ATTACHMENT C

City of Columbus

LONG-TERM CONTROL PLAN UPDATE RECEIVING WATER MODELING METHODOLOGY MEMORANDUM

CITY OF COLUMBUS OVERALL ENGINEERING COORDINATION CONTRACT
COLUMBUS, OHIO

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1.0 INTRODUCTION AND OVERVIEW OF ANALYSIS METHODS

The US Environmental Protection Agency Combined Sewer Overflow Guidance documents (USEPA, CSO) present the demonstration approach and presumptive approach as two methodologies for complying with the water quality requirements of a Long Term Control Plan (LTCP). The purpose of this paper is to present possible modeling and analysis methods available to comply with the CSO policy. In particular, these methods support characterization of existing CSO impacts on receiving waters, and provide a mechanism for comparing abatement alternatives. As part of presenting the modeling and analysis methodologies, this paper will also present the results and implications of previous efforts conducted by Malcolm Pirnie.

This paper focuses primarily on the City of Columbus's proposed LTCP update. The City currently has CSO discharge points on Alum Creek, the Olentangy River, and the Scioto River. FIGURE 1 (located at the end of this document) shows the proposed study area along with the location of CSO discharge points. One significant issue with the study area is the fact that there are several dams within the study area and that the majority of CSO discharge locations are upstream of these low-head dams. The most significant CSO discharge is the Whittier Street Storm Stand-By Tanks, which is at the toe of Greenlawn Dam, the most downstream dam on the Scioto River. FIGURE 1 also shows the location of the dams relative to the CSO discharge points.

The City of Columbus currently has a comprehensive SWMM model for evaluating the hydraulic characteristics of the sewage collection system including the CSO areas of the City. The City also has a comprehensive QUAL2E water quality model for evaluating steady-state water quality conditions in the receiving waters within parts of the study area. The current QUAL2E model can evaluate water quality conditions from Greenlawn Dam on the Scioto River to just upstream of Circleville and from Livingston Avenue on Alum Creek to the mouth of Big Walnut Creek on the Scioto River.

There are a number of analyses that could be completed to support the demonstration or presumptive approach, i.e., project the attainment of water quality standards and use designations, or quantify the impacts of a LTCP alternative on a receiving water or reduce CSO discharges to 4 per year. There are three approximation methods with special relevance to the City's goals; these are briefly explained below and further explained in later sections.

A critical step in selecting appropriate receiving water modeling and analysis techniques for LTCP development is identifying the water quality parameters of primary interest. The screening and selection of analysis techniques presented in this paper is predicated on the assumption that pathogens are the controlling water quality parameter for the City's LTCP. This assumption is based on the simple reality that in order to preclude CSOs from violating current bacteriological standards, effective reduction of CSO discharge for small storms (12-Month or less) is often the only option. With reduction of CSOs to control pathogens, control of other water quality parameters in the CSO discharge is obviously also accomplished. In this situation, sophisticated water quality analysis of other parameters becomes unnecessary.

Disinfection is also a viable alternative for reducing pathogen levels in CSO discharge. Facility requirements for disinfection make it a less feasible alternative for some CSO discharge locations. Also, disinfection rather than reduction of CSO discharge does not preclude the need for water quality analysis for other parameters such as ammonia or dissolved oxygen. Effective disinfection of CSO discharge can reduce pathogen concentrations to less than the water quality standard of 2000 MPN/100ml.

1.1 FIRST APPROXIMATION – END OF PIPE ANALYSIS

A first approximation would involve an end of pipe analysis using output from a continuous SWMM model simulation. The assumption with an end of pipe analysis is that any CSO discharge would cause bacteria concentrations greater than 2000 MPN/100ml at the end of the discharge pipe since CSO discharge typically has bacteria concentrations near 10^6 to 10^7 MPN/100ml. This approach would not include analysis of the transport, fate, or decay of pathogens in the receiving stream.

Estimates of annual CSO measures are the basis for the first approximation analysis. These measures would be obtained from SWMM model simulations for each alternative, for example, total annual CSO volume, a count of CSO activations per year, hours of activation per year, maximum discharge rates and CSO discharge frequencies. Alternatives would be compared based on a comparison of the statistical analyses. Concentrations could also be applied to the CSO volume to estimate loadings of contaminants.

The first approximation is especially applicable for pathogens, given that with current bacteriological water quality standards an exceedance of the 2000 MPN/100ml is effectively triggered with any CSO occurrence. The first approximation is not as applicable for assessing attainment of water quality standards for other parameters, e.g. dissolved oxygen.

1.2 SECOND APPROXIMATION – DILUTION ANALYSIS

The second approximation incorporates a concentration and dilution analysis and is built upon the first approximation. All of the analysis included in the first approximation would be completed and combined with concentrations and river flows thereby providing an estimate of the dilution of the CSO discharge and instream concentrations. The second approximation does explicitly account for CSO discharge concentrations, and also for background concentrations in the stream. It still does not include transport, fate or decay processes. The second approximation again assumes that bacteriological standards are the most critical and the most difficult criteria to meet. There are two ways to estimate concentrations and dilution when combining the background receiving water with the CSO discharge hydrographs from SWMM model output.

1.2.1 Spreadsheet Analysis

Spreadsheet analysis is the simplest form of the second approximation approach. Using this approach would involve combining the probability of a stream discharge rate with the predicted CSO discharge rates (from the SWMM model). Event mean concentrations would be incorporated into the SWMM model discharge rates to predict concentrations.

1.2.2 Monte Carlo Simulation

A Monte Carlo simulation is a more complex approach to the second approximation. The Monte Carlo simulation would incorporate uncertainties in the values of concentrations and flow rates. The results would be very similar to the spreadsheet analysis.

1.3 THIRD APPROXIMATION – DILUTION/DECAY ANALYSIS

The third approximation is the most complex and comprehensive analysis that could be performed in support of the demonstration approach. A continuous SWMM simulation similar to the analysis mentioned above would be used to predict CSO discharge hydrographs as input for subsequent receiving water analysis. This approach would account for the transport, fate and decay of the parameters of interest. The choice of modeling tools depends on the specific questions that need to be answered and how detailed the simulation needs to be to obtain necessary information.

1.3.1 Spreadsheet Steady-State Analysis (Pathogen)

Analysis via spreadsheet is possible but not recommended. It would be possible to build a spreadsheet model to estimate the transport and decay for pathogens but other models already exist for performing the similar types of analyses more efficiently.

1.3.2 Worst Case Steady-State Analysis

The USEPA QUAL2EU model includes transport, fate, and decay for dissolved oxygen (DO), nitrogen, phosphorus, carbonaceous biochemical oxygen demand (CBOD) and fecal coliforms. QUAL2EU is a steady state model which would yield conservative estimates of the impacts that result from CSO discharges. Using the current QUAL2EU model would require accounting for all CSO loads as a single point source at the upstream end of the model, i.e., the transport and decay through the low-head dam pools would not be modeled. Extending the QUAL2EU further upstream into the dam pool areas is not considered cost-effective for a conservative pathogen analysis.

1.3.3 Complex Dynamic Analysis

The most extensive dilution-decay analysis would be a full dynamic simulation using modeling tools such as the USEPA Water Quality Analysis Simulation Program (WASP). The WASP model includes all of the parameters that can be modeled by QUAL2EU; in addition it is a transient or dynamic model. The WASP model would be much more data intensive and would be able to provide more in-depth answers to how the river would be impacted by CSO discharges with the various alternatives, not just for a worst-case condition but for dynamic conditions during and after wet-weather events. The WASP model would still use the output of the SWMM model to characterize CSO inputs. Results would include the spatial extent and duration of water quality exceedances. Although WASP would be the most realistic model for CSO impacts on receiving water quality, the extra effort and cost associated with developing a WASP model is not expected to impact the outcome of the alternative analysis significantly with the assumption that pathogen control is the primary objective.

The complex dynamic analysis can be applicable in two situations:

- When a parameter other than pathogens is of primary interest, especially a parameter where in-stream fate and transport impacts attainment of water quality standards (e.g., DO).

- When a permitee is considering the option of requesting a change in water quality standards as part of their wet-weather control plan.

2.0 DATA REQUIREMENTS

Each of the relevant methods introduced in Section 1 above have certain data requirements. These data requirements are summarized below, with additional details on each of the data types provided in the subsequent subsections.

The first approximation requires:

- SWMM model, which has already been developed. A time-intensive data collection effort for the SWMM model is not anticipated. Data collection would likely be limited to compiling historical rainfall data to develop an average, or typical, precipitation year.

The second approximation requires:

- SWMM model.
- Compilation of streamflow records.
- Instream water quality.
- CSO discharge water quality

The third approximation requires:

- SWMM model.
- Compilation of streamflow records
- Instream water quality.
- CSO discharge water quality
- Worst-Case Steady State: QUAL2E model, which has already been developed. A time-intensive data collection effort for the QUAL2E model is not anticipated.
- Complex Dynamic: WASP model, which has not been developed. Additional water quality and hydrodynamic data would be required to develop the WASP model

It should be noted that the City of Columbus has already suggested doing a bacteria study for the CSO impacted streams, which would support the instream water quality and CSO discharge water quality data needs.

2.1 HISTORICAL RAINFALL

Historical rainfall data analysis is necessary for the SWMM model. The historical rainfall data will be analyzed to develop an average, or typical, precipitation year. The analysis will include approximately 50 years of rainfall data. The average rainfall year will be the baseline for all of the SWMM model simulations, for both existing conditions and the alternative analysis.

2.2 HISTORICAL STREAM FLOW

Historical stream flow data would be necessary for performing dilution models and dilution-decay models. Similar to rainfall, an average annual stream flow would have to be developed for the receiving water. Further analysis that compares streamflow to rainfall would better solidify the relationship or correlation between the two datasets. A significant correlation may not exist, but the goal would be to isolate an annual streamflow record that corresponds to the average rainfall year.

2.3 INSTREAM WATER QUALITY (BACKGROUND CONDITIONS)

There are two main data types for instream water quality that are of particular interest for modeling the impacts of CSOs on receiving streams – pathogens and DO/CBOD/nutrients. For both of these data types, it is important to characterize concentration not only in the impacted waters but also the background concentrations. Furthermore, sampling of dry and wet weather conditions is also necessary. The background conditions may on their own exceed water quality standards with no CSO inputs. It is possible that many pollutants typically associated with CSO discharges could also be originating from other sources (wildlife, pets, fertilizer) during rain events.

The USEPA Combined Sewer Overflows Guidance For Monitoring and Modeling, January 1999 notes that CSOs can affect several receiving water quality parameters. It also states that the impact on one parameter is frequently much greater than other parameters; therefore, relieving the impact by the one parameter will likely relieve the other parameters. Pathogens are most likely the highest impact considering current water quality standards and relieving pathogen impacts through reduction of CSOs will most likely eliminate any DO, CBOD and nutrient impacts.

2.3.1 Pathogens

As noted at the beginning of this section, the City of Columbus has suggested a bacteria study to identify background levels and sources of bacteria.

2.3.2 Dissolved Oxygen, CBOD and Nutrients

DO, CBOD and nutrient data would be necessary for the transport, fate, and decay modeling using QUAL2EU or WASP. The data would be used to develop boundary conditions and calibration points for either model. The WASP model would require the most extensive data collection effort.

2.4 CSO DISCHARGE WATER QUALITY

Sampling of CSO discharge is necessary to develop an understanding of "typical" CSO discharge quality. The typical CSO discharge quality would be applied to the SWMM CSO discharge results to estimate loadings, as part of the existing condition assessment and alternatives analysis.

2.4.1 Pathogens

The collection of pathogen data for the CSO discharge points would be included in the previously noted bacteria study. Sampling of CSO discharges would need to begin during early activation and continue through the end of the event. A full data set for a CSO discharge would allow the determination of an event mean concentration.

2.4.2 Dissolved Oxygen, CBOD, and Nutrients

Sampling procedures would be similar to the procedures for pathogens. Sampling would need to begin at activation and continue at regular intervals during the entire overflow event. Event mean concentrations would be determined from the sampling data and applied to existing conditions and alternatives analysis.

2.5 HYDRODYNAMIC DATA

The requisite hydrodynamic data already exist for Alum Creek and Big Walnut Creek. In addition, the Ohio EPA developed hydraulic information for the Scioto River south of the Greenlawn Dam. The US Corp of Engineers has a well-developed HEC-RAS model for the Scioto River north of the Jackson Pike WWTP. All of the existing data will be useful for evaluating CSO impacts on the receiving waters with two possible exceptions.

The area of the Scioto River upstream of the Greenlawn Avenue Dam would require additional hydrodynamic data if a WASP model is developed for that area. Although there is an existing HEC-RAS model for the area upstream of the Greenlawn Avenue Dam, it was developed for significantly higher flow rates than what would be used for CSO impact modeling.

The Ohio EPA developed the hydraulic coefficients downstream of the Greenlawn Avenue Dam in the early 1980's and Malcolm Pirnie revised some of the coefficients between Greenlawn Dam and the JPWWTP in 2001. Given the age of the hydraulic coefficients on the Scioto River, there may be a need to update them as well for a CSO impact analysis. This would only need to be completed if there is a significant lack of confidence in the dilution/decay model results when run with wet weather flow rates.

2.5.1 Flow Monitoring

Flow monitoring at key locations along the Scioto River and Olentangy River would be required for transport, fate, and decay modeling. The flow monitoring would involve continuously recording level meters. Rating curves would have to be developed for each flow monitoring point.

2.5.2 Cross Sections

Cross section data would be necessary for the areas upstream of the Greenlawn Dam to develop hydrodynamic data for transport, fate, and decay modeling.

2.5.3 Time of Travel

Time of travel data is extremely useful for developing hydrodynamic models. If it is determined that dilution decay modeling must be completed in the areas upstream of the Greenlawn Dam, then two separate time of travel studies would be necessary. One study would need to be completed at a lower flow rate and another at a higher flow rate. If time of travel work is completed for this reach of the river, it would be advisable to extend the study south into Pickaway County. Extending the study south would allow a more complete evaluation of the existing hydraulic data for the Scioto River and could increase confidence in current and future models.

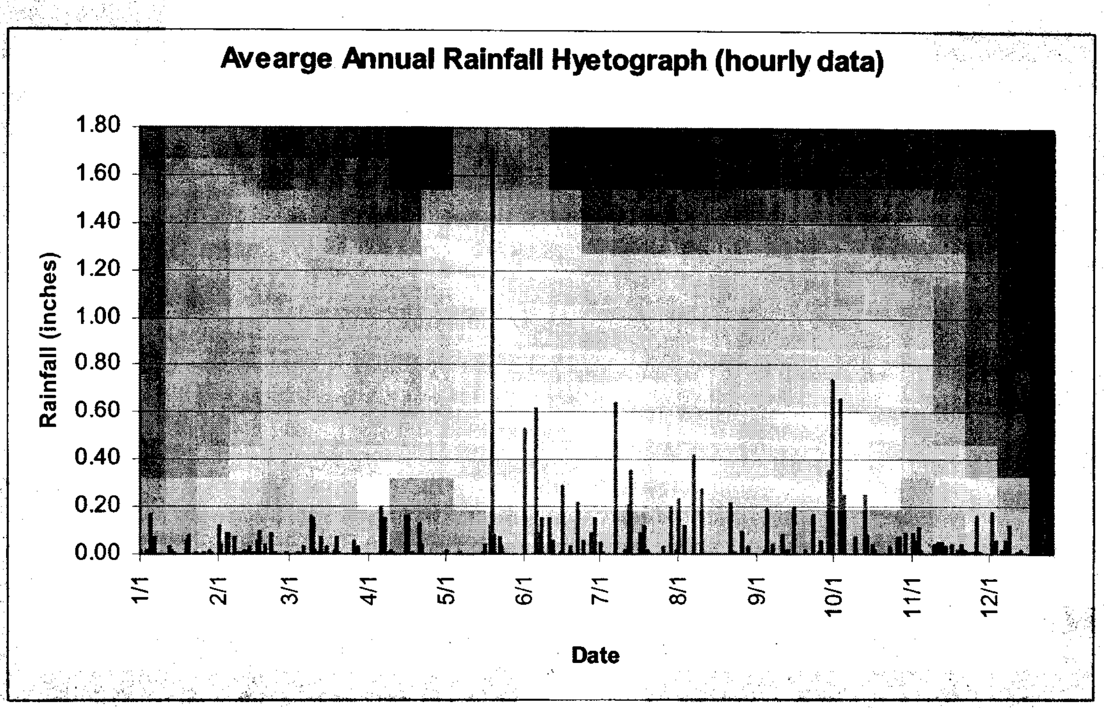
3.0 FIRST APPROXIMATION ANALYSIS

The first approximation method analyzes the results of SWMM model output and uses the model predictions of end-of-pipe CSO activity to compare CSO abatement alternatives. The assumption for this analysis is that any CSO discharge will cause an exceedance of 2000 MPN/100ml for pathogens regardless of background concentrations. Also assuming the minimum sampling frequency of five per month, two discharges in a 30-day period could be an exceedance of the primary contact water quality standard. Data requirements for this analysis include historical rainfall data only. The current SWMM model used by the City will be the primary tool for the analysis.

3.1 CONTINUOUS SWMM SIMULATIONS

The SWMM model will be used to simulate the sewer collection system for the entire recreational season in which the bacteria use designation is applied. The recreational season is May 1st to November 1st (6 months). It is possible to extend the simulation to a full 12-month period, but this would require some analysis of snowfall.

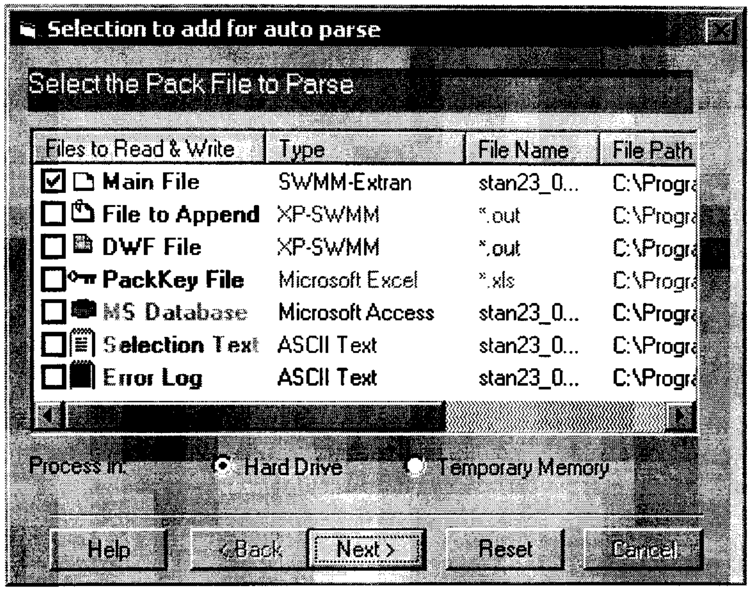
A representative annual rainfall pattern, or typical precipitation year, would need to be developed as an input for the SWMM model. All of the rainfall data available from a local or nearby National Weather Service station, typically more than a 40 year record, will be analyzed. This analysis establishes average annual measures and average monthly measures (e.g., total depth, number of events, etc.) for the entire period of record. Using these definitions of average characteristics, each year is reviewed to identify the real historical year that is the closest to an average year. Once the closest real historical year is identified, the distribution of rainfall events within that year and within individual months is compared to the long-term average. Where necessary, individual events are added, deleted, or traded to represent the long-term average distribution of events. The final result is a synthetic, average annual rainfall record, developed entirely from real historical data. This average annual rainfall has already been developed by Columbus and will be the baseline for all SWMM continuous simulations. The figure below is an example of an average annual rainfall record developed for the Buffalo Sewer Authority SWMM model.



3.2 SUMMARIZING ESTIMATED END-OF-PIPE MEASURES FROM THE SWMM MODEL OUTPUT

The output of each SWMM model simulation will be processed and statistically summarized. The statistics for the end-of-pipe measures for each alternative will be entered into a matrix for comparison.

The SWMM model output file will be processed using result-processing tools developed by Malcolm Pirnie. These software programs extract the information from SWMM output files and place them in readily usable Microsoft Excel tables. The tools can then be used to begin summarizing the relevant end-of-pipe results of each model simulation. The image below is an example of one of the Malcolm Pirnie developed programs.



A number of relevant end-of-pipe results from SWMM model analyses are listed in the following sections. The full performance of any single alternative must be compared to other alternatives by an aggregate of these results. No single summary such as number of activations would be an accurate assessment by itself. For instance, there could be many activations per year but the maximum flow rate, duration and volume may be low in comparison to other alternatives. The system-wide summaries of all results will provide the best snapshot of alternative performance.

3.2.1 Number of Activations

The LTCP guidance documents consider the number of activations a valid measure of CSO performance for the demonstration and presumption approaches. In fact, the presumptive approach is largely based on this metric. A summary of the number of activations for each CSO can be developed from each SWMM model simulation. The activation summary is developed on a CSO by CSO basis; these results can then also be combined into a system-wide basis. Different alternatives can be compared to determine if the number of activations increases or decreases. As introduced previously, given the current bacteriological water quality standard, estimates of the number of CSO activations in a 30-day period can serve as a surrogate for estimating the number of water quality standard exceedances for bacteria assuming that disinfection or treatment of CSO discharge is not employed.

3.2.2 Hours of Overflow

The duration or time extent from activation to zero flow of each CSO discharge event is another valid measure of the performance of alternatives. The total time of duration or sum of all events for each CSO can be computed. A further evaluation would compute the frequency or cumulative frequency of different durations for each CSO and/or the system. This frequency analysis would answer questions such as what percent of the events exceeded a 1-hour or 3-hour duration.

3.2.3 Total Overflow Volume

The volume of CSO discharge for each event is another important measure of combined sewer system performance. Each rain event that causes an overflow will produce a certain volume of discharge. The total volume of CSO discharge for each alternative will be summarized for each CSO and on a system-wide basis. Furthermore, the frequency or cumulative frequency of event volume per CSO or for the system will permit a more in-depth understanding of system behavior. Since volume can be directly converted to a load if concentrations are applied, it is considered one of the most important measures of combined sewer performance and receiving water impacts.

3.2.4 Maximum Flow

The maximum flow rate from any CSO will vary depending on the event and the level of control. A frequency analysis of maximum flow rates for each CSO will help assess the performance of the various alternatives.

3.2.5 CSO Flow Frequency

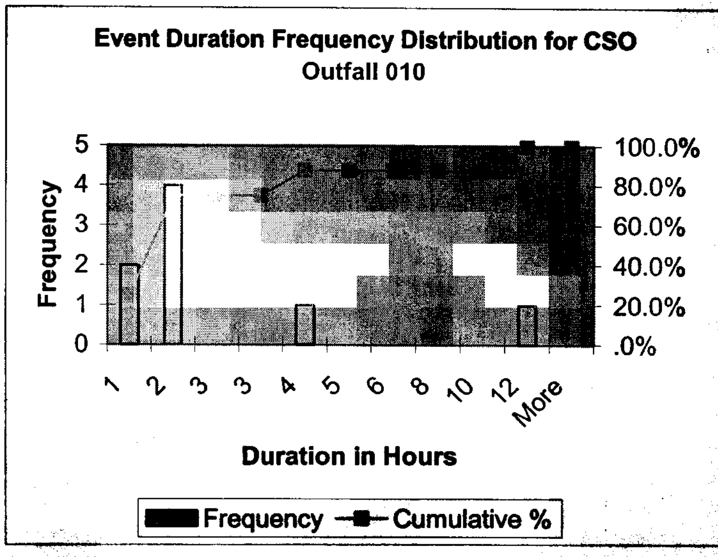
A CSO flow frequency analysis would be similar to the maximum flow analysis but it would also include a time variable. The frequency of various flow rates could be plotted for each CSO. For instance, a CSO could discharge at 1-cfs for a total of 10 hours per year, 1.5-cfs for 5 hours per year and 2-cfs for 0.5 hours per year. The value of the y-axis would be hours and the x-axis would be flow rate.

3.3 EXAMPLE CSO LTCP ALTERNATIVE ANALYSIS – USE OF CONTINUOUS SIMULATION RESULTS

The following table is a partial list of CSO discharge points from a 3-month continuous SWMM simulation presented for example purposes. The data is from a Malcolm Pirnie project (2002) for the Buffalo Sewer Authority in Buffalo, NY. The table shows the total duration of overflow (in hours) that the model predicted for each CSO. The table also shows the number of activations or overflow events. Events were defined using a 6-hour inter-event duration, i.e., an event was considered a new event if the preceding 6 hours had zero flow.

CSO Outfall	Model Node	Model Link	Duration of Overflow (hr)	Number of Overflows
001a	WWTPOF	WETWELLOF	22	9
003	5494	5500	103	8
004	10208	10213	4	1
004	10210	10221	4	1
005	5868	5873	2	1
006	5708	5710	468	10
008	5904	5906	139	16
010	5551	5553	26	8
011	6728	6729	31	5
012	6362	6363	31	10
013	10034	10047	11	1
014	9009	L9201	10	1
015	15669	15670	8	1
016	14964	14968	159	19
016	BR0.00	SPP39w	5	2
017	14580	14584	385	14
021	15439	L15434	6	1
022	14690	L14678	34	3
025	15467	15468	9	1

CSO Outfall ID	Model Outfall Node ID	March - May Total Overflow Volume (cu. ft.)
001	WWTPGRIT	764,500,000
001a	WWTPOF	0
002	TBD	TBD
003	5494	993,500
004	10208 & 10210	2,741,000
005	5868	114,200
006	5708	109,800,000
008	5904	642,800
010	5551	898,800
011	6728	2,015,000
012	6362	2,220,000
013	10034	1,961,000
014	9009	1,666,000
015	15669	1,477,000
016	14964 & BR0.00	429,100
017	14580	13,170,000
021	15439	79,630
022	14690	824,600
025	15467	362,700

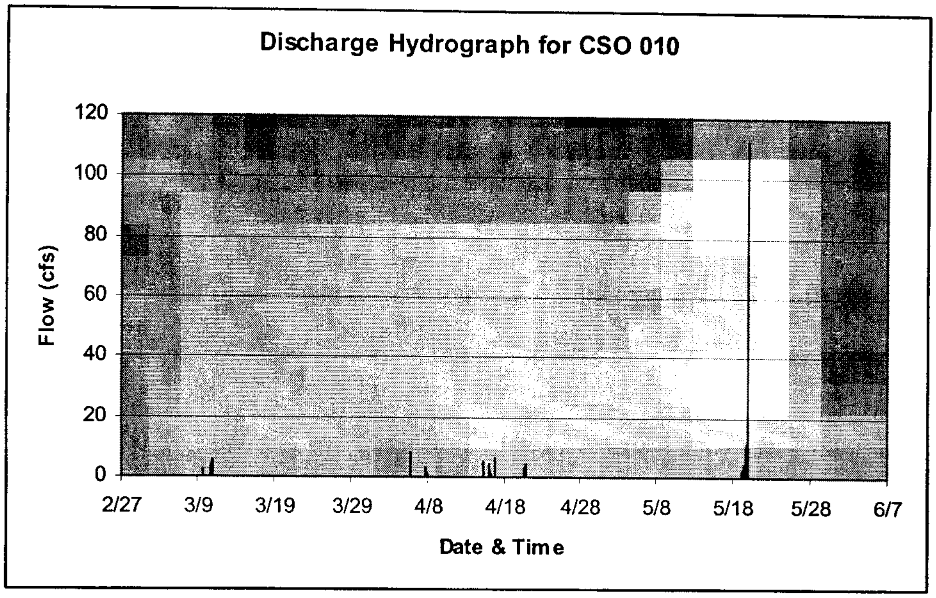


An examination of the flow duration per event for CSO Outfall 010 is shown in the figure above and right. The cumulative distribution shows that 75-percent of all events were 2 hours in duration or less.

The table above and left is from the same model run and shows the total discharge volume for each of the CSO discharge points (a partial list). For example, the total volume discharged by CSO 010, as predicted by the model, was 898,800 cubic feet. A frequency distribution for event volume frequency (very similar to the event duration frequency distribution) could also be developed from the model output.

Other analyses such as establishing the maximum flow rate frequency distribution are similar in concept to the event duration frequency analysis.

The final figure presented below is the predicted annual hydrograph for CSO 010. This hydrograph can serve as the input to a subsequent water quality analysis under the second or third approximation methods.



Discharge Hydrograph for CSO 010
Flow (cfs)
120
100
80
60
40
20
0
2/27
3/9
3/19
3/29
4/8
4/18
4/28
5/8
5/18
5/28
6/7
Date & Time

4.0 SECOND APPROXIMATION ANALYSIS

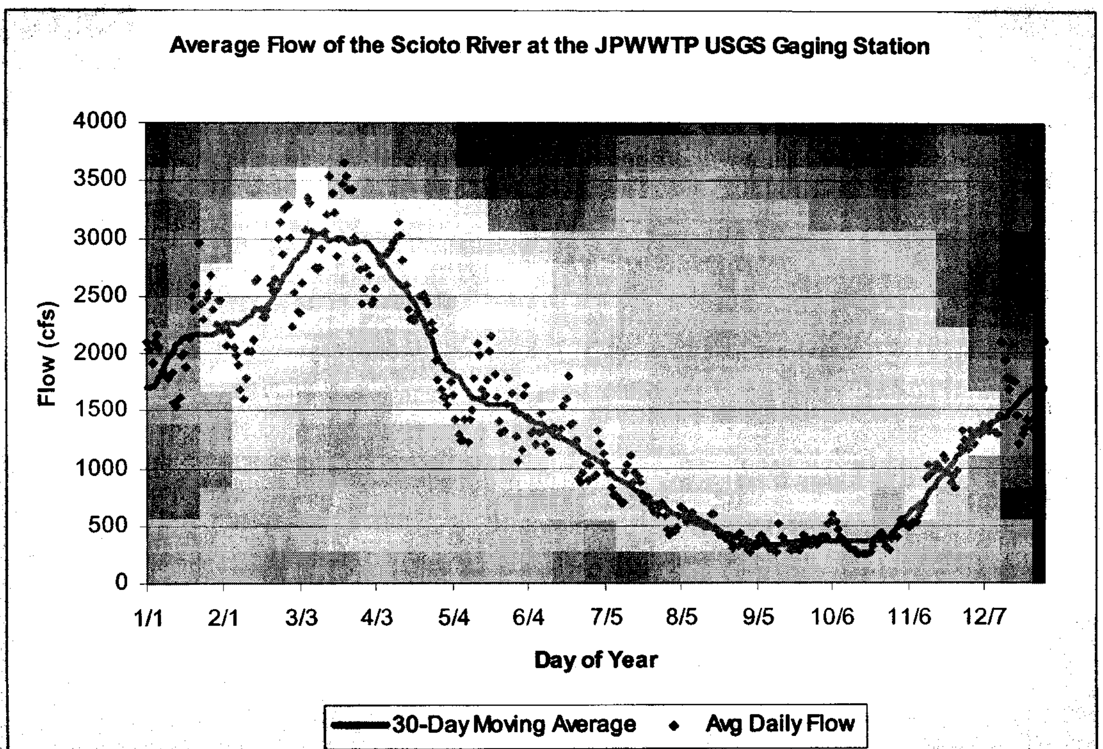
The second approximation method will directly build upon the first approximation by adding concentrations and stream flow to account for dilution effects and to identify potential instream concentrations. This step is a natural extension of the first approximation approach, although the answers will typically be similar with respect to estimates of bacteriological water quality exceedances. Adding dilution via background streamflow will reduce the duration of exceedances at the beginning and tail end of each event because exceedances will be based on a comparison of predicted instream concentrations to water quality standards, rather than on CSO activations. The advantage of this analysis would be the ability to predict instream concentrations of contaminants at the discharge points (under the simplifying assumption of complete mixing) including background concentrations.

4.1 SUMMARIZING ESTIMATED END-OF-PIPE MEASURES FROM THE SWMM MODEL OUTPUT

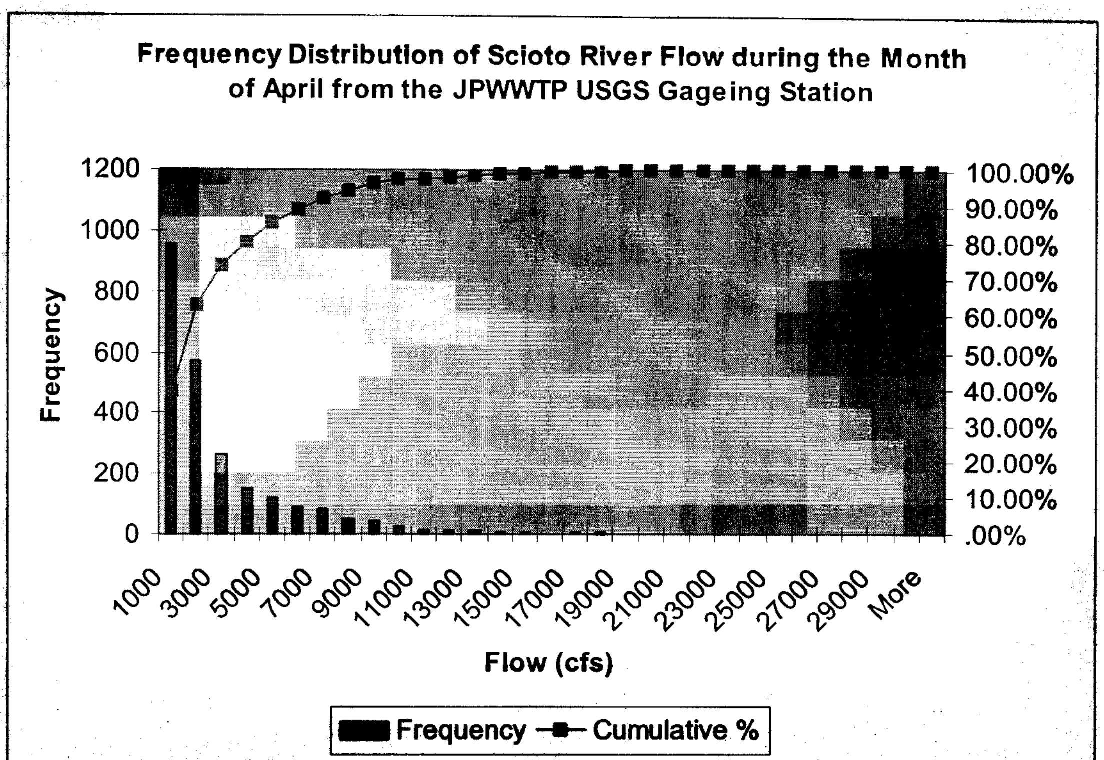
The end-of-pipe analysis described in SECTION 3.0 will still be applicable for the second approximation analysis. The significant additional step that would be necessary for this analysis but unnecessary for the previous analysis is the application of concentration to the CSO discharge. This requires a definition of "typical" CSO discharge quality, as noted in SECTION 2.0. If CSO discharge concentrations were not accounted for in the calculation, the only information that could be determined from the dilution analysis is the percentage of river flow that is CSO.

4.2 STREAM FLOW PROBABILITY FOR THE DILUTION CALCULATION

The base streamflow for any CSO event can vary depending on the season and preceding rain events. Because background flow varies, applying a single background flow is not an entirely accurate method of estimating dilution. As a simplifying assumption, the average monthly flow would be a reasonable estimate. The figure below represents the average monthly streamflow for the entire period of record at the JPWWTP USGS Gaging Station.



Using the average plus some standard deviation from the average to predict instream concentrations would be slightly more robust than just applying the appropriate monthly average value. To extend beyond use of an average streamflow (or band around the average), one would need to examine the frequency distribution of the monthly streamflow and apply the probability of stream flow rates to the dilution calculations. The figure below is a histogram of the flow rate for the month of April. The end result of the analysis would be a probability distribution of a particular concentration occurring in the stream for a given CSO event.



There is also some correlation between rainfall and stream flow. The correlation of historical rainfall and streamflow datasets would need to be analyzed and incorporated into the analysis. Incorporating the correlation would better account for the probability of a concentration occurring in the stream for a given CSO event. For example, during a very wet spring with significant volumes of rainfall, the stream flow rate would most probably be higher than average. The opposite would most probably be true during a dry or low rainfall volume spring.

4.3 SPREADSHEET ANALYSIS FOR COMBINED PROBABILITY OF CSO DISCHARGE AND STREAMFLOW

A spreadsheet analysis can be performed to provide a single value for the probability of exceedance of a single instream concentration, for example 2000 most probable number per 100ml (MPN/100ml) bacteria. To obtain the single value, the probability of background streamflow and concentration would be combined with the probability of CSO flow rate and concentration.

The process of combining probabilities would be completed along the length of the stream for each CSO encountered. For each new CSO encountered, the background streamflow will have increasingly higher concentrations of bacteria if the upstream CSO was also discharging. The analysis would not include decay; therefore, travel time would be irrelevant. The other possible approach is to sum all CSO discharges system wide and apply the system wide flow and concentration probability (i.e. load) to the stream background flow and concentration. The system wide approach would best be applied at the downstream end of the CSO areas.

4.4 MONTE CARLO ANALYSIS TO COMBINE PROBABILITIES OF CSO DISCHARGE AND STREAMFLOW

A Monte Carlo analysis would be a more advanced approach as compared to the dilution only model. A Monte Carlo analysis would use the probability distributions of stream flow rates, instream concentrations, CSO flow rates, and CSO concentrations as inputs to the dilution equation. The equation would be solved 1000 or more times with each solution using a randomly selected value from each probability distribution.

The Monte Carlo results would be presented as frequency or cumulative frequency distributions of the resulting modeled set of instream concentrations.

Determination of the percent of time that the instream concentration will exceed any value can be easily extracted from the distribution.

4.5 EXAMPLE CSO LTCP ALTERNATIVE ANALYSIS – USE OF DILUTION RESULTS

The results from the second approximation would be very similar to the statistical summaries from the first approximation. For example, a histogram of the duration of concentrations could be created that would be similar to the histograms presented in SECTION 3. The difference would be that the histograms and distributions would reflect predicted concentrations in the receiving stream, as opposed to end-of-pipe CSO measures.

5.0 THIRD APPROXIMATION ANALYSIS

The third approximation method incorporates dilution, transport, fate, and decay modeling using either a steady state or dynamic model. The dilution-transport-fate-decay modeling is the only analysis that is capable of predicting the complex interactions between multiple CSO contaminants such as ammonia and CBOD impacts on dissolved oxygen. Again, it is important to recognize that the impacts of bacteria will most likely dominate the analysis since it will be the most difficult water quality criterion to meet. Identifying an alternative that meets bacteria water quality standards through CSO reduction is expected to also meet other water quality standards such as ammonia and instream DO levels.

5.1 USE OF ESTIMATED END-OF-PIPE MEASURES FROM THE SWMM MODEL OUTPUT

The specific use of the SWMM model output in this third approximation analysis depends on the choice of steady state or dynamic modeling. If steady state modeling in QUAL2E is chosen, then the end-of-pipe summary statistics determined in SECTION 3.2 above will be used as inputs for the QUAL2E model. If dynamic modeling is used, then the full hydrograph output of the continuous SWMM simulation will be used as the input to the dynamic WASP model. In either case, an event mean concentration of the modeled parameters would have to be combined with the SWMM model output to develop the appropriate load inputs.

5.2 QUAL2E MODEL SIMULATION – WORST CASE STEADY STATE

QUAL2EU is a USEPA developed receiving water model capable of predicting the steady-state transport, fate, and decay of DO, CBOD, nitrogen, phosphorus, suspended algae, and fecal coliforms as well as three user defined constituents. The City already has a well-developed QUAL2E model for the Scioto River downstream of Greenlawn Dam and for Alum Creek and Big Walnut Creek downstream of Livingston Avenue. The QUAL2E analysis can be used to examine the instream DO response and pathogen decay under steady-state flow conditions. It is important to realize that the pathogen capability of QUAL2E is a simple first order decay process and it is only affected by temperature. Pathogens have no effect on, nor are they affected by, any other process in the QUAL2E model.

For this application, the existing QUAL2E model would be run at low wet-weather flow rates determined from historical streamflow data. The lower flow rates are considered conservative and would reduce reaeration and travel time, causing reduced pathogen transport and greater dissolved oxygen sags to occur in the stream. The inputs at CSO discharge points are entered as boundary conditions.

On the Scioto and Olentangy Rivers, all of the CSO discharge points would be entered at the headwater of the existing model, which is Greenlawn Dam. Greenlawn Dam is also the location of the most significant CSO on the Scioto River, the Whittier Street Storm Tanks. Any CSO discharge points downstream of the Greenlawn Dam would be input at the appropriate location.

There is only one CSO discharge point on the Alum Creek. The Alum Creek Storm Tanks are approximately 3100-feet upstream of the current upper boundary of the QUAL2E model of Alum and Big Walnut Creeks. The Alum Creek Storm Tank would be input as part of the headwater condition of the model.

The QUAL2E model is a conservative method of examining the stream response for CSO LTCP development because all of the loadings will be entered as constant, and at their maximum level, rather than time-varying. The USEPA LTCP Modeling Guidance recognizes QUAL2E as a model valid for analyzing receiving water impacts. Furthermore, the guidance documents note that QUAL2E is conservative in this application and will provide worst-case predictions. In other words, the instream concentrations would not be expected to exceed the results predicted by the model. Different alternatives would be compared based on the results of the QUAL2E model. The longitudinal extent of the impacts from CSO contaminants could also be identified from the QUAL2E model, although the predicted longitudinal extent may be non-conservative given the use of lower streamflow rates.

The current QUAL2E model will require validation with wet weather data. The validation work is currently proposed to be completed.

5.2.1 QUAL2EU Uncertainty Analysis

The Monte Carlo analysis option of QUAL2EU could be invoked for a more robust analysis of the receiving water quality impacts. The Monte Carlo analysis would be very similar to the spreadsheet version of Monte Carlo analysis in SECTION 4.4 except QUAL2EU has a built-in Monte Carlo tool. The characteristics of all of the modeled constituents would have to be examined to identify the best probability distribution and also the coefficient of variance (standard deviation/mean). The Monte Carlo analysis results could be presented in a frequency distribution or cumulative frequency distribution.

5.3 WASP MODEL SIMULATION – COMPLEX DYNAMIC ANALYSIS

WASP is another USEPA-developed model that can be used to model the transport, fate, and decay of the same parameters as QUAL2E, along with many more parameters. WASP is a dynamic model that can simulate time-varying streamflow rates along with time varying loading sources such as CSOs, rather than applying them as worst-case, steady-state sources. The WASP model would be a more realistic representation of the river and CSO system under wet-weather conditions.

The information on the physical configuration of the river reaches in the current QUAL2E models could be used to develop the WASP models for those reaches. Extending the WASP model upstream of the Greenlawn Dam would be significantly more difficult and costly due to the required data collection effort.

5.3.1 Coupling WASP with SWMM Model

The SWMM model output hydrographs would be used as a time-varying input for the WASP model. Event mean concentrations would be applied to the hydrograph thereby developing the appropriate loads for the modeled parameters. The location of the CSO inputs incorporated in the model will depend on the extent of the modeled network.

5.3.2 WASP Based on Existing QUAL2E Network

The representation of river reach characteristics and hydrodynamics in the current QUAL2E model can be converted for use in WASP. The WASP model would require calibration and validation to existing wet-weather flow and water quality data and quite possibly some new wet-weather data.

5.3.3 WASP Based on Extended Network for Dam Pools

WASP (or more generally a dynamic model) is the only recommended dilution, transport, fate, and decay model for the area upstream of Greenlawn dam. The extensive pools created by the dams result in slow moving water and applying constant CSO sources would be overly conservative. Using time-varying CSO loading in the dam pools would be more appropriate. Extending the model network upstream of Greenlawn Dam would allow the CSO inputs to be located at their actual discharge points into the pools.

Extending the network upstream of Greenlawn Dam will require a significant data collection effort to define the hydraulics in the dam pools. The data collection effort was noted previously in SECTION 2.0. In particular, data would need to include continuous flow monitoring at multiple sites, stage-discharge curve development and time of travel studies.

5.3.4 Simulation of Conservative and Non-Conservative Pollutants

WASP can readily model DO, CBOD, ammonia, nitrogen, phosphorus and bacteria. Furthermore, WASP has the capability to model sediment processes, although sediment modeling adds a significant level of complexity to the model and data collection effort. Bacteria are still the most likely contaminant to focus on given the difficulty in meeting bacteriological water quality standards under wet weather conditions.

The WASP model for either network will be run continuously for the same time period as the SWMM model. The results of the WASP model are time-varying instream concentrations for the modeled parameters. These results can be presented as a cumulative frequency distribution of parameter concentrations, and these distributions can be used to compare abatement alternatives. The longitudinal extent of the water quality impacts resulting from CSO discharges can also be reasonably predicted via the WASP model.

5.4 EXAMPLE CSO LTCP ANALYSIS – USE OF WASP MODEL OUTPUT

The following table presents an example of how continuous WASP model output can be used to assess the impact of CSOs in terms of water quality standards exceedances. These results are from a continuous 6-month simulation using a calibrated WASP model of the Cuyahoga River. Several points can be identified from the table.

- The table shows that the majority of the modeled river reaches violated the Fecal Coliform Geometric Mean requirement of 1000 coliform per 100ml for 2 months out of the 6-month recreational period (see SECTION 7 for details on the water quality standard for fecal coliforms).
- The 10-percent rule of the fecal coliform water quality standard, i.e. no more than 10-percent of the samples in a 30-day period can exceed 2000 coliform per 10ml, was exceeded every month by 35 of the 38 discharge points. The remaining 3 discharge points exceeded the standard 5 months out of the 6-month simulation.
- The table shows that there were no exceedances of the DO standard in the stream during the six-month period. This particular result is in some ways unique to the project situation being used in this example.

The 10-percent rule observation highlights the concept that virtually any CSO discharge will result in an exceedance of the bacteriological water quality standard. The dynamic modeling used on the example project was necessary for other parameters; however, it is very relevant to observe that in terms of bacteria, the same conclusion regarding water quality exceedances could have been achieved using the first approximation analysis. The first approximation would have taken significantly less time and dollars to complete.

TABLE 12-11
Summary of Water Quality Violations
Cuyahoga River
(Based on Predictions From the Water Quality Model for the Six-Month Recreational Period (May-October))

	Number of Months when the Fecal Coliform Geometric Mean is greater than 1000 col. per 100 ml	Number of Months that the Fecal Coliform samples exceed 2000 col. per 100 ml more than 10% of the time	Number of Months in Violation of the Primary Contact Bacteriological Standard	Number of Days in Violation of the DO Standard
CR(46-38)	0	6	6	0
CRL(45-85)	0	6	6	0
CR(45-08)	0	6	6	0
CRL(44-86)	0	6	6	0
Dam	0	6	6	0
CR(44-3)	0	6	6	0
CR(43-4)	0	6	6	0
CR(43-3)	0	6	6	0
CR(43-2)	0	6	6	0
CR(43-1)	0	6	6	0
CR(42-5)	0	6	6	0
CRL(42-4)	0	6	6	0
CR(41-4)	2	6	6	0
CR(41-3)	2	6	6	0
CRL(41-2)	2	6	6	0
CR(40-4)	2	6	6	0
CR(40-3)	2	6	6	0
CR(40-2)	2	6	6	0
CR(40-1)	2	6	6	0
CR(39-4)	2	6	6	0
CR(39-3)	2	6	6	0
CR(39-2)	2	6	6	0
CR(39-1)	2	6	6	0
CR(38-4)	2	6	6	0
CR(38-3)	2	6	6	0
CR(38-2)	2	6	6	0
CR(38-1)	2	6	6	0
CR(37-5)	2	6	6	0
CR(37-4)	2	6	6	0
CRL(37-45)	2	6	6	0
CR(37-30)	2	6	6	0
CR(37-10)	2	6	6	0
CR(36-30)	2	5	5	0
CR(35-60)	2	5	5	0
CR(34-38)	2	5	5	0
CRL(42-2)	2	6	6	0
CRL(44-2)	0	6	6	0
CRL(45-42)	0	6	6	0

6.0 PREVIOUS WORK

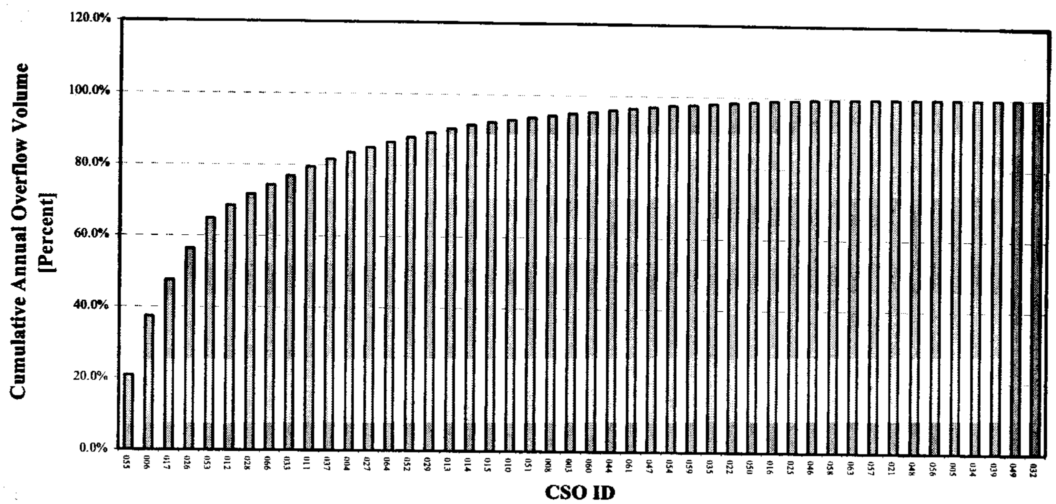
6.1 BUFFALO SEWER AUTHORITY, NEW YORK

Malcolm Pirnie is the Coordinating Consultant for the Buffalo Sewer Authority's development of a CSO LTCP. As the Coordinating Consultant, Malcolm Pirnie is leading a team of four consultants on the project, and is responsible for model development, characterization of existing conditions, and preparing data collection and alternative screening protocols for use by the other three consultants working in their respective drainage areas (Districts).

BSA's 68 CSOs discharge into the Buffalo River, Black Rock Canal, and Niagara River, along with several major urban streams that run through the City of Buffalo. Early in the project, it was recognized that attainment of water quality standards would be an imperfect measure for comparing CSO abatement alternatives, given the significant background concentrations in BSA's receiving waters. Therefore, sophisticated water quality modeling was not incorporated in the project; rather, predicted end-of-pipe CSO measures were used to prioritize CSOs under existing conditions, and provide a measure of benefit for abatement alternatives. Sophisticated water quality modeling may still be pursued in local sensitive areas, but only where its usefulness is demonstrable; its use as a system-wide analysis tool was not warranted.

An example of the use of predicted end-of-pipe measures from continuous XP-SWMM model simulations for the BSA project is shown below. This figure shows predicted annual overflow volume by CSO, and can be used to quickly identify the significant contributors in terms of annual CSO volume. From this figure, it is clear that approximately 80 percent of the annual system-wide CSO volume comes from the top ten CSOs.

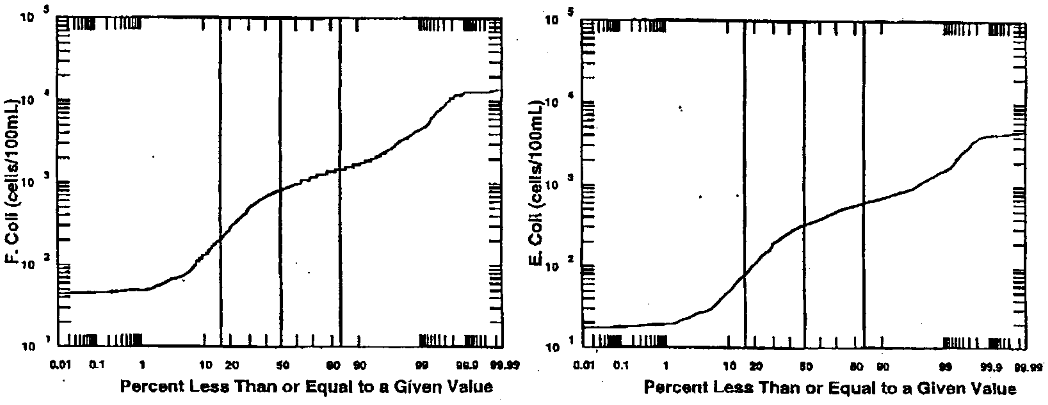
Figure 5-2
Cumulative percent of total 12 month overflow volume by CSO



6.2 CITY OF FORT WAYNE, INDIANA

The City of Fort Wayne, Indiana, submitted their draft CSO LTCP to the Indiana Department of Environmental Management and USEPA in July of 2001. The draft LTCP has been reviewed by USEPA, and the City is currently engaged in comment response and negotiation.

A team of consultants led by Malcolm Pirnie developed the LTCP for the City, including dynamic collection system and receiving water modeling tools. The receiving water modeling tools were used to characterize CSO impacts under existing conditions to a high level of detail, resulting in concentration frequency distributions such as those shown below.



Example Pathogen Frequency Distribution in a Fort Wayne Receiving Water Reach

Predicted end-of-pipe measures were used as the primary method to characterize the benefit of improvement alternatives, with reductions in CSO activations used as a surrogate for reduction in number of bacteriological water quality exceedances.

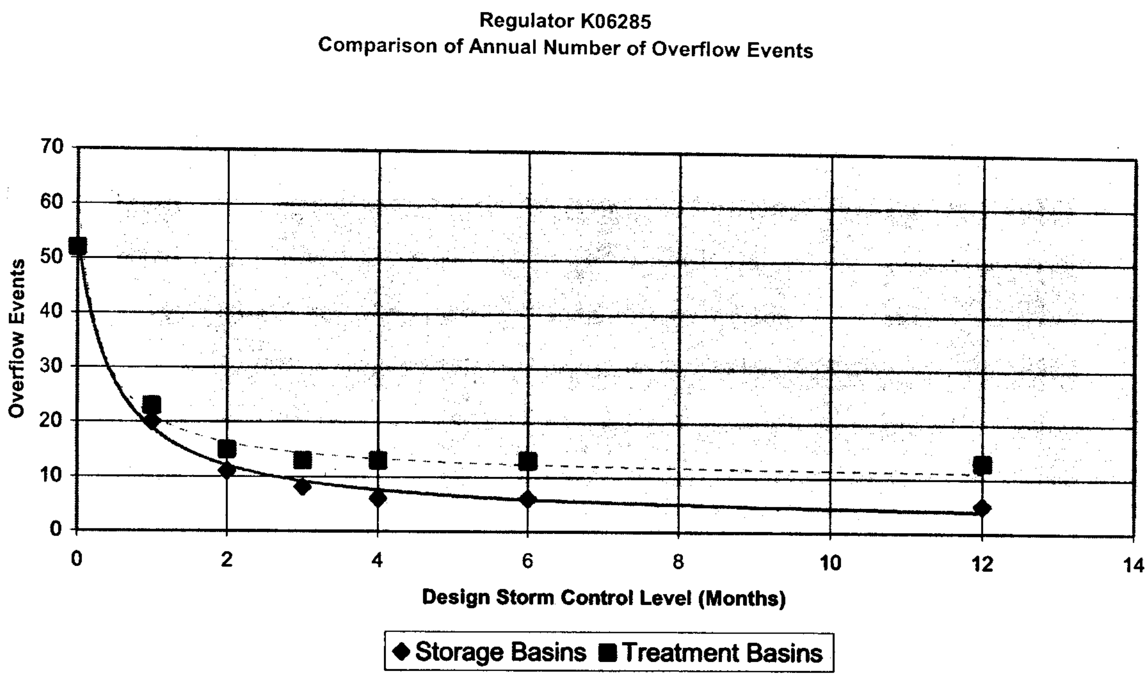
6.3 CITY OF AKRON, OHIO

The City of Akron submitted their draft CSO LTCP to Ohio EPA in early 2000. They are currently in the final stages of negotiating the final LTCP with Ohio EPA and USEPA.

Malcolm Pirnie was the modeling consultant on the City's LTCP development team. Using XP-SWMM for the collection system, and WASP for the receiving streams, a number of continuous annual simulations were performed. Conclusions from the modeling of existing conditions were as follows:

- Dissolved oxygen depression does occur during wet-weather events, but exceedances of DO water quality standards are rare.
- Exceedance of bacteriological water quality standards occurs regularly during wet weather, due to both upstream concentrations and CSO discharges.

Given these conclusions, widespread use of the water quality modeling tools to assess the benefit of alternatives in terms of attainment of water quality standards was not warranted, since attainment would not be sensitive to CSO control levels to to background concentrations. Rather, reduction in end-of-pipe measures was used as the primary measure of benefit for assessment of abatement alternatives. This approach allowed the team to identify a "knee-of-the-curve" control point for each CSO, where the incremental increase in benefit (as measured by reduction in end-of-pipe activity) starts decreasing with increase in control level. An example of this level of control relationship is shown below.



7.0 PATHOGEN MODELING

Throughout this paper, pathogens have been identified as the single most difficult water quality parameter of concern with the City's CSO discharges. The basis of this concern includes the current water quality standards for pathogens, the average concentration of pathogens in CSO discharge, and previous LTCP development experience.

The current water quality standard for pathogens is as follows:

Primary contact pathogen standard for Ohio requires that one of the two following bacteriological standards are met:

Fecal coliform *- geometric mean fecal coliform content (either MPN or MF), based on not less than five samples within a thirty-day period, shall not exceed 1,000 per 100 ml and fecal coliform content (either MPN or MF) shall not exceed 2,000 per 100 ml in more than ten per cent of the samples taken during any thirty-day period.*

E. coli *- geometric mean E. coli content (either MPN or MF), based on not less than five samples within a thirty-day period, shall not exceed 126 per 100 ml and E. coli content (either MPN or MF) shall not exceed 298 per 100 ml in more than ten per cent of the samples taken during any thirty-day period.*

Typical total coliform concentrations for CSOs are reported as 10^5 to 10^7 MPN/100ml. With these discharge concentrations, the volume of dilution water alone would have to be at least 3 orders of magnitude greater than the CSO volume. For instance, if the CSO discharge rate were 10 cfs and bacteria concentrations were 10^7 MPN/100ml, then the stream would have to be flowing at 50,000 cfs and have zero background coliform concentrations. This would meet the 2,000 MPN/100ml limit. To put 50,000 cfs into perspective, a 500-year flood on the Olentangy River is 28,700 cfs. The 10-year and 50-year floods at the USGS gaging station located at JPWWTP on the Scioto River are 37,000 cfs and 60,400 cfs respectively. According to 10-State Standards, a wastewater treatment plant can cease operations past 25-year flood events.

In addition, the current bacteriological standard does not explicitly allow for dilution to be accounted for in assessing attainment. Because there is no guidance on when or where samples are to be taken, the standard creates the possibility that a sample could be taken at a location where the effect of dilution or mixing has not been achieved. Because of this, the standard might be interpreted to effectively require that the concentration limits be met at all times, at all locations, in the receiving stream.

7.1 FIRST APPROXIMATION SUFFICIENT FOR CURRENT PRIMARY CONTACT USE DESIGNATION STANDARDS

For the reasons stated above, the first approximation analysis (summary analysis of end-of-pipe estimates from continuous SWMM model simulation) is considered a valid measure of existing conditions and abatement alternative performance. Any CSO discharge will most likely cause an exceedance of the current primary contact standard for bacteria, so the "measure" of exceedance for the purposes of the analysis is a predicted CSO activation.

7.2 ADVANTAGES/DISADVANTAGES OF FIRST APPROXIMATION

The first approximation analysis for evaluating the LTCP alternatives has the following advantages:

- Rapid Analysis of Pathogen Impacts
- Significant Cost Savings
- Does Not Require an Extensive Data Collection Effort
- Readily Available Tools
- Does Not Require Instream Background Concentrations
- Attainment of Pathogen Criteria Through CSO Reduction will most likely result in Attainment of other Water Quality Criteria

The disadvantages of the first approximation analysis are as follows:

- Does Not Identify Instream Concentrations of Pathogens
- Omits Dilution, Transport, Fate, and Decay (Duration and Longitudinal Extent of Exceedance is Not Determined)
- Does Not Allow for Analysis of Parameters With Significant Instream Fate and Transport Characteristics (e.g., CBOD/DO).
- Does Not Support Discussion of Modifying Water Quality Standards.

8.0 CITY OF COLUMBUS RECOMMENDATION

There are many ways to approach the evaluation of CSO impacts on receiving waters as part of a CSO LTCP development process. Obviously, conducting the full suite of evaluations is typically not feasible due to cost and schedule considerations. More importantly, complex analyses will most likely not result in significant differences in the outcome of the CSO LTCP recommended alternative, given that the controlling factor is typically the requirement to attain current water quality standards for pathogens

8.1 SELECTING CRITERIA OF INTEREST

The first major step to determining an acceptable modeling and analysis approach is to determine the criteria of interest. The single most difficult water quality standard to attain is that for pathogens; therefore, it is the recommended focus for the City's LTCP analysis. Ammonia toxicity and dissolved oxygen depletion are also parameters of concern with CSO contaminants, but it is anticipated that they will not be an issue if the water quality standards for bacteria are attained through CSO reduction. If technology such as disinfection is used at any CSO discharge point, it may be necessary to consider other parameters.

8.2 RECOMMENDED MODELING APPROACH

8.2.1 Pathogens and Second Approximation

The recommended primary modeling approach for the CSO LTCP is to use the second approximation analysis as outlined in SECTION 4.0. The second approximation approach can be applied to the CSO discharge points on the Olentangy River, the Scioto River, and the Alum Creek. This includes the analysis of the dam pools, which have significantly different hydraulics than the areas on the Alum Creek and the Scioto River downstream of Greenlawn Dam. Additional types of modeling in the dam pools would require significant data collection efforts to define the hydraulics of the pools, with potentially no additional benefit to analyzing and comparing alternatives in terms of attainment of bacteriological water quality standards.

8.2.2 Detailed Dilution Decay Modeling

If analysis of the CSO impacts for parameters such as DO and ammonia is required, an analysis can be effectively conducted using the existing QUAL2E models. Analysis of DO, ammonia and CBOD would be necessary if there is still a significant discharge volume at any CSO location but the discharge is disinfected. SECTION 5 covers the QUAL2E modeling in more detail. The USEPA LTCP Guidance documents support QUAL2E and note that it can be used in this manner, with the understanding that the results will represent worst-case conditions.

8.3 PRESENTATION OF RESULTS

8.3.1 Summary Statistics of Exceedances

The results of the second approximation analysis would primarily be summary statistics of in stream concentrations based on the SWMM model output and historical streamflow. The output can be processed into frequency distributions that would allow the likelihood of exceedance of bacteriological water quality standards to be determined. The LTCP alternatives would be compared based on the statistical evaluation.

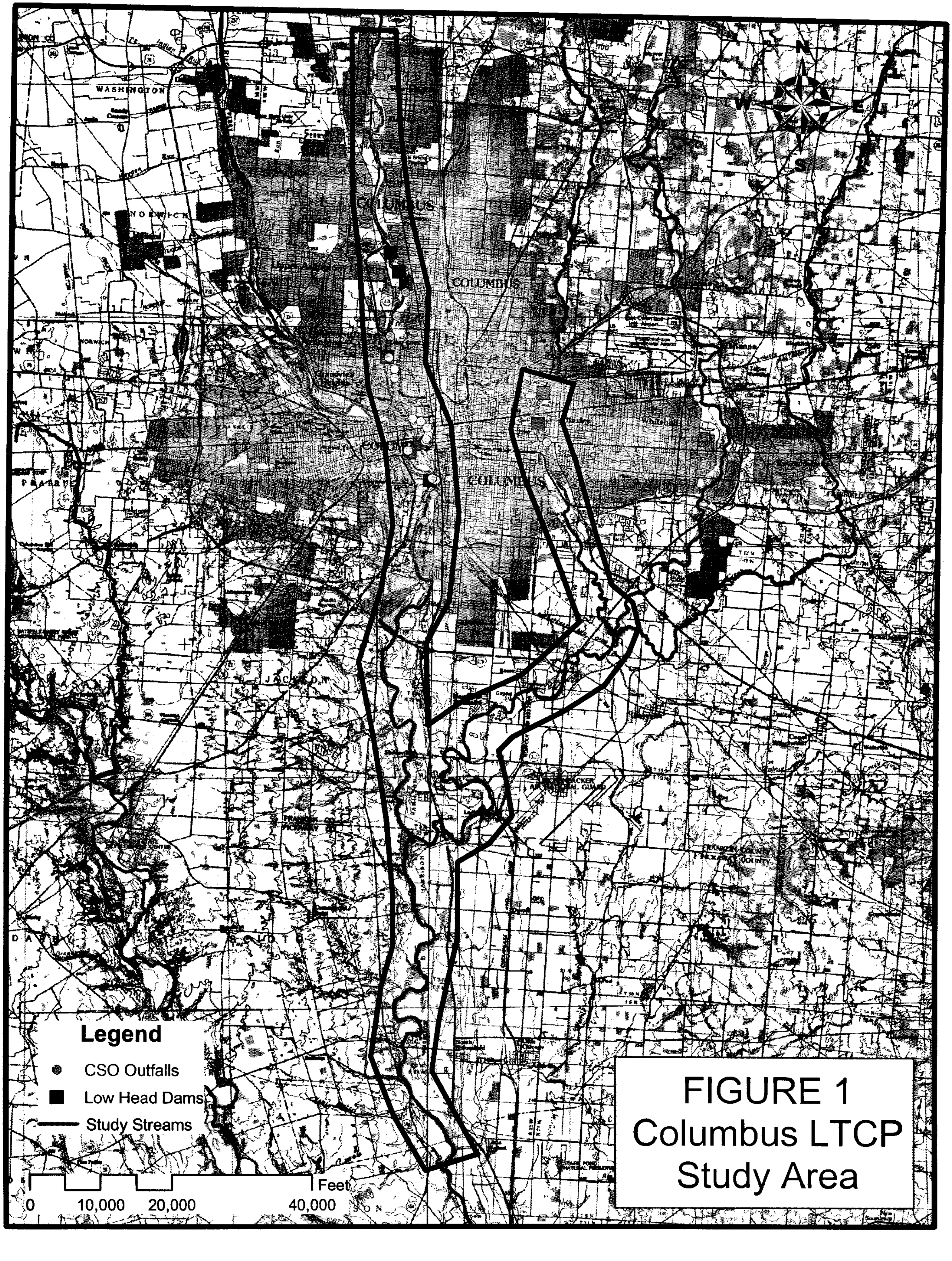


FIGURE 1
Columbus LTCP
Study Area