

Modeling Fecal Coliform In Mill Creek

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In 1995, the Northeast Ohio Regional Sewer District (NEORS D) initiated the Mill Creek Interceptor (MCI) Project, a multi-year undertaking aimed at developing a comprehensive facilities plan for the area. It is envisioned that, once implemented, the plan will alleviate sewer system surcharging and control combined sewer overflows (CSOs) within the Mill Creek drainage basin, at the same time complying with current and potential state and local permitting requirements.

In light of the fact that significant water quality impacts to Mill Creek had been identified as part of previous studies of the area, it was determined that an assessment of Mill Creek be undertaken. As part of the assessment of Mill Creek, an extensive monitoring program was completed, the results of which complemented the considerable data previously collected. The results of the monitoring program, along with the previously collected data, were used to develop a water quality model for Mill Creek. Once developed, the Mill Creek water quality model was used to assist in the formulation of an overall drainage basin plan, as well as in the analysis of a Use Attainability Analysis for the Mill Creek.

This chapter discusses the process undertaken to set up, calibrate and apply a water quality model to support the CSO facility planning process. Specifically, in the Mill Creek drainage area, there was a significant amount of effort spent in defining and quantifying sources of fecal coliform whether from CSOs, stormwater, dry weather seepage, or other sources contributing to Mill Creek that were

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identified in the watershed. Source identification was extremely important to the water quality model in order that the impact of source correction could be reliably predicted. Fecal coliform was modeled by the TRANSPORT module of XP-SWMM in the study. The calibrated water quality model was used in continuous simulations to evaluate the sensitivity of water quality in Mill Creek to various control alternatives being considered and for the evaluation of the overall facility plan.

18.1 Study Area

Mill Creek is a small tributary of the Cuyahoga River that discharges to Lake Erie in the Cleveland area. Mill Creek is approximately 20 kilometres (12 miles) in length and has a total drainage area of 6,000 hectares (15,000 acres).

The MCI drainage basin comprises the south-eastern portion of the Mill Creek basin and is tributary to the Southerly Wastewater Treatment Plant (SWTP). The MCI drainage basin covers an area of approximately 6,880 hectares (17,000 acres) and includes all or part of eleven communities. The sewerage system tributary to the Interceptor is comprised of separate (53%), combined (26%), and dual (21%) sewers.

Land use within the drainage basin is primarily urban, most of it zoned for single and multiple family dwellings. Commercial and industrial areas are generally adjacent to main streets, with open space limited to small parks, one large park (Garfield Heights) on the south side of the Creek, cemeteries, a golf course and a race track.

There are 175 outfalls documented as having outlets that discharge directly into Mill Creek and its tributaries from areas serviced by combined sewer, separate sewers and dual sewers. The creek also receives effluent discharges from septic tanks and semi-public disposal systems. Mill Creek is, as well, subject to both municipal and industrial spills and inputs of leachate from three landfill sites (one active and two closed) in its lower reaches through bank seepage.

Wet weather discharges to Mill Creek are mainly from combined sewer overflows, stormwater, and overflows from the dual sewer areas. There are two dual sewer systems in the Mill Creek drainage basin. The first has been designated a common trench - dividing wall (CTDW) system. The CTDW system consists of separate storm and sanitary pipes constructed in a common trench and a partial wall in common manhole structures that separate sanitary and storm flows. During wet weather periods, it is possible for sanitary flows to overflow into the storm system and/or for the stormwater to overflow into the sanitary system, resulting in both cases in combined sewage flow. The second type of dual sewer has been designated a common trench - separate (CTS) system. The CTS system is characterized as having both sanitary and stormwater pipes within the same

trench, similar to the CTDW system. However, the systems do not share common manhole structures. Nevertheless, cross-mixing of flows can occur as a result of leakage from one conveyance system infiltrating the other.

18.2 Model Set-Up

18.2.1 Overview

The TRANSPORT module of XP-SWMM was used to simulate fecal coliform levels in the Mill Creek water quality study. Figure 18.1 shows the schematic of the Mill Creek water quality model. The Mill Creek model includes about 9.3 miles (15 km) of stream and it is divided into 24 segments averaging a half mile (0.8 km) each.

For the water quality model, the number of outfalls was reduced through grouping common pollutant source types. In total, 62 pollutant loading points that contribute both flow and pollutants into Mill Creek are used in the model.

18.2.2 Bacterial Decay

Fecal coliform (FC) modeling involves the use of a first-order decay expression to describe bacterial die-off. The coliform levels are a function of initial loading and the disappearance rate. The disappearance rate is a function of:

- time or distance of travel from the source, and
- environmental factors such as temperature, salinity, and light intensity.

The following formula was used to calculate the decay of fecal coliform in the model:

$$C_t = C_0 e^{-kt} \quad (18.1)$$

where:

- C_0 = initial fecal coliform concentration, org/100 ml
- C_t = fecal coliform concentration, org/100 ml
- k = decay rate constant, day⁻¹ or hr⁻¹ (accounts for various factors including temperature, salinity, and light intensity)
- t = exposure time, days or hours (travel time)

The decay rate in the context of the Mill Creek was not a sensitive parameter during wet weather. The length of Mill Creek and the flow velocity was such that there was minimal decay of fecal coliform levels observed. Calibration of decay rates was undertaken using dry weather data collected at the four instream monitoring locations. The fecal levels at the upstream station were compared to

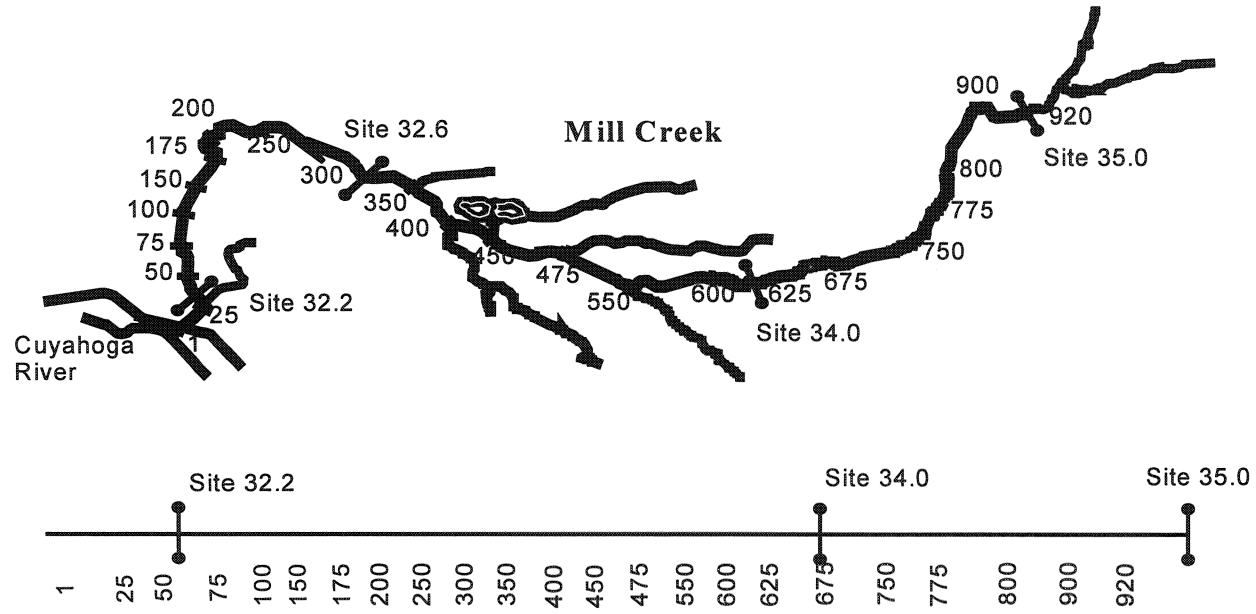


Figure 18.1 Mill Creek model schematic.

the level of the next station downstream and intermediate sources accounted for in determining the overall decay factor for each reach. Overall, a decay factor of 0.3 hr^{-1} was found to be representative for Mill Creek for dry weather conditions. This rate agrees with the decay rate ranges listed in EPA surface water quality modeling report (Tetra Tech, 1985).

18.2.3 Model Inputs

Stream Flows

Modeling of the collection system within the Mill Creek drainage basin was completed by Metcalf & Eddy Inc. using the SWMM RUNOFF and EXTRAN blocks. The collection system SWMM output hydrographs are used as inflow hydrographs to the Mill Creek water quality model. In the water quality model, the TRANSPORT block is used to route the flow hydrographs, and pollutographs, in the stream. This process required the development of suitable tools to reformat the collection system interface files containing the flow hydrographs into importable files for the XP-SWMM water quality model.

Collection system runoff and routing parameters were adjusted to calibrate the stream flows in the water quality model. Fecal coliform calibration was undertaken following the flow quantity calibration and is discussed later in the chapter.

Source Concentrations

Fecal coliform concentrations were input at the same 62 loading points as the flow hydrographs.

Dry weather fecal coliform densities were established using source outfall, boundary, tributary and in-stream water quality and flow data collected as part of the monitoring and sampling program.

An event mean concentration (EMC) method was employed for wet weather fecal coliform inputs. Event mean concentrations of fecal coliform were calculated based on sampling and monitoring data collected at various source outfalls. Specifically, the event mean concentrations were calculated using data collected from five wet weather events at 17 different source sampling sites and four instream monitoring sites during the period May to July 1995.

It was important to identify the source of fecal coliform loadings. To this end, wet weather source flows from the collection system were classified into the following groups based on the sewer service types contained in each of the subcatchments:

- combined sewer overflows (CSO);
- stormwater - common trench dividing wall (CTDW);
- stormwater - common trench separate (CTS);
- stormwater - highway drainage (HWY);

- stormwater - separate sewer (S); and,
- stormwater - open space, unserviced area 9 (i.e. park) (OS).

Fecal coliform EMCs were calculated for each flow source type and applied in the receiving water model.

18.3 Model Calibration

18.3.1 Flow Calibration

The water quality model was calibrated using flow data (stage-discharge relationships) collected at three stream sites (sites 35, 34 and 32.2) between May and July 1995. Four dry weather calibration events were used to establish a typical level of dry weather flow in Mill Creek, representing the summer period. Three wet weather events were used to calibrate and one event was used to verify the model for wet weather conditions.

Figures 18.2 to 18.4 show the results of the model verification using the July 15, 1995 event. These figures show very good agreement between the modeled and measured flows. The event flow volume difference between modeled and measured flows was less than 10% at all three flow monitoring sites for the event. The peak flow rates compared well except for Site 35, the most upstream monitoring location. In reviewing the flow data provided by the United States Geological Survey (USGS) it was found that the site was calibrated for flows of less than 3 feet (0.9 m) in depth, beyond 3 feet, the flow rate is extrapolated. In all calibration events Site 35 shows a significantly higher peak flow which is not reflected downstream. As such, it was determined that if flows were greater than 3 feet the flow rate was not representative. The timing of measured flows versus modeled flows compared well for all events.

18.3.2 Water Quality Calibration

Dry weather fecal coliform densities were established using source outfall, boundary, tributary and in-stream water quality and flow data collected as part of the monitoring and sampling program. The decay rate of fecal coliform was calibrated using the four dry weather events. The decay rate accounts for decay between instream monitoring sites and dry weather inputs from other intermediate sources (i.e. dry weather seepage, leachate).

The three May 1995 wet weather events were used to validate wet-weather bacterial model calibration while the July 15, 1995 event was employed for verification. Fecal coliform densities for the July 15, 1995 verification event are presented for sites 35, 34 and 32.2 in Figures 18.5 to 18.7, respectively. FC loadings for the July 15, 1995 event for sites 35, 34 and 32.2 are presented in

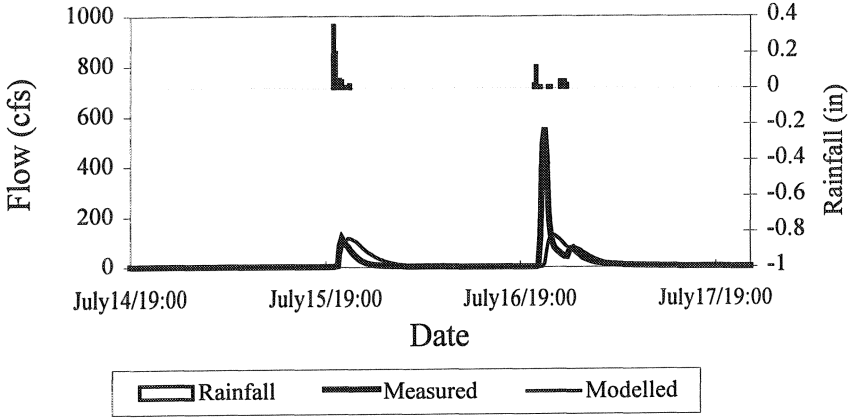


Figure 18.2 Wet weather flow calibration event - July 15, 95 Site 35.

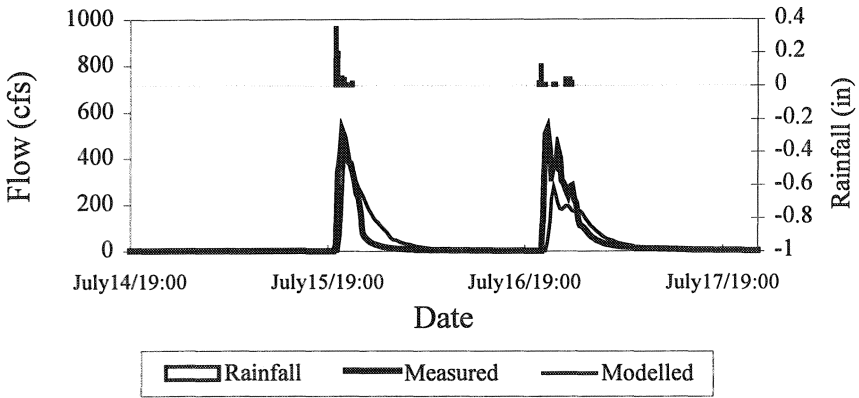


Figure 18.3 Wet weather flow calibration event - July 15, 95 Site 34.

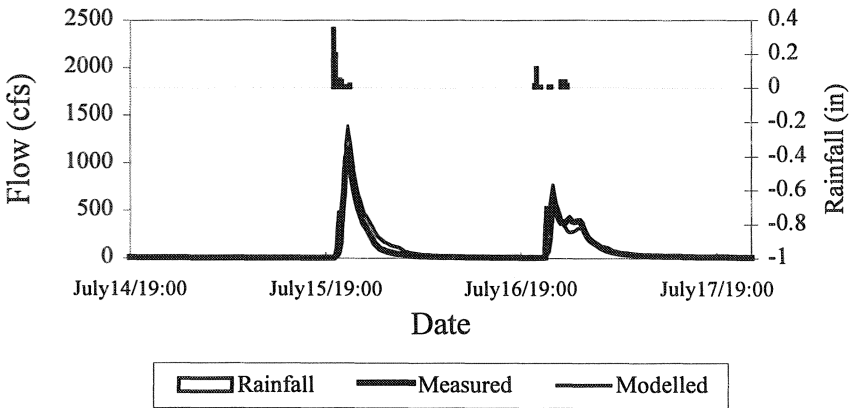


Figure 18.4 Wet weather flow calibration event - July 15, 95 Site 32.2.

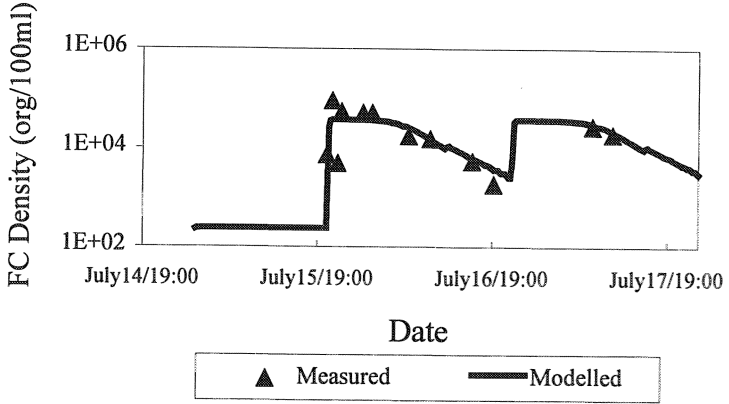


Figure 18.5 Wet weather FC concentration verification event - July 15, 95 Site 35.

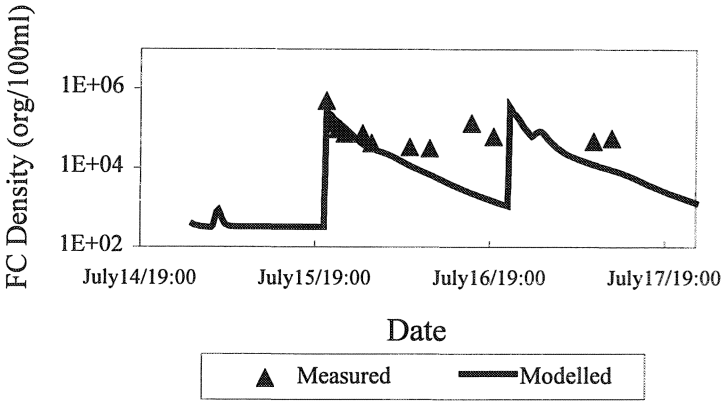


Figure 18.6 Wet weather FC concentration verification event - July 15, 95 Site 34.

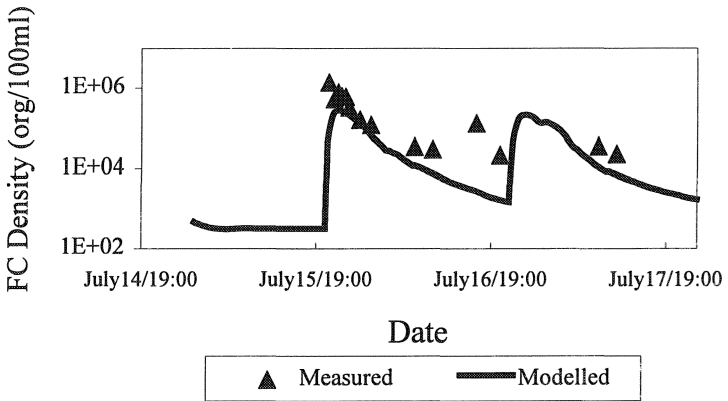


Figure 18.7 Wet weather FC concentration verification event - July 15, 95 Site 32.2.

Figures 18.8 to 18.10, respectively. The verification results of the fecal coliform densities and loadings show very good agreement following the calibration process. [Editor's note: Figures 18.8-18.10 present the same information as Figures 18.2-18.7.]

18.4 Water Quality Simulations

Following calibration and verification of the Mill Creek water quality model, continuous simulations were performed to examine the water quality of Mill Creek in support of pollutant source control plans. A total of six alternative cases were simulated for the swimming season from May 1st to October 15th; three cases are discussed in this chapter. The remaining three simulations were variations of the three presented and were found to reflect similar results with regards to fecal coliform concentrations and loadings.

The runoff hydrographs for the simulations were generated from the collection system model with one hour time steps for a typical year of rainfall developed by others. All the simulations were carried out using the defined baseline dry weather water quality stream model.

The continuous simulation results for fecal coliform were compared with the current Ohio State Water Quality Standards (WQS). As part of the WQS, each water body is assigned a Recreational Use Designation. Mill Creek is defined as having a "primary contact" recreational use, meaning that it is suitable for full body contact such as swimming or canoeing. The primary contact recreational criteria require that:

- geometric mean fecal coliform content based on not less than five samples within a 30 day period shall not exceed 1,000 per 100 ml; and
- geometric mean fecal coliform content shall not exceed 2,000 per 100 ml in over 10% of the samples taken during any 30 day period.

The three cases simulated by the receiving water model are for the following conditions:

- Case 1 - Baseline - existing conditions;
- Case 2 - No CSO - assumes that all combined sewer overflows will be collected by a proposed tunnel and removed from Mill Creek;
- Case 3 - Complete separation - assumes that all wet weather flows from combined sewer overflows; sewer overflows from common trench - dividing wall; and sewer overflows from common trench - separate become stormwater. In this scenario, the stream receives all of the wet weather source flows with the same fecal coliform density of stormwater from a separate system. This is in effect a fully separated system.

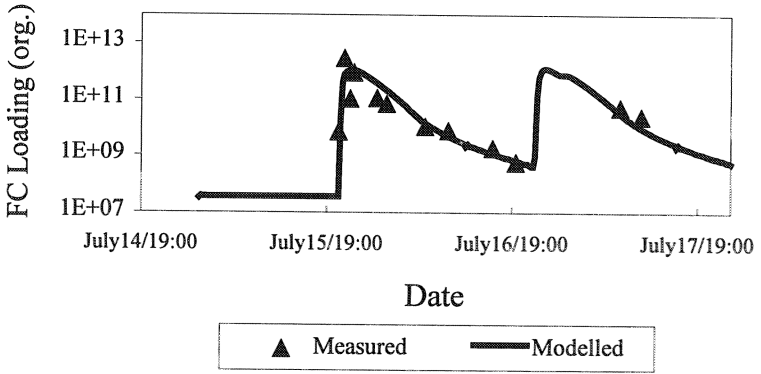


Figure 18.8 Wet weather FC loading verification event July 15, 95 Site 35.

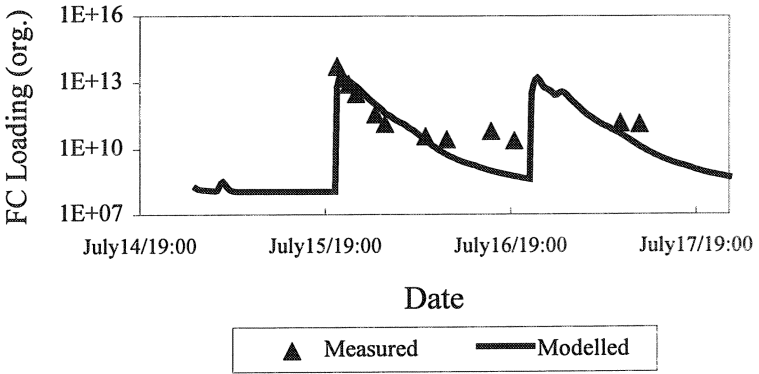


Figure 18.9 Wet weather FC loading verification event July 15, 95 Site 34.

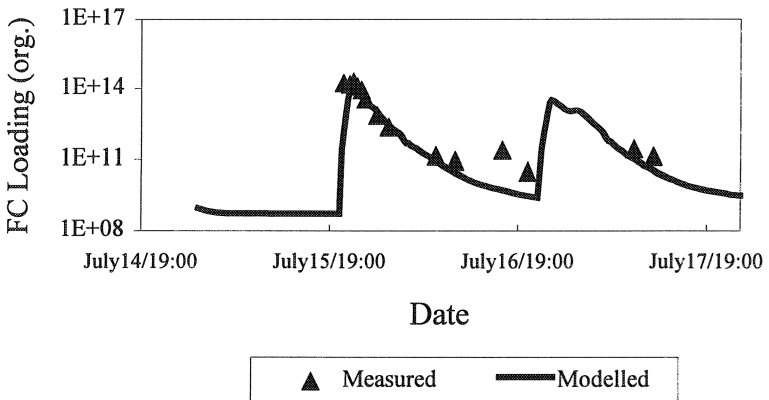


Figure 18.10 Wet weather FC loading verification event July 15, 95 Site 32.2.

Table 18.1 shows the seasonal geometric means of computed fecal coliform densities for the three cases. The computed fecal coliform densities in Case 1 - Baseline exceed the primary contact recreational criteria in the middle and lower reaches. The fecal coliform results of Case 2 - No CSO show that only the middle reaches exceed the criteria. The computed fecal coliform densities in Case 3 present quite similar results: the computed fecal coliform densities exceed the criteria in the middle section of the Creek, and meet the criteria in the upper and lower portions of the stream. Figure 18.11 displays profiles of geometric means calculated for the above three cases over the May 1st to October 15th period.

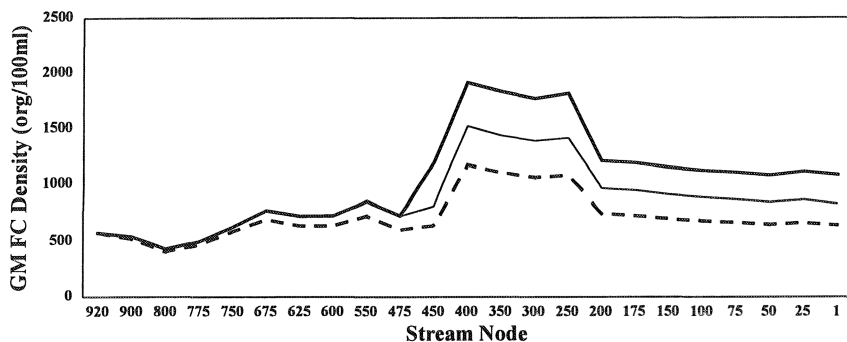
Table 18.1 Seasonal summary. FC Geometric mean (May 1-Oct. 15). org/100ml.

Stream Node	Baseline	No CSO	Complete Separation
920	580	580	580
900	547	547	524
800	436	436	411
775	500	500	472
750	630	630	589
675	779	773	698
625	727	722	643
600	732	726	641
550	854	849	727
475	732	728	605
450	1188	814	644
400	1911	1521	1164
350	1829	1433	1094
300	1766	1385	1053
250	1811	1411	1071
200	1199	954	750
175	1179	935	730
150	1140	903	704
100	1111	878	683
75	1093	862	669
50	1068	841	651
25	1102	857	667
1	1070	828	644

A similar trend is shown in Table 18.2. In Case 1 - Baseline, the percentages of the time that computed fecal coliform densities exceed the criteria of 2,000 org/100 ml range between 19% to 36%. When the CSO sources are removed from the model, the computed percentages of the time are reduced to a range of between 17% and 20%. Case 3 - complete separation, the percentages of the time that

Table 18.2 Seasonal summary; computed hours with FC density >2000 org/100ml (May 1 - October 15).

Stream Node	Baseline		No CSO		Complete Separation	
	Hours	%	Hours	%	Hours	%
920	784	19%	783	19%	781	19%
900	754	19%	753	19%	742	18%
800	735	18%	734	18%	718	18%
775	732	18%	731	18%	717	18%
750	733	18%	732	18%	713	18%
675	698	17%	697	17%	677	17%
625	703	17%	702	17%	680	17%
600	696	17%	695	17%	671	17%
550	697	17%	696	17%	671	17%
475	713	18%	712	18%	684	17%
450	1439	36%	780	19%	699	17%
400	1326	33%	826	20%	679	17%
350	1303	32%	815	20%	676	17%
300	1297	32%	815	20%	681	17%
250	1311	33%	826	20%	699	17%
200	912	23%	715	18%	609	15%
175	915	23%	717	18%	610	15%
150	878	22%	720	18%	621	15%
100	877	22%	733	18%	635	16%
75	879	22%	743	18%	642	16%
50	841	21%	741	18%	649	16%
25	850	21%	758	19%	658	16%
1	835	21%	759	19%	662	16%



Case1 - Baseline Case2 - No CSO Case3 - Complete Separation
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Figure 18.11 FC density profile (May 1-October 15).

computed fecal coliform densities exceed the criteria range between 15% and 19%, which includes no significant improvement when compared with Case 2.

18.5 Conclusions

The field program undertaken was critical to the success of the water quality model to ensure a reliable and representative model for assessing various control alternatives. Careful evaluation of the monitoring data was imperative to ensure that the data accurately represents the existing condition.

The Event Mean Concentration method which associated a fecal coliform EMC with a specific service area type (i.e. CTDW, storm, etc.) combined with TRANSPORT module of XP-SWMM model has been shown to be a successful tool in fecal coliform density and loading simulations. This methodology allowed the water quality model to be used to simulate the correction of fecal coliform pollutant sources. The sensitivity analysis investigated the removal of CSO and the complete separation of the combined and mixed service areas. The outcome of the simulations indicated computed fecal coliform levels would still exceed primary contact limits despite correction of all sanitary sources. These findings indicate that correction of CSOs alone will not be sufficient to bring the fecal coliform levels into compliance with regulatory requirements.

The sensitivity analysis undertaken using the water quality model was used by others in developing the CSO Facility Plan. To this end, the benefits of the recommended CSO Facility Plan were simulated. The simulated fecal coliform levels in Mill Creek, following the implementation of the CSO Facility Plan, were similar to those presented in Case 2, No CSO. The CSO Facility Plan would not be sufficient to control computed fecal coliform levels to meet the primary contact recreational criteria. Additional analysis was undertaken using the water quality model in the form of a stream loadings assessment. The loadings assessment indicated that the CSO Facility Plan would reduce computed pollutant loadings, such as suspended solids, metals, total phosphorus, BOD₅ by up to 40 to 50%.

The water quality model developed for the Mill Creek project is a tool that the NEORS can use in the future to estimate fecal loadings and pollutant loadings as the CSO Facilities Plan is implemented to compare their progress with their objectives.

Reference

Tetra Tech, Inc., 1985, Rates, Constant, and Kinetics Formulations in Surface Water Quality Modeling. For USEPA Environmental Research Lab., Athens, GA., by Tetra Tech Inc, Lafayette, CA. Second Edition. NTIS. Springfield, Virginia. Page 436-437.

