City of St. Joseph, Missouri

Facilities Plan

Technical Memorandum No. TM-CSO-2

CSS Model Calibration and Existing Conditions

By

BLACK & VEATCH
Building a **world** of difference.

Work Order No. 09-001
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Table of Contents

Tables

Figures

Appendices

CSS Model Calibration and Existing Conditions

1.0   Executive Summary

The purpose of this memorandum is to summarize the additional model calibration performed and provide a revised estimate of the combined sewer overflow (CSO) volume from the existing collection system. As part of the Long Term Control Plan (LTCP), the typical year CSO volume and potential combined sewer system (CSS) improvements were evaluated using a mathematical model. 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 basin is determined by the amount of impervious area, soil infiltration, depression storage and surface wetting, and the basin geometry. These variables cannot be determined exactly so estimates are developed using standard engineering methods. However, these are only estimates; therefore, the CSS model should be calibrated using actual monitored data. For the 2008 LTCP Update, some rainfall and flow monitoring data was provided, but it was limited. For some basins, data was non-existent while only a few good wet weather calibration events were provided for the other basins. Due to the limited rainfall and flow monitoring data, additional model calibration was recommended at that time to help refine the model.

The model calibration process involves adjusting the runoff variables to more accurately represent the actual basin conditions. To comply with the monitoring requirement of the United States Environmental Protection Agency (USEPA) Nine Minimum Controls for combined sewers, the City of St. Joseph has been collecting rainfall and flow data. For this study, the City provided Black & Veatch with additional monitoring data to perform additional calibration and refinement of the existing CSS model.

The monitoring data provided for this study indicated that the runoff response of the Mitchell basin was greater in peak flow and runoff volume than the 2008 LTCP Update study. The new flow data provided in this study allowed for a detailed check of level, velocity, and flow conversion, and the data appeared reasonable. Therefore, Mitchell was calibrated using the data collected for this study, which resulted in higher

runoff volumes and peak flows for the Mitchell basin than was estimated for the 2008 LTCP Update study.

Additionally, the 2008 LTCP Update monitoring data did not have any smaller rainfall events that were suitable for calibration. The data collected for this study did have some smaller events, and from these events, it was apparent that the monitored runoff volumes and peak flows were greater for many of the basins than was estimated from the 2008 LTCP Update CSS model. To make the CSS model produce more representative flows for smaller events, each subbasin was split into two subbasins where one subbasin represented the directly-connected impervious area and the other the pervious area of the subbasin. The resulting model better simulates the monitored runoff volumes and peak flows for Blacksnake, Charles, Messanie, Mitchell, Olive, and Patee. Francis was also adjusted, and although the runoff volume and peak flow calibration graphs still show some scatter, it is reasonable since the drainage basin is so small (approximately three acres). Adjustments to the hydrologic response of Brown's Branch were also made to better simulate the monitored responses; however, there is still substantial variance between the monitored and calculated hydrographs, which would indicate the need for additional monitoring.

The Brown's Branch and Whitehead level sensing flowmeters appear to be inappropriate flowmeter technologies for their respective locations. Both sensors are fine for indicating when the monitoring water level has risen above the overflow weirs; however, determining flow from only a level measurement is unreliable if the locations are under a backwater influence (i.e. water level in the Missouri River is above the overflow weir or mild-sloped downstream channels). From the flow data provided for these meters, visually it would appear that Brown's Branch flowmeter provides reasonable estimates during some events so some calibration was performed. However, there is a backwater influence when the Missouri River is at high stage, and when this occurs, the meter does not provide good flow data. Hydrograph data for the Whitehead level sensor flowmeter extends too long after precipitation events and tapers off too suddenly towards the end of the flow event. Visually and quantitatively, the Whitehead

flows do not appear reasonable, so the data were not used for calibration. Additional flow monitoring using area-velocity meters is recommended for both sites.

Using the updated model, the typical year design storms were then simulated to provide a revised estimate of the typical year CSO volume for existing conditions. The revised CSS model produces more CSO for smaller rain storm events than was estimated for the 2008 LTCP Update. The estimate of the existing conditions typical year CSO is 4.13 billion gallons, which is approximately 1.5 billion gallons greater than the estimate provided in the 2008 LTCP Update. For Design Event E, which was the selected design event to achieve the LTCP Phase 3 level of control, the revised version of the CSS model produces 17 percent more CSO volume than was estimated by the 2008 LTCP model. In other words, the facilities required to achieve the Phase 3 level of control are preliminarily estimated to be within 17 percent of the original facility sizes. As part of the ongoing Facilities Plan, the sizes of the Phase 2 and Phase 3 controls will be further refined and discussed in an upcoming technical memorandum.

The monitoring data collected for this study proved valuable in identifying an issue with the previous version of the CSS model, and the calibration results produced in this study clearly show that the model is better representing the system. However, some basins within the system have not been monitored (Duncan, Hickory, and Maple) and the level sensing flowmeter at the Missouri Avenue diversion structure has not produced any usable flow data. It is possible that additional flow monitoring would justify additional model refinement for these three basins.

2.0   Purpose of Technical Memorandum

The purpose of this memorandum is to summarize the additional model calibration performed and provide a revised estimate of the CSO volume from the existing collection system. In addition, potential system bottlenecks within the collection system are to be evaluated including the Charles Street diversion structure, Duncan Street diversion structure, Whitehead diversion structure, and the Brown's Branch pump station. Since the recommended improvements will be evaluated in the next phase of this work, the evaluation of these bottlenecks will be presented in the subsequent technical

memorandums covering the recommended alternatives (TM-CSO-3A, 3B, and 3C). The scope of this task also includes coordination with the modeling effort of the Blacksnake detention basin. Preliminary discussions have been made with the United States Army Corps of Engineers (USACE) with regards to the Blacksnake project, however, the USACE has not issued their report on the detention basin as of yet, so this effort will be performed at a later date.

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 LTCP (Black & Veatch, 2008). As part of the CSS evaluation for the LTCP, Black & Veatch developed a detailed model of the CSS. The CSS model contains 595 individual hydrologic subbasins which are linked to a sewer network consisting of over 100 miles of sewer pipe. 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 flowmeters 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 additional model calibration and the revised estimate of the existing conditions CSO volume.

4.0   Additional Wet Weather Events for CSS Model Calibration

During the 2008 LTCP Update, the City provided rainfall and flow data for the monitoring period of March 1 to October 1, 2007. Rainfall data was collected from four rain gage locations and flow data was collected from nine flow monitoring gages (the tenth flowmeter, Missouri Avenue, did not provide any data during the flow monitoring period). The data was evaluated to determine the number of significant wet weather

events that occurred during the monitoring period. From this data, four wet weather events were identified that appeared suitable for model calibration. Table 1 lists the dates, times, and approximate precipitation depth for those events.

Table 1 Wet Weather Calibration Events for 2008 LTCP Update				
Event Name	Start Date and Time	End Date and Time	Average Precipitation, in	Average Peak Intensity, in/hr
Event 17	7/23/07, 7:00	7/23/07, 17:00	0.7	2.4
Event 19	8/8/07, 6:00	8/9/07, 4:00	1.1	1.9
Event 20	9/6/07, 22:00	9/7/07, 18:00	1.8	2.3
Event 21	9/18/07, 12:00	9/19/07, 8:00	0.7	1.6

Using these four events, only limited calibration could be performed on the model and it included the following three basins: Charles, Olive, and Mitchell. These four events were the basis for the 2008 LTCP Update model calibration. For the refinement phase of the work documented herein, the City provided additional monitoring data covering the period of November 1, 2007 to July 31, 2008. In Technical Memorandum TM-CSO-1, 12 wet weather events were reviewed to identify the ones that appeared to be suitable for additional model calibration. Table 2 lists the dates and times of suitable wet-weather events used for the Facilities Plan.

Table 2 Wet Weather Calibration Events for Facilities Plan				
Event Name	Start Date and Time	End Date and Time	Estimated Precipitation, in	Average Peak Intensity, in/hr
Event 28	1/10/08, 6:00	1/11/08, 6:00	0.6	0.2
Event 29	2/3/08, 10:00	2/4/08, 3:00	0.3	0.3
Event 30	2/5/08, 6:00	2/6/08, 7:00	0.4	0.3
Event 31	2/8/08, 10:00	2/9/08, 0:00	0.3	0.2
Event 35	3/2/08, 14:00	3/4/08, 10:00	0.8	0.5
Event 38	4/3/08, 6:00	4/4/08, 2:00	0.4	0.7
Event 39	4/8/08, 0:00	4/9/08, 12:00	1.5	0.9
Event 44	4/25/08, 2:00	4/26/08, 0:00	0.3	0.8
Event 48	5/10/08, 12:00	5/11/08, 12:00	0.8	1.1

| | | | Estimated | |
Event Name	Start Date and Time	End Date and Time	Precipitation, in	Average Peak Intensity, in/hr
Event 52	6/8/08, 0:00	6/9/08, 2:00	0.5	1.2
Event 53	6/12/08, 0:00	6/13/08, 0:00	2.4	4.4
Event 63	7/25/08, 0:00	7/25/08, 16:00	0.8	1.5

Table 2
Wet Weather Calibration Events for Facilities Plan

From review of Table 1 and Table 2, it is apparent that there are many more suitable rainfall events during the November 1, 2007 to July 31, 2008 monitoring period than were available for the 2008 LTCP Update. Furthermore, the additional events monitored tended to be smaller rainfall events with lower rainfall intensities, which represent wet weather event characteristics missing from the data used for the 2008 LTCP Update.

5.0   Additional Model Calibration

The *Combined Sewer Overflow Control Manual* (USEPA, 1993) states that "an adequate number of storm events (usually five to ten) should be monitored and used in calibration", however; in the same document it is stated that calibration and verification are often done with two or three storms each.

For model calibration, it is desirable to have a range of actual wet weather events that cover the range of design events that will be simulated by the model. It is generally accepted that during a few months of monitoring, it is unlikely that the entire range of typical year events will occur. However, with the City's additional monitoring data now available, the range of storms that fit within the typical year design storm range is more complete. While the rain gages have had some minor intermittent problems that last generally less than a month, the main ongoing problem with the monitoring data is getting the flowmeters to consistently provide quality flow data. For example, some flowmeters have gaps in the monitoring period much greater than a month. After reviewing and identifying suitable wet weather events, the calibration process was initiated by simulating all of the wet weather events presented previously in Table 2 using the CSS XP-SWMM model. After simulating the events, the model simulated

hydrograph was compared with the observed hydrograph at each flowmeter to determine if the observed hydrograph resembles the simulated hydrograph. If the observed hydrograph response tracks the rainfall pattern and the simulated hydrograph, then model calibration of the basin can begin. If not, the data for the flowmeter data and rainfall data are further evaluated to determine if the reason for the discrepancy can be determined. Table 3 presents the results of this evaluation.

If a cell is blank in Table 3, then the data appears reasonable for calibration. The remainder of the data was categorized as follows: system issue, questionable, bad data, and no data. Events classified as "system issue" are those wet weather events where flowmeters recorded a flow response extending after the rain event. System issues were noticed most frequently on Blacksnake and a conversation with plant personnel provided the reason for the issue at Blacksnake (although this may be happening at Whitehead and to a lesser degree at Brown's Branch). At Blacksnake, Whitehead, and Brown's Branch, the bar screens that cover the low flow openings to the interceptor can clog with debris during a wet weather event. This results in reduced capacity to the interceptor and overtopping the bypass weir. This situation can occur until plant personnel clean the bar screen. When the bar screen is cleaned, the flow monitoring shows that the flow overtopping the overflow weirs quickly goes to zero. A typical system issue response for the Blacksnake CSO looks like Figure 1 (measured is the observed CSO response). The figure shows CSO flow prior to the rain event, which is the result of an event that occurred less than a day before. For Mitchell and Patee, this extended period of flow bypassing the interceptor occurred once during the monitoring period and is probably related to surcharging in the main interceptor, which resulted in extended overflow events at these locations as they are the two lowest elevation weirs on the main interceptor. These issues are difficult to simulate as it is unclear when the surcharging begins and to what degree it occurs. Therefore, these events cannot be used in calibration.

Event	Blacksnake	Brown's Branch	Charles	Francis	Messanie	Mitchell	Olive	Patee	Whitehead
Event 28					No data		Questionable		N/A
Event 29					No data		Questionable		N/A
Event 30					No data		Questionable		N/A
Event 31			Questionable		No data	Questionable	Questionable		N/A
Event 35	System issue				Questionable	System issue	Questionable	System issue	N/A
Event 38	Questionable		Bad data		Questionable		Questionable	Questionable	N/A
Event 39	System issue		Bad data	Bad data			Questionable	No data	N/A
Event 44	System issue		Bad data	Bad data	Questionable		Questionable	No data	N/A
Event 48			Bad data	Bad data		Questionable	Questionable	No data	N/A
Event 52		Backwatered	Bad data	Bad data	Questionable	Questionable	Questionable	No data	N/A
Event 53		Backwatered	Bad data	Bad data	Bad data	Questionable	Questionable	No data	N/A
Event 63			Bad data	No data	No data	No data	Questionable	No data	N/A

Table 3
Flowmeter Data Evaluation After Simulating Wet Weather Events

Note: If cell is blank, data is acceptable for model calibration.
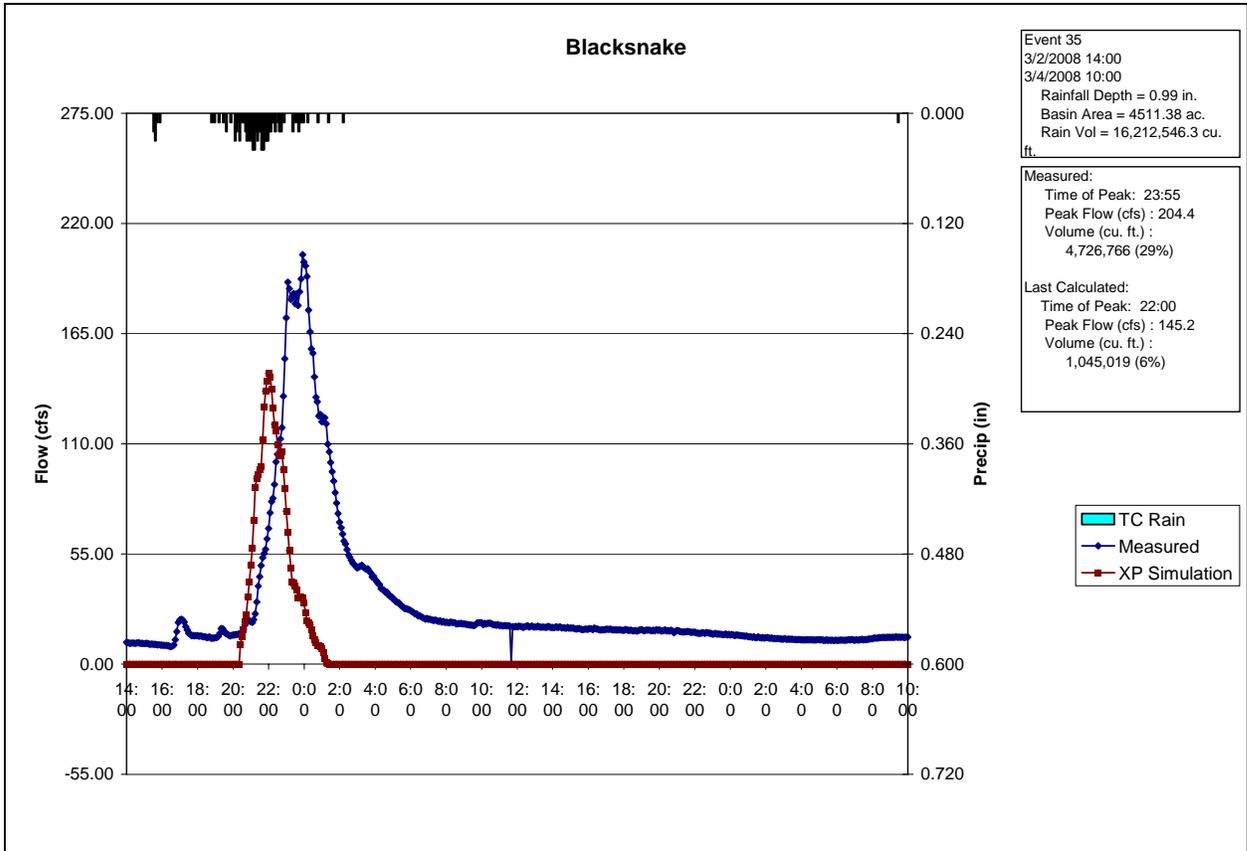
Figure 1 Blacksnake CSO Hydrograph when Bar Screen is Clogged

Meter responses that were classified as questionable are ones that showed no resemblance to the other meter responses or the rain that fell during the event. The flow responses classified as bad data were data in the flowmeter database where it was clear that the meter was not recording accurate flow data and usually these periods occurred for months at a time. The no data classification was used when the flow database has nothing logged for the event.

For Whitehead, no calibration could be performed so all of the events were marked as "N/A." The reason for this designation is that it appears that using the weir equation to transform the level reading from the level sensing flowmeter into a flow rate is not applicable. From the flow responses, the meter appears to sense the water level correctly and provides a reasonable estimate of when a bypass event begins and ends; however, the flow response shape and flow magnitude appears incorrect when compared to the model. This could be caused by a variety of reasons: the meter offset (3.3 feet as

discussed in TM-CSO-1) could be incorrect, the flow location could be backwatered by the downstream channel or Missouri River (it depends on the stage in the Missouri River), or significant groundwater flows could be infiltrating into the system upstream of the combined sewer system making the flow response unlike any other basin in the watershed. Figure 2 shows a typical response where the flow stays elevated for a significant amount of time following a rainfall event and quickly drops to zero following a point of inflection near the end. At this time, this location cannot be calibrated, but additional flow monitoring will occur later this year using an area-velocity flowmeter (rather than a level sensing flowmeter), which should better determine the flows that are produced in this basin.
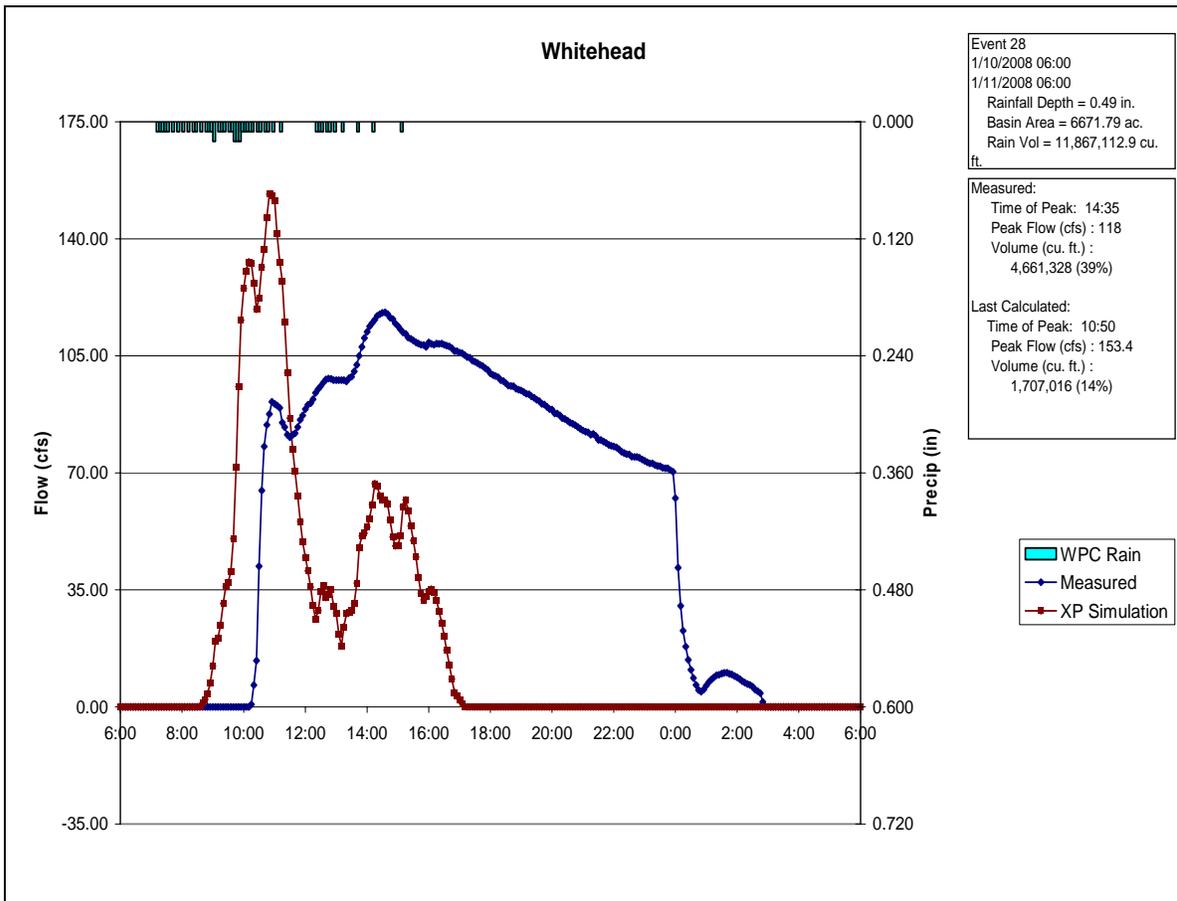

Figure 2 Whitehead CSO Hydrograph Under Backwater Condition

The next step in the calibration process was to calculate the event runoff ratio for each of the meters to determine if the ratio remained similar for the monitored events. The runoff ratio is calculated using the following equation:

$$R = V_{flow} / V_{rain}$$

> Where R is equal to the runoff ratio
> V_{flow} is equal to the volume of water that went past the flowmeter during the event
> V_{rain} is equal to the volume of rain that fell on the basin during the event

Generally, the runoff ratio will be smaller for smaller rainfall events where the surface wetting, depression storage, and infiltration takes up a larger fraction of the rainfall event. Table 4 shows that all of the meters were generally in a reasonable range for the runoff ratio; however, Francis showed more inconsistency during the last flow monitoring period (there was so much inconsistency, Francis was not adjusted last time) and Mitchell during this flow monitoring period produced significantly more runoff than during the 2008 LTCP Update. The consistency among events is an indicator that the data is reasonable for calibration.

Table 4							
Observed Runoff Ratios Determined from Monitoring Data							
Event	**Blacksnake**	**Brown's Branch**	**Charles**	**Francis**	**Messanie**	**Mitchell**	**Olive**	**Patee**
Event 28	4%	0.2%	13%	8%		32%		86%
Event 29	4%	0%	17%	12%		13%		55%
Event 30	7%	0%	11%	0%		21%		54%
Event 31	0%	0%		0%				48%
Event 35		5%	22%	13%				
Event 38		0%		21%		28%		
Event 39		7%			60%	28%		
Event 44		4%						
Event 48	15%	2%			81%			
Event 52	9%							
Event 53	14%							
Event 63		5%						
Total Events	**7**	**10**	**5**	**6**	**2**	**5**	**0**	**4**
Range	**0 – 15%**	**0 – 7%**	**11 – 22%**	**0 – 21%**	**60 – 80%**	**13 – 32%**		**48 – 86%**
2008 LTCP Calibration Events			**4**	**4**	**2**	**3**	**3**	**1**
Range			**10 – 24%**	**15 – 119%**	**54 – 86%**	**7 – 10%**	**41 – 59%**	**62%**
Note: If a cell is blank, data was either bad or did not exist for the event.								

For calibration performed for the 2008 LTCP Update, events were chosen that were not influenced by wet or dry conditions, but some of the events chosen for calibration for this study did have some wet and dry conditions that might influence the calibration. Therefore, the first adjustment to the model was to change the antecedent moisture condition (AMC) of the basins for each event based on the previous five days of rainfall. The criteria used are described in the following table (Chow, 1988):

Table 5 Antecedent Moisture Conditions		
Antecedent Moisture Condition (AMC)	**Dormant Season**	**Growing Season**
I	Less than 0.1 inch per previous day	Less than 0.28 inch per previous day
II	0.1 to 0.22 inch per previous day	0.28 to 0.42 inch per previous day
III	Greater than 0.22 inch per previous day	Greater than 0.42 inch per previous day
Notes: 1. Dormant season for St. Joseph was assumed to be beginning of November until the end of February. Growing season was assumed to be beginning of March until the end of October. 2. Previous day is defined as up to five previous days.		

In the 1999 Comprehensive Stormwater Management Plan, each basin had a curve number that represented AMC II conditions on the basin, which is commonly used for design conditions. The adjustments to AMC I and AMC III conditions were made with the following equations (Chow, 1988):

$$CN(I) = 4.2CN(II) / (10-0.58CN(II))$$
$$CN(III) = 23CN(II) / (10+0.13CN(II))$$

Where CN(I) is AMC I

CN(II) is AMC II

CN(III) is AMC III

These adjustments were made for each event based on the monitored rainfall. The adjustment of the curve number adjusts both the infiltration and the initial abstraction. Table 6 shows the condition used for each event simulation.

| Table 6 Wet Weather Event AMC Condition	
Event	AMC Condition
Event 28	I
Event 29	I
Event 30	I
Event 31	II
Event 35	I
Event 38	I
Event 39	I
Event 44	III
Event 48	III
Event 52	II
Event 53	II
Event 63	II

After establishing which of the flowmeter responses appeared reasonable for calibration and the AMC condition, the 12 wet weather events were simulated using the existing conditions model from the 2008 LTCP Update calibration. This initial run of the 12 events showed that the 2008 LTCP Update CSS model did not produce much or any runoff on small events (i.e rain events less than 0.5 inches). This issue was not present during the last calibration effort as the smallest calibration event was still 0.7 inches of rain and had relatively-high peak rain intensity. After confirming the results, adjustments were made to the hydrology of the CSS model.

As described in the 1999 Comprehensive Stormwater Management Plan, the XP-SWMM stormwater model (which became the basis of the CSS model) used the SCS method for hydrology, however in applying this method, it used a composite curve number approach (i.e. area-average curve number), which is common for stormwater modeling. In the SCS hydrology method, land that drains to a common point is delineated and assigned a curve number based on the contributing land cover and soil type. The percent of that contributing land which is impervious is then determined and

the impervious area is assigned a representative curve number. The curve numbers for the pervious and impervious portions of the subbasins are then area-averaged to compute the composite curve number. However, the monitored flow data indicated that the composite curve number method resulted in too much initial abstraction for small events, which resulted in the subbasins not producing runoff for small storm events.

Therefore, the hydrology was modified so that the impervious and pervious areas of each subbasin became separate areas, each with its own assigned curve number. So for one delineated subbasin, it is represented in XP-SWMM as two catchments, one for the impervious fraction and one for the pervious fraction. As a result of this adjustment, the model has less depression storage on small events and produces runoff from the directly-connected impervious area on small events. For large events, the excess precipitation for either the composite or split subbasin method is similar (i.e., as the rainfall depth increases, the two runoff method results converge). After making this adjustment, the model produced hydrographs that more closely represented the smaller wet weather events collected between November 1, 2007 and July 31, 2008.

For the additional model calibration, adjustments were made in the percent impervious, the pervious curve number, and the initial abstraction. After each adjustment was made, the model was executed, then evaluated to determine if the adjustments made in the previous simulation resulted in better fit of the monitored response. In total, five different model calibration runs to calibrate the model (each calibration run simulated all 12 wet weather events selected for calibration). In addition, after completing calibration, the wet weather events from the 2008 LTCP Update were also simulated with the adjusted hydrology to demonstrate that calibration for this data set could be applied to events monitored for the 2008 LTCP Update. Figure 3 through Figure 16 show the comparison between the 2008 LTCP Update CSS model and the updated CSS model for runoff volume and peak flow while Appendix A has tables showing the percent difference for all simulated events.
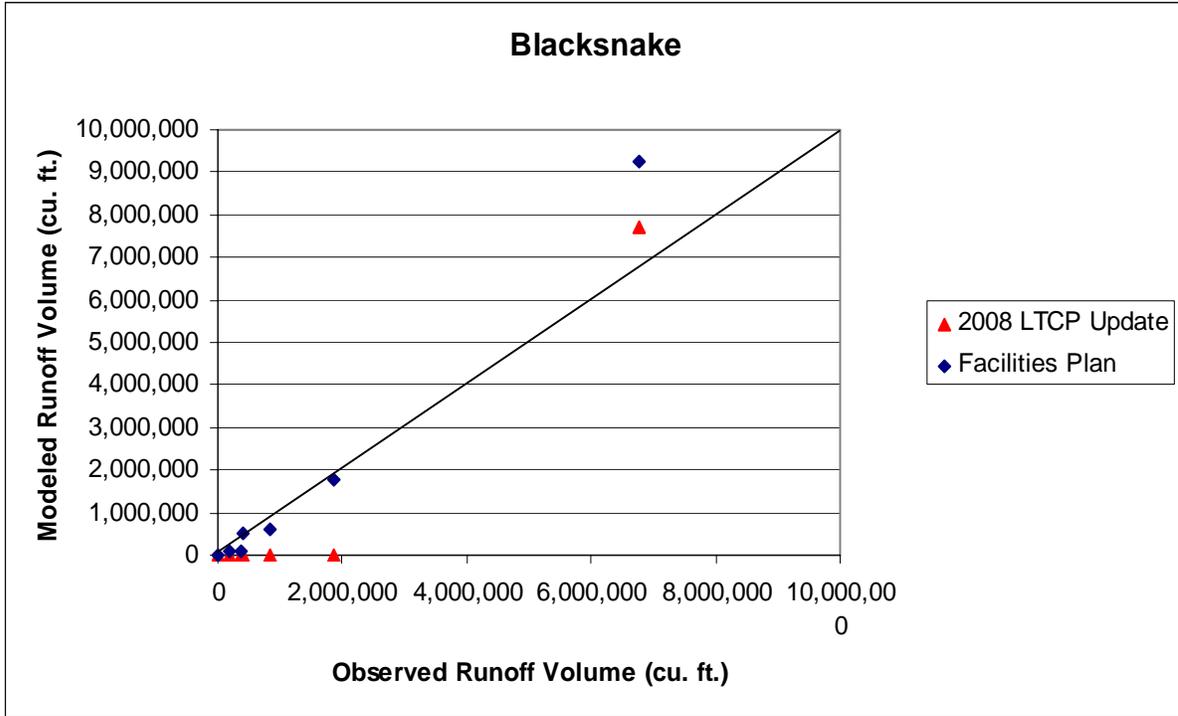
Figure 3 Blacksnake Runoff Volume – Observed Compared to Modeled
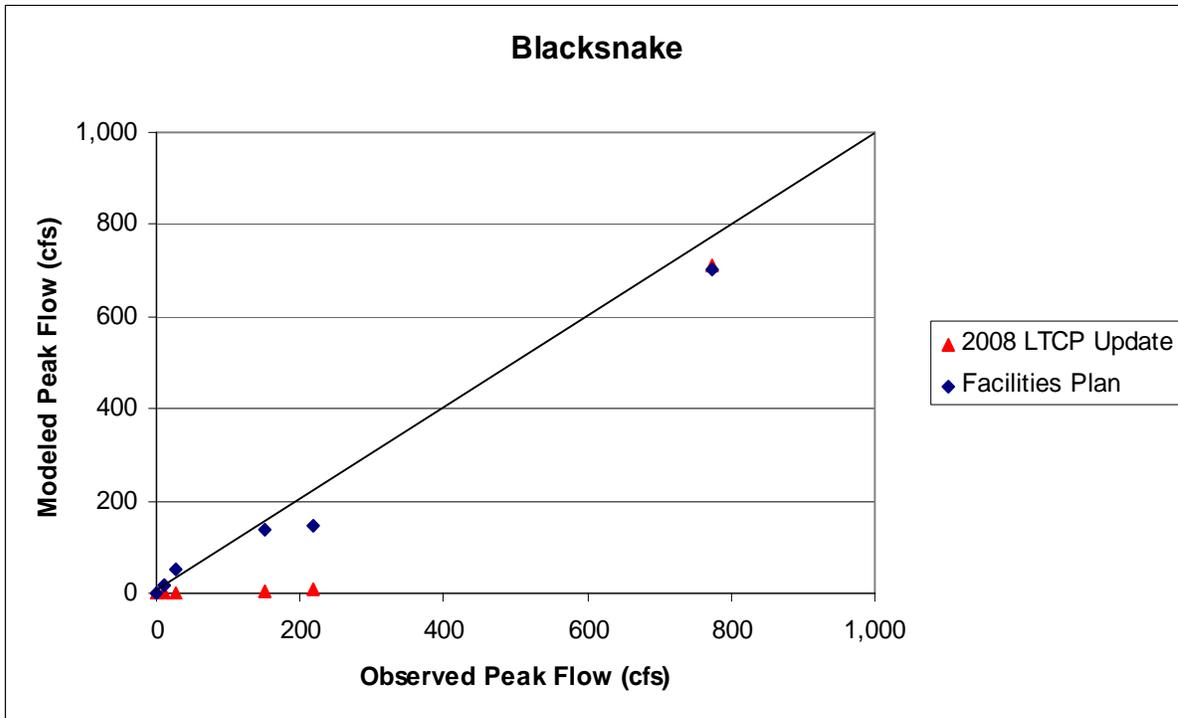
Figure 4 Blacksnake Peak Flow – Observed Compared to Modeled
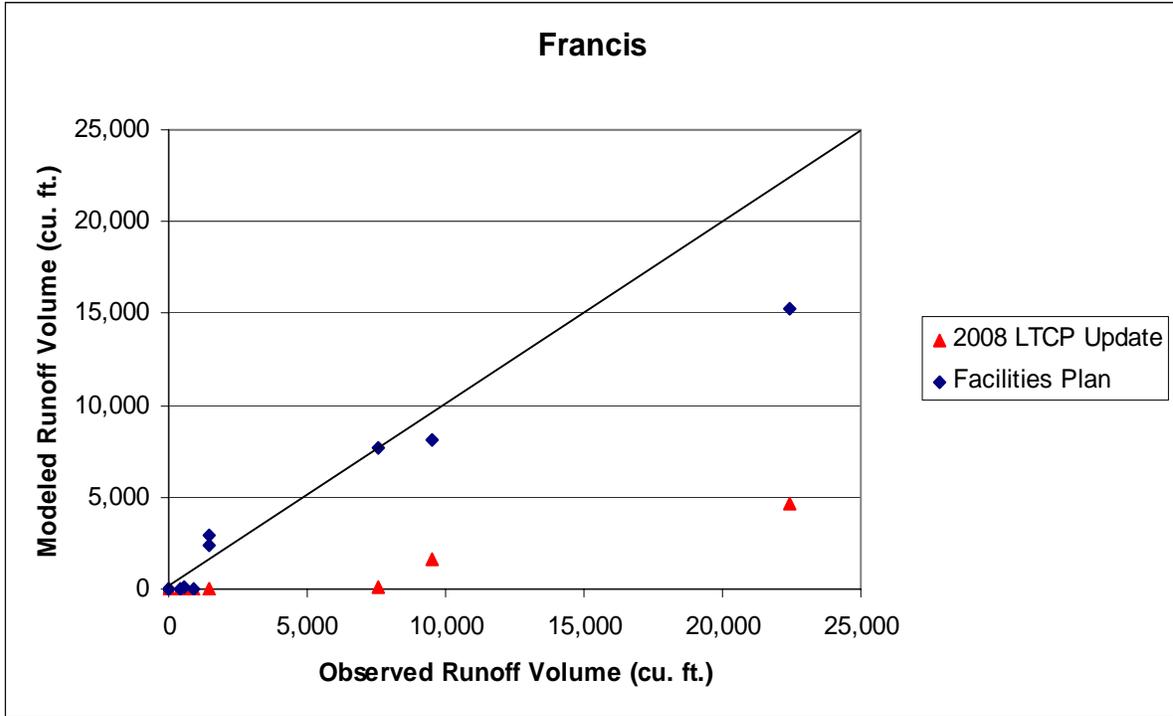
Figure 5 Francis Runoff Volume – Observed Compared to Modeled
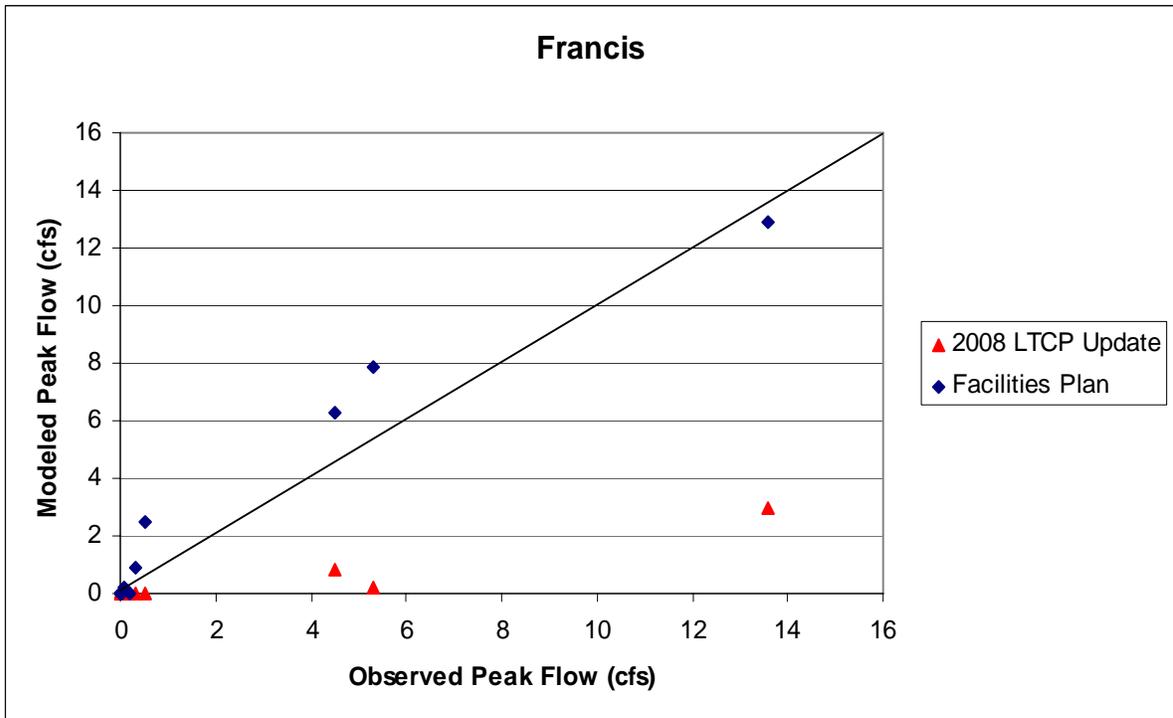
Figure 6 Francis Peak Flow – Observed Compared to Modeled
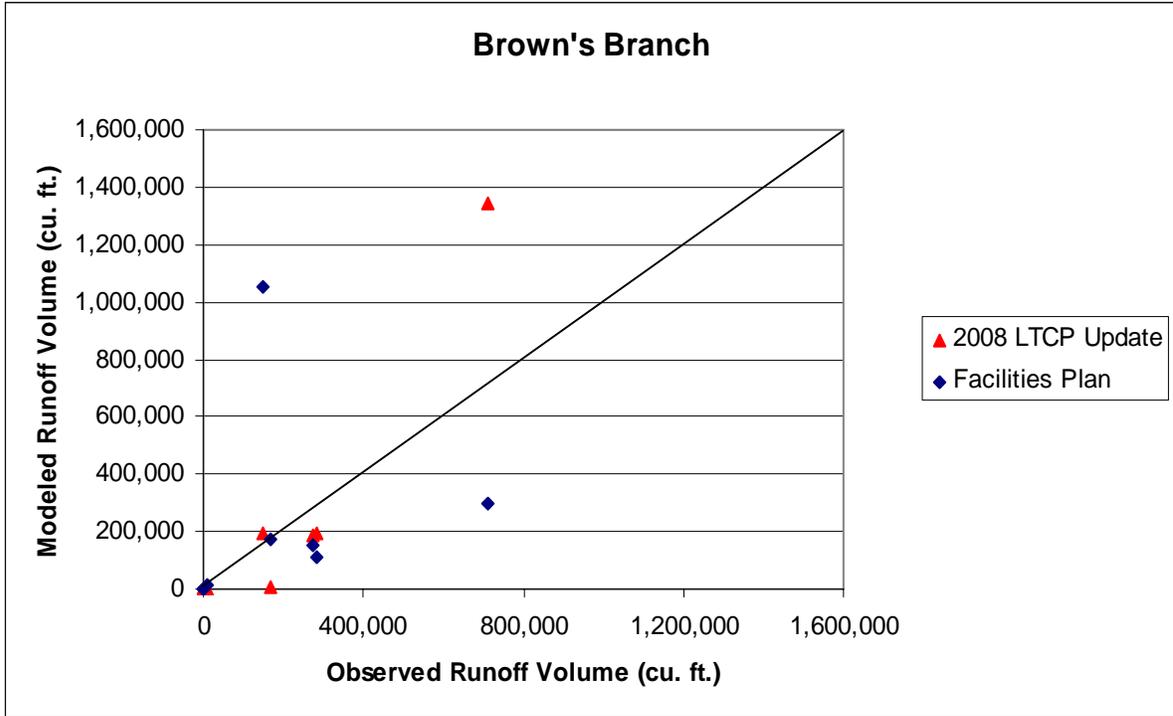
Figure 7 Brown's Branch Runoff Volume – Observed Compared to Modeled

Figure 8 Brown's Branch Peak Flow – Observed Compared to Modeled

Figure 9 Charles Runoff Volume – Observed Compared to Modeled

Figure 10 Charles Peak Flow – Observed Compared to Modeled

Figure 11 Mitchell Runoff Volume – Observed Compared to Modeled

Figure 12 Mitchell Peak Flow – Observed Compared to Modeled
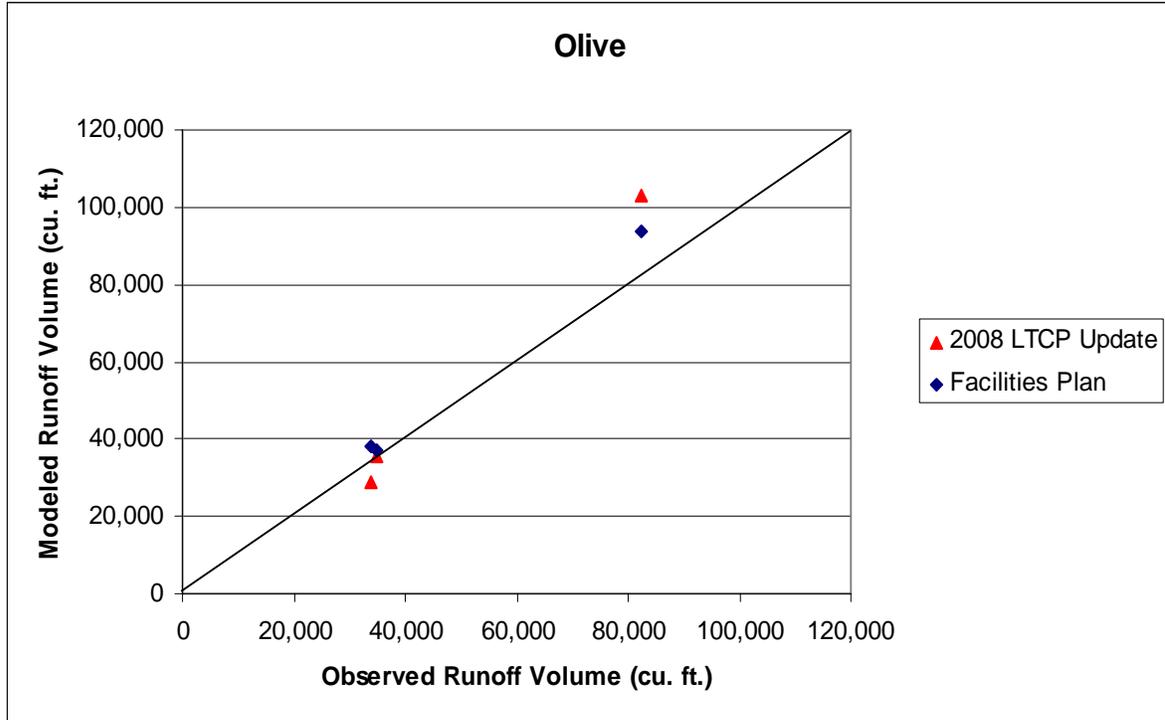
Figure 13 Olive Runoff Volume – Observed Compared to Modeled
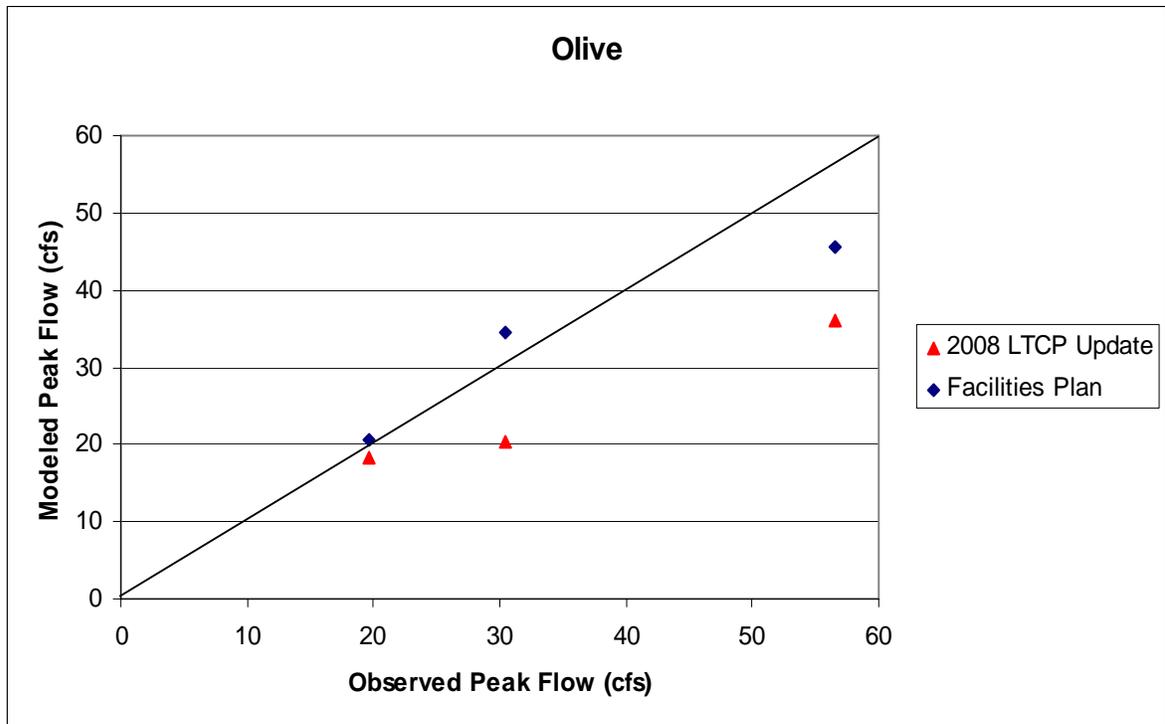
Figure 14 Olive Peak Flow – Observed Compared to Modeled
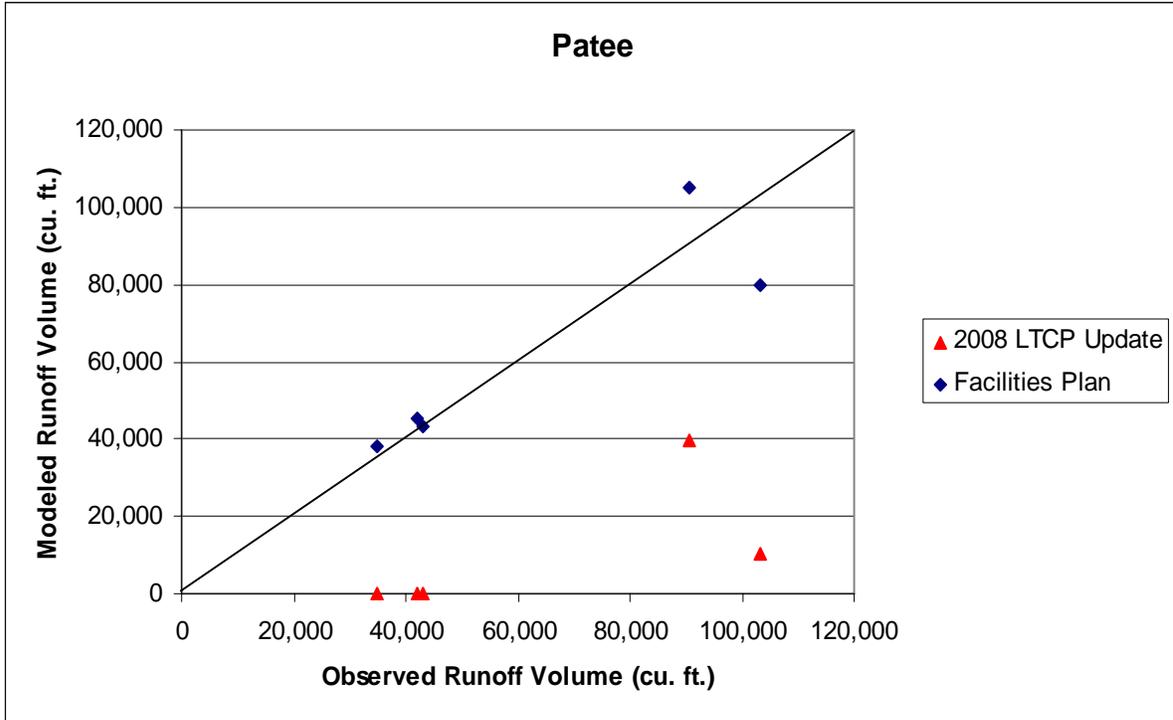
Figure 15 Patee Runoff Volume – Observed Compared to Modeled
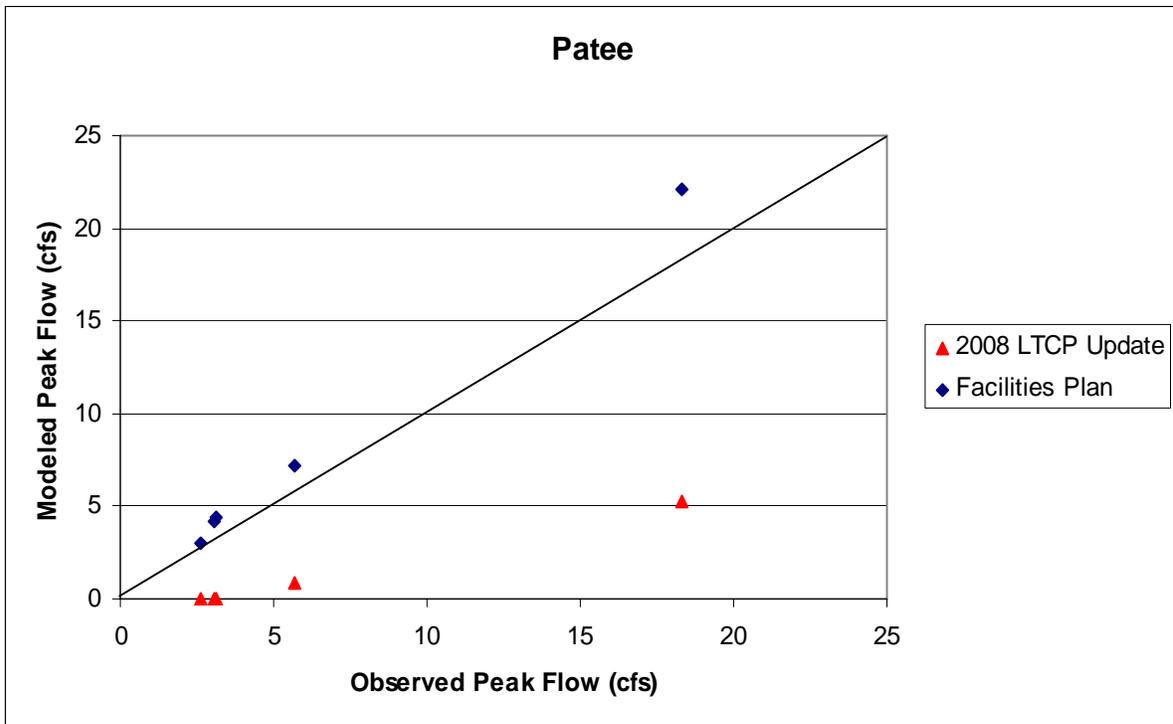
Figure 16 Patee Peak Flow – Observed Compared to Modeled

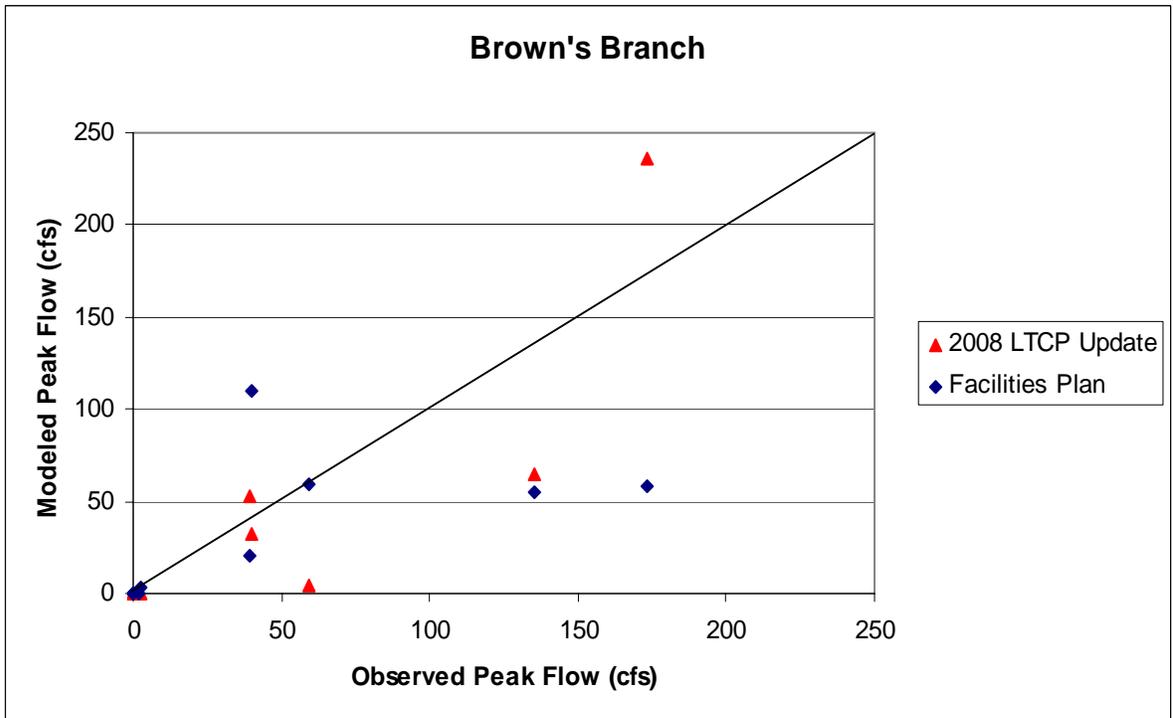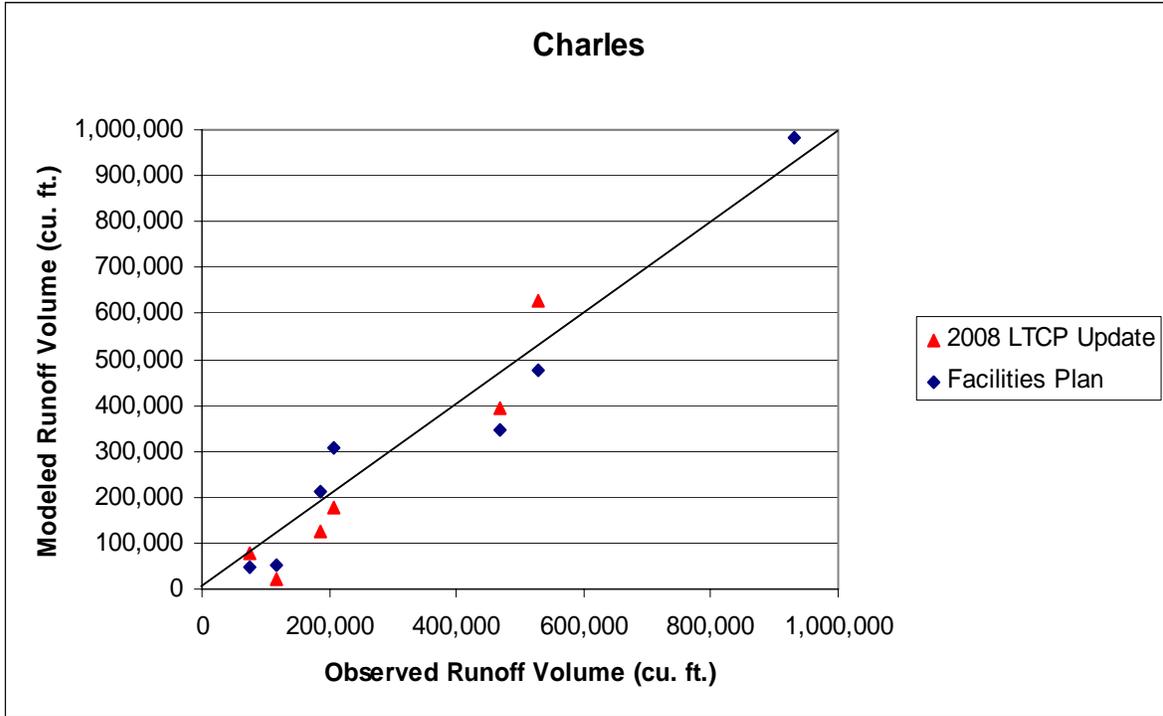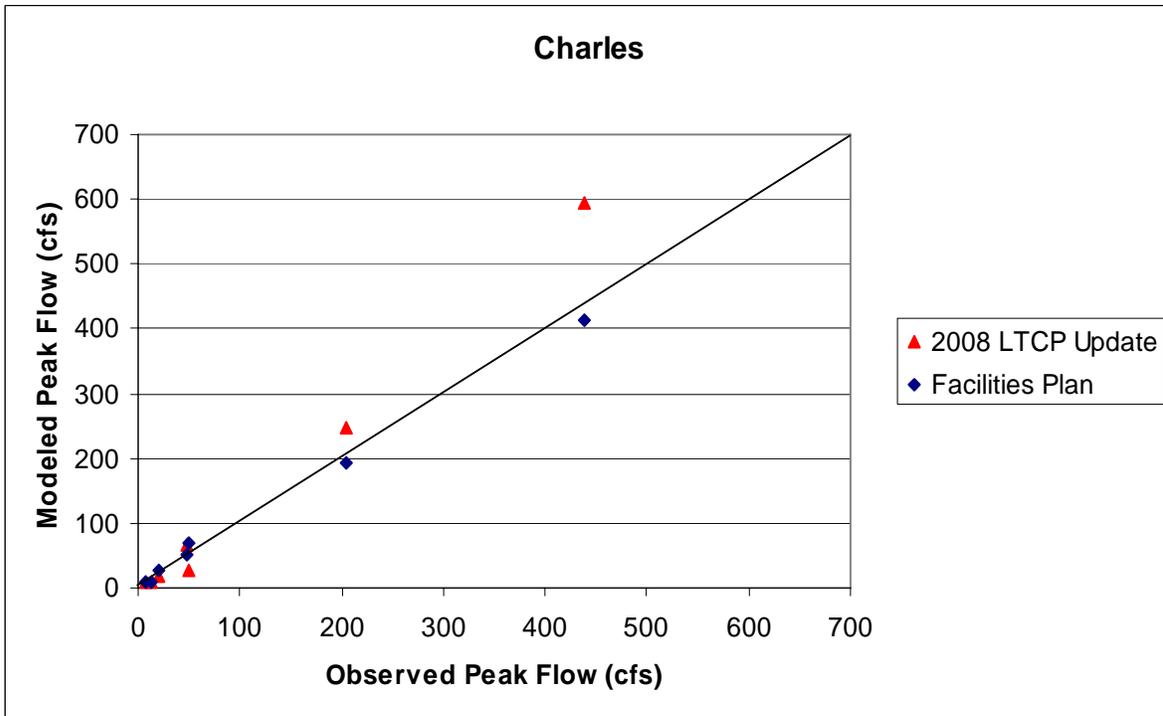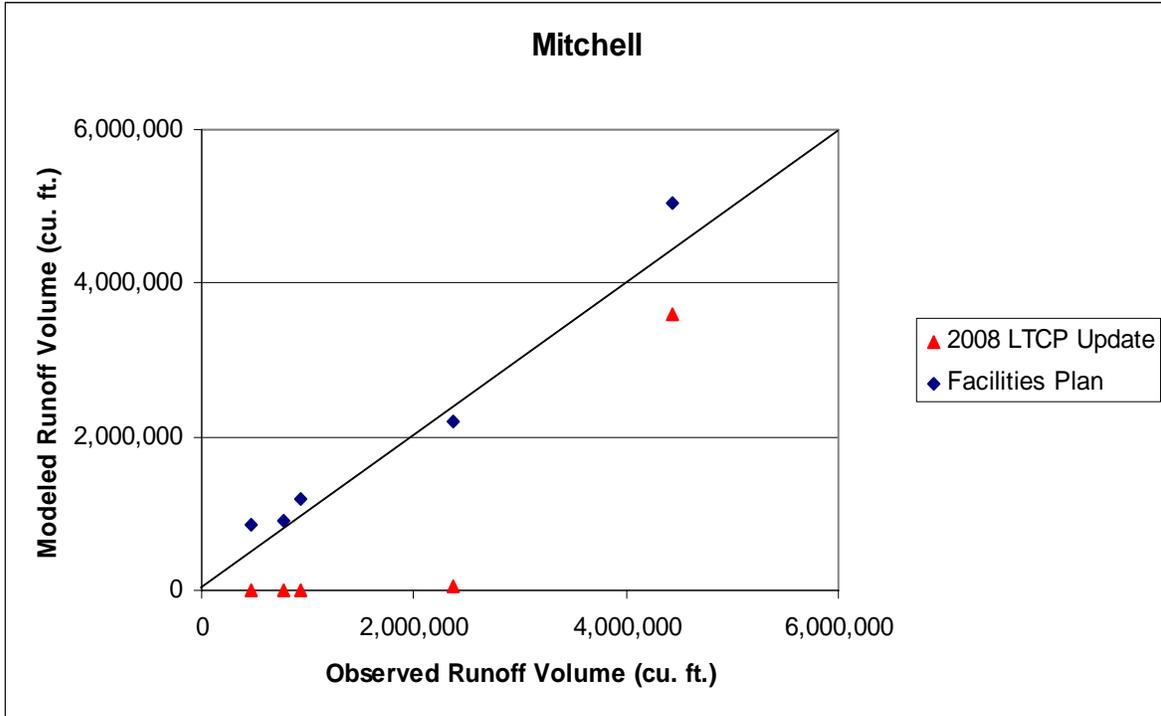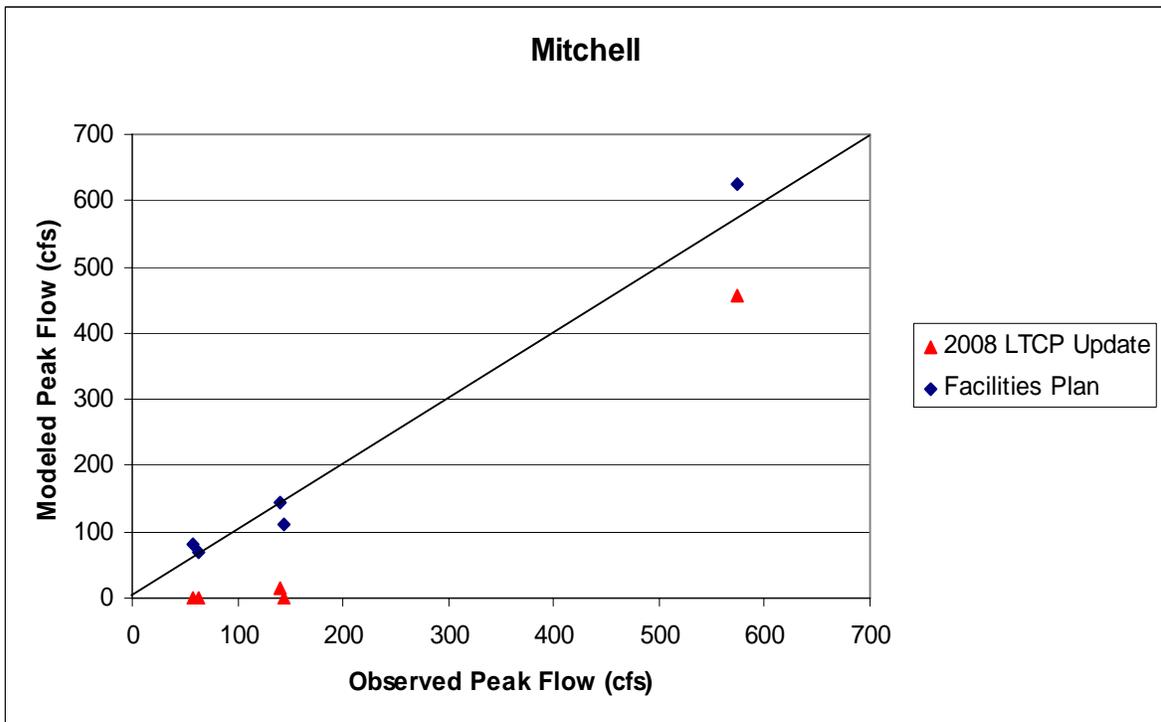As can be seen in the calibration figures, Blacksnake, Charles, Messanie, Olive, Patee, and Mitchell appear to be reasonably well calibrated, while Brown's Branch and Francis show significant scatter. Both Brown's Branch and Francis have been adjusted to more closely simulate the observed results, but additional data may result in further refinement.

6.0   Typical Year Overflow Determination for Existing Conditions

The CSS model is used to estimate the frequency and volume of CSO for a "typical year". A "typical year" of wet weather events is representative of long-term average annual conditions of the CSS basin. The frequency and volume of rainfall events that define the typical year were based on a methodology developed for the City of Kansas City, Missouri to support its CSO Long Term Control Plan. The "typical year" is 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, which vary in frequency and duration Table 7 presents the eight design storms that comprise the typical year and the characteristics of these events.

		Table 7			
		Typical Year Rainfall Event Characteristics			
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

Using the simulated runoff volumes and the event frequency, the typical year CSS overflow volume is calculated. The total overflow volume for a particular design event is

the sum of the overflow at all diversion structures. Table 8 shows the typical year CSS overflow from the model simulation run during the 2008 LTCP Update.

Event	Events Equal to or Greater Than	Overflow Volume, MG	Average Overflow Volume, MG	Events in this Range	Overflow Volume for Range, MG
Table 8 Typical Year Existing Conditions CSS Overflow Volume from 2008 LTCP Update CSS Model					
Events less than A	78	0.00			
			0.015	42	0.62
A	36	0.030			
			1.135	18	20.40
B	18	2.24			
			13.155	6	78.91
C	12	24.07			
			75.575	6	453.45
D	6	127.08			
			179.760	2	359.52
E	4	232.44			
			260.275	1	260.28
F	3	288.11			
			349.670	1	349.67
G	2	411.23			
			497.170	1	497.17
H	1	583.11			
			583.110	1	583.11
			Total	78	2,603.13

To further explain the typical year CSO volume calculation, in the table above, Event A produced a runoff volume in the model of 0.03 million gallons (MG) while Event B produced a runoff volume of 2.24 MG. The average runoff volume between Events A and B would be 1.135 MG, and there are 18 rainfall events that have rainfall depths between Events A and B in the typical year. Therefore, the overflow volume produced by events in this range for the typical year would be 20.40 MG. This process is repeated for each event range in the typical year. So to complete the calculation, the typical year overflow volume for each event range is summed to determine the overall typical year volume. Event H is considered the 1-year event so its volume is not averaged; it is added directly to the typical year overflow volume.

Using the monitoring data collected by the City for this study, additional calibration to the 2008 LTCP Update model was conducted. Some of the monitoring data collected for this study showed that the 2008 LTCP model generated less runoff than was monitored for precipitation events less than 1.5 inches in depth, and in addition, the Mitchell basin runoff ratios were significantly greater for this monitoring period than during the 2008 LTCP Update monitoring; therefore, the calibration of the Mitchell basin using this data resulted in larger flows. The additional model calibration for this study resulted in a CSS model producing a larger volume of overflow in a typical year. Table 9 shows the results of the typical year overflow for the revised CSS model.

Table 9 Typical Year Existing Conditions CSS Overflow Volume from Facilities Plan CSS Model					
Event	Events Equal to or Greater Than	Overflow Volume, MG	Average Overflow Volume, MG	Events in this Range	Overflow Volume for Range, MG
Events less than A	78	0			
			6.8	42	296.52
A	36	13.5			
			24.6	18	462.15
B	18	35.7			
			55.4	6	345.09
C	12	75.1			
			124.8	6	749.37
D	6	174.4			
			223.8	2	444.99
E	4	273.2			
			280.7	1	299.21
F	3	288.1			
			363.8	1	383.64
G	2	439.5			
			526.7	1	530.71
H	1	613.9			
			613.9	1	619.57
			Total	78	4,131.25

The revised calibration model generates approximately 1.0 billion gallons (BG) of additional overflow volume for events smaller than Event C (0.86 inches of rain) and approximately 1.7 billion gallons of additional flow for the typical year overflow volume.

7.0 Conclusions and Recommendations

The rainfall and flow monitoring data provided for this study indicates that the CSS runoff from the Mitchell basin was greater in runoff volume and peak flow than what was monitored during the 2008 LTCP Update study. The new flow data provided in this study allowed for a detailed check of level, velocity, and flow conversion, and the Mitchell data appeared reasonable. Therefore, Mitchell was calibrated using the data collected for this study, which resulted in significantly higher runoff volumes and peak flows for the Mitchell basin.

Additionally, the rainfall and flow data monitored for the 2008 LTCP Update did not have any small rainfall events that were suitable for calibration. The monitoring data for this study did provide smaller event data, and from these events, it was apparent that the monitored runoff volumes and peak flows were greater than calculated with the 2008 LTCP Update CSS model. To make the CSS model produce more representative flows for smaller events, each subbasin was split into two subbasins where one subbasin represented the directly-connected impervious area and the other the pervious area of the subbasin. The resulting model better simulates the monitored runoff volumes and peak flows for Blacksnake, Charles, Messanie, Mitchell, Olive, and Patee. Francis was also adjusted, and although the runoff volume and peak flow calibration graphs still show some scatter, it is reasonable since the drainage basin is so small (approximately three acres). Adjustments to the hydrologic response of Brown's Branch were also made to better simulate the monitored responses; however, there is still substantial variance between the monitored and calculated hydrographs, which would indicate the need for additional monitoring.

The Brown's Branch and Whitehead level sensing flowmeters appear to be inappropriate flowmeter technologies for their respective locations. Both sensors are fine for indicating when the monitoring water level has risen above the overflow weirs; however, determining flow from only a level measurement is unreliable if the locations are under a backwater influence (i.e. water level in the Missouri River is above the overflow weir or mild-sloped downstream channels). From the flow data provided for these meters, visually it would appear that the Brown's Branch flowmeter provides

reasonable estimates during some events so some calibration was performed. However, there is definitely a backwater influence when the Missouri River is at high stage, and when this occurs, the meter does not provide good flow data. The hydrograph data for the Whitehead level sensor flowmeter extends too long after precipitation events and tapers off too suddenly towards the end of the flow event. Visually and quantitatively, the Whitehead flows do not appear reasonable, so the data were not used for calibration. Additional flow monitoring using area-velocity meters is recommended for both sites.

The revised version of the CSS model produces an estimated typical year CSS overflow volume of approximately 4.1 BG. This is approximately 59 percent greater annual CSO volume than estimated in the 2008 LTCP Update. This is a result of smaller storm events producing more runoff than the 2008 LTCP Update version of the model and the higher runoff ratios observed for Mitchell during this last flow monitoring period. It should be noted that the 59 percent increase is related to an annual average. This increase does not imply that the facilities required to achieve the Phase 3 level of control (see the 2008 LTCP for description) need to be upsized by this factor. It only implies that the treatment facilities will operate more often and the associated annual operation and maintenance costs for the recommended facilities would be higher than originally estimated.

For Design Event E, which was the selected design event to achieve the Phase 3 level of control, the revised version of the CSS model produces 17 percent more CSO volume than was estimated by the 2008 LTCP model. In other words, the facilities required to achieve the Phase 3 level of control are preliminarily estimated to be within 17 percent of the original facility sizes. As part of the ongoing Facilities Plan, the sizes of the Phase 2 and Phase 3 controls will be further refined and discussed in upcoming technical memorandums.

The monitoring data collected for this study proved valuable in identifying an issue with the previous version of the CSS model, and the calibration results produced in this study clearly show that the model is better representing the system. However, some basins within the system have not been monitored (Duncan, Hickory, and Maple) and the level sensing flowmeter at the Missouri Avenue diversion structure has not produced any

usable flow data. It is possible that additional flow monitoring would justify additional model refinement for these three basins.

8.0   References

1.   Black & Veatch Corporation, <u>Plans for Sewerage Improvements St. Joseph, Missouri Contract R-3 Section A – Interceptor Sewer</u>, 1968.

2.   Black & Veatch Corporation, <u>Plans for Sewerage Improvements St. Joseph, Missouri Contract R-3 Section B – Interceptor Sewer</u>, 1970.

3.   Black & Veatch Corporation, <u>Combined Sewer System Long Term Control Plan 2008 Update</u>, 2008.

4.   Chow, V.T., et. al., <u>Applied Hydrology</u>, 1988.

Appendix A
Calibration Results of Observed and Calculated Runoff Volumes and Peak Flows

	Table A-1 Percent Difference Between Observed and Calculated Runoff Volumes Before Calibration									
Event	**Event Depth, in**	**Blacksnake**	**Brown's Branch**	**Charles**	**Francis**	**Messanie**	**Mitchell**	**Olive**	**Patee**	**Whitehead**
Event 17	0.9				-99%	-61%		-14%		
Event 19	1.01			19%	-83%			1%		
Event 20	1.78			59%	-79%	16%		25%		
Event 21	0.67			-14%	-100%				-56%	
Event 28	0.27	-100%	-100%	-81%	-100%		-98%		-96%	
Event 29	0.288	-100%	0%	-95%			-100%		-100%	
Event 30	0.24	-100%	0%	-75%			-100%		-100%	
Event 31	0.21	0%	0%						-100%	
Event 35	0.408		-32%	-70%	-100%					
Event 38	0.576		-100%		-100%		-100%			
Event 39	0.792		89%			-45%	-45%			
Event 44	0.624		-93%				-100%			
Event 48	1.05	-100%	32%			-86%				
Event 52	1.08	-99%								
Event 53	3.528	14%								
Event 63	1.536		-32%							
Range		**-100 - 14%**	**-100 - 89%**	**-95 - 59%**	**-100 - -79%**	**-86 - 16%**	**-100 - -45%**	**-14 - 25%**	**-100 - -56%**	
Note: If a cell is blank, data was either bad or did not exist for the event.										

			Table A-2							
		Percent Difference Between Observed and Calculated Runoff Volumes After Calibration								
Event	**Event Depth, in**	**Blacksnake**	**Brown's Branch**	**Charles**	**Francis**	**Messanie**	**Mitchell**	**Olive**	**Patee**	**Whitehead**
Event 17	0.9				2%	-31%		12%		
Event 19	1.01			-10%	-15%			6%		
Event 20	1.78			5%	-32%	27%		14%		
Event 21	0.67			47%	98%				16%	
Event 28	0.27	21%	38%	14%	-76%		-7%		-23%	
Event 29	0.288	-57%	0%	-53%			84%		1%	
Event 30	0.24	-76%	0%	-36%			16%		7%	
Event 31	0.21	0%	0%						7%	
Event 35	0.408		-61%	-26%	67%					
Event 38	0.576		-100%		-100%		26%			
Event 39	0.792		-58%			35%	13%			
Event 44	0.624		23%				-29%			
Event 48	1.05	-4%	610%			2%				
Event 52	1.08	-29%								
Event 53	3.528	36%								
Event 63	1.536		-44%							
Range		**-76 - 36%**	**-100 - 610%**	**-53 - 47%**	**-100 - 98%**	**-31 - 35%**	**-29 - 84%**	**6 - 14%**	**-23 - 16%**	
Note: If a cell is blank, data was either bad or did not exist for the event.										

Table A-3										
Percent Difference Between Observed and Calculated Peak Flows Before Calibration										
Event	**Event Depth, in**	**Blacksnake**	**Brown's Branch**	**Charles**	**Francis**	**Messanie**	**Mitchell**	**Olive**	**Patee**	**Whitehead**
Event 17	0.9				-96%	-72%		-33%		
Event 19	1.01			21%	-81%			-7%		
Event 20	1.78			36%	-78%	-27%		-36%		
Event 21	0.67			-45%	-100%				-71%	
Event 28	0.27	-100%	-100%	-70%	-100%		-92%		-92%	
Event 29	0.288	-100%	0%	-79%			-100%		-100%	
Event 30	0.24	-100%	0%	-62%			-100%		-100%	
Event 31	0.21	0%	0%						-100%	
Event 35	0.408		36%	-38%	-100%					
Event 38	0.576		-100%		-100%		-100%			
Event 39	0.792		36%			-56%	-46%			
Event 44	0.624		-95%				-100%			
Event 48	1.05	-96%	-20%			-89%				
Event 52	1.08	-96%								
Event 53	3.528	-8%								
Event 63	1.536		-53%							
Range		**-100 - 0%**	**-100 - 36%**	**-79 - 36%**	**-100 - -78%**	**-89 - -27%**	**-100 - -46%**	**-36 - -7%**	**-100 - -71%**	
Note: If a cell is blank, data was either bad or did not exist for the event.										

				Table A-4						
				Percent Difference Between Observed and Calculated Peak Flows After Calibration						
Event	**Event Depth, in**	**Blacksnake**	**Brown's Branch**	**Charles**	**Francis**	**Messanie**	**Mitchell**	**Olive**	**Patee**	**Whitehead**
Event 17	0.9				48%	-32%		13%		
Event 19	1.01			-6%	40%			4%		
Event 20	1.78			-5%	-5%	1%		-20%		
Event 21	0.67			39%	392%				21%	
Event 28	0.27	98%	29%	40%	225%		4%		27%	
Event 29	0.288	59%	0%	-19%			44%		41%	
Event 30	0.24	39%	0%	13%			9%		38%	
Event 31	0.21	0%	0%						14%	
Event 35	0.408		-48%	9%	188%					
Event 38	0.576		-100%		-93%		-22%			
Event 39	0.792		-67%			-9%	9%			
Event 44	0.624		-26%				2%			
Event 48	1.05	-10%	175%			-50%				
Event 52	1.08	-32%								
Event 53	3.528	-9%								
Event 63	1.536		-59%							
Range		**-32 - 98%**	**-100 - 175%**	**-19 - 40%**	**-93 - 392%**	**-50 - 1%**	**-22 - 44%**	**-20 - 13%**	**14 - 41%**	
Note: If a cell is blank, data was either bad or did not exist for the event.										