Appendix E
November 30, 2018 Suncor Flume Assessment Technical Memorandum by Brown and Caldwell

Technical Memorandum- DRAFT

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Prepared for: Suncor Energy (U.S.A.) Inc.

Project Title: Suncor Flume Assessment

Project No.: 150222.101

Technical Memorandum [No. 2]- Draft

Subject: Combined Flume Assessment

Date: November 30, 2018

To: Eric Marler and Pete Christos

From: Erin Tracy and Amy West

Prepared by: ______________________________
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Limitations:

This is a draft memorandum and is not intended to be a final representation of the work done or recommendations made by Brown and Caldwell. It should not be relied upon; consult the final report.

This document was prepared solely for Suncor Energy in accordance with professional standards at the time the services were performed and in accordance with the contract between Suncor Energy and Brown and Caldwell dated October 1, 2005. This document is governed by the specific scope of work authorized by Suncor Energy; it is not intended to be relied upon by any other party except for regulatory authorities contemplated by the scope of work. We have relied on information or instructions provided by Suncor Energy and other parties and, unless otherwise expressly indicated, have made no independent investigation as to the validity, completeness, or accuracy of such information.

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Executive Summary

The Suncor Energy (U.S.A.) (Suncor) Colorado Refinery, located in Commerce City, has three Parshall flumes installed to measure the flowrate of wastewater discharged from the facility. Flow from two upstream flumes, Flume 002 and Flume 003, combine in a 24-inch-diameter pipe which flows into an aeration sump. This sump feeds the downstream flume, Flume 020. Level transmitters at each flume measure the level of water at the inlets to calculate the flowrate. The flumes are configured such that the sum of the flow rates from Flume 002 and Flume 003 should equal the flowrate measured at Flume 020. However, data shows that the flowrate measured at Flume 020 is lower than the sum of the two upstream flumes. Brown and Caldwell (BC) analyzed flow data from the control system to help diagnose the sources of this discrepancy.

Two trends associated with the large deviations were observed in the September 2018 data set which attribute discrepancies to flow scenarios through Flume 002: one when flows are below approximately 500 gallons per minute (gpm), and the other when flow rapidly increases by relatively large amounts. Neither of these are considerably concerning but being aware of trends within the data is important in understanding limits of the system and knowing when deviations are a sign of a systematic error or temporary disruptions.

As a supplement to the previous Flume 003 model, BC modeled all three flumes together based on drawings received from the plant. The model identified two pinch-points at locations downstream of Flume 002 and an upper limit to flows through both upstream flumes. The deeper investigation into interdependency of the three flumes' hydraulics revealed that if Flume 020 is not freely-flowing, then flow through the two upstream flumes will be affected. However, Flume 020 submergence greater than 60% is unlikely.

In addition to investigating possible causes of flume measurement deviations, Suncor requested that BC model proposed system modifications to predict the expected hydraulic effects. These modifications included raising the invert elevation of the discharge pipe at Flume 002 and increasing the flow through Flume 002 to approximately 1600 gpm. Raising the invert elevation of the discharge pipe did not show any problems in the model but allowing 1600 gpm to continuously flow through Flume 002 did.

Section 1: Data Analysis

This section reviews the two sets of flume system flow data provided to BC and identifies trends in the relationships between flumes.

1.1 Overview

Two sets of flume measurement flow data have been provided to BC to supplement the modeling effort. Flow data is collected continuously from level sensors which measure flow rates at Flumes 002, 003, and 020 simultaneously. Figures 1 and 2, below, are plots exported from the control system that records the flows by flume in gpm. Excel files with the collected data were provided to BC: one file of the tabulated 1-minute average data from July 13, 2018 through July 23, 2018, and the second file of 15-minute averages from September 1, 2018 through October 1, 2018.

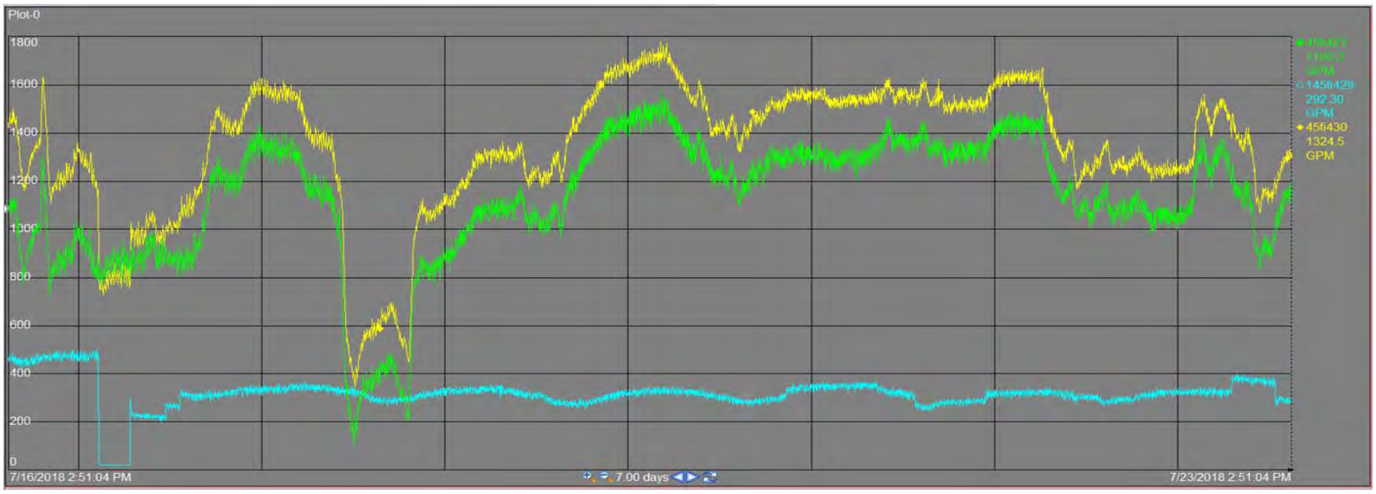

Figure 1. Plotted data for flow measurements (in gpm) recorded between July 16, 2018 and July 23, 2018. The yellow, green, and blue lines represent flumes 020, 002, and 003, respectively.

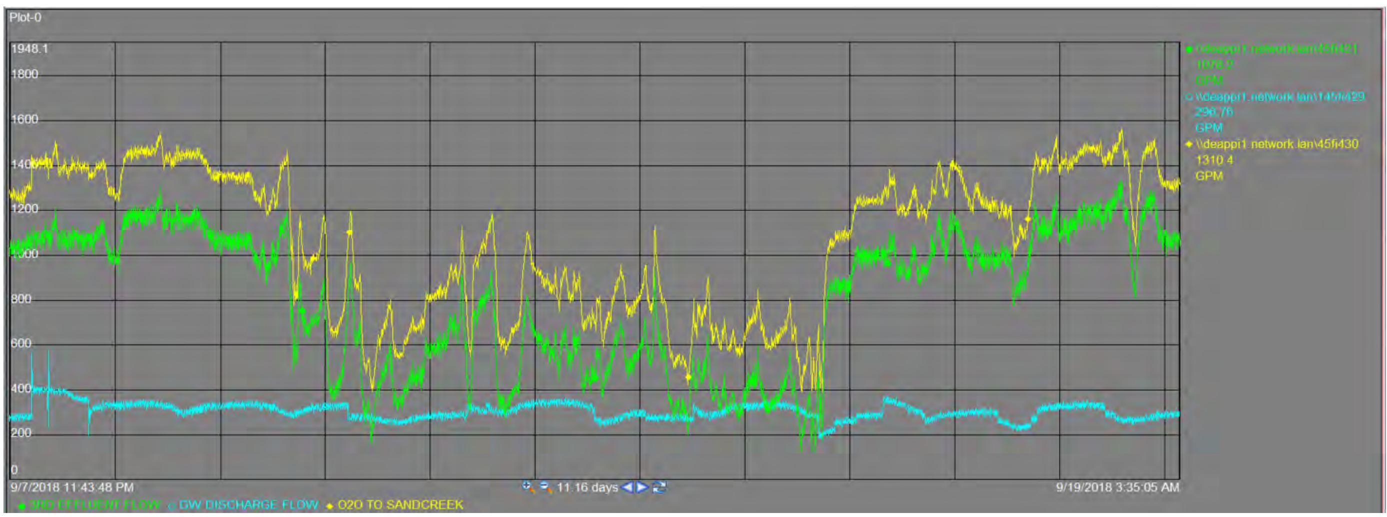

Figure 2. Plotted data for flow measurements (in gpm) recorded between September 7, 2018 and September 19, 2018. The yellow, green, and blue lines represent flumes 020, 002, and 003, respectively.

Using the tabulated data, measurements at Flume 020 were compared to the sum of the measurements at Flume 003 and Flume 002. The difference between the two values is referred to as the deviation in the data. The flow measurement data and associated deviations were analyzed for the following observations and trends:

- Deviation consistency vs. time: How consistent are the deviations for specific flow rates across multiple days?
- Deviation consistency in changing conditions: How the measurements at each of the flumes responded as flow increased and decreased. For example, if flow rate increased at Flume 002, did Flume 020's flow rate increase the same amount while flow at 003 was static?

- Deviation consistency vs. flow: Did the total system flow rate affect the magnitude of the deviations? How did deviations vary with respect to high or large flows? For example, were deviations higher or lower when flow through Flume 002 was reduced?
- Outliers versus inaccuracy: For single points in time where there was a uniquely large deviation, the surrounding data was analyzed.

Additionally, the deviations and percent deviations were analyzed to establish a baseline range for each data set and used for comparisons in evaluating the observations and trends described above. The baseline range and trend analyses were used to look for hydraulic relationships between flumes and for potential submergence conditions to supplement the results of the hydraulic modeling.

1.2 Baseline

Deviations between the measured flow at Flume 020 and the sum of Flumes 003 and 002 in the July data set were relatively large compared to the plant staff's experience. Plant staff indicated that the level sensor at Flume 002 was recalibrated and that the deviations had generally decreased in September, which is supported by the second data set.

A statistical analysis was used to compare the baseline ranges between the June and September data sets. Average flow through each flume and total system flow rates were very similar and made for a reasonable comparison between the two sets of data. In June, the baseline deviation was 90-130 gpm. The baseline range for September was 30-60 gpm, which is a significant improvement. The average deviation reduced by over 50% from a 9% deviation in June, to a 4% deviation in September. Additionally, the percentage of data with deviations less than 10%, increased from 69% in June to 96% in September. Summary statistics are presented in Table 1, below.

Table1: Summary of Statistical Analysis of Flow Measurement Data

		June	September
Based on Averages of Data			
Average Flow Rate at Flume, gpm	002	1,116	1,034
	003	310	300
	020	1,316	1,288
	002 + 003	1,426	1,333
Average Deviation (020-(002+003)), gpm		111	47
Based on Individual Data Points			
Baseline Range of Deviation, gpm		90-130	30-60
Average Deviation, %		9%	4%
Maximum Deviation, %		63%	31%
Percentage of data with < 10% deviation		69%	96%

1.3 Trends

Through analysis of the flow data sets, two trends were observed:

1. Periods of large discrepancies occurred when flow measured at Flume 002 was low.
2. Outlying large discrepancies corresponded to large, rapid increases of flow measured at Flume 002.

While the above trends were observed in both sets of flow data, they were more pronounced in the September data set, where the flow through Flume 003 was relatively consistent as the flow through Flumes 002 and 020 varied.

The first trend described is that the majority of large deviations occur when the flow measured though Flume 002 is low (less than approximately 500 gpm). This trend was observed on September 12, 14, and 15. The percent deviations during these periods were approximately 10-20%. The majority of the data with large deviations occurred for a few hours at a time. Table 2 provides samples of the flow data where this trend was observed. The first sample shows a period of low flow through Flume 002 and the deviation has increased from the baseline range of 30-60 gpm to 69-80 gpm. The second sample shows that when average flows through Flume 002 are occurring, the deviation is smaller, ranging from 15-25 gpm. Note that the decrease in percent deviation at average Flume 002 flows is not believed to be due to lower flows through Flume 003, as this possibility was investigated in the available data and no trend could be established to support this possibility.

According to the Open Channel Flow flume manual, a pre-fabricated 9-inch flume should have +/- 3-5% accuracy in measuring flow down to approximately 40 gpm. Flume 002 is not a pre-fabricated flume and so the accuracy at 40 gpm may not hold true. While it is expected that Flume 002 would be able to accurately measure a flow rate of 300 gpm, this might be an experimentally-proved limit of the flume. Other possible explanations, like submergence (>60%) or incorrect positioning of the flow sensor, can be eliminated due to the low flow and precision of readings at other flows.

Table 2: Deviations associated with Low and High Flow Measurements in Flume 002

Timestamp	Flume 002, gpm	Flume, 003gpm	Flume 020, gpm	Sum of Flumes 002 and 003, gpm	Difference, gpm (020-(002+003))
September 14; large deviations with low flow through Flume 002					
9/14/18 8:14 AM	326	282	529	608	79
9/14/18 8:29 AM	337	279	547	616	69
9/14/18 8:44 AM	349	279	548	628	80
September 7; small deviations with high flow through Flume 002					
9/7/18 4:59 PM	1191	252	1422	1443	22
9/7/18 5:14 PM	1199	250	1435	1449	15
9/7/18 5:29 PM	1194	253	1423	1447	25

The second trend describes the observations of large deviations that did not fall into the first trend, referred to as the outliers. These deviations were characterized by their occurrence over a much shorter sample period, less than an hour, and were observed when flow through Flume 002 rapidly increased but flow through Flume 003 was consistent. Table 3 shows two periods when this trend was observed. In the examples, Flume 003 flow is steady. When flow through Flume 002 increases quickly, there is a corresponding increase in the difference between flow measured at Flume 020 and the sum of flows measured at Flumes 002 and 003. A larger-than-normal deviation is recorded, sometimes for a few consecutive timestamps, however the flow soon levels out and the deviation starts to decrease back to the baseline range.

This trend represents a measurement lag, which is momentary and expected due to the physical distance (roughly 800 feet) between the two flumes. The water levels throughout the system play a role in the magnitude of the lag, which is why there is not a large deviation every time flow through Flume 002 experiences a rapid increase. Similar to the trend described above, awareness is key to identifying when large deviations should be concerning. This scenario is not concerning as it only occurs when the scale of the flow increases is considerable, and its effect on the deviation is momentary.

Table 3: Large Deviations with Rapidly Increasing Flow Measurements in Flume 002					
Timestamp	Flume 002, gpm	Flume, 003gpm	Flume 020, gpm	Sum of Flumes 002 and 003, gpm	Difference, gpm (020-(002+003))
September 11					
9/11/18 10:29 AM	217	276	405	493	87
9/11/18 10:44 AM	221	276	421	497	76
9/11/18 10:59 AM	279	271	442	550	108
9/11/18 11:14 AM	342	272	512	614	101
9/11/18 11:29 AM	392	269	558	661	103
9/11/18 11:44 AM	407	272	600	679	79
September 12					
9/12/18 8:44 AM	352	321	602	673	71
9/12/18 8:59 AM	334	319	572	654	82
9/12/18 9:14 AM	403	320	603	722	119
9/12/18 9:29 AM	583	318	747	900	154
9/12/18 9:44 AM	714	318	905	1,031	127
9/12/18 9:59 AM	738	320	982	1,058	76

1.4 Conclusions

Identifying trends and establishing baselines from the collected flow data is useful to investigating the hydraulic interdependence between the three flumes and determining possible reasons for flow measurement inaccuracy. These trends provide supplemental information to the hydraulic model results discussed in Section 2.

The overall flow data collected from September show improved flow measuring precision. The trends observed indicate that Flume 002 flow measurement accuracy decreases at lower flow rates, and that there is a lag in flow measurement between flow through Flume 002 and Flume 020. Neither of these trends are concerning, but awareness of the trends would serve to explain discrepancies.

If the recalibration of Flume 002 is the only notable change in the system between the two sets of data, then it is the likely cause of improved precision from June to September. This does not directly indicate, however, that the remaining deviation should be completely attributed to known challenges with Flume 003. This is the case as flow measurement discrepancies tend to decrease slightly when flow through Flume 003 is drastically reduced in both data sets, but deviation is not eliminated. Flow measuring devices inherently are not 100% accurate, and so a deviation of zero between three flow devices is highly unlikely. The analysis of the two data sets indicate that the measured flow rates are generally within the expected range of accuracy at each flume. The recommendations to increase accuracy is to routinely recalibrate the flow measuring devices, monitor the data for increasing deviations, and check for submerged flume conditions. The potential for submerged flume conditions is further explained with results from the hydraulic modeling performed.

Additionally, elimination of the surging effects at Flume 003 will further improve the accuracy. Reference the Flume 003 technical memorandum (TM) for further details on Flume 003 surging and effects to flow measurement.

Section 2: Combined Hydraulic Model Results

This section explains the purpose of the hydraulic model, how it was used, and an analysis of the results.

2.1 Set Up for the Combined Model

A computer-based hydraulic model of Flume 003 was created using Visual Hydraulics, as previously summarized in the Flume 003 TM. As a follow-up to the results of the Flume 003 model, the model was expanded to include all three flumes. The combined model assumes that Flume 020 is operating under free-flowing conditions and that downstream conditions are not limiting the flow through the flume.

The model uses a starting downstream water surface level (WSL) of 5,127 feet in the downstream outlet channel of Flume 020. From there, the model builds upon the starting WSL, calculating head loss based on the process configuration, such as the 10-inch-diameter discharge pipe from Flume 003 and the 24-inch-diameter discharge pipe from Flume 002. The model simulates flow through the flumes under varying flow rates to model different scenarios. For each scenario, the model calculates the water surface elevation before and after each flume which is then used to calculate the submergence ratio. As a result, a hydraulic grade line can be created for each flow scenario through the system.

The purpose of the combined model is to indicate the hydraulic relationships between the flumes. Because the plant is considering raising the elevation of the Flume 002 discharge pipe, the model is also used to explore possible hydraulic limitations for future modifications to the system.

2.2 Model Results

Figure 3, below, shows the hydraulic grade line through the 24-inch-diameter pipe between the Flume 002 outlet and the downstream sump. Along this pipe system, there are two potential pinch-points where flow may become constricted, creating a back-up in the pipe. These two pinch-points are located at the two 4-foot-diameter manholes where the inlet pipe invert is lower than the outlet pipe invert.

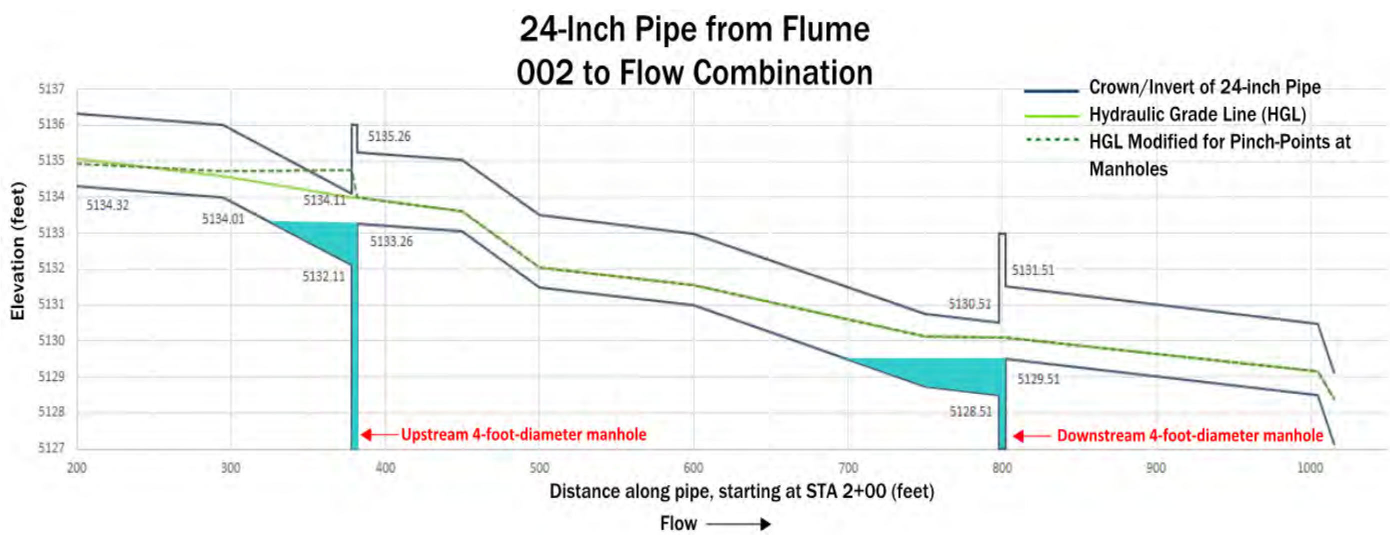

Figure 3. Profile of the 24-inch discharge pipe from Flume 002 to the location where flow from Flume 003 combines with flow from Flume 002.

As illustrated by the light blue areas in Figure 3, water will flow into the upstream manhole and fill-up the manhole until the water level is high enough to flow into the outlet pipe. The difference between inlet pipe crown and the outlet pipe invert is approximately 10 inches, meaning the manhole hydraulically acts as a 10-inch orifice for flow to pass through. The 10-inch orifice constricts flow from the 24-inch-diameter pipe, and at a high enough flow, the pipe will be full-flowing, and water will back-up in the pipe, eventually submerging the upstream Flume 002.

According to the model, the flow at which Flume 002 becomes submerged is approximately 1,300 gpm, but it is time-dependent. This means that an increased flow rate will not immediately result in flow back-up but will take some amount of time depending on the magnitude of flow rate, how rapidly the flow increases, and the amount of time the increased flow rate is sustained. Based on the model results, raising the inlet of the discharge pipe by a few inches would not have any major effect on the hydraulics, besides reducing the amount of time it takes for the pinch-point manhole downstream to back-up the flow. The second, downstream 4-foot diameter manhole is also a potential pinch-point for the same reason. However, the impact on flow is lower with the downstream manhole because the difference between the inlet pipe crown and the outlet pipe invert is larger (12 inches) allowing more flow to pass through and because it is further downstream.

Various flow scenarios were modeled based on the flow data sets provided to model real flow rates that have been observed and compare the flow measurement data to the model results at Flumes 002, 003, and 020. As mentioned above, Flume 002 is hydraulically limited at flows greater than 1,300 gpm because of the pinch-points downstream. Flumes 003 and 020 are not hydraulically limited in typical operating ranges as the model did not report any issues up to flows of approximately 600 gpm through Flume 003. Submergence was noted at Flume 003 with flow near 600 gpm due to constraints in the downstream 10-inch pipe. These constraints are due to the slope of the downstream pipe, before flow from Flume 003 combines with Flume 002 flow, where the pipe transitions from a mild slope to a steep slope. As long as flow through Flume 003 remains below 600 gpm, acceptable flow conditions are expected for Flume 003.

2.3 Summary of Analysis and Conclusions

This model assumes that Flume 020 is operating under free-flow conditions because a downstream free water surface level was not provided. If Flume 020 becomes submerged, then the upstream flumes will be affected. The extent of the effect of Flume 020 submergence on upstream conditions will be related to the flowrate so that the effect will be less at low flow rates and greater at high flow rates. Submergence of Flume 020 can be determined by measuring the depth of water directly upstream and downstream of the flume. Because flow data typically records lower flow at Flume 020 than the sum of Flumes 002 and 003, Flume 020 is likely not experiencing submergence issues.

The model shows that Flume 002 becomes submerged at around 1,300 gpm due to the configuration of the manholes in the system. Flow data from July and September do not reflect this expected submergence. In fact, deviations between the flumes in the September flow data are consistently low, particularly at higher flows such as 1,600 gpm through Flume 002, when the model predicts submergence. It is possible that both flumes 002 and 020 are submerged and reporting higher than actual flows, but it is unlikely. It is more likely that that the submergence predicted is not experienced in the field because high flows (greater than 1,600 gpm) have not been sustained long enough for the system to back-up from the manhole to the flume. The configuration of the pipe in and out of the manholes generates complexity in accurately modeling the hydraulic interactions, and the headloss calculated at that location in the model could be larger than the actual headloss.

As mentioned in Section 2.2, raising the discharge pipe inlet at Flume 002 should not cause any major changes to the hydraulics downstream of the flume based on the model results. The increased slope resulting from raising the discharge pipe starting elevation is not a concern because the hydraulic pinch-point at the upstream manhole (downstream of the modified pipe) effectively reduces the changes in slope between the pipe segments upstream of the manhole.

The model predicts that increasing the normal flow through Flume 002 to 1,600 gpm will cause submergence and an associated decline in measurement accuracy due to the constriction at the downstream manhole. However, models are not perfect replications of field conditions. Before permanently increasing flow, this scenario should be tested in the field to confirm the model results. Allowing high flow rates through Flume 002 and measuring the water depth directly upstream and downstream of the flume to calculate submergence at timed intervals would provide reasonable support of whether or not Flume 002 could accurately measure up to 1,600 gpm in the future. If sustaining a flow of at least 1,600 gpm through Flume 002 for at least 24 hours is problematic either at Flume 002 or at Flume 020 during these trials, then increasing flows in the future are not recommended as the current system is configurated (or when the discharge pipe is raised). Problems to note would be large deviation increases in the measured flow data, negative deviations (Flume 020 measuring larger than the sum of 003 and 002 flows), and field measured submergence greater than 60% at Flume 002 or 020. This exercise would serve as a stress test for the proposed modifications.

The hydraulic model of all three flumes in the system has identified potential pinch-points, hydraulically limiting interactions, and approximate flows at which submergence greater than 60% may occur. In addition to the test flow runs suggested in the previous Flume 003 Assessment, measuring the water depths directly upstream and downstream of Flumes 002 and 020 to check for submergence will further narrow down the cause of flow measurement deviation.

Brown AND Caldwell

Site Visit Report

Prepared for: Suncor Energy (U.S.A.) Inc.
Project Title: Suncor Flume Assessment
Project No.: 150222.101

Purpose of Visit: Flume observation and measurements
Date: July 23, 2018
Time: 1:00 p.m. to 3:15 p.m.
Prepared by: Erin McGregor, Brown and Caldwell

Attendees:

Name	Organization
Eric Marler	Suncor
Pete Christos	Jacobs
Erin McGregor	Brown and Caldwell

Summary of Site Visit

- Erin met Eric and Pete at the visitor building at 1 pm to complete visitor orientation and collect PPE. We proceeded drove to the plant site control room to sign in before visiting three Parshall flumes used to measure treated effluent flow.
- Issue under investigation:
  - Flumes 002 and 003 feed Flume 020. The sum of flow measured at Flumes 002 and 003 are higher than the flow measured at Flume 020. The plant suspects that Flume 003 is reading high.
- Flume 003 is a 6” flume fed by upstream media filters. The flume was uncovered and accessible for measurement
  - Flume 003 is fed by an underground pipe, with the elbow into the ground shown in the photos.
  - There is a certified, bolt-on-style ultrasonic flow meter in the treatment process upstream of Flume 003, which also predicts that the flow measurement at 003 should be lower than currently measured there.
  - Rainwater has collected in the concrete compartment directly upstream of the flume (see photos). This water is not associated with the flume/pipeline. The clear tubing shown in the photos is the intake for the autosampler.
  - There is some surface disturbance directly after the inlet of the flume, including bubbles. The 10”-diameter inlet pipe is filled to approximately 9” above the pipe invert. Grit has accumulated at the flume inlet, which Eric and Pete suspect is filter media from the upstream process.
  - Flow surging is occurring throughout the flume, causing the water surface elevation to continuously fluctuate by approximately 1”. This fluctuation made accurate measurement of the water surface elevation difficult.
  - The water surface elevation was measured at 5 points along the flume cross-section. Water surface elevation across the cross-section is relatively uniform.

  - Water surface elevation is measured by a level indicating transmitter. Eric suspects that the flume cover may be causing deflection of the instrument mount. Deflection of the instrument mounting would likely result in measurement discrepancy depending on the magnitude of the deflection. Eric will look at the data to see if a there was a step change when the flume is covered vs. uncovered.
  - The flume has a 10"-diameter outlet pipe. Submergence of the outlet is also affected by surging. The water surface elevation at the outlet pipe is approximately 6.5" above the pipe invert.
  - Flume 003 discharges to an underground HDPE pipeline with more 200' of run before any elbows. Due to underground interference, the discharge pipeline was installed at a lower slope than the original design (see record drawing markups).
  - The filter reject pipeline was observed with significant flow surging. The filters are being fed by a portable diesel pump but are normally fed by trash pumps. The suction line for the diesel pump was fully submerged.
  - Measured flow displayed on the local readout was fluctuating between 280 and 290 gallons per minute (gpm).
- Flume 020 is a 9" flume that receives flow from Flumes 002 and 003. It is fed from an upstream sump and manhole. Flume 020 was observed through grating. No measurements were taken to avoid confined space entry, but Eric will forward recent measurements.
  - No surging was observed at Flume 020.
  - The flume 020 discharge pipe was more than 60% full. The flume discharges to an underground pipeline.
  - Measured flow displayed on the local readout was fluctuating between 1985 and 1920 gallons per minute (gpm). Eric reports that this is higher than typical.
- Flume 002 receives flow from the lagoon system. Flume 002 was observed through grating, so no measurements were taken.
  - No surging was observed at Flume 002.
  - There was not local readout of flow, but Flume 002 accounts for a majority of the Flume 020 flow.
  - Flume 002 has a drop-off before the discharge pipe. No outlet submergence issue was observed.
  - Suncor has plans to raise the discharge pipe on Flume 002. The planned discharge pipe will be 24"-diameter with an invert elevation 2" below the invert elevation of the flume. Suncor wants to put up to 1600 gpm through Flume 002 in the future.
- The group existed the plant site around 2:30. Erin and Eric reviewed PI data at the office afterwards. Eric has pulled data for all three flumes into a spreadsheet and emailed to Erin.

Summary of Site Visit

- Brown and Caldwell will analyze the plant data to study the flow balance deviation between in the system.
- Brown and Caldwell will perform calculations to model Flume 003 with the as-built conditions to support troubleshooting.
- Suncor has requested that Brown and Caldwell preform calculations on Flume 002 to assess the proposed outlet pipe modifications.

Visual Hydraulics Summary Report - Hydraulic Analysis

Project: **Flume Assessment - Base.vhf**
Company: **Brown and Caldwell**
Date:

Current flow conditions

Forward Flow =	1400 gpm
Return I Flow =	-----
Return II Flow =	-----
Return III Flow =	-----

Section Description	Water Surface Elevation
Starting WSE, estimated WSE of aeration	**5128.5**
08 - aeration sump	**5128.5**

Channel shape = Rectangular
Manning's 'n' = 0.014
Channel length = 20 ft
Channel width/diameter = 20 ft
Flow = 1400 gpm
Downstream channel invert = 5127.14
Channel slope = 0 ft/ft
Channel side slope = not applicable
Area of flow = 27.21 ft^2
Hydraulic radius = 1.197
Normal depth = infinite
Critical depth = 0.09 ft
Depth downstream = 1.36 ft
Bend loss = 0 ft
Depth upstream = 1.36 ft
Velocity = 0.11 ft/s
Flow profile = Horizontal

07 - 10.4 ft of 24 inch pipe of combined flow **5128.54**

Pipe shape = Circular
Diameter = 24 in
Length = 10.41 ft
Flow = 1400 gpm
Friction method = Manning's Equation
Friction factor = 0.012

Section Description	Water Surface Elevation

Total fitting K value = 2.5
Pipe area = 3.14 ft²
Pipe hydraulic radius = 0.5
Age factor = 1
Solids factor = 1
Velocity = 0.99 ft/s
Friction loss = 0 ft
Fitting loss = 0.04 ft
Total loss = 0.04 ft

06 - Flumes 002 + 003 Combination

05.3 - 26 ft of 9.2% **5131.31**

Channel shape = Circular
Manning's 'n' = 0.012
Channel length = 26.1 ft
Channel width/diameter = 0.83 ft
Flow = 300 gpm
Downstream channel invert = 5128.5
Channel slope = 0.092 ft/ft
Channel side slope = not applicable
Area of flow = 0.16 ft^2
Hydraulic radius = 0.157
Normal depth = 0.18 ft
Critical depth = 0.37 ft
Depth downstream = 0.37 ft
Bend loss = 0.04 ft
Depth upstream = 0.41 ft
Velocity = 2.87 ft/s
Flow profile = Steep

05.2 - 138 ft of 1.8% **5133.81**

Channel shape = Circular
Manning's 'n' = 0.012
Channel length = 138.7 ft
Channel width/diameter = 0.83 ft
Flow = 300 gpm
Downstream channel invert = 5130.91
Channel slope = 0.018 ft/ft
Channel side slope = not applicable
Area of flow = 0.2 ft^2
Hydraulic radius = 0.177
Normal depth = 0.26 ft
Critical depth = 0.37 ft
Depth downstream = 0.4 ft
Bend loss = 0.03 ft
Depth upstream = 0.4 ft
Velocity = 2.58 ft/s

Section Description	Water Surface Elevation

Flow profile = Steep

05.1 - 164 ft of .7% — **5135.01**

Channel shape = Circular
Manning's 'n' = 0.012
Channel length = 164.4 ft
Channel width/diameter = 0.83 ft
Flow = 300 gpm
Downstream channel invert = 5133.44
Channel slope = 0.0068 ft/ft
Channel side slope = not applicable
Area of flow = 0.21 ft^2
Hydraulic radius = 0.184
Normal depth = 0.34 ft
Critical depth = 0.37 ft
Depth downstream = 0.37 ft
Bend loss = 0.09 ft
Depth upstream = 0.46 ft
Velocity = 2.87 ft/s
Flow profile = Steep

Pipe from Flume 020 — **5128.6**

Pipe shape = Circular
Diameter = 24 in
Length = 800 ft
Flow = 1100 gpm
Friction method = Manning's Equation
Friction factor = 0.01
Total fitting K value = 0
Pipe area = 3.14 ft^2
Pipe hydraulic radius = 0.5
Age factor = 1
Solids factor = 1
Velocity = 0.78 ft/s
Friction loss = 0.06 ft
Fitting loss = 0 ft
Total loss = 0.06 ft

04 - D.S. End Adapter — **5135.02**

Channel shape = Rectangular
Manning's 'n' = 0.012
Channel length = 1.5 ft
Channel width/diameter = 1.29 ft
Flow = 300 gpm
Downstream channel invert = 5134.56
Channel slope = 0 ft/ft
Channel side slope = not applicable
Area of flow = 0.59 ft^2

Section Description	Water Surface Elevation
Hydraulic radius = 0.267 Normal depth = infinite Critical depth = 0.2 ft Depth downstream = 0.45 ft Bend loss = 0 ft Depth upstream = 0.46 ft Velocity = 1.14 ft/s Flow profile = Horizontal	
03 - Flume 003	**5135.31**
Flume invert = 5134.81 Flume throat width = 0.5 ft Flow through flume = 300 gpm Flume 'm' value = 2 Flume 'e' value = 1.58 Head through flume = 0.5 ft	
02 - U.S. End Adapter	**5135.32**
Channel shape = Rectangular Manning's 'n' = 0.012 Channel length = 2.25 ft Channel width/diameter = 2 ft Flow = 300 gpm Downstream channel invert = 5134.81 Channel slope = -0.22 ft/ft Channel side slope = not applicable Area of flow = 1.5 ft^2 Hydraulic radius = 0.429 Normal depth = infinite Critical depth = 0.15 ft Depth downstream = 0.5 ft Bend loss = 0 ft Depth upstream = 1 ft Velocity = 0.67 ft/s Flow profile = Adverse	
01 - 20.5 ft of 10 inch Inlet Pipe from Vertical Drop	**5135.36**
Pipe shape = Circular Diameter = 10 in Length = 20.5 ft Flow = 300 gpm Friction method = Manning's Equation Friction factor = 0.012 Total fitting K value = 1 Pipe area = 0.55 ft^2 Pipe hydraulic radius = 0.208 Age factor = 1 Solids factor = 1	

Section Description	Water Surface Elevation
Velocity = 1.23 ft/s Friction loss = 0.02 ft Fitting loss = 0.02 ft Total loss = 0.04 ft	

Visual Hydraulics Summary Report - Hydraulic Analysis

Project: **Flume Assessment - Base.vhf**
Company: **Brown and Caldwell**
Date:

Current flow conditions

Forward Flow =	1000 gpm
Return I Flow =	-----
Return II Flow =	-----
Return III Flow =	-----

Section Description	Water Surface Elevation
Starting WSE, estimated WSE of aeration	**5128.5**
08 - aeration sump	**5128.5**

Channel shape = Rectangular
Manning's 'n' = 0.014
Channel length = 20 ft
Channel width/diameter = 20 ft
Flow = 1000 gpm
Downstream channel invert = 5127.14
Channel slope = 0 ft/ft
Channel side slope = not applicable
Area of flow = 27.21 ft^2
Hydraulic radius = 1.197
Normal depth = infinite
Critical depth = 0.07 ft
Depth downstream = 1.36 ft
Bend loss = 0 ft
Depth upstream = 1.36 ft
Velocity = 0.08 ft/s
Flow profile = Horizontal

07 - 10.4 ft of 24 inch pipe of combined flow **5128.52**

Pipe shape = Circular
Diameter = 24 in
Length = 10.41 ft
Flow = 1000 gpm
Friction method = Manning's Equation
Friction factor = 0.012

Section Description	Water Surface Elevation

Total fitting K value = 2.5
Pipe area = 3.14 ft²
Pipe hydraulic radius = 0.5
Age factor = 1
Solids factor = 1
Velocity = 0.71 ft/s
Friction loss = 0 ft
Fitting loss = 0.02 ft
Total loss = 0.02 ft

06 - Flumes 002 + 003 Combination

05.3 - 26 ft of 9.2% **5131.24**

Channel shape = Circular
Manning's 'n' = 0.012
Channel length = 26.1 ft
Channel width/diameter = 0.83 ft
Flow = 214.286 gpm
Downstream channel invert = 5128.5
Channel slope = 0.092 ft/ft
Channel side slope = not applicable
Area of flow = 0.12 ft^2
Hydraulic radius = 0.136
Normal depth = 0.15 ft
Critical depth = 0.31 ft
Depth downstream = 0.31 ft
Bend loss = 0.03 ft
Depth upstream = 0.34 ft
Velocity = 2.59 ft/s
Flow profile = Steep

05.2 - 138 ft of 1.8% **5133.74**

Channel shape = Circular
Manning's 'n' = 0.012
Channel length = 138.7 ft
Channel width/diameter = 0.83 ft
Flow = 214.286 gpm
Downstream channel invert = 5130.91
Channel slope = 0.018 ft/ft
Channel side slope = not applicable
Area of flow = 0.15 ft^2
Hydraulic radius = 0.154
Normal depth = 0.22 ft
Critical depth = 0.31 ft
Depth downstream = 0.33 ft
Bend loss = 0.03 ft
Depth upstream = 0.34 ft
Velocity = 2.34 ft/s

Section Description	Water Surface Elevation

Flow profile = Steep

05.1 - 164 ft of .7% **5134.94**

Channel shape = Circular
Manning's 'n' = 0.012
Channel length = 164.4 ft
Channel width/diameter = 0.83 ft
Flow = 214.286 gpm
Downstream channel invert = 5133.44
Channel slope = 0.0068 ft/ft
Channel side slope = not applicable
Area of flow = 0.17 ft^2
Hydraulic radius = 0.16
Normal depth = 0.29 ft
Critical depth = 0.31 ft
Depth downstream = 0.31 ft
Bend loss = 0.07 ft
Depth upstream = 0.38 ft
Velocity = 2.59 ft/s
Flow profile = Steep

Pipe from Flume 020 **5128.55**

Pipe shape = Circular
Diameter = 24 in
Length = 800 ft
Flow = 785.714 gpm
Friction method = Manning's Equation
Friction factor = 0.01
Total fitting K value = 0
Pipe area = 3.14 ft^2
Pipe hydraulic radius = 0.5
Age factor = 1
Solids factor = 1
Velocity = 0.56 ft/s
Friction loss = 0.03 ft
Fitting loss = 0 ft
Total loss = 0.03 ft

04 - D.S. End Adapter **5134.94**

Channel shape = Rectangular
Manning's 'n' = 0.012
Channel length = 1.5 ft
Channel width/diameter = 1.29 ft
Flow = 214.286 gpm
Downstream channel invert = 5134.56
Channel slope = 0 ft/ft
Channel side slope = not applicable
Area of flow = 0.49 ft^2

Section Description	Water Surface Elevation
Hydraulic radius = 0.239	
Normal depth = infinite	
Critical depth = 0.16 ft	
Depth downstream = 0.38 ft	
Bend loss = 0 ft	
Depth upstream = 0.38 ft	
Velocity = 0.98 ft/s	
Flow profile = Horizontal	
03 - Flume 003	**5135.21**
Flume invert = 5134.81	
Flume throat width = 0.5 ft	
Flow through flume = 214.286 gpm	
Flume 'm' value = 2	
Flume 'e' value = 1.58	
Head through flume = 0.4 ft	
02 - U.S. End Adapter	**5135.22**
Channel shape = Rectangular	
Manning's 'n' = 0.012	
Channel length = 2.25 ft	
Channel width/diameter = 2 ft	
Flow = 214.286 gpm	
Downstream channel invert = 5134.81	
Channel slope = -0.22 ft/ft	
Channel side slope = not applicable	
Area of flow = 1.31 ft^2	
Hydraulic radius = 0.396	
Normal depth = infinite	
Critical depth = 0.12 ft	
Depth downstream = 0.4 ft	
Bend loss = 0 ft	
Depth upstream = 0.91 ft	
Velocity = 0.59 ft/s	
Flow profile = Adverse	
01 - 20.5 ft of 10 inch Inlet Pipe from Vertical Drop	**5135.24**
Pipe shape = Circular	
Diameter = 10 in	
Length = 20.5 ft	
Flow = 214.286 gpm	
Friction method = Manning's Equation	
Friction factor = 0.012	
Total fitting K value = 1	
Pipe area = 0.55 ft^2	
Pipe hydraulic radius = 0.208	
Age factor = 1	
Solids factor = 1	

Section Description	Water Surface Elevation
Velocity = 0.88 ft/s Friction loss = 0.01 ft Fitting loss = 0.01 ft Total loss = 0.02 ft	

Visual Hydraulics Summary Report - Hydraulic Analysis

Project: **Flume Assessment - Base.vhf**
Company: **Brown and Caldwell**
Date:

Current flow conditions

Forward Flow =	2000 gpm
Return I Flow =	-----
Return II Flow =	-----
Return III Flow =	-----

Section Description	Water Surface Elevation
Starting WSE, estimated WSE of aeration	**5128.5**
08 - aeration sump	**5128.5**

Channel shape = Rectangular
Manning's 'n' = 0.014
Channel length = 20 ft
Channel width/diameter = 20 ft
Flow = 2000 gpm
Downstream channel invert = 5127.14
Channel slope = 0 ft/ft
Channel side slope = not applicable
Area of flow = 27.21 ft^2
Hydraulic radius = 1.197
Normal depth = infinite
Critical depth = 0.12 ft
Depth downstream = 1.36 ft
Bend loss = 0 ft
Depth upstream = 1.36 ft
Velocity = 0.16 ft/s
Flow profile = Horizontal

07 - 10.4 ft of 24 inch pipe of combined flow	**5128.58**

Pipe shape = Circular
Diameter = 24 in
Length = 10.41 ft
Flow = 2000 gpm
Friction method = Manning's Equation
Friction factor = 0.012

Section Description	**Water Surface Elevation**

Total fitting K value = 2.5
Pipe area = 3.14 ft²
Pipe hydraulic radius = 0.5
Age factor = 1
Solids factor = 1
Velocity = 1.42 ft/s
Friction loss = 0 ft
Fitting loss = 0.08 ft
Total loss = 0.08 ft

06 - Flumes 002 + 003 Combination

05.3 - 26 ft of 9.2% **5131.39**

Channel shape = Circular
Manning's 'n' = 0.012
Channel length = 26.1 ft
Channel width/diameter = 0.83 ft
Flow = 428.571 gpm
Downstream channel invert = 5128.5
Channel slope = 0.092 ft/ft
Channel side slope = not applicable
Area of flow = 0.2 ft^2
Hydraulic radius = 0.179
Normal depth = 0.21 ft
Critical depth = 0.44 ft
Depth downstream = 0.44 ft
Bend loss = 0.05 ft
Depth upstream = 0.49 ft
Velocity = 3.28 ft/s
Flow profile = Steep

05.2 - 138 ft of 1.8% **5133.89**

Channel shape = Circular
Manning's 'n' = 0.012
Channel length = 138.7 ft
Channel width/diameter = 0.83 ft
Flow = 428.571 gpm
Downstream channel invert = 5130.91
Channel slope = 0.018 ft/ft
Channel side slope = not applicable
Area of flow = 0.26 ft^2
Hydraulic radius = 0.202
Normal depth = 0.32 ft
Critical depth = 0.44 ft
Depth downstream = 0.48 ft
Bend loss = 0.04 ft
Depth upstream = 0.48 ft
Velocity = 2.91 ft/s

Section Description	**Water Surface Elevation**

Flow profile = Steep

05.1 - 164 ft of .7% **5135.11**

Channel shape = Circular
Manning's 'n' = 0.012
Channel length = 164.4 ft
Channel width/diameter = 0.83 ft
Flow = 428.571 gpm
Downstream channel invert = 5133.44
Channel slope = 0.0068 ft/ft
Channel side slope = not applicable
Area of flow = 0.28 ft^2
Hydraulic radius = 0.21
Normal depth = 0.42 ft
Critical depth = 0.44 ft
Depth downstream = 0.45 ft
Bend loss = 0.11 ft
Depth upstream = 0.55 ft
Velocity = 3.2 ft/s
Flow profile = Steep

Pipe from Flume 020 **5128.7**

Pipe shape = Circular
Diameter = 24 in
Length = 800 ft
Flow = 1571.429 gpm
Friction method = Manning's Equation
Friction factor = 0.01
Total fitting K value = 0
Pipe area = 3.14 ft^2
Pipe hydraulic radius = 0.5
Age factor = 1
Solids factor = 1
Velocity = 1.12 ft/s
Friction loss = 0.11 ft
Fitting loss = 0 ft
Total loss = 0.11 ft

04 - D.S. End Adapter **5135.11**

Channel shape = Rectangular
Manning's 'n' = 0.012
Channel length = 1.5 ft
Channel width/diameter = 1.29 ft
Flow = 428.571 gpm
Downstream channel invert = 5134.56
Channel slope = 0 ft/ft
Channel side slope = not applicable
Area of flow = 0.71 ft^2

Section Description	**Water Surface Elevation**

Hydraulic radius = 0.296
Normal depth = infinite
Critical depth = 0.26 ft
Depth downstream = 0.55 ft
Bend loss = 0 ft
Depth upstream = 0.55 ft
Velocity = 1.36 ft/s
Flow profile = Horizontal

03 - Flume 003 — **5135.44**

Flume invert = 5134.81
Flume throat width = 0.5 ft
Flow through flume = 428.571 gpm
Flume 'm' value = 2
Flume 'e' value = 1.58
Head through flume = 0.63 ft

02 - U.S. End Adapter — **5135.44**

Channel shape = Rectangular
Manning's 'n' = 0.012
Channel length = 2.25 ft
Channel width/diameter = 2 ft
Flow = 428.571 gpm
Downstream channel invert = 5134.81
Channel slope = -0.22 ft/ft
Channel side slope = not applicable
Area of flow = 1.75 ft^2
Hydraulic radius = 0.467
Normal depth = infinite
Critical depth = 0.19 ft
Depth downstream = 0.63 ft
Bend loss = 0 ft
Depth upstream = 1.13 ft
Velocity = 0.76 ft/s
Flow profile = Adverse

01 - 20.5 ft of 10 inch Inlet Pipe from Vertical Drop — **5135.53**

Pipe shape = Circular
Diameter = 10 in
Length = 20.5 ft
Flow = 428.571 gpm
Friction method = Manning's Equation
Friction factor = 0.012
Total fitting K value = 1
Pipe area = 0.55 ft^2
Pipe hydraulic radius = 0.208
Age factor = 1
Solids factor = 1

Section Description	Water Surface Elevation
Velocity = 1.75 ft/s Friction loss = 0.03 ft Fitting loss = 0.05 ft Total loss = 0.08 ft	