Appendix 2-1

Terre Haute 2007 Wet Weather Sampling Program Results Summary

LimnoTech
Water | Environment | Scientists | Engineers

MEMORANDUM

FINAL

DATE: March 4, 2008

FROM: Carrie Turner

PROJECT: TRHWW

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CC: Billy Goodrich (City of Terre Haute), Chuck Ennis (City of Terre Haute)

SUBJECT: Terre Haute 2007 Wet Weather Sampling Program Results Summary

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Summary

The City of Terre Haute is updating their Combined Sewer Overflow (CSO) Long Term Control Plan (LTCP) because new monitoring data in the collection system suggested that previous analyses used inaccurate volume estimates. The update to the LTCP includes updates to the collection system and river models that incorporate new monitoring data into their calibrations and better constrain their application in CSO control planning. This memorandum presents a summary of the wet weather sampling program conducted by LimnoTech for the City of Terre Haute to monitor water quality impacts from the City's CSOs on the Wabash River. These data will be used to calibrate and validate the updated river model.

The wet weather sampling program consisted of the collection of water samples from the Wabash River, selected combined sewer overflows, and tributaries that receive storm water for *E. coli* analysis and measurements of river bathymetry (depth). Six rounds of river sampling and two rounds of source sampling were conducted over a 72-hour period during three discrete storm events with varying characteristics (City of Terre Haute Sampling Plan, July 2007). LimnoTech mobilized on four separate occasions between August and October, 2007, and gathered data for three wet-weather events and one dry period.

The results from the wet weather sampling were used to characterize impacts of the City's CSOs on river quality by monitoring the amount of *E. coli* found in the river over the course of the storm event. Temporal, spatial and statistical analyses were used to assess the river data by event, location and hour of sampling. Major findings from the river sampling program include:

- The City's CSOs impact water quality in the Wabash River but impacts tend to last less than a day;
- Local precipitation conditions do not significantly alter in-stream pollutant loads originating upstream of the City;
- Upstream sources do not impact the City until one or two days after the local storm event; and,
- The magnitude of the impact from the City's CSOs on the river water quality is positively correlated with the magnitude of the rainfall.

The goal of the source sampling program was to identify representative concentrations for estimating *E. coli* loadings from the City's CSOs and storm water. Major findings from the source sampling program include:

- No first flush effect was evident in the source sampling data;
- The data from CSO-009 was significantly different from the data from the other CSOs;
- An event mean (representative) concentration of 210,000 cfu/100 ml was determined from the data for CSO-009 while an event mean concentration of 675,000 cfu/100 ml was determined from the data for the remaining CSOs (CSO-007, CSO-006, and CSO-004);
- An event mean concentration of 5,000 cfu/100 ml was determined from the storm water data; and,
- The data from the CSO and storm water sites are consistent with values in the literature and at other Indiana CSO communities.

The Sampling Program was successful in generating data from three storm events that can be used to calibrate and validate the river model. More detail on the storm event characteristics and associated data are described in the following sections of this memorandum.

Sampling Program Overview

The wet weather sampling program consisted of the collection of water samples for *E. coli* analysis and river bathymetry (depth) data. Water samples were collected from the Wabash River, selected combined sewer overflows (CSOs), and tributaries that receive storm water during three discrete storm events with varying characteristics. Desired conditions for water sampling were storm events having at least 0.5 inches of rainfall over a period of three hours or more and at least 72 hours since the last rainfall.

Sampling in the Wabash River was conducted at the five locations shown in Figure 1 and described in Table 1. At each transect location a single composite sample was generated for analysis by compositing equal volumes from the left, center, and right sections of the river channel. Sampling further downstream was not feasible because of accessibility issues with the Federal Penitentiary located adjacent to the river just downstream of the City's wastewater treatment plant.

Six rounds of sampling were performed during each event at selected intervals based on the time elapsed from the start of rainfall. These sampling intervals were designed to capture first flush effects (if any) from the City's CSO discharges on river water quality as well as extend long enough to capture the river's return to dry weather conditions. Samples were collected representing hour 0-1, hour 6, hour 12, hour 24, hour 48, and hour 72 of the storm event. If possible a pre-storm round was collected to characterize the baseline river conditions. Field measurements of dissolved oxygen and temperature were made at each location during each round of sampling. The dissolved oxygen data were deemed unreliable due to instrument drift and other malfunctions and were not used.

Table 1. River Monitoring Locations.

Order for Sampling	Station ID	Description	Longitude (dec. degrees)	Latitude (dec. degrees)	Rationale
1	RS-1	½ mile upstream of Spruce St. CSO	-87.42193904	39.47672107	Define loads from upstream sources/ upstream model boundary
2	RS-2	Highway 40 Bridge	-87.42023918	39.46745261	Define impacts of CSO 010 and 009; Corresponds to USGS gage location
3	RS-3	Across from boat dock @ Fairbanks Park	-87.4212888	39.45560988	Define impacts of CSOs at Fairbanks Park; Potential area of recreation use
4	RS-4	¼ mile downstream of Hulman St. CSO	-87.42884065	39.44597866	Define impacts of CSO 004 and 011, Captures impact of ~90% of total CSO volume
5	RS-5	½ mile downstream of WWTP	-87.43921555	39.42621451	Downstream of all City CSO sources; Define downstream boundary

Source monitoring included CSOs and storm water (or tributary) sampling. Four CSO locations were selected for sampling based on the service area and land use characteristics of each CSO basin. Three storm water monitoring locations were also identified to characterize runoff quality in the separated storm water system and from more rural land uses outside of the City. Table 2 describes each source sample location. These locations are also shown in Figure 1. All CSO samples were collected at the outfall (although manhole locations were identified for sampling if the river stage precluded sampling at the outfalls). Storm water samples were collected at the outfall whenever possible. If a storm water outfall was not flowing, then the sample was collected in the tributary receiving the outfall discharge. Locations were selected so that if a tributary was sampled, the volume would be comprised primarily of storm water or nonpoint runoff (as noted in Table 2) during wet weather.

Grab samples were collected at each location roughly corresponding to hour 0-1 and hour 1-3 of each storm event. The sampling intervals were selected to capture "first flush" effect (e.g. initial runoff may contain elevated pollutant loadings if the pollutants have had sufficient time to accumulate on the land surface and the rainfall is of sufficient intensity to wash the accumulated pollutants off), if any, in source quality.

The river and source samples were analyzed for *E. coli* using method 9223B (Standard Methods) by E.C. Labs (Farmersburg, IN). All analytical requirements, including hold time (6 hours), sample preservation and storage, were met during the course of the sampling program. Field quality was also evaluated by collecting field blanks and field duplicates at a frequency of one per twenty and one per ten samples, respectively. The QA/QC results suggest that the field and laboratory activities were in control and no qualification of the data were needed.

River bathymetry is the measurement of depth within a water body. River bathymetry data was collected at the same locations used for the river water quality sampling. Individual depth measurements were collected by lowering a weighted tape measure over the side of the boat. Depth measurements were made at approximately 10-20 points across each sampling location transect. Location of the depth measurement was recorded with a handheld GPS unit, which allowed distance from shore to be calculated. Bathymetry measurements were collected over a range of flow conditions so that the geometry algorithms required for the river model could be developed.

Table 2. CSO and Storm water Monitoring Locations.

Station ID	CSO Basin	Description	Longitude (dec. deg.)	Latitude (dec. deg.)	Reason
C-1	009	Chestnut St. Outfall	-87.41923665	39.47046024	Service area is primarily university, high imperviousness
C-2	007	Walnut St. Outfall	-87.41917772	39.46450140	Large service area, more commercial area
C-3	006	Oak St. Outfall	-87.4192270	39.4614780	Large service area, more commercial area
C-4[a]	004	Hulman St. Outfall	-87.42466899	39.44842373	Large service area, primarily residential, lowest imperviousness
C-4 alternate	011	Idaho St. Outfall	-87.42578110	39.44753399	Use if 004 is not discharging
S-1	Storm	Storm water outfall at 13th St. and Elizabeth (discharges to Lost Creek)	-87.39788981	39.50195145	Characterize storm water concentrations from City
S-2	Storm	Lost Creek at Fruitridge	-87.36011732	39.48637543	Characterize non-urban, non-point source runoff concentrations
S-3	Storm	New Thompson ditch at Wallace Rd.	-87.369440	39.4433830	Characterize storm water load from primarily residential area

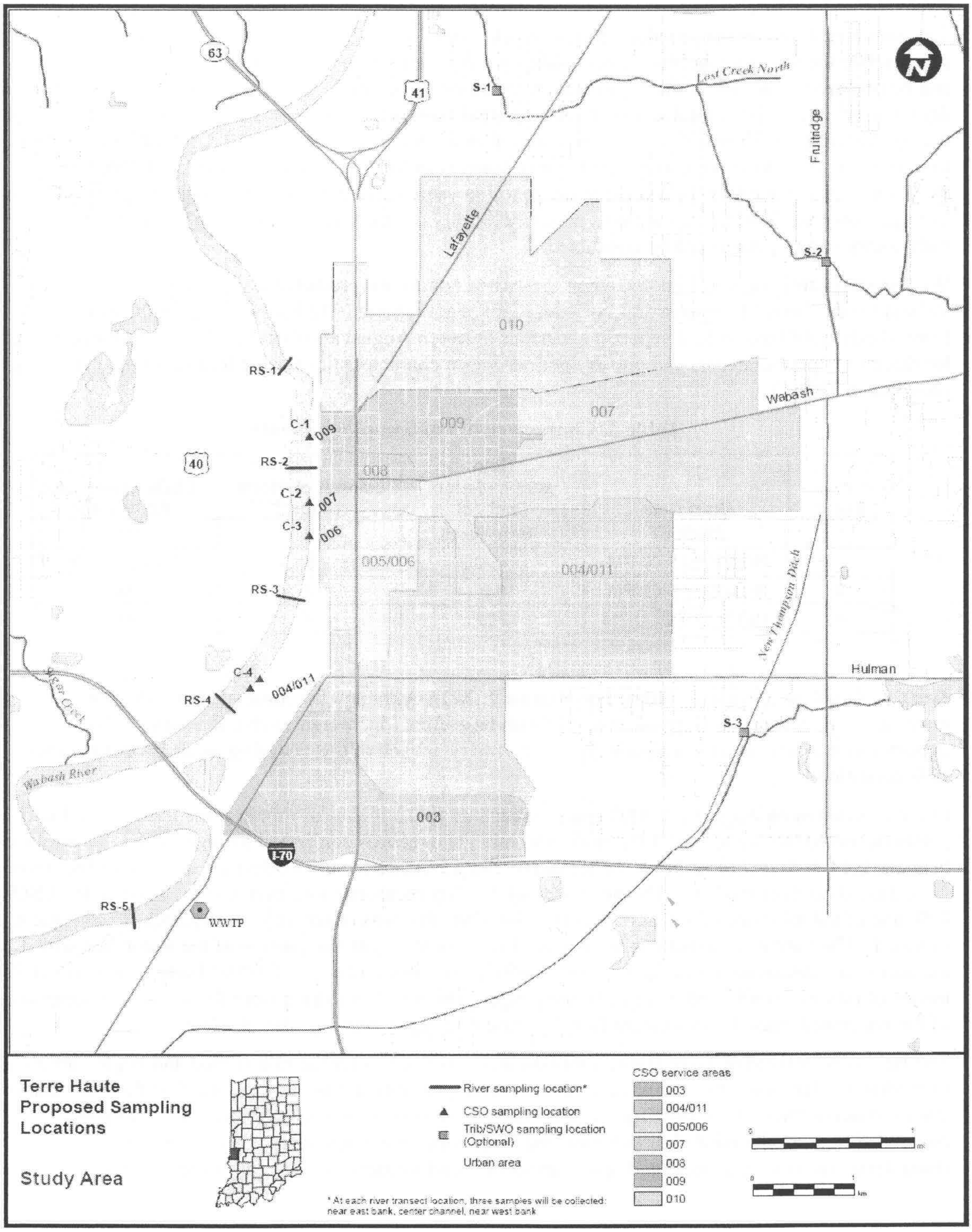


Figure 1. Map of Sampling Locations.

Event Descriptions

The Sampling Program was conducted from August 2007 through October 2007. To accurately characterize the storm impacts on water quality, field personnel needed to anticipate significant storms and be prepared to sample at the beginning on the storm. Rainfall in the summer was uncharacteristically dry (August 2007 rainfall totaled 1.63 inches whereas five-year average was 3.73 inches). Storm events during the Sampling Program were often scattered in intensity and total rainfall, confounding the decision to sample or not. Flows were also significantly lower than long-term averages during the Sampling Program. The average flow in August in the past five years was 6,300 cfs, whereas in August 2007, the average flow was 3,700 cfs. Low flows persisted throughout the fall and limited the number of bathymetry surveys that could be conducted.

Wet-weather sampling was initiated when forecasted conditions predicted a significant storm ($\geq$ 0.50 inches) for the Terre Haute area and the antecedent event criteria (~72 hours with no rain) were met. LimnoTech mobilized on four separate occasions between August and October, 2007, and gathered data for three wet-weather events and one dry period. Storm characteristics for the four sampling events are provided in Table 3.

Table 3. Characteristics of Sampling Events.

Event	Start Date	Rain accumulation (inches)	Length of Storm (hours)	CSOs Observed Activating
1	8/9/2007	Base flow	0	None
2	8/20/2007 3:00 PM	0.16-0.3	6	CSO-009 only
3	9/25/2007 5:00 PM	0.5	7	All
4	10/17/2007 3:00 PM	2.22	16	All

The first sampling event was initiated on August 9, 2007. Although the forecasted rain did not materialize, river samples were taken to establish base-flow (dry weather) characteristics. This opportunity was also used to measure river bathymetry at each of the sampling locations during a low flow condition.

Event 2 occurred on August 20, 2007 and produced up to 0.3 inches of rain in some local areas. Field personnel noted the scattering of the storm and rain gage records confirmed a range of rain accumulation between 0.14-0.30 inches in Terre Haute, and 0.15-1.85 inches in surrounding areas. Most of the storm front drifted north of the City. The north side of the City received more rain than the south side. CSO-009, one of the most northern CSOs, was the only CSO that was observed discharging and subsequently sampled. The rainfall distributions were much higher in the upstream portion of the watershed with 1.85 inches of rain measured in Lafayette, approximately 70 miles upstream of Terre Haute, while only 0.30 inches of rain were collected in Terre Haute gauges. The runoff resulting from the rain in the upper areas of the watershed caused a significant flow increase that began one day after the local event.

The field crew arrived in Terre Haute approximately six hours after the rain started and began sampling immediately. However, the sampling from this storm probably did not capture the first flush or peak in-stream concentrations from the City's CSOs. Despite the non-uniformity of this event, sampling proceeded because the rainfall distribution and forecasted river stage offered an opportunity to characterize the timing of local and upstream source load impacts on in-stream water quality.

Table 4. Local Rainfall Amounts from Event 2 (August 20, 2007).

Location	Rain (inches)	Distance from and Relative to Terre Haute
Brazil	0.50	16 mi E-NE
Clinton	0.60	14 mi N
Terre Haute	0.30	0
Vincennes	0.15	55 mi S
Lafayette	1.85	70 mi N-NE

The storm for Event 3 met all of the Sampling Program criteria and the team's early mobilization provided an extensive dataset ideal for calibrating the river model. Following a 72-hour dry period, the September 25, 2007 storm produced 0.50 inches of rain uniformly across the City. All CSOs overflowed and were sampled. The team arrived several hours before the storm started and collected a round of pre-event samples to provide a comparison of dry and wet weather conditions in the river. River and source sampling was conducted in accordance with the Sampling Plan.

Event 4 took place on October 17, 2007, during a storm that resulted in 2.22 inches of rain over several hours. Field personnel start sampling one to two hours after the rain event had initially started, although roughly half of the rain fell after a 5-hour intermittent period when there was no rainfall. All CSOs activated, although the 5-hour rainfall pause confounded the CSO effect on river water quality. Field observations indicated the CSOs stop flowing during the 5-hour dry intermittent period. To gather more information, a second set of CSO samples were collected when the rain resumed and the CSOs reactivated. Therefore, this storm deviated from the Sampling Plan in that two discrete CSO sampling events were monitored during this single storm event. Due to limited resources, storm water locations were not sampled during Event 4. River sampling was also suspended partway through the 6-hour sampling round because lightning was observed in the vicinity.

River Sampling Data Summary

Overview

This section presents major findings from the river water quality component of the Sampling Program. The results from the wet weather sampling were used to characterize impacts of the City's CSOs on river quality by monitoring the amount of *E. coli* found in the river over the course of the storm event. Temporal, spatial and statistical analyses were used to assess the data by event, location and hour of sampling. Results are presented in summary and for each event in this section. Additional figures are provided in Appendix 1. Major findings from the river data include:

- The City's CSOs impact water quality in the Wabash River but impacts tend to last less than a day;
- Local precipitation conditions do not significantly alter in-stream pollutant loads originating upstream of the City;
- Upstream sources do not impact the City until one or two days after the local storm event;
- The magnitude of the impact from the City's CSOs on the river water quality is positively correlated with the magnitude of the rainfall; and,
- The City's 2001 and this 2007 Sampling Programs provide complementary datasets for use with the river model.

The river data suggest that CSO discharges impact the river in the vicinity of the City of Terre Haute for less than a day, as shown in Figure 4. Upstream flow and loads, which are driven primarily by the extent and magnitude of precipitation in the upper watershed rather than local conditions, may impact the City from one to three days after the storm event. In this figure, a statistical analysis of river data upstream (at the RS-1 sampling location) and within the CSO discharge areas (at RS-2, RS-3, and RS-4 sampling locations) of the river is presented. The boundaries of the box represent the 25th and 75th percentiles of the data. The line in the center of the box corresponds to the median concentration. The whiskers correspond to the minimum and maximum concentrations observed in the data. As this figure illustrates, the concentrations in the CSO area of the river peak within the first 6 hours of the storm event whereas the concentration at the upstream location tends to be highest approximately 24-48 hours after the local storm event begins.

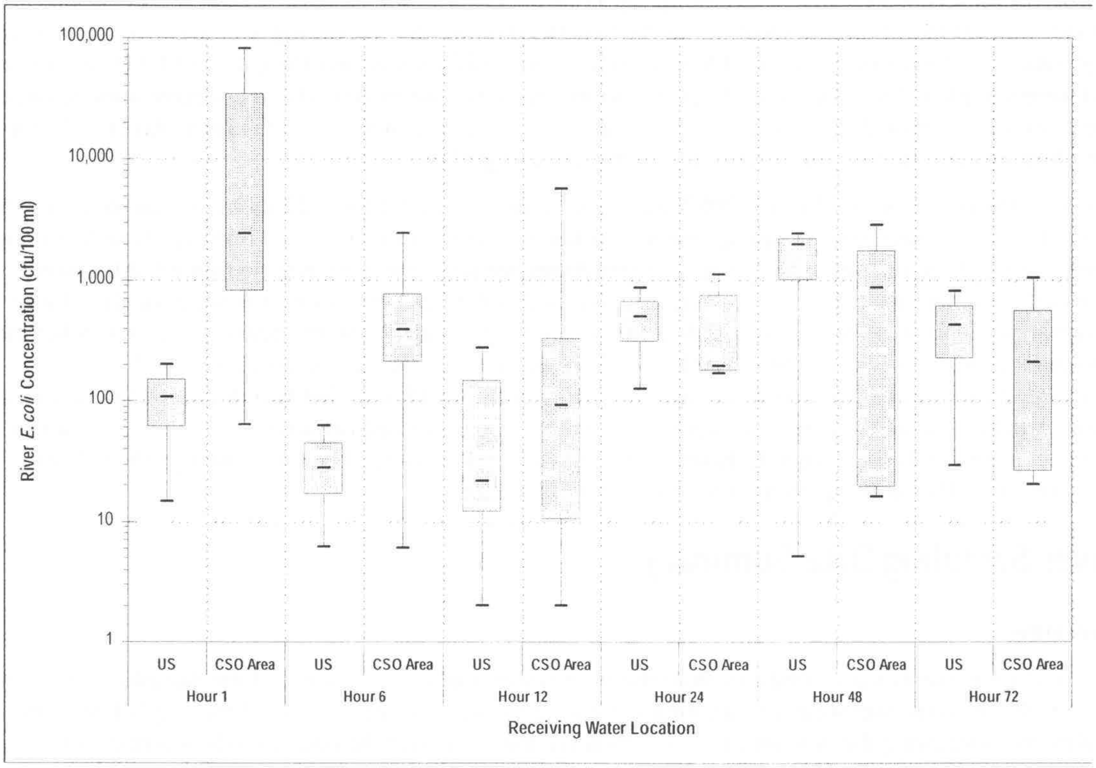
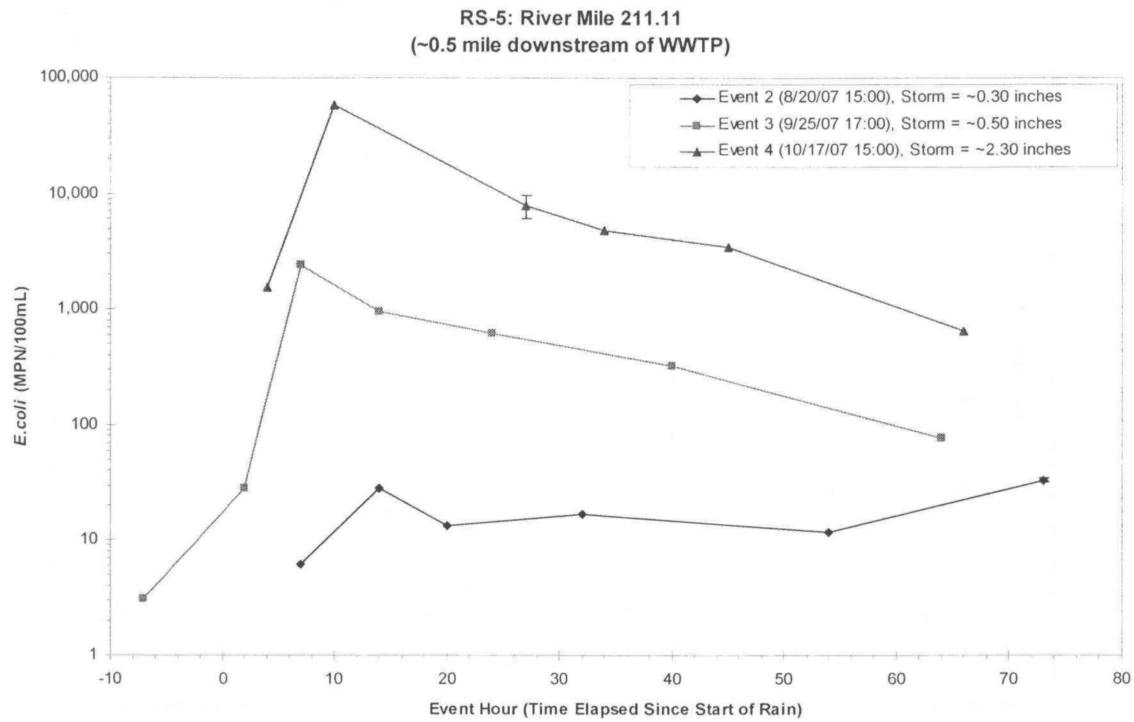


Figure 4. Box-and-whisker Plot of River Data by Event Hour.

Graphs of *E. coli* concentration during the storm events demonstrated a positive correlation between the magnitude of the storm size and the magnitude of observed *E. coli* concentrations. This is illustrated in Figure 5, which shows the *E. coli* concentrations at sampling location RS-5 (downstream of all CSOs) during the three wet-weather events. Event 2 had the lowest amount of precipitation, 0.16-0.30 inches, and resulted in lower *E. coli* concentrations in comparison to the other storms. Event 4 was the largest storm, with 2.22 inches measured in Terre Haute, and resulted in the highest *E. coli* concentrations. More figures of the *E. coli* concentrations at the other river station during the three events are shown in Figures A.1 – A.5 in Appendix 1.



Note: The lines connecting the sampling data points are included to enhance the graphic. Actual in-stream concentrations between sampling times may differ from the values on the lines.

Figure 5: *E. coli* concentrations at RS-5 during wet-weather events.

Base (dry weather) conditions

Event 1 was sampled to characterize the water quality conditions during dry conditions. There are no significant dry weather *E. coli* sources immediately upstream of the City. An evaluation of the historical data collected by the Indiana Department of Environmental Management (IDEM) at several upstream locations provide additional support that there are no significant dry weather sources in and around the City. Figure 6, below, shows the concentration of *E. coli* in the river at base flow. The highest concentration of *E. coli* was 9.8 cfu/100 mL, which is much lower than the State of Indiana *E. coli* single sample maximum water quality standard of 235 cfu/100mL.

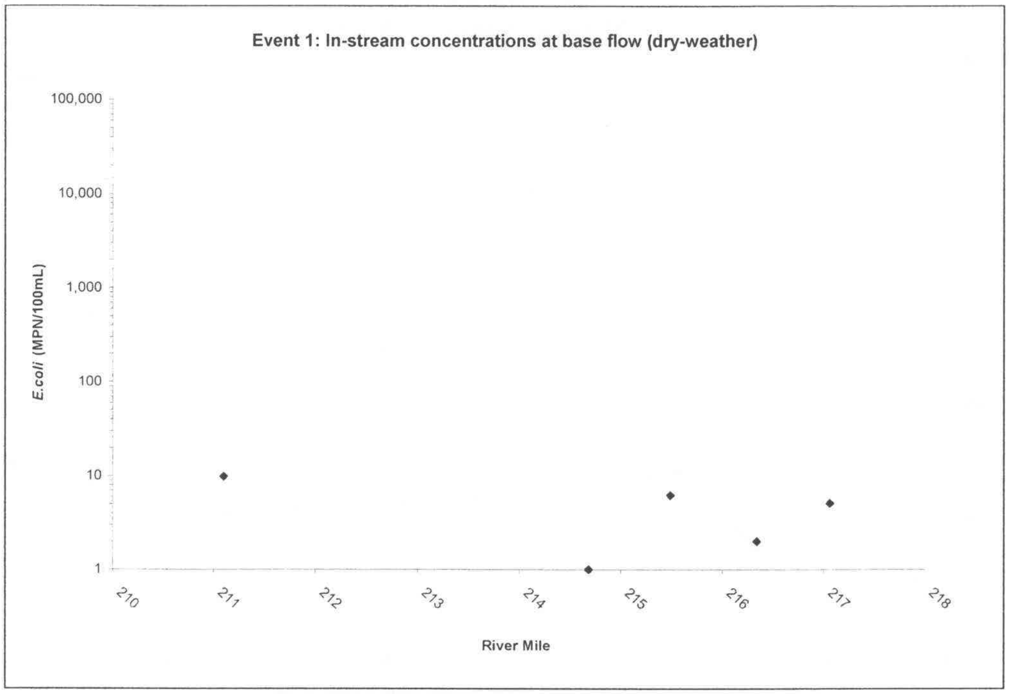


Figure 6: Dry Weather *E. coli* Concentrations During Event 1 (8/9/07).

Event 2 (Wet weather #1) conditions

Event 2 was the smallest storm sampled (~0.30 inches). The field crew mobilized and began sampling approximately 6 hours after the storm began. Figure 7 shows the concentrations and flow at each river sampling location. The first sampling round, approximately seven hours after the rain started, had the highest in-stream concentrations, though it is likely that peak concentrations occurred in the river before the field crew began sampling. Nevertheless, the sampling indicated that a storm of this magnitude produced violations of the Indiana *E. coli* water quality standard (235 cfu/100 ml), those the elevated concentrations are limited to only a portion of the first day of the storm.

As described in the Event Summary section, the rainfall for this event was scattered and as a result, CSO-009, the northernmost CSO, was the only CSO that activated and was sampled. Maximum concentration occurred immediately downstream of Fairbanks Park (RS-3), which is in the middle of the CSO area, providing additional evidence that rain in the southern part of the City did not activate any of the CSOs in this portion of the City.

The sampling from this event allowed the City to characterize the impact of the additional rainfall in the upper watershed (approximately 0.50-1.50 inches of additional precipitation) on the timing and magnitude of in-stream water quality in Terre Haute. The delayed upper watershed effect can be seen in the results for the most upstream location (RS-1), where the peak concentration occurs ~24 hours after the start of the storm. Over the next 48 hours, flow in the river continued to rise but concentrations decreased, likely reflecting the dilution from all of the runoff upstream.

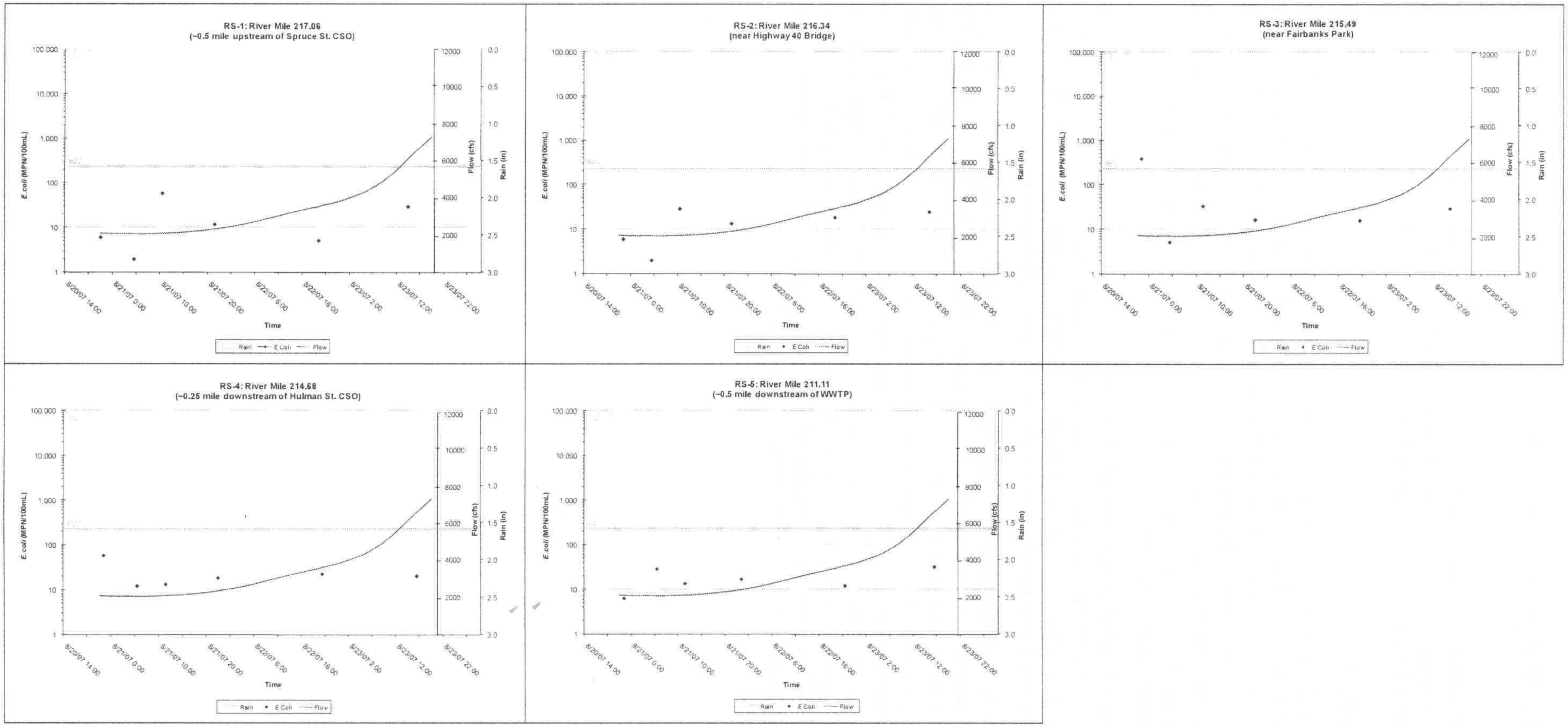


Figure 7. Wabash River *E. coli* Concentration versus River Mile During Event 2.

Overall, the concentrations of *E. coli* resulting from wet-weather events were much lower in comparison to the other storms due to the lower volume of rain (see Table 3). Other plots describing the *E. coli* concentrations during Event 2 can be found in Appendix 1, Figures A.6 - A.11.

Event 3 (Wet weather #2) conditions

In contrast to Event 2, the rainfall during Event 3 was uniform and abundant (~0.50 inches), resulting in activation of all of the City's CSOs. Sampling was initiated when the storm started (September 25, 2007, 17:00). Figure 8 shows the concentrations and flow at each river sampling location. The field crew collected a round of samples before the rain event began so that baseline conditions could be characterized. Results from this round (the first set of dots on each graph) were well below 235 cfu/100 ml (Indiana water quality standard), and are similar to concentrations observed during Event 1, which also measured dry weather conditions in the river.

Concentrations at RS-1, which is upstream of all of the City's CSOs, captures the *E. coli* load originating upstream of the City. Results at this station throughout the event were below the State's water quality standard criterion. Peak concentrations from upstream sources reached Terre Haute approximately 24 hours into the event, similar to the results from the other wet weather surveys.

The City's CSOs started discharging within the first hour of rainfall. All of the City's CSOs overflowed and were sampled according to the Sampling Plan protocol. Results at RS-2, RS-3, RS-4 and RS-5 illustrate the CSO impact on in-stream water quality, with peak concentrations measured in the second or third round of sampling (which corresponds to the first and six hours into the storm). The load from the CSOs reaches the wastewater treatment plant (RS-5) approximately six hours into the storm. Data from this station also shows the effect of in-stream mixing as the CSO load is mixed longitudinally as it moves downstream, resulting in elevated concentrations through hour 48. However, by hour 72, the last round of sampling, results at all locations were returning to dry weather levels. Additional figures showing the river sampling results are provided in Appendix 1, Figures A.12-A.18.

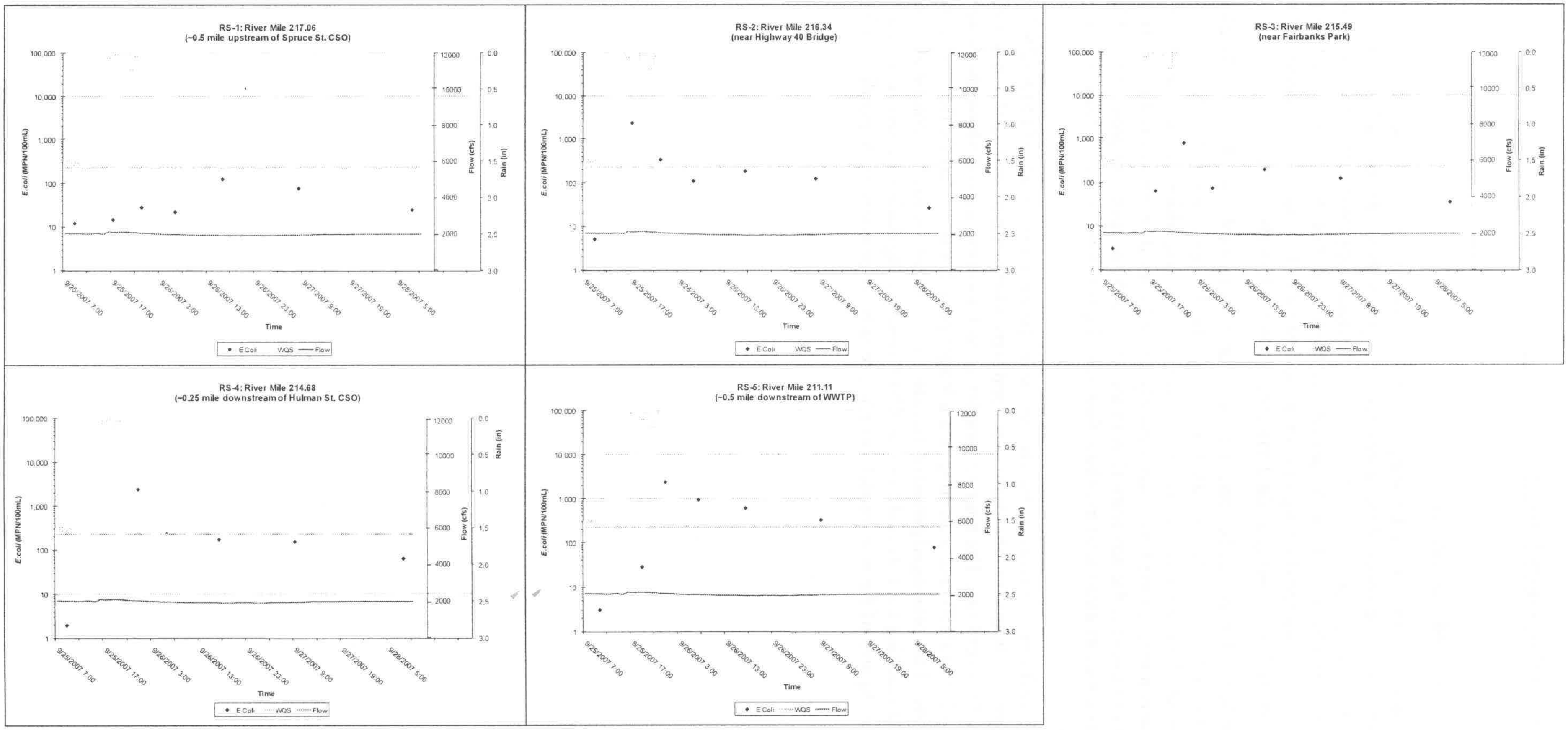


Figure 8. Wabash River *E. coli* Concentration versus River Mile During Event 3.

Event 4 (Wet weather #4) conditions

Event 4 was the largest storm sampled, having a total accumulation of 2.22 inches. The field crew began sampling within the first two hours of the storm event. Figure 9 shows the rainfall, *E. coli* concentrations and flow at each river sampling location. As shown in the figure, approximately half of the rain fell in the first two hours, followed by a five hour dry period, and then the rest of the rain fell over the next nine hours. The City's CSOs started discharging during the first half of the storm, then stopped during the dry period, and then started overflowing again during the second half of the storm.

The upper watershed influence can be seen at the most upstream sample site, RS-1, by the elevated *E. coli* levels. The rainfall data from Lafayette (approximately 70 miles upstream) indicated that most of the rain in the upper watershed occurred during the second half of the storm, which may explain the lag in the upstream load, which reached the City approximately 24-48 hours after the storm started. However, unlike conditions in Event 2, the upstream flow in this event did not appear to provide any dilution of the upstream load, as concentrations tend to follow flow (e.g. higher flow corresponded to higher concentrations).

The maximum *E. coli* concentrations at the stations immediately downstream of CSOs (RS-2, RS-3, RS-4) occurred roughly six hours into the storm event and were likely caused by *E. coli* loads originating from the initial CSO overflows. The hour 72 samples at each location are still above the State's water quality standard (235 cfu/100 ml), indicating that a longer period was needed for the river to return to dry weather conditions. This prolonged period of elevated concentration is likely a combination of the lag in the upstream load reaching the City and from the CSOs reactivating during the second half of this storm event. Additional figures of the river model sampling results are provided in Appendix 1, Figures A.19-A.25.

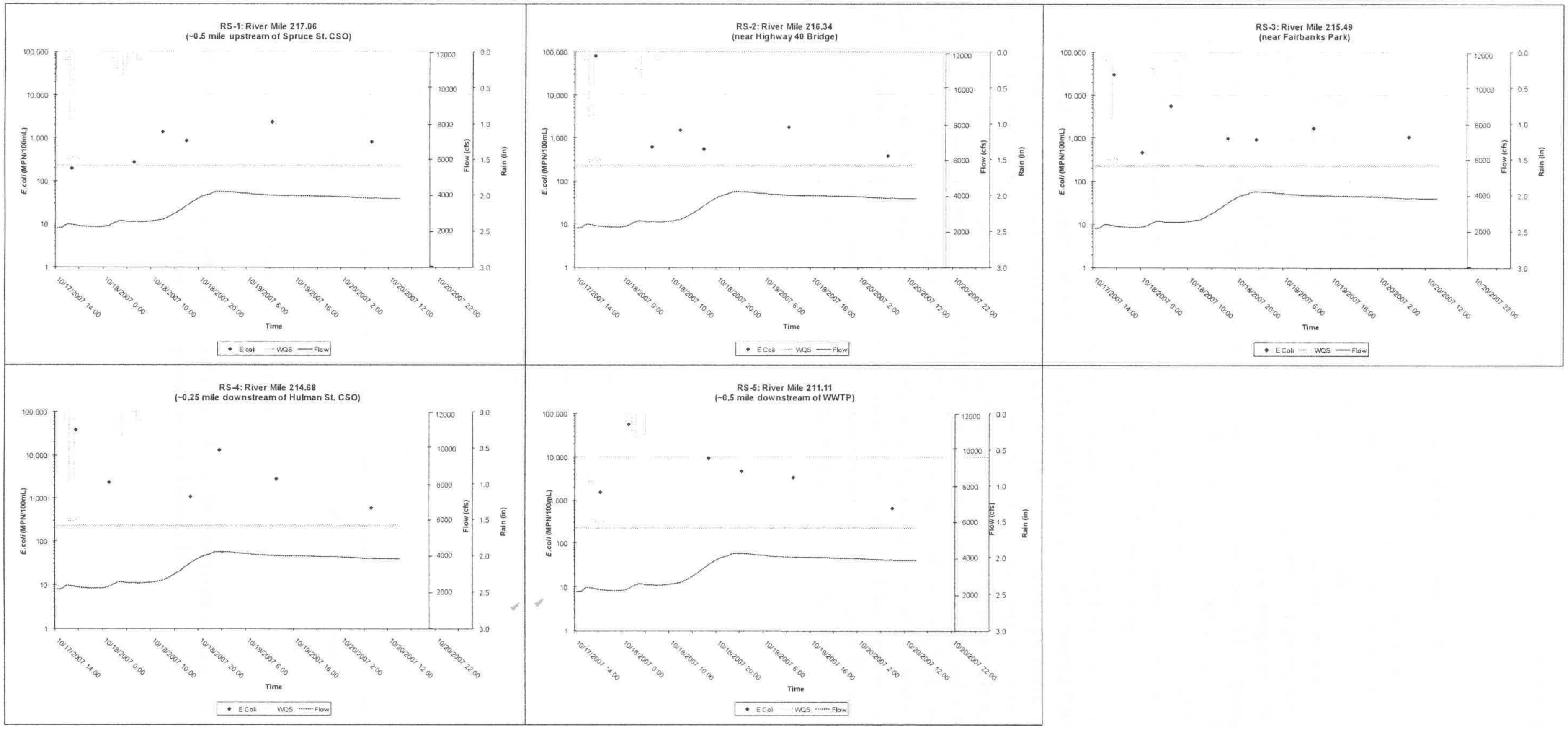


Figure 9. Wabash River *E. coli* Concentrations versus River Mile During Event 4.

Comparison to 2001 City Monitoring Program

During earlier technical work to support the LTCP development, the City conducted a 3-month sampling program in 2001 to inform the river model calibration (City of Terre Haute Draft LTCP, March 2002). One survey of the river was conducted each week of the 3-month period but City staff were restricted from sampling when it was raining or at night due to safety and insurance considerations. The City initiated the 2007 Sampling Program partly to address these limitations in the earlier data. By comparison, the 2007 program was much more time intensive, with at least six samples collected over a 72-hour period during and immediately after a storm event and sampling was conducted at all hours of the day and night. The City's objective with the 2007 program was to design and execute a sampling program that would capture wet weather impacts in the monitoring data so that the updated river model calibration will be better constrained. The City also gained a better understanding of their source loads and impacts on water quality from the 2007 Sampling Program.

A comparison of the 2001 and 2007 data, shown in Figure 10, reflect the differences in the sampling programs. The 2007 dataset shows a wider range of concentrations than the 2001 dataset. This reflects the time-intensive sampling design of the 2007 program, which enabled the City to monitor the rapidly changing concentrations during wet-weather events for a variety of storms with different characteristics. Because the City could not sample when it was raining, any wet weather data in the 2001 dataset reflect conditions at least a day after a storm event. As the 2007 data indicate that CSO loads are transported downstream beyond the City within a day, the City's 2001 sampling were unlikely to capture the CSO impacts on water quality. The weekly sampling performed in 2001 captures primarily the impact of upstream sources on water quality in the Terre Haute vicinity, as shown by the similarity in ranges of *E. coli* concentrations at all sample sites along the river. These data provide additional support that local wet weather impacts affect water quality over a short duration (less than a day) that were observed in the 2007 Sampling Program data.

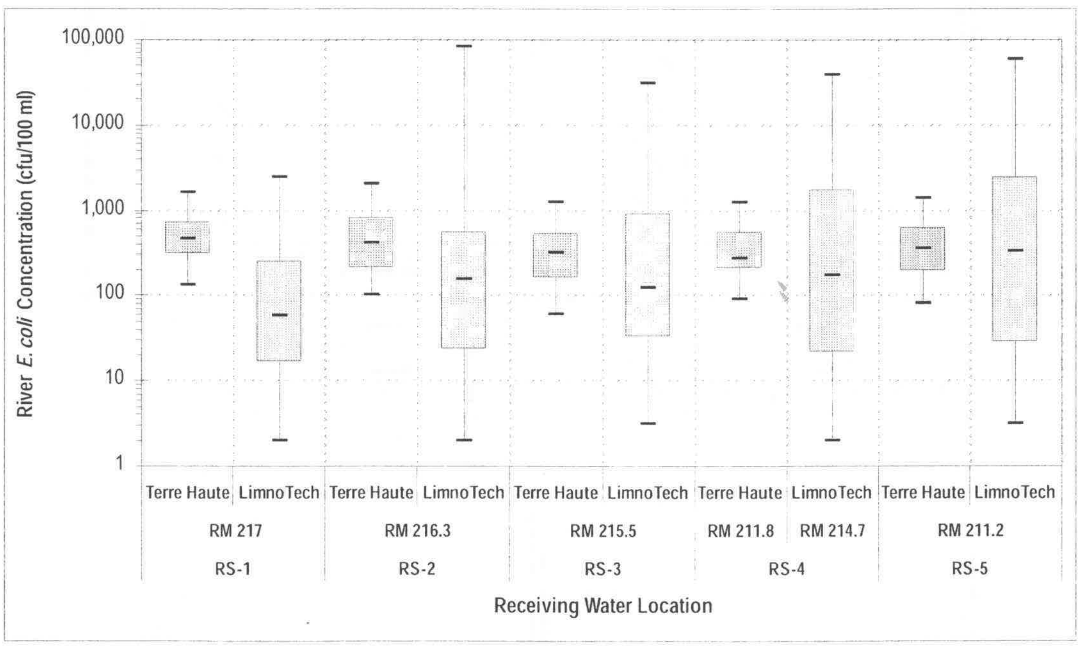


Figure 10. Comparison of the *E. coli* Data from the 2001 (City) and 2007 (LimnoTech) Sampling Programs.

The data from the two Sampling Programs complement each other by providing extensive data that reflect different conditions in the Wabash River. Data from both programs will be useful in updating the river model.

Combined Sewer and Storm Water Source Sampling Data Summary

Summary

CSOs and tributaries receiving storm water are sources of *E. coli* to the Wabash River during wet weather. A subset of the City's CSOs and storm water were sampled so that loadings from these sources could be estimated in planning scenarios for the river model. The following section presents the results of the source sampling component of the Sampling Program. Results were assessed using a variety of statistical methods to evaluate whether the CSO quality differed by location and whether a first flush effect was evident.

The goal of the analysis of the data from the source sampling program was to identify representative concentrations for estimating *E. coli* loadings from the City's CSOs and storm water. Major findings from the source sampling program include:

- No first flush effect was evident in the source sampling data;
- The data from CSO-009 was significantly different from the data from the other CSOs;
- An event mean concentration of 210,000 cfu/100 ml was determined from the data for CSO-009;
- An event mean concentration of 675,000 cfu/100 ml was determined from the data for the remaining CSOs (CSO-007, CSO-006, and CSO-004);
- An event mean concentration of 5,000 cfu/100 ml was determined from the storm water data; and,
- The data from the CSO and storm water sites are consistent with values in the literature and at other Indiana CSO communities.

The geometric mean concentration, which is often used as a representative or event mean concentration, calculated from all of the CSO data was 475,000 cfu/100 ml. However, a detailed statistical analysis suggested that the data from CSO-009 was significantly different from the data from the other sampled CSOs. The CSO source sampling data suggest that an event mean concentration of 210,000 cfu/100 ml be used for CSO-009 and any other CSOs with service areas comprised of the university area or having high imperviousness. An event mean concentration of 675,000 cfu/100 ml can be used for the remaining CSOs, based on data from CSO-007, CSO-006 and CSO-004.

CSO Results

Figure 11 shows the *E. coli* CSO sampling results. The boundaries of the box represent the 25th and 75th percentiles of the data. The line in the center of the box corresponds to the median concentration. The whiskers correspond to the minimum and maximum concentrations observed in the data. The numbers above the upper whisker indicate the number of measurements.

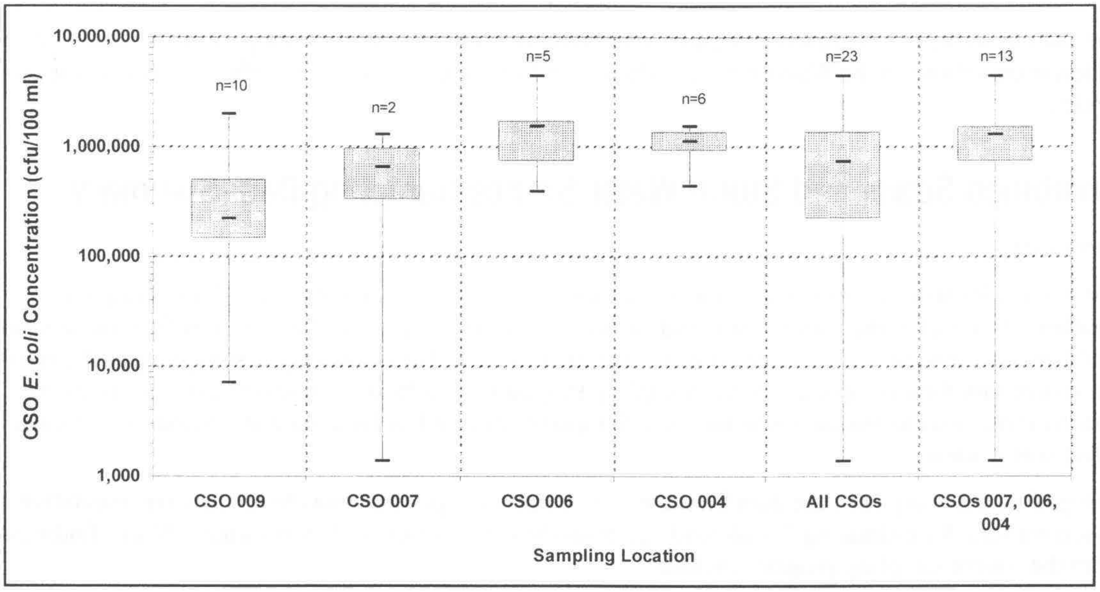


Figure 11. Box-and-Whisker Plot of CSO *E. coli* Concentrations by Location.

Results for each CSO measurement are shown in Table 5. The range in concentration for all sampling locations (All CSOs) was 1,350 – 4,350,000 cfu/100ml. The geometric mean concentration was 475,000 cfu/100 ml while the median concentration was 727,000 cfu/100ml. Twenty of the twenty-three measured concentrations were within the 100,000 – 10,000,000 cfu/100ml range reported in the national literature (EPA, 2002).

Table 5. Concentrations Measured at the City's CSO Sampling Locations.

	CSO 009		CSO 007		CSO 006		CSO 004	
	Time Elapsed Since Start of Storm (hrs)	*E. coli* Conc. (cfu/100 ml)	Time Elapsed Since Start of Storm (hrs)	*E. coli* Conc. (cfu/100 ml)	Time Elapsed Since Start of Storm (hrs)	*E. coli* Conc. (cfu/100 ml)	Time Elapsed Since Start of Storm (hrs)	*E. coli* Conc. (cfu/100 ml)
EVENT 2 (8/20/07)	5	197,600						
	6	1,299,700						
	13	129,970						
	15	24,192						
EVENT 3 (9/25/07)	1	193,500	1	1,299,700	1	4,350,000	2	1,299,700
	4[a]	517,200 248,100			2	1,553,100	4	920,800
EVENT 4 (10/17/07)	2	488,400	9	1,350	3	387,300	3	435,200
	9	7,170			11	727,000	11[a]	1,413,600 920,800
	33	1,986,300			33	1,732,900	33	1,553,100

Notes:

[a] Field duplicate collected. Both results shown.

Concentrations for CSO-004 and CSO-006 are similar; despite having different land cover characteristics in their respective service areas (CSO-004 is largely residential and less impervious while CSO-006 is largely commercial and more impervious). CSO-007 and CSO-006 have similar drainage area characteristics but different concentrations. However, data for CSO-007 may not be representative since it did not overflow long enough to get two samples in each of the two sampling events when it activated. CSO-009, which drains the University, tended to have lower concentrations.

Two statistical tests, ANOVA and unpaired t-test, were applied to the CSO dataset to determine whether the data for CSO-009 were significantly different than the data from the remaining CSOs. Statistical relationships were not evaluated for CSO-007 alone because of the limited number of data points from this CSO.

The ANOVA test compares the mean values of the groups indicated and answers the following question: "If the concentrations at each location have the same mean value, what is the probability that random sampling would result in mean values as far apart (or more so) as observed in the sample data?" If the p-value is large, the sampling data do not provide reason to believe that the mean value changes with location. The ANOVA test was applied to the following groups using log-transformed values of the *E. coli* data:

- CSO-009
- CSO-006
- CSO-004
- All CSOs
- CSOs 007, 006 and 004

The p-value for this analysis was 0.15, which is a fairly small value. If the p-value is small, it is unlikely that observed differences in mean values between locations is a coincidence of random sampling. A small p-value does not indicate that every mean value differs, only that at least one mean value differs from the rest.

The ANOVA analysis was further refined by only considering two groups:

- CSO-009
- CSOs 007, 006 and 004

The p-value for this analysis was 0.145, which provides additional support that the mean values for these two groups are significantly different.

The unpaired t-test is designed to answer this question: "If the concentrations at each location have the same mean, what is the chance that random sampling would result in means as far apart (or more so) as observed in the sampling data?" If the p-value is small (<=0.05), there is a low probability of randomly collecting samples that show a significant difference between the two locations when such a difference does not really exist. A small p-value suggests that there is a significant difference between pairs (that can't be explained by random sampling). The higher the p-value, the stronger the statistical evidence that the means of the pairs are similar. Table 6 presents a summary of the unpaired t-test applied to different combinations of the data groups listed above. Small p-values are shown in italics to highlight their occurrence.

Table 6. Results of the Unpaired t-Test.

t-Test p-values	CSO-009	CSO-006	CSO-004	All CSOs	CSOs-004,006,007	CSOs-004,006
CSO-009		***0.047***	***0.045***	0.348	0.145	***0.007***
CSO-006			0.603	0.208	0.507	0.763
CSO-004				0.261	0.633	0.743
All CSOs					0.447	0.098
CSOs-004,006,007						0.427
CSOs-004,006						

The results for CSO-009 suggest that the CSO 009 mean concentration is different than the mean concentrations for CSO 006 and CSO 004 and the lumped data from CSO 004 and CSO-006.

Similar statistical analysis of the first and second samples at each CSO location for each event did not yield any indications of a rainfall 'first flush' effect or statistically meaningful differences between CSO locations.

Storm Water Results

The purpose of the storm water sampling was to constrain loading estimates of nonpoint source runoff with site-specific data. Results indicate that runoff from the City's separate storm sewer system are comparable to concentrations observed in the literature from other municipalities. Figure 12 below shows the box and whisker plots for *E. coli* storm water sampling results. The boundaries of the box represent the 25th and 75th percentiles of the data. The line in the center of the box corresponds to the median concentration. The whiskers correspond to the minimum and maximum concentrations observed in the data. The numbers above the upper whisker indicate the number of measurements.

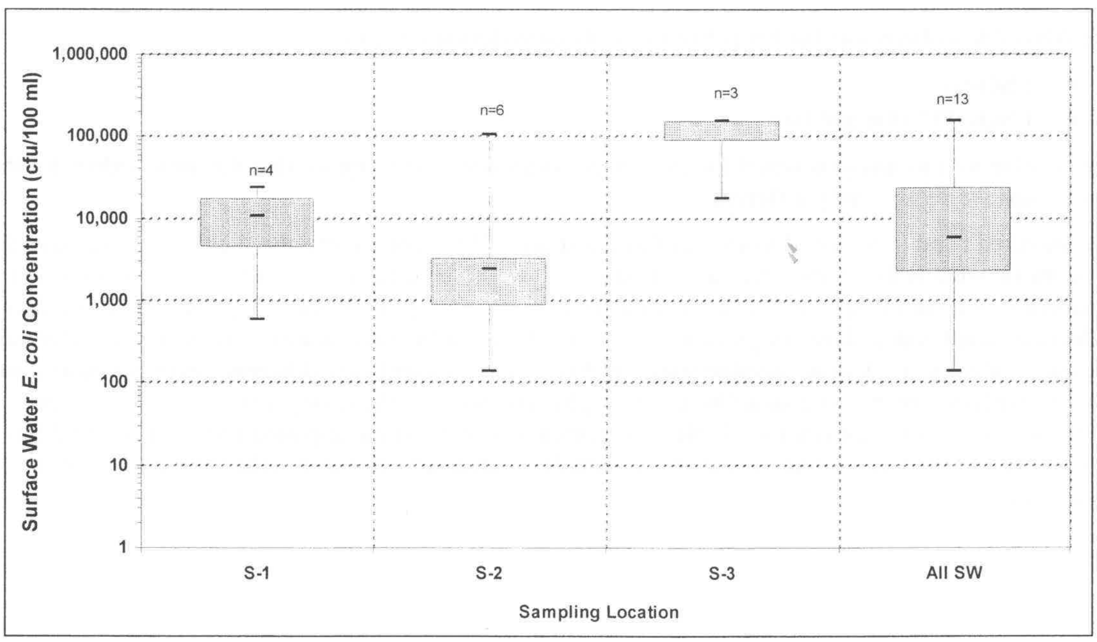


Figure 12. Box-and-Whisker Plot of Storm Water *E. coli* Concentrations by Location.

Results for each storm water measurement are shown in Table 7. The range in concentration for all locations (All SW) was 135 - 155,310 cfu/100ml. The geometric mean concentration and median concentrations were similar, 6,768 cfu/100 ml and 5,794 cfu/100ml, respectively. While significantly lower than the CSO discharges, the median result is higher than the median *E. coli* concentration of 1,750 cfu/100ml compiled in the National Storm water Quality Database (Pitt, 2008), as shown in Table 8. However, the City's storm water data are comparable to summer data in the NSQD, which may be a more meaningful comparison since the conditions during the 2007 Sampling Program were very summer-like.

Table 7. Concentrations Measured at the City's Storm Water Sampling Locations.

	S-1 (Lost Creek near 13th and Elizabeth)		S-2 (Lost Creek at Fruitridge)		S-3 (New Thompson Ditch at Wallace)	
	Time Elapsed Since Start of Storm (hrs)	*E. coli* Conc. (cfu/100 ml)	Time Elapsed Since Start of Storm (hrs)	*E. coli* Conc. (cfu/100 ml)	Time Elapsed Since Start of Storm (hrs)	*E. coli* Conc. (cfu/100 ml)
EVENT 2 (8/20/07)	7	24,192	8	104,620	8[a]	155,310 155,310
	14	579	14[a]	2,247 3,448	15	17,329
EVENT 3 (9/25/07)	1	15,650	1	2,613	No discharge	
	3	5,794	4	411		
EVENT 4 (10/17/07)	Not sampled		Not sampled		Not sampled	

Table 8. Comparison of City Storm Water Sample Results to Data in Literature.

	City Storm Water Data	National Storm water Quality Database (NSQD)	
	(Aug-Oct)	All Data	Summer Data
No. of Observations	13	160	14
% Non-Detect	0%	7%	0%
Geometric Mean Concentration	6,768	774	6,512
25th Percentile Concentration	2,247	149	3,800
Median Concentration	5,794	1,000	7,900
75th Percentile Concentration	24,192	4,125	23,850
Maximum Concentration	155,310	66,000	35,000

Bathymetry Survey Summary

Bathymetry measurements were made in the Wabash River to supplement physical river data collected by the USGS at the US-40 Bridge. The data will be used to configure the physical representation of the river in the river model domain (nominally from the US-63 Bridge downstream to the Vigo County line). Data were collected at each river quality sampling transect during the events shown in the Table 10. Twenty transects (four per location) were surveyed.

Table 10. Summary of Bathymetry Transect Data Collections.

Event ID	Date	River Flow (cfs)
Dry 1	8/9/07	2,230
Wet 1	8/21/07	2,344
Wet 1	8/22/07	3,594
Wet 1	8/23/07	6,472

The bathymetry data were analyzed to generate relationships between flow and the river's physical (e.g. depth, width, cross-sectional area) and hydraulic (e.g. velocity) characteristics. Figure 13 is one example of the data analysis at RS-1 that shows the relationship between flow and depth. Appendix 2 contains all river bathymetry plots by transect.

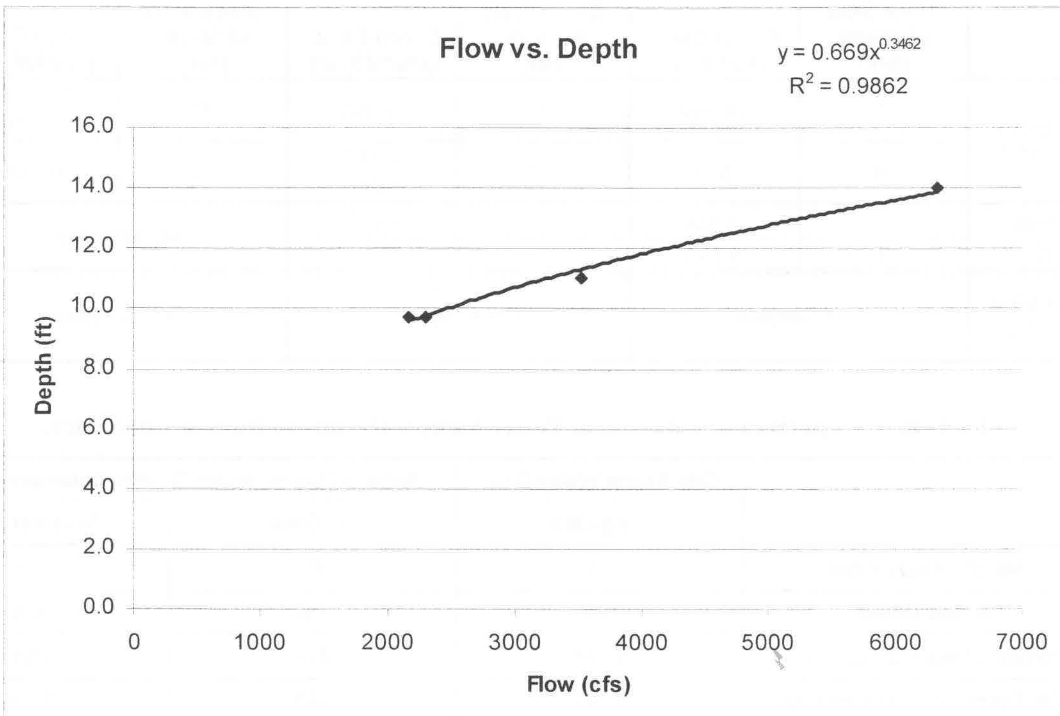


Figure 13. Flow versus Depth Relationship from Bathymetry Data Collected at River Location RS-1.

Appendix 1:
River Temporal and Spatial Plots

Appendix 1: River Temporal and Spatial Plots

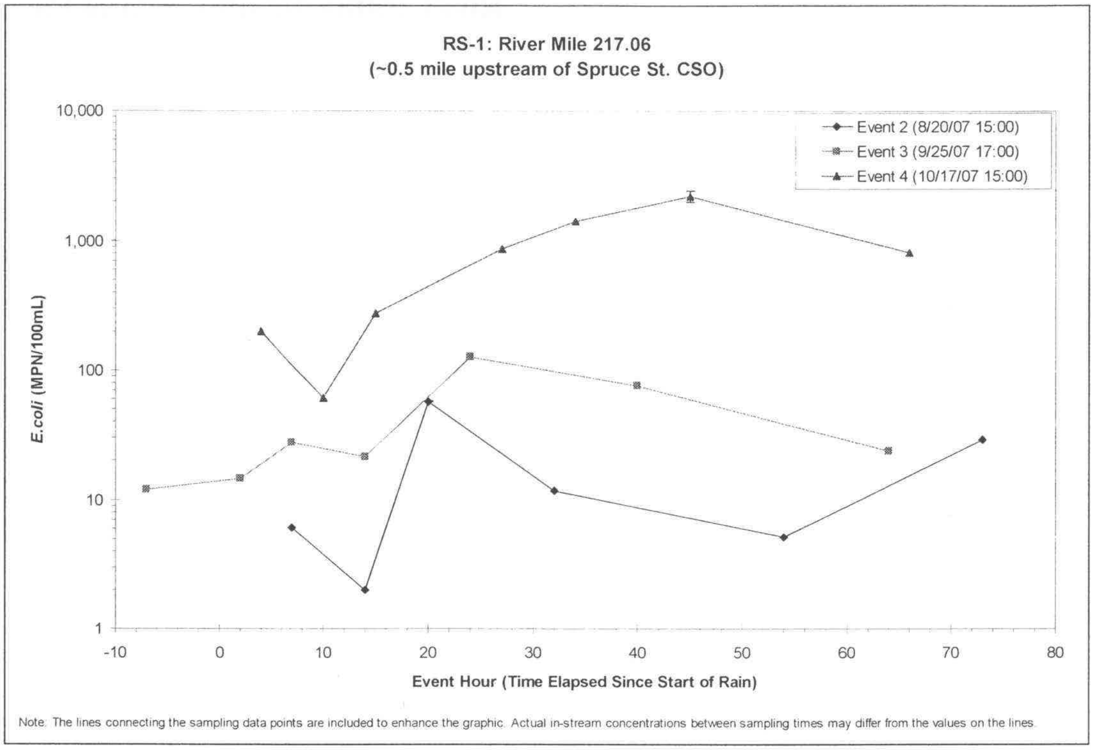


Figure A.1: *E.coli* concentrations over time at RS-1.

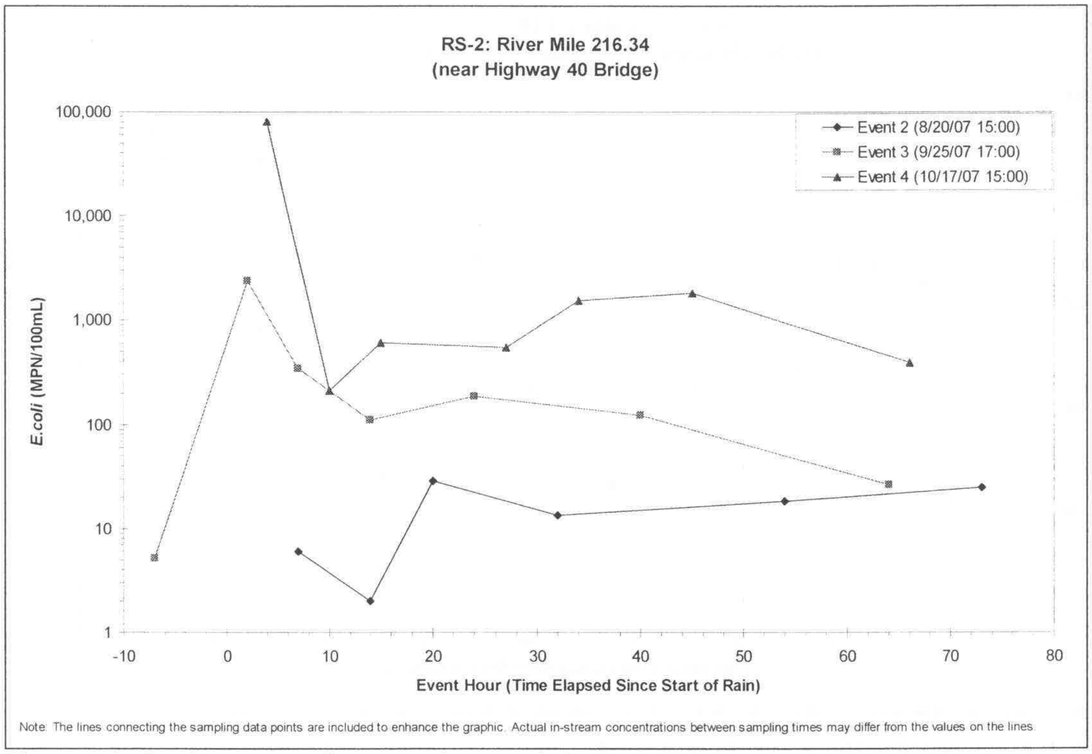


Figure A.2: *E.coli* concentrations over time at RS-2.

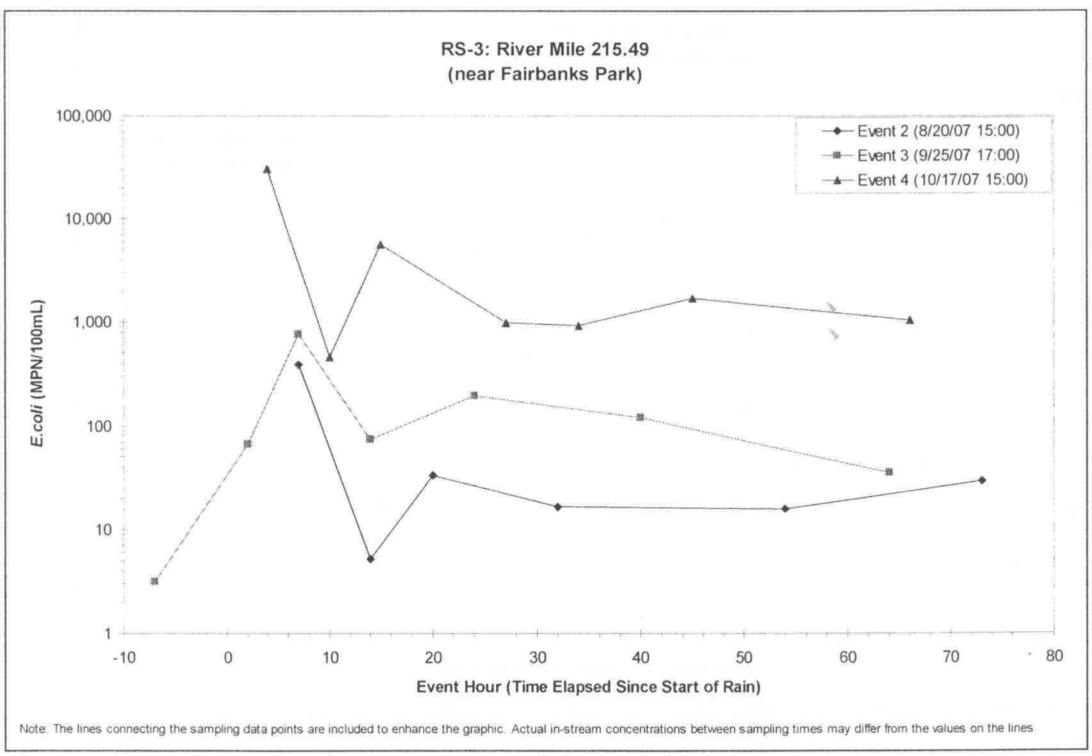


Figure A.3: *E.coli* concentrations over time at RS-3.

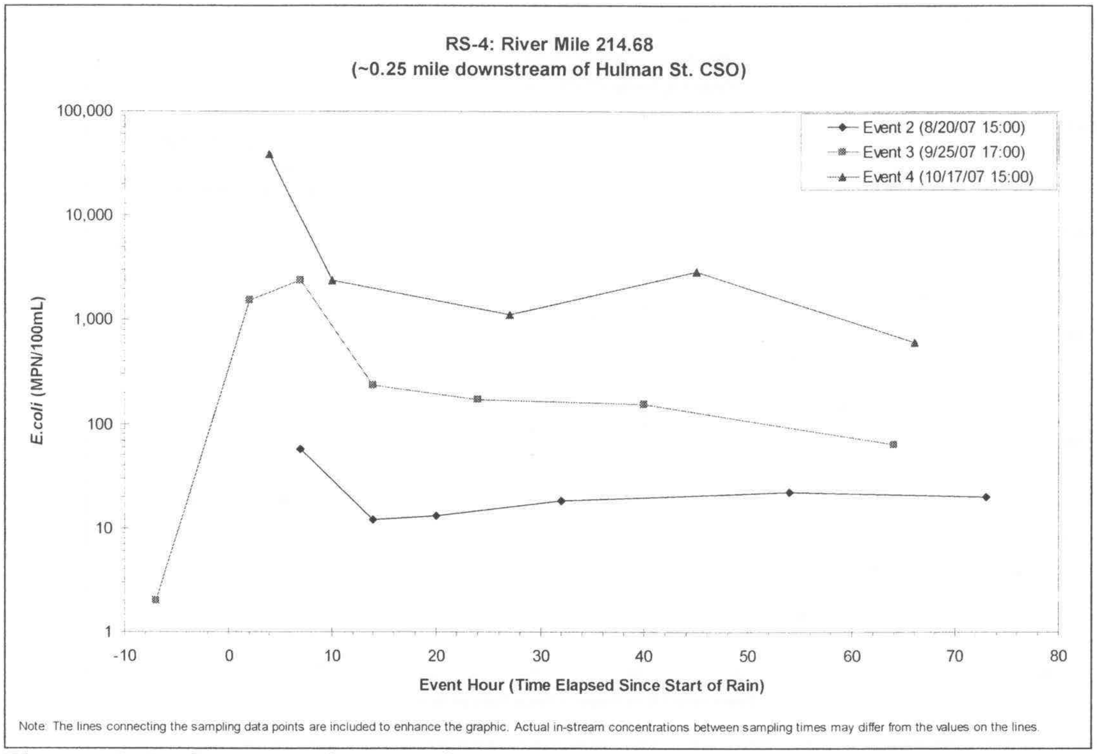


Figure A.4: *E.coli* concentrations over time at RS-4.

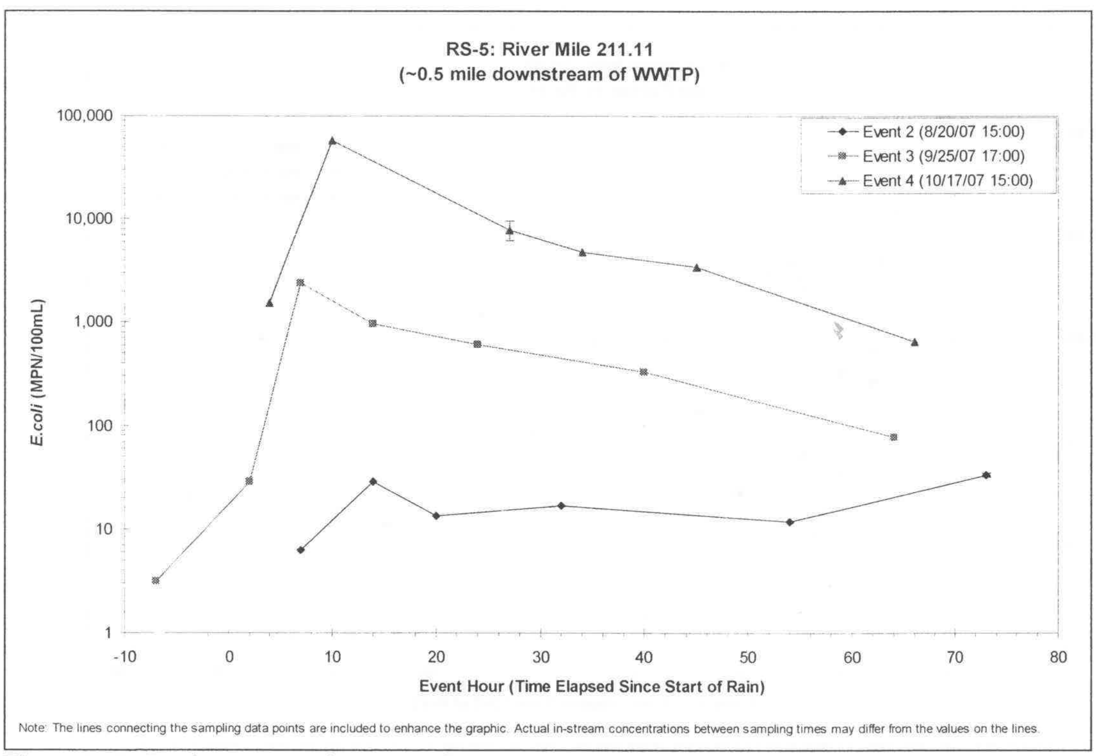


Figure A.5: *E.coli* concentrations over time at RS-5.

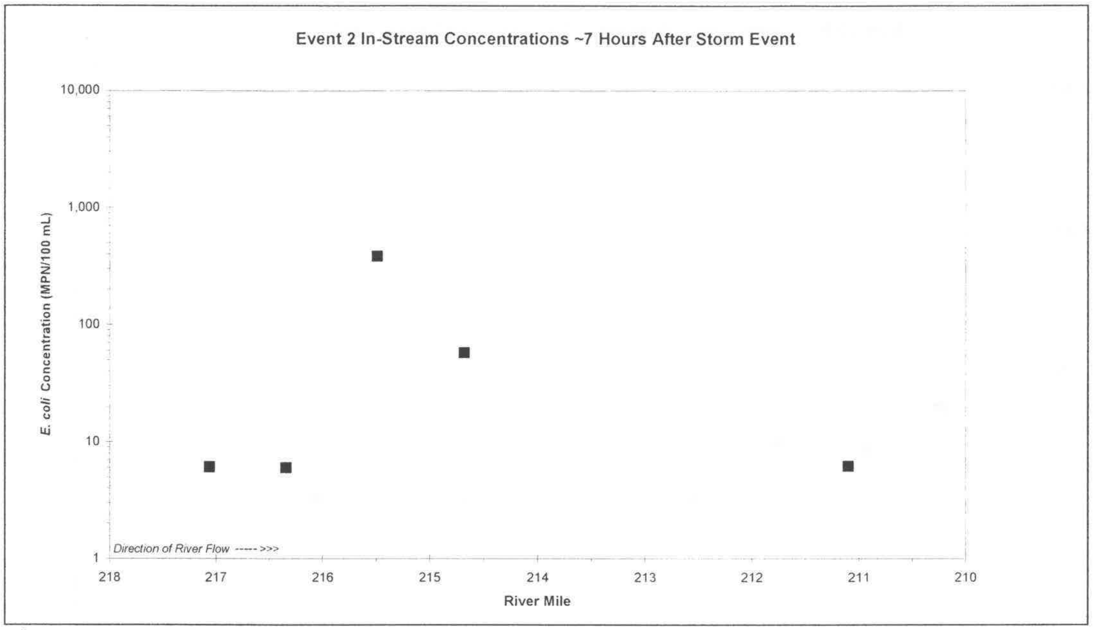


Figure A.6: *E.coli* concentrations 7 hours after Event 2.

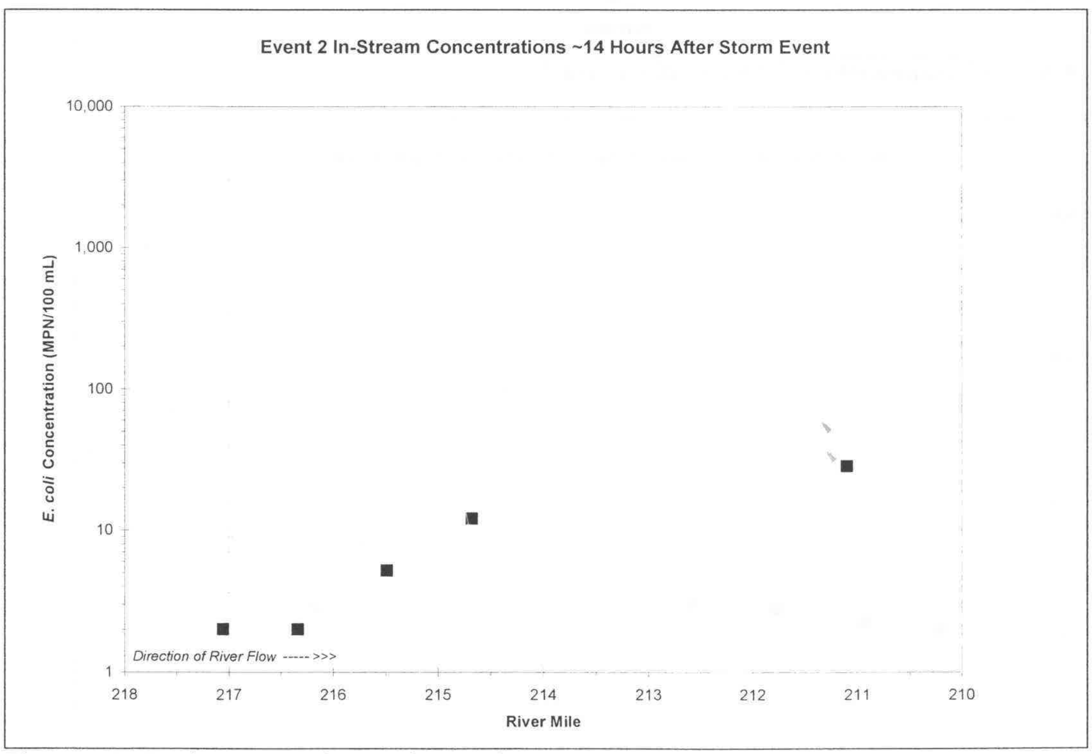


Figure A.7: *E.coli* concentrations 14 hours after Event 2.

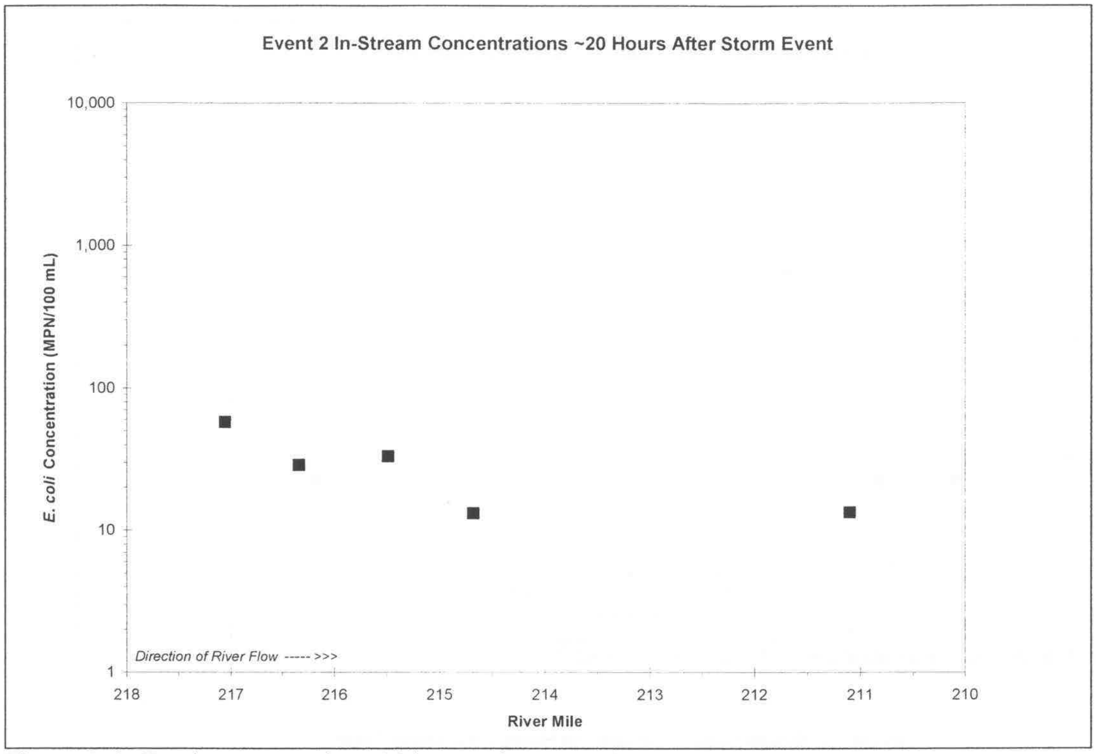


Figure A.8: *E.coli* concentrations 20 hours after Event 2.

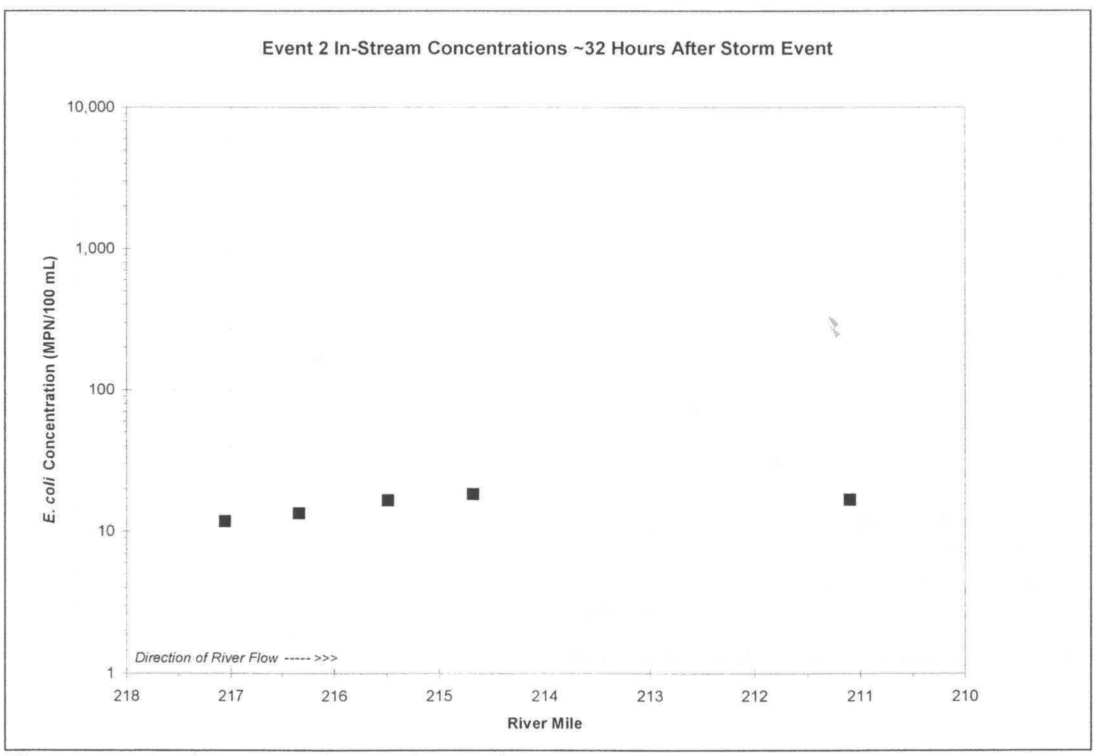


Figure A.9: *E.coli* concentrations 32 hours after Event 2.

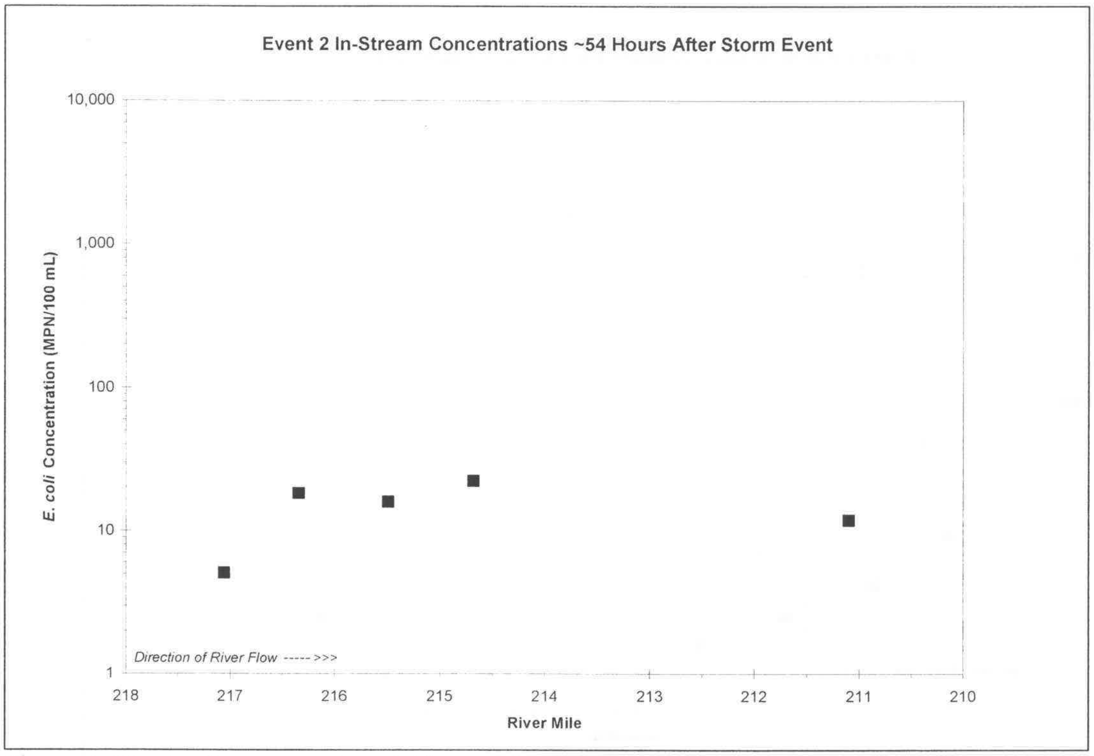


Figure A.10: *E.coli* concentrations 54 hours after Event 2.

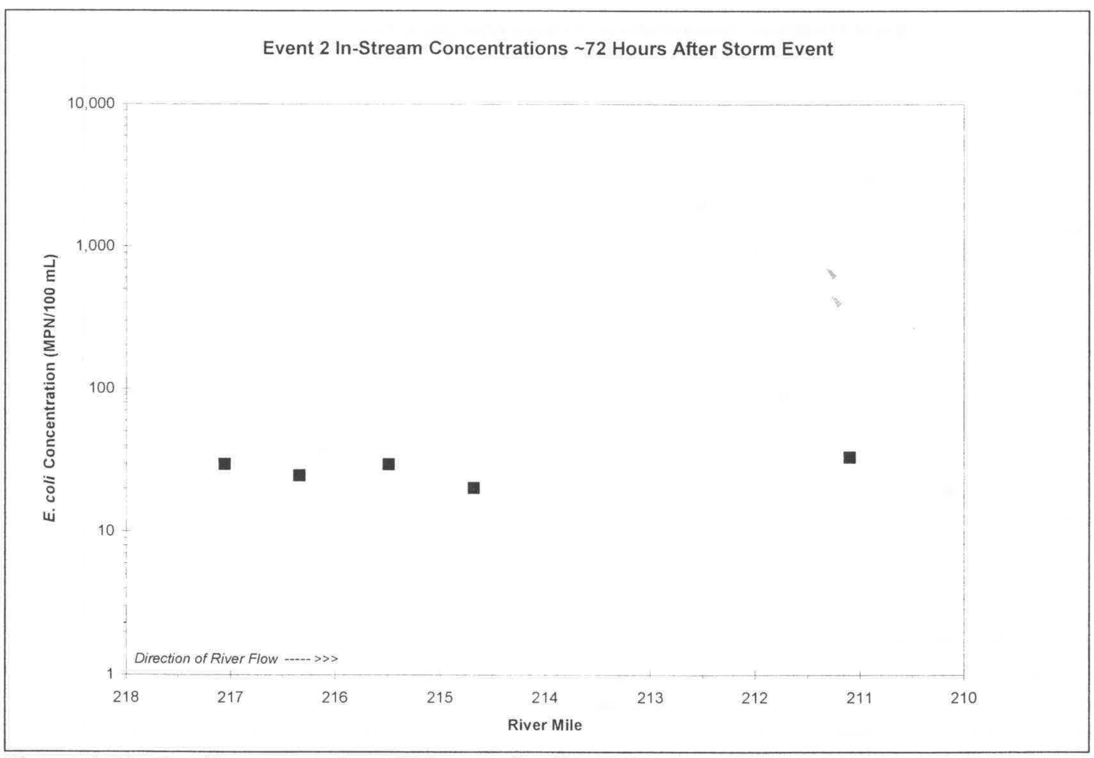


Figure A.11: *E.coli* concentrations 72 hours after Event 2.

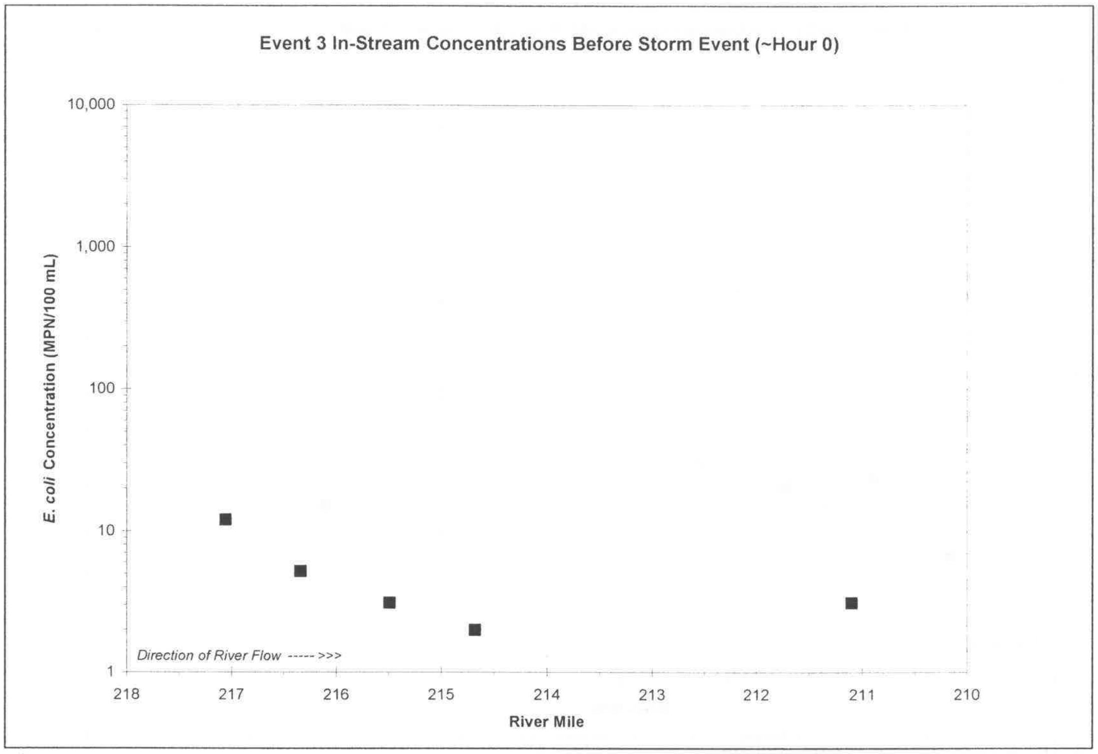


Figure A.12: *E.coli* concentrations immediately before Event 3.

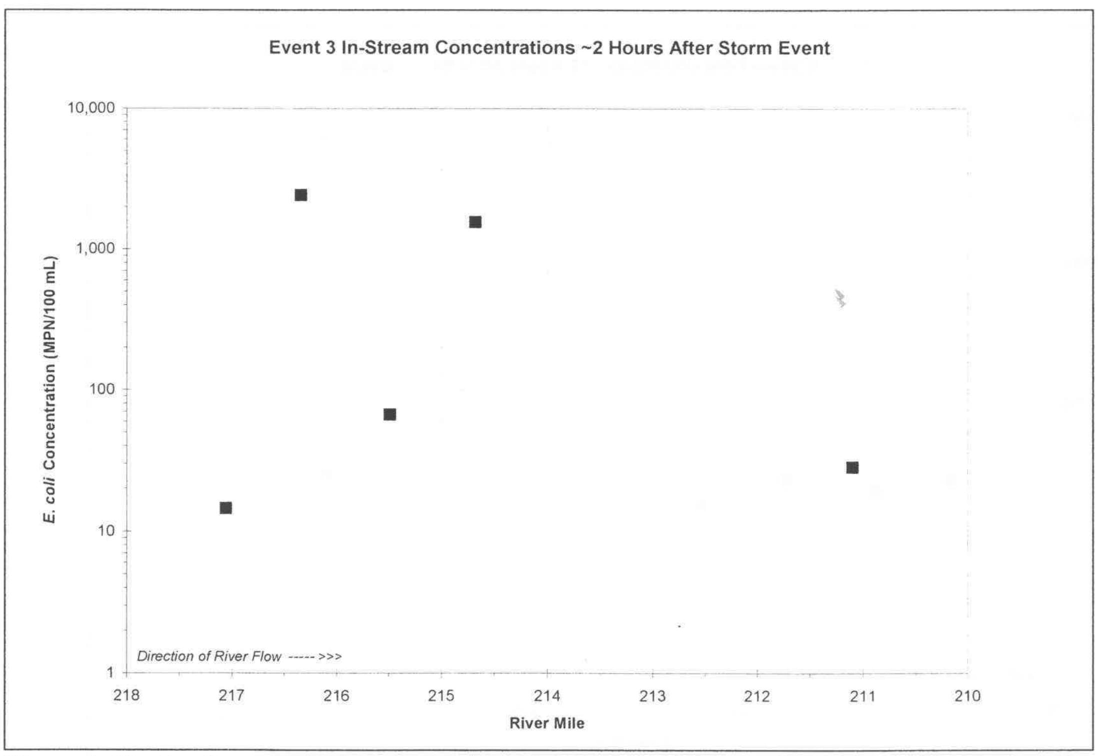


Figure A.13: *E.coli* concentrations approximately 2 hours after Event 3.

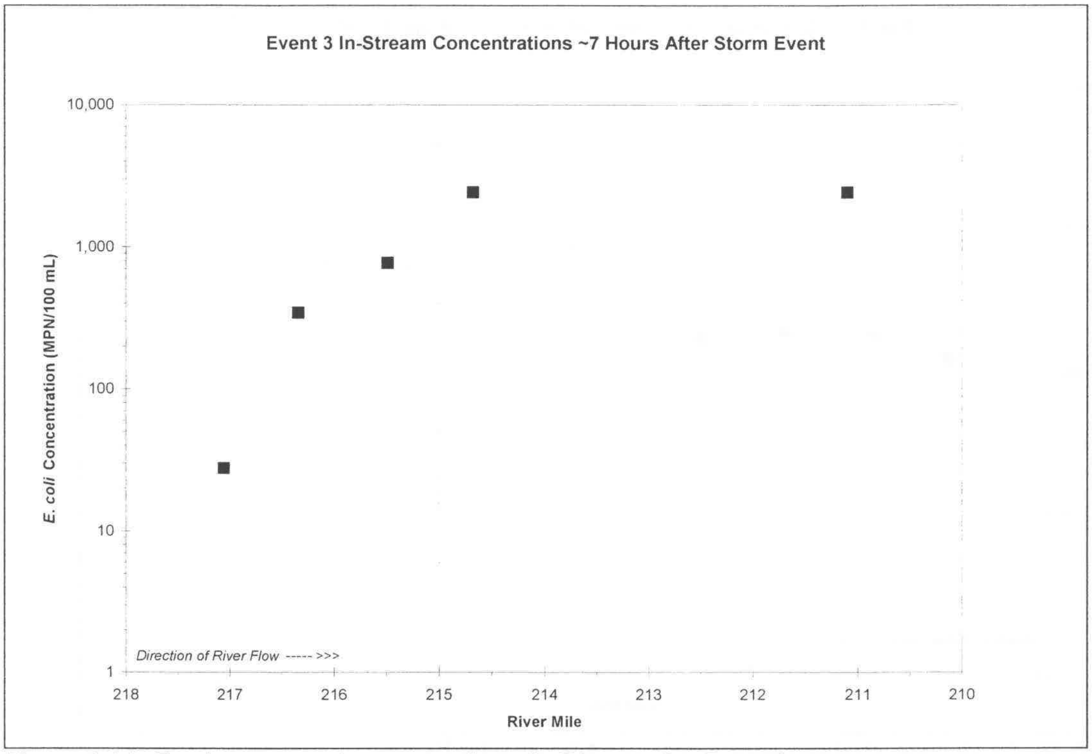


Figure A.14: *E.coli* concentrations approximately 7 hours after Event 3.

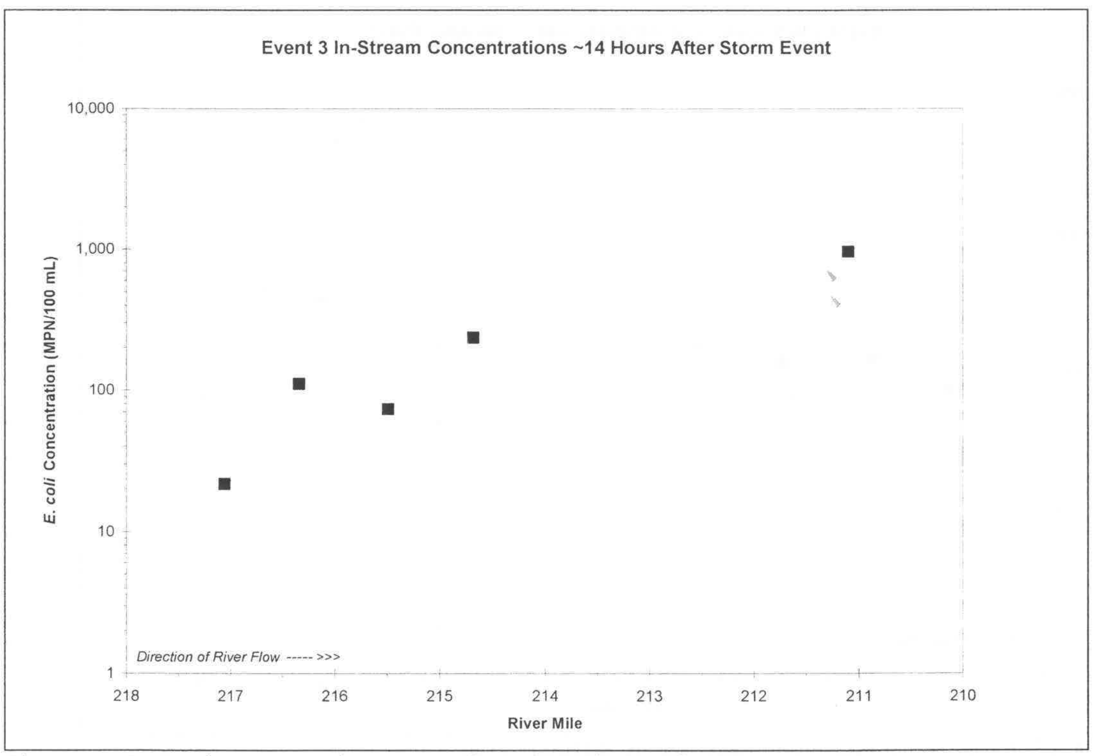


Figure A.15: *E.coli* concentrations approximately 14 hours after Event 3.

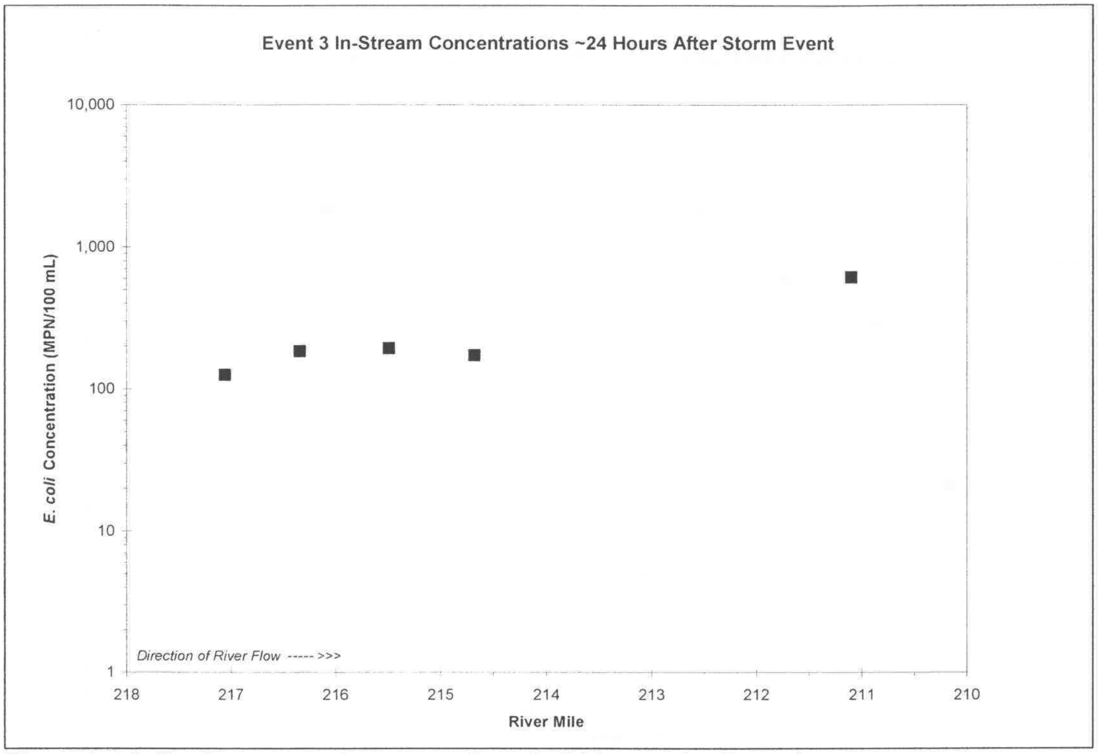


Figure A.16: *E.coli* concentrations approximately 24 hours after Event 3.

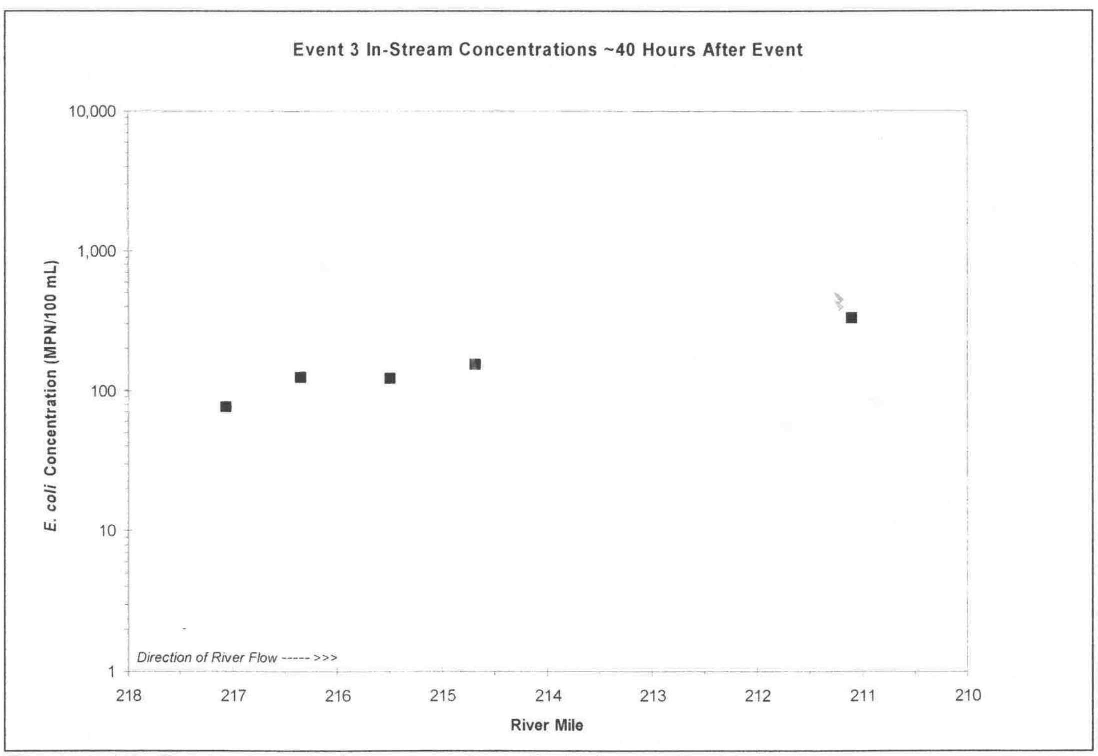


Figure A.17: *E.coli* concentrations approximately 40 hours after Event 3.

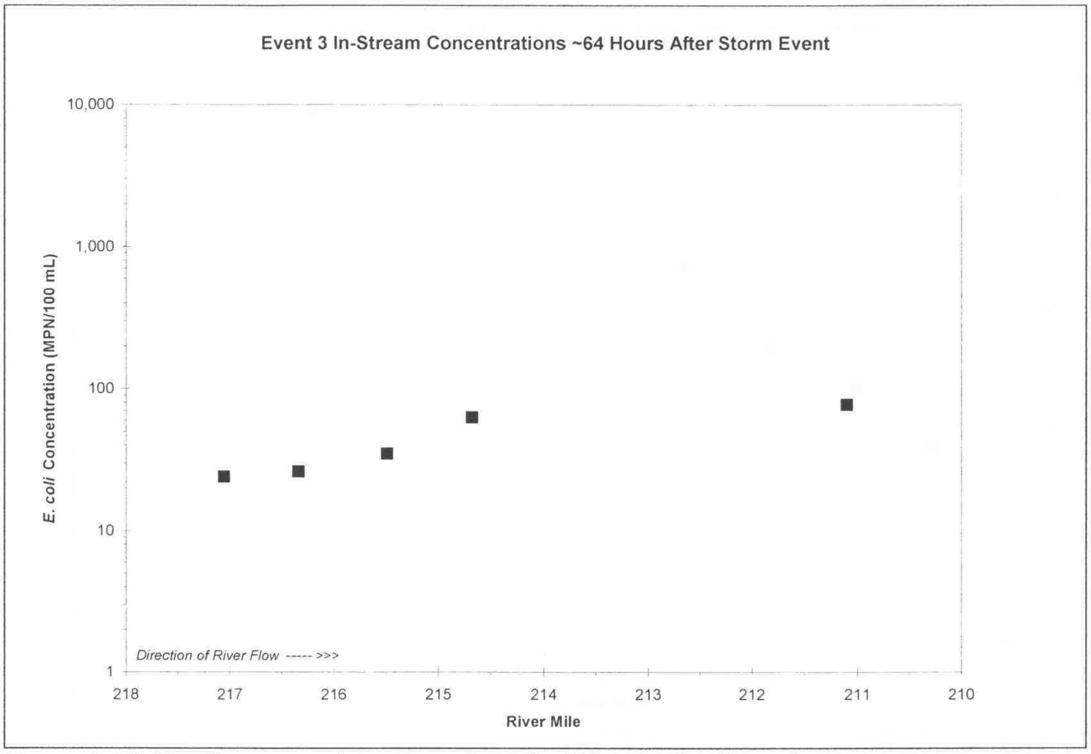


Figure A.18: *E.coli* concentrations approximately 40 hours after Event 3.

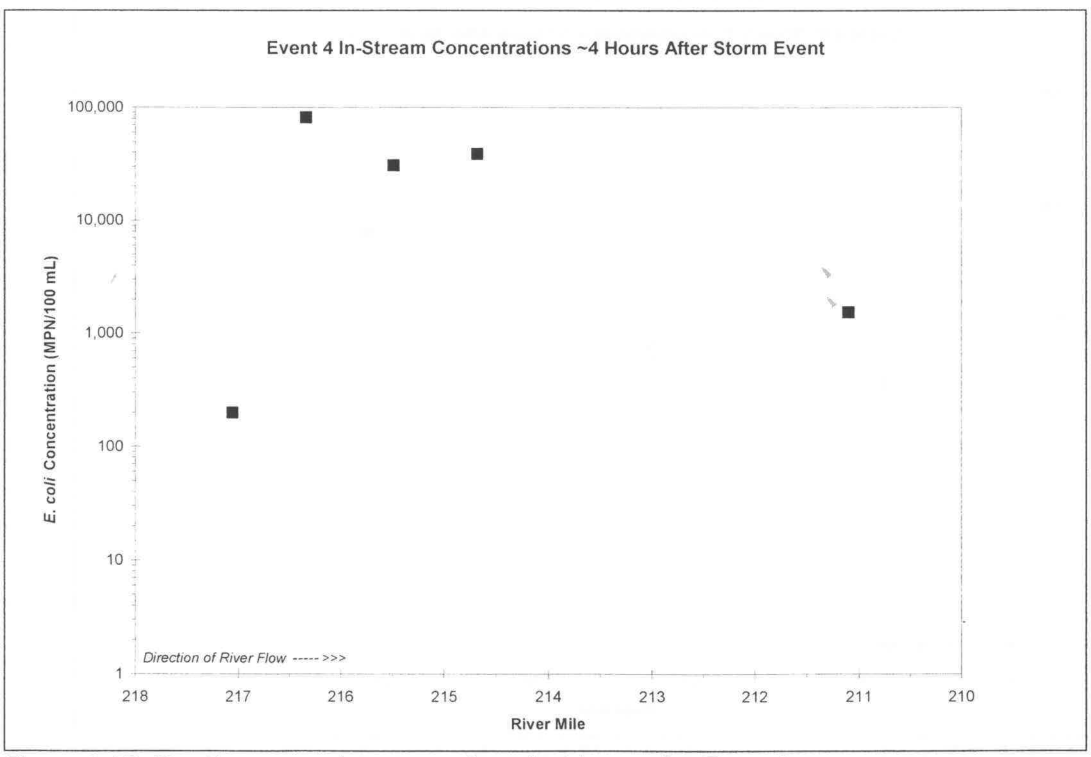


Figure A.19: *E.coli* concentrations approximately 4 hours after Event 4.

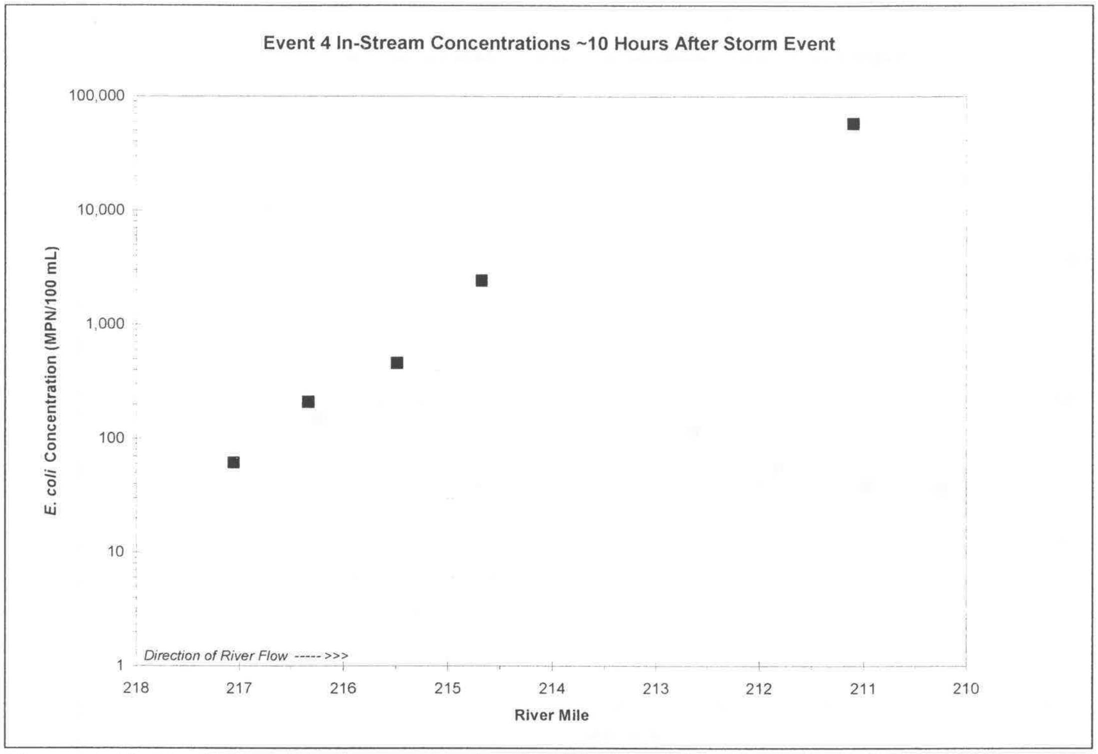


Figure A.20: *E.coli* concentrations approximately 10 hours after Event 4.

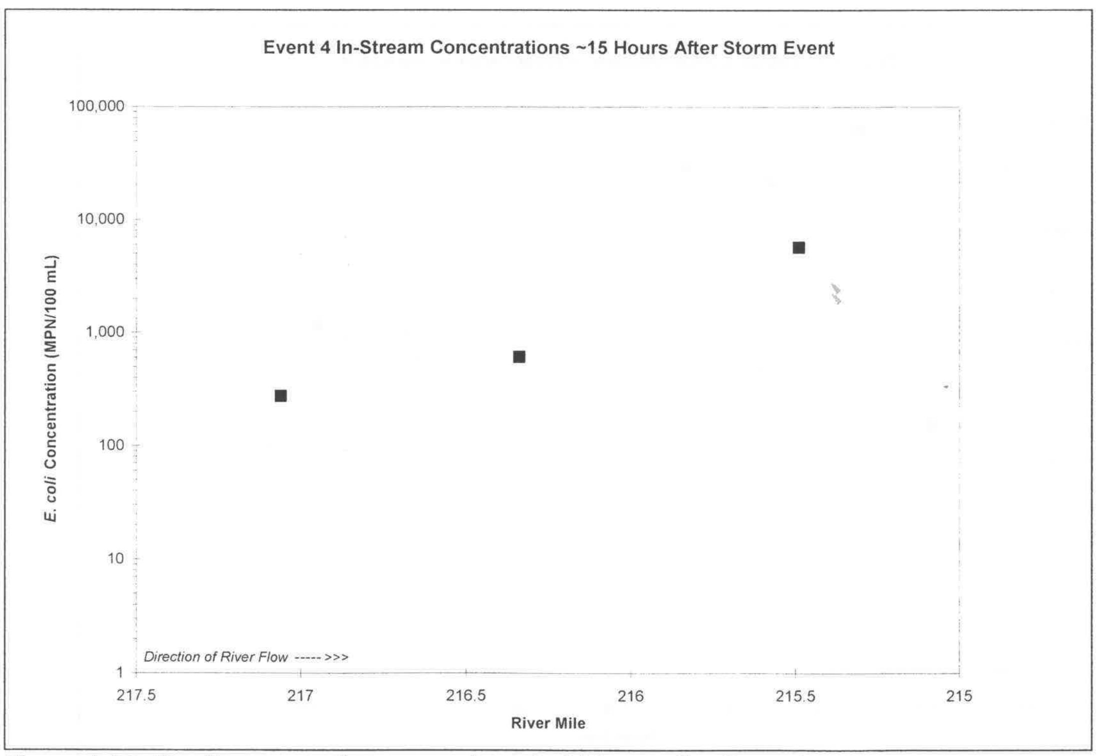


Figure A.21: *E.coli* concentrations approximately 15 hours after Event 4.

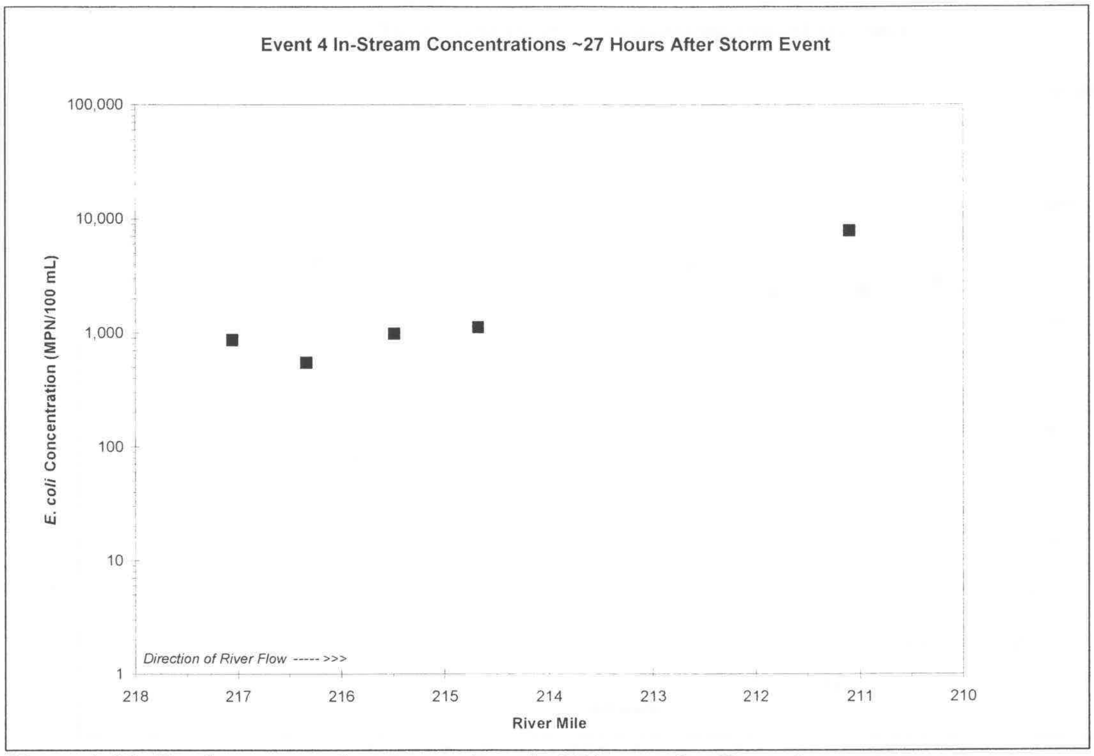


Figure A.22: *E.coli* concentrations approximately 27 hours after Event 4.

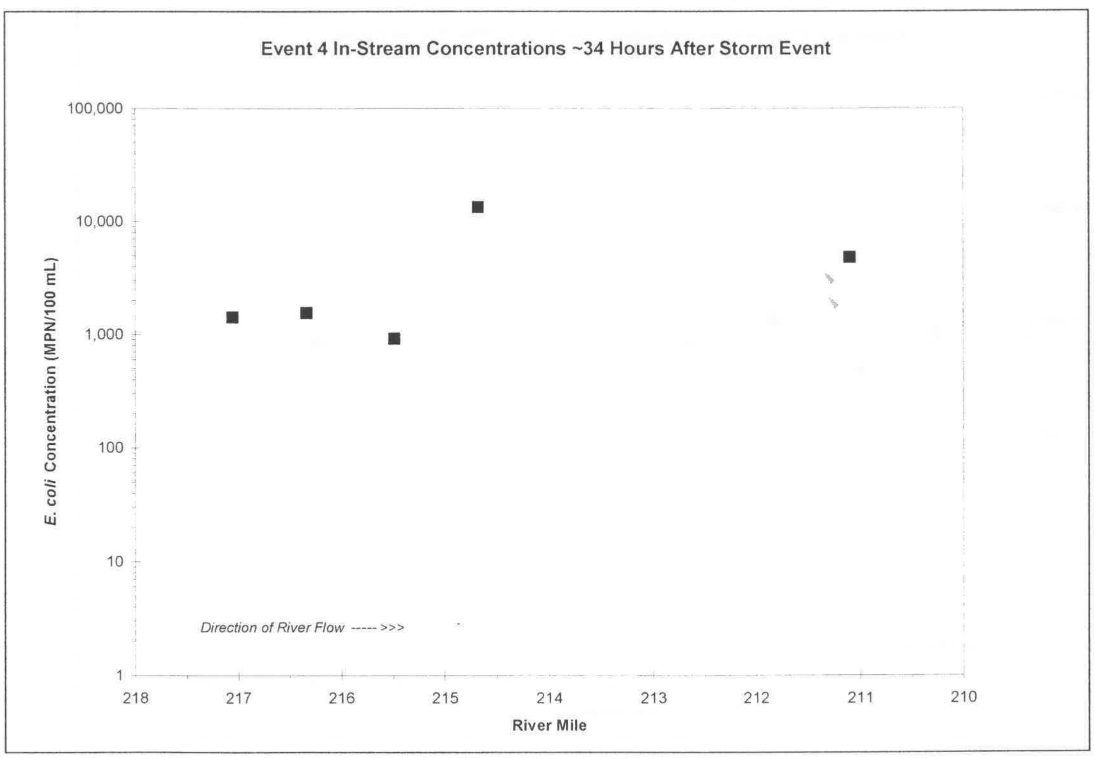


Figure A.23: *E.coli* concentrations approximately 34 hours after Event 4.

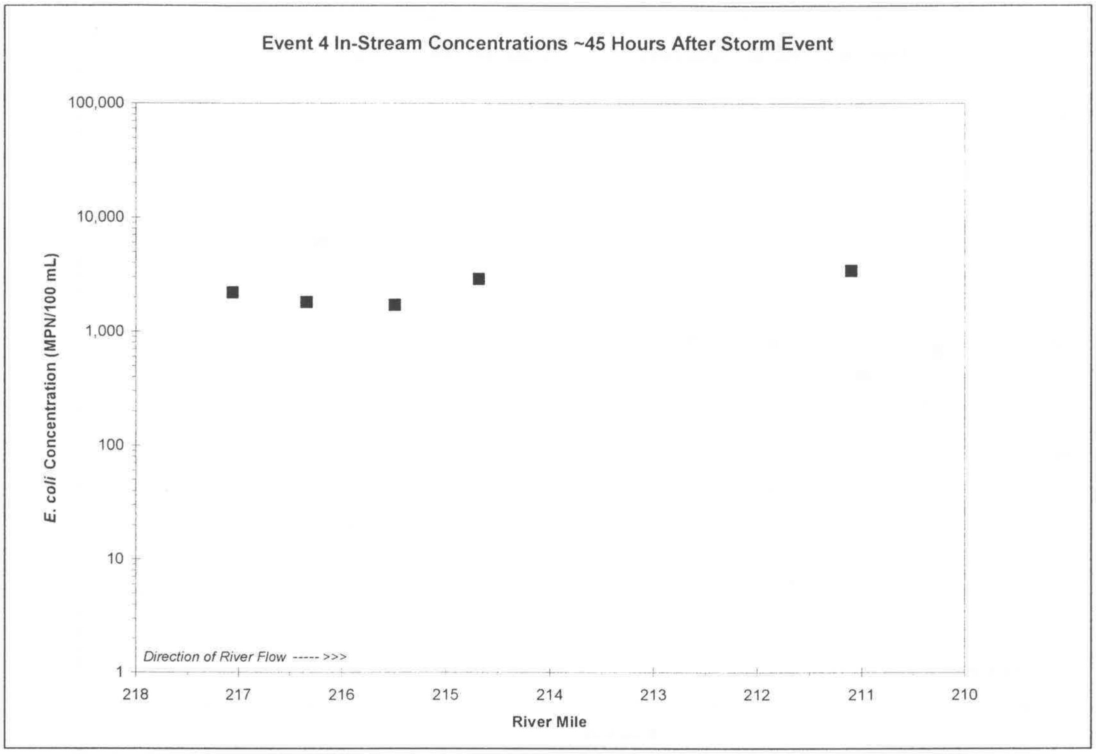


Figure A.24: *E.coli* concentrations approximately 45 hours after Event 4.

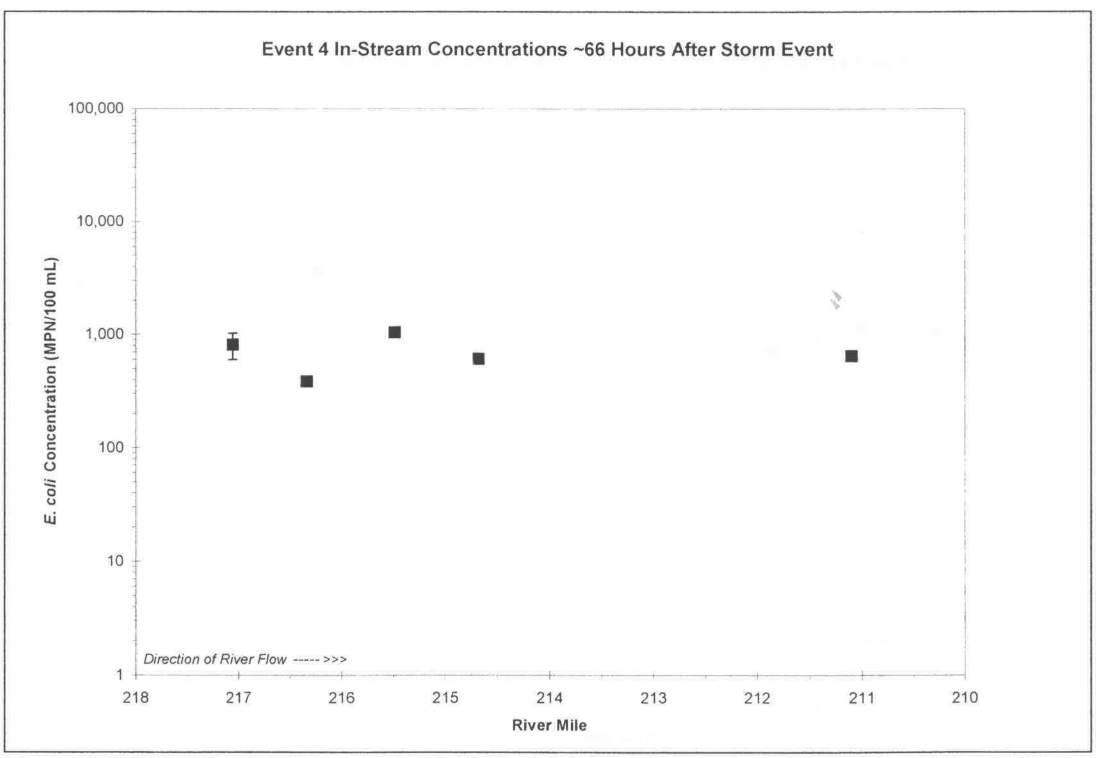
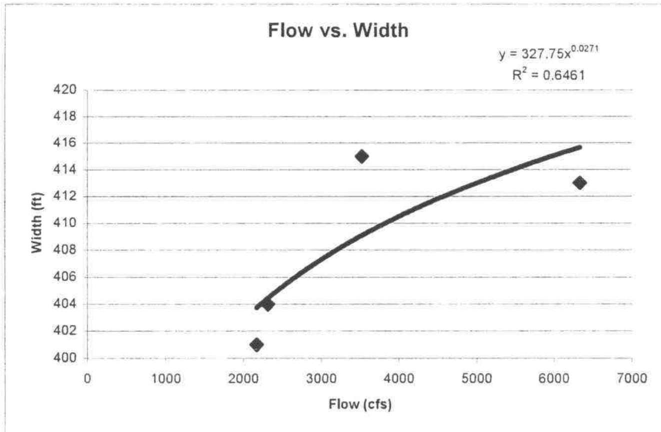
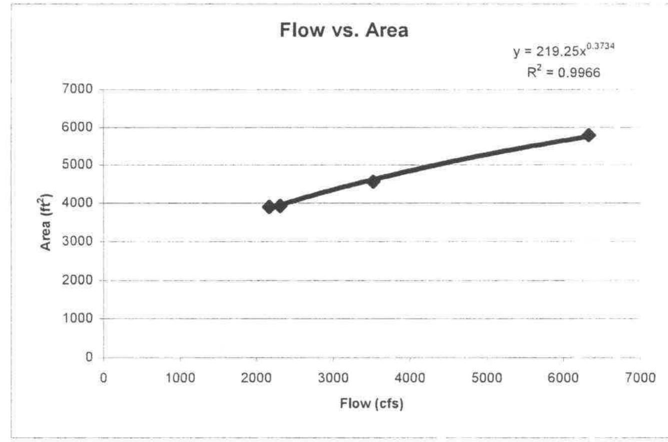


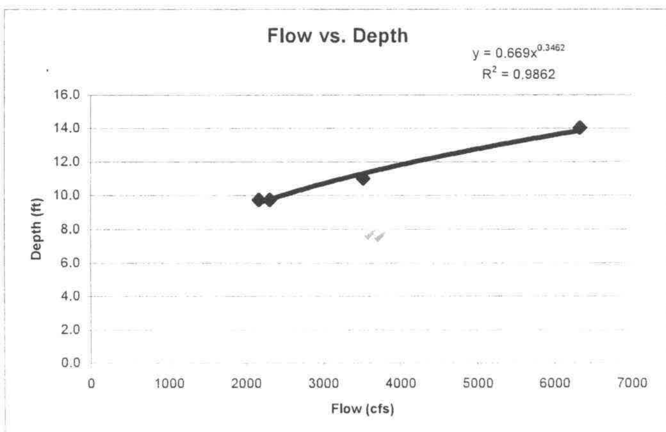
Figure A.25: *E.coli* concentrations approximately 66 hours after Event 4.

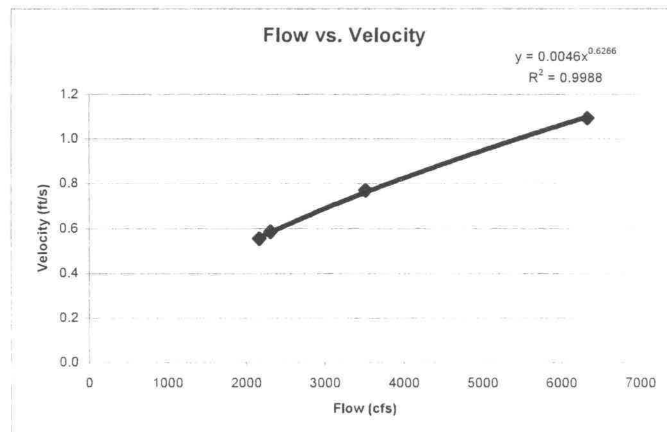
Appendix 2: River Bathymetry Plots

Wabash River transect location RS-1, ½ mile upstream of Spruce St. CSO, River Mile 217.06

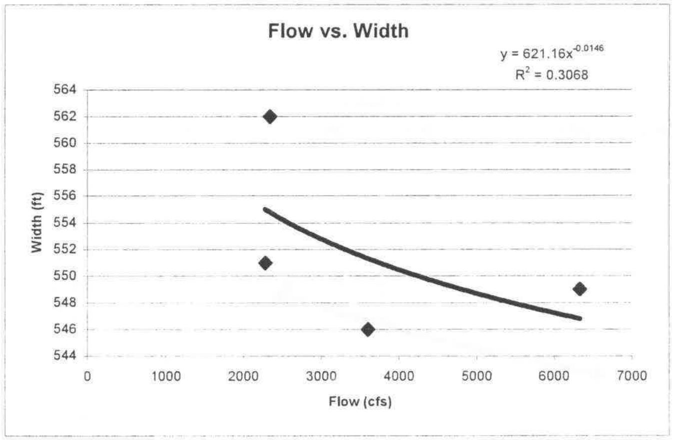


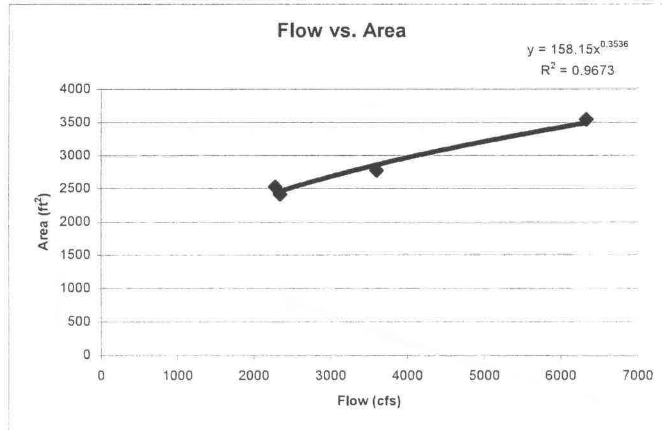


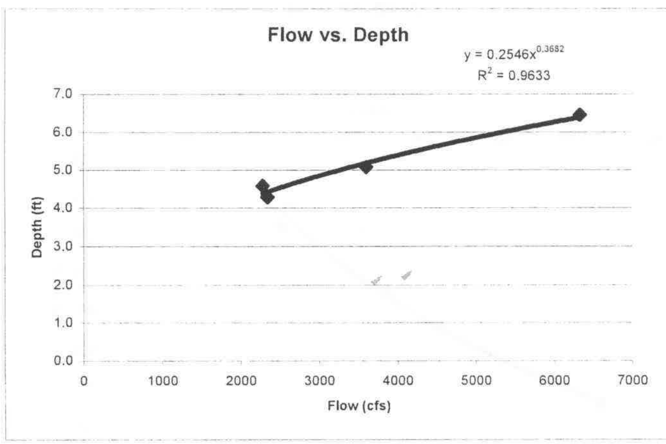


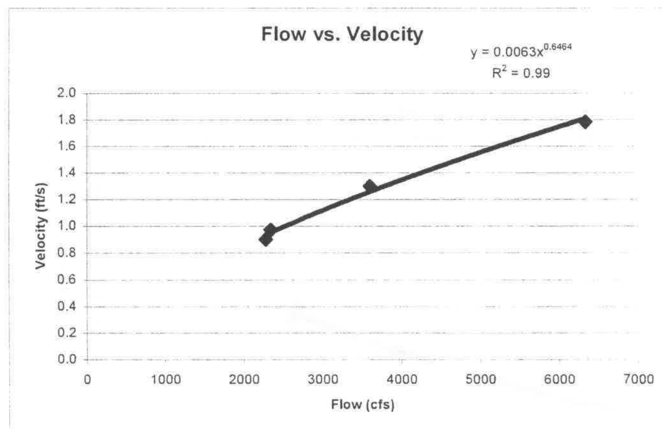


Wabash River transect location RS-2, Highway 40 Bridge, River Mile 216.34

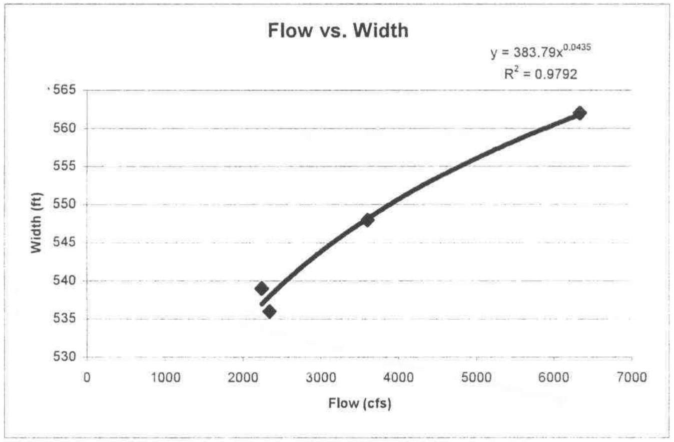


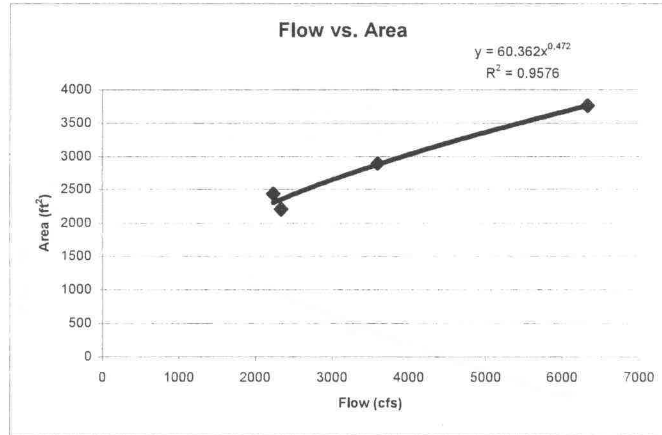


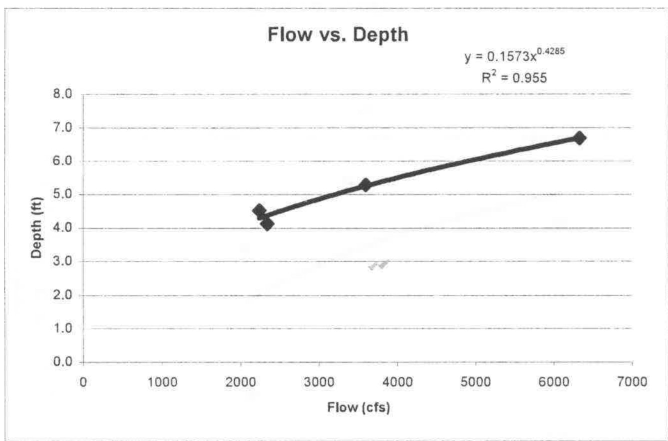


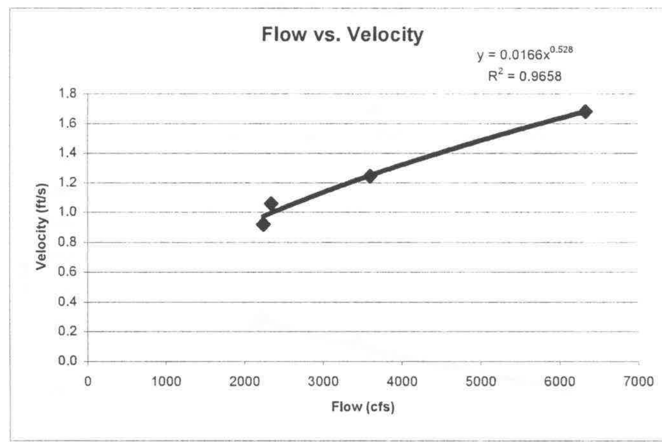


Wabash River transect location RS-3, Across from boat dock at Fairbanks Park, River Mile 215.49

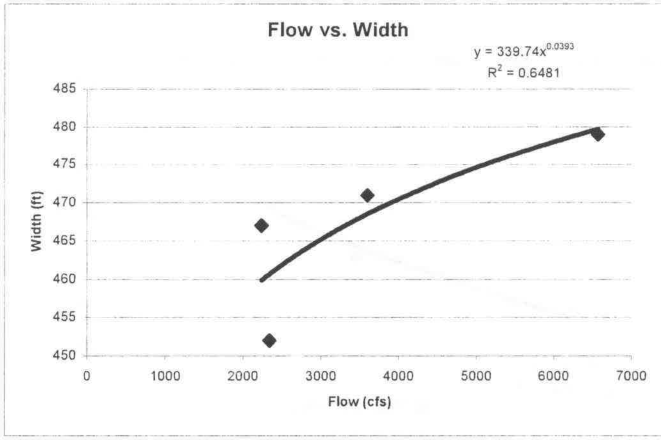


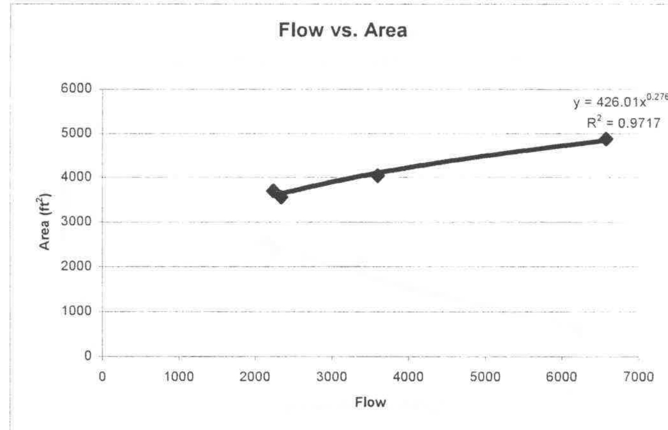


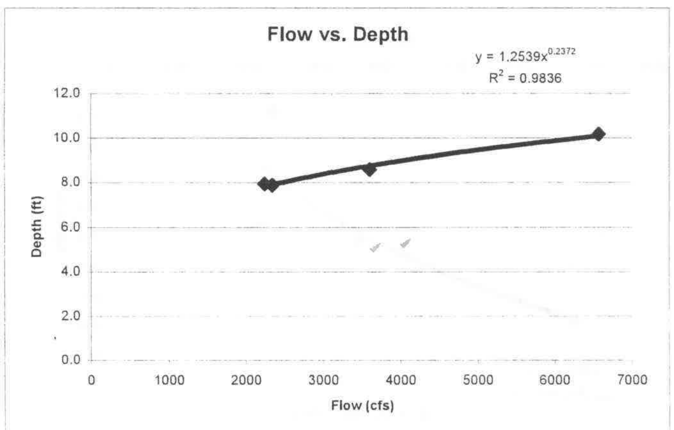


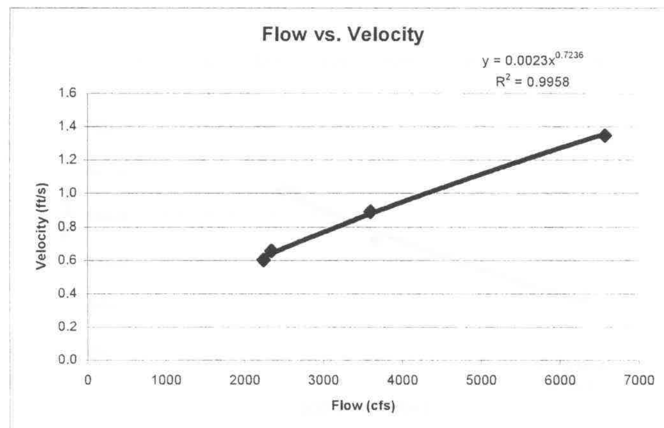


Wabash River transect location RS-4, ¼ mile downstream of Hulman St. CSO, River Mile 214.68

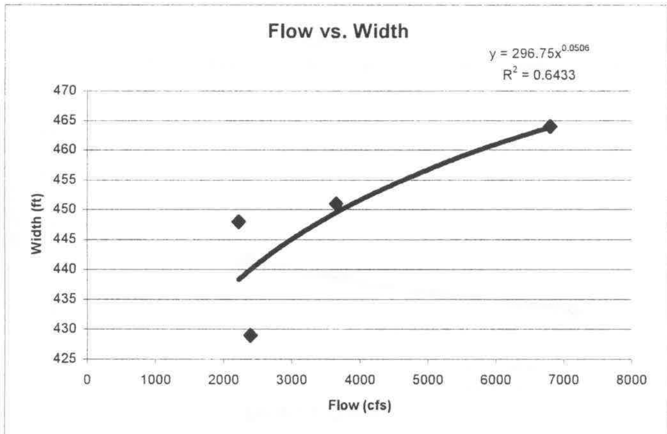


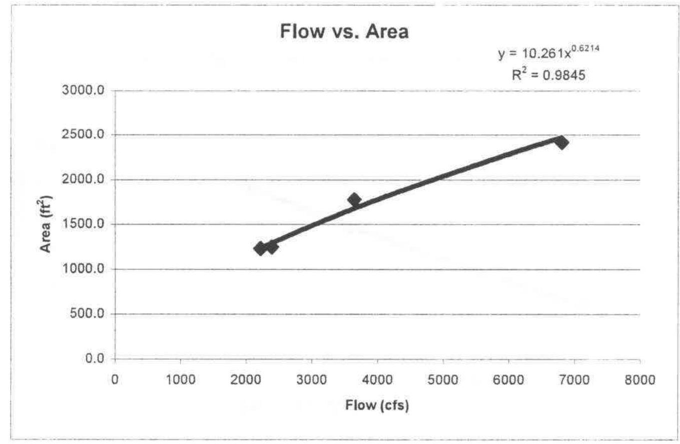


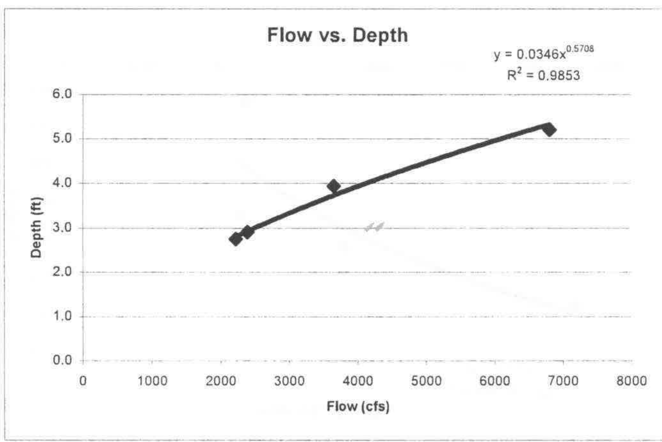


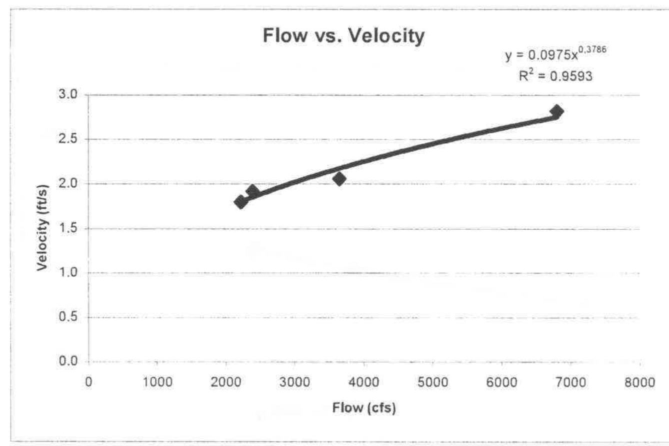


Wabash River transect location RS-5, ½ mile downstream of WWTP, River Mile 211.10

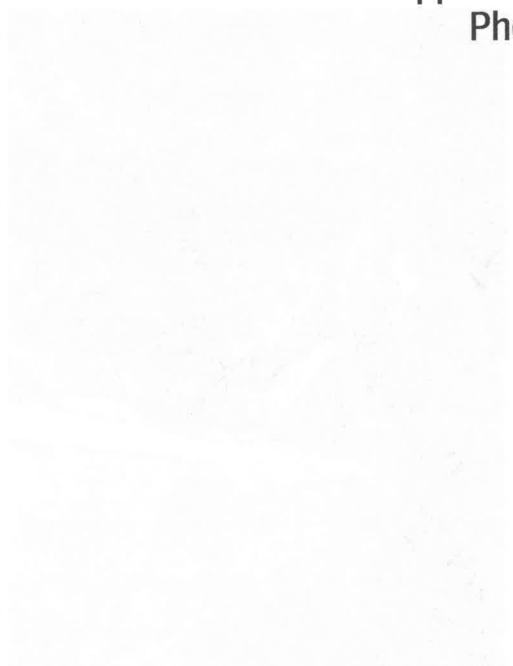


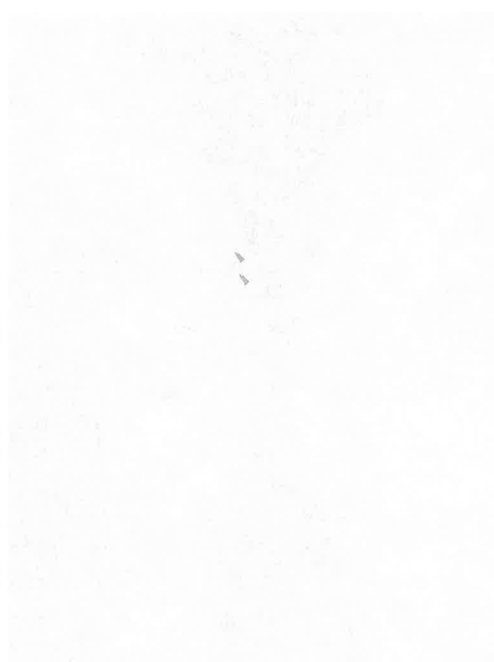






Appendix 3: Photos

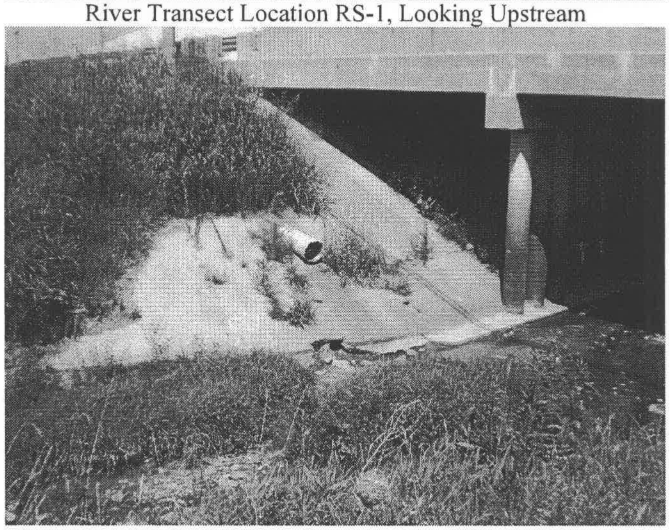




Event 1 – Dry Weather 8/9/07

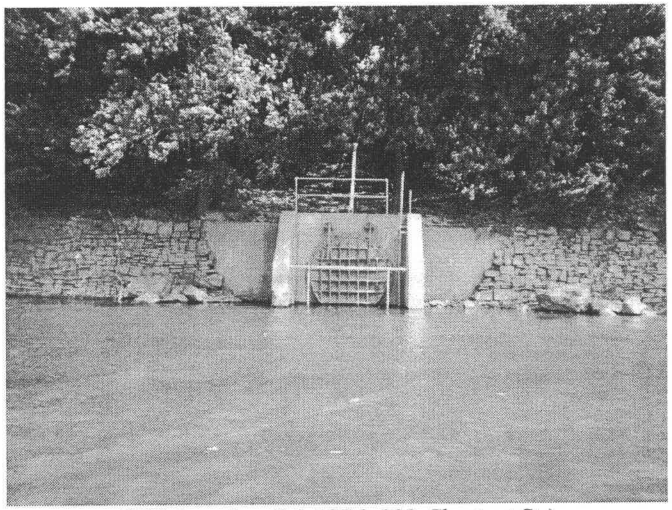

River Transect Location RS-1, Looking Upstream


Outfall Pipe at Storm Water Sampling Location S-1 (13th & Elizabeth)

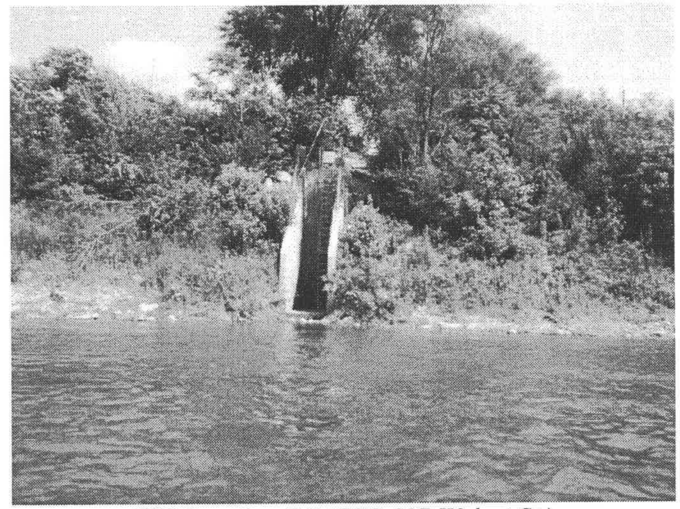

Outfall Pipe at Storm Water Sampling Location S-2 (Fruitridge at Lost Creek)


Ditch at Storm Water Sampling Location S-3 (New Thompson Ditch)

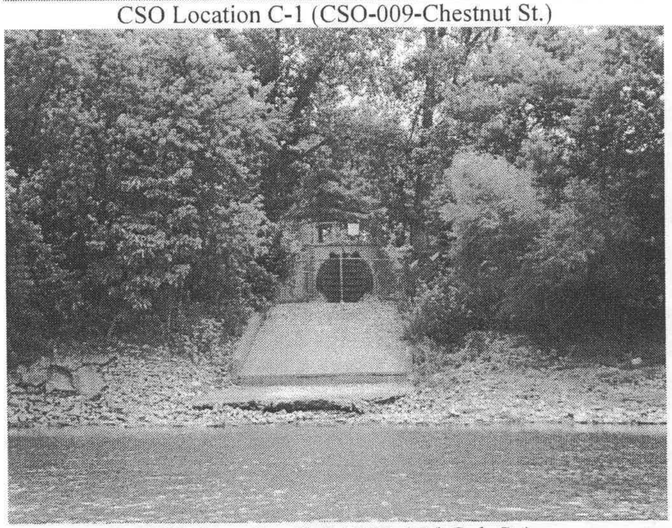
Event 2 – Wet Weather 8/21/07 (Note: Rain event started on 8/20/07)



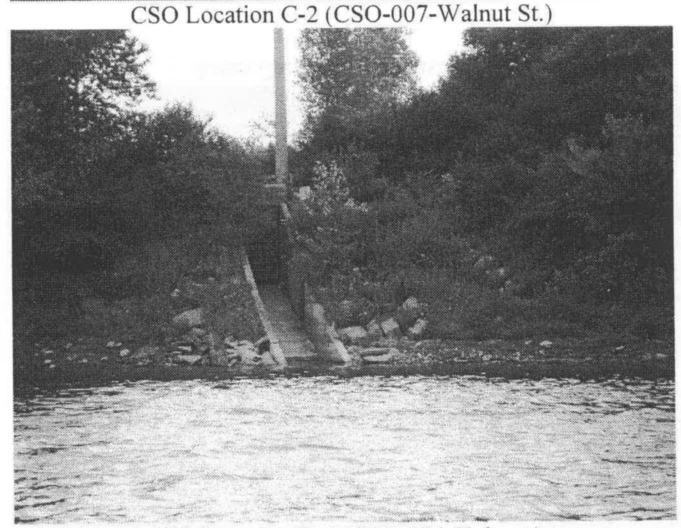
CSO Location C-1 (CSO-009-Chestnut St.)



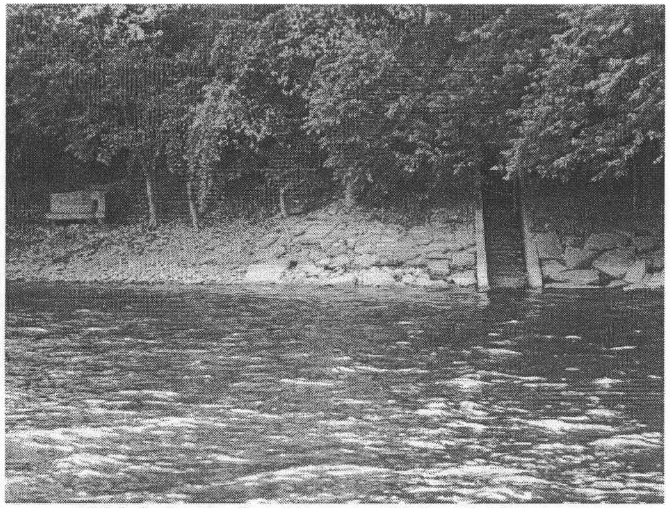
CSO Location C-2 (CSO-007-Walnut St.)



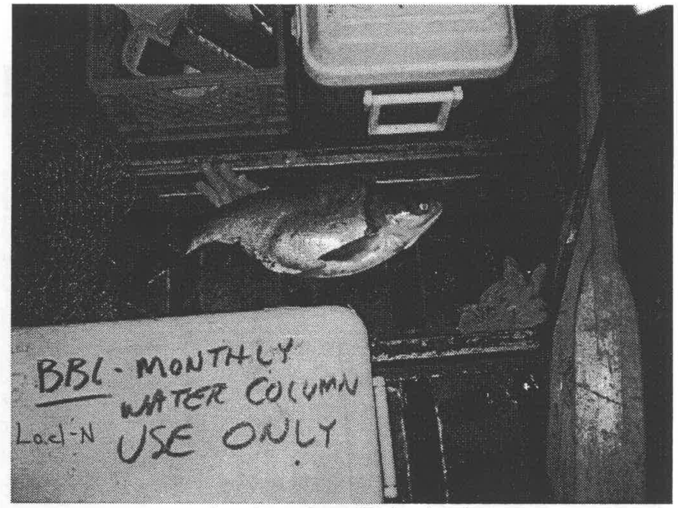
CSO Location C-3 (CSO-006-Oak St.)



CSO Location C-4 (CSO-004-Hulman)

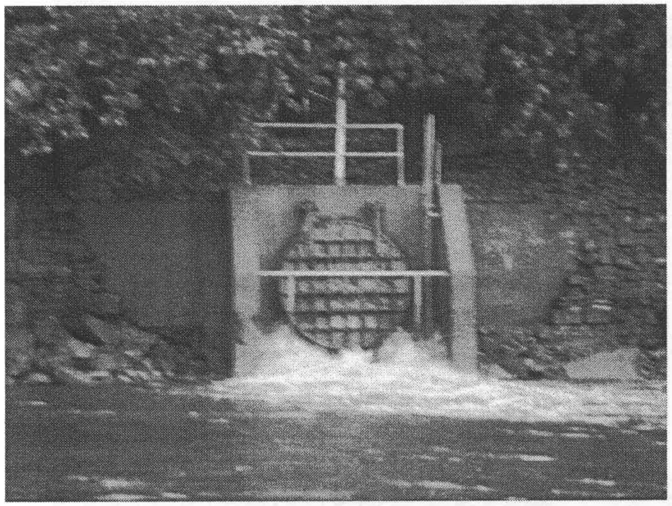


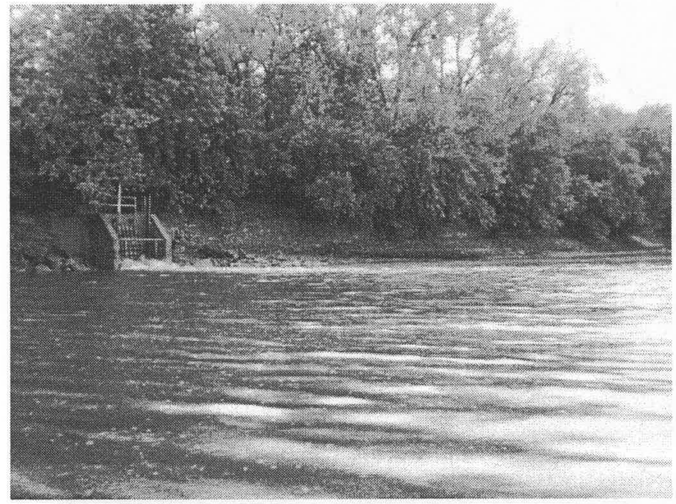
CSO Location C-4 Alternate (CSO-011-Idaho St.)

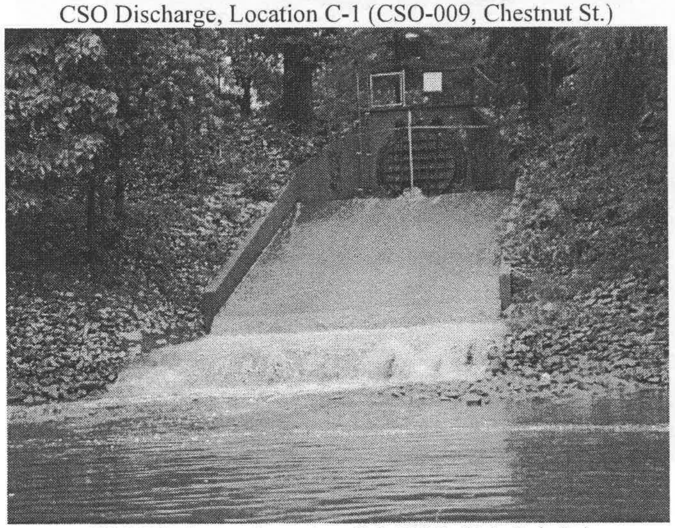


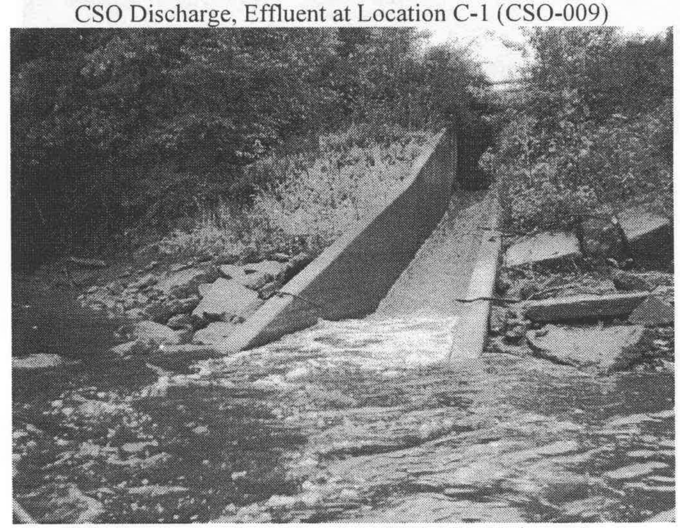
Asian Carp from Wabash River

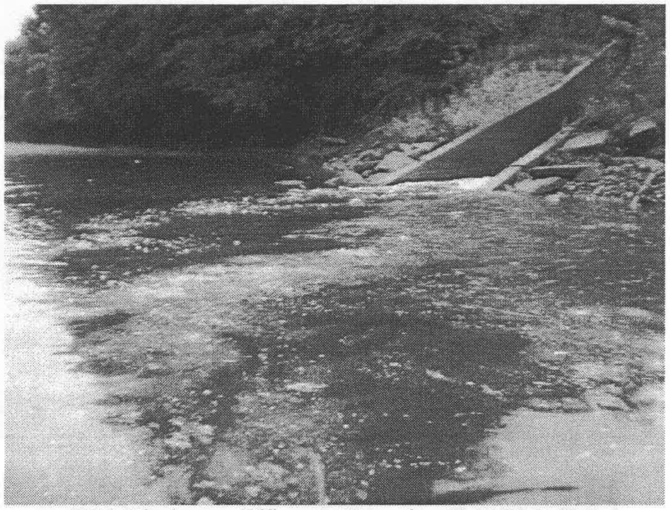
Event 3 – Wet Weather 9/25/07


CSO Discharge, Location C-1 (CSO-009, Chestnut St.)


CSO Discharge, Effluent at Location C-1 (CSO-009)

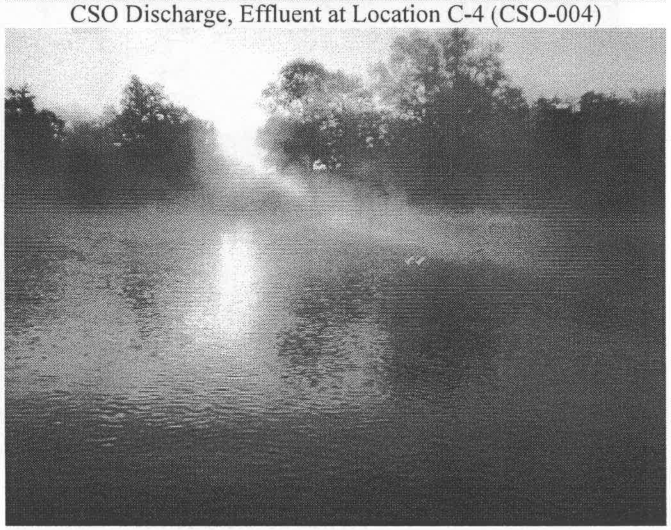

CSO Discharge, Location C-3 (CSO-006, Oak St.)


CSO Discharge, Location C-4 (CSO-004, Hulman Ave)

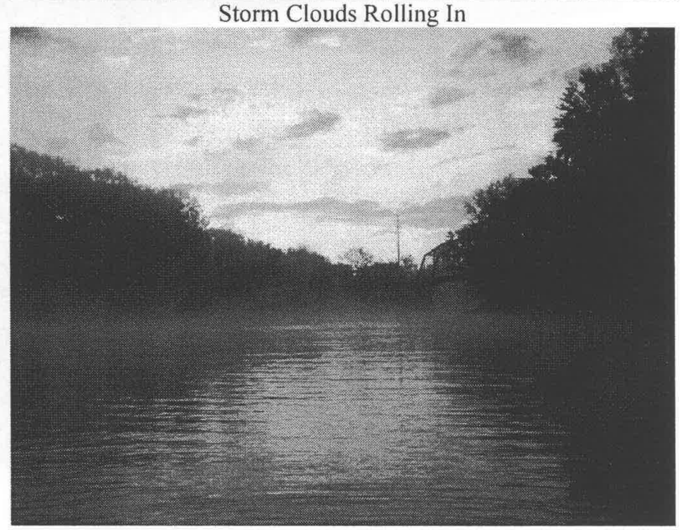


CSO Discharge, Effluent at Location C-4 (CSO-004)

Storm Clouds Rolling In



The Wabash River The Morning After the Storm



The Wabash River at Sunrise

Event 4 – Wet Weather 10/17/07

No photos taken during this event.