quality System is accredited to ISO 17025:2005

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This document certifies that the unit conformed to applicable specifications upon successful completion of the calibration. Any number of factors may cause the calibration item to drift out of calibration before the recommended interval has expired. The standards used are traceable to NIST or a National Measurement Institute.

This calibration was performed in compliance with the ESSCO Quality System manual, ECL1 Rev 35, dtd 20 Mar 2015, ISO 9001:2008, ANSI/NCSL Z540.1, ISO 10012:2003, ISO 13485, TS 16949, and when required contractually, 10CFR21 and 10CFR50 App. B.

This report must not be used to claim product certification, approval, or endorsement by NVLAP, NIST, or any agency of the Federal Government.

Richard A. Berry Jr.
RICK BERRY
Releasing Authority

Internal Use Only: 11/06/2015 DATA MDY ALD100 146688

Test Points

Seq.	Description	Nominal	Tolerance	Unit Measure	As Found	As Left	Uncertainty
1	REPEATABILITY STDEV 4kg	0.00	0.10 0.00	g	0.00	0.00	< 0.018 g
2	LINEARITY & ACCURACY	0.0	0.1 -0.1	g	0.0	0.0	0.058 g
3	LINEARITY & ACCURACY	1000.0	1000.1 999.9	g	1000.0	1000.0	0.058 g
4	LINEARITY & ACCURACY	2000.0	2000.1 1999.9	g	2000.0	2000.0	0.058 g
5	LINEARITY & ACCURACY	3000.0	3000.1 2999.9	g	3000.1	3000.1	0.058 g
6	LINEARITY & ACCURACY	4000.0	4000.1 3999.9	g	4000.1	4000.1	0.058 g
7	LINEARITY & ACCURACY	2000.0	2000.1 1999.9	g	2000.1	2000.1	0.058 g
8	LINEARITY & ACCURACY	0.0	0.1 -0.1	g	0.1	0.1	0.058 g
9	2kg LOAD-SHIFT C	0.0	0.1 -0.1	g	-0.1	-0.1	0.058 g
10	2kg LOAD-SHIFT L	0.0	0.1 -0.1	g	0.1	0.1	0.058 g
11	2kg LOAD-SHIFT R	0.0	0.1 -0.1	g	0.1	0.1	0.058 g
12	2kg LOAD-SHIFT F	0.0	0.1 -0.1	g	0.1	0.1	0.058 g
13	2kg LOAD-SHIFT B	0.0	0.1 -0.1	g	0.1	0.1	0.058 g

End of Data

Note: A = Adjusted F = Failed L = Limited ** = Outside Scope of Accreditation

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NVLAP LAB CODE 200972-0

CERTIFICATE OF CALIBRATION

ISSUE DATE: 11/10/2015 **Certificate #: 1245494**

CUSTOMER / LOCATION	EQUIPMENT INFORMATION
ALDEN RESEARCH LABORATORY INC 30 SHREWSBURY STREET HOLDEN, MA 01520	MANUFACTURER:OHAUS MODEL NO:SP4001 SERIAL NO:7123101312 CONTROL NO:0826
PURCHASE ORDER: HYD-PO-0069	TYPE: DIGITAL BALANCE

AS FOUND	OUT OF TOLERANCE	Remarks: LIMITED TO 500G ONLY ON SITE
AS LEFT	IN TOLERANCE	

Limited Calibration

METHOD / ENVIRONMENT

PERFORMED: ON SITE	TEMPERATURE (deg C): 23
METHOD:ECP NO. 1.5.16 Rev.5 2/25/2010	REL HUMIDITY (%RH): 63

CALIBRATION

CALIBRATION DATE:11/6/2015	METROLOGIST: Jose Galindez Jr
CALIBRATION DUE: 11/6/2016	

Standards Used To Calibrate Equipment

I.D.	Template	Type Equipment	Report No.	Last Cal. Date	Cal. Due Date
E3285	@ TROEMNER 7212-1W	6110X1G CLASS 1 WEIGHT SET	1191723	06/30/2014	06/30/2016

The ESSCO Quality System is accredited to ISO 17025:2005

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Richard A. Berry Jr.
RICK BERRY
Releasing Authority

Test Points

Seq.	Description	Nominal	Tolerance	Unit Measure	As Found	As Left	Uncertainty
1	REPEATABILITY STDEV 4kg	0.00	0.10 0.00	g	0.00	0.00	< 0.018 g
2	LINEARITY & ACCURACY	0.0	0.1 -0.1	g	0.0	0.0	0.058 g
3	LINEARITY & ACCURACY	1000.0	1000.1 999.9	g	L		0.058 g
4	LINEARITY & ACCURACY	2000.0	2000.1 1999.9	g	L		0.058 g
5	LINEARITY & ACCURACY	3000.0	3000.1 2999.9	g	L		0.058 g
6	LINEARITY & ACCURACY	4000.0	4000.1 3999.9	g	L		0.058 g
7	LINEARITY & ACCURACY	2000.0	2000.1 1999.9	g	L		0.058 g
8	LINEARITY & ACCURACY	0.0	0.1 -0.1	g	0.0	0.0	0.058 g
9	LINEARITY & ACCURACY	0.0	0.1 -0.1	g	0.1	0.1	0.058 g
10	LINEARITY & ACCURACY	200.0	200.1 199.9	g	199.9	199.9	0.058 g
11	LINEARITY & ACCURACY	300.0	300.1 299.9	g	299.9	299.9	0.058 g
12	LINEARITY & ACCURACY	400.0	400.1 399.9	g	400.0	400.0	0.058 g
13	LINEARITY & ACCURACY	500.0	500.1 499.9	g	500.0	500.0	0.058 g
14	LINEARITY & ACCURACY	300.0	300.1 299.9	g	299.9	299.9	0.058 g
15	LINEARITY & ACCURACY	0.0	0.1 -0.1	g	0.0	0.0	0.058 g
16	2kg LOAD-SHIFT C	0.0	0.1 -0.1	g	0.1	0.1	0.058 g
17	2kg LOAD-SHIFT L	0.0	0.1 -0.1	g	0.1	0.1	0.058 g

Test Points

Seq.	Description	Nominal	Tolerance	Unit Measure	As Found	As Left	Uncertainty
18	2kg LOAD-SHIFT R	0.0	0.1 -0.1	g	-0.1	-0.1	0.058 g
19	2kg LOAD-SHIFT F	0.0	0.1 -0.1	g	0.0	0.0	0.058 g
20	2kg LOAD-SHIFT B	0.0	0.1 -0.1	g	0.0	0.0	0.058 g

End of Data

Note: A = Adjusted F = Failed L = Limited ** = Outside Scope of Accreditation

LIMITED TO 500G ONLY