METROPOLITAN SEWER DISTRICT of greater CINCINNATI

Date: October 8, 2012

To: Commissioner Greg Hartmann
Commissioner Chris Monzel
Commissioner Todd Portune

Cc: Christian Sigman, County Administrator
Jeff Aluotto, Asst. County Administrator

From: James A. Parrott, Executive Director JAP

Subject: Model and Local Data Risk Mitigation for LMCPR

MSD is confident the hydraulic and hydrologic model used to develop the recommended Lick Run sustainable projects and the larger LMCPR Sustainable Alternative is a reasonable and rational approach for decision making. Focusing on the Lick Run sustainable project, our confidence stems from several factors including:

- MSD has made a comprehensive effort to visually review every pipe, manhole, parcel, land use, & drainage pattern for all 87 sub-catchment areas directed to CSO 5.
- Existing local data provides a good understanding of the quantity of water in the existing sanitary and storm collection sewers and how they lead into the combined trunk sewers. We know what will be removed.
- The model inputs and assumptions have been fully vetted with leading industry experts including the third party County expert and the federal, state, and local Regulators.
- The LMC Partial Remedy is based upon the results of modeling software developed by USEPA. The Regulators have reviewed the local data inputs and the adjustments made to the model assumptions. They have indicated "no red flags".
- It is reasonable to assume the Lick Run section of the model is correct when the upstream and downstream sections have been validated.
- The limited risk associated with limited flow monitoring data at CSO 5 is minimized through the collective wealth of local data and sophistication of the current modeling technology that has been deemed a rational tool by the Regulators and is within industry standards.

The County monitor has suggested MSD explain how data input into the system-wide model supports the sizing and ultimately costs developed for the Sustainable Alternative. The monitor team specifically inquired about the correlation of local data and stormwater separation effectiveness. MSD understands the issues posed by the County monitor team. This memorandum highlights the key issues and explains how the data input into the model is appropriate for decision making including sewer separation vs. strategic separation; accounting of local data and system flows; industry standards and procedures for data gaps; and experiences of other cities.

Model & Local Data Risk Mitigation

1. Sewer Separation vs. Strategic Separation

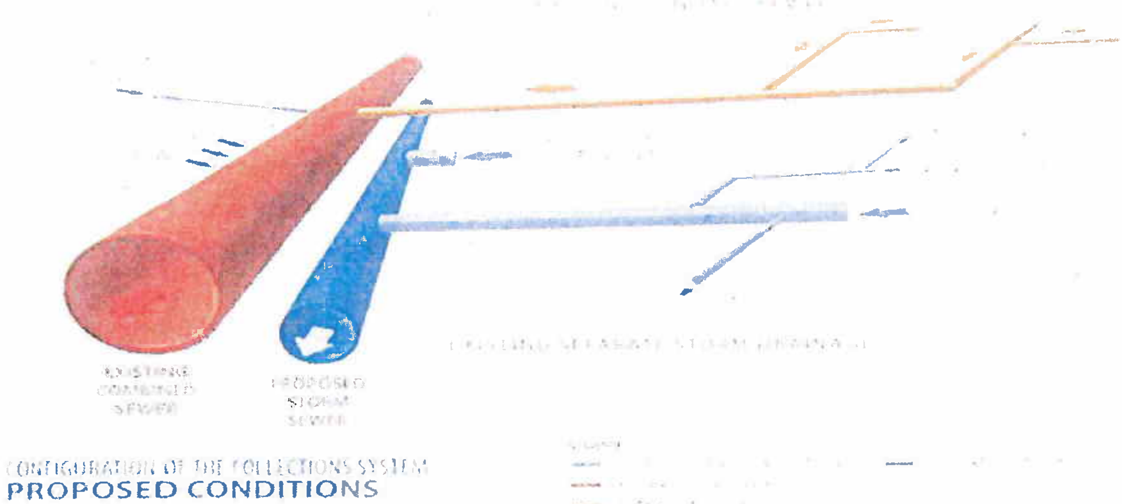
Traditional Sewer separation has been proven to be a very effective component to many CSO long term control plans. This form of separation involves constructing a new partially separated combined or storm sewer network to off-load wet weather flow from an existing combined sewer. It is typically applied to systems comprised solely of combined sewers without existing storm sewers. The legitimate criticisms of this technique include:

- House to house separation is often challenging and disruptive. There is typically a concern that sanitary connections will remain after separation, thus creating an illicit discharge.

- Historically, communities that performed separation did not provide any "treatment" to the separated stormwater and this resulted in some water quality issues from the increased stormwater discharges.

The proposed Lick Run project, an example of various projects included in the LMCPR Sustainable Alternative, addresses both of these issues. MSD is proposing "strategic separation" which focuses on street inlets and undeveloped hillsides. It generally does not involve house to house separation, except in rarte cases when cost-effective. A schematic of this concept is presented in Figure 1.

FIGURE 1 – STRATEGIC SEWER SEPARATION



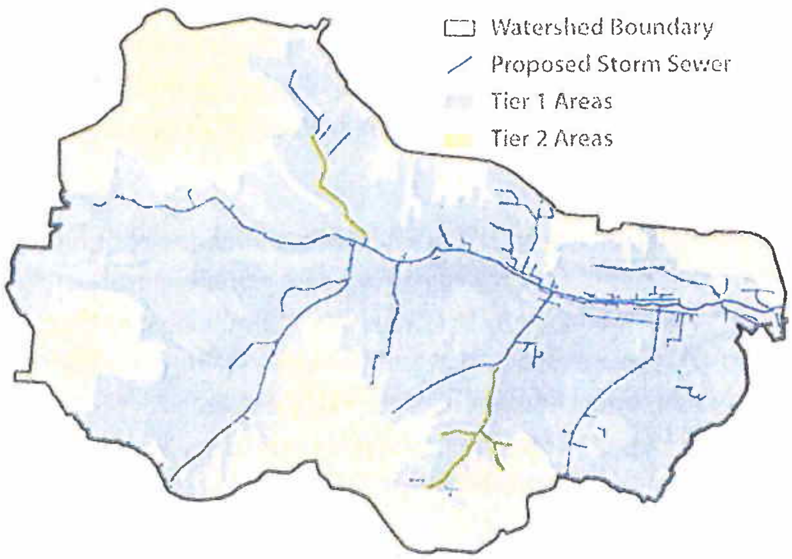
Strategic sewer separation differs from traditional separation and is not applicable to all communities. It is only viable in communities like MSD where wet weather flows are collected via existing storm sewers and sanitary flows are collected via sanitary only sewers. The existing storm and sanitary sewers are then interconnected into a large "combined sewer" network. MSD is proposing to eliminate the existing interconnection and re-route the existing separated storm sewer flow to a new storm trunk sewer –in lieu of the existing combined sewer. The sanitary flow will continue to be directed to the existing combined sewer system.

An understanding of the watershed characteristics of Lick Run and its constituent neighborhoods and the financial constraints led to the development of the strategic sewer separation approach. The limits of the proposed sewer separation within the watershed were determined with the goal of capturing as much stormwater as possible with focused investments in new infrastructure. With that goal in mind, the sewer separation approach targeted stream entry points, large undeveloped hillsides, and areas already served by separate storm and sanitary systems that eventually discharge into the combined sewer system. These targeted areas of the watershed were termed priority areas (referred to as Tier 1 areas) and represent approximately 1,800 acres.

Highly developed areas on the upper reaches of the watershed requiring extensive separation, and therefore expense, were **excluded** from the Tier 1 areas unless it was reasonably efficient to extend new separated storm trunk sewers to connect with existing separated drainage collection systems. These upland areas were termed non-priority areas (referred to as Tier 2 areas) and represent approximately 900 acres. The boundaries of the Tier 1 areas are shown in Figure 2 with the area shaded in blue representing the Tier 1 areas.

Strategic sewer separation is proposed primarily through the installation of new storm sewers or natural conveyance systems sized to convey stormwater from the Tier 1 areas only. In some isolated cases within Lick Run (approximately 10% of the Lick Run pipe to be installed), it was deemed more cost effective to install new partially separated combined sewers and utilize the existing combined sewer infrastructure for stormwater conveyance.

FIGURE 2 – TIER 1 PRIORITY AREAS OF LICK RUN WATERSHED



A summary of the fate of various flows after strategic separation has been completed in the Lick Run Watershed is as follows:

Flows to new storm sewer trunk system

- Existing storm sewers in Tier 1 areas
- Downspouts connected to existing storm sewer in Tier 1 areas
- Hillsides, ravines, and inlets in Tier 1 areas
- Overland flow from Tier 1 and 2 areas
- Stream inlets in Tier 1 areas
- Roadway inlets from 1,800 acres of Tier 1 areas

Flows to remain in existing combined sewer system

- Foundation drains
- Downspouts connected to combined sewer system
- Existing infiltration and inflow
- Stream inlets in Tier 2 areas
- Roadway inlets in 900 acres of Tier 2 areas

The situation of unknown sanitary laterals being connected to a new storm line, resulting in illicit discharges is not an issue with the approach being proposed in Lick Run. The proposed Lick Run strategy also provides for water quality treatment of all separated stormwater, thus avoiding the second issue associated with traditional storm separation projects.

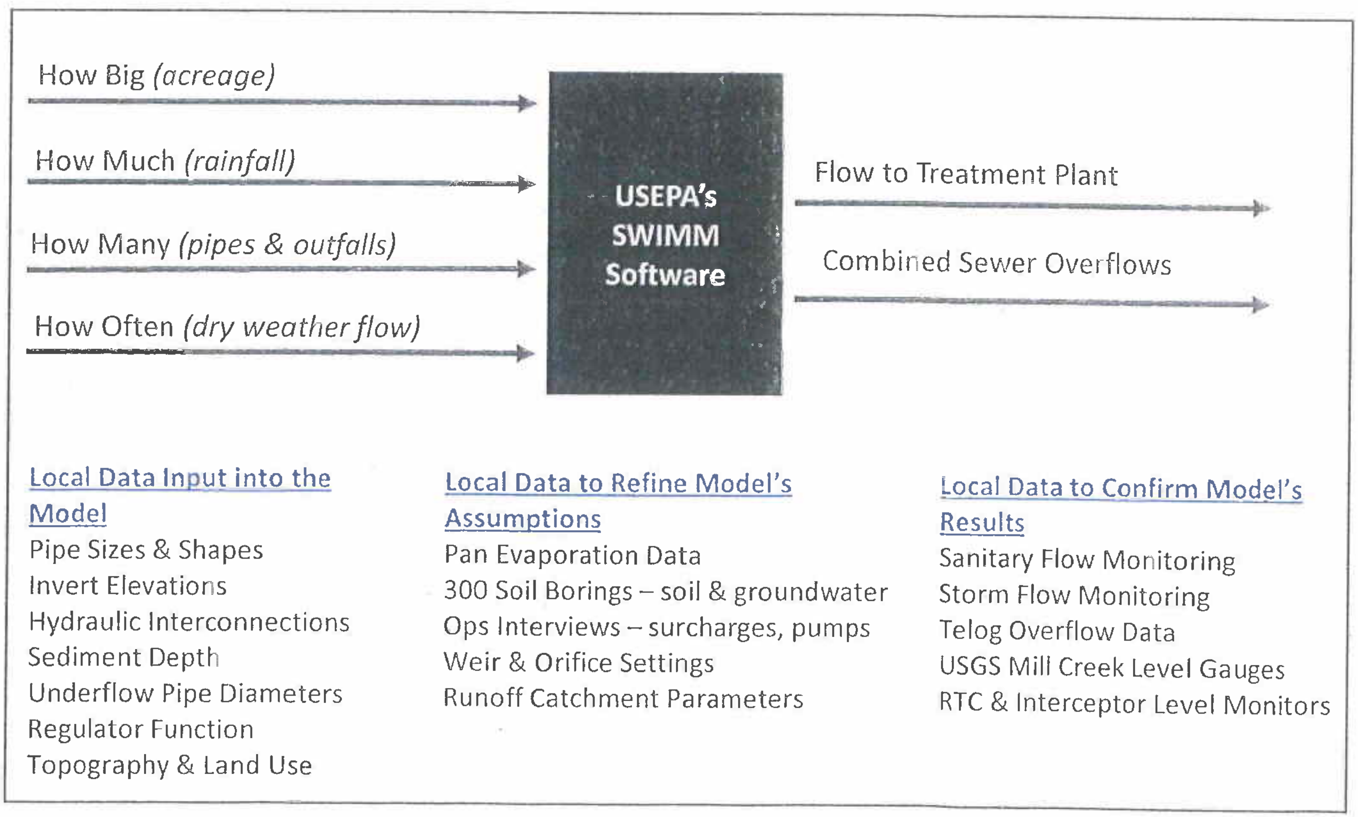
2. Accounting of Local Data and System Flows

Simply speaking, a mass balance approach is used to estimate stormwater separation effectiveness. The volume of water redirected to the storm system plus the volume of water remaining in the combined sewer system is equal to the sum of water in the combined sewer system before separation. Model inputs and results are carefully vetted to verify this volume balance.

MSD is confident the engineering and field evaluations conducted throughout the Lower Mill Creek (LMC) Study accurately accounts for capture the stormwater runoff. MSD has performed field visits and refined percent capture volumes based on actual site/drainage area conditions. Assumptions have been peer reviewed (multiple times) and deemed to be reasonable.

In order to fully understand the brevity of the mass balance approach utilized, it is important to understand the sources and impact local data has played with the LMC Study. A schematic of the hydrologic and hydraulic modeling process is shown in Figure 3.

FIGURE 3 – PROCESS OF HYDROLOGIC AND HYDRAULIC MODELING

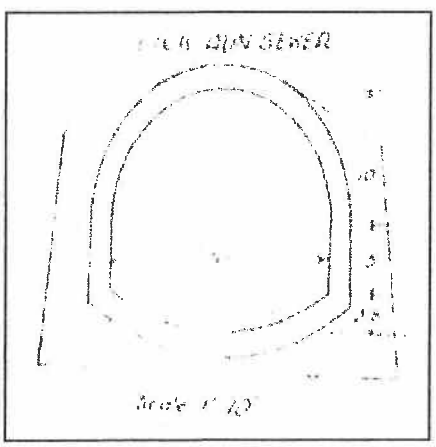


Local Data Input into the Model

The Consent Decree requires a wet weather solution that is based on USEPA's hydraulic and hydrologic modeling software developed by USEPA. During the LMC Study MSD reviewed and evaluated local data to verify information input into the model software accurately represents MSD's sewer system. Record drawings, aerial photographs, and Cincinnati Area Geographic Information System (CAGIS) were utilized extensively to quantify acreages of sub-basins, pipe sizes, local topographic conditions, impervious area, land use, topography, soil group, and hydraulic interconnections of the storm, sanitary, and combined sewer systems.

The Lick Run watershed was broken down into sub-catchment areas, as delineated in the combined sewer model. CAGIS has an impervious area shapefile, but a distinction between types of impervious areas is not made. In addition, discrepancies between the shapefile and aerial photography were noted in some locations. Consequently, the existing CAGIS impervious area shapefile was not deemed accurate enough for this evaluation. The LMC Study Team conducted field investigation to develop a new shapefile for the Lick Run Watershed which subdivided impervious area into buildings, roadways, driveways and sidewalks, parking lots, and miscellaneous impervious areas. Any area that was severely compacted, such as a gravel lot, was considered a miscellaneous impervious area. Driveways and sidewalks, parking lots, and other miscellaneous impervious areas were digitized by hand using 2011 aerial photography. This level of effort was extensive but necessary to ensure local data was utilized to reflect the existing infrastructure and land conditions input into the USEPA model.

In addition the elevations of pipe inverts, manhole rims, control gates, and weirs were verified using a combination of record drawings, CAGIS data and field surveys. Field investigations were conducted at key locations to measure and record the depth of sediment present in the existing sewers.



Local data was also gathered in the field with respect to pipe shapes. The model will assume a uniform pipe shape if different information is not input by the users. Given the age of much of the existing sewer infrastructure throughout MSD's service area ranges from 1 to 120 years, it is important to use local data to properly account for pipe shapes. The LMC Study Team had to create custom shapes for conduits for select pipes. Figure 4 shows a portion of a record drawing for a sewer segment and also lists a sampling of pipes that were customized in the hydraulic model.

Model & Local Data Risk Mitigation

FIGURE 4 – CUSTOMIZED CONDUIT SIZES

Conduit	Original Shape	Original Size	New shape	New size
28605024-28605025	HORIZ_ELLIPSE	17.83' x 20'	CUSTOM	17.8' x 20'
28605025-28605026	HORIZ_ELLIPSE	17.83' x 20'	CUSTOM	17.8' x 20'
28605026-28605029B	RECT_CLOSED	17.83' x 20.5'	CUSTOM	17.8' x 20'
28605029B-29408023	RECT_CLOSED	17.75' x 20.5'	CUSTOM	17.8' x 20.5'
29408023-29408050	CIRCULAR	14.5'	CUSTOM	17.8' x 20.5'
29408050-29408049	CIRCULAR	14.5'	CIRCULAR	19.5'

Another example of MSD's use of field investigations to improve the quality of data input into the model was confirmation of the multiple components of underflow structures. The Lick Run CSO 5 is a complex outfall structure with a myriad of interrelated pieces. MSD operations staff was instrumental in assisting the technical team with understanding the working relationship of those pieces. Figure 5 represents a profile view of the Lick Run underflow structure. The field investigation and monitoring data study resulted in tweaks to the model inputs regarding the entry loss coefficient and pipe diameter and offset measurements.

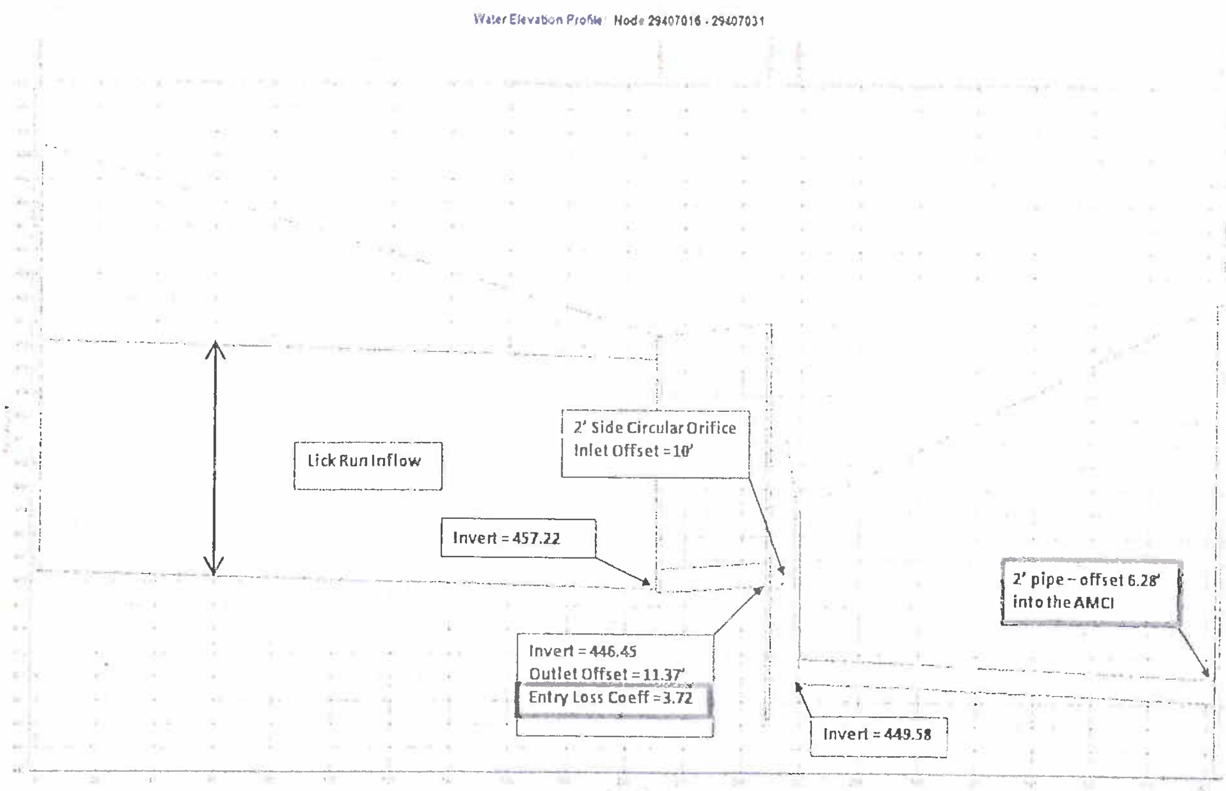


FIGURE 5 – VERIFICATION OF UNDERFLOW PIPE CHARACTERISTICS

MSD is confident this level of effort has significantly enhanced the quality of local data input into the hydraulic and hydrologic model. Earlier versions of the model used the data available at that time (before MSD's field investigation and records review) as model inputs. MSD invested time and capital into fully vetting the Sustainable Alternative and one component of that vetting process was to confirm and reaffirm local data was used to refine model inputs.

Local Data to Refine Model Assumptions for Existing System

USEPA's SWMM model software uses a complex set of engineering equations combined with logic sequences and performance assumptions to predict the flows directed to the treatment plant and the streams. The assumptions built into the model were developed by the Regulators and have been used for decades with hydraulic and hydrologic models. By improving the details of the assumptions built into the model, MSD was able to improve the accuracy of model results. Assumptions addressed by the LMC Study Team include:

- Pan evaporation data based upon local NOAA information was added into the model to account for local climatic conditions.
- 300 soil borings were advanced to confirm soil conditions and the groundwater elevation for the Lick Run area.
- Operational staff interviews were conducted to gain an accurate understanding of the locations of surcharges in the existing system and control settings for pumps, gates, and other key infrastructure.
- Weir and orifice control settings and operational logic were adjusted to match actual conditions in lieu of using typical values.
- Runoff catchment parameters were field verified to account for local data unique to each sub-catchment areas in lieu of using regional published information.

The issue of the appropriate runoff catchment parameters to utilize for the model has been an item of discussion between MSD and the County monitor team. This is an important criterion in that the model uses these parameters to simulate the volume of stormwater captured and directed to local surface waters in lieu of the combined sewer. The parameters would be more complex to develop if MSD were proposing traditional sewer separation in lieu of strategic sewer separation.

Local Data to Refine Model Assumptions for Proposed Separation Improvements

The specific details of work conducted to verify the percent capture and effectiveness for the Lick Run Watershed are presented in the *"Lick Run Percent Effectiveness Technical Memorandum" prepared by Strand and Associates, September 2012.* A brief discussion of the key issues is presented herein. It is easy to confuse the concepts of percent capture and percent effectiveness in the context of runoff catchment parameters. The definitions are as follows.

$$Percent\ Effectiveness = \frac{volume\ of\ stormwater\ removed\ from\ combined\ sewer\ system}{total\ wet\ weather\ volume\ currently\ conveyed\ to\ CSS}$$

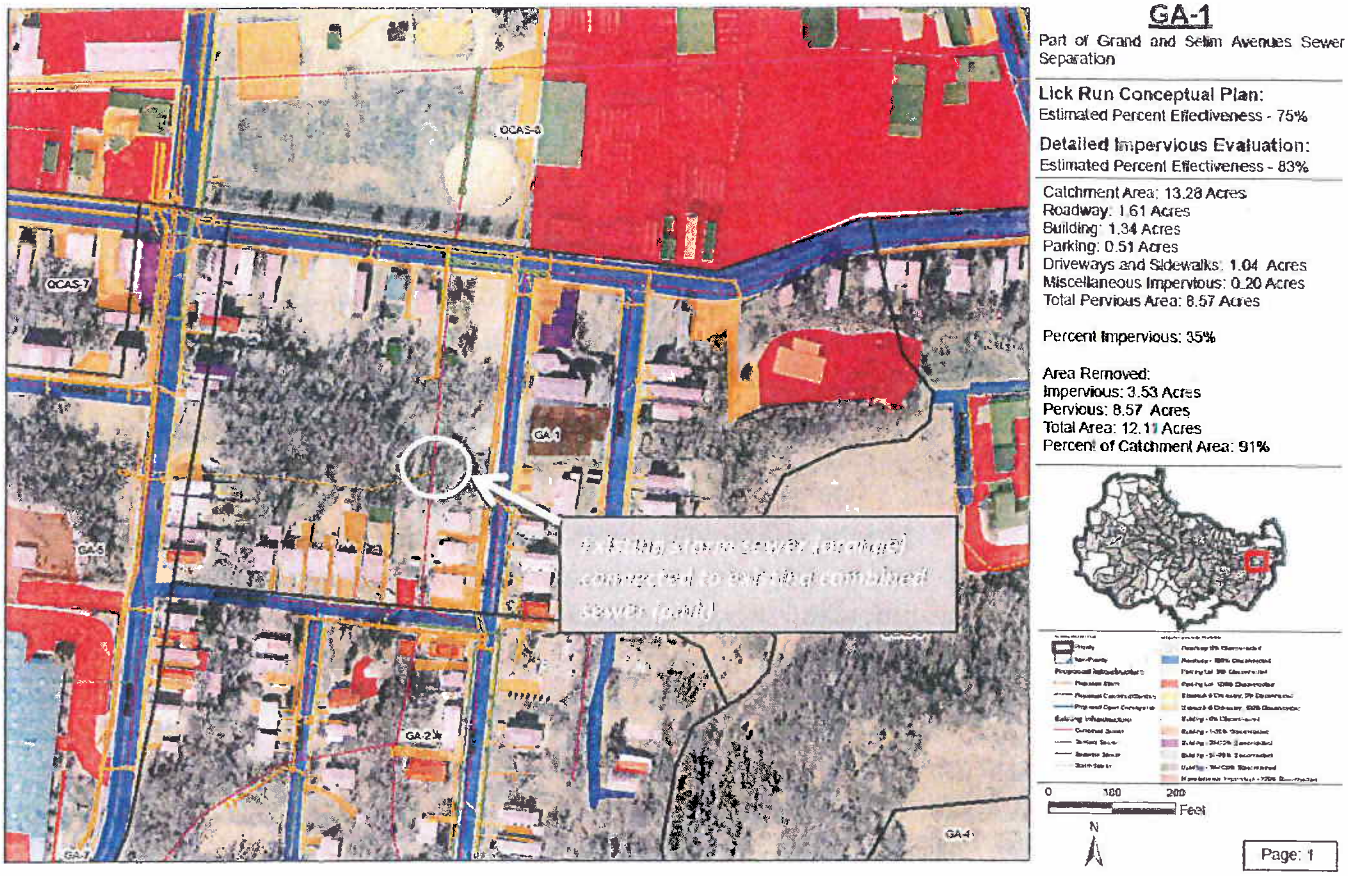
$$Percent\ capture = \frac{volume\ of\ rainfall\ directed\ to\ storm\ sewer}{total\ rainfall\ volume}$$

Stormwater separation effectiveness is calculated as the volume of water redirected to the storm systems divided by the total wet-weather volume tributary to that location in the storm sewer. Total wet-weather volume includes both stormwater runoff and rainfall derived infiltration and inflow (RDII). Percent effectiveness is one of the primary assumptions leading to the modeled results. As such, MSD understands the importance of getting accurate local data to optimize assumptions and calculations.

The model software assumes a percent effectiveness based upon the data input into the model (impervious area, land use, etc). The LMC Study Team assessed, evaluated, and visited each of the sub-catchment areas. The results of the LMC Study indicated adjustments were made to a few sub-catchment areas to better reflect actual field conditions. The results of the evaluations for each sub-catchment area are provided in the Lick Run Percent Effectiveness Technical Memorandum.

To provide a level of understanding for the comprehensive nature of the field evaluations conducted for each sub-catchment area in the context of percent effectiveness, the following two examples are provided in Figures 6 and 7. Figure 6 presents the information for a sub-catchment area in which the assumptions were revised resulting in a higher percent effectiveness value. Figure 7 represents a sub-catchment area resulting with a lower percent effectiveness.

FIGURE 6 – SUB-CATCHMENT AREA GA-1 (RESULTED WITH HIGHER PERCENT EFFECTIVENESS)



The information used to revise the percent effectiveness is largely driven the by refinement of impervious and pervious areas within the sub-catchment area. When specific local data regarding roadway areas, parking, buildings, driveways, sidewalks, and gravel areas was considered it was determined this particular sub-catchment's percent effectiveness was higher than originally estimated. Similarly, for the FA-2 sub-catchment area for the Queen City Avenue and Cora Avenue location, the percent effectiveness was lower than originally estimated. This exercise was repeated for all the sub-catchment areas. The results are summarized for all the Lick Run sub-catchment areas in Figure 8.

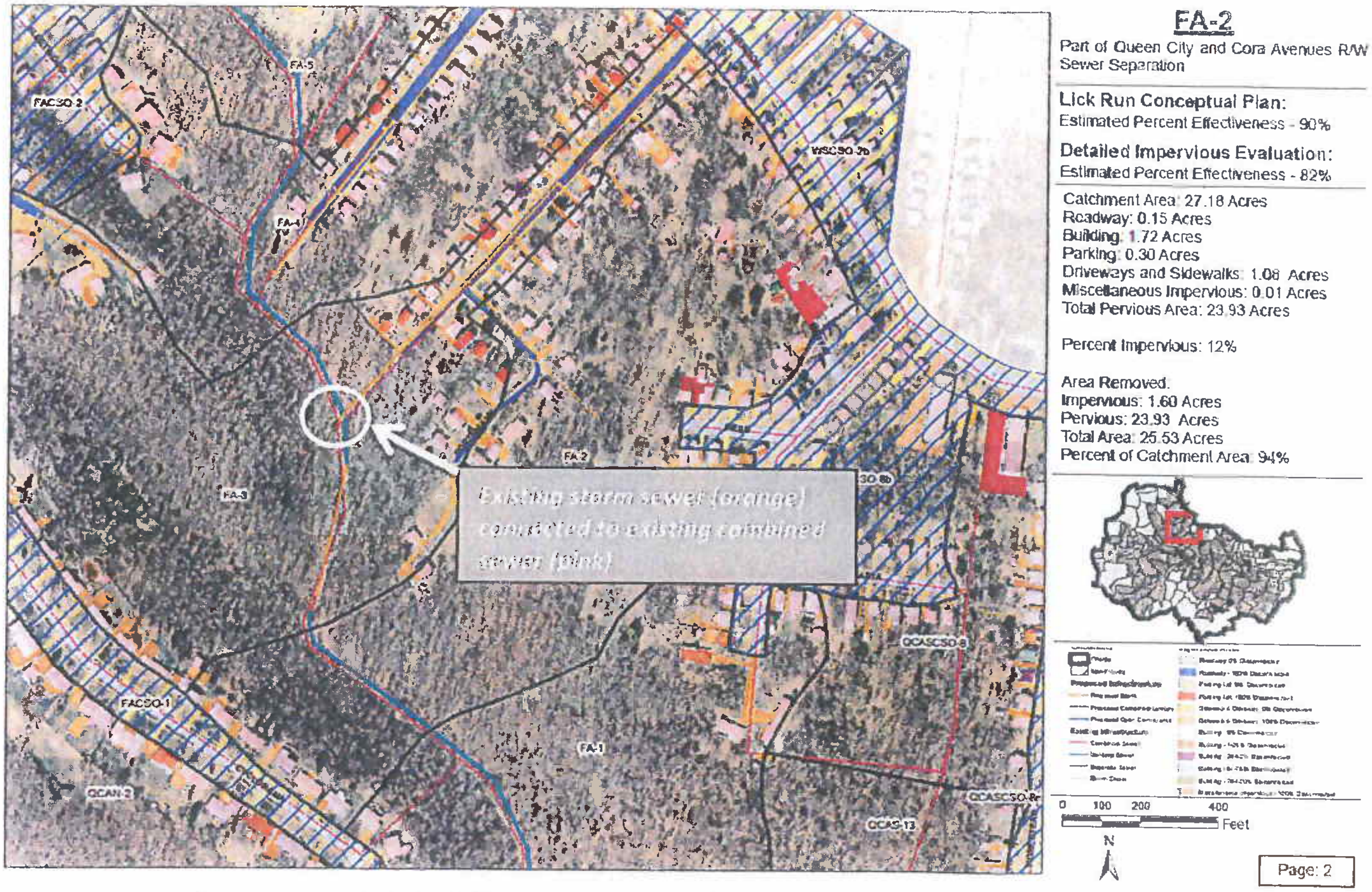


FIGURE 7 – SUB-CATCHMENT AREA FA-2 (RESULTED WITH LOWER PERCENT EFFECTIVENESS)

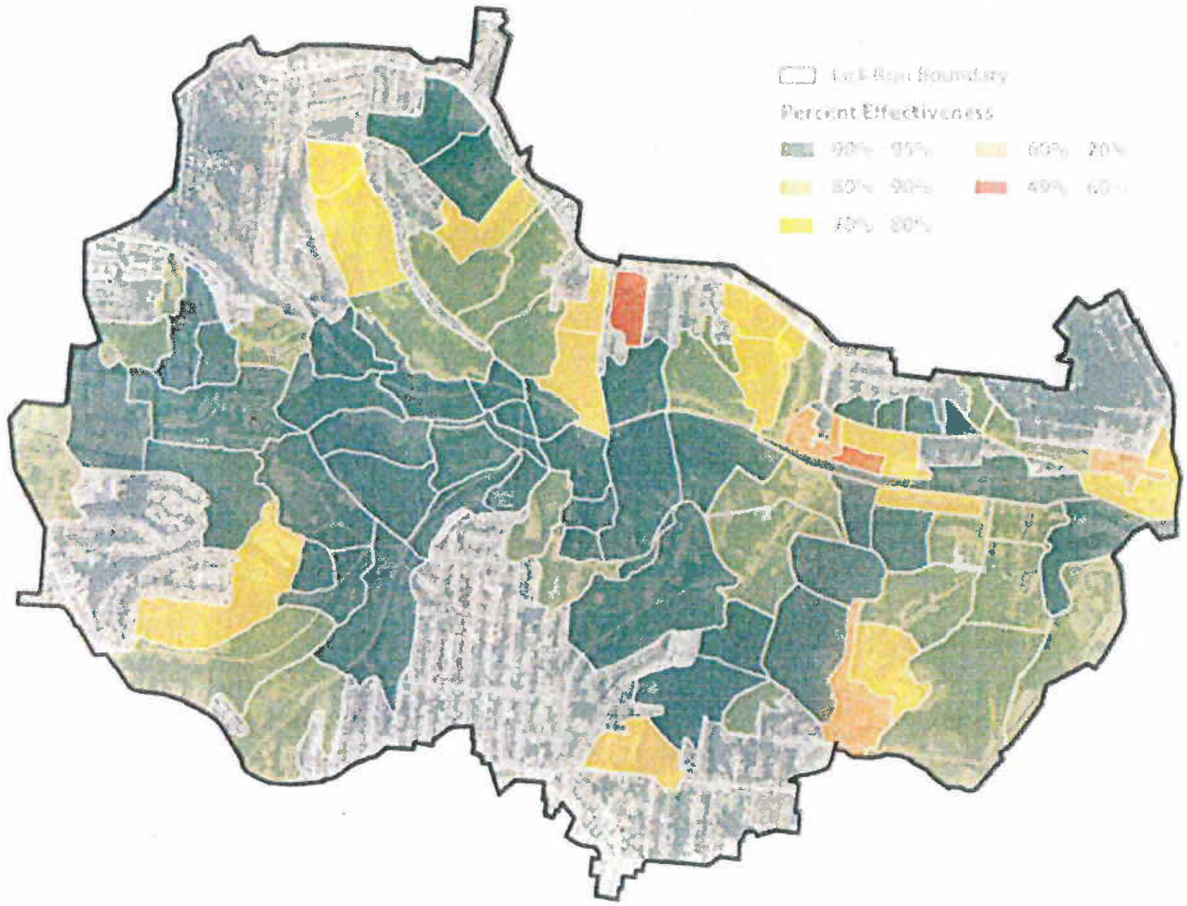


FIGURE 8 – SUMMARY OF LICK RUN SUB-CATCHMENT AREAS PERCENT EFFECTIVENESS

Figure 8 provides the revised percent effectiveness values. Land use/development type, pre-existing stormwater systems, nearby combined sewer systems, influence the percent effectiveness, which is realistically achievable through cost effective separation. An average overall percent effectiveness of the Tier 1 developed and developed with open space areas was 83%. Tier 1 open space/transportation areas resulted with an overall average of 92%. The revised percent effectiveness procedure and results are detailed in the Technical Memorandum issued by Strand Associates. Differences exist for individual sub-catchments; however, overall percent effectiveness remained consistent with original assumptions. An independent technical review of the sustainable project sub-basin models was conducted by the LMC Study Team.

Lick Run was not the only watershed where this type of detailed evaluation was conducted. The LMC Study Team performed similar analyses for six sets of sustainable sub-basin projects. Three of these projects, King's Run, Lick Run, and West Fork, are included in the LMCPR Sustainable alternative. A summary of the results are presented in Table 1.

Sub-Basin	Tier 1 Open Space/ Transportation Areas	Tier 1 Developed Areas	Weighted Average over Tier 1 Areas
Bloody Run	56%	61%	60%
Denham	62%	53%	58%
Kings Run	95%	76%	86%
Lick Run	92%	83%	87%
Ludlow Run	96%	59%	78%
West Fork	81%	72%	79%

TABLE 1– SUMMARY OF SUSTAINABLE ALTERNATIVE SUB-BASIN PERCENT EFFECTIVENESS SEPARATION

The last column in Table 1 represents the percent of stormwater runoff and RDII that would be directed to the storm system and removed from the combined sewer system. Therefore, 87% of the stormwater from the Tier 1 areas currently being directed to the combined sewer throughout the Lick Run Watershed would be captured and conveyed directly to Mill Creek under the LMCPR Sustainable Alternative. The remaining 13% in the Tier 1 areas would stay in the combined sewer system.

Sensitivity Analysis to Validate Projected Benefit of Sustainable Alternative

Assumed effectiveness for any project, no matter how studied during the analysis, may not be achieved during implementation. The success achieved through separation projects can vary significantly depending on several factors, including the actual stormwater runoff sources removed, and implementation practices during construction. To consider these uncertainties, a sensitivity analysis was performed to evaluate changes in performance metrics with decreasing success in CSO separation. Decreased success in separation was simulated by assuming uniform reductions in the runoff drainage area diverted to storm systems through separation (i.e., additional area remained tributary to the combined sewer system).

For example reducing the total area routed to the storm system within the Tier 1 priority areas by 15% and thereby increasing the tributary area and runoff volume routed to the combined sewer system resulted in 5% incremental decrease in the overall percent control at CSO 5 (85% to 80% based on Version 3.2 wet weather inflow volumes). This emphasizes the relationship between stormwater volume and CSO reduction is not linear. If theoretically, MSD's model is off by 15%; negligible impact would result regarding the size of the conveyance projects included in the Sustainable Alternative. There would be no change to any storm sewer and storm sewer detention/retention projects, including the Valley Conveyance System. Only combined sewer improvements projects that are downstream of proposed sewer separation areas would be potentially affected. There are only a few of these types of projects proposed for Phase 1, in West Fork and Kings Run. The sustainable modeling sensitivity analyses for these watersheds showed very small reductions in CSO volumes as separation effectiveness was reduced to 15%, but individual consolidation sewer or storage facility sizing might be affected to a slightly greater degree.

Furthermore, the sensitivity analysis shows that even with a 25% reduction in separation areas (analogous to a 25% lower-than-expected effectiveness from separation) the Lick Run, West Fork, and King's Run sustainable projects in total reduced the overall percent control by only 5% (90 to 85%), a decrease of 226 MG.

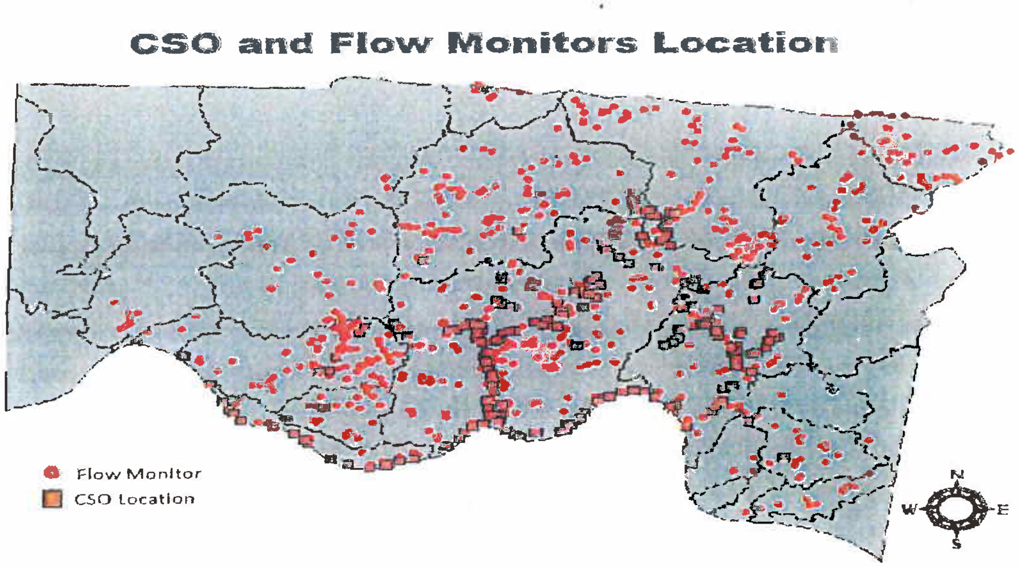
This sensitivity analysis demonstrates that projected CSO reductions for these candidate sustainable projects are realistic, even if the achieved separation success differs significantly from the assumed implementation and performance assumptions.

For the watershed as a whole, the average percent effective value did not change significantly. However, the percent effective values for individual catchments did change significantly in some cases. These changes can be attributed to design modifications, field verifications, and new construction within the watershed. MSD is confident the comprehensive technical effort invested to refine the assumptions used in the hydraulic and hydrologic model with local data will provide results that are reasonable and rational for decision making.

<u>Local Data to Confirm the Results from the Model</u>

MSD uses local data from flow monitors and level indicators to confirm the results from the hydraulic and hydrologic model. MSD's on-going program of monitoring has been used to collect additional local data since the LTCP update in 2006. Flow monitors have been located on existing storm sewers, sanitary sewers, and combined sewers. Wet weather flows have been monitored from more than 300 locations throughout MSD's service area as shown in Figure 9.

FIGURE 9 – FLOW MONITOR LOCATIONS



There are three major uses of flow monitoring data:

- Overall Monitoring of the Combined Sewer System - The overall monitoring uses long term flow monitoring sites on major pipes and interceptors that can be used to calibrate and validate the System Wide Model.

- Specific Project Monitoring - Specific project monitoring uses a number of monitoring sites in and around near term projects to develop calibration of detailed models of the project area. The project area calibration supports the sizing of the specific project, modeling the impacts of the proposed project, and adds areas of detailed calibration to the System Wide Model.

- Overflow Monitoring - Overflow monitoring consists of level monitors at the overflow locations. The overflow monitoring is focused on detecting dry weather overflows and to aid in developing overflow reports to regulators. While not intended for model calibration, the overflow monitoring data can be used as a check on the overflow modeling.

The Lick Run sub-basin had only one flow meter active from 2004 through early 2010. Meter MC-LM-001 is located in manhole 29408051. This meter is in the 19.5-foot section of the trunk sewer 1,150 feet upstream of the CSO regulator and monitors a majority of the sub-basin flows. MSD has worked for many years to reliably collect flow data at this location. The site is very challenging to measure flows due the large range in depths (10 inches to over 150 inches) and velocities (less than 1.0 to over 10 fps) as well as debris and sediment in the combined sewer flows. The monitoring effort has included using a number of different flow monitors as well as using more than one monitor at a time. The various combinations have not consistently produced reliable flow data for a range of wet weather events.

Several time periods of monitored data from this meter show that the observed flows are not accurately captured by this meter for significant storm events. High flows often cause the velocity or depth readings to drop out during the storm event. The most likely cause of the data loss is the burying of the meter probe in debris and sediment. MSD has collected flow-monitoring data from multiple locations throughout Lower Mill Creek over the past five years. During the LMC Study period, adverse field conditions resulted in the data collected from the Lick Run sub-basin to be unsuitable for the updated system-wide model. However, it is reasonable to expect MSD's system-wide model will correlate well with predictions regarding the flow conditions at CSO 5, because the model results for other key infrastructure (Mill Creek Wastewater Treatment Plant, Mill Creek Interceptor, and Mill Creek Auxiliary Interceptor) match available flow monitoring data from other locations.

A validation study comparing the model results, the flow data from MC-LM-001, and the data collected at the Lick Run RTC is described in the Lick Run Calibration Validation Report, February 2012.

FIGURE 10 – LMC MODEL CALIBRATION GOOD MATCHES

For validating the entire system-wide model, the 2009 rainfall dataset was used to calibrate the updated hydraulic and hydrologic model. The modeled results closely matched the actual conditions reported by the flow monitors. Details regarding the model validation and calibration work are presented in the *"MSDGC's Lower Mill Creek Partial Remedy System Wide Model Validation Report", February 24, 2012 and "MSDGC's LMC-SA System Wide Model Restructuring Version 3.2, Version 4.1.0 and Version 4.2" June 1, 2012, prepared by XCG Consultants.*

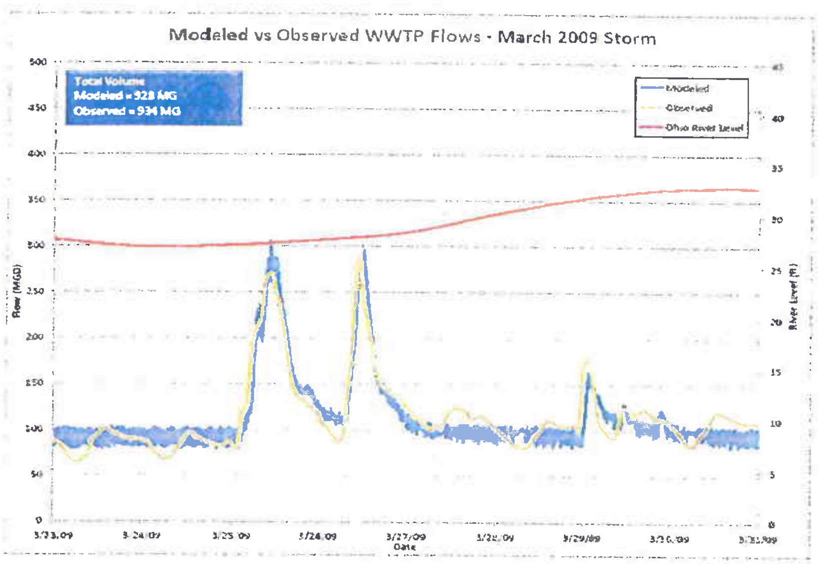
In summary, the model calibrated well at the Mill Creek Wastewater Treatment Plant; along the Auxiliary Mill Creek Interceptor near the Mill Creek Treatment Plant; along the Mill Creek Interceptor north of the West Fork Watershed; along the Auxiliary Mill Creek Interceptor at CSO 18; at CSO 181 in the Bloody Run Watershed; and at CSO 487 in the Ross Run Watershed.

Hydrographs for each of these locations are presented below to demonstrate the relative consistency of the modeled vs. observed results.

The County monitor team has accurately reported the flow monitoring data at CSO 5 for the Lick Run Watershed did not provide useful and reliable data for which to fully calibrate model results at that location. As noted in the *Lick Run Calibration/Validation Report* and in previous discussions, MSD efforts to-date have focused on identifying viable alternatives for the purposes of alternative evaluation and not for detailed design of specific projects. In the Lick Run calibration, the data sets did not agree and there were various aspects (depth of flow, flow rate, volume of flow, percentage of rainfall captured) that were not in agreement from one year to the next. In reconciling the data, MSD considered and evaluated level data for the RTC and CSO 5 and compared four years of data with the 2011 level data.

Model & Local Data Risk Mitigation

The data set that best matched up and were most appropriate to use were identified. MSD remains confident in the model results for Lick Run. Although the data was not able to fully calibrate the model at CSO 5, which does not translate to an inaccurate model. Since the model results closely match observed local data upstream and downstream of CSO 5 – at multiple locations – it is reasonable and rational to assume the results for CSO 5 are acceptable for current model applicatons. Moving forward, MSD will continue to maximize existing data and collect additional calibration data in the Lick Run Watershed to further refine the Lick Run model for future applications. These expanded data collection



efforts are described in the next section.

FIGURE 11 – LMC MODEL CALIBRATION DATA AT MILL CREEK TREATMENT PLANT

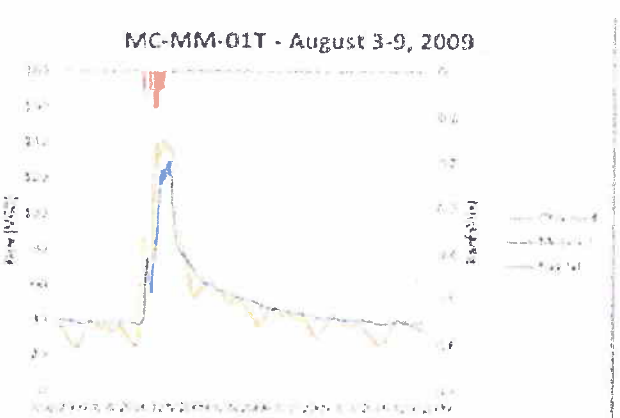


FIGURE 12 – LMC MODEL CALIBRATION DATA ALONG AMCI AT CSO 18

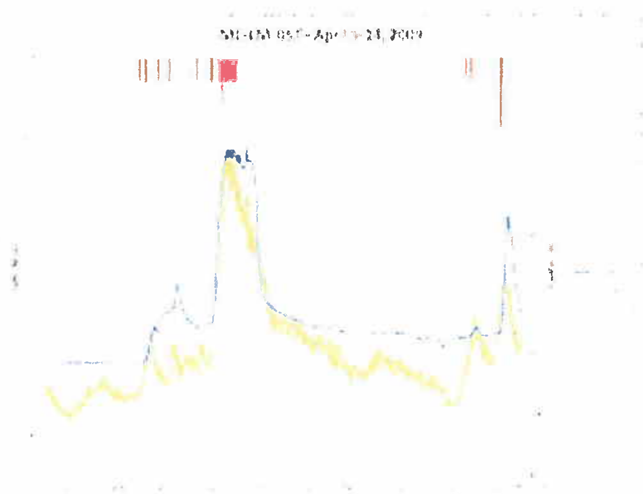


FIGURE 13 – LMC MODEL CALIBRATION DATA ALONG MCI AT WEST FORK

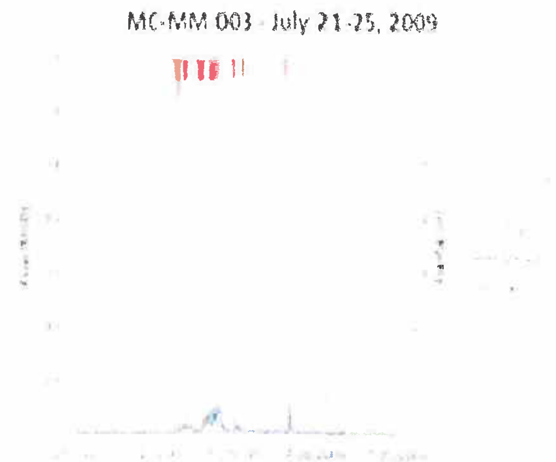


FIGURE 14 – LMC MODEL CALIBRATION DATA AT CSO 487 IN ROSS RUN

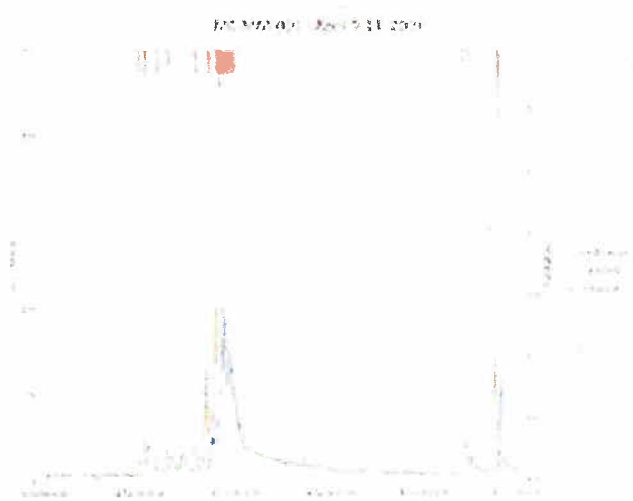


FIGURE 15 – LMC MODEL CALIBRATION DATA AT CSO 181 IN BLOODY RUN

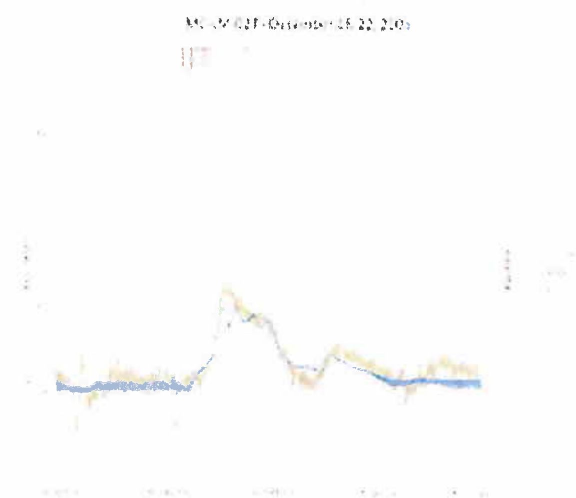


FIGURE 16 – LMC MODEL CALIBRATION DATA AT AMCI AT WWTP

Recognizing the limited dataset available at CSO 5 due the large size of pipes and the large swings in depth and velocities during wet weather, the Lick Run system is challenging to measure. As noted in the *Lick Run Calibration Validation Report, February 7, 2012, prepared by XCG Consultants,* the 2009 flow monitoring data set was not usable for validation because of the high flows and velocities in the 19.5-foot diameter sewer coupled with the lack of reliable flow and velocity measurements from the monitoring devices deployed in 2009. The 2009 data set did not compare well with volumes and rainfall as well as other metrics; it was concluded that the solution is to conduct additional flow monitoring at more suitable locations to collect more data for model validation.

Expanded Data Collection Program in Lick Run Basin

MSD's prior and current flow monitoring efforts throughout the Lick Run basin demonstrates its commitment to identify the unique issues and diligence to resolve them. A one-size-fits-all approach is not appropriate for Consent Decree Programs. MSD has and continues to pursue every available action to collect useful and suitable flow monitoring data. The topography and existing infrastructure have posed unique challenges that continue to be overcome through an iterative process. Recognizing these challenges, MSD will continue to refine and verify model performance at CSO 5 using additional basin datasets to support future model applications.

2010-2011 Water Level Dataset

In the spring of 2010, the Lick Run Real Time Control (RTC) Facility was completed and operation began. The Lick Run underflow has a relatively small capacity compared to total flow from the watershed. Therefore, the peak depth of the water stored by the RTC closely reflects the total volume being contributed by the Lick Run watershed. With the RTC, overflows still typically occur during the peaks of larger storms. Small to medium storms are stored in the combined sewer upstream of the RTC without causing overflows. Therefore, the peak depth at the meter when the RTC overflows is indicative of the peak flow rate. However, when the facility is overflowing, the water levels will not vary as much, resulting in less accurate volume comparison.

The level data measured during 2010 and 2011 appeared to be more reliable than the flow monitoring data. The RTC facility includes a sensor for monitoring water level upstream of the RTC so the facility operates to maximize storage without excessive surcharge. A review of available level data at the RTC independently confirms that the levels sensors are acceptably accurate during wet weather events.

Spring 2011-2012 Flow Monitoring Dataset

MSD conducted flow monitoring in the Lick Run and Bloody Run Watersheds to collect additional local data to confirm the stormwater removal assumptions used for the hydraulic and hydrologic model. Five flow monitors in the Lick Run watershed and three flow monitors in the Bloody Run watershed were used to develop a "pre-construction baseline" of wet weather flows. MSD also used the Flodar® monitoring technology at one of these locations. Data was collected from April 2011 through January 2012 from multiple storm events. A summary of these flow monitors is presented in Table 2. Additional information is provided in MSD's quarterly flow monitoring analysis reports.

TABLE 2 – FLOW MONITOR SUMMARY

Name	Manhole ID	Manhole Depth (ft)	Pipe Diameter (in)	Sewer Type	Installation Date
MC-LR-001	24013007	7	12	Sanitary	4/13/2011
MC-LR-002	24013022	24.4	18	Combined	4/13/2011
MC-LR-003	40124018	90	12	Storm	4/12/2011
MC-LR-004	25110005	10.3	8	Sanitary	4/14/2011
MC-LR-005	51102003	6.8	18	Storm	4/14/2011
MC-BR-001	81034016	12.2	42	Storm	4/14/2011
MC-BR-002	38106001	1.4	12	Sanitary	4/14/2011
MC-BR-003	81062015	16	27	Storm	4/14/2011

Indications of modeling results to date are that initial estimates of separation effectiveness are within an acceptable tolerance.

Fall 2012 Flow Monitoring Dataset

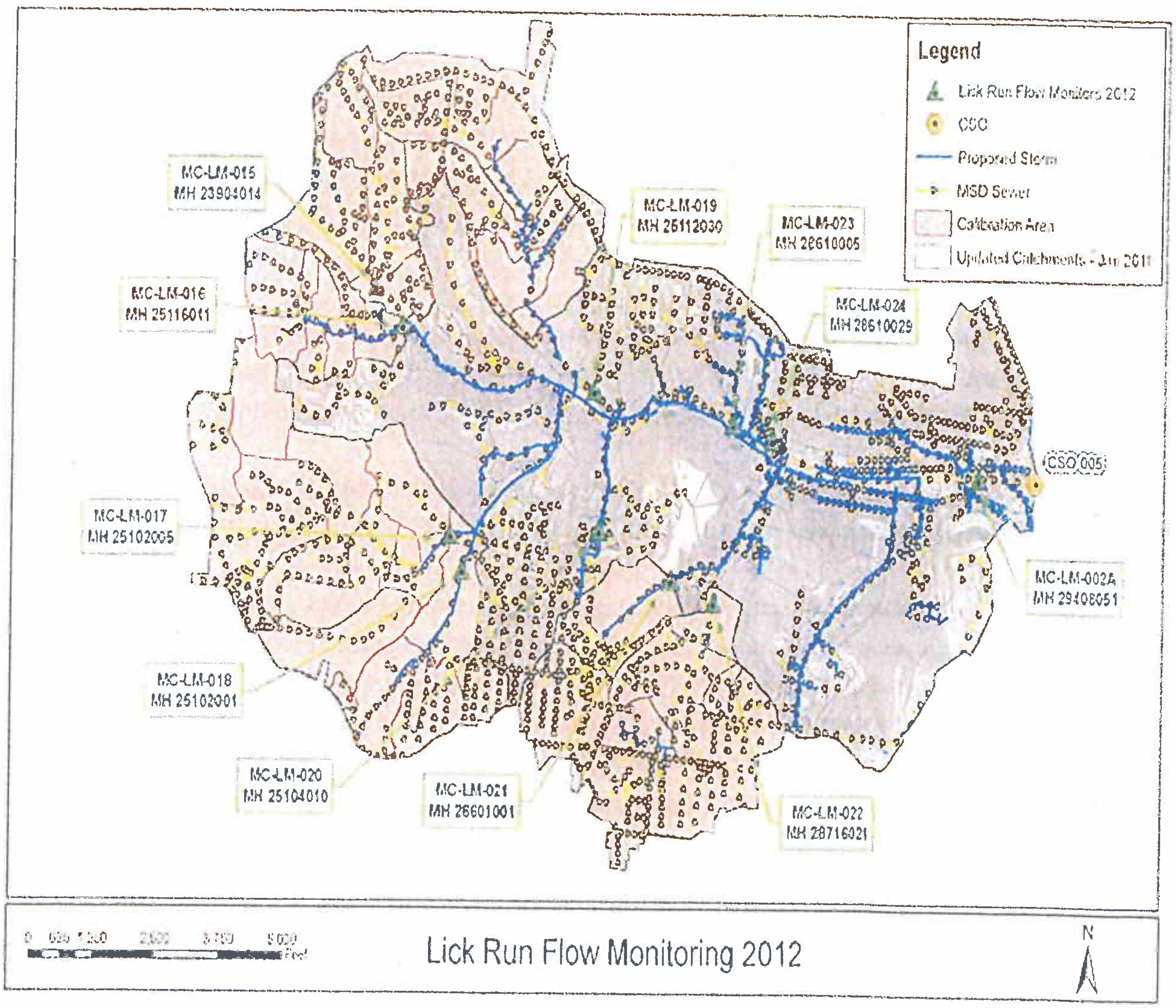
MSD has begun additional monitoring at 11 locations (10 temporary, 1 permanent) shown on Figure 17 to confirm and refine model calibration in the continuing, iterative modeling refinement efforts. Additional flow monitoring data collected during the design phase, which is typical in all WWIP projects, will be used for Lick Run projects for the purpose of validating pre-construction conditions. MSD is confident that its approach represents sound engineering practice and a solid, common-sense approach to the demands of this project.

MSD's current flow monitoring plan takes many of the Lick Run challenges into account – such as slope, debris, pipe size, velocity. The plan recently underwent refinement and verification through field inspection and additional meters were installed upstream of the current locations. The site selection criteria were based on smaller pipe sizes and slower velocities. Initial field inspections were conducted for the 11 locations to confirm the suitability of the manholes with regard to crew safety and ability to install monitoring equipment. Further inspections, including a confined space entry at each location to record initial depth and velocity measures, were also completed. The flow meters have been installed and will measure flows and levels at locations more likely to produce useful data individually, and as a set of locations that can be used to provide greater confidence in the flows at CSO 5 outfall and in the rainfall distribution and conditions of runoff attributed to land use, slope, infiltration, etc. These locations will also provide good pre-construction flow data for many of the Lick Run separation projects. This additional monitoring data will help refine the design of the remainder of the projects and verify that the proposed projects will meet the overall reduction objectives.

In summary, the draft Flow Monitoring Plan will monitor flows in the upstream areas of the watershed in pipes no greater than 66-inch diameter and maximum velocities no greater than 12 feet per second. The sensors measure velocity and depth and MSD's selected sites are within the reliable range of the equipment. Historical data shows that there is greater success when focusing on sewers smaller than approximately 60-inch diameter and velocities less than 12 feet per second. The 11 locations are shown in the following figure via green shapes.

As flow monitoring continues, MSD will use the data to refine the calibration for Lick Run for the pre-construction conditions; after improvements are made, a modified model will be developed for post-construction conditions. Following construction, a recalibration of the model based on the installed improvements and the post construction monitoring will proceed. The 1970 Typical Year rainfall will be run through the models and the difference will indicate actual CSO reduction achieved as directed by the Consent Decree.

FIGURE 17 - NEW FLOW MONITORING LOCATIONS WITHIN LICK RUN



Industry Standards for Data Gaps

MSD is not in a unique situation of having gaps in the data used to calibrate the hydraulic and hydrologic model. Given the nature of modeling, it is difficult to compare actual data to modeled results for all locations across the watershed because rainfall is not equally distributed and the wet weather for a specific time period may or may not closely match the typical year analysis used by the model software. Modeling is a combination of computational analyses and engineering judgment. For this reason, MSD has discussed the details of the model update and validation and calibration processes with the federal and state Regulators on a weekly basis since late July 2012.

USEPA has published guidelines/requirements related to hydraulic and hydrologic modeling. EPA Publication 832-B-99-002 January 1999 Combined Sewer Overflows Guidance for Monitoring and Modeling is a general discussion of monitoring & modeling. It is interesting to note the USEPA guidelines are less detailed than MSD's System-Wide Modeling Guidelines. MSD's guidelines closely follow the Wastewater Planning Users Group (WaPug) *Code of Practice for Hydraulic Modeling of Sewer Systems*. The Code is divided into 10 sections covering all aspects of model building for hydraulic analysis and testing, flow surveys and verification, and documentation, all of which are necessary for a quality model.

From the Code of Practice, WaPuG recognizes three levels of model detail. Generally the level of detail in MSD's system-wide model corresponds to the most detailed WaPuG "Type III Detailed Design Model" The other WaPuG modeling levels include some degree of simplification or skeletonization.

The WaPug Code of Practice specifically discusses situations similar to MSD's regarding the quality of data available from a discrete location, such as CSO 5. Section 3.1 of the Code of Practice states:

> *"Input data can be collected at a number of different levels of accuracy. The level used will depend on the purpose of the model and the required accuracy of the results of the final model. In some cases inaccuracies in the data will have little impact on the accuracy of the final model while in other cases these will be highly significant. Where the accuracy of data is suspect, it is often possible to increase the effort of verification so that the problem areas are highlighted, rather than spend large amounts of effort checking the input data. Too much emphasis on data checking or, at the other extreme, verification, will not usually be cost effective. The most cost effective balance between these two philosophies will depend on the purpose of the model and should be considered carefully. Whatever approach is taken it is important that any concerns about the data are included in the documentation."*

MSD's approach for addressing the flow monitoring data from CSO 5 following the approach explicitly outlined in the WaPug Code of Practice. Additionally, MSD has been working with the Regulators to ensure adequate "documentation" has been provided explaining the approach, technical evaluations, and engineering judgments used by the LMC Study Team for the LMCPR Sustainable Alternative. Refer to the meeting minutes of the weekly Regulator meetings for details regarding the documentation.

Section 5.1 of the Code of Practice states: *"Although the collection of flow data from a sewer network using velocity and depth monitors is the primary aim of any flow survey, it is sometimes necessary for the modeler to obtain other flow measurement data."* This document demonstrates and documents MSD's intent and continuing efforts to obtain local data from multiple sources, including a diligence with finding flow monitoring sites to yield good quality data.

Additionally, Section 6.4 of the Code of Practice states: *"The main differences in the levels of verification will be in the number of points at which the model is verified rather than the exactness of the fit."* MSD has demonstrated multiple upstream and downstream locations in which the model accurately predicted observed data. MSD is confident the local data and model results are reflective of the infrastructure and provide the Co-Defendants a reasonable and rational tool for decision making.

3. Strategic Separation Programs of Other Cities

Other large cities such as Boston, Minneapolis and Lansing have relied heavily on sewer separation to achieve their CSO-reduction goals and have been successful. Boston utilized a modeling approach similar to MSD's with successful results. Both Minneapolis and Lansing have been separating sewers for over twenty years, and their success has been measured and it is significant. Lansing has reduced their 1.65-billion-gallon CSO volume by over 50 percent with sewer separation projects since the early 1990s. Minneapolis has reduced an over 1-billion-gallon annual CSO volume in the 1980s to less than 1 million gallons per year every year since 2005. More recently, other cities such as Omaha, Nebraska have included major sewer separation components in their Long Term Control Plan that was accepted by state regulators in 2010.

A number of CSO communities across the nation have successfully implemented sewer separation projects to reduce CSO discharges. The following is a brief listing of example communities:

- Lansing Michigan
- Minneapolis and St. Paul, Minnesota
- Omaha, Nebraska
- Boston, Massachusetts
- Atlanta, Georgia
- Detroit's Rouge River Project
- Portland, Oregon
- Henderson, Kentucky
- Port Huron

Lansing, Michigan

The City of Lansing began separating their combined sewers in 1991. As of November 2010, the City has successfully separated or redirected 4,929 of its 7,102 acres of combined sewer tributary area (=69% reduction). This equaled a separation of 203 miles of combined sewer pipe. Before the separation project began, the City had an estimated annual overflow volume of 1.65 billion gallons. To-date, an estimated 952 million gallons of overflows per year has been removed due to separation projects. The City has eliminated or abandoned 21 of its original 41 CSOs between 1992 and 2010 as a result of the sewer separation program. Lansing's CSO control approach won a 1994 USEPA National CSO Control Award.

- Total 1991 combined sewer tributary area, acres: 7,167
- Combined area separated by the City of Lansing, acres: 2,880
- Combined area separated by others (Tollgate Drain): 226
- Separated sewer area redirected from combined sewer areas: 443
- Total area removed from contribution to overflow, 3,549 (50%) acres:
- Total number of CSO structures eliminated: 16 of 40 (40%)
- New sanitary sewer constructed, miles: 43
- New water main constructed, miles: 20
- New roadway constructed, miles: 50
- Average annual overflow before project: 1.65 billion gallons
- Average annual overflow removed to date: 550 million gallons (33%)

For more information regarding Lansing's successful sewer separation projects is available at the following internet site: http://www.lansingmi.gov/Lansing/pubserv/cso/cso_project_progress.pdf.

Minneapolis and St. Paul, Minnesota

Sewer separation began in the Twin Cities in the 1960s, but an accelerated separation program began in 1986. In 1984, Minneapolis/St. Paul experienced 77 CSO events with a combined volume over 1 billion gallons. Thanks to widespread sewer separation (only 5% of the service area still requires separation) in the years since, the annual overflow volume has not exceeded 1 million gallons since 2005, and four of the last five years have experienced zero CSO events.

For more information regarding Minnesota's successful sewer separation projects is available at the following internet site:
http://www.minneapolismn.gov/www/groups/public/@publicworks/documents/webcontent/wcms1p-093612.pdf.

Omaha, Nebraska

In Omaha's approved Long Term Control Plan (LTCP) a major component is sewer separation, which will occur in 5,735 acres of the combined service area. For more information regarding Omaha's successful sewer separation projects is available at the following internet site: http://omahacso.com/docs/OmahaLTCP_Executive_Summary.pdf.

Boston, Massachusetts

The Massachusetts Water Resources Authority (MWRA) evaluated the effectiveness of both the sewer separation in the Stony Brook area of Boston, Massachusetts and the pre-separation GIS and modeling analysis used to plan the effort. The goal of the separation was to reduce CSO discharges to the Charles River from twenty-two to two or fewer overflows during a typical year as per the facilities plan agreed upon by the federal and state Regulators (USEPA and Massachusetts DEP). During preliminary design, extensive field survey data was linked with GIS analysis and collection system modeling to develop a sewer separation plan. The sewer separation plan developed during the preliminary design in 1999 was implemented, with construction completed in 2006. To evaluate the effectiveness of the sewer separation, flow monitoring equipment was installed at seven regulators within the separated area. Comparisons of pre- and post-monitoring data indicate that sewer separation in the Stony Brook area performed as predicted by the planning model. Observed reductions in inflow were similar to the reductions predicted by the preliminary design modeling.

4. Conclusions

MSD and the County team have been discussing the sewer separation approach, model update, and local data with the Regulators for the past four months. The Regulators have articulated the approach MSD used to model separation is the accepted method.

- The Regulators have confidence MSD's CSO model is effectively capturing the sewer separation.
- The Regulators have stated MSD's model leaves the infiltration & inflow component of stormwater in the combined sewer system. They said this is a conservative approach and can be refined in the future if pipes are lined or more data is collected.
- The Regulators said for the alternatives analysis, MSD has a model that can be relied on to predict what will happen to a reasonable degree of accuracy.
- Both the Regulators and MSD are comfortable the information produced by the model is adequate for making decisions.
- The Regulators noted the "adaptive management" language of the Consent Decree provides a vehicle to address future change.