SSO 700 IWAP
Task 2.6.1 Watershed and Water Quality Models Gap Analysis and Update Assessment

PREPARED FOR:	Andrew Spurgeon, MSDGC
PREPARED BY:	CH2M HILL
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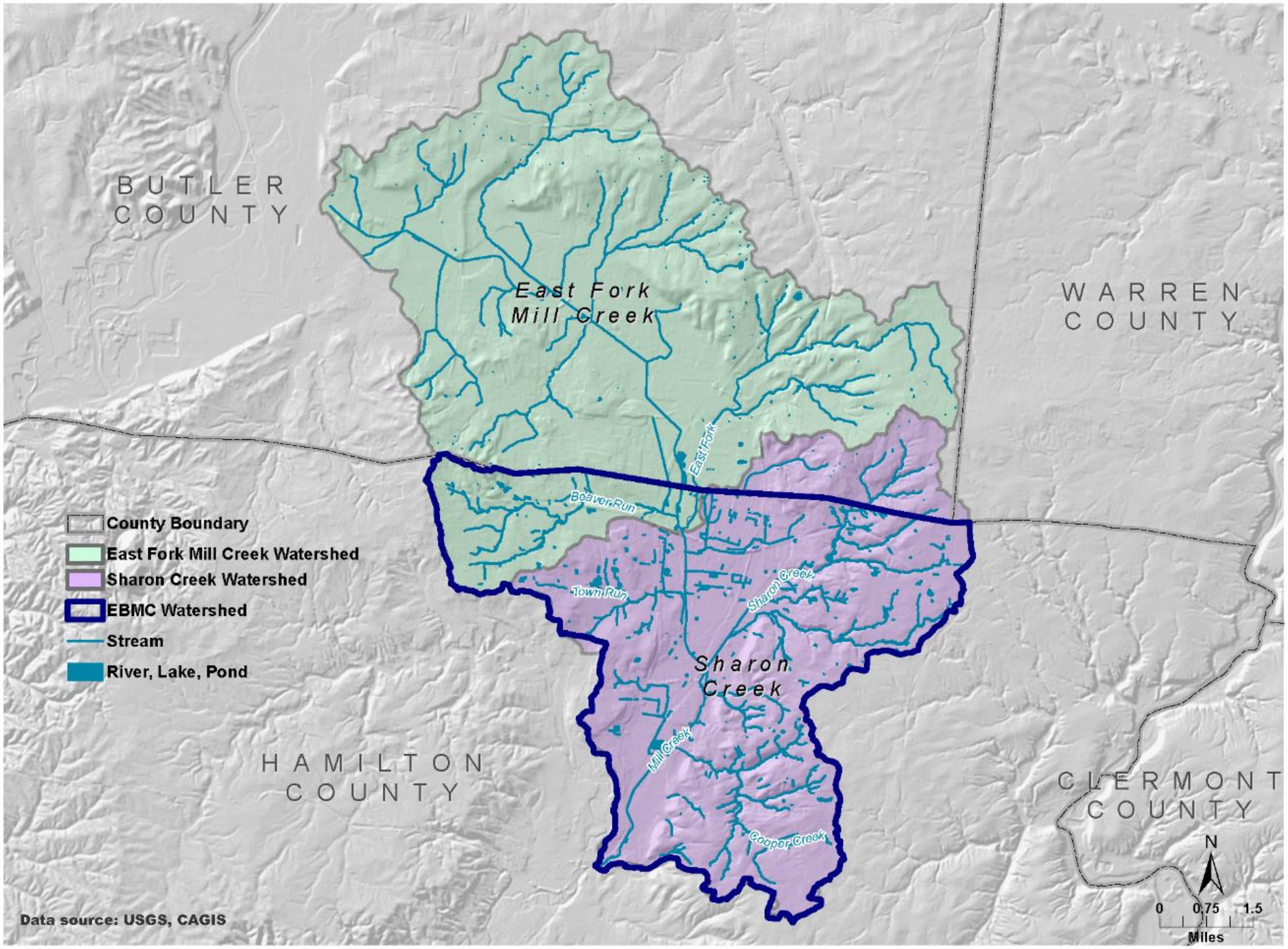
Hamilton County and the Metropolitan Sewer District of Greater Cincinnati (MSDGC) are developing an Integrated Watershed Action Plan (IWAP) for the SSO 700 watershed. The objectives of this work are to maximize improvement to water quality and meet the Consent Decree and Final WWIP SSO and CSO control requirements. To achieve these objectives, CH2M HILL, Hamilton County, and MSDGC will characterize the various sources of pollution and the roles they have in impairments in the SSO 700 watershed. The team will also identify an optimum combination of cost-effective and affordable gray infrastructure, sustainable infrastructure, and watershed-based controls for the watershed. Mathematical modeling of collection systems, watersheds, and surface water quality will be necessary to perform characterizations and evaluate plan alternatives. This technical memorandum documents a watershed and surface water quality modeling gap analysis and update assessment on existing modeling resources. It also provides an assessment and gap analysis of the available water quality data that is pertinent to the SSO 700 IWAP.

Section 1 - Introduction

Watershed models and a surface water quality model will be required for the development of the IWAP for the SSO 700 watershed, shown as the East Branch Mill Creek Watershed (EBMC) in Figure 1. Existing models developed by previous planning and engineering efforts are available for the project area. An Environmental Fluid Dynamics Code (EFDC) surface water model of the Mill Creek was developed in 2012 as a part of a regional Ohio River Water Quality Model project. The MSDGC collection system model and other tools were used to calculate flows and loads into the EFDC model. Under Task 2.6.1 of the SSO 700 IWAP task order, the EFDC model and associated watershed models were reviewed to evaluate their representation of the SSO 700 watershed, their applicability in supporting the development of the IWAP, any calibration and validation deficiencies, shortfalls in existing source data used to develop the models, and other potential gaps in the existing models. The purpose of this technical memorandum is to summarize that evaluation and provide recommendations to MSDGC and Hamilton County for using and updating the EFDC and watershed models or developing new models as necessary to meet industry best practices for calibration and use in assessing water quality to meet the goals of the SSO 700 IWAP.

FIGURE 1
SSO 700 IWAP Watershed Areas



IWAP Modeling Objectives

Management and control of CSOs, SSOs, point sources, non-point sources, and stormwater will result in improvements in instream water quality and potentially a reduction, if not an elimination, of impairments. A modeling system can be used to quantify these improvements and enable MSDGC to evaluate different control alternatives. The modeling system must be able to quantify hydrologic and water quality characteristics including flow volume and velocity, temperature, chlorides, total suspended solids (TSS), bacteria, nutrients, and dissolved oxygen (DO) within the SSO 700 study area on a temporal scale that allows for comparison to applicable water quality standards. The evaluation must also be able to quantify changes in pollutants, such as pH, metals, and oil/grease, but these may not be calculated directly within the tool.

IWAP Model Assessment Methodology Based on Known Impairments

The model assessment methodology is focused on determining the ability of current models to meet the objectives specified for the project. The objectives are based in large part on the Midwest Biodiversity Institute's *Biological and Water Quality Study of Mill Creek and Tributaries 2011* (MBI, 2012). This study was developed to satisfy requirements of the MSDGC's National Pollutant Discharge Elimination System (NPDES) CSO discharges and was designed to comprehensively assess water quality and biological health within the Mill Creek drainage area. The study indicates that the streams in the study area either support or are recommended to support the warm water habitat (WWH) aquatic life use (ALU) with the exception of a tributary to Sharon Creek, which is recommended for Primary Headwater Habitat (PWHIIIA). Many of the streams are not meeting or are only partially meeting their ALU criteria. The causes of the biological impairments as described by the MBI Report are sedimentation, low flow, chlorides, nutrients, and DO. Copper, lead, and pH levels are also outside of the desired ranges at five stations. The summary of the impairments from the MBI report are provided as Attachment A. All segments, except for one site on Sharon Creek (MC20) and one site on Cooper Creek (MC19), do not meet the recreational standard for bacteria. A more detailed description of water quality conditions and impairments of the receiving waters are described in the *SSO 700 IWAP, Task 2.4 Inventory and Gap Analysis* technical memorandum (CH2M HILL, 2015). It should be noted that there is a TMDL for the Mill Creek that must be taken into consideration (Ohio EPA, 2004).

Considering the causes of biological impairments identified in the MBI report, the modeling system for the SSO 700 IWAP will need to, at a minimum, have the following capabilities:

- Calculate discharge flows and pollutant loadings from SSOs, CSOs, other significant point sources, municipal separate storm sewer systems (MS4s) discharges, and watershed runoff at a temporal and spatial resolution appropriate to drive surface water modeling for dry and wet weather planning and design conditions.
- Temporally and spatially quantify pollutant loadings by source categories.
- Route flows through the Mill Creek system.
- Calculate the fate and transport of instream concentrations of water quality parameters used for assessing compliance with water quality standards and biological indices.
- Produce output at a spatial and temporal scale for calibration, validation, and assessment of water quality impairments at the same resolution as evaluated by the 2011 MBI study (2012).
- Enable a component analysis to link pollutant sources to impairments and thus identify integrated control strategies to reduce or eliminate the impairments.
- Represent and evaluate the water quality and habitat benefits of implementing collection system and nonpoint source controls and other restoration strategies.

Model System Components

The modeling needs described in the previous section are comprised of three components shown in Figure 2: (1) the calculation of flow and pollutants from the watershed, (2) hydraulics and hydrodynamics of surface waters, and, (3) calculation of the fate, transport and impact of pollutants on surface waters and habitat. The models must also have the capabilities to quantify loadings and link the loadings to the impairments, as well as the flexibility to be modified to calculate the potential benefits of integrated control strategies. A number of models are available to model each of these individual components. Due to the complexity of each of these components, few models are designed to model more than one component. For this reason, the objectives of the project may best be achieved by adopting a model framework that includes a system of models.

FIGURE 2
SSO 700 IWAP Model Framework Components

Watershed Model

Purpose - Simulate runoff volume and pollutant loading from watershed

- Calculate runoff from pervious and impervious surfaces
- Route flow to outlet
- Calculate pollutant load associated with runoff
- Outputs drive hydrodynamic/hydraulic and surface water quality models

Hydraulic Model

Purpose - Simulate instream flow, sediment transport, and simple pollutant fate and transport

- Represent significant hydraulic features in system
- Route flows and calculate surface water advection and dispersion
- Calculate transport of conservative pollutants (chloride)
- Calculate transport and 1st order decay of pollutants (bacteria)
- Calculate transport and simple fate of pollutants (sediment and sediment associated parameters)
- Generate output for use in assessing compliance

Surface Water Model

Purpose - Simulate complex instream pollutant concentrations

- Calculate water quality conditions including:
  - Nutrient cycling
  - Algal populations
  - Eutrophication
  - Dissolved Oxygen
- Supplement hydrodynamic models
- Generate output for use in assessing compliance

Watershed Models – Stormwater and Non-point Sources

Watershed runoff models calculate the watershed discharge of flows and pollutants from land surfaces to surface waters through natural flow paths. A variety of methods for calculating runoff have been developed, but the overall concept is based on determining what fraction of rainfall is captured or infiltrated on the land surface and what fraction remains. The fraction that remains is treated as runoff for a basin and is routed to a drainage outlet. Depending on the complexity of the model, flows may be surface runoff only or may include estimates of surface runoff and shallow groundwater.

Stormwater runoff volume depends greatly on the extent of pervious and impervious areas in the basin. The more pervious the surfaces in the basin, the less runoff occurs and more stormwater gets infiltrated into the soil. In an urban setting, altered land uses change the natural hydrologic cycle. Stormwater runoff volumes increase due to a reduction in infiltration and evapotranspiration. The higher the stormwater runoff volume, the greater the pollutants release and transport from the different surfaces to the waterways within the watershed.

Watershed runoff models directly calculate pollutant loadings from the watershed, or event mean concentrations (EMCs) may be applied to the calculated discharge to estimate pollutant loadings. Outputs from the watershed runoff models are converted into formats used as inputs by surface water models.

Watershed Models - Collection Systems

Collection system models calculate discharges from man-made systems to surface waters or treatment facilities. A collection system model calculates flow in sanitary, combined, and storm sewer conveyance systems. These models calculate base flows and inflows and infiltration (I/I) into the collection system, routing them through the system and estimating discharge from the system. The models may calculate pollutant loadings dynamically or EMCs may be applied to the discharges to calculate pollutant loadings. Outputs from the collection system model are converted into the format used as inputs by the surface water models.

Surface Water Models

Surface water models calculate the fate, transport, and impacts of pollutants in receiving waters such as the Mill Creek. Hydraulic and hydrodynamic models calculate advective and dispersive transport of pollutants based on hydraulic factors such as upstream flow, stream morphometry, channel roughness, bed slope, control structures and impoundments, and downstream surface water elevations. Hydraulic models typically calculate only advective hydraulics and are calibrated to observed water depths and velocities. Hydrodynamic models calculate advective and dispersive hydraulics as well as the fate and transport of conservative substances (conductivity, salinity, dye) that can be used to calibrate the model. Physical processes, such as settling and first order decay, can also be calculated with hydrodynamic models for sediment transport and coliform bacteria simulations, respectively.

Surface water quality models calculate the fate and impacts of pollutants with mathematical expressions of physical processes (settling, evaporation), chemical and biological processes (oxidation of ammonia to nitrate, algal growth and death) and the interdependency of modeled parameters (biochemical oxygen demand and dissolved oxygen). Water quality models range from simple steady state calculations to highly sophisticated systems, depending on the complexities of the fate and transport algorithms, the representation of the system (1-D, 2-D, 3-D), and the water quality constituents of interest. Water quality models, once calibrated and validated to observations, can be used to fill gaps in space and time of monitoring datasets, as well as to evaluate the effects of changes to the watershed and pollutant loadings on instream conditions.

Section 2 - Suitability of Existing Models for the SSO 700 IWAP

Watershed and surface water models are available for use in the SSO 700 IWAP. MSDGC maintains its calibrated hydraulic model of its combined and sanitary collection system, and a surface water quality model was developed for the Ohio River. The following section reviews the suitability of applying the existing models for the purpose of water quality characterizations and planning for the SSO 700 IWAP.

Existing Watershed Runoff Models

A small portion of the drainage in the SSO 700 IWAP study area is served by combined sewer systems. The majority of the study area is served by sanitary sewers with stormwater drainage systems (either constructed storm sewer systems or natural surface drainage networks). See Figure 3 for a map of the SSO 700 IWAP sewer system. Although MSDGC has a collection system model for its combined and sanitary sewers (described below), there are no calibrated models of the storm sewer systems or models for calculating runoff from non-point sources in non-sewered parts of the project study area.

In lieu of watershed runoff models, the existing EFDC model of the Ohio River, including the main stem of the Mill Creek, used calculated flows in the SSO 700 project study area based on regression analyses of stream flows for given precipitation events. MSDGC collection system models were used to calculate overflows to the waterways in the model, including Mill Creek and the Ohio River. Pollutant loads were calculated for the EFDC model using EMCs.

Watershed Runoff Modeling Gaps

Flows and pollutant loadings from separate sewer areas need to be quantified for source characterizations and as inputs to surface water models. Since no calibrated models exist for the headwaters, stormwater and runoff areas in the project study area, this is a model gap. Therefore, relative to water quality modeling, the watershed runoff model gaps are identified as follows:

- Calculations of flows and pollutant loads from the East Fork Mill Creek headwaters in Butler County.
- Calculations of flows and pollutant loads from the East Fork Mill Creek in Hamilton County at a scale suitable for modeling impaired perennial tributaries.

Potential methods of addressing these gaps are described in Section 3.

Existing Collection System Model Capabilities

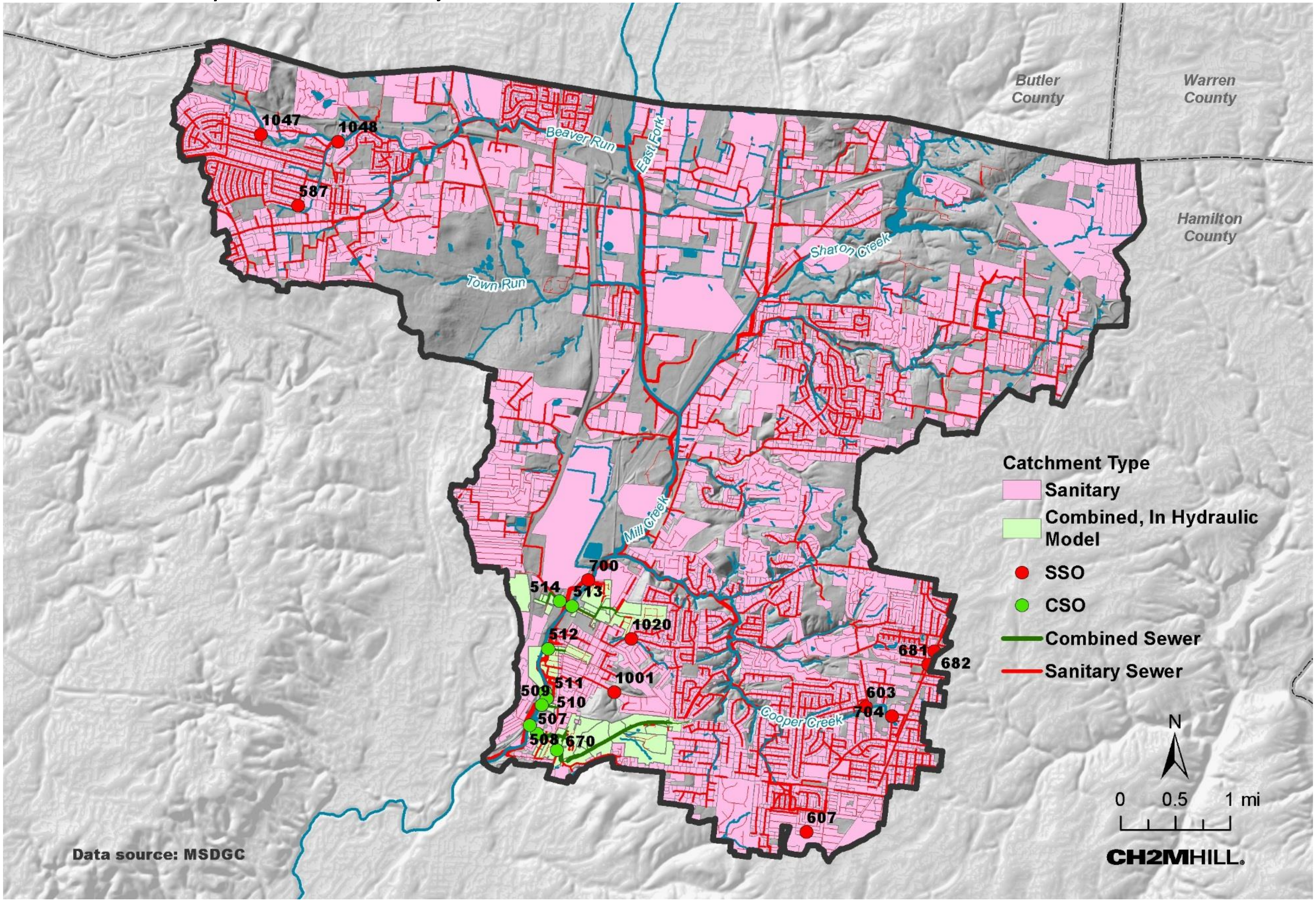
MSDGC maintains a detailed SWMM collection system model for the Mill Creek Basin, referred to as MSDGC's Mill Creek System Wide Model. A detailed assessment of this model relative to the SSO 700 IWAP study area will be provided in the *Watershed Collection System Hydraulic Models Gap Analysis and Update Assessment Technical Memorandum* per Task 2.7.1 of the project task order (currently under development). The system-wide model was designed to model flows within the collection system and calculate overflow volumes from the system during a typical year of rainfall. The spatial extent and composition of the system-wide model relative to the SSO 700 IWAP study area is shown in Figure 3.

The model calculates overflow volumes on an hourly or sub-hourly time step for each CSO and SSO location in the combined and sanitary sewer systems. As can be seen in Figure 3, only a small portion of the SSO 700 IWAP project area is served by combined sewers. Within the combined sewer areas, the collection system model calculates sewer flows and runoff generated within the drainage catchments.

Collection System Modeling Gaps

The model is sufficient for calculating CSO and SSO discharge flows to the Mill Creek from combined and sanitary sewered areas, respectively. However, there are no pollutant load calculation capabilities at the present time within the model, other than applying pollutant concentrations to discharges for calculating pollutant loads to surface waters. Potential methods of addressing this gap are presented in Section 3 of this memo.

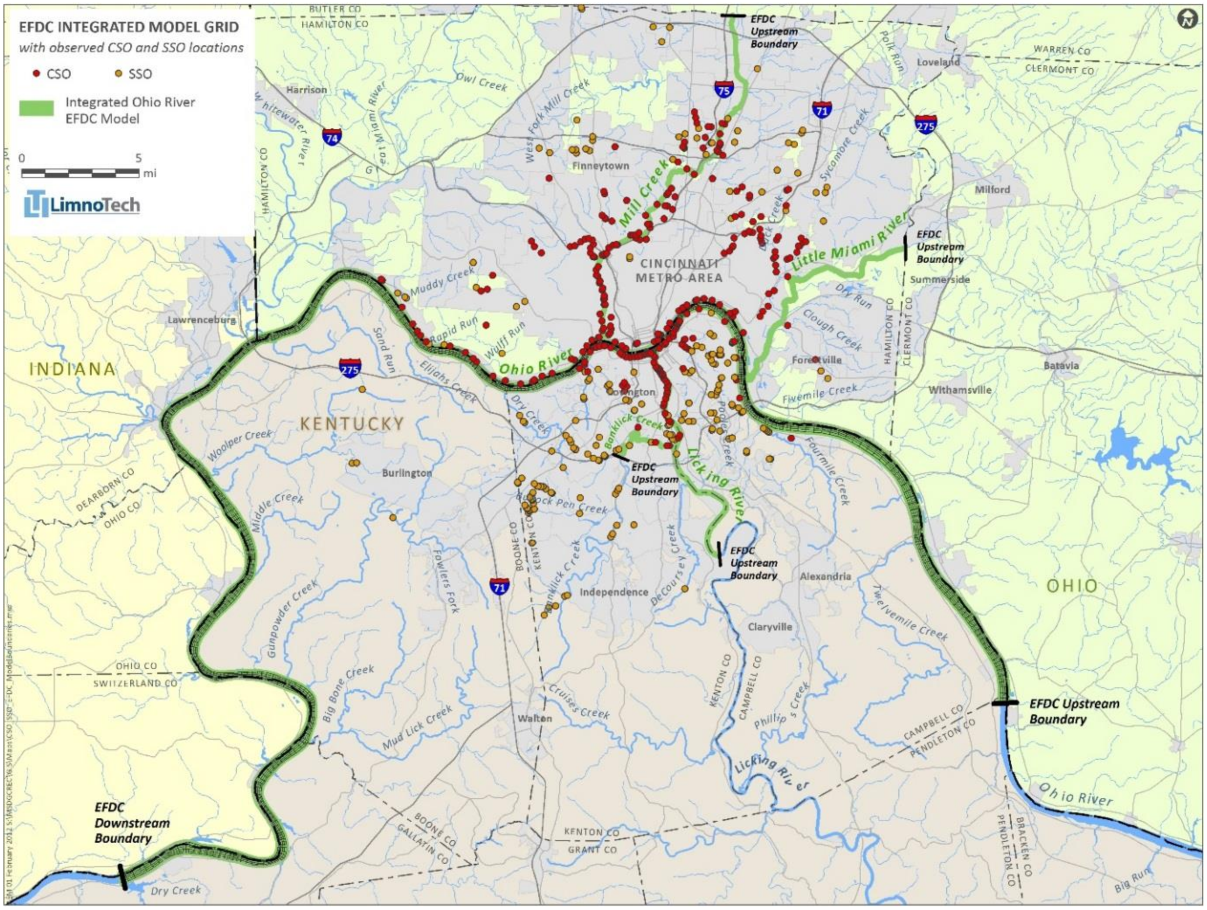
FIGURE 3
Combined and Sanitary Sewered Areas in the Project Area



Existing Surface Water Quality Model Capabilities

The current surface water quality model of Mill Creek was developed as part of a larger cooperative agreement between MSDGC and Sanitation District No. 1 of Northern Kentucky (SD1) to have a single detailed water quality model of the Ohio River and major tributaries in the Cincinnati/Northern Kentucky area. As shown in Figure 4, the model domain includes 90 miles of the Ohio River from just downstream of Meldahl Dam to downstream of Markland Dam, the lower 11 miles of the Little Miami River, the lower 18 miles of Mill Creek, the lower 11 miles of the Licking River, and the lower 4 miles of Banklick Creek.

FIGURE 4
Existing Ohio River Surface Water Model Domain
Source: LimnoTech, 2012a

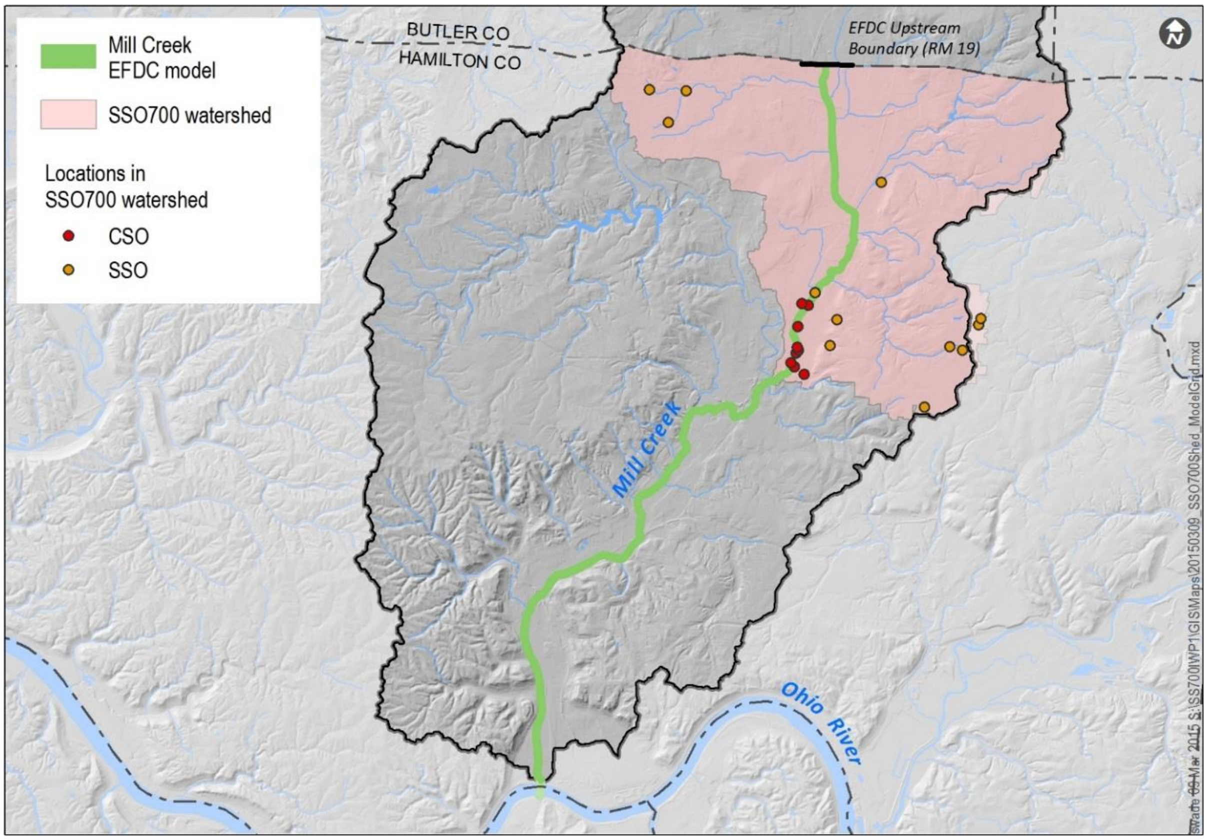


Because bacteria was the only pollutant of concern in each utility's Long Term Control Plan/Watershed Plans, the water quality model was constructed solely to calculate the fate and transport of *Escherichia coliform (E. coli)* bacteria in these waterways. The model was developed using EPA's Environmental Fluid Dynamics Code (EFDC) modeling framework, a publicly available model that can simulate both *E. coli* and hydraulics in the same model block, which is a more efficient setup than other water quality models where the hydraulics and water quality are simulated in separate blocks. MSDGC subsequently applied the EFDC model to evaluate *E. coli* conditions in Mill Creek as part of the development of the Lower Mill Creek Partial Remedy Plan and to support evaluations of source control options at SSO 700 Storage and Treatment Facility (SSO 700 STF) (LimnoTech, 2012b, c).

The existing EFDC surface water quality model can simulate creek flows and *E. coli* levels in the main stem of Mill Creek from the Hamilton-Butler county line to the Ohio River, corresponding to approximately the lower

18 miles of the creek. The Mill Creek portion of the EFDC model contains 200 grid cells with each grid cell spanning the channel cross section for a one-dimensional representation of the creek. The average grid cell is approximately 490 feet long and 67 feet wide. The size of individual grid cells varies based on creek sinuosity, changes in stream width or depth, and locations of significant flow and load sources, such as tributaries, CSO and SSOs. The spatial extent pertinent to the SSO 700 IWAP study area is shown in Figure 5. There are 96 model grid cells spanning the SSO 700 IWAP study area. The model runs on an hourly or sub-hourly basis depending on the time step of the input that is available.

FIGURE 5
Mill Creek Portion of EFDC Model Pertinent to SSO-700 IWAP Project Area



The full EFDC model was calibrated to *E. coli* data collected by MSDGC, SD1, and the Ohio River Valley Water Sanitation Commission (ORSANCO) between 2006 and 2010. Nearly 9,000 *E. coli* observations across all of the waterbodies were used to calibrate the model. The Mill Creek portion of the model was calibrated to *E. coli* data collected at four locations (RM 3.5, RM 7.4, RM 11.5, and RM 18.6). Of these stations, only the location at the Hamilton-Butler County line at RM 18.6 is within the SSO 700 IWAP study area. At each location in Mill Creek, there were 105 observations in the calibration dataset, and these included 17 observations collected over four wet weather events.

The EFDC model calibration and validation was conducted and evaluated by the developers (LimnoTech) and Owners (MSDGC, SD1) with commonly used statistical and graphical tools. The CH2M HILL project team reviewed the statistical performance metrics presented in the model documentation (LimnoTech, 2012a) and found them to be very good and acceptable for wet weather planning (relative error and average percent differences by waterbody were less than 20%). MSDGC also conducted a third-party peer review of the model (Tetra Tech, 2012) and no changes or updates to the existing EFDC model were needed to improve the water quality calibration.

From a hydraulic perspective, the existing EFDC model is an excellent model for simulating hydraulic/hydrodynamic conditions in the Mill Creek and its tributaries because it can represent both free flowing and controlled (e.g., impounded) stream reaches, incorporate backwater effects from the Ohio River on Mill Creek flow and velocity, and simulate the dynamic changes (e.g. "flashiness") of the creek during wet weather when flow rapidly increases and subsequently declines. It is also well suited to simulate the transport and fate of *E. coli*, using a conventional modeling approach of a simple first-order loss rate to represent the net effect of settling, re-suspension, and die-off. Although it has additional water quality features to simulate other constituents, some of these capabilities, such as nutrient cycling, have not been widely applied and are inferior to other, more established models. Although EPA has made the water quality block of the EFDC model publicly available, it does not currently support it. However, the EFDC model is a state-of-the-art model for simulating hydraulic conditions and is often linked to more robust water quality models, such as EPA's Water Quality Analysis Simulation Program (WASP), that can better simulate the fate of the suite of water quality indicators for the SSO 700 IWAP.

The physical configuration of the EFDC model requires data on channel cross-section, bottom surface elevations, and bed slope. To simulate the movement of water in the creek, the model requires flow and water surface elevation at the upstream and downstream boundaries of the model extent. These boundary inputs span the duration of the simulation period but can vary with time. Similarly, flows from the adjacent watershed, such as tributaries, CSO, SSO and stormwater discharges, and non-point source runoff, are input to the model as time series. A similar method is used to specify pollutant load inputs to the EFDC model extent. In previous applications of the EFDC model for MSDGC, hourly time series were developed for each input flow and load, and a daily time series was developed for the downstream water surface elevation boundary.

The EFDC model capabilities are summarized as follows:

- Existing model provides calculations of flow and *E. coli* in the main stem of the Mill Creek.
- Flow and water quality are calculated at any segment specified by the user. These segments are typically less than 500 feet long, allowing for direct comparison to individual monitoring station or other points of interest.
- The model can calculate flows and *E. coli* concentrations on an hourly or sub-hourly time scale.
- The model is calibrated for flow and *E. coli* for the 2006 to 2010 time frame.
- The model is suitable for evaluating compliance with recreation use requirements assessed by *E. coli* concentrations in the main stem of Mill Creek.

Surface Water Modeling Gaps

Although the existing EFDC model is suitable for calculating flows and *E. coli* concentrations in the main stem of the Mill Creek within the SSO 700 IWAP study area, there remain gaps in spatial coverage and water quality calculations. These gaps are summarized as follows:

- The model does not represent the impaired tributaries of interest.
- The model can calculate sediment transport and net deposition but is not currently calibrated for this.
- The model can calculate chlorides and metals, if they are assumed to be conservative, but is not currently calibrated for this.
- The model is not capable of calculating complicated water quality processes, such as nutrient cycling and dissolved oxygen responses.

Potential methods of addressing this gap are described in Section 3.

Section 3 - Potential Methods of Filling Watershed and Surface Water Quality Modeling Gaps

Current modeling capabilities include calibrated models of the collection system for calculating CSO and SSO discharges to the Mill Creek. The existing EFDC model is capable of calculating flows, conservative parameters, and *E. coli* in the main stem of the Mill Creek only. The gap analysis indicated that there are no calibrated models for calculating the following in the project study area:

- Upstream headwater flows and pollutant loads into the Mill Creek from Butler County
- Stormwater and non-point source runoff at a refined scale in the project area
- Surface water hydraulics/hydrodynamics in the Mill Creek tributaries
- Dissolved oxygen and other water quality parameters necessary for impairment characterizations and planning purposes.

The following suggests methods of filling these gaps.

Headwater Flow and Load Estimates

A few options are available for calculating the headwater flows and loads from Butler County into Hamilton County in the Mill Creek. These include (1) developing a watershed runoff model or (2) scaling flow observations made by the U.S. Geological Survey.

Under the first option, a SWMM runoff model could be developed for the watershed. In 2012, a coarse SWMM runoff model was developed for the Mill Creek watershed for MSDGC to assess the value of sustainable controls as compared to traditional infrastructure. This previous model included both runoff development and water quality estimate components. Progress made in this previous model could be integrated into a new SWMM runoff model, developed to a finer resolution necessary for integration with the IWAP's water quality model.

As an alternate approach, watershed runoff could also be calculated using a different watershed model, such as the EPA's Hydrologic Simulation Program–FORTRAN (HSPF) or the Loading Simulation Program in C++ (LSPC). SWMM provides a simple interface for developing basic runoff models, but its water quality capabilities are limited. HSPF can simulate runoff, sediment, transport and pollutant loadings for a wide variety of land uses. It also provides a more complete representation of the hydrologic cycle, including shallow groundwater, evaporation, and transpiration. Pollutant loads in runoff during individual storms vary as a function of storm size, slope, land use, pre-storm conditions, season, and other factors, making the model more representative of actual conditions. However, this type of model is more difficult to develop and calibrate.

The final option is to calculate the drainage area above the county line and scale the flows measured at USGS 03255300 (Mill Creek at Kemper Road) to create a surrogate flow time series. This has the benefit of being based directly on observed flow instead of model estimates. Pollutant loading can be calculated by multiplying the flow by observed water quality data. However, this method can have significant uncertainty when applied to periods without flow and/or water quality data, or in forecasting the benefits of pollutant reduction strategies in the headwater areas.

Stormwater and Non-point Source Runoff Areas

Due to the range of hydrologic conditions which will occur in streams of different sizes in the runoff area, the option of scaling flows is not recommended for estimating flows in the runoff areas. Therefore, only one option remains: develop a new watershed model.

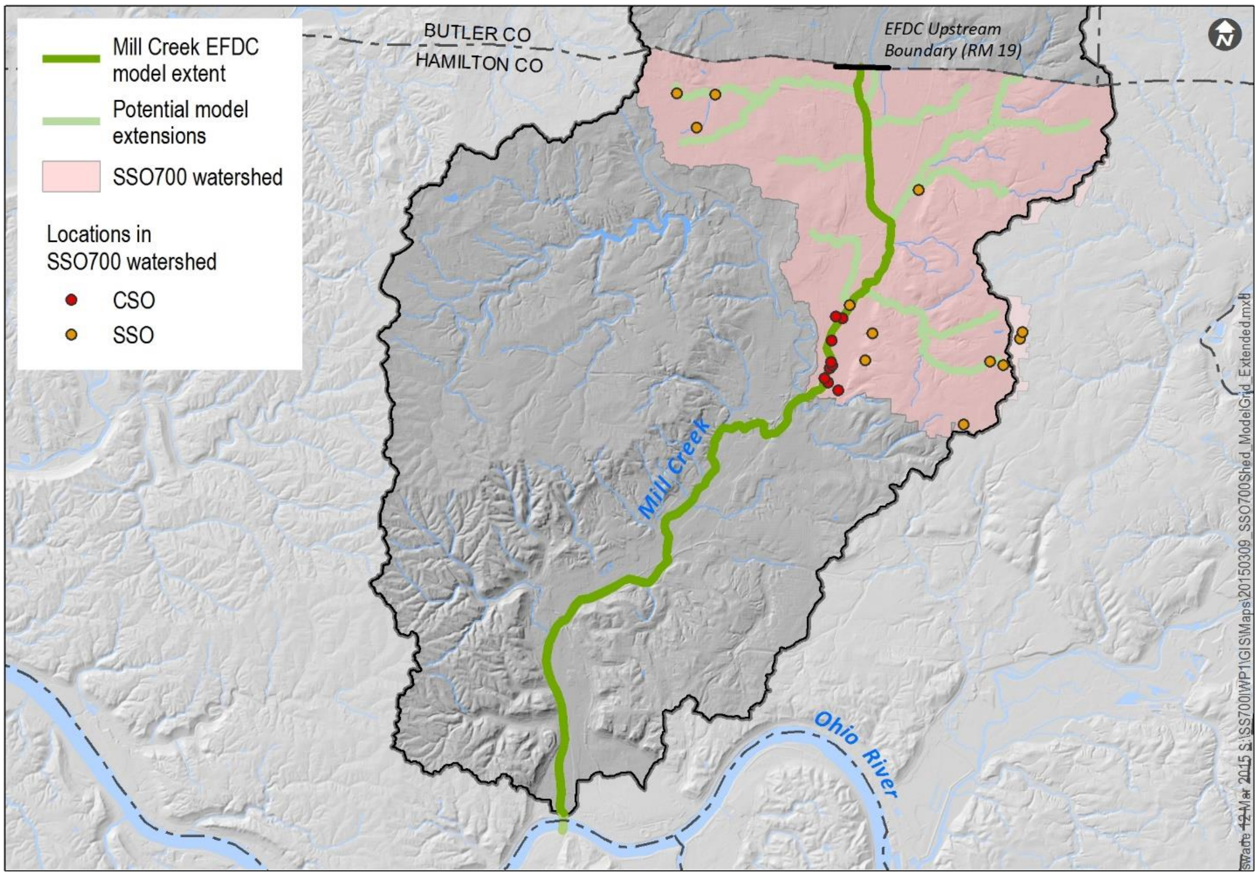
A new watershed runoff model could be developed in SWMM. Under this method, the previous 2012 SWMM modeling would be used to inform the water quality components of the new model and streamline the overall model-building effort.

Watershed runoff could also be calculated using a different watershed model, such as HSPF. HSPF can calculate runoff, sediment, transport and pollutant loadings for a wide variety of land uses. It also provides a more complete representation of the hydrologic cycle, including shallow groundwater, evaporation, and transpiration.

Surface Water Quality Modeling

To address the surface water hydraulics/hydrodynamics in the Mill Creek tributaries, the EFDC model will have to be extended into several of the impaired tributaries and to connect with individual SSO locations. A suggested build-out of the model is shown in Figure 6.

FIGURE 6
Potential Extensions of the Existing Surface Water Model into Mill Creek Tributaries



A more robust water quality model, such as EPA's WASP, would need to be added to the modeling framework to calculate the fate and impact of the suite of water quality parameters of interest to the SSO 700 IWAP. The water quality model will compliment, not replace, the existing EFDC model. The EFDC and water quality model can be run in series such that certain parameters, such as *E. coli*, can remain in the EFDC model while more complicated water quality calculations would be performed in the water quality model. WASP is the current standard for simulation of complex water quality interactions in streams, lakes, and estuaries and is capable of integrating with the EFDC model.

Section 4 - Summary of Gap Analysis Findings

A number of conclusions can be drawn from the review of the existing models for use in the determination of water quality impairment in the SSO 700 watershed. These conclusions are summarized in this section.

Watershed Models

A sufficient stormwater runoff model does not exist for the SSO 700 IWAP study area. A model will need to be developed. Flow estimates from this model should be estimated at a scale that allows output at a tributary scale at a minimum. Catchments of approximately 1 mi^2 would enable quantification of effects of larger BMPs. These catchments would be delineated to represent homogenous areas of the same characteristics and be based on topography and physical features which would affect flow paths.

Previous coarse SWMM modeling included water quality components to calculate bacteria, TSS, TN, and TP loads based on literature values for EMCs. Model calibration or verification of loading rates would provide more robust estimates. Calculation of chlorides or metals would also need to be included in the model or a method using a surrogate would need to be developed.

Collection System Model

MSDGC's system wide hydraulic model calculates runoff only in subcatchments that drain to the combined sewer system. Only a small portion of the SSO 700 IWAP study area is served by combined sewers. Therefore, runoff flows and pollutant loads from the remainder of the study area will need to be modeled separately.

With respect to the CSOs and SSOs, MSDGC's system wide model only calculates overflow volume. It does not calculate the composition of pollutants in the overflow. The model must be modified to include the water quality components or EMCs may be applied to the volume estimates.

Surface Water Modeling

The resolution of the existing surface water quality model in EFDC model segmentation (~500 feet length/segment) appears to be suitable for the SSO 700 IWAP project, providing somewhat finer resolution than the distribution of the MBI sampling locations. However, the existing surface water quality model in EFDC represents only the main stem of Mill Creek. It has not been extended into the tributaries, such as Beaver Run, Sharon Creek, and Cooper Creek, which are waterways of interest for the SSO-700 IWAP project.

The existing surface water quality model in EFDC is suitable to simulate flow velocity and *E. coli* bacteria concentrations only. The EFDC modeling framework is less well suited to simulate the nutrient cycle and resulting DO levels. Although solids can be modeled in EFDC, it would require a more complex configuration of the model and it would be more efficient to include solids in a linked water quality model. A water quality model such as WASP needs to be added to the modeling framework.

Summary of Model Capabilities

Each of the models discussed have a different focus or are better suited to specific aspects of water quality simulation. A tabulation of the constituents and related model capabilities is provided in Table 1.

TABLE 1
Summary of parameters of interest and model capabilities

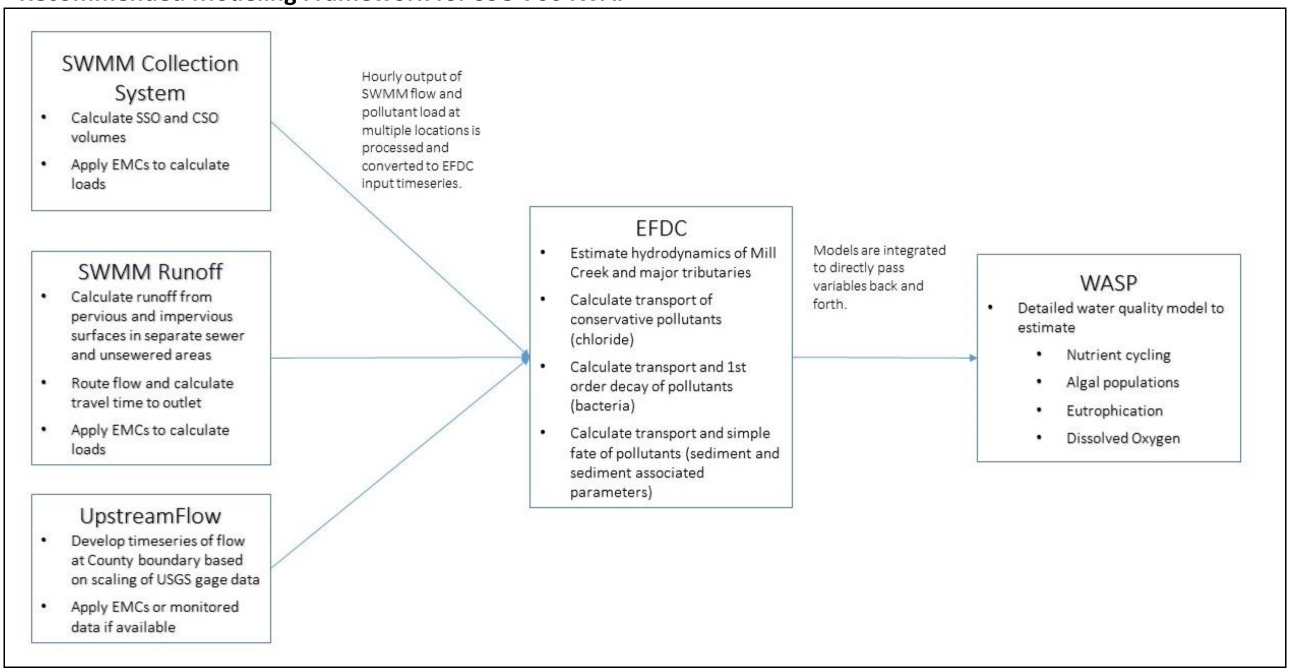
Parameter	SWMM	EFDC	WASP*	HSPF
Watershed Hydrology	Basic	None	None	Complex
Instream Hydraulics	Basic	Complex	None	Moderate
Low flow	Runoff volume	Flow, volume, and velocity	No	Flow, volume, and velocity
Watershed Pollutant Loading	Basic	None	None	Complex
Sedimentation	TSS loading	Sediment transport and net deposition	Net deposition	Sediment transport and net deposition
Chlorides	Conservative constituent	Conservative constituent	Conservative constituent	Conservative constituent
Nutrients	Conservative constituent	Simple decay	Full kinetics and cycling, can also simulate algal classes	Simple decay
Algae/eutrophication	No	No	Yes	Yes
Dissolved oxygen	Not applicable	No	Yes	Yes
Copper	Conservative constituent	Conservative constituent	Yes	Yes
Lead	Conservative constituent	Conservative constituent	Yes	Yes
pH levels	No	Limited	Limited	Limited
Bacteria	Conservative constituent	Simple decay	Simple decay	Simple decay

* As an add on to EFDC

Section 5 - Recommendations

A review of the existing modeling tools needed to meet the study's objectives has determined that a number of gaps exist. The following sections summarizes CH2MHILL's recommendations that would be needed to quantify hydrologic and water quality characteristics, including flow volume and velocity, temperature, chlorides, total suspended solids (TSS), bacteria, nutrients, and dissolved oxygen (DO) within the SSO 700 study area on a temporal scale that allows for comparison to applicable water quality standards. An illustration of the recommendations is shown in Figure 7.

FIGURE 7
Recommended Modeling Framework for SSO 700 IWAP



Headwaters, Watershed and Non-point Source Runoff Models:

A watershed model or estimate based on measured hydrology is required to generate flows and loadings from headwaters and all stormwater and non-point source runoff areas within the East Branch Mill Creek drainage area. The following items are CH2MHILL's recommendations to meet these needs.

- The upstream boundary condition, Mill Creek at the Butler County line, should be quantified using scaling of gage data and monitored water quality data. This will provide a direct linkage to observed data without the use of approximations that a watershed model requires.
- The stormwater and non-point source runoff areas should be modeled using a newly developed SWMM model using the watershed module. This model provides a moderate level of parameterization and input data while providing the necessary level of detail for flow and pollutants. The SWMM runoff area model should be developed using catchments of 1 mi^2 or less. These would be based on topography and physical features and would coincide if possible with primary tributaries and major storm sewer outfalls.
- Chloride, bacteria, nutrient, and TSS should be modeled directly by SWMM using land use-based estimates of EMCs.

Collection System Modeling

The MSDGC's collection system model should continue to be used to calculate CSO and SSO discharges in combination with EMCs for pollutant loadings.

Surface Water Quality Modeling

EFDC is a state of the art model which can provide the basis of the surface water assessment. Its primary focus is calculation of instream hydraulics and basic pollutant fate and transport. CH2M HILL recommends that it be refined as follows to provide a system that fully meets the project objectives.

- The EFDC model will need to be extended into the tributaries of interest.
- The EFDC capabilities will need to be expanded and calibrated to calculate sediment transport and chlorides and metals.

Complicated processes in the EFDC model, such as nutrient cycling, have not been widely applied and are inferior to other, more established models. A more robust water quality model, such as EPA's WASP, should be added to the modeling framework to calculate the fate of the suite of water quality parameters of interest to this project.

Section 6 - Water Quality Data Assessment to Support Modeling

Water Quality data are data that may be used to calibrate or otherwise inform the water quality model system. This section summarizes the available water quality data received to date and provides a data gap analysis. Not all available data have been received. Remaining outstanding data will be addressed in the final draft of this technical memorandum.

IWAP Modeling Data Needs

Water quality data needs specific to the SSO 700 IWAP are the following:

- Runoff Quality – Observations from different land use types for parameters of interest including biochemical oxygen demand (BOD), nutrients, sediment, bacteria, and metals used to characterize and calibrate watershed models. These data are associated with storm events and are difficult to collect due to the timing and variability of storm magnitude and the challenge of finding drainage areas that are of a fairly uniform land use.
- Surface Water Quality - Observations for parameters of interest including pH, conductivity, chlorides, nutrients, sediment, bacteria, dissolved oxygen, algae, and metals used to characterize and calibrate the watershed model. These data are required at multiple locations in the study area for a variety of seasons and conditions (i.e., summer low flow and spring storm events). Low flow measurements provide a baseline level for calibration of the surface water quality model. Storm event data are used to determine peak constituent concentrations resulting from these events and whether the model or inputs need to be adjusted to provide accurate calculations for storm event periods. Multiple samples during multiple storm events are required to properly characterize the pollutographs during wet weather events, if accurate representation of the pollutographs are used as a calibration target (e.g. reproducing the timing and magnitude of peak pollutant concentrations, duration of wet weather impact, etc.).

Assessment of Available Data

Water quality data within the SSO 700 study area are available from several sources, including MBI, MSDGC, Hamilton County Soil & Water Conservation District (HCSWCD), and Hamilton County Public Health Department (HCPH). The following is a summary of water quality data received to date that are relevant to the water quality modeling framework described in previous sections of this technical memorandum.

Midwest Biodiversity Institute Reporting

As summarized in MBI's *Biological and Water Quality Study of Mill Creek and Tributaries 2011*, MBI collects and compiles water quality and biological survey data to characterize and assess the current (baseline) conditions in each of MSDGC's service areas, including Mill Creek, on a 4-year rotational basis. Per the MBI report (MBI, 2012), the studies serve to achieve the following:

1. Determine the extent to which biological assemblages are impaired, using Ohio EPA methods and criteria
2. Determine the categorical stressors and sources that are associated with those impairments
3. Add to the broader databases for the Mill Creek and MSDGC watersheds to track and understand changes through time that occur as the result of abatement actions or other factors.

The Mill Creek study was completed in 2011 and provides a comprehensive look at water quality, biological health, and designated use support across the watershed. As shown in Figure 8, thirty-nine locations on the Mill Creek main stem and tributaries within the SSO 700 IWAP study area were evaluated as part of the study. MBI's sample locations and data have been supplied by MBI through MSDGC. MBI data are limited to 2011.

Historic MSDGC Data

The available historic in-stream water quality monitoring and runoff water quality monitoring collected within the SSO 700 IWAP study area were also requested from MSDGC to support the modeling for the SSO 700 IWAP project. The project team continues to work with MSDGC to obtain these data.

Additionally, between 2006 and 2010, MSDGC conducted bacteria sampling in the Ohio River, Mill Creek, and Little Miami River to support the development of a recreation forecasting tool. Samples were collected at four locations in Mill Creek approximately weekly during this period and analyzed for *E. coli*. Daily sampling was conducted for 72 hours during three storm events in 2009 and one storm event in 2010. These data were used to calibrate the existing EFDC water quality model. However, this dataset is limited to *E. coli* only and does not provide information regarding solids, nutrients or dissolved oxygen-related conditions in the creek.

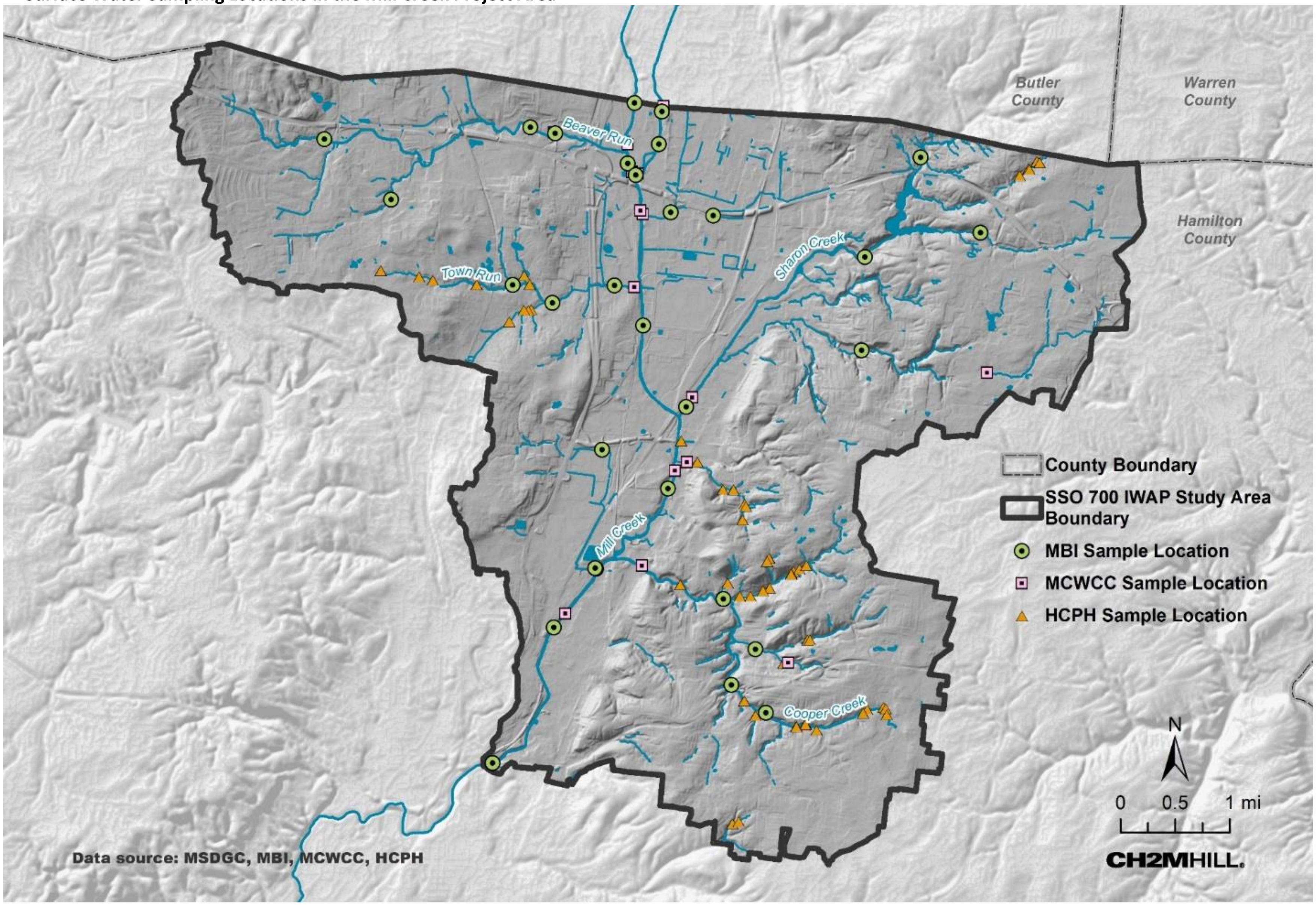
US Environmental Protection Agency Data

Other potential data sources were investigated to determine whether they could provide a dataset suitable for water quality model development. The first avenue explored was the US EPA STOrage and RETrieval Data Warehouse. STORET is used by the EPA to store instream water quality that are collected by a variety of agencies in an area. A query of the STORET database identified a number of stations within the Middle Ohio – Laughery hydrologic basin, including Mill Creek; however, no stations or data within the SSO 700 IWAP study area were identified. While STORET is used by most states for compiling water quality data, it is not a requirement. Follow-up with Ohio EPA is being undertaken to determine whether they compile relevant data outside of STORET.

U.S. Geological Survey Data

The U.S. Geological Survey (USGS) has maintained several stream flow gages in the Mill Creek watershed. These gages include gage height, flow and other hydraulic data that describe conditions in the creek. USGS has been monitoring conditions for over 50 years at some locations, such as the gage at Carthage (03259000). These records provide a useful dataset for informing flow boundaries and for calibrating the hydraulic conditions in the surface water quality model.

FIGURE 8
Surface Water Sampling Locations in the Mill Creek Project Area



Mill Creek Watershed Council of Communities

The Mill Creek Watershed Council of Communities (MCWCC) has organized a volunteer monitoring program to collect and analyze stream samples throughout Mill Creek (MCWCC, 2015). The monitoring network includes 15 stations within the study area. See Figure 8 for the locations of these monitoring stations. Monthly collection and analysis have been performed on a monthly basis since the summer of 2013. Parameters measured are conductivity, pH, turbidity, nitrates, total phosphorus, and bacteria. While these monthly data are not sufficient for calibration of the EFDC model, they can provide information on the accuracy of the watershed model estimates. The observations and conclusions of the volunteers can also provide valuable insight into conditions within the watershed, which may inform the overall modeling and assessment effort.

Hamilton County Public Health Department

The Hamilton County Public Health Department (HCPH) performs water quality sampling as part of their management of septic systems and at the request of the Hamilton County Stormwater District when an illicit discharge is suspected. HCPH's sample locations and data have been received. See Figure 8 for the sampling locations received from HCPH. HCPH sampling is not performed under a regular schedule. Sampling is performed during dry weather to locate a temporary condition that would subsequently be eliminated. Data collected by the HCPH will continue to be obtained during the project to determine its suitability for source characterization and surface water quality modeling.

Hamilton County Soil & Water Conservation District

Hamilton County Soil & Water Conservation District recently provided water quality sampling data to the project team. While this data have not yet been analyzed for use in this study, the data appear to be from 5 sample sites from 2010 through 2014. Samples were analyzed for the following parameters: specific conductivity, pH, turbidity, nitrate, total phosphorus, and *E. coli*.

Data Gaps

Runoff Quality Data

No specific runoff quality data are available for the SSO 700 IWAP study area.

Surface Water Quality Data

The surface water quality data collected to date are of use but are insufficient for developing a watershed or surface water model. The MBI study provides an excellent understanding of current conditions. However, the data collected as part of the study were focused on the objectives of the assessment, a comprehensive snapshot of conditions. While the health of a biological community is relatively steady, water quality conditions fluctuate significantly as a result of rainfall events and changes in other environmental conditions. Setup and calibration of a dynamic model relies on comparison of instream data to model estimates over time periods ranging from months to years.

Data Collection Recommendations to fill Gaps

Monitoring of runoff quality data would be useful, and may be collected in targeted areas, but would be difficult and costly to perform comprehensively. Estimates of pollutant concentrations by land use, known as event mean concentration (EMC) values, have been developed under various studies. *MSD Water Quality Evaluation* white paper (MSDGC, 2013) provides a summary of relevant studies and suggested EMCs. It is recommended that the EMCs recommended in this white paper be utilized in the development of the watershed runoff models that feed the water quality model.

Available instream surface water quality data are limited and will need to be collected to support the development of calibrated water quality models. Under Task 2.5 of the SSO 700 IWAP task order, a detailed water quality sampling plan with data collection recommendations to support watershed and surface water modeling will be developed and submitted to MSDGC for review and approval.

Section 7 - References

CH2M HILL, 2015. *SSO 700 IWAP, Task 2.4 Inventory and Gap Analysis.* DRAFT Technical Memorandum prepared for MSDGC. March 9, 2015.

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Ohio EPA, 2004. Total Maximum Daily Loads for the Mill Creek Basin - Final Report. Ohio Environmental Protection Agency, Division of Surface Water. September 2004.

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Attachment A

Summary of Midwest Biodiversity Institute's Biological and Water Quality Study of Mill Creek and Tributaries 2011 Findings

Table A-1. Aquatic life use attainment status at Mill Creek basin stations sampled in summer 2011. *Index of Biotic Integrity (IBI), Modified Index of Well-Being (MIwb), and Invertebrate Community Index (ICI) scores are based on performance of the biotic community. The Qualitative Habitat Evaluation Index (QHEI) measures physical habitat quality and the streams ability to support a biotic community. Proximate causes and sources of impairment are listed at sites that did not fully attain their use. All sites are located within the Interior Plateau ecoregion. Sampling locations grouped by the HUC 12 subwatershed level WAU (watershed assessment unit).* ***Source:*** *Midwest Biodiversity Institute's Biological and Water Quality Study of Mill Creek and Tributaries 2011 (MBI, 2012)*

Site ID	DA (mi2)	Fish/ Invert. RM	IBI	MIwb	ICI	QHEI/ HHEI	Attainment Status	Causes	Sources
WAU 01-01									
23-001 Mill Creek (WWH Aquatic Life Use – Existing)									
MC12	26.5	19.65/ 19.90W	28*	3.8*	26ns	49.25	NON	Sedimentation; Low Flow	Altered Hydrology; Hydromodification
MC10	27.0	18.75/ 18.70W	32*	5.2*	38	67.00	NON	Sedimentation; Chlorides	Altered Hydrology; Hydromodification; Urban runoff
MC08	32.4	18.15/ 18.15W	34*	7.4	G	61.50	PARTIAL		
23-006 East Fork of Mill Creek (WWH Aquatic Life Use – Existing)									
MC26	2.7	4.75/ 4.75H	20*	NAa	F*	53.8/77	NON		
MC21	4.9	3.45/ 3.45H	34*	NA	F*	61.00	NON	Sedimentation; Low Flow Chlorides	Altered Hydrology; Hydromodification; Urban runoff
MC18	9.1	1.2/ 1.2H	28*	NA	34	54.00	PARTIAL		
MC15	9.1	1.0/ 1.0H	42	NA	32	56.00	FULL	-	-
MC14	9.1	0.8/ 0.8H	34*	NA	42	57.25	PARTIAL		
MC14	9.1	0.7/H	24*	NA		63.25	NON	Organic Enrichment; Cond./Chlorides; Sedimentation	WWTP; Altered Hydrology; Hydromodification;
MC17	9.5	0.4/ 0.4H	26*	NA	44	56.00	PARTIAL		
MC16	9.5	0.05/ 0.05H	32*	NA	MGns	60.75	PARTIAL		
23-023 Beaver Creek (WWH Aquatic Life Use – Existing)									
MC41	0.8	3.3/ 3.3H	18*	NA	P	53.0/71	NON	Sedimentation; Chlorides; Low Flow	Altered Hydrology; Urban runoff
MC23	4.4	1.0/ 0.95H	36ns	NA	G	54.50	FULL		
MC22	4.6	0.75/ 0.70H	28*	NA	MGns	64.50	PARTIAL	Sedimentation; Chlorides	Altered Hydrology; Urban runoff
23-038 Tributary to Beaver Cr at RM 2.27 (Aquatic Life Use Undesignated / WWH Recommended)									
MC39	0.9	0.5/ 0.5H	22*	NA	P*	57.0/67	NON	Sedimentation	Altered Hydrology;
23-055 Tributary to East Fork Mill Creek at RM.2.35 (Aquatic Life Use Undesignated / WWH Recommended)									
MC35	1.2	1.75/ 1.70H	40	NA	F*	57.3/84	PARTIAL	Sedimentation	Altered Hydrology;
MC31	2.0	0.80/ 0.80H	48	NA	G	64.00	FULL		