City of St. Joseph, Missouri

Facilities Plan

Technical Memorandum No. TM-CSO-1

Flow and Rainfall Data Evaluation

By

BLACK & VEATCH

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1.0 Executive Summary

The purpose of the Combined Sewer Overflow (CSO) Control Facilities Assessment is to further refine the Long Term Control Plan (LTCP) and provide more design information for the LTCP facility recommendations. As part of the LTCP, the typical year CSO volume and potential combined sewer system (CSS) improvements were evaluated using a mathematical model of the system. The CSS model was constructed using the one-dimensional, unsteady state hydrology and hydraulics computer model, XP-SWMM. Within the model, the flow that leaves a watershed is determined by the impervious area, the pervious soil infiltration, basin depression storage and surface wetting, and basin geometry. These variables cannot be determined precisely so estimates are developed using standard engineering methods; however, these are only estimates; therefore, the CSS model will be calibrated using actual monitored data.

The calibration process involves adjusting the runoff variables to more closely estimate the actual watershed conditions. To calibrate the CSS model and conform to a requirement of the United States Environmental Protection Agency (USEPA) Nine Minimum Controls for combined sewers, the City of St. Joseph has been collecting flow and rainfall data. The City provided Black & Veatch with this flow and rainfall data to calibrate the CSS model. This technical memorandum reviews the data provided and determines which wet weather events will be used for model calibration. Of the 44 wet weather events that were monitored during the period from November 2007 to July 2008, 12 were identified as possible calibration events and may be used to calibrate the CSS model. Additionally, recommendations are made to improve the data collection program.

2.0 Purpose of Technical Memorandum

The purpose of this flow and rainfall technical memorandum is to summarize the collected data, the preliminary data review, identify potential wet weather calibration events, and make some possible recommendations for additional monitoring data collection.

3.0 Introduction

The City of St. Joseph, Missouri is developing a facilities plan for sewer system upgrades that will be required by the USEPA as part of the existing CSO LTCP (Black & Veatch, 2008). As part of the CSS evaluation for the LTCP, Black & Veatch developed a model of the CSS. The model was used for evaluating potential improvements to the CSS. The model encompasses the area of the City that is serviced by combined sewers, which is roughly the western half of the City.

As part of the 2008 CSO LTCP Update, the CSS model was calibrated with rainfall and flow data that was collected by the City; however, a number of the flow meters produced data that was unsuitable for calibration so additional data collection was recommended (Black & Veatch, 2008). As a result, the City has been collecting additional flow and rainfall data to further calibrate and verify the CSS model. This memorandum documents the data collected between November 2007 and July 2008.

4.0 Additional Flow and Rainfall Data Collection

For the 2008 LTCP Update, flow and rainfall data was collected for the monitoring period from early March 2007 until early November 2007. Rainfall data were collected from five rain gages and flow data were collected from nine flowmeters. These data were evaluated to determine the number of wet weather events that occurred during the monitoring period. After reviewing the collected data and running CSS model simulations, only some of the data could be used for calibration; therefore, additional data collection was recommended (Black & Veatch, 2008). Therefore, the City collected and provided additional monitoring data for the period from November 1, 2007 to July 31, 2008. The data collected during this time frame were generated from the same rainfall and flowmeter locations from the 2008 LTCP Update and are shown in Figures 1 and 2.

Upon receipt of these data, a data inventory and review was performed to identify data gaps and identify some data quality issues; however, some data issues will still likely be identified later during the CSS model calibration phase. One measure of the data quality was to aggregate the rainfall data into monthly totals for each gage and compare these monthly totals to the other gages to identify gages that may not be functioning properly. Table 1 presents the monthly rainfall totals for the rainfall gages while Table 2 presents a summary of the reviewed precipitation data.

Table 1
Monthly Rain Gage Totals

Month	Rain Gages					
	Easton	**Corinth**	**Faraon**	**Waterworks**	**WPC**	**Average**
November 2007	0.04	0.25	0.06	0.23	0.05	**0.126**
December 2007	1.08	2.79	3.17	1.55	1.49	**2.016**
January 2008	0.1	1.25	0.95	1.08	0.89	**0.854**
February 2008	2.54	2.95	2.32	2.6	2.35	**2.552**
March 2008	1.88	2.22	1.77	2.43	2.01	**2.062**
April 2008	4.74	5.34	4.34	5.25	4.8	**4.894**
May 2008	3.95	3.73	1.4	3.77	4.36	**3.442**
June 2008	8.24	7.75	2.55	6.8	7.29	**6.526**
July 2008	3.08	5.9	2.7	4.41	4.01	**4.02**
Totals	**25.55**	**30.93**	**18.31**	**27.04**	**26.36**	**25.638**

Data highlighted in yellow indicates that rainfall total appears incorrect when compared with other gages.

Table 2
Summary of Precipitation Data Reviewed

Rain Gage	Time Period of Data Reviewed	Data Missing or Inconsistent	Months of Data
Waterworks (Rain)	November 2007 – July 2008		9
WPC (Rain)	November 2007 – July 2008		9
Corinth Estates (Rain)	November 2007 – July 2008		9
Easton Road (Rain)	November 2007 – July 2008	January 2008 rainfall total is inconsistent with other gages.	8
Faraon Street (Rain)	November 2007 – July 2008	May 2008 and June 2008 rainfall totals are inconsistent with other gages.	7

The flowmeter data was visually reviewed to identify gaps in the flow monitoring records. Table 3 provides a summary of the additional flowmeter data and identifies periods of missing or inconsistent data.

Table 3
Summary of Flow Data Reviewed

Flowmeter	Time Period of Data Reviewed	Data Quality	Months of Data
Blacksnake	January 2008 – July 2008	November 2007 – December 2007	7
Francis	January 2008 – March 2008, Some of July 2008	November 2007 – December 2007, April 2008 – June 2008	3.5
Charles	November 2007 – February 2008, Some of July 2008	March 2008 – June 2008	4.5
Messanie	March 2008 – July 2008	November 2007 – February 2008	5
Mitchell	November 2007 – July 2008	Some of July 2008	8.5
Patee	November 2007 – March 2008, Some of July 2008	April 2008 – June 2008	5.5
Olive	November 2007 – March 2008	Between April and July 2008	9
Whitehead	November 2007 – July 2008	High Missouri River stage makes most of June unusable	8
Brown's Branch	November 2007 – July 2008	High Missouri River stage makes most of June unusable	8

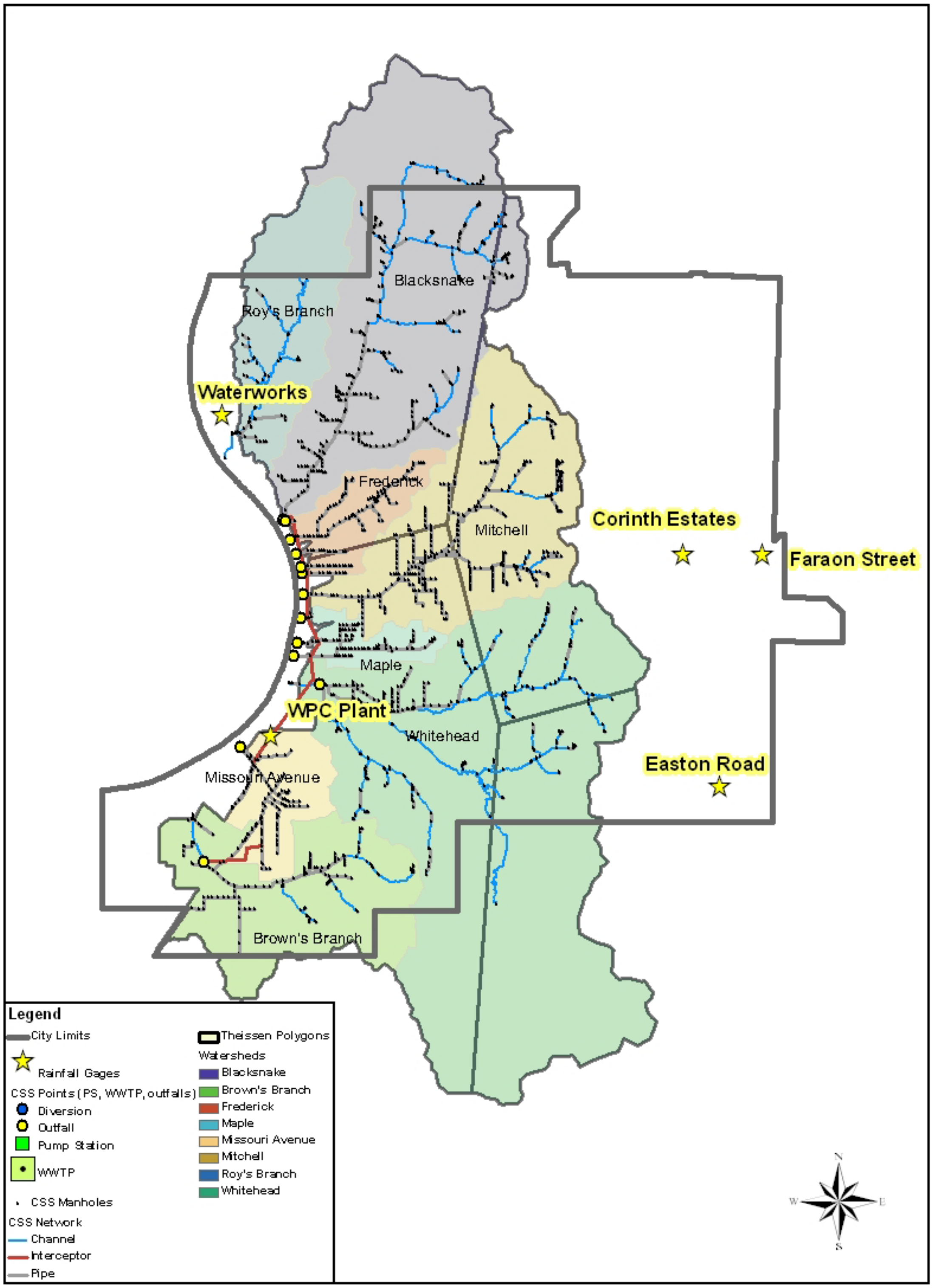

Figure 1 – Rain Gage Locations within St. Joseph

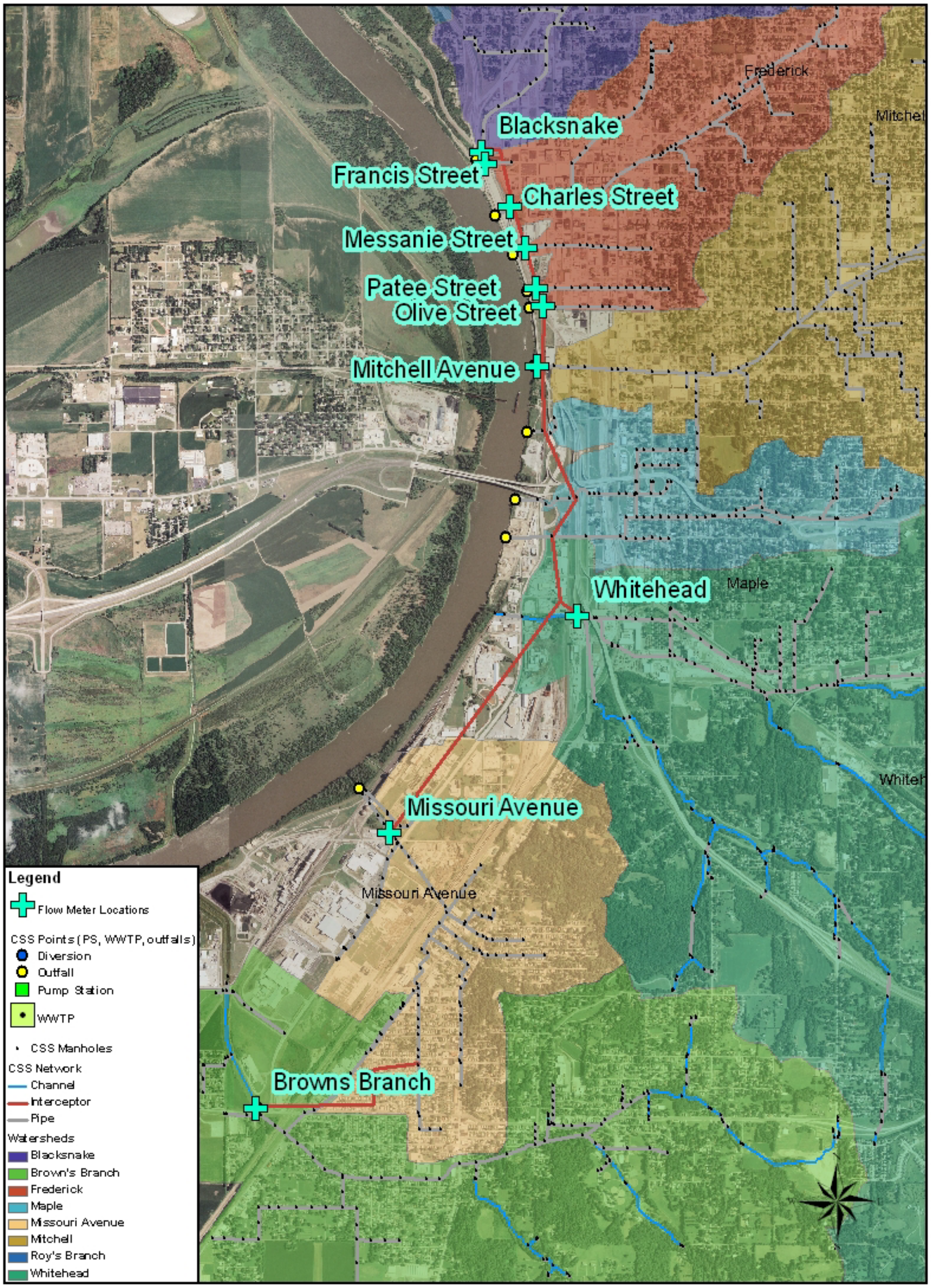

Figure 2 – Flowmeter Locations within St. Joseph

The rain gages used by St. Joseph are tipping bucket-type gages. Therefore, the data output from the gage is the time that a fixed depth of rain is collected by the gage. For these specific rain gages, the buckets tip after every 0.01 inches of rainfall. These data were provided to Black & Veatch in an electronic format.

Most of the flowmeters are area-velocity flowmeters; however, two of the flowmeters, Whitehead and Brown's Branch, are level-sensing flowmeters. The area-velocity flowmeters have two sensing elements, one that records the depth of water above the flowmeter and one that records the velocity of the water, while the level-sensing flowmeter only records the depth (or the distance from the sensor to the water surface, which is converted into a depth). For the area-velocity meters, the depth must be converted into a flow area, which is then multiplied by the average velocity to determine flow, while the level-sensing meters use the level measurement directly in an equation to determine flow. For both level-sensing meters, a weir equation was used to calculate flow.

The flowmeter data was provided in multiple ISCO Flowlink® database files. The database files that contained the monitored data were consolidated into one database file. After the data consolidation, the information needed to calculate flow in the ISCO Flowlink® software was determined from engineering drawings of the diversion structures (Black & Veatch, 1968 and 1970). Tables 4 and 5 contain the flow conversion information used for the area-velocity flowmeters.

Table 4
Flow Conversions for Area-Velocity Flowmeters

Flowmeter	Depth to Area Conversion Method
Blacksnake	Depth-Area Curve *
Francis	Round pipe, 2-ft diameter
Charles	Round pipe, 9-ft diameter
Messanie	Round pipe, 4-ft diameter
Mitchell	Depth-Area Curve *
Patee	Round pipe, 3.5-ft diameter
Olive	Round pipe, 6-ft diameter
* Provided in Table 5.	

Table 5
Depth-Area Conversions for Blacksnake and Mitchell Sites

Blacksnake		Mitchell	
Level, ft	**Area, sq ft**	**Level, ft**	**Area, sq ft**
0	0	0	0
2.7	35.6	7	98
5.4	73.56	14	174.97
8.1	111.82		
10.8	143.3		
13.5	163.17		

For the level-sensing flowmeters, both sensor locations are upstream of diversion weirs so there is always a water level measurement, and as the water rises, flow eventually begins to go over the weir. Therefore, the level monitored by these sensors must be adjusted by subtracting the water depth required to overtop the weir crest, referred to as an offset. Table 6 contains the information needed to convert the level measurement into flow within Flowlink® software; however, getting the offset adjustment was not easy to do within the software so the level was exported into Excel, and the flow was calculated using the following broad-crested weir equation:

$$Q = CLH^{(3/2)}$$

Where

C: discharge coefficient, 3.0

L: length of weir

H: head over weir (in this case, the level after subtracting 3.3 feet)

This calculation is an approximation of the flow and is not appropriate when backwater conditions are present from the Missouri River.

Table 6
Flow Conversions for Level-Sensing Flowmeters

Flowmeter	Depth to Flow Conversions	Level Offset *
Whitehead	Weir, Rectangular without end contractions, 20-ft	3.3 ft
Brown's Branch	Weir, Rectangular without end contractions, 18-ft	3.3 ft
* Estimated by City personnel.		

Combining both the rain and flow data, time series charted at weekly intervals were created and used to identify wet weather events. For wet weather events where rain was not continuous, a dry period of 12 hours before and after the event was used to distinguish between two separate wet weather events. In other words, if rainfall stopped and started within 12 hours, the event was considered to be the same event. If the rainfall stopped for longer than 12 hours, then the events were considered to be "separate" events.

From the weekly charts, 44 wet weather events were identified. These events were numbered consecutively from Event 23 to Event 65. The first event for this monitoring period was labeled Event 23 to avoid confusion with Events 1 through 22 collected and identified in the 2008 LTCP Update. Events 23 thought 65 were then further evaluated to identify specific events that appear to be suitable for additional CSS model calibration.

5.0 Selection of Calibration Events

The goal of calibrating the CSS model is to develop a model of the CSS that closely represents the runoff response of the system during wet weather events. The runoff response of the CSS model is determined by the contributing area, landuse, soil infiltration, and basin time of concentration. Time of concentration is defined as the time it takes for water to flow from the most hydraulically distant location in the basin to the watershed outlet.

Originally, the stormwater system model was developed using the best estimates of land use, soil infiltration parameters, and time of concentration. The stormwater system model was calibrated using the Rational Method, which provides an estimate of reasonable peak flows, but this method of calibration does not use historical flow data. The stormwater model had most of the CSS, so this model was used to develop a model of the CSS after adding the interceptor sewers and sewer pump stations. The development of the CSS model occurred in 2006, and it was recommended that flow and rainfall data be collected to calibrate the CSS model. During 2007, actual flow and rain data was collected and these data were used to calibrate the CSS model to the extent possible.

In choosing calibration events, it is desirable to choose rainfall events that are similar to those events that will be simulated with the model. The CSS model is used to estimate the combined sewer overflow volume during a typical year, and for St. Joseph, a statistical design storm approach is used to determine the typical year overflow volume. As described in the 2008 LTCP Update, the typical year was defined by eight design storm events (A through H), ranging in depth from 0.29 inches for Event A to 2.90 inches for Event H (Black & Veatch, 2008). Table 7 presents the data for the eight rainfall design events that comprise the typical year.

Table 7
Typical Year Rainfall Events

Event	Return Period	Number of Events Greater Than Or Equal To	Precipitation Depth, in	Peak Intensity, in/hr	Duration, hr
A	0.33 month	36	0.28	0.16	6
B	0.67 month	18	0.52	0.25	8.75
C	1 month	12	0.86	0.38	12.25
D	2 months	6	1.4	0.60	16.75
E	3 months	4	1.8	0.73	19.75
F	4 months	3	2	0.82	21
G	6 months	2	2.4	0.95	23.75
H	12 months	1	2.9	1.2	26.75

Upon review of 44 wet weather events that occurred during the monitoring period, a number of the rainfall events were small events (events less than 0.25 inch of rain) that do not contribute a large percentage of the typical year overflow volume and therefore are not good events for CSS model calibration. In addition, as presented in

Figure 3, some precipitation events collected during the monitoring period were either high-intensity, short-duration events or low-intensity, long-duration events. Although these events occur from time to time, these events are not representative of the typical year rainfall events in St. Joseph. Figure 3 shows the precipitation depth as a function of event duration for both the typical year design events and the events identified from the monitoring data. The points that lie within the dashed region are those rainfall events that approximate typical year rainfall events. Events within this region are the most appropriate for calibration of the CSS model. From the 2008 LTCP Update, the City is targeting to have no more than four overflow events during a typical year at the end of the LTCP implementation, which would require storage and treatment for all rainfall events less than or equal to the 3-month design event (Event E).

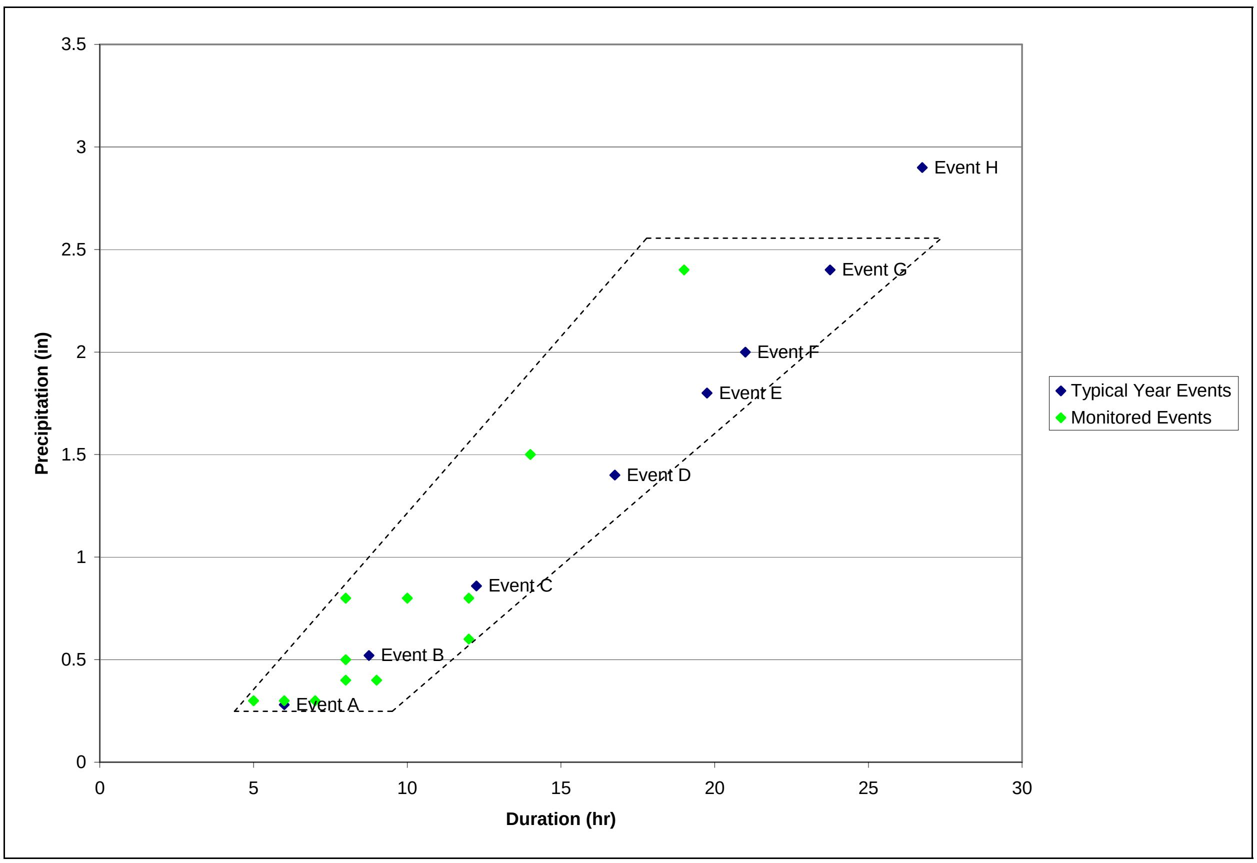

Figure 3 – Depth-Duration Chart of Typical Year Events Versus Monitored Events

From Figure 3, 12 of the 44 wet weather events monitored are potentially good calibration events. The collected rainfall data will need to be imported into the CSS model and each calibration event will be simulated to determine if the model inputs need to be adjusted. Generally, it would be desirable to have at least three rainfall events to calibrate the CSS model. Table 8 shows the list of those rainfall events selected for CSS model calibration.

Table 8
Wet Weather Events for Calibration

Event Name	Start Time	End Time	Averaged Event Depth, in	Approximate Rain Duration, hr
Event 28	1/10/08 6:00	1/11/08 6:00	0.6	12
Event 29	2/3/08 10:00	2/4/08 3:00	0.3	6
Event 30	2/5/08 6:00	2/6/08 7:00	0.4	9
Event 31	2/8/08 10:00	2/9/08 0:00	0.3	7
Event 35	3/1/08 23:00	3/5/08 0:00	0.8	12
Event 38	4/3/08 6:00	4/4/08 2:00	0.4	8
Event 39	4/8/08 0:00	4/9/08 12:00	1.5	14
Event 44	4/25/08 2:00	4/26/08 0:00	0.3	5
Event 48	5/10/08 12:00	5/11/08 12:00	0.8	10
Event 52	6/8/2008	6/9/2008 2:00	0.5	8
Event 53	6/12/2008	6/13/2008 0:00	2.4	19
Event 63	7/25/08 0:00	7/25/08 16:00	0.8	8

6.0 Conclusions and Recommendations

During the monitoring period, 44 wet weather events were identified. By comparing these events with the typical year rainfall design events, 12 of the rainfall events were identified as being potential CSS model calibration events. Additional calibration of the CSS model will proceed using the selected rainfall events to the extent possible.

The City will need to continue monitoring rainfall and flow to continue characterizing the CSO volume, and ultimately, this monitoring data will be used to determine the effectiveness of CSO control projects. In the process of collecting flow and rainfall data from the City, additional information was informally presented such as pictures of the flowmeter sites and conversations with City personnel regarding the data collection process. This additional information suggests that there are parts of the City's data collection effort that could be improved that would increase the quantity and quality of the collected data. The following items are recommendations that could be implemented to improve the data collection effort by the City:

- Some of the flowmeters appeared to be mounted within the manhole structure. Generally, flowmeters are mounted within the upstream or downstream pipe, a few diameters from the manhole. The flow sensors that are not located within a pipe should be evaluated to see if the flow sensors could be moved into a pipe segment and mounted a few pipe diameters from the nearest manhole.
- Flowmeter and rain gage data collections could occur on a more frequent basis. One recommendation would be to use a weekly frequency. Most flowmeters and rain gages can hold much more data than a week; however, if an instrument problem does occur, long data gaps can result if the data is not evaluated on a frequent basis. Regular and more frequent site visits would encourage more routine maintenance and reduce the amount of missing or invalid data.
- Whitehead and Brown’s Branch flowmeters should be evaluated to see if area-velocity meters can replace the existing level-sensing meters. During the month of June, both locations were under backwater influence due to a high river stage in the Missouri River. Level-sensing meters are not appropriate flowmeter types for locations that frequently experience backwater. In other words, the depth of water is not always correlated with the flow rate if backwater exists. Area-velocity meters installed at the Blacksnake, Messanie, Mitchell, and Patee sites had depth data that indicated backwater conditions from the Missouri River were experienced at these sites as well. However the velocity-sensing element allowed the meters to provide reasonable flow measurements during high river stages unlike the existing Whitehead and Brown’s Branch level sensing flowmeters.
- Some flowmeters are collecting data at 15 minute intervals. From past

CSS studies, 5 minutes may be a more appropriate reporting interval for flow data as it would better capture peak runoff flows from storm events.

7.0 References

1. Black & Veatch Corporation, Plans for Sewerage Improvements St. Joseph, Missouri Contract R-3 Section A – Interceptor Sewer, 1968.
2. Black & Veatch Corporation, Plans for Sewerage Improvements St. Joseph, Missouri Contract R-3 Section B – Interceptor Sewer, 1970.
3. Black & Veatch Corporation, Combined Sewer System Long Term Control Plan 2008 Update, 2008.