# Appendix 4-2

Wabash River Model Baseline "Typical Year" Scenario

LimnoTech
Water | Environment | Scientists | Engineers

# MEMORANDUM

**DATE:** October 30, 2008 (Draft submitted June 2008)
**FROM:** Carrie Turner
**PROJECT:** TRHCSO, Baseline River Model

**FINAL FOR AGENCY REVIEW**

**TO:** Toni Presnell (HWC)

**CC:** Mark Thompson (City of Terre Haute), Chuck Ennis (City of Terre Haute)

**SUBJECT:** Wabash River Model Baseline "Typical Year" Scenario

---

## Introduction

This memorandum presents the results of the baseline scenario simulation of a "typical" year (1978) from the Wabash River water quality model being used by the City of Terre Haute to evaluate in-stream impacts from bacteria sources in the watershed, including discharges from their combined sewer overflows (CSOs). The river model's spatial extent spans over 17.5 miles of the Wabash River, from upstream of the City of Terre Haute at river mile (RM) 217.5 downstream to RM 200.0. The model extends approximately 11.5 miles downstream of the City's wastewater treatment plant (WWTP), the City's most downstream source of *E. coli* from Terre Haute.

The model framework being used for this simulation is the Branched Lagrangian Transport Model (BLTM) in cohort with Diffusion-Analogy Flow Model (DAFLOW), both developed by the United States Geological Survey (USGS). The framework for the Wabash River model was developed and calibrated using water quality data collected by the City in 2007. The sampling data used to calibrate and validate the model were described in the March 4, 2008 LimnoTech draft memorandum. The model calibration and validation were described in the April 30, 2008 LimnoTech draft memorandum. The model calibration and validation demonstrated that the linked water quality model framework was a reliable tool for the City to evaluate in-stream impacts from a variety of *E. coli* sources and that the model was suitable for evaluating the benefits of different CSO control alternatives.

The CSO Policy and subsequent EPA guidance recognizes that the annual performance of CSO controls will vary based on rainfall conditions. Long-term hourly rainfall and daily stream flow data were examined on an annual and summer (recreation season, April-October) basis, and compared to historical averages to identify 1978 as a "typical" period of rainfall and stream flow (LimnoTech, October 29, 2008 memorandum). This memorandum provides the results of the application of the river model for the selected "typical" or average year environmental conditions. The City plans to use the results of this scenario as a baseline to compare the effectiveness of CSO control alternatives on improving water quality in the Wabash River.

## River Model Inputs

The calibrated BLTM river model was applied for the baseline simulation. The configuration of the river model was described in detail previously (LimnoTech, April 30, 2008 memorandum) and so, is briefly reviewed in this section, including a description of the model domain, and the treatment of *E. coli* loss kinetics. External forcing (e.g. flows, bacteria loads, climate) inputs were adjusted to reflect 1978 conditions for this simulation and are also described in this section.

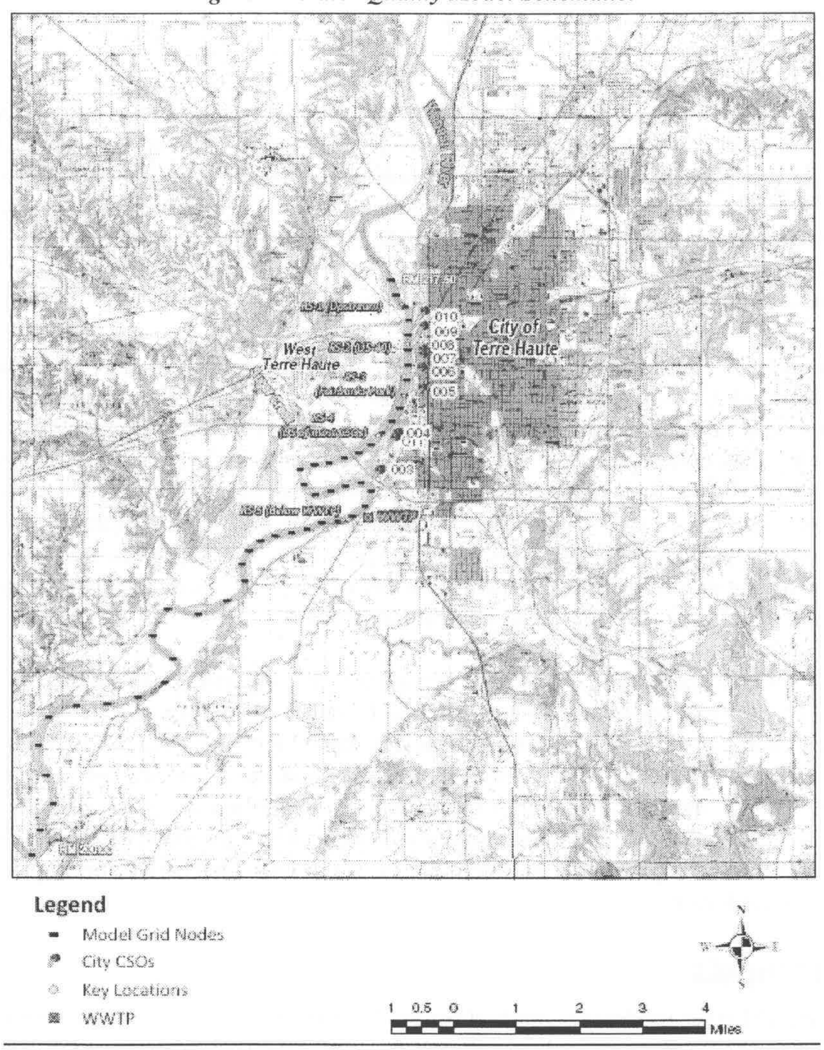
501 Avis Drive
Ann Arbor, MI 48108
**734-332-1200**
Fax: 734-332-1212
www.limno.com

## Model Domain

The model domain for the Wabash River extends from Vigo County at RM 217.5 downstream to RM 200.0, 11.5 miles downstream of the City's WWTP and all of the City's CSOs. A schematic of the model is shown in Figure 1. The extent of the model domain of the Wabash River was chosen for several reasons;

- The upstream boundary of the model is upstream of the City's CSOs and will provide insight to the loads not originating from Terre Haute;
- The model domain includes Sugar Creek, a tributary to the Wabash River, which may identify another potential source of *E. coli*; and
- The model extends over fourteen miles beyond the last CSO outfall and 11.5 miles beyond the City's WWTP (at RM 211.50), which allows an assessment of the impact of the City's sources on water quality downstream of the City.

***Figure 1. Water Quality Model Schematic.***




## In-stream Loss Rate

The bacterial loss rate is a first-order rate that accounts for losses of *E. coli* in the water column due to die-off and net settling. A loss rate of 1.0/day, with an Arrhenius temperature correction coefficient of

1.02, was applied to calibrate the model (LimnoTech, April 30, 2008 memorandum). These values will be used in all subsequent simulations, including the baseline scenario presented in this memorandum.

## Hydrologic Data

The BLTM river model requires temporal and spatial inputs of flows and concentrations. Historical hydrology records from 1978 were obtained from a USGS gage (gage no 03341500) at US-40, which is less than a mile downstream from the model's upstream boundary. The additional inflow from watershed sources between the model boundary and the gage are nominal compared to the river volume so the data were used directly in the model for the baseline simulation.

In-stream water temperatures, which affect the rate of bacteria die-off, were input as monthly average values that were calculated from historical data (collected by the City, IDEM and USGS) and data from the City's 2007 Sampling Program.

## *E. coli* Sources

This section describes the specific data used to develop flows and loads for each bacteria source included in the baseline scenario simulation. Table 1 presents a summary of the sources of bacteria included in the model. For this baseline scenario, specific sources were tracked within the model by assigning them to a unique state variable. The state variables were set up so that the City could easily assess contributions to in-stream concentration by major source types (e.g. CSO vs. upstream, tributary vs. WWTP). *E. coli* source types included in the model are upstream, tributary nonpoint source, CSOs, storm water (SWOs), wastewater treatment plant (WWTP) effluent, and drainage from areas adjacent to the rivers (direct drainage). The model calculates the total *E. coli* concentration as the sum of the results from the individual state variables.

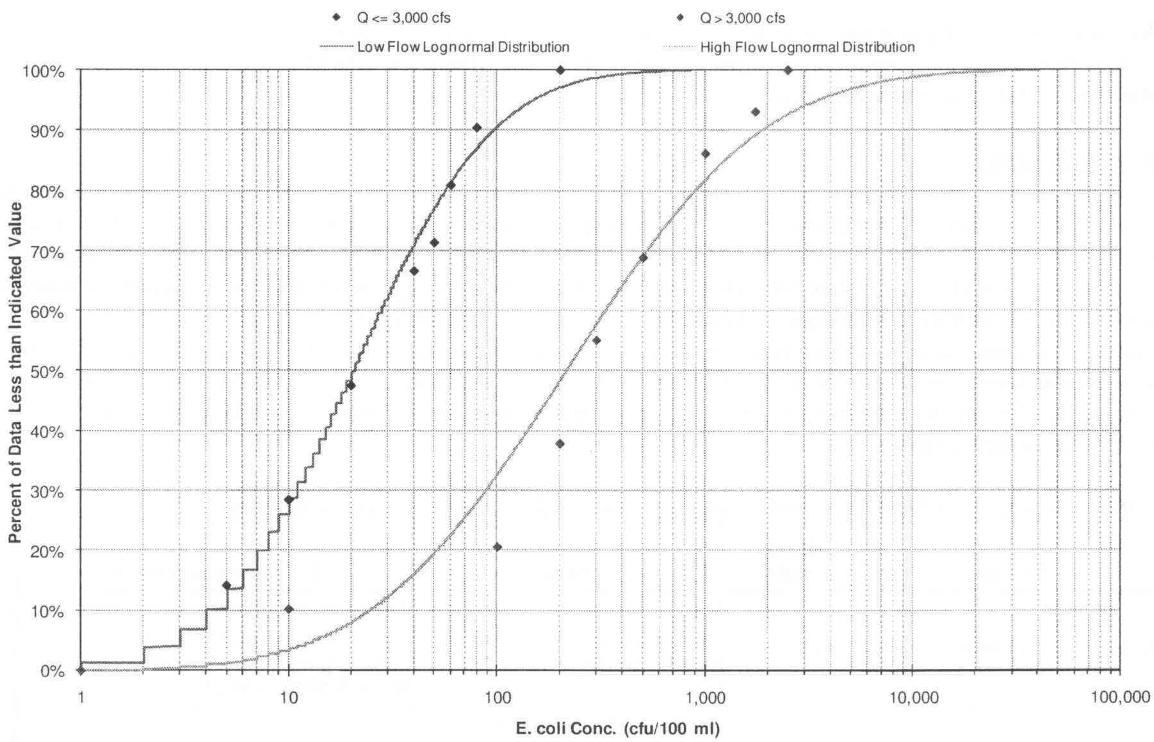
***Table 1. Summary of Flow and E. coli Load Data Sources for the Typical Year Simulation.***

| Source | State Variable | Flow | *E. coli* Concentration |
|---|---|---|---|
| Wabash River-Upstream | $EC_{US}$ | USGS gauge (03341500) at US-40. Bridge | Algorithm based on flow and rainfall to reproduce characteristics in all sampling data near the most upstream River Station (RM 217.50) |
| Sugar Creek- Tributary | $EC_{TRIB}$ | Average of drainage area ratio-adjusted flows from USGS gauges at Mill Creek (03358000) and Wabash River (03341500) | Derived representative high-flow and low-flow E coli concentrations (used in calibration) |
| Direct Drainage | $EC_{DD}$ | Calibration value | Calibration values |
| Terre Haute CSOs | $EC_{CSO}$ | Collection system model | EMC = 475,000 (cfu/100mL), established from 2007 sampling events |
| Terre Haute SWOs | $EC_{SWO}$ | Rational method (Q=ciA) | EMC = 5,000 cfu/100 ml (median concentration from 2007 SWO Sampling Program) |
| Terre Haute WWTP | $EC_{WWTP}$ | Collection system model | Monthly geometric mean values, determined from WWTP MRO data (2003 - 2008) |

<u>*Upstream E. coli Load*</u>

A representative upstream *E. coli* concentration time series was developed by analyzing all available *E. coli* data near the model's boundary at river mile 217.5. The 2007 Sampling Program and subsequent analysis indicated that upstream conditions (e.g. flow and concentration) are not significantly changed by local precipitation. However, the analysis of *E. coli* data indicated that concentrations were relatively consistent at flows below 3,000 cfs and showed more variability at flows greater than 3,000 cfs. The data were segregated into two datasets based on this flow threshold and a lognormal statistical distribution was fitted to each dataset, as shown in Figure 2.

***Figure 2. Statistical Distribution of Upstream E. coli Concentration Data.***



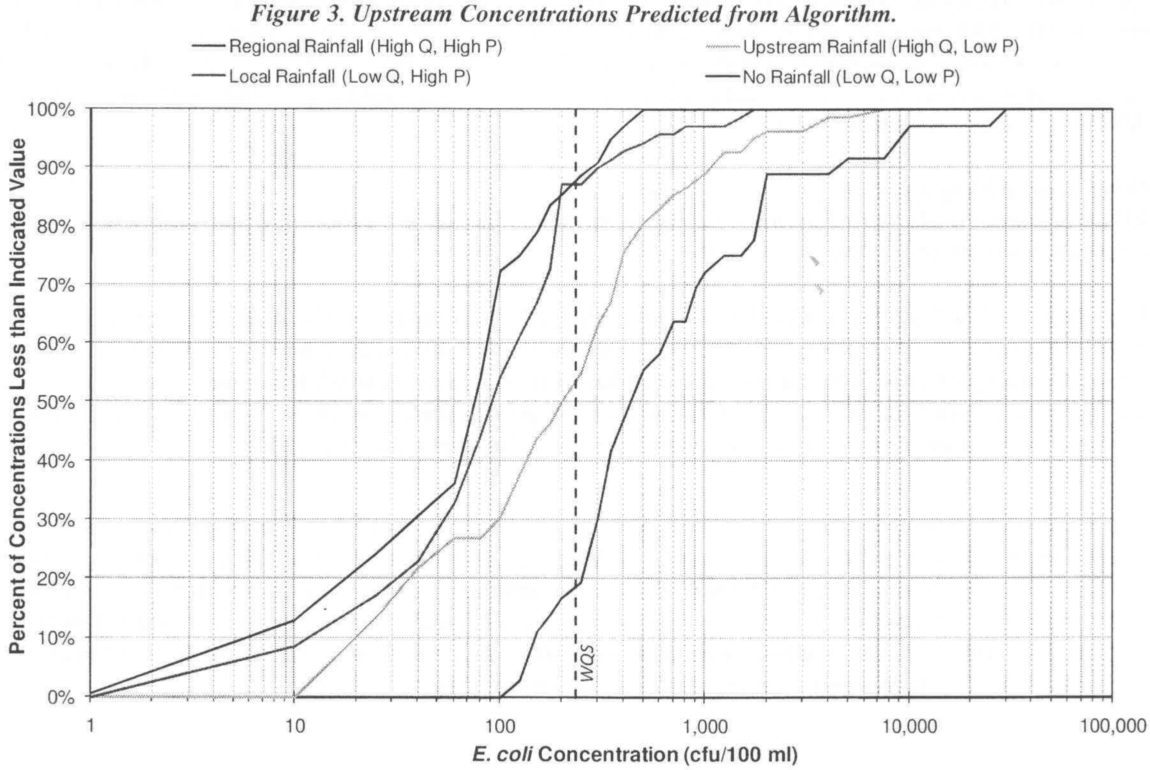

The rainfall data were characterized as local versus regional while the flow was characterized as high or low based on comparison to the long-term average flow for that day. An algorithm was developed that randomly selected a daily concentration value from the appropriate distribution shown in Figure 2 based on the combination of flow and rainfall. The assumptions and corresponding algorithm are described in Table 2.

***Table 2. Upstream E. coli Concentration Algorithm Assumptions***

| | | Local Precipitation | |
| --- | --- | --- | --- |
| | | High | Low |
| Flow | High | **Regional rainfall (36 days)**<br>• Upstream load effect, likely elevated.<br>• Select values from upper 2/3 of high flow distribution (orange line in Figure 2)<br>• Conc. Range: 104 - 28,263 cfu/100 ml<br>GM = 624 cfu/100 ml<br>81% of 36 values > 235 cfu/100 ml | **Upstream rainfall (82 days)**<br>• Upstream load effect.<br>• Select values from entire range of high flow distribution (orange line in Figure 2)<br>• Conc. Range: 13 – 5,945 cfu/100 ml<br>GM = 169 cfu/100 ml<br>45% of 82 values > 235 cfu/100 ml |
| Flow | Low | **Local rainfall (70 days)**<br>• Limited upstream load effect<br>• Select values from entire range for flows in low flow distribution (blue line in Figure 2) and from lower half of high flow distribution (orange line in Figure 2)<br>• Conc. Range: 3 – 1,595 cfu/100 ml<br>GM = 80 cfu/100 ml<br>13% of 70 values > 235 cfu/100 ml | **No rainfall (177 days)**<br>• Little upstream load effect<br>• Select values from lower 2/3 of low flow distribution (blue line in Figure 2)<br>• Conc. Range: 1 - 446 cfu/100 ml<br>GM = 58 cfu/100 ml<br>13% of 177 values > 235 cfu/100 ml |

The resulting distribution of concentrations for each flow-precipitation combination used in the model are shown in Figure 3. The daily time series was interpolated to an hourly time series to better represent the dynamics of the upstream load.

***Figure 3. Upstream Concentrations Predicted from Algorithm.***



*CSO Flow and Concentration Inputs*
An hourly time series of CSO discharge volumes was provided by Greeley and Hanson using a calibrated model of the Terre Haute combined collection system. The model used the 1978 rainfall data as input to generate an output containing hourly flows from each CSO outfall. The flow time series for each CSO was used directly in the Wabash river model. The CSO discharges were assigned the same concentration used to calibrate and validate the model (475,000 cfu/100 mL), which was determined from the 2007 Sampling Program, discussed in detail in LimnoTech, April 30, 2008 memorandum. Table 3 summarizes the overflow characteristics for each of the City's CSOs for a "typical" year.

***Table 3. Overflow Characteristics by CSO for a Typical Year.***

| | | Total Overflow Volume (MG): | Total Hours of Overflow: | Total Number of Events: |
|---|---|---|---|---|
| CSO 010 | Spruce | 76.1 | 93 | 21 |
| CSO 009 | Chestnut | 76.3 | 339 | 30 |
| CSO 008 | Ohio | 12.6 | 131 | 32 |
| CSO 007 | Walnut | 116.7 | 145 | 27 |
| CSO 006 | Oak | 7.8 | 74 | 21 |
| CSO 005 | Crawford | 15.4 | 145 | 29 |
| CSO 004 | Hulman | 229.3 | 222 | 33 |
| CSO 011 | Idaho | 137.1 | 165 | 29 |
| CSO 003 | Turner | 18.6 | 90 | 21 |
| Totals | | 690.0 | 362 | 33 |

*Wastewater Treatment Plant (WWTP) Flow and Concentration Inputs*
The WWTP hourly discharge volume time series was also provided from the collection system model applied by Greeley and Hansen. The monthly average *E. coli* effluent concentrations calculated from the plant's 2003-2008 monitoring data were applied to the WWTP effluent during the recreation season. For the winter season, a data-derived non-disinfection value of 5,000 cfu/100 mL was used in the model. This value is consistent with monitoring data collected by other Indiana communities during the winter when WWTPs typically do not disinfect.

*Other Source Flow and Concentration Inputs*
All other source loads were determined in the same manner as for the calibration period. These load determinations are briefly explained below.

The tributary flow from Sugar Creek was derived from flows observed in the Wabash River (gage no 03341500) and a nearby tributary (Mill Creek, gage no 03358000) because limited flow data were available in Sugar Creek. The drainage areas of Mill Creek and the Wabash River were used in ratio to the drainage area of Sugar Creek to determine an appropriate estimate of flow. A daily flow time series for the periods of interest in Sugar Creek were generated for use in the river model.

A number of dates from the Sugar Creek USGS gage (gage ID 03341540) dataset contained both measurements of flow and *E. coli* concentration. These data were used to establish a relationship between the flow and average *E. coli* concentration. *E. coli* concentrations were assigned for high-flow and low-flow conditions in Sugar Creek using the average *E. coli* concentration measured above and below the median flow. These *E. coli* concentrations were applied to the daily flow series calculated for Sugar Creek to estimate the *E. coli* concentration at the mouth of Sugar Creek.

Storm water volumes and loads for the City were calculated using the same methods used in the model calibration. Rainfall data from the typical year were input into a Rational Method model of each storm water area to estimate the volume from each storm. An event mean concentration (nominally 5,000 cfu/100 ml, from 2007 Sampling Program) was applied to the volume to estimate the *E. coli* load.

A direct drainage load was added at two nodes along the Wabash River to allow the model to simulate *E. coli* loads outside of the Terre Haute collection system, such as wildlife contribution and failing septic systems. The model domain includes other developed areas, such as Taylorville, which may be a direct source of *E coli* loading to the river. Flow and load time series were estimated using values from literature.

### Climate Data

The river model requires climate information as model inputs. Hourly precipitation data were compiled from nearby gages (e.g. Clinton, Brazil) maintained by the National Oceanic and Atmospheric Administration (NOAA) as described in the memorandum describing the analysis and selection of the "typical" year (LimnoTech, October 29, 2007 memorandum). These data were used to estimate CSO volumes (with the City's collection system model), stormwater and nonpoint source runoff to tributaries over the simulation period.

## Baseline Results

This section describes the results of the model simulation of typical year conditions using the current collection system models applied in a continuous simulation configuration. A summary of the loads for each source type and a comparison to in-stream water quality standards are discussed in this section. In summary, CSOs and upstream sources are the predominant sources of *E. coli* in the Wabash River.

Indiana water quality standards include numeric criteria for single sample and 30-day geometric mean concentrations from April through October, inclusive, to protect recreational uses. Both criteria are important when evaluating total *E. coli* results. The river exceeds the State's single sample maximum criterion approximately 30% of the time during the recreation season. Terre Haute's CSOs alone cause exceedances of the single sample maximum criterion less than 5% of the time during the recreation season. Compliance with the 30-day geometric mean criterion were evaluated for total E. coli (e.g. the sum of all source contributions). The evaluation was done using a rolling 30-day period. The river complies with this criterion approximately half of the time.

### Summary of E. coli loads

Figure 4 summarizes the simulated percent contributions of each source type to the total *E. coli* load and flow volumes during the typical year simulation to the Wabash River. Tallies are presented for the entire year and for the recreation season only (April through October), which is when Indiana water quality standards are applicable. In both periods, upstream sources are the predominant source of *E. coli,* largely because this source is active in both dry weather and wet weather. CSOs, which are only active during wet weather, are also a significant source of *E.coli* and may be the predominant source of bacteria during storm events. Examples of bacteria load distribution over shorter periods of time were provided in the April 30 memorandum describing the model calibration to the 2007 Sampling Program data. Over a typical year, CSO discharges contribute 12% of *E.coli* load but less than 1% of flow volume. Table 4 provides a numerical tally of flow and load for each source type.

*Figure 4. Summary of Volume and E. coli :Load Contributions by Source Type*

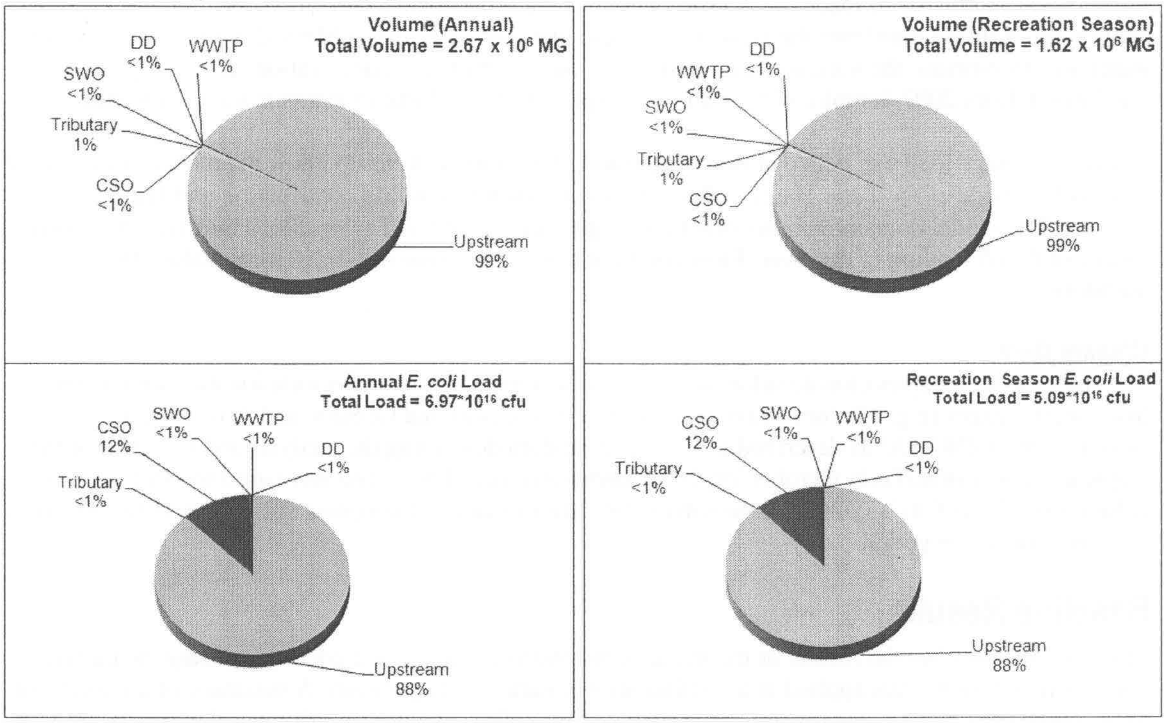



*Table 4. Total Flow and E. coli Load for Each Source Type During the Typical Year Simulation.*

| Source | Volume (MG) | E. coli Load (cfu) | Percent of Total Load |
|---|---|---|---|
| Upstream Wabash River | 2,641,607 | 6.12E+16 | 87.8% |
| Sugar Creek | 23,975 | 1.70E+13 | 0.0% |
| CSOs | 690 | 8.21E+15 | 11.8% |
| Terre Haute WWTP | 2,893 | 2.10E+14 | 0.3% |
| Stormwater | 493 | 9.33E+13 | 0.1% |
| Other (Direct Drainage) | 2.411 | 1.86E+11 | 0.0% |

<u>Water quality criteria exceedance evaluation</u>

The typical year baseline scenario simulation was used to evaluate the frequency with which in- stream *E. coli* concentrations are likely to exceed water quality standard numeric criteria developed by the State of Indiana to protect recreational uses. Two water quality criteria were used for the evaluation:

- The Indiana single sample standard of 235 cfu/100 mL, applied at all locations during Indiana's recreation season (April-October) and;
- The 30-day geometric mean standard of 125 cfu/100 mL, applied at all locations during Indiana's recreation season (April-October).

The exceedance frequency was evaluated at five key locations within the model domain as described in Table 5 and shown in Figure 1. These locations were also used as sampling stations during the 2007 Sampling Program.

**Table 5. Key Locations Used for Water Quality Exceedance Evaluation.**

| Location ID | Description | RM | Loading Sources |
|---|---|---|---|
| RS1 | Upstream Station | 217.50 | Upstream sources |
| RS2 | US-40 Bridge | 216.30 | CSOs 010 and CSO 009 |
| RS3 | Fairbanks Park | 215.50 | CSOs 005, 006, 007, and 008 |
| RS4 | Downstream of all but one of the City's CSOs | 214.70 | CSOs 004 and 011 |
| RS5 | Downstream of WWTP | 211.20 | CSOs 002 and 003, Sugar Creek, and WWTP |

The comparison to the single sample maximum standard was evaluated for total *E. coli* and for the portion of total *E. coli* originating from the City's CSOs. Results are shown in Table 6 at each of the key locations and include a summary of all hourly outputs during the specified period that exceeded the specified criteria. Approximately one-third of the hours during the recreation season exceed the criterion, due largely to upstream source loads. The impact from the City's CSOs alone cause exceedances for less than five percent of the hours in the recreation season.

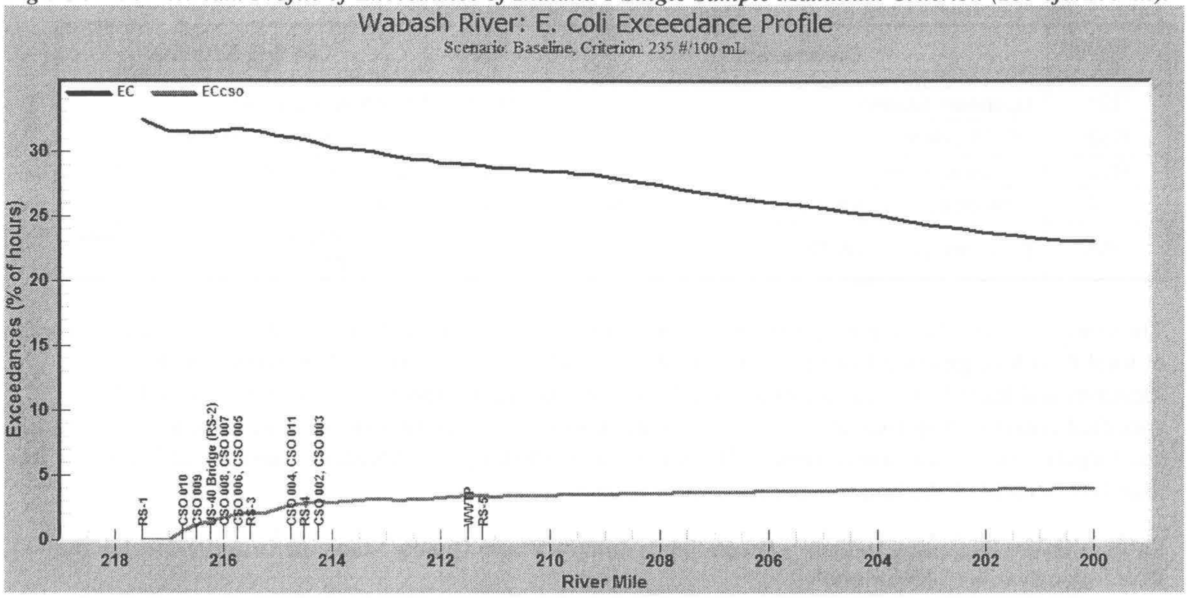
**Table 6. Hours Exceeding Indiana's *E. coli* Single Sample Water Quality Standard Criterion During the Recreation Season (5,136 hours)[1]**

| Location | River Mile | All Sources | | Terre Haute CSOs Alone | |
|---|---|---|---|---|---|
| | | hours | % hours | hours | % hours |
| Upstream of City CSOs | 217.50 | 1621 | 31.6% | 0 | 0.0% |
| US-40 Bridge | 216.30 | 1615 | 31.4% | 72 | 1.4% |
| Fairbanks Park | 215.50 | 1627 | 31.7% | 104 | 2.0% |
| Downstream of CSOs 004 and 011 | 214.70 | 1588 | 30.9% | 143 | 2.8% |
| Downstream of WWTP | 211.20 | 1484 | 28.9% | 174 | 3.4% |

Notes:
[1] Defined for Recreation Season only (April-October); Single Sample Maximum Criterion = 235 cfu/100 mL

The results in Table 6 indicate that no specific reach of the river tends to exceed the single sample maximum water quality standard criterion more than another reach. Figure 5 shows a comparison of compliance with the State single sample maximum criterion when all sources are considered (total *E.coli*) and from the City's CSOs alone for the entire modeling reach. The key locations presented in Table 6 are shown on the figure.

***Figure 5. Downstream Profile of Exceedance of Indiana's Single Sample Maximum Criterion (235 cfu/100 ml).***




For comparison to the 30-day geometric mean water quality standard criterion, the model results were tallied for rolling 30-day periods within the recreation season (April-October). There are 184 30-day periods in the recreation season. The geometric mean concentration for each 30-day period was calculated and compared to the criterion. Table 7 presents a summary of exceedances of this criterion at the key locations for all sources.

**Table 7. Frequency of Exceedance of Indiana's 30-day Criterion for Rolling 30-day Periods During the Recreation Season.**

| Location | River Mile | Indiana 30-day Criterion (125 cfu/100 ml) # of 30-day periods | % 30-day periods |
|---|---|---|---|
| Upstream of City CSOs | 217.50 | 102 | 47.7% |
| US-40 Bridge | 216.30 | 109 | 50.9% |
| Fairbanks Park | 215.50 | 116 | 54.2% |
| Downstream of CSOs 004 and 011 | 214.70 | 115 | 53.7% |
| Downstream of WWTP | 211.20 | 105 | 49.1% |

When considering the impact from all sources, the 30-day criterion is more restrictive than the single sample maximum criterion because a higher percentage (~50%) of rolling 30-day periods exceed the criterion (125 cfu/100 ml) than the number of days or hours (~30%) that exceed the single sample maximum criterion (235 cfu/100 ml). Though results are not summarized in this memorandum, in-stream impacts from the Cities' CSO loads alone were compared to these criteria. Consistent with the intermittent nature of CSO discharges, only the single sample maximum standards are exceeded.

An additional evaluation was performed by calculating the monthly average concentration to provide insight into seasonal in-stream concentration trends. The results of this analysis are presented in Table 8. Monthly concentrations during the recreation season that exceed the State's 30-day criterion are highlighted in yellow. Information on rainfall and flow during each month are also provided in this table. The high concentrations in April and May appear to reflect upstream loadings as the flow during these months was higher than normal. The high concentrations during the months of July and August are more likely due to the amount of rainfall and storm size during these months than from upstream sources (because flow tended to be closer to normal).

**Table 8. Monthly Geometric Mean *E. coli* Concentrations.**

| Location | Geometric mean in-stream concentration (cfu/100 mL) by month | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Upstream of City CSOs | 124 | 109 | 174 | 407 | 349 | 110 | 190 | 138 | 46 | 27 | 70 | 159 |
| US-40 Bridge | 121 | 104 | 172 | 398 | 340 | 102 | 190 | 144 | 42 | 26 | 74 | 164 |
| Fairbanks Park | 124 | 107 | 181 | 395 | 336 | 102 | 210 | 161 | 52 | 37 | 92 | 175 |
| Downstream of CSOs 004 and 011 | 122 | 103 | 179 | 392 | 334 | 100 | 211 | 163 | 50 | 36 | 93 | 179 |
| Downstream of WWTP | 133 | 115 | 189 | 377 | 314 | 90 | 190 | 146 | 45 | 35 | 126 | 198 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Monthly Rainfall (in) | 1.16 | 0.31 | 3.21 | 1.98 | 2.19 | 1.23 | 7.58 | 9.20 | 0.67 | 2.27 | 4.22 | 4.15 |
| Largest Storm Event (in) | 0.32 | 0.25 | 1.05 | 0.50 | 0.96 | 0.45 | 2.16 | 3.35 | 0.30 | 1.48 | 2.47 | 1.25 |
| Number of High Flow Days in Month | 9 | 0 | 17 | 30 | 29 | 4 | 13 | 10 | 3 | 0 | 0 | 3 |

Notes:
[1] 30-day Geometric Mean Standard Criterion= 125 cfu/100 mL for Recreation Season only (April-October). High values in November through March are not flagged since the water quality standard is not applicable during this period.

## References

Jobson, H.E., Schoellhamer, D.H. 1993. *Users Manual for a Branched Lagrangian Transport Model.* United States Geological Survey Water Resources Investigations Report 87-4163. Reston, VA.

Jobson, H.E. 1997. *Enhancements to the Branched Lagrangian Transport Modeling System.* United States Geological Survey Water Resources Investigations Report 97-4050. Reston, VA.

LimnoTech (LTI). August 2007. *Sampling Plan.* Draft memorandum for the City of Terre Haute, submitted on August 8, 2007.

LimnoTech (LTI). October 2007. *"Typical" Period Analysis for the City of Terre Haute.* Draft memorandum the City of Terre Haute, submitted to the City on October 29, 2007.

LimnoTech (LTI). March 2008. *Terre Haute 2007 Wet Weather Sampling Program Results Summary.* Draft memorandum for the City of Terre Haute, submitted to the City on March 24, 2008.

LimnoTech (LTI). April 2008. *Wabash River Model Calibration.* Draft memorandum for the City of Terre Haute, submitted to the City on April 30, 2008.

National Stormwater Quality Database (NSQD). 2005. *NPDES Phase I Data – Municipal Separate Storm Sewer System. Version 1.1.* University of Alabama and Center for Watershed Protection. Updated March 4, 2005.

United States Environmental Protection Agency (USEPA). 1985. *Rates, Constants, and Kinetics Formulations in Surface Water Quality Modeling.* Environmental Research Laboratory. EPA 600/3-85/040. June 1985.

USEPA. 1999. *Combined Sewer Overflows: Guidance For Monitoring And Modeling*. Office of Water. EPA 832-B-99-002. January 1999.

USEPA. 2001. *Report to Congress: Implementation and Enforcement of the Combined Sewer Overflow Control Policy*. December.