SAUCON CREEK

TMDL ALTERNATIVES REPORT

PART 2

Lehigh Valley Planning Commission

September 2012

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A. INTRODUCTION

Since the 1990's, to satisfy the conditions of the Clean Water Act, Pennsylvania's Department of Environmental Protection (DEP) has been monitoring the physical, chemical, and biological health of the Waters of the Commonwealth. As part of this process, DEP has been monitoring and testing the streams in the state to determine whether they are meeting their designated uses. These designated uses include aquatic life, fish consumption, potable water supply, and recreation. In accordance with Section 303(d) of the Clean Water Act, waters that are not meeting one or more of their designated uses are classified as "impaired" and placed on an action list. Further, all of the impaired waters on the action list must have a Total Maximum Daily Load (TMDL) established for the pollutant or pollutants determined to be the source(s) of the impairment. A TMDL is a quantity of a pollutant that represents the theoretical maximum amount that can be discharged to a water body and have that body maintain its uses. The Saucon Creek in Lehigh and Northampton counties has been included as impaired on the 303(d) action list. Of the 85.48 mile long Saucon Creek and tributaries, 56.90 miles have been found to be impaired with respect to their aquatic life use. Figures 1 and 2 show the location of the Saucon Creek watershed and the major tributaries of the watershed. The source of the impairment is sediment. Therefore, the intent of a Saucon Creek TMDL would be to identify a numerical limit on sediment that would ultimately result in the stream attaining its aquatic life use.

To facilitate development of the sediment TMDL for the Saucon Creek, DEP has enlisted the Lehigh Valley Planning Commission (LVPC) to evaluate alternatives for TMDL development. In February 2011, the LVPC published the *Saucon Creek TMDL Alternatives Report*, which detailed three possible alternatives DEP could use to develop a sediment TMDL of the Saucon Creek. These three alternatives consisted of using the Manatawny Creek as a paired watershed, using a tributary of the Saucon Creek that is attaining uses as a paired watershed, and implementing Best Management Practices (BMPs) without additional sediment modeling. The technique of using paired watersheds involves finding another watershed for comparison that is similar to the subject watershed (with regards to tributary area, physiographic province, land use, geology, soils, rainfall, etc.), but is not impaired. The annual sediment load for the reference watershed is calculated (usually using the ArcView Generalized Watershed Loading Function, or AVGWLF) and then scaled up or down to account for differences in total tributary area. Using the Manatawny Creek as a paired watershed would involve modeling part of the Manatawny Creek (located west of the Saucon Creek watershed in Berks County) to determine the existing sediment loads. Since the upper reaches of the Manatawny Creek are currently attaining their uses, this sediment load could be used as a target for the Saucon sediment loads that, if reached, in theory, would restore the Saucon to attaining status. The second alternative, using a tributary of the Saucon Creek as a paired watershed, would utilize a similar process using an upstream section of the Saucon Creek that is currently not impaired and then scaling that sediment load up to be

FIGURE 1
SAUCON CREEK WATERSHED STUDY AREA LOCATION MAP

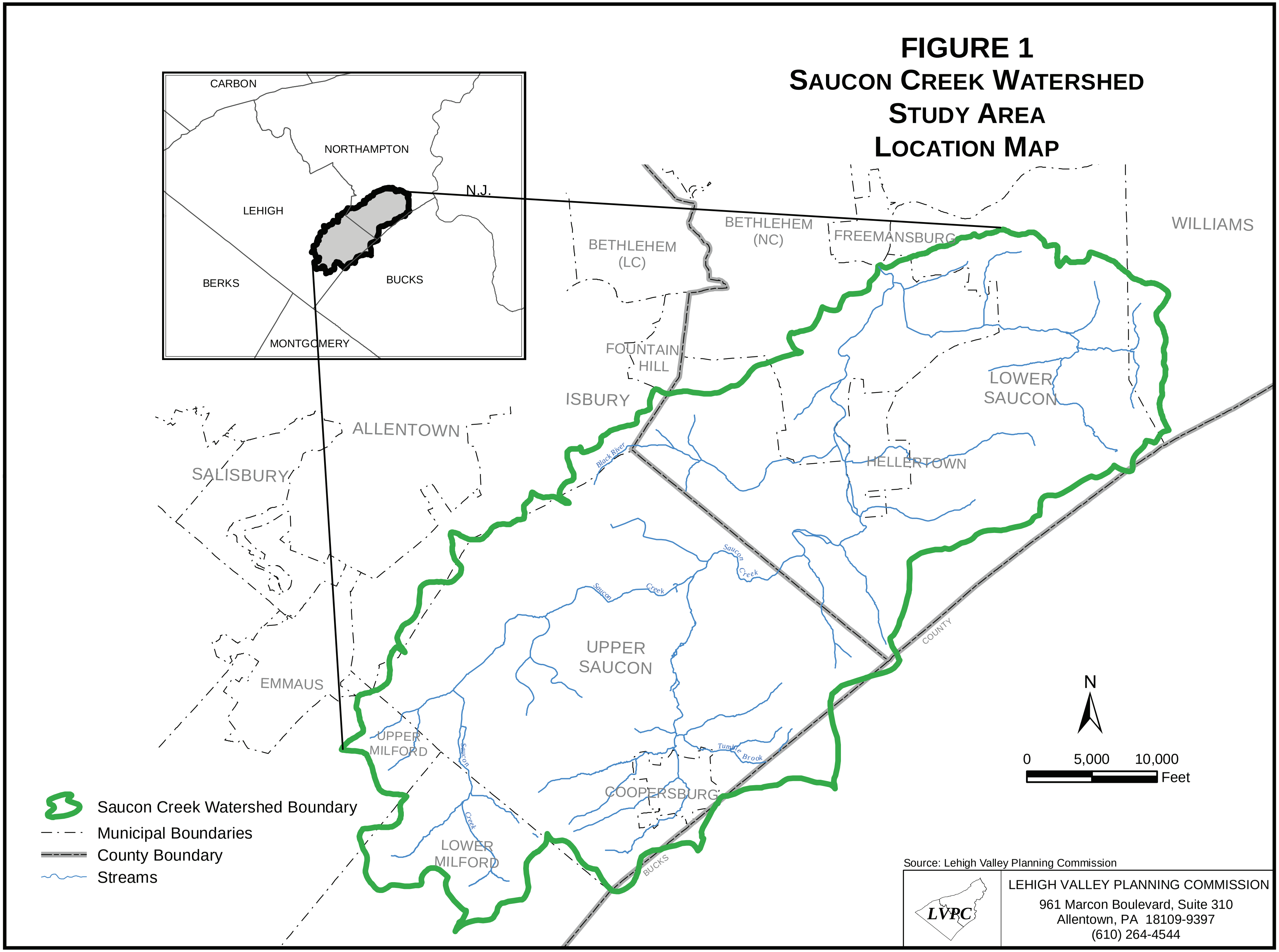
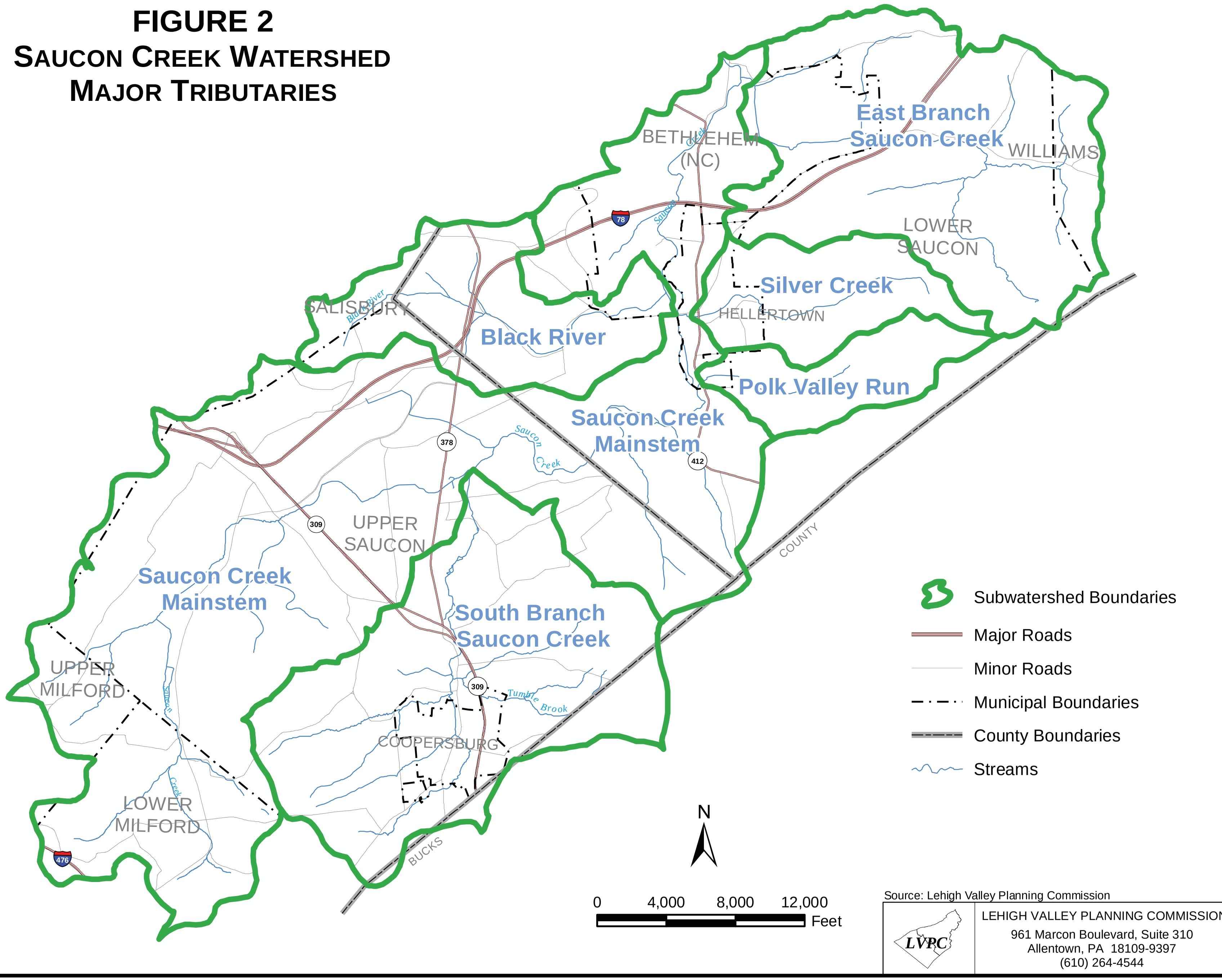


FIGURE 2
SAUCON CREEK WATERSHED MAJOR TRIBUTARIES



proportional to the total watershed area. The report recommended that additional data was necessary to implement either of these alternatives with confidence: long-term sediment monitoring data (in the Saucon Creek watershed and in the Manatawny where applicable) was recommended to develop more accurate annual sediment loads to calibrate the model results. Additionally, it was recommended that sediment "fingerprinting" techniques, or the attempt to classify sources of suspended sediment using concentrations of radioisotopes adsorbed by the sediment in the stream, be expanded to include additional Saucon Creek testing areas as well as parts of the Manatawny Creek. This additional fingerprinting in the Manatawny Creek would improve the knowledge of how much bank erosion occurs in an attaining watershed compared to the Saucon Creek. The third alternative detailed possible BMPs that could be deployed immediately within the watershed. This was the only alternative provided for which additional data collection was not directly suggested.

As part of the additional study of the Saucon Creek, additional funding was secured to design and implement a sampling program that would collect data to provide a clearer understanding of the Saucon Creek annual sediment load and sediment contributing from legacy sediment, further evaluate a paired watershed approach, and perform additional sediment modeling to assist in the creation of a TMDL. A sampling program was coordinated between DEP, the Lehigh County Conservation District (LCCD), and Lehigh University. Additional sediment modeling was to be conducted by the LVPC.

B. DISCHARGE AND SEDIMENT DATA

The purpose of this report was to attempt to collect additional data to supplement the paired watershed alternatives. The data collection program undertaken by DEP, LCCD, and Lehigh University was supposed to accomplish two goals. The first goal was to better define the total annual sediment load moved by the Saucon Creek. This value could be used to improve the Saucon sediment model by allowing it to be calibrated to a known value. The second goal was to determine how much (i.e. what percentage) of the total annual sediment load originated from the channel banks themselves. The banks in the Saucon Creek are heavily influenced by "legacy sediments," or sediments that were deposited behind colonial mill dams over several centuries as the Saucon Valley developed. With the dams now breached or removed, these sediments are easily excised by the now freely-mobile stream and this erosion is theorized to be a contributing factor (and possibly the most significant contributing factor) to the Saucon Creek's impairment.

To improve the understanding of the sediment transport processes in the Saucon Creek, Lehigh University worked to collect suspended sediment data in 2011 to be used by the LVPC to calibrate the sediment model. Samples were also collected for sediment fingerprinting analyses to attempt to determine the sources of the eroded sediment. This data collection was performed as part of a master's thesis project by Rachel T. Baxter under the supervision of Professor Frank Pazzaglia. The data was provided to the LVPC as a report titled "Sediment Provenance and Transport in a Mixed Use, Mid-Sized, Impaired Mid-Atlantic Watershed, Saucon Creek, Pennsylvania, April 2012." This report detailed the data collection methods and results of the project and discussed the findings and their implications.

Stream discharge and sediment data was collected at four locations within the watershed between June 23, 2011 and December 14, 2011, although all records do not exist for that entire duration. Figure 3 maps the locations of these stations within the watershed. The four sampling locations are listed as follows:

G1: Located on the mainstem of the creek on the Animals in Distress property off of Limeport Pike. This station has a tributary area of 7.53 square miles. The discharge record at this station runs from August 16 to December 24, 2011. The sediment record runs from August 27 to November 30, 2011.

G2: Located on the mainstem of the creek just downstream of the confluence with Black River off of Creek Road. This station has a tributary area of 44.06 square miles. The discharge record at this station runs from June 23 to December 14, 2011. The sediment record runs from August 23 to November 4, 2011.

GT1: Located at Reservoir Road on the Polk Valley Run. This station has a tributary area of 1.41 square miles. The discharge record at this station runs from June 23 to December 14, 2011. The sediment record runs from August 15 to September 7, 2011.

GT2: Located at East Depot Street on Silver Creek. This station has a tributary area of 2.85 square miles. The discharge record at this station runs from August 26 to December 14, 2011. The sediment record runs from August 27 to September 7, 2011.

The stations at G1 and G2 were the data sources used in the LVPC analysis; the amount of sediment data for GT1 and GT2 was extremely limited (with respect to number of data points) and therefore was determined to be not useful in this investigation. Discharge data was collected using Onset HOBO water level data loggers to record water stage and the stage data was converted to flow using rating curves. Lehigh University created the rating curves for the sampling sites by making channel surveys with a Topcon total station and velocity measurements with a Marsh McBirney Flo-mate velocity meter. Sediment data at sites G1 and G2 was collected using in-stream YSI turbidity sondes. Turbidity data was used as a surrogate for total suspended solids (TSS). The conversion from turbidity (NTU) to TSS (g/L) was done by comparing benchtop turbidimeter readings with laboratory TSS measurements (dry and weigh technique). The relationship between the benchtop readings and TSS was applied to each of the sites to convert the in-stream turbidity data to TSS.

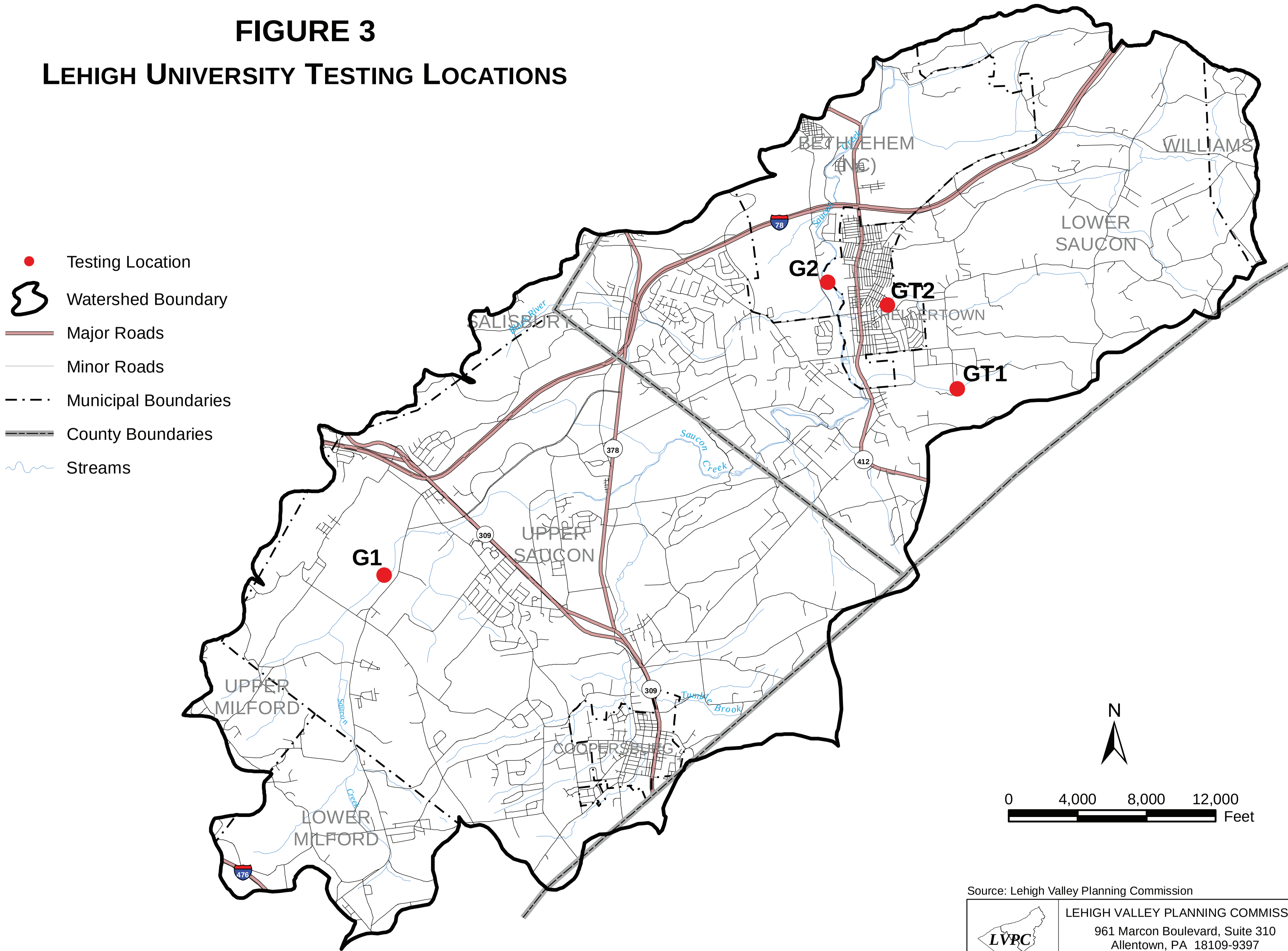
In-stream samples for sediment fingerprinting were collected from four locations along the stream in 2010 and five locations in 2011 during Hurricane Irene. Samples were also collected from possible sediment sources: forest, agricultural field, the bottom of a detention basin, a construction site, and legacy sediment from stream banks. Lead-210 radioisotope data is reported as the method for analyzing the fingerprinting samples.

Although a sediment monitoring program for the Manatawny Creek in Berks County was discussed as part of a paired watershed approach, no monitoring was able to be conducted by either Lehigh University or LCCD.

Rainfall data was provided by Lehigh University along with the discharge and sediment data. Rainfall data was collected by a weather station at Williams Hall at Lehigh's Packer Campus. This data was recorded in 15 minute intervals from August 1 to November 30, 2011. There is a two week gap in the record from October 29 to November 14, 2011.

FIGURE 3

LEHIGH UNIVERSITY TESTING LOCATIONS



Source: Lehigh Valley Planning Commission

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Data was also collected regarding existing point sources within the watershed. The LVPC performed a literature review of implemented sediment TMDLs throughout Pennsylvania. This review focused on how the sediment loads from point sources were included in the TMDL when point source data existed. Data on existing and proposed NPDES permits was provided to the LVPC by LCCD. The data provided documenting the point sources varied. For all points, a location was known and was provided by LCCD via a GIS layer. Construction permits that were still under construction also included the permit number and total acreage. For many discharges, the size of the discharge (i.e. the diameter of the discharge pipe) was also included. This also included the discharge pipe material in many cases. The LVPC organized this data according to the tributary receiving the discharge and the pipe diameter. Occasionally, a brief description of the outfall condition was also provided, such as whether there was a headwall or if the discharge tied into an existing bridge. In some cases a subdivision or facility name was also included. However, in no circumstance was a regulated sediment or flow discharge included in the data. In absence of numerical data, it was determined that this point source data would have no impact on the TMDL alternatives as part of this work program and was not explored further.

There are three sewage treatment plants located in the Saucon Creek in Lower Milford, Upper Saucon, and Bethlehem City. However, only the Lower Milford and Upper Saucon plants discharge to the creek; the main outfall of the Bethlehem plant goes directly to the Lehigh River. The Lower Milford plant is a new discharge that began operating in 2011. The Upper Saucon facility has been in operation since the early 1970's (although the discharge location changed in 1989 from the South Branch of the Saucon Creek to the mainstem of the creek). The total annual loads permitted from these facilities are 10 mg/L for Lower Milford and 30 mg/L for Upper Saucon. The permitted annual load from the facilities is about 92 tons per year. Compared to the annual sediment load estimate from AVGWLF created by the LVPC as part of the 2011 TMDL Alternatives Report of 20,688 tons, the treatment plant contributes less than 1% of the sediment load created by erosion.

C. LEHIGH UNIVERSITY REPORT CONCLUSIONS AND DISCUSSION

In the Lehigh University report, estimates of annual sediment loads were created for sampling sites G1 and G2 using two different methods. The first method was a calculation performed by taking the total sediment flow through the period of record (approximately 70 days) and multiplying by a factor of 4. A factor of 4 was used instead of a factor of 5 (which would have brought the duration covered by the sediment load estimate to approximately a year's time) based on the assumption that sediment transport during the winter months was significantly less than the recorded transport and was effectively negligible. The second method involved classifying the recorded rainfall events into two types: average storms and large storms. The criteria involved in differentiating between "average" and "large" events was not explained in the report, but since only two large storms were used it can be inferred that large events are hurricane-scale storms and average events are everything else. If a typical sediment load is calculated for an average and a large event, this typical load can be multiplied by the number of events occurring annually to get a total annual sediment load.

The sediment loads reported by Lehigh University varied greatly depending on the estimation method. Using the first method (multiplication of the total record load by four), they present annual sediment loads of 5,400 cubic meters at G1 and 6,400 cubic meters at G2. Using the second method (using typical storm loads multiplied by the number of events), they report loads of 330 cubic meters at G1 and 1,700 cubic meters at G2. Lehigh University assumes that the soil density is 2,000 kilograms per cubic meter, so the annual mass of sediments passing G1 is between 728 and 11,905 tons and the annual sediment load at G2 is between 3,748 and 14,110 tons. In the LVPC AVGWLF model, the total annual sediment load was calculated to be 20,688 tons at the mouth of the creek. Accounting for the differences in watershed area, the total load at the mouth of the creek from the Lehigh University data would be expected to be up to 84,861 tons based on the G1 data or up to 19,214 tons based on the G2 data.

Lehigh University did not produce new estimates of bank sediment loads. They drew conclusions based on their radioisotope testing regarding which parts of the watershed (i.e. upstream or downstream) were likely to contribute more or less bank erosion, but quantitative data on annual loads of legacy sediments were not produced.

D. LVPC ANALYSIS OF THE LEHIGH UNIVERSITY DATA

The sediment data that was acquired by Lehigh University was not exclusively of a quality that was usable for analysis in determining an annual sediment load. At both G1 and G2, the turbidity probes experienced a large amount of instability, with readings frequently spiking up to unrealistically high levels and remaining at those levels for long periods after the stream returned to baseflow conditions. In fact, most of the sediment data at site G2 is affected by this phenomenon, making large periods of the record unusable for sediment analysis. Sections of readings at site G1 are also affected. Lehigh University accounted for this fact in the report by limiting the maximum turbidity value to 300 NTU for purposes of sediment loading calculations.

DEP also expressed issues with the Lehigh University data. DEP analysis of the G2 data (which DEP was responsible for maintaining) indicated about 11 days of turbidity data rated as “good” or “excellent.” None of this data includes storm events, only baseflow. DEP analysis of G1 data (which Lehigh University was responsible for maintaining) showed similar periods of good or excellent turbidity data, which also did not include a complete storm event. Therefore, based on DEP classification, none of the storm event turbidity data collected should be used for analysis. However, the LVPC decided to proceed by using sediment data points that remained for turbidity levels less than Lehigh University’s 300 NTU cut-off. Without this consideration, there would not be any data usable to attempt to improve the Saucon Creek sediment model. After this instability is taken into account, only seven data points in 2011 (5 points at G1 and 2 points at G2) were determined by the LVPC to be usable for additional analysis.

An additional issue with the sediment data is the inconsistent turbidity responses to runoff events. This is problematic in that the sediment flux peaks at approximately the same time as the runoff peak, but the sediment level does not return to base level in the same fashion after all events. After some events, the sediment rapidly returns to its base level. After other events, the sediment takes a long time (i.e. days) to return to the base level. This inconsistent behavior made it difficult to single out “typical” sediment responses to runoff events in an attempt to better quantify the annual sediment load. This drastically reduced the data available for several analyses that are discussed later in the report in Section G. It is not clear whether this is a natural process or an issue with the in-stream probe.

Further, the analytical processes used in the Lehigh University report were not sufficiently detailed for the purpose of updating the Saucon Creek sediment model. The methods used for approximating the annual sediment load discussed in Section C were not rigorous calculations; rather, they were approximations based on rules-of-thumb. This is shown in the large band of possible annual sediment loads at the mouth of the creek as detailed in Section C. While the total load calculated based on the site G2 data is close to the AVGWLF data and could be interpreted as supporting the original modeling, the probe at G2 suffered from extensive periods of instability which imply that the conclusions should not be based on this data. The calculations from G1 data, which had a more stable sediment record, show annual loads far in excess of the AVGWLF data. Due to lack of more detailed calculation by Lehigh University, the LVPC decided that additional hydrologic and turbidity data analysis would be required to attempt to infer annual sediment loads from the data.

Finally, in the 2011 LVPC report, the AVGWLF data and data documented in an October 23, 2008 report entitled "Saucon Creek Watershed Study Background and Recommendations for Public Policy" by Frank Pazzaglia and Matthew Bennett corresponded very closely on how much of the total annual load was comprised of sediment from channel erosion. The Bennett report compared aerial photos from 1947 and 1999 to approximate the widening (and by extension, the annual erosion of the banks) of the Saucon Creek channel over that time period. Both this analysis and the AVGWLF model estimated that approximately 60% of the total annual sediment originated from the stream banks. The intention for the 2011 Lehigh University data was to use the radioisotope data to verify this relationship. The conclusions regarding the radioisotope data that was collected did not provide any useful new information. There is no correlation between the radioisotope readings from the individual sources and the in-stream data. The in-stream samples have much higher readings than any of the individual sources, and the theorized cause of this is "enrichment" by high concentrations of radiogenically "hot" organics that get washed off in the runoff but are not accounted for in the source sampling. Without any correction for these organic particles, the radioisotope data is incapable of revealing any new information regarding the source of the Saucon Creek sediment.

E. HYDROLOGIC MODELING

In an attempt to provide a more rigorous calculation of annual sediment loads than those produced by the Lehigh University analysis, the LVPC looked to couple the flow and sediment monitoring data with a hydrologic model of the watershed. If the hydrologic model could produce storm hydrographs similar to those monitored, then the sediment data for these events could be used to estimate sediment loadings for an annual series of events. To accomplish this analysis, the LVPC employed a hydrologic model to generate storm runoff events. The relationships from the measured sediment data could then be applied to these modeled events and an approximation for the annual sediment load would be obtained. The LVPC used a hydrologic model that was previously created as part of the Act 167 Plan update process for the Saucon Creek watershed. The model divides the watershed into 199 "subareas" of approximately 0.3 square miles each and uses the Hydrologic Engineer Center's Hydrologic Modeling System (HEC-HMS) to calculate runoff from design or observed rainfall events.

To better analyze the Lehigh University rainfall data, the LVPC separated the continuous record into discrete events. The events were analyzed in an existing LVPC hydrologic runoff model as discussed in Section E. The LVPC did not have sufficient data to create a new continuous-simulation model, so it was necessary to separate the record into individual events for simulation in the model. The events were separated by assuming that at least a 24-hour gap in rainfall constituted a new event. Small events were considered to move small amounts of sediment (i.e. small enough to be considered inconsequential), so these were omitted from consideration in the analysis (i.e. they were separated as individual events and then discarded). Only events where more than 0.4 inches of rainfall fell over a 24-hour period were considered in the data set the LVPC used for sediment analyses. These stipulations resulted in a total of 15 rainfall events in the data set. However, the actual analysis was more strictly limited by the sediment data, so all rainfall events were not run at both sampling locations.

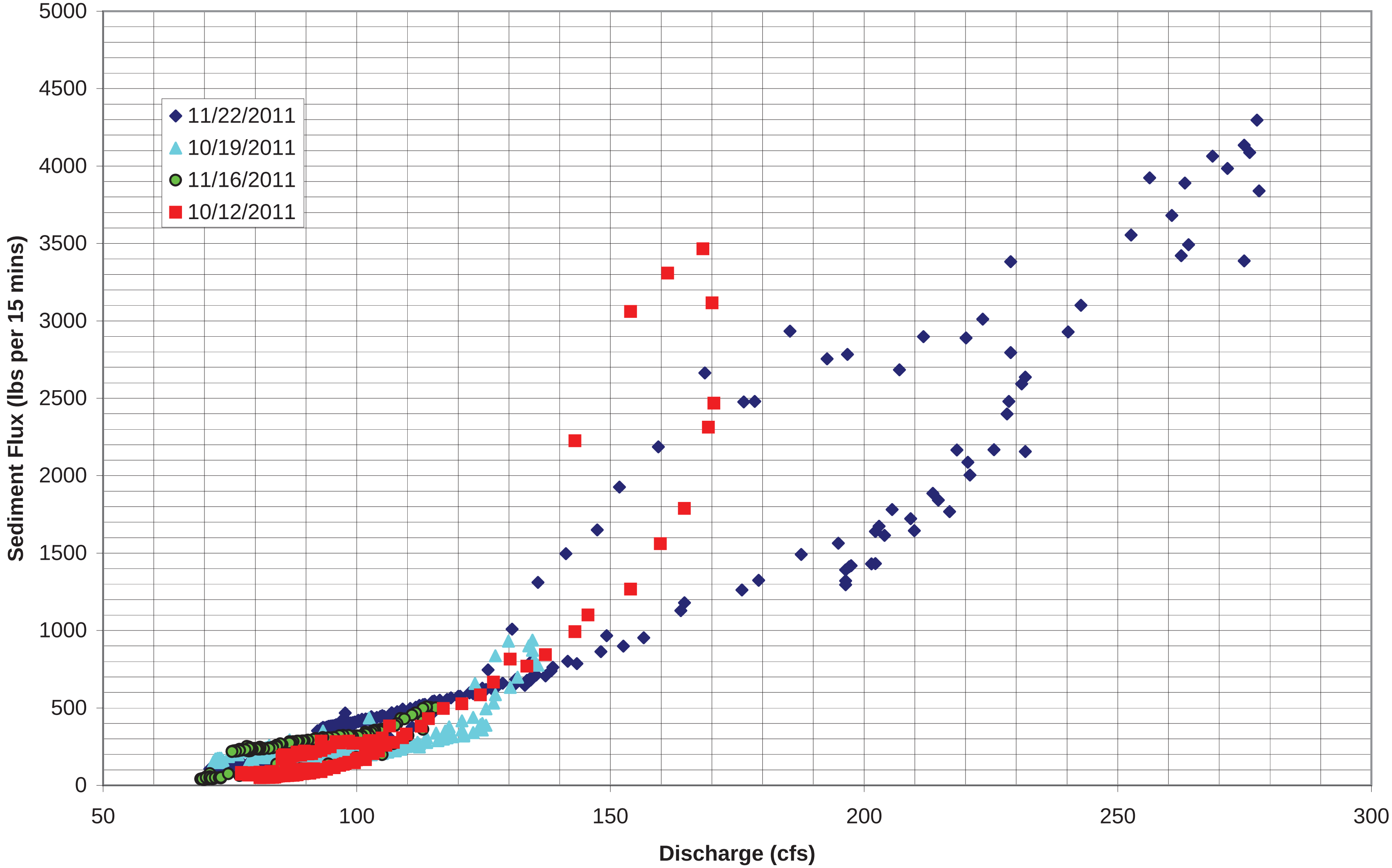
The HEC-HMS model was run for the entire watershed, and flow data at both locations G1 and G2 was captured. The "significant" events described above were used as the rainfall input for the model. The output from the HEC-HMS model was then compared to the recorded discharge data as collected by Lehigh University. For both discharge points, the modeled peak discharges for Hurricanes Irene and Lee were many times larger than the recorded discharges. These events both represent likely occurrences for out-of-bank flow. However, the rating curves created by Lehigh University to calculate the peak discharges are noted to only include the channel itself. Therefore, the Lehigh University discharge data cannot be considered to be reliable for the hurricane events. Both of these events were excluded from additional analysis. At G1, the HEC-HMS model consistently under-predicted the peak discharge in comparison to the recorded discharges. However, at G2 the model neither consistently over- or under-predicted peak discharge, and was quite close to the recorded discharge in many cases. Four of the eleven non-hurricane events modeled were within 20% of the recorded peak. Two more were within 30%. Hydrographs showing the recorded flows as well as the modeled flows have been included in this report in Appendix A as Figures 9 through 34. These results lead to the conclusion that the model does not do as well predicting smaller subsections of the watershed, but it is relatively accurate at predicting whole-watershed flow. This is to be expected since the model was originally calibrated to design flood flows at the mouth of the creek. Given the performance of the model at G2 and the ultimate goal of simulating sediment loads from the entire watershed, the model was determined to be sufficient to simulate discharges for recorded events in the Saucon Creek.

F. RELATIONSHIPS BETWEEN SEDIMENT AND DISCHARGE

Through the HEC-HMS model, there exists a method to develop more rigorous approximations of the annual sediment load than those produced in the Lehigh University report. If a relationship between the observed discharge and the observed sediment could be quantified, that relationship could be applied to the discharges from the HEC-HMS model to calculate the sediment load for any modeled storm event. If a year's worth of storm events were modeled, the sum of the sediment discharged from these events would be an approximation of the average annual sediment load.

The first relationship explored was a simple mapping of sediment flux (sediment transported per 15-minute time step) versus discharge. This analysis was performed for four events at G1. The analysis was only done at G1 and not at G2 due to having a more robust data set at G1 via better turbidity sonde performance. It was assumed in this analysis that the sediment and flow relationship at G1 and G2 are similar. Four events with usable data were plotted for this analysis. The sediment flux versus discharge data plot is included as Figure 4. These plots show the skewed distribution of the sediment in the storm: more sediment is generally moved during the rising limb of the storm hydrograph than in the

FIGURE 4
Sediment Flux and Discharge Relationships from Lehigh University Sampling Location G1



receding limb (i.e. the larger sediment discharge at a given flow discharge is on the rising limb). This is assumed to be an effect of rising storm flows mobilizing weak sediments in the banks or sediments already deposited in the stream bed from prior bank failure. However, there are several issues with the approach. For one, these curves could not be applied to any given event. Any modeled event with a discharge higher than the maximum value of the sediment curve cannot have that curve applied to it. Also, the maximum discharge value from the sediment should not be too much larger than the modeled event, since then the modeled event would be using data predominantly in the very steep beginning part of the curve which would likely not be representative of the actual sediment loads. Therefore, a larger number of sediment curves would be required, possibly as many as one for each modeled event, with similar peak discharges to the modeled events.

The overall relationship between sediment and discharge is obviously quite complex. In an effort to deduce a more easily applicable relationship, analyses were performed focusing only on the peak sediment fluxes. Since most of the observed 2011 events were more drawn-out events with multiple local sediment peaks, we simplified the analysis by constraining it to only the largest peaks for each storm. In addition to the 2011 data collected by Rachel Baxter, we also used data from 3 storm events in 2007 and 2008 collected by Lehigh University and documented in an October 23, 2008 report entitled "Saucon Creek Watershed Study Background and Recommendations for Public Policy" by Frank Pazzaglia and Matthew Bennett. The 2007/2008 sediment data is not as detailed as the 2011 data, since the sediment was collected by an ISCO sampler rather than the constant monitoring provided by the turbidity probes. Therefore, it could not be used in the previous analyses presented in Figure 4 due to the low number of data points. However, since only the peak rate of sediment flux is needed for this analysis we can include these three data points. The 2007/2008 data was only collected at G2.

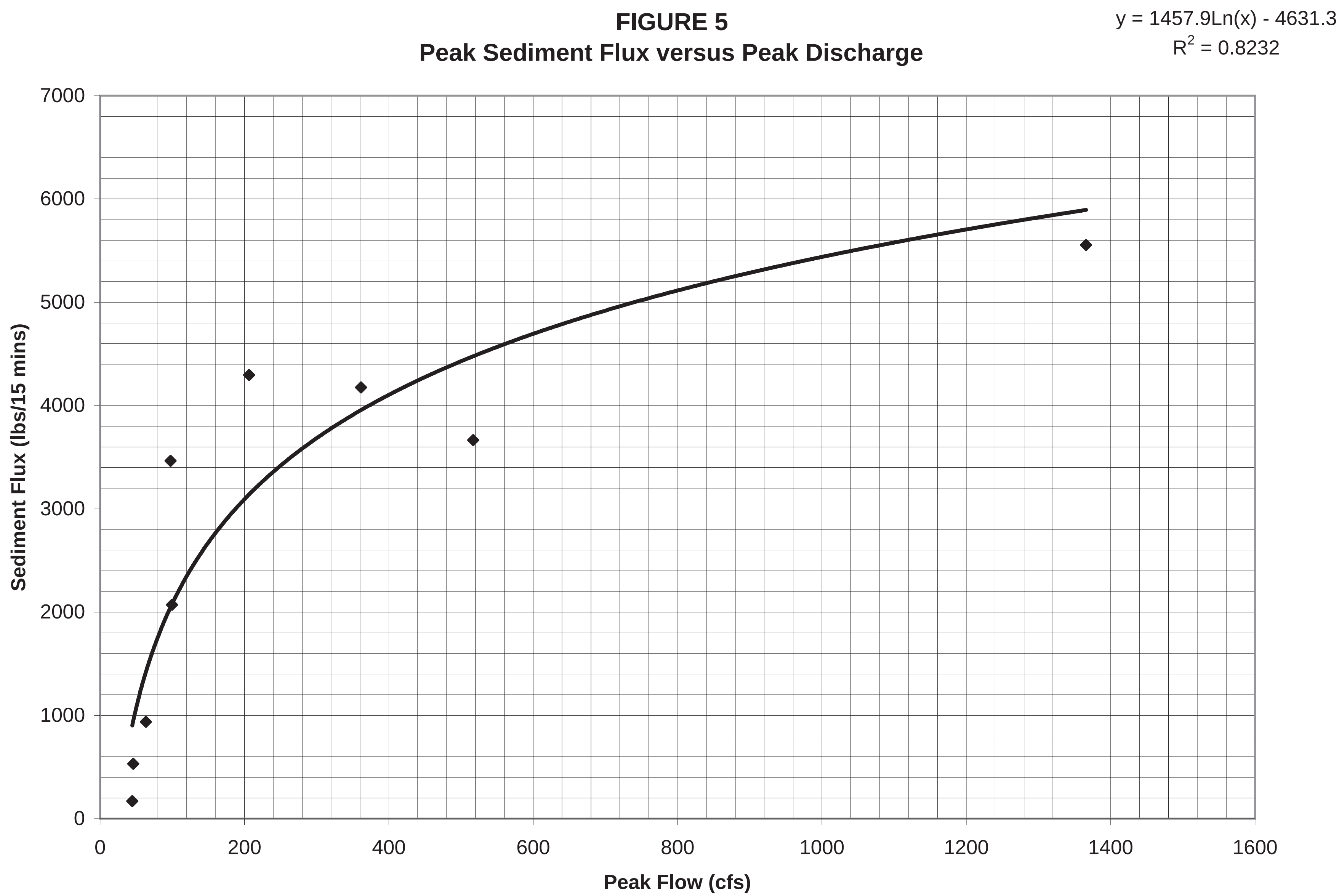
Several relationships between sediment flux and storm properties were tested. These included peak discharge (includes baseflow), peak runoff discharge (excludes baseflow), total precipitation, total precipitation in the preceding two weeks before the event, and peak 15 minute rainfall intensity. There were a total of nine storms included in the analysis between the two sampling points:

G1: October 12, 2011; October 19, 2011; November 16, 2011; November 22, 2011; November 29, 2011

G2: October 27, 2011; August 21, 2007; October 26, 2007; March 7, 2008

The relationship that seemed most clear was the relationship between the peak runoff and the peak sediment flux. The plot of this relationship is included as Figure 5. The correlation coefficient (R^2) for this relationship is 0.8232, and the Spearman rank correlation coefficient is 0.8788. Values for these variables close to 1.0 indicate strong relationships. This was the most well-defined relationship between flow and sediment that we tested and could be applied to the HEC-HMS model discharges. Therefore, this relationship was applied to modeled peak discharges to approximate the magnitudes of the peak sediment fluxes in the modeled events. The data sample defining this relationship is obviously quite limited (9 points) but, as stated previously, it represents the best current information available. Future monitoring efforts could and should be used to supplement this information and more rigorously define the relationship.

FIGURE 5
Peak Sediment Flux versus Peak Discharge



G. SEDIMENT TRANSFORMS

The sediment flux analysis described in Section F is only sufficient to calculate the peak sediment flux associated with a given flow peak. To determine the total sediment transport in a storm event, a method to convert the peak sediment flux into a graph of sediment flux throughout the storm event is required. The observed records of both flow and sediment collected by Lehigh University at G1 and G2 were inspected to see if a relationship could be extracted from the data and applied to the model. Many of the recorded events showed peculiar sediment behavior in the receding limb of the larger peaks, where the sediment would not return to its baseline levels after the peak discharge had receded. Rather, it would decay fairly slowly, still showing high levels of sediment flux well after the peak flow had returned to conditions close to baseflow. However, two of the events (see Figures 23 and 25 in Appendix A) showed sediment conditions in the largest peak that more closely followed the behavior of the hydrograph. Therefore, these two storms were selected for further study to determine flow and sediment relationships over time.

For each of these two events, the main sediment peak was isolated from the rest of the event for analysis. The baseline sediment flux (approximately 169 lbs per 15 minutes for Figure 23 and 156 lbs per 15 minutes for Figure 25) was subtracted out of each data point so that the effects of the runoff could be isolated. The sediment flux data points were then each divided by the maximum flux, so that each point was expressed as a percentage of the peak value. Then, the data points for the two events were aligned so that the peaks occurred at the same time, and points corresponding in time between the two graphs were averaged to merge them into a single "unit graph." The unit graph produced by this analysis is included as Figure 6. This graph could then be used to convert a peak sediment flux (calculated from the peak discharge as per the relationship in Figure 5 and discussed in Section F) into a sediment flux over the discharge hydrograph. If necessary, this graph could also be applied to multiple discharge peaks within the same event, with larger sediment fluxes overriding smaller fluxes in areas of overlap (rather than being additive). The integral of this combined graph would give the approximation of the sediment transported by the event. Ideally, additional events would be included in the determination of this graph to make it more representative of events of different durations, but this was not feasible given the limitations in the quality of the sediment data.

This relationship was tested using data from Matthew Bennett's 2008 report. The relationship in Figure 6 was applied to the observed rainfall data from August 2007. The total estimated sediment load was about 132,500 pounds. The sediment transport measured by the ISCO sampler for this event was about 89,000 pounds. The estimated load is about 49% larger than the measured sediment load. A graphical representation of this test scenario is included as Figure 7.

H. AVERAGE ANNUAL SEDIMENT LOAD ANALYSIS

With methods in hand to determine the estimated sediment load from the storm event from the peak discharge, the final step was to apply these tools to actual rainfall events that had been run through the HEC-HMS model. Since the goal of the project is to determine an average annual sediment load, an average rainfall year was chosen as the subject of the modeling efforts. The average annual rainfall at the Lehigh Valley International Airport (ABE) is about 44.2 inches according to National Climatic Data Center (NCDC) hourly precipitation data. The NCDC record analyzed ran from May

FIGURE 6
Sediment Flux "Unit Graph"

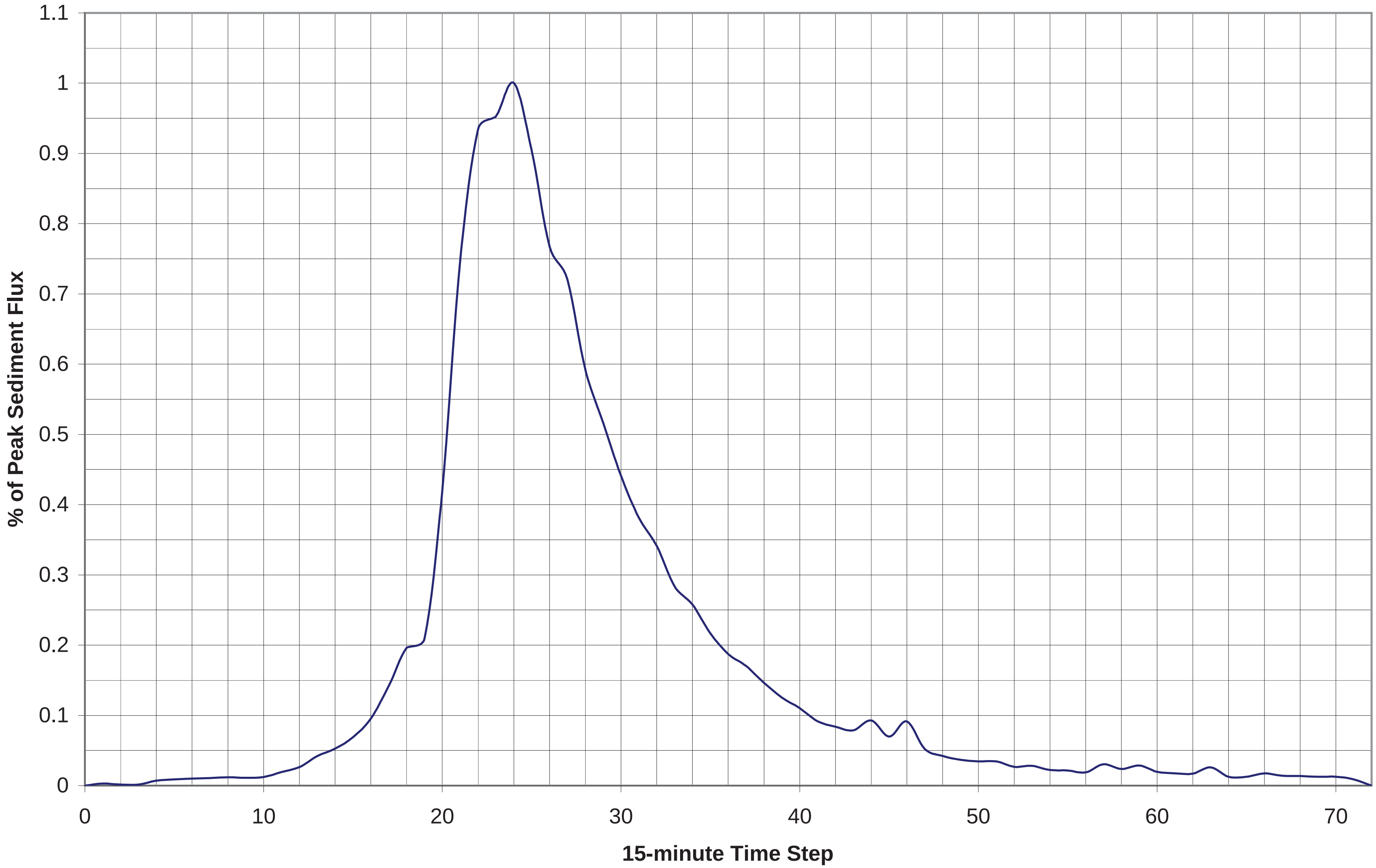
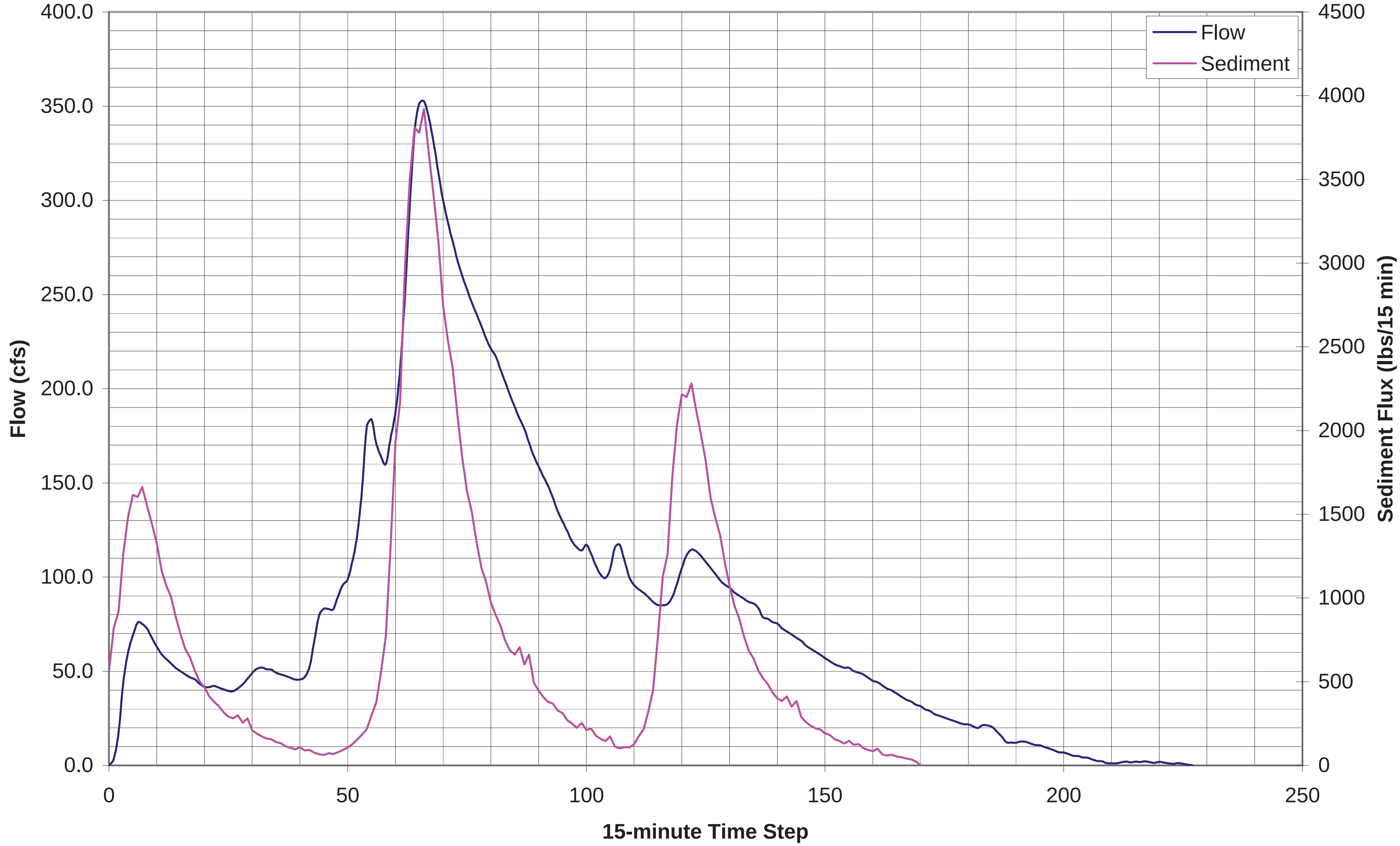


FIGURE 7
Synthetic Sediment Flux Test - August 21, 2007 Event

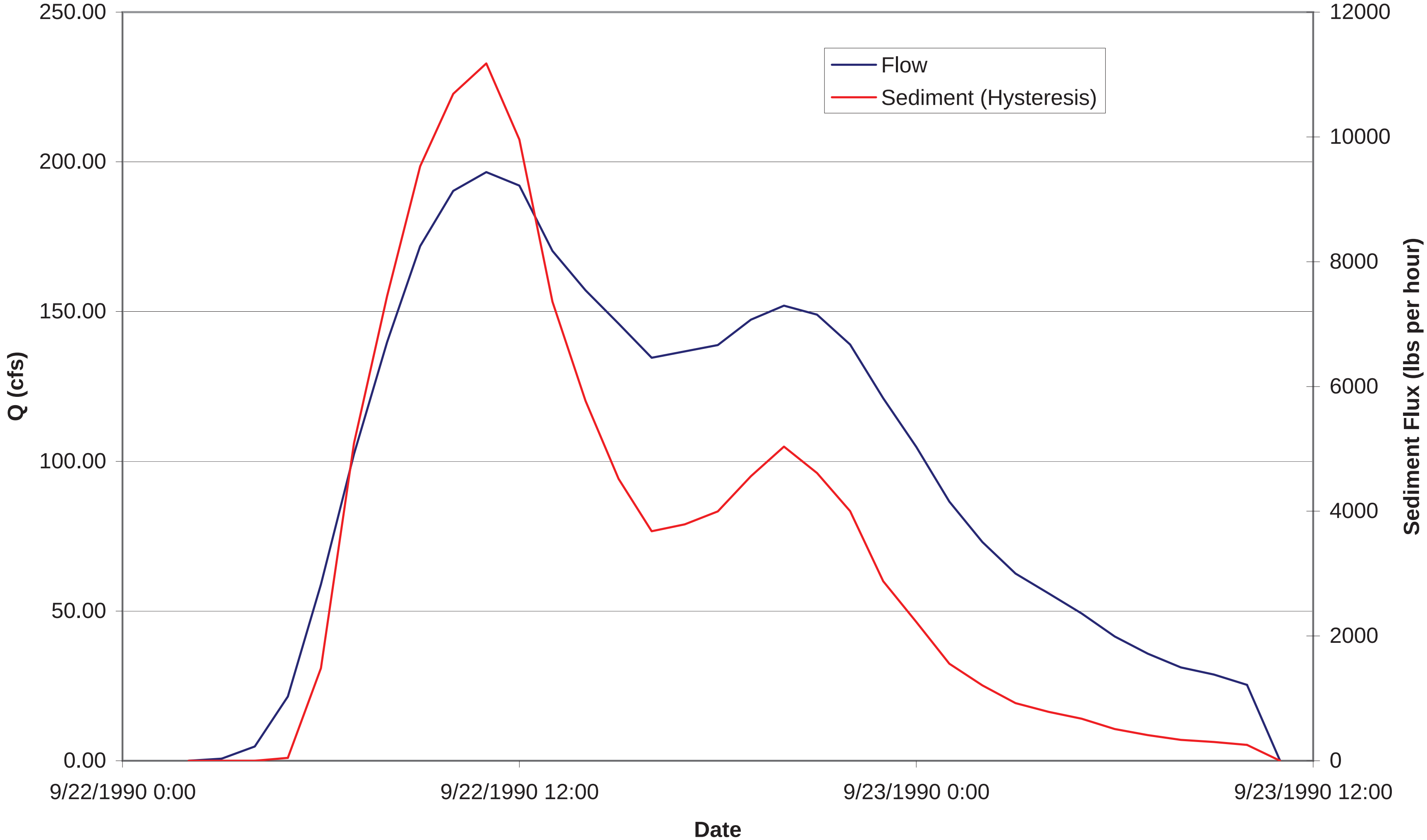


1948 through September 2011. With a total annual rainfall of 44.37 inches, 1990 was selected as the modeling input.

Assuming that 24 hours between positive rainfall readings constitutes a new storm event, there were 57 rainfall events in 1990. The methods used in the HEC-HMS model become less accurate with less precipitation (i.e. infiltration loss via the curve number method), so the analysis was limited to only the 29 events that deposited at least 0.5 inches of rainfall. Thirteen of these events delivered at least 1.0 inch of rainfall. The resultant hydrographs from the modeling are included in Appendix B as Figures 35 through 63. On these graphs, the results of the sediment analysis are also illustrated. Based on the summation of these volumes, the total sediment load was 1,363 tons. This value is only about 6.5% of the estimated annual load of 20,688 tons as calculated by the AVGWLF model as documented in the LVPC 2011 report. General assumptions were made regarding the loading from the storms less severe than 0.5 inches assuming that each of these events moved approximately 20,000 pounds based on the trends in the sediment loads of the larger events. Applying this assumption, the annual load estimate can be increased slightly to 1,643 tons. However, this is still much less than the AVGWLF estimate.

One of the problems with the analysis is that the sediment transform is not time-independent. This potentially limits the application of the curve, as storm durations that differ significantly from the duration of the storms the curves are derived from would skew the results of the sediment analysis. This is mostly a limitation of data: there were not enough events monitored with clean data to allow a clear analysis over a period longer than a few hours due to the nature of the storm events. Data from one or more single, intense, and unsaturated soil (i.e. no precipitation preceding the storm) rainfall events would have been ideal for further exploring the sediment relationship with time. To make an approximation for the change in sediment movement approximation that a more thorough time-related analysis could provide, the sediment flux versus discharge curves illustrated in Figure 4 were used on a sample 1990 event to see how this method compared to the unit graph approach. The runoff data from the September 20, 1990 event (see Figure 47) was used along with the November 22, 2011 sediment vs. discharge relationship. These events were used since their peak discharges were very similar: 197 cubic feet per second (cfs) for the 1990 event and 207 for the 2011 event. Since the time step in Figure 4 is 15 minutes and the modeling time step is 1 hour, the sediment data from Figure 4 needed to be converted into a concentration (i.e. pounds per cubic foot) for the analysis to be consistent. A curve was sketched over the scatter plot of the sediment data to use as the guideline for the analysis. This method is obviously a very general approximation since slight differences in the placement of this sketched line will affect the total sediment load. This curve was used to apply the sediment concentrations to the hourly volume from the 1990 event. The higher “rising” limb of the curve was applied to the discharge points before the peak flow. After the peak flow, the sediment concentrations from the lower “receding” limb were used instead. The sediment graph produced by this analysis is included as Figure 8. The total sediment moved by the event was approximately 114,812 pounds. This is 67% larger than the total of 68,677 pounds predicted by the unit graph approach for the same event. If the sediment load of every 1990 event that was modeled was increased by a similar amount, the total annual sediment load would increase to about 2,730 tons. However, this is still only 13.2% of the total annual load predicted by AVGWLF. The resultant sediment loads from the modeling process and sediment analyses are included in Table 1 at the end of Appendix B.

FIGURE 8
9/22/1990 Event - 1.00"
Sediment Flux Created Using Relationships from Figure 4



I. CONCLUSIONS AND RECOMMENDATIONS

The main goal of the work program was two-fold. Lehigh University's goal was to determine the total annual sediment load of the Saucon Creek, as well as the total annual contribution of the stream banks to this load. The LVPC goal was to use the data provided by Lehigh University to refine and calibrate the sediment model and use the updated sediment model to revise the proposed TMDL alternatives.

The results of the sediment analysis discussed in Section H gave estimates on annual sediment loads that are much less than the estimates derived from the AVGWLF model as documented in the 2011 *Saucon Creek TMDL Alternatives Report*. However, there is not sufficient data at this time to determine which of the estimates is more representative of the actual sediment loads in the Saucon Creek. The deficiencies in the data collected by Lehigh University in 2011 as discussed in Section D do not allow for robust, scientifically based annual load estimates. Additional data would ideally allow the observed sediment data to be applied confidently to HEC-HMS model discharges for any number of storms to estimate the annual load. The data as collected presently is not accurate or robust enough for conclusive analysis. We cannot currently infer anything about the accuracy or inaccuracy of the AVGWLF sediment load that was previously calculated. This lack of quality data does not make it possible to further refine the AVGWLF model as originally expected.

In addition to the inability to further calibrate the model, it was also not possible to make further advances on finding a more accurate target sediment load for the TMDL. Two alternatives outlined in the 2011 LVPC report involved using paired watersheds: either the upper reaches of the Manatawny Creek, or an upstream segment of the Saucon Creek that is not impaired. No sediment data has been collected in the Manatawny Creek watershed to date, so the accuracy of the previous sediment estimate for this watershed has not improved. Additionally, there has not been sediment data collected on an attaining segment of the Saucon Creek. Therefore, that option still lacks data for verification or calibration.

Another goal of Lehigh University's work program was to use sediment fingerprinting techniques to be able to determine the source or sources of the sediment transported through the Saucon Creek. The focus of this analysis was to determine how much of the suspended sediment in the stream had come from overland erosion versus bank erosion of legacy sediments. Due to the absence of corrections for the contribution from organic particles as discussed in Section D, the data collected by Lehigh University was not successful in sourcing the suspending sediment in the Saucon Creek.

Since neither of the Lehigh University's goals was able to be achieved, the recommendations from the LVPC's 2011 report remain valid. Additional data collection would be necessary to determine a sediment load with more confidence. More careful monitoring of in-stream measurement devices is necessary to make sure that a usable data set is obtained over the monitored record. Additionally, sediment data would need to be collected for a potential paired watershed. Either the upper reaches of the Manatawny Creek or an upstream branch of the Saucon Creek would need to be sampled. If the Saucon Creek were sampled, the upstream section of the East Branch of the creek would be an ideal sampling location, as this area has the highest invertebrate testing scores. In addition to in-stream sediment sampling, other measures can be taken to improve the understanding of the sediment processes in the Saucon and Manatawny creeks. Aerial photography analysis of the Manatawny in accordance with the methods used by Michael Bennett in the 2008 Lehigh University report could be performed to get a better estimate of the historical bank erosion in the watershed compared to the Saucon Creek. Bank erosion pins could also be utilized in both watersheds to provide additional erosion volume data points for integration in the analysis. Sediment fingerprinting may also still be a viable method to determine sources of the sediment in the stream, but more rigorous sampling protocols would need to be implemented and methods to account for the “enrichment” of the sediment by highly radioisotope-charged organic particles in the in-stream data readings would need to be applied.

Finally, the third alternative proposed in the 2011 report remains valid. Applying BMPs to sensitive areas now, particularly to areas where riparian areas have been degraded or removed, is the most direct and likely the most effective way of addressing the macroinvertebrate health, and by extension, the impairment of the Saucon Creek. Since water temperature was found in the 2011 LVPC report to be one of the most closely linked indicators to macroinvertebrate health, BMPs that reduce temperature (e.g. riparian buffer restoration, stream/floodplain restoration, legacy sediment remediation, etc.) should be prioritized.

J. REFERENCES

Baxter, Rachel T. “Sediment Provenance and Transport in a Mixed Use, Mid-sized, Impaired Mid-Atlantic Watershed, Saucon Creek, Pennsylvania.” Lehigh University, Department of Earth and Environmental Sciences, Bethlehem, PA, 80p

Lehigh Valley Planning Commission. “Saucon Creek TMDL Alternatives Report.” February 2011.

Pazzaglia, Frank J. and Matthew S. Bennett. “Saucon Creek Watershed Study Background and Recommendations for Public Policy.” Lehigh University, Department of Earth and Environmental Sciences, Bethlehem, PA, 45p

APPENDIX A:

LVPC HEC-HMS MODEL DISCHARGES COMPARED TO LEHIGH UNIVERSITY'S OBSERVED HYDROGRAPHS

FIGURE 9
Site G1 - August 21, 2011 - 0.90"

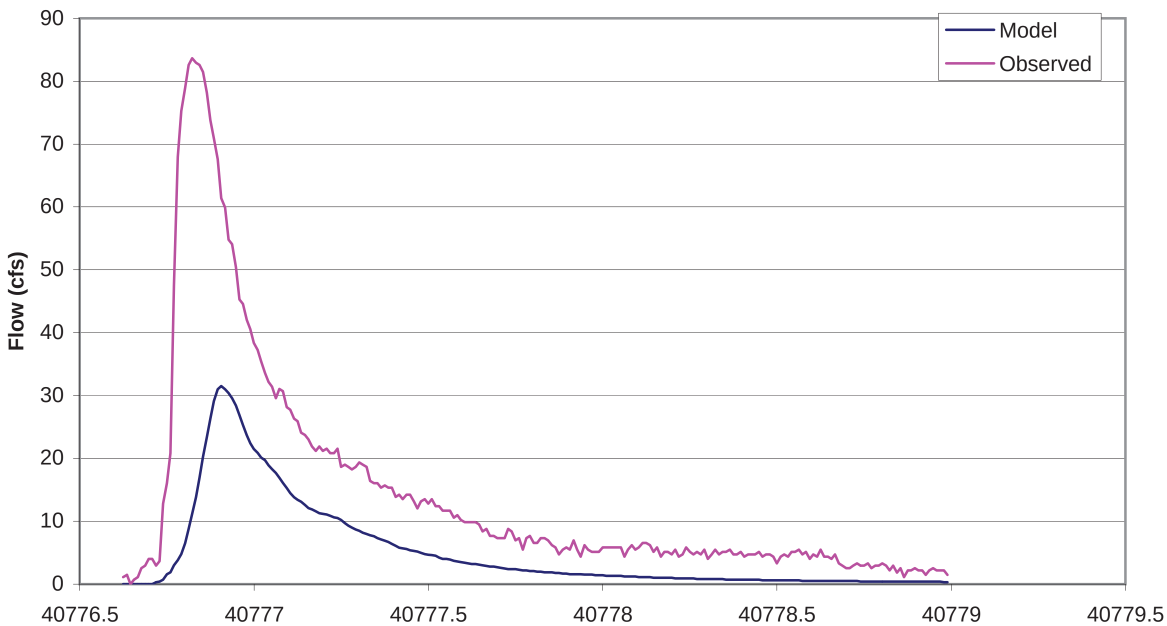


FIGURE 10
Site G2 - August 21, 2011 Event - 0.90"

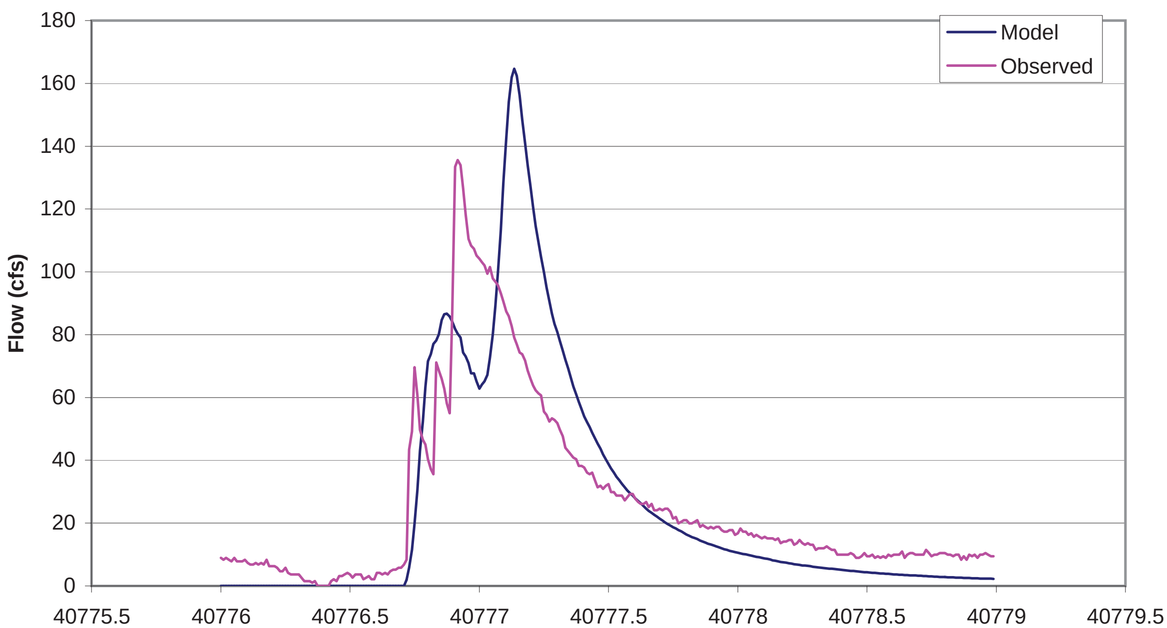


FIGURE 11
Site G1 - August 25, 2011 - 0.49"

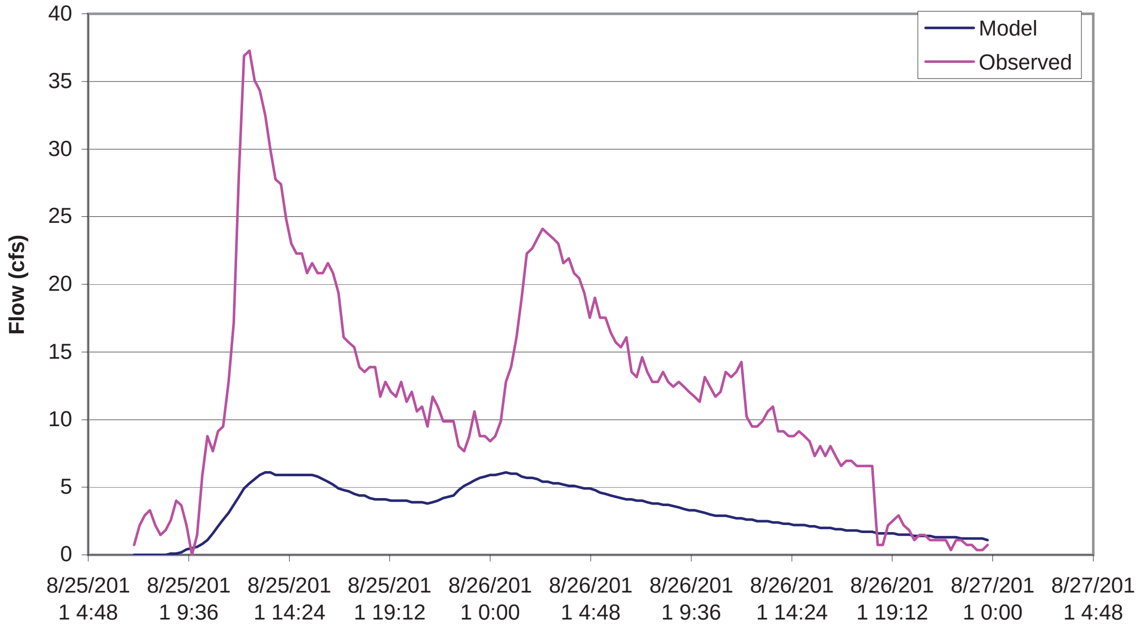


FIGURE 12
Site G2 - August 25, 2011 - 0.49"

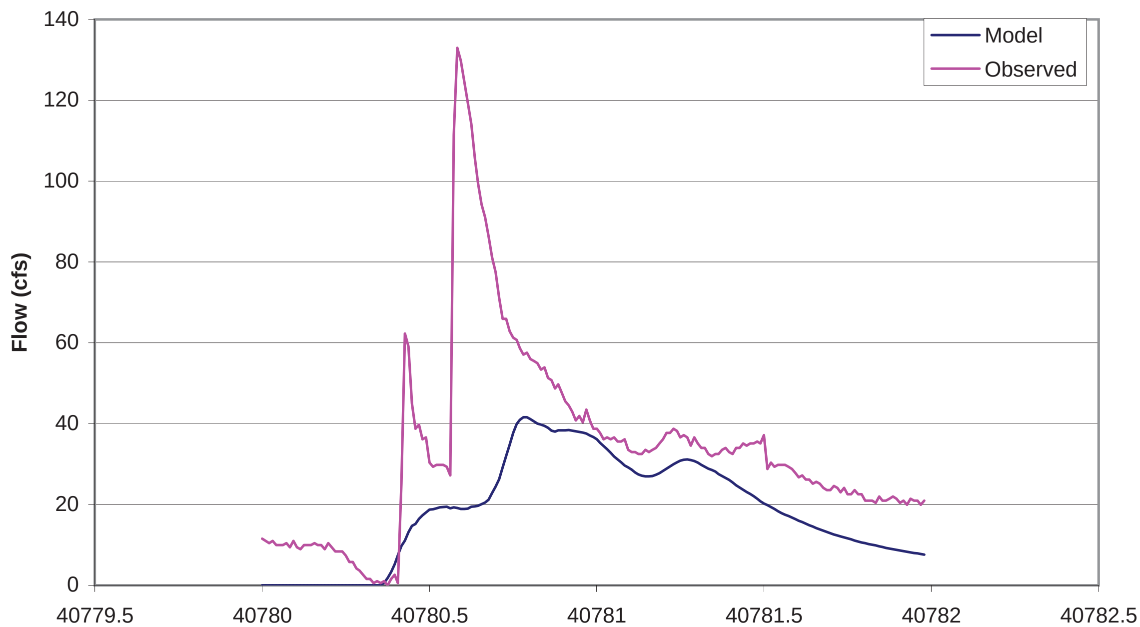


FIGURE 13 - HURRICANE IRENE
Site G1 - August 27, 2011 - 6.20"

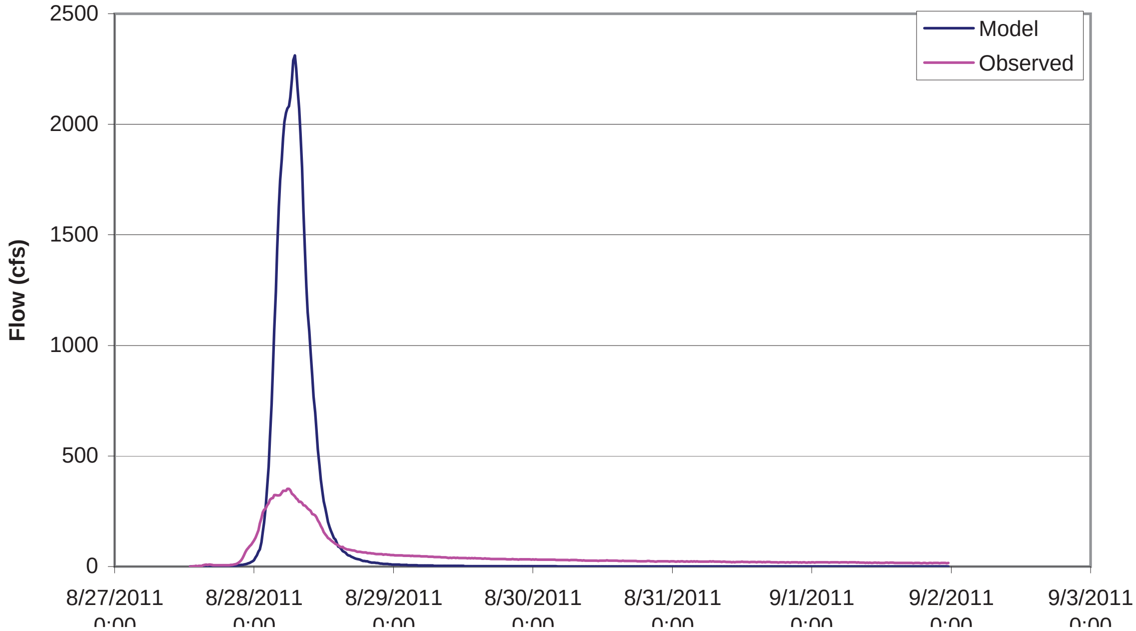


FIGURE 14 - HURRICANE IRENE
Site G2 - August 27, 2011 - 6.20"

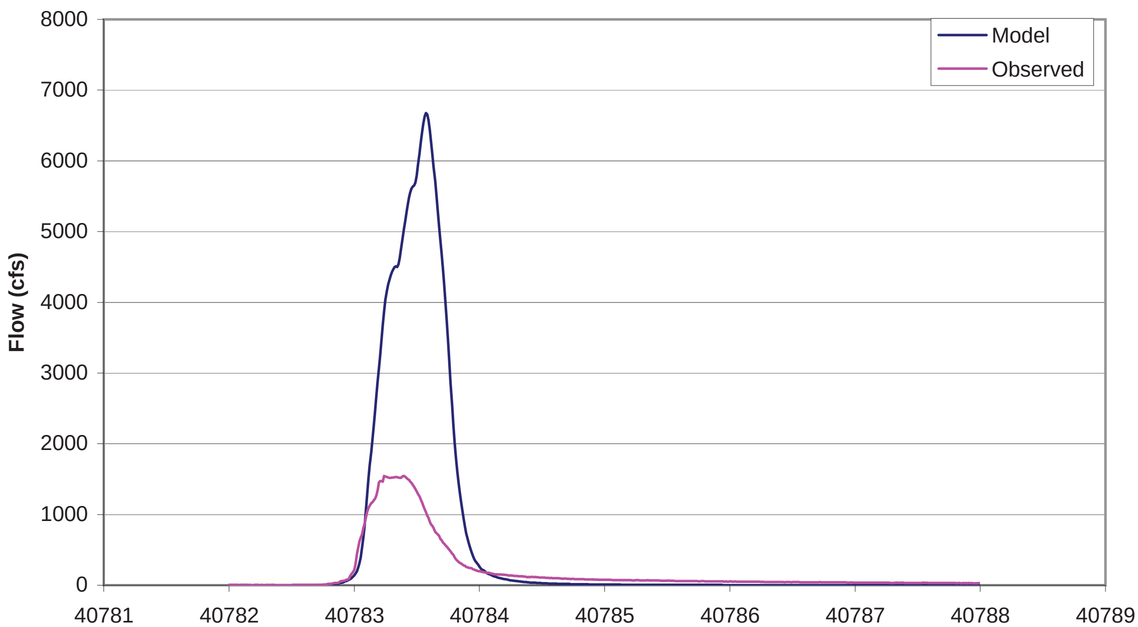


FIGURE 15 - HURRICANE LEE
Site G1 - September 5, 2011 - 7.42"

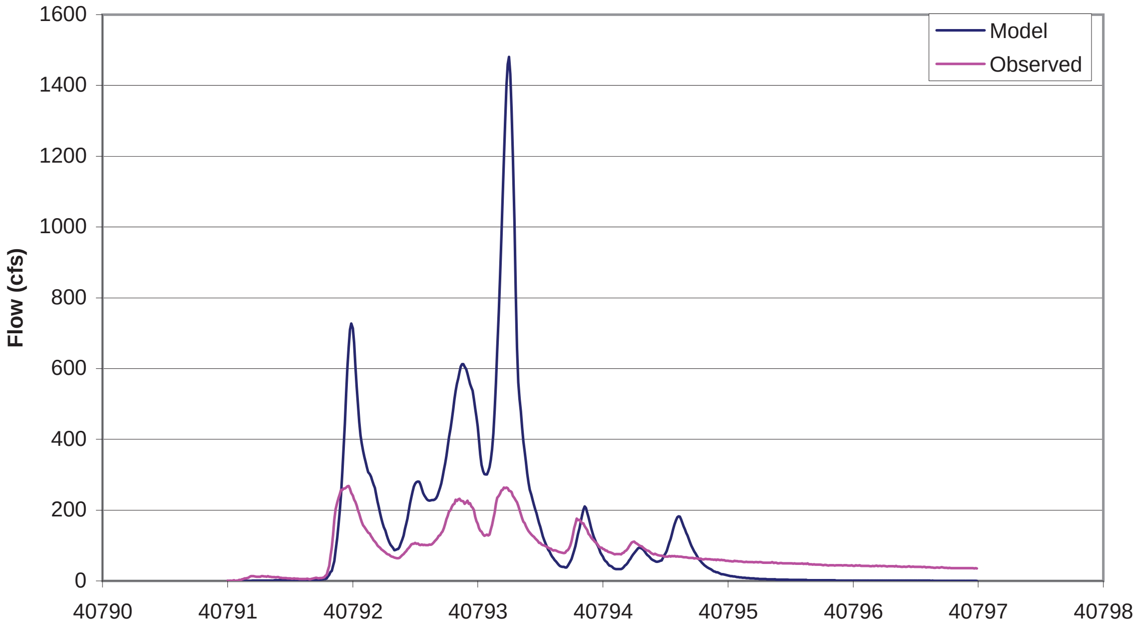


FIGURE 16 - HURRICANE LEE
Site G2 - September 5, 2011 - 7.42"

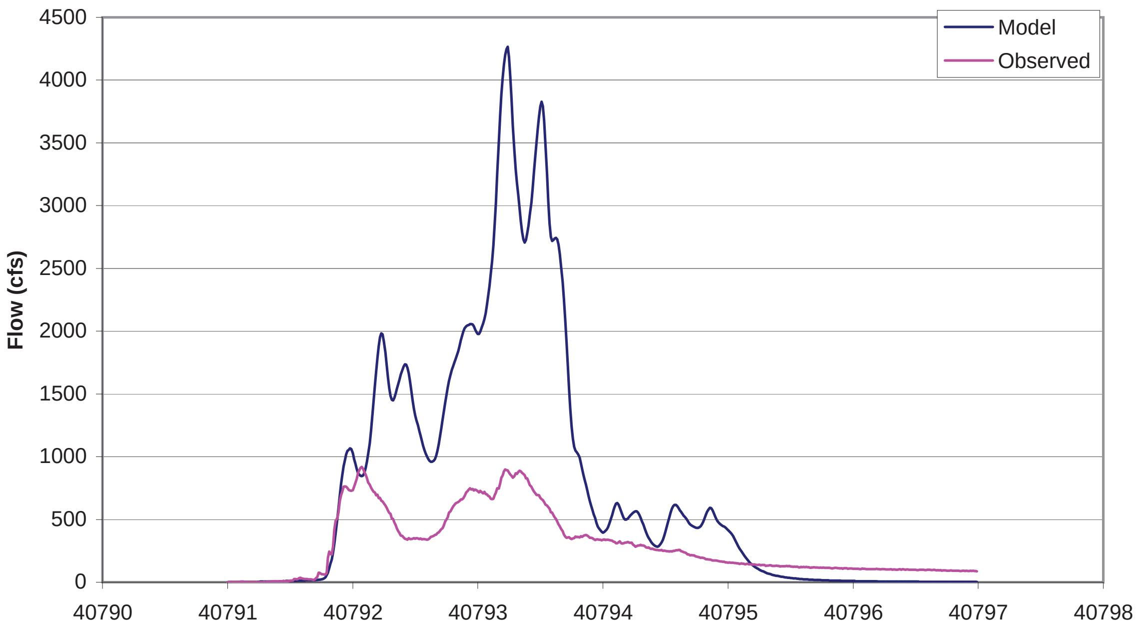


FIGURE 17
Site G1 - September 23, 2011 - 1.65"

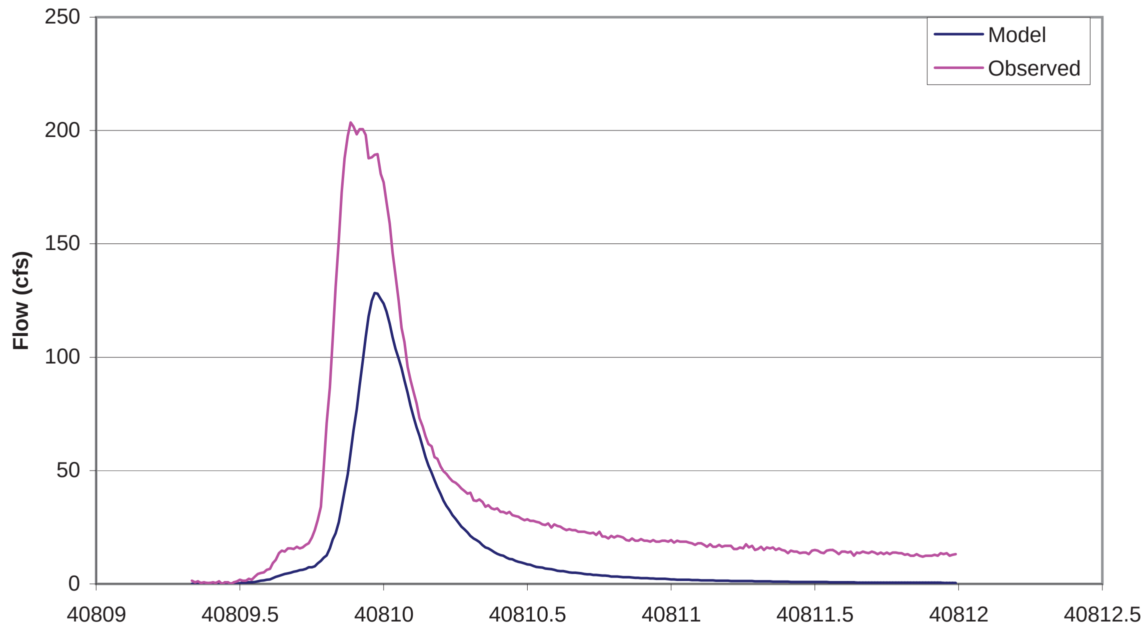


FIGURE 18
Site G2 - September 23, 2011 - 1.65"

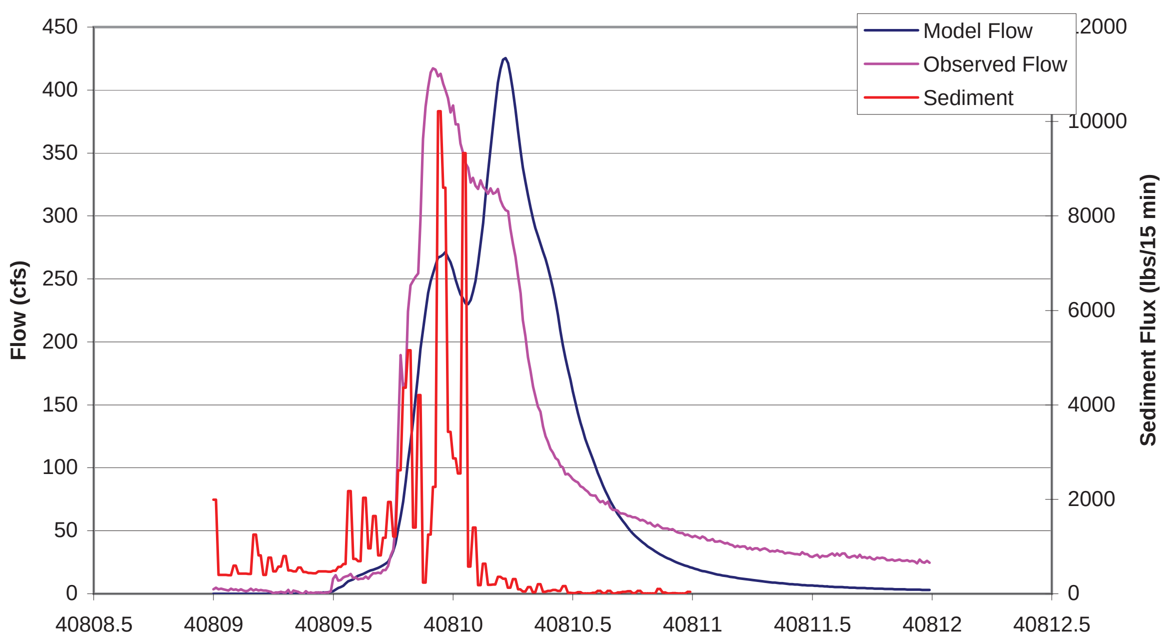


FIGURE 19
Site G1 - September 28, 2011 - 1.74"

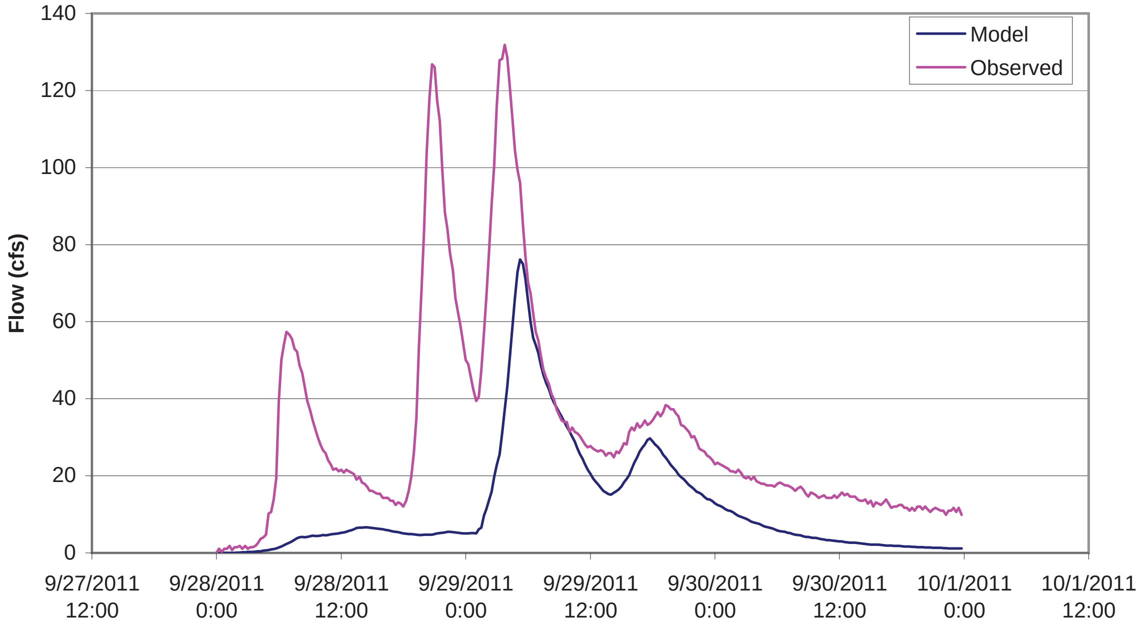


FIGURE 20
Site G2 - September 28, 2011 - 1.74"

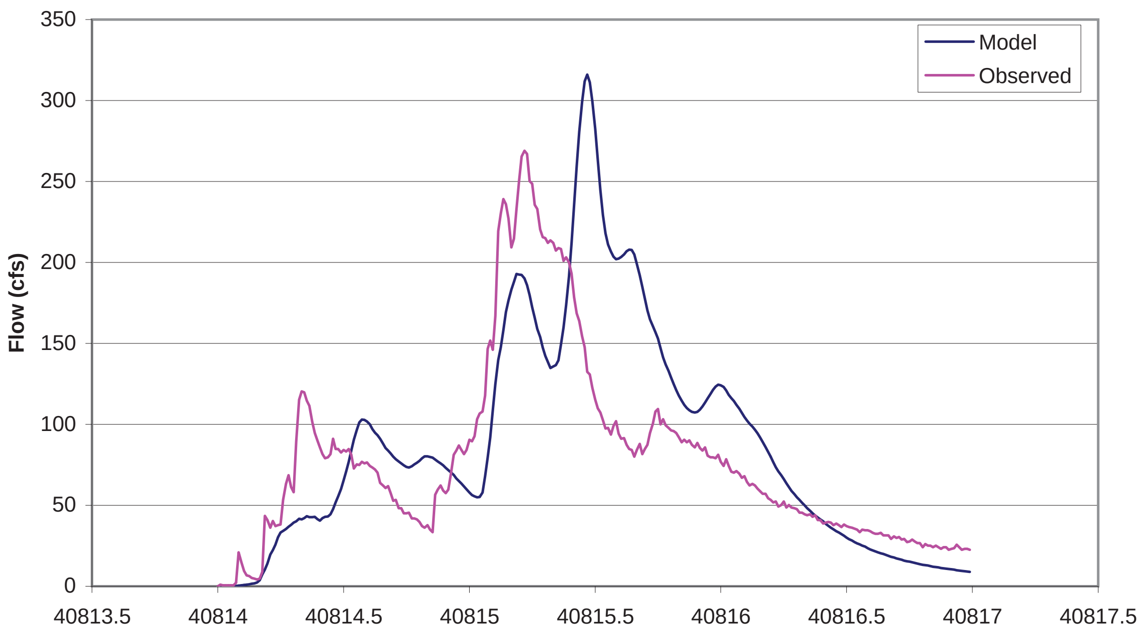


FIGURE 21
Site G1 - October 1, 2011 - 0.42

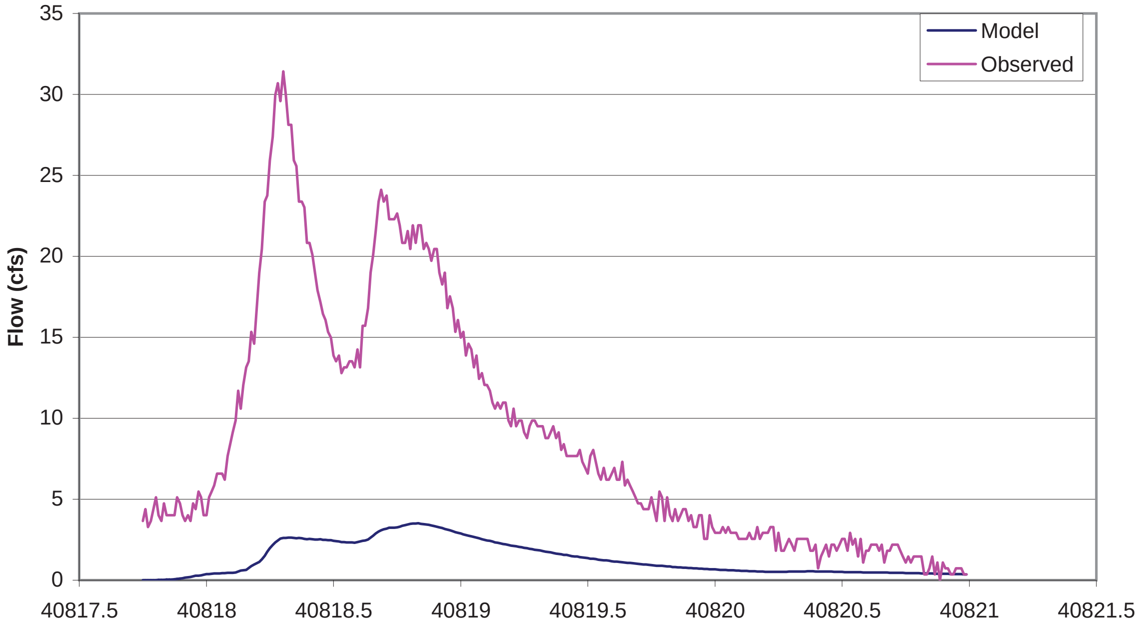


FIGURE 22
Site G2 - October 1, 2011 - 0.42"

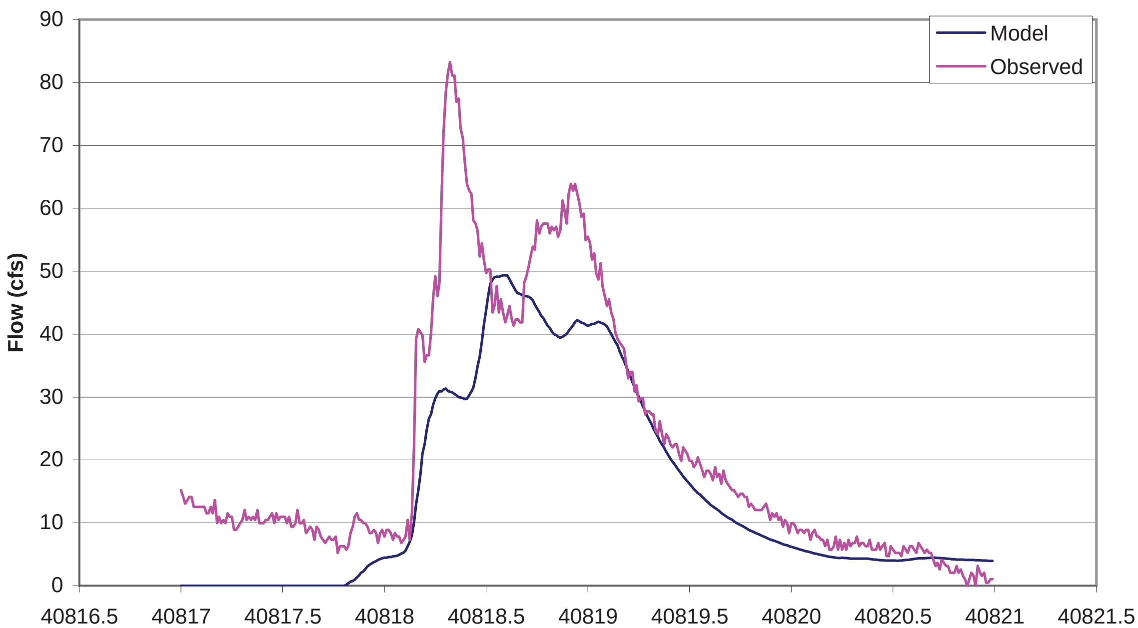


FIGURE 23
Site G1 - October 12, 2011 - 1.24"

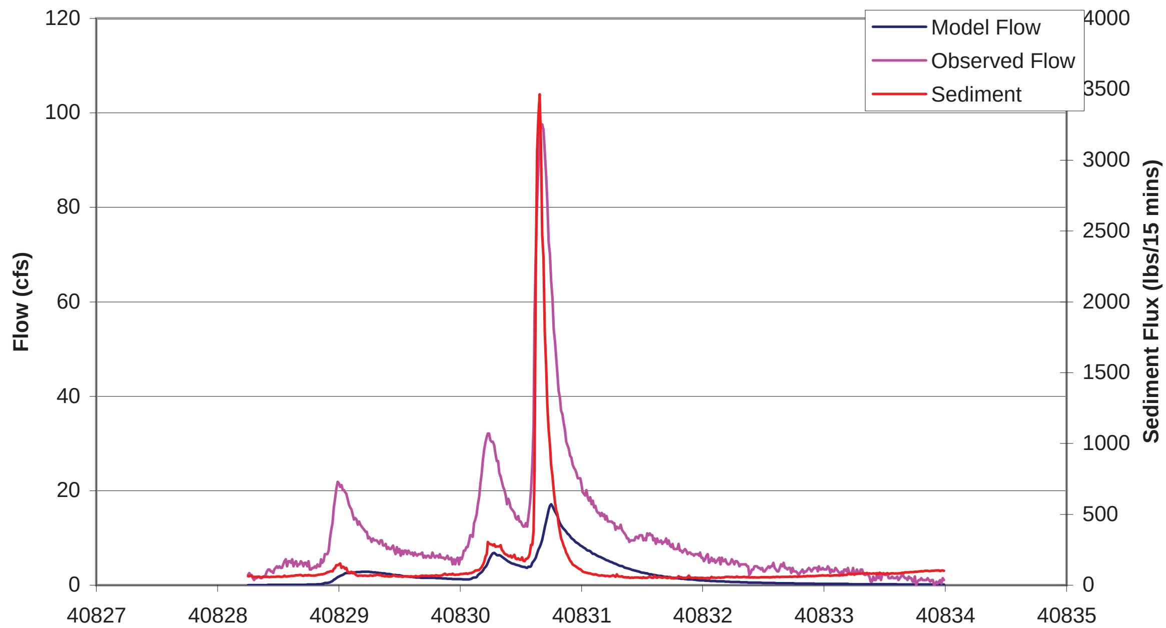


FIGURE 24
Site G2 - October 12, 2011 - 1.24"

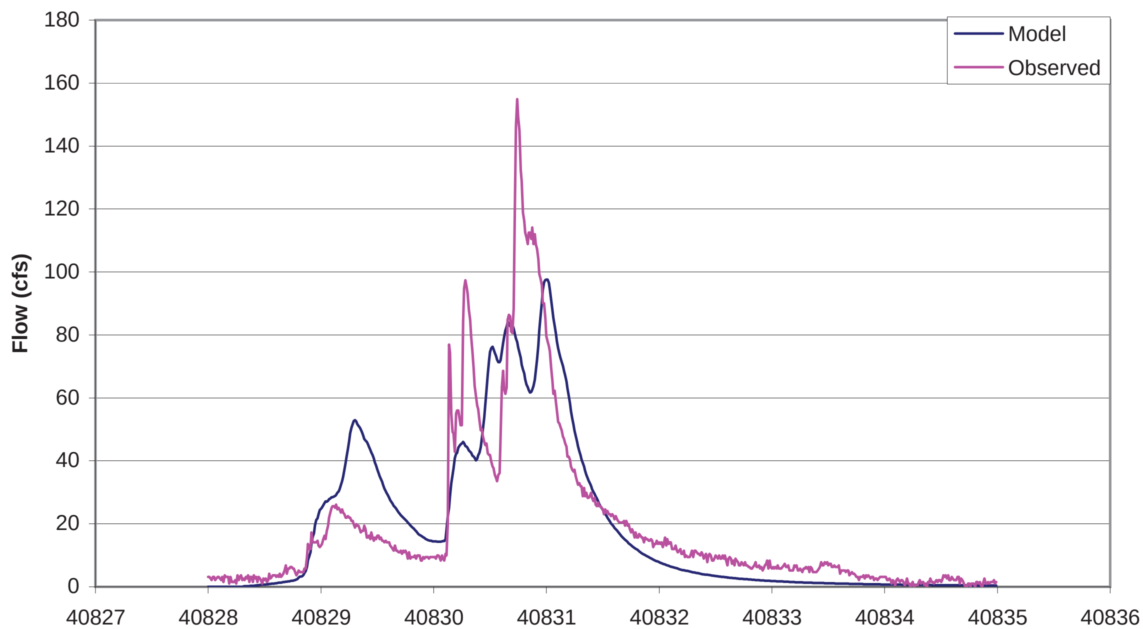


FIGURE 25
Site G1 - October 19, 2011 - 1.49"

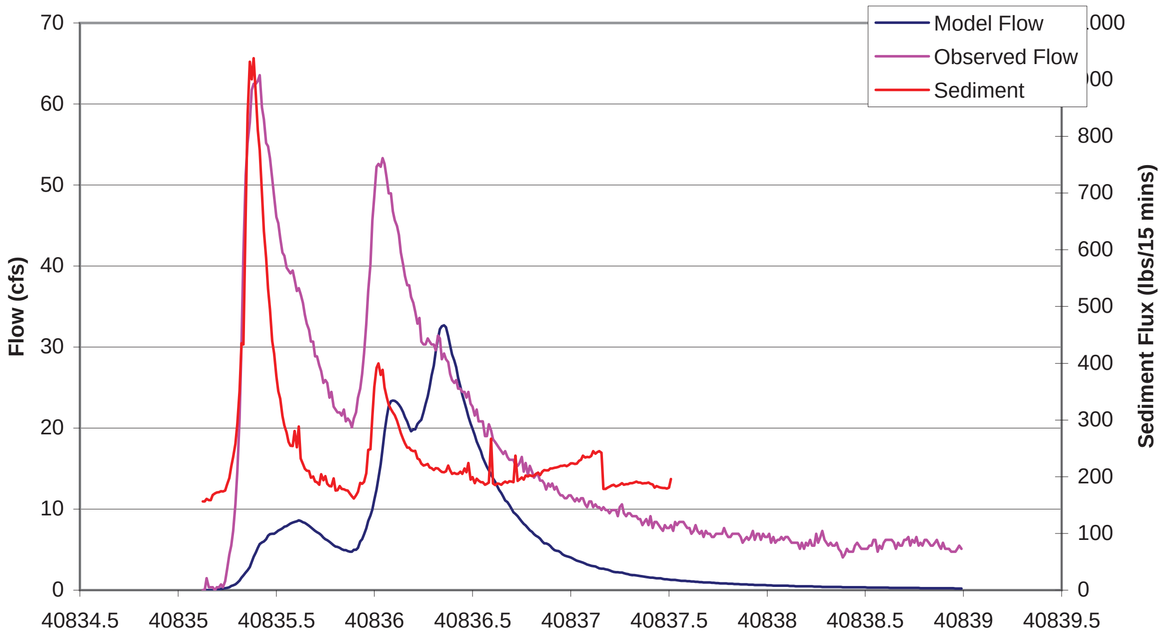


FIGURE 26
Site G2 - October 19, 2011 - 1.49"

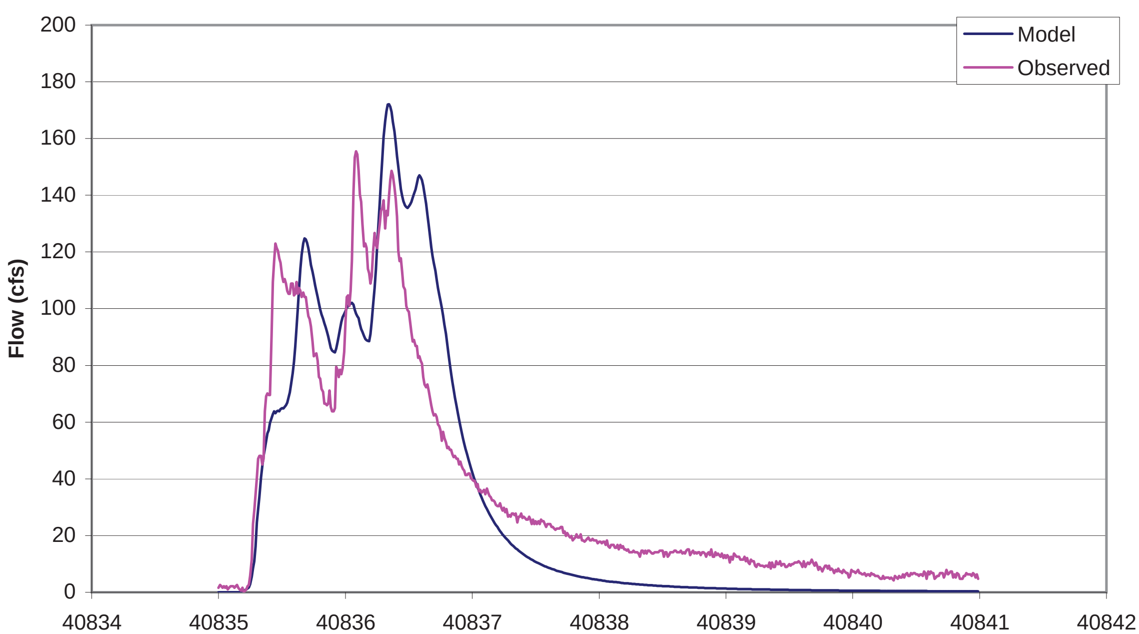


FIGURE 27
Site G1 - October 27, 2011 - 0.60"

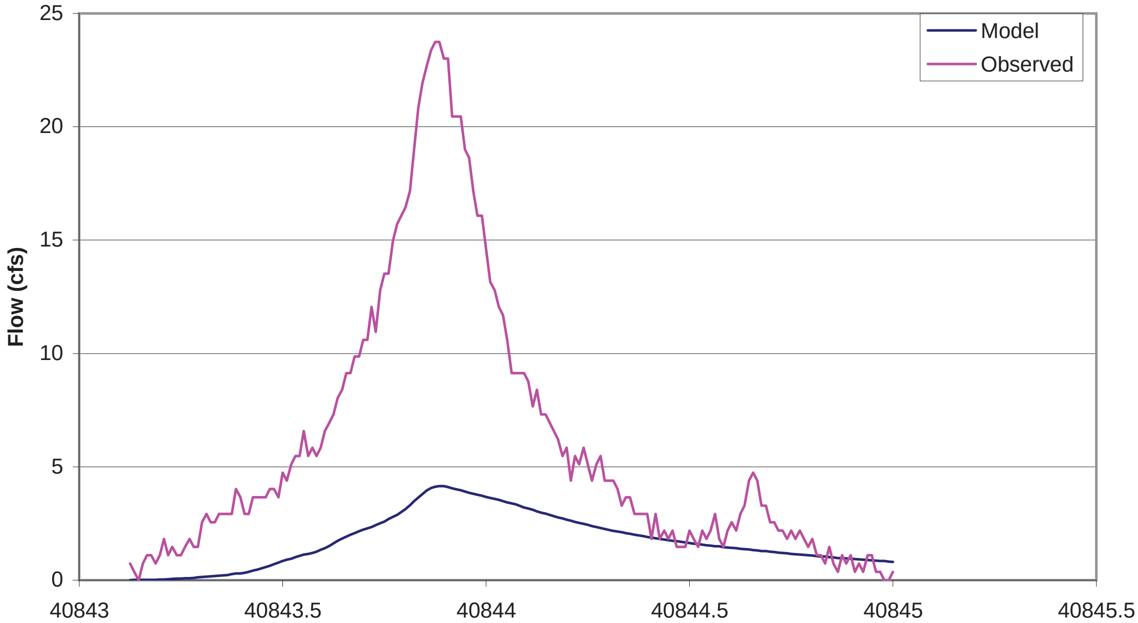


FIGURE 28
Site G2 - October 27, 2011 - 0.60"

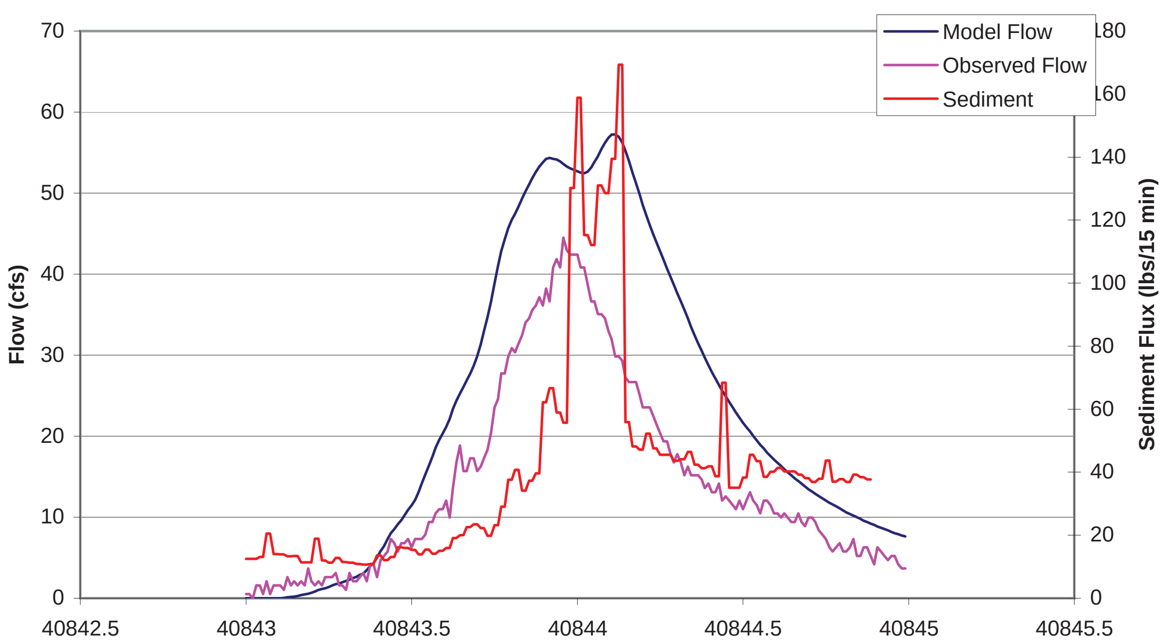


FIGURE 29
Site G1 - November 16, 2011 - 0.84"

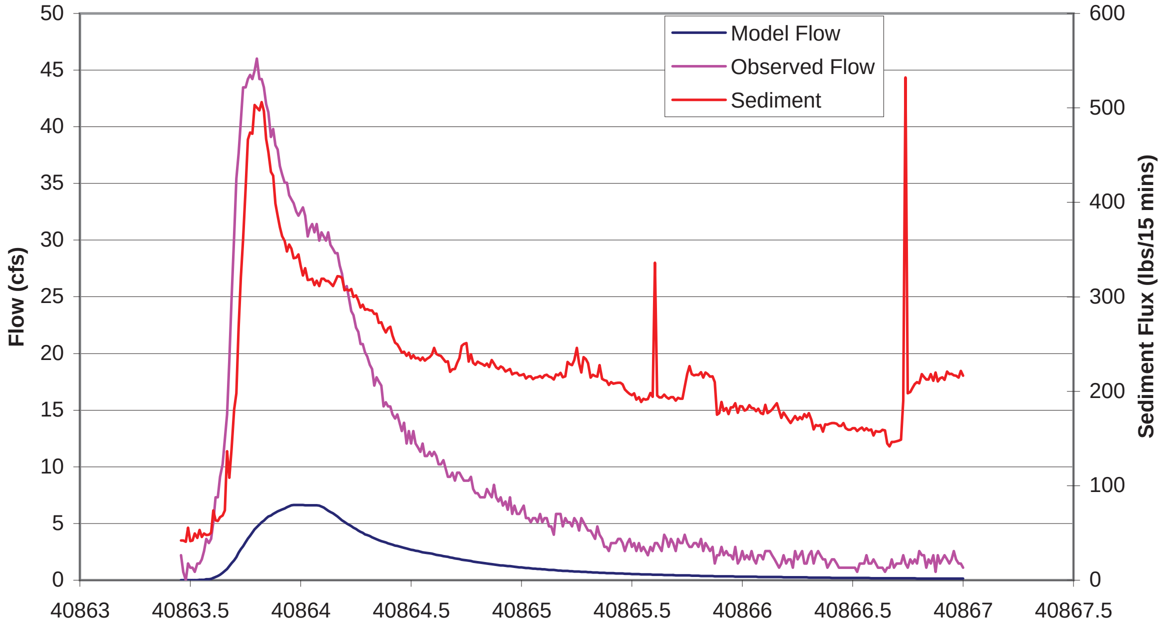


FIGURE 30
Site G2 - November 16, 2011 - 0.84"

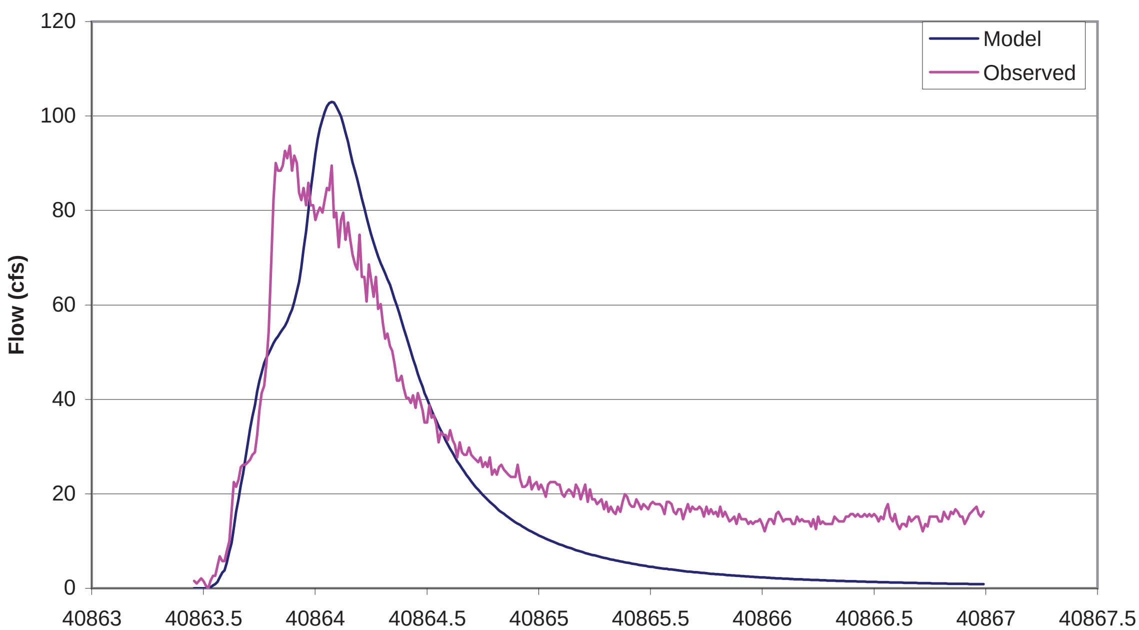


FIGURE 31
Site G1 - November 22, 2011 - 2.62"

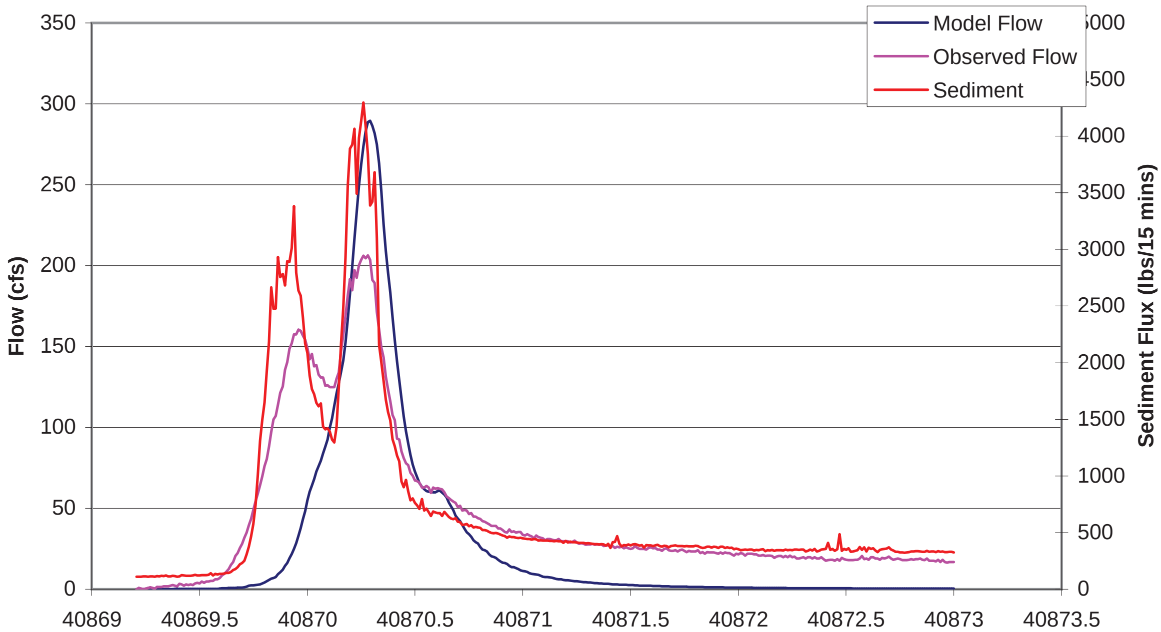


FIGURE 32
Site G2 - November 22, 2011 - 2.62"

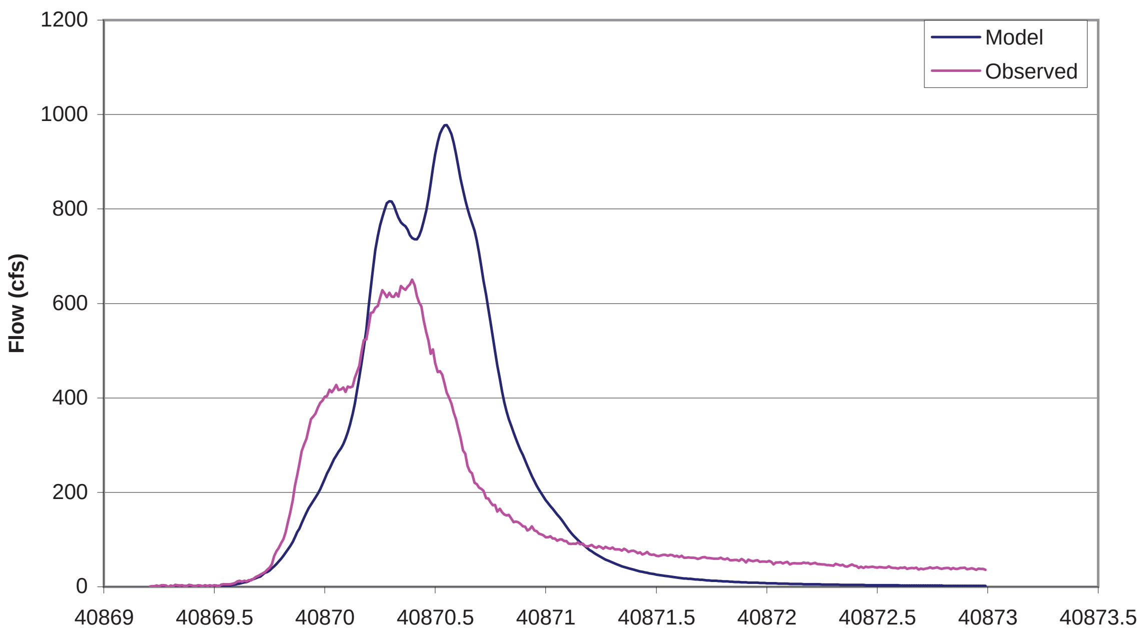


FIGURE 33
Site G1 - November 29, 2011 - 0.77"

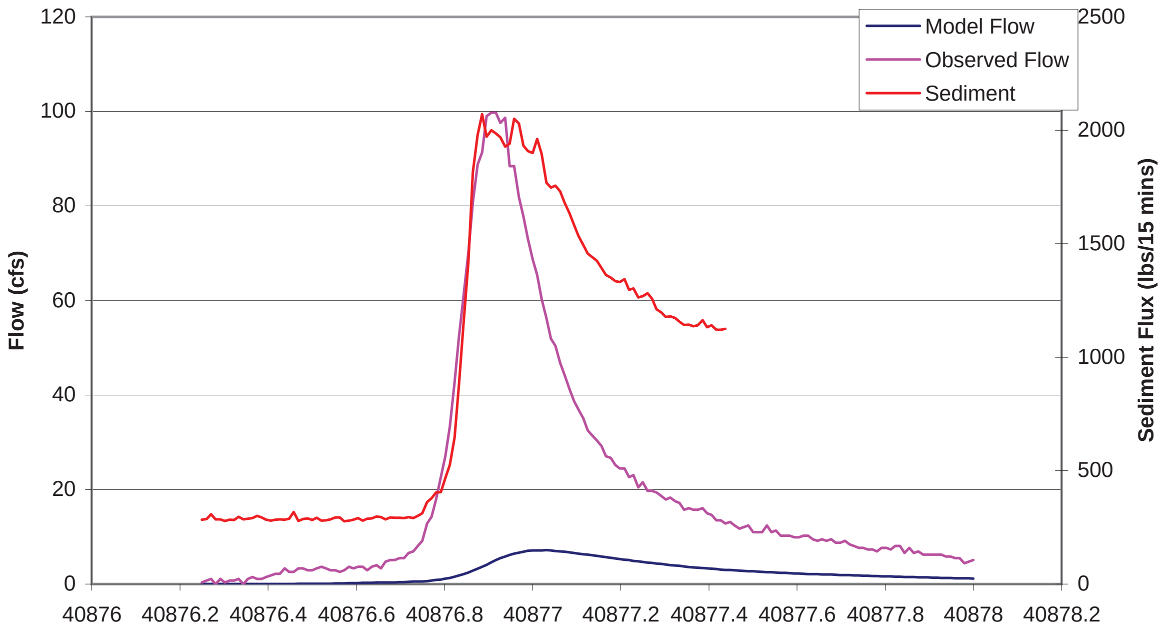
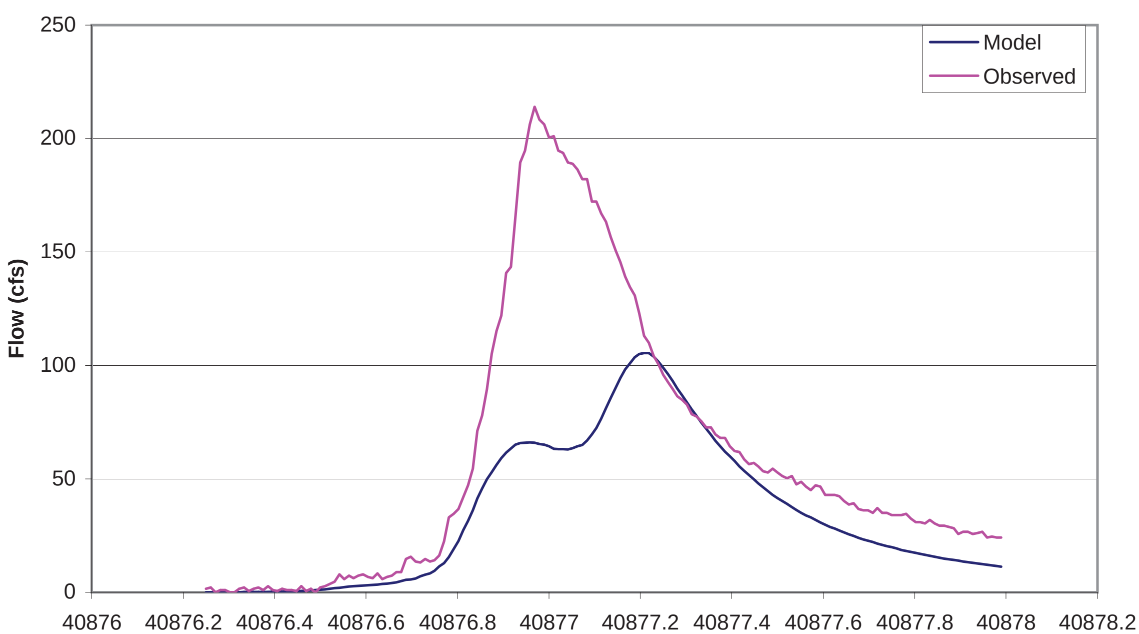


FIGURE 34
Site G2 - November 29, 2011 - 0.77"



APPENDIX B:

1990 MODELED EVENTS AND SEDIMENT LOADS

FIGURE 35
8/5/1990 Event - 4.10"

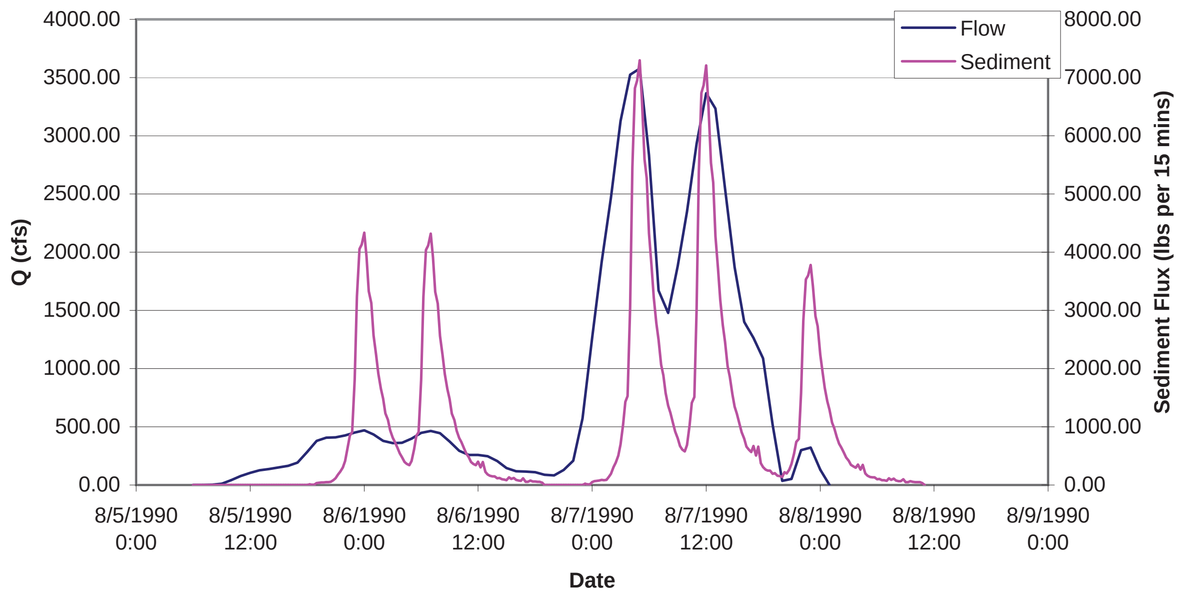


FIGURE 36
5/29/1990 Event - 2.93"

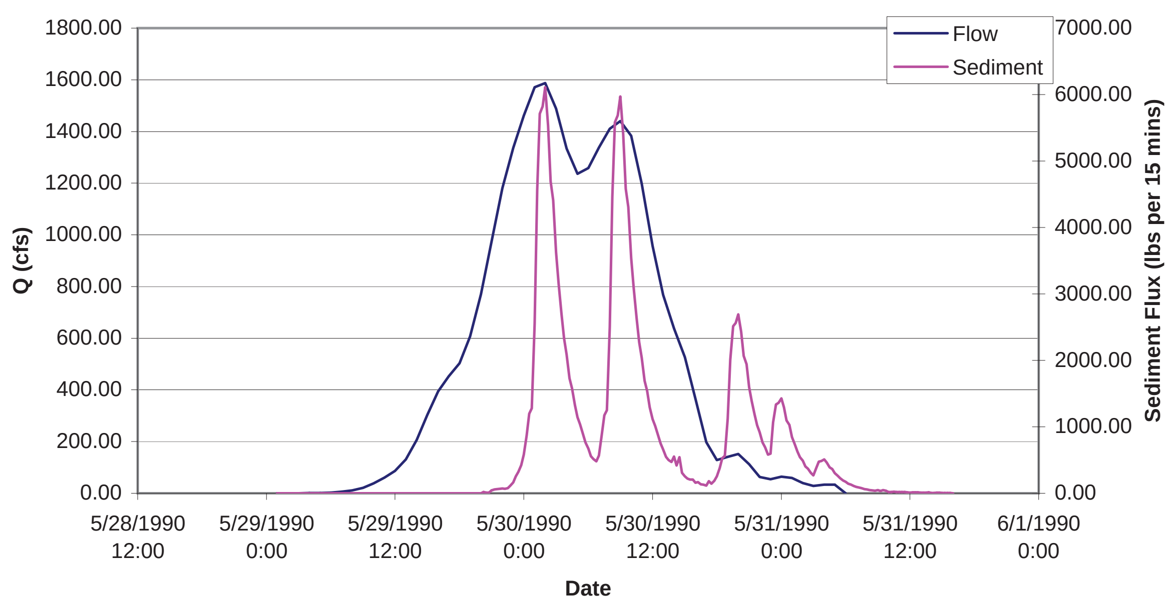


FIGURE 37
11/9/1990 Event - 2.67"

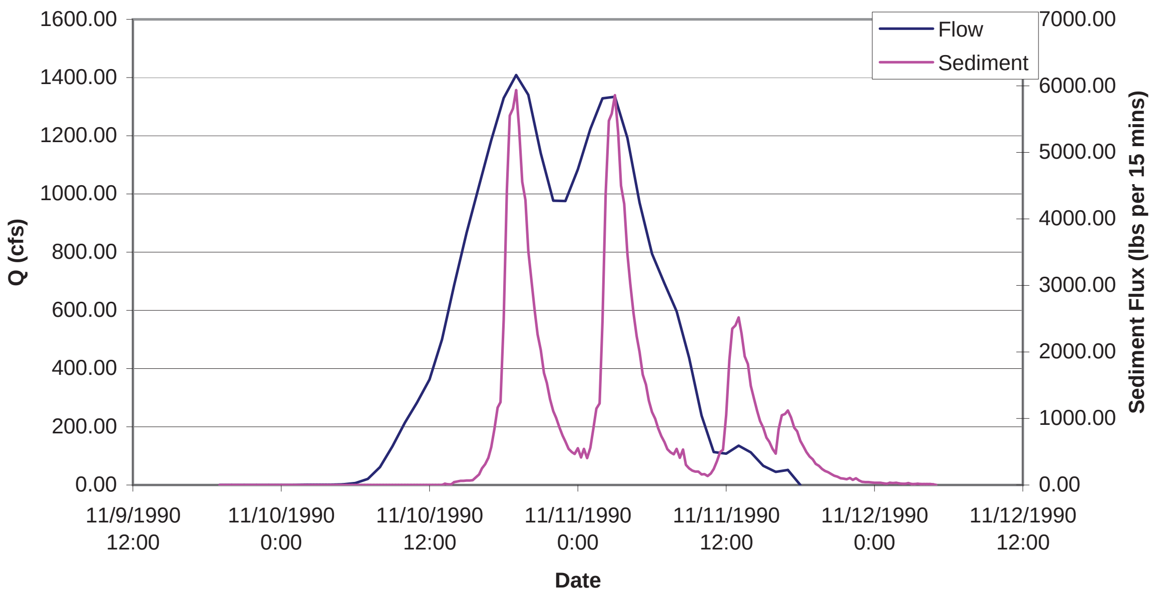


FIGURE 38
7/11/1990 Event - 2.43"

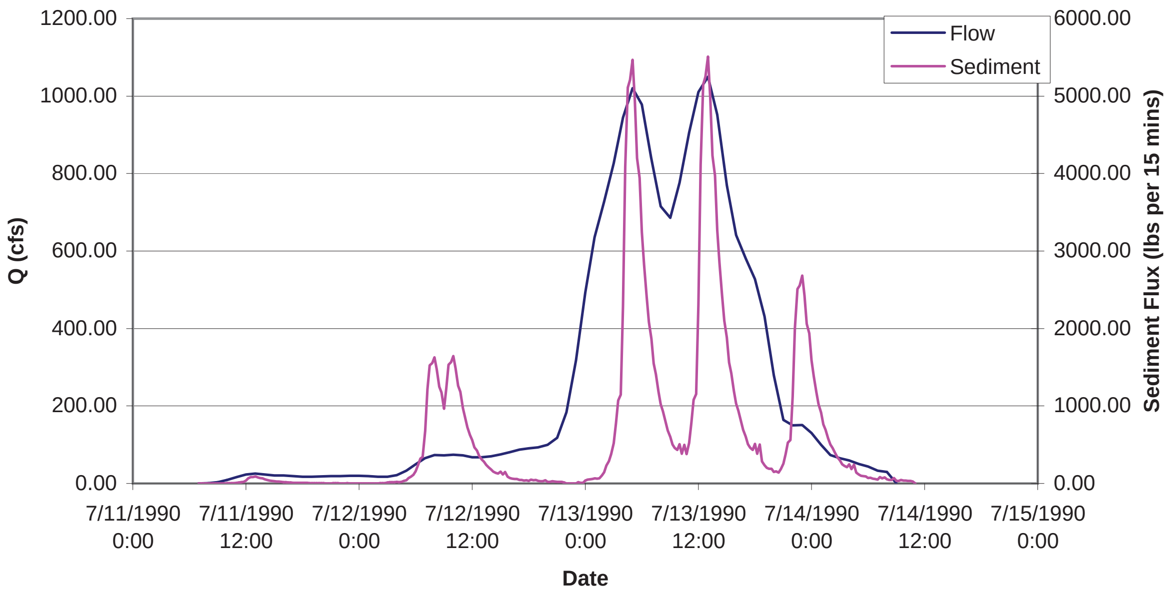


FIGURE 39
12/3/1990 Event - 2.23"

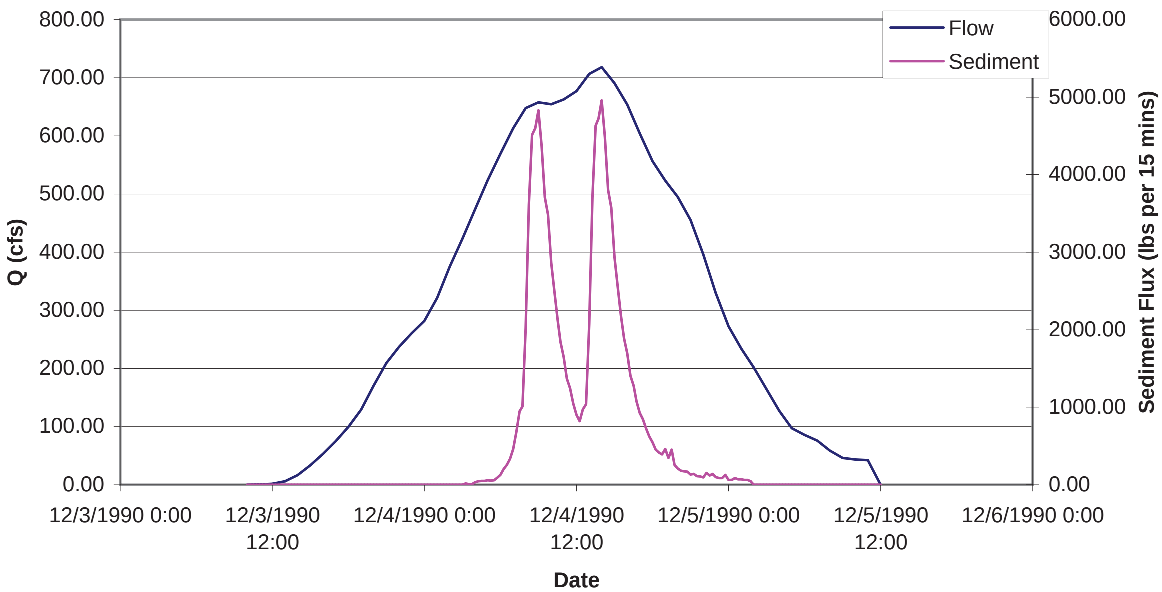


FIGURE 40
1/29/1990 Event - 1.75"

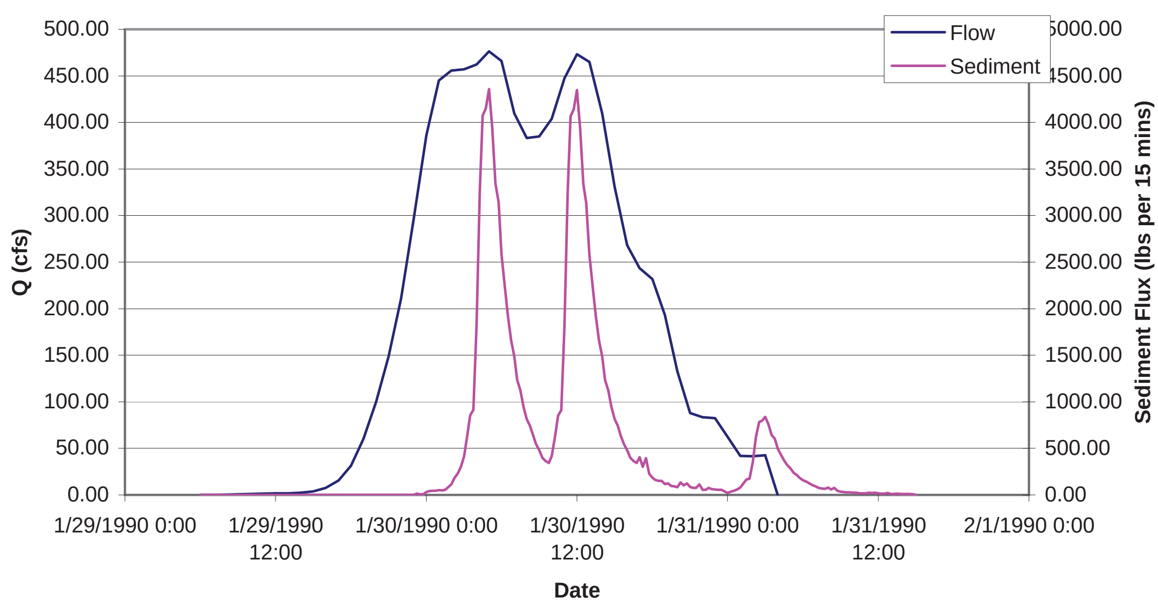


FIGURE 41
10/22/1990 Event - 1.43"

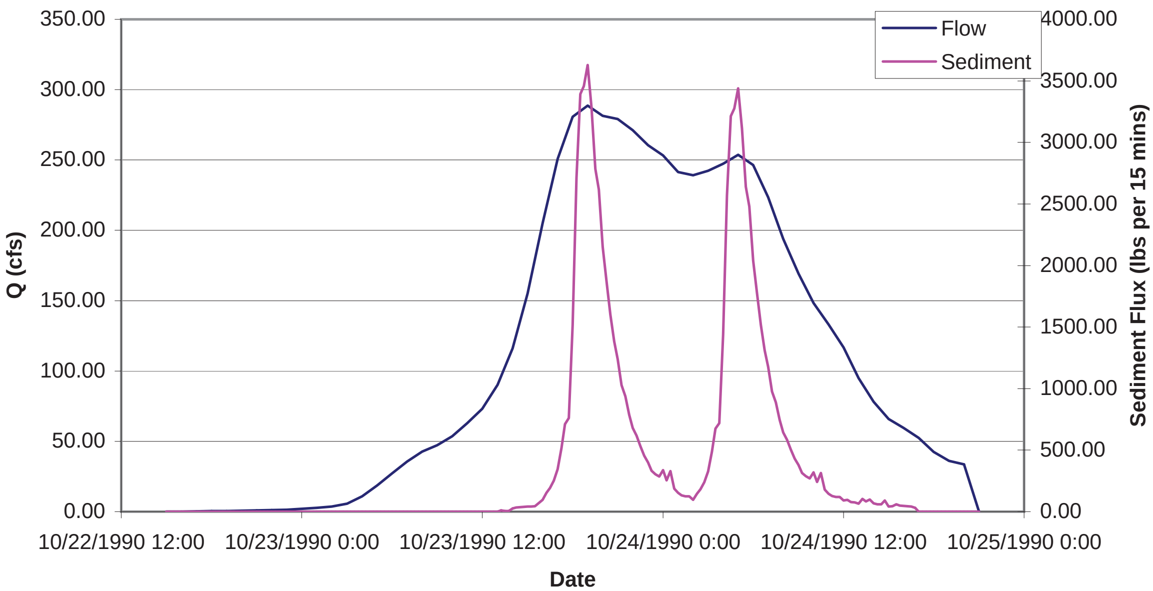


FIGURE 42
5/10/1990 Event - 1.37"

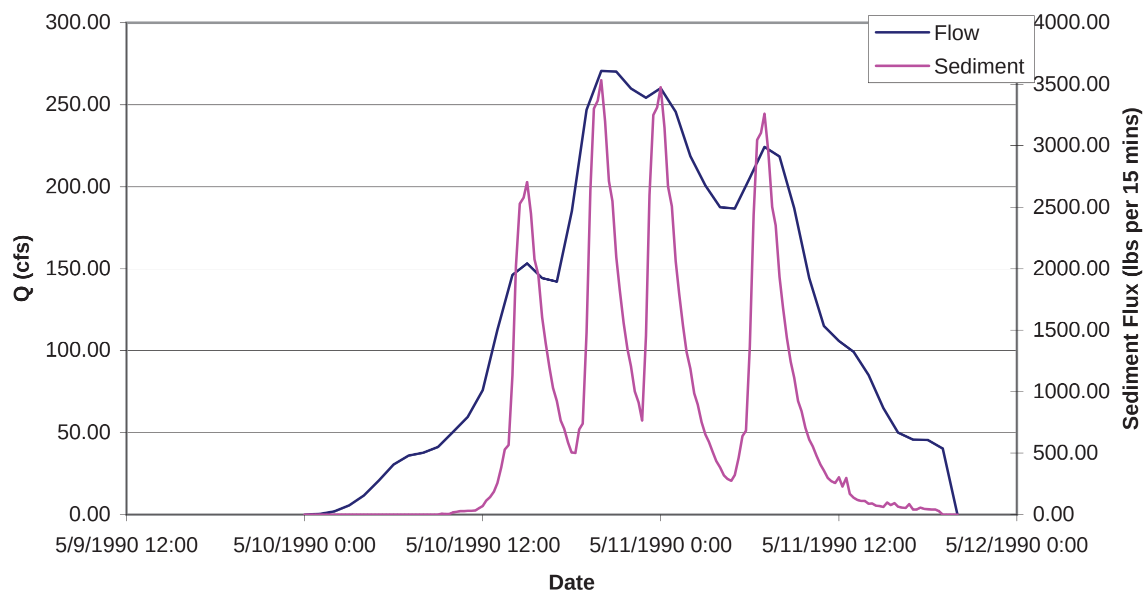


FIGURE 43
1/25/1990 Event - 1.34"

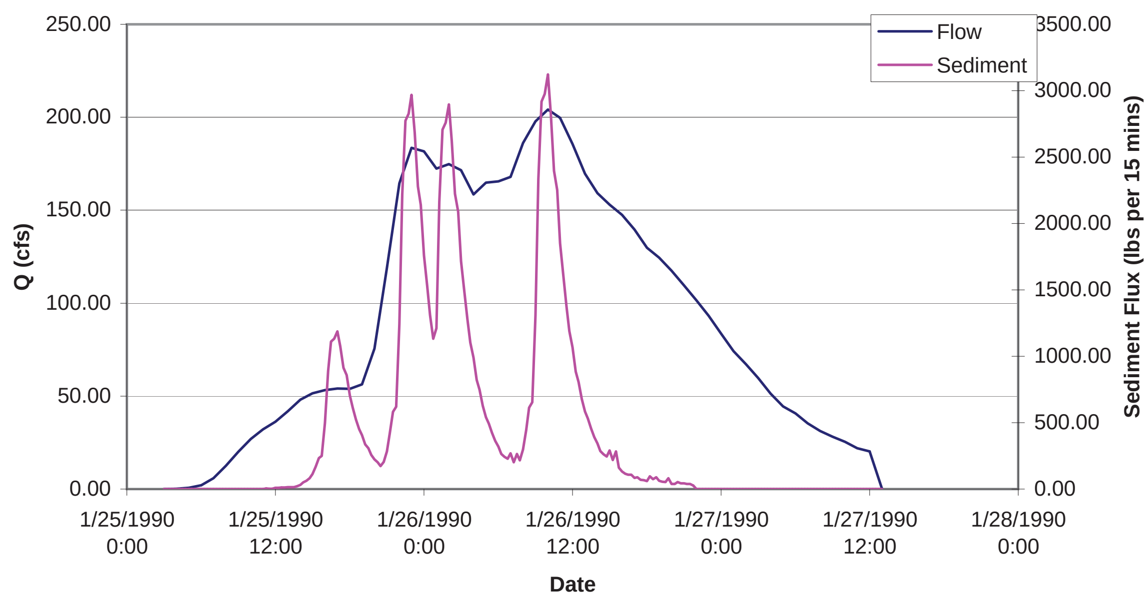


FIGURE 44
6/8/1990 Event - 1.27"

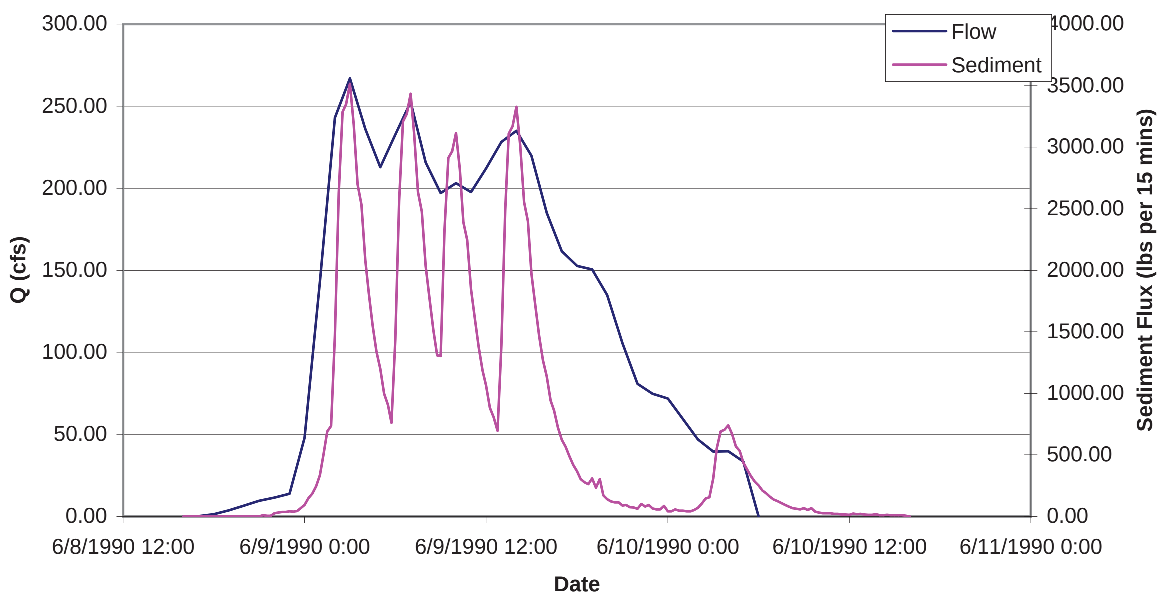


FIGURE 45
5/16/1990 Event - 1.09"

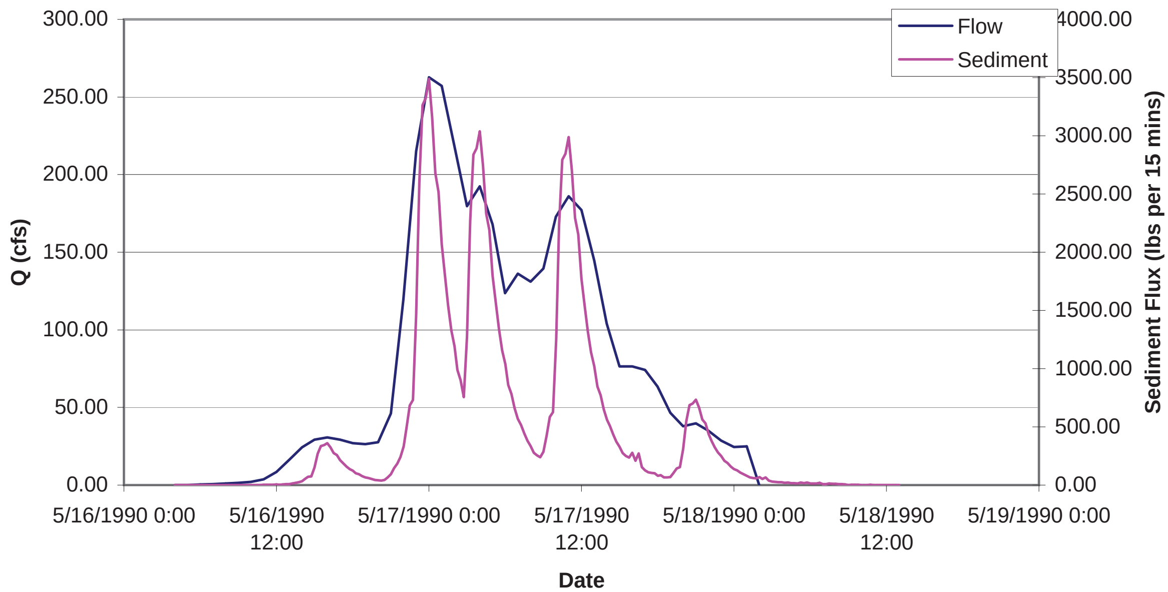


FIGURE 46
4/1/1990 Event - 1.07"

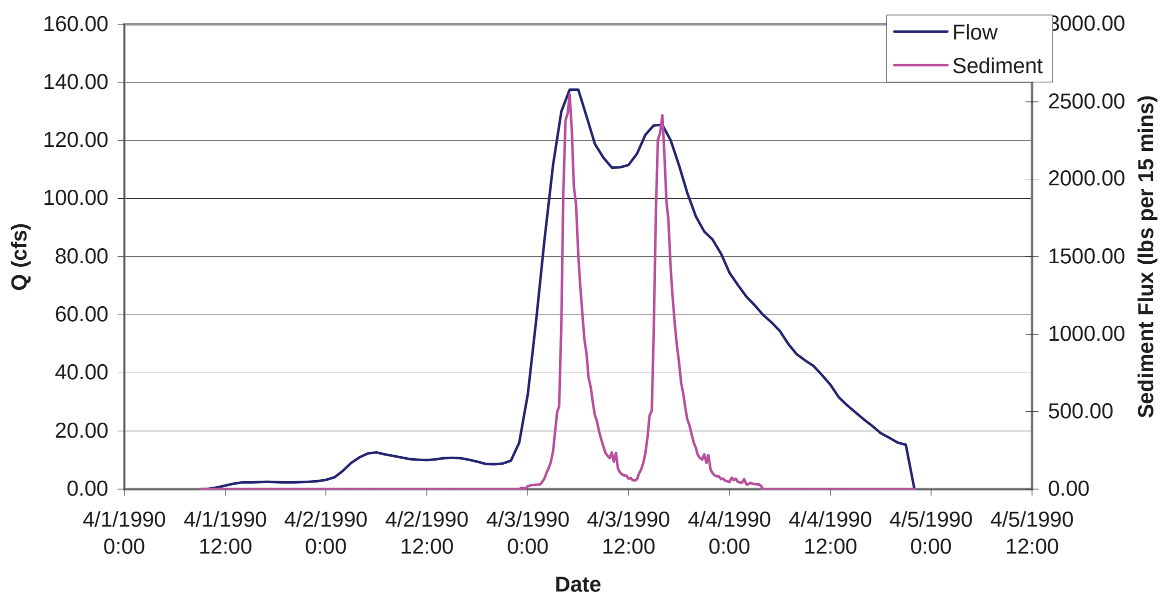


FIGURE 47
9/22/1990 Event - 1.00"

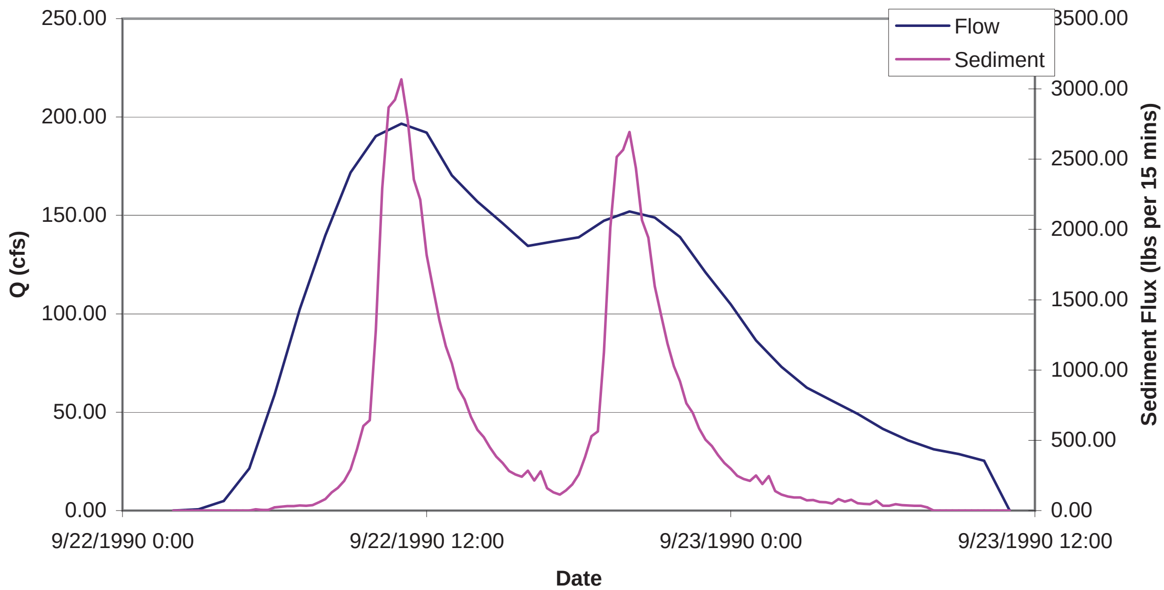


FIGURE 48
2/22/1990 Event - 0.97"

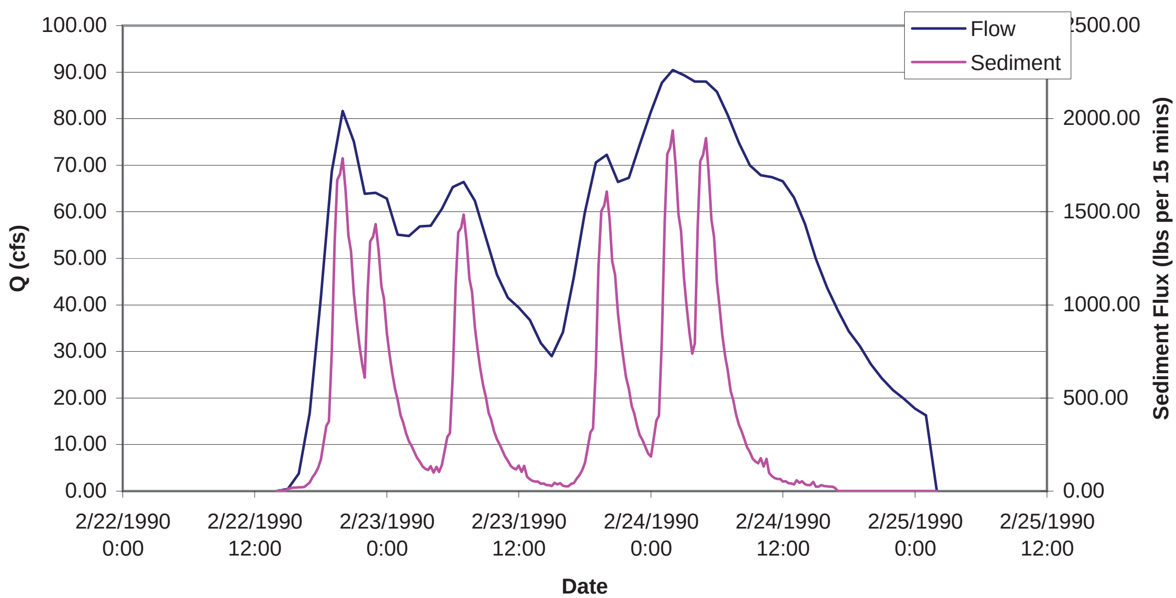


FIGURE 49
8/19/1990 Event - 0.94"

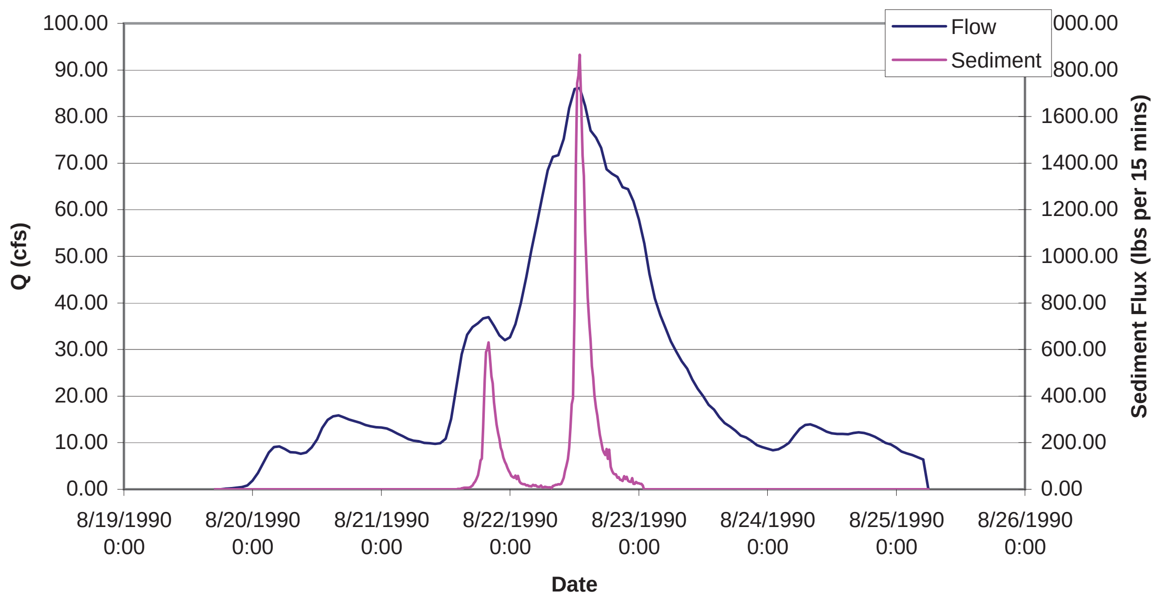


FIGURE 50
12/27/1990 Event - 0.89"

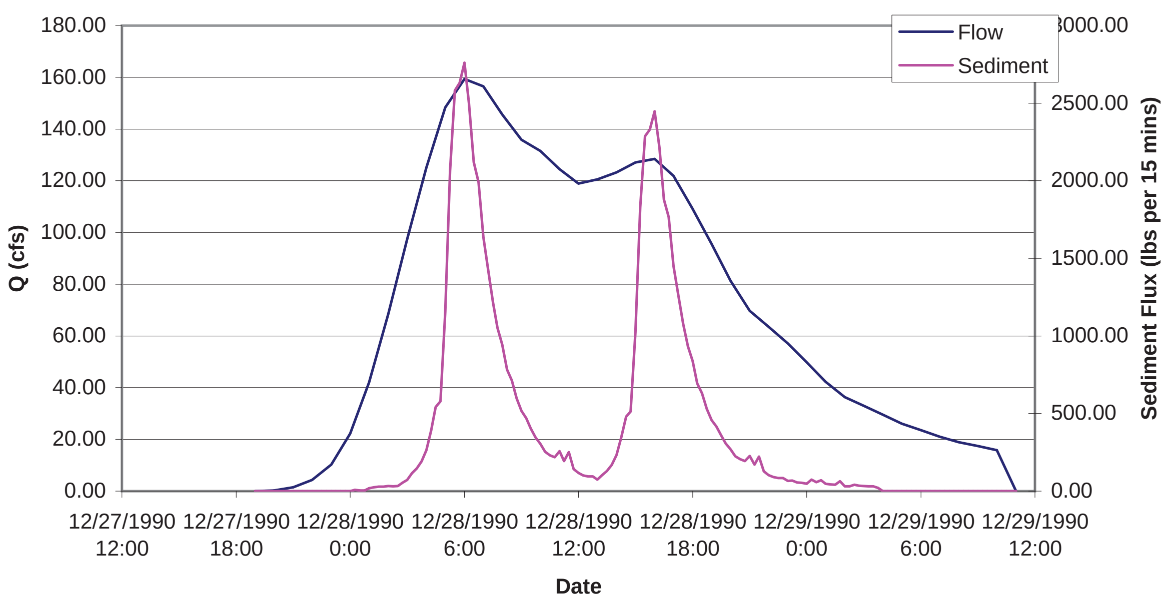


FIGURE 51
12/23/1990 Event - 0.83"

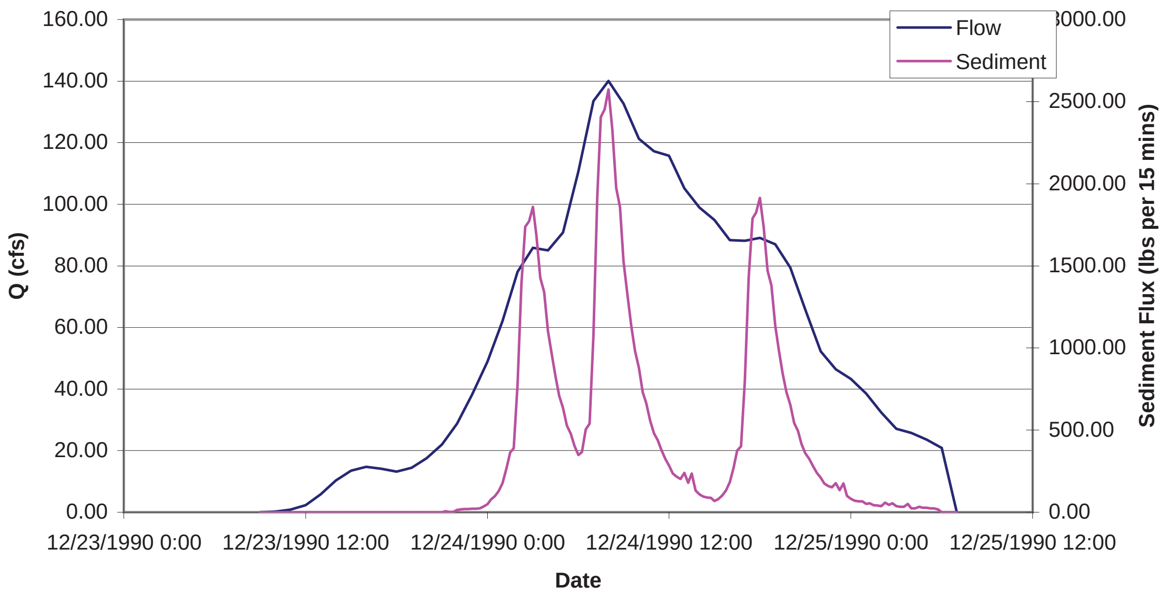


FIGURE 52
10/18/1990 Event - 0.81"

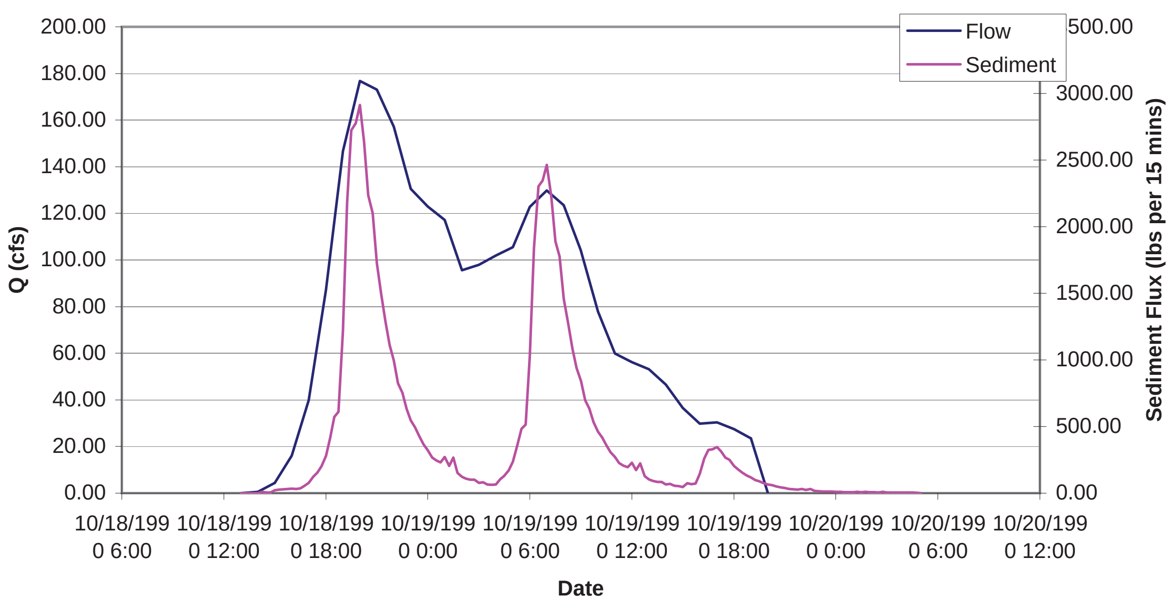


FIGURE 53
5/4/1990 Event - 0.76"

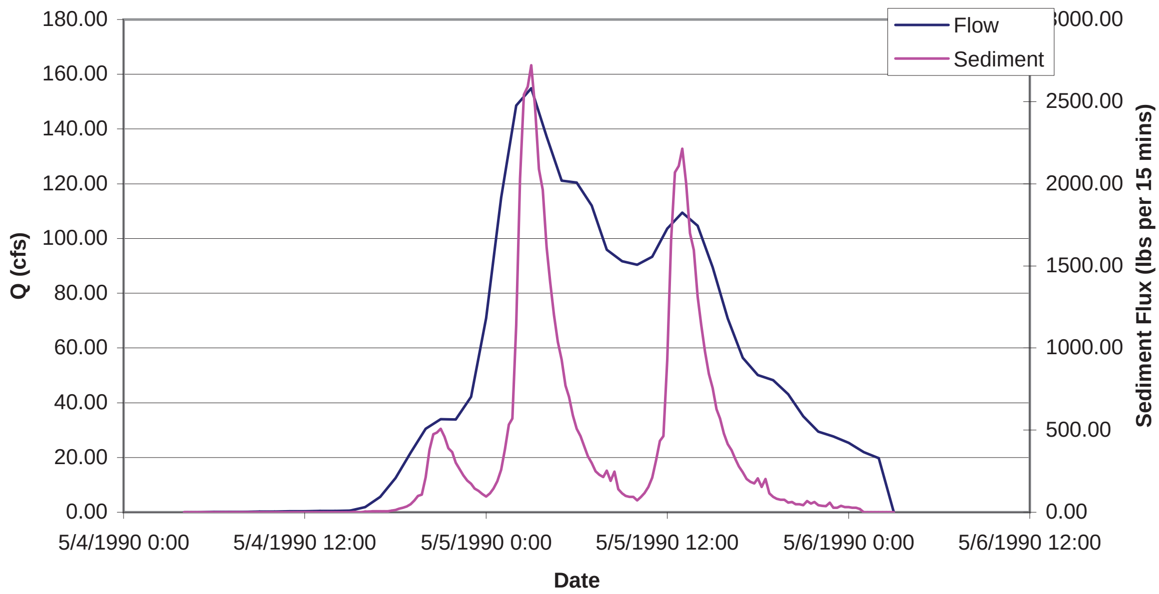


FIGURE 54
3/16/1990 Event - 0.75"

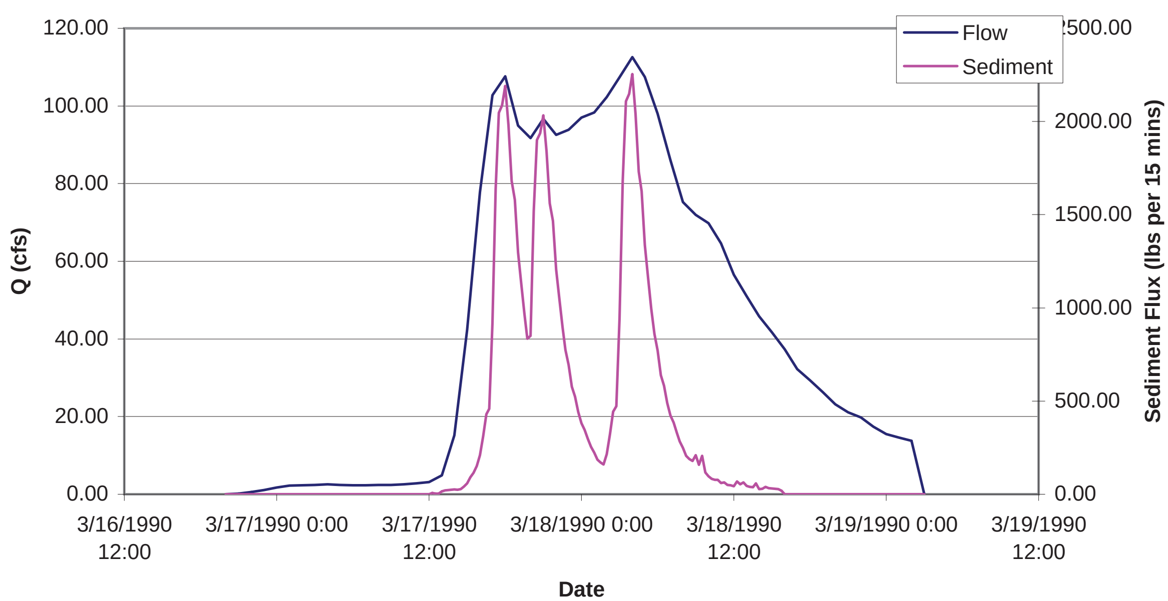


FIGURE 55
1/20/1990 Event - 0.66"

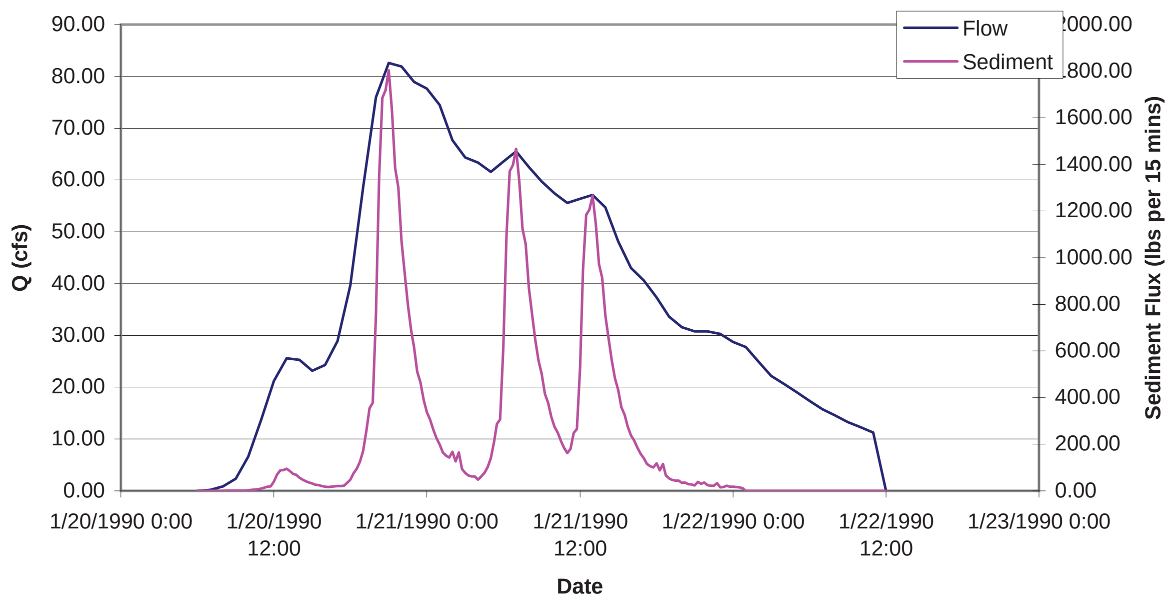


FIGURE 56
8/13/1990 Event - 0.65"

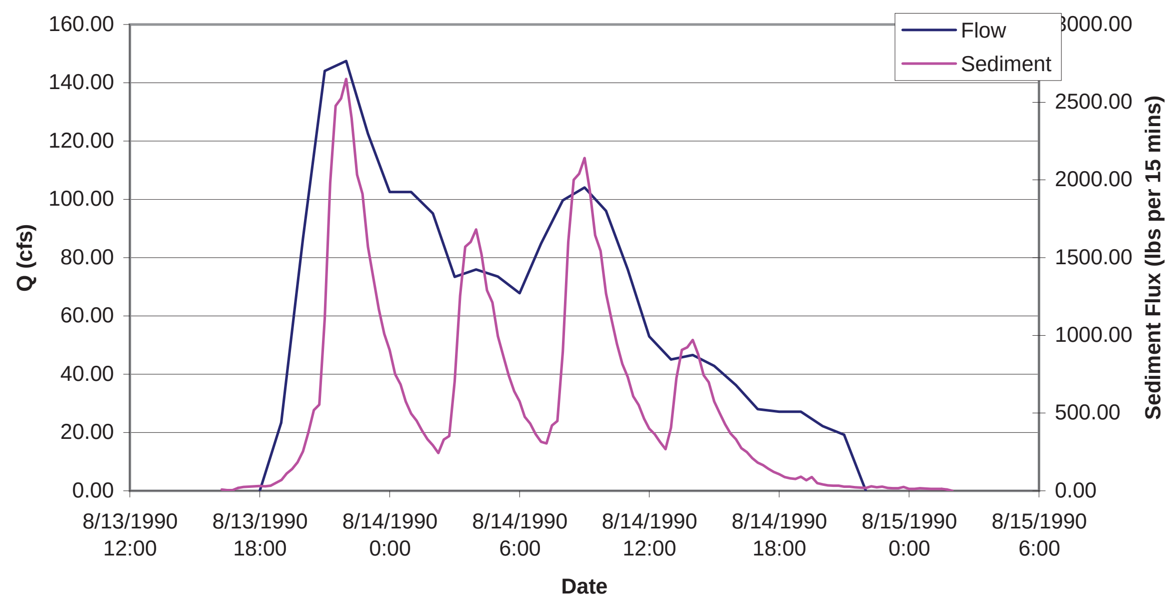


FIGURE 57
8/9/1990 Event - 0.61"

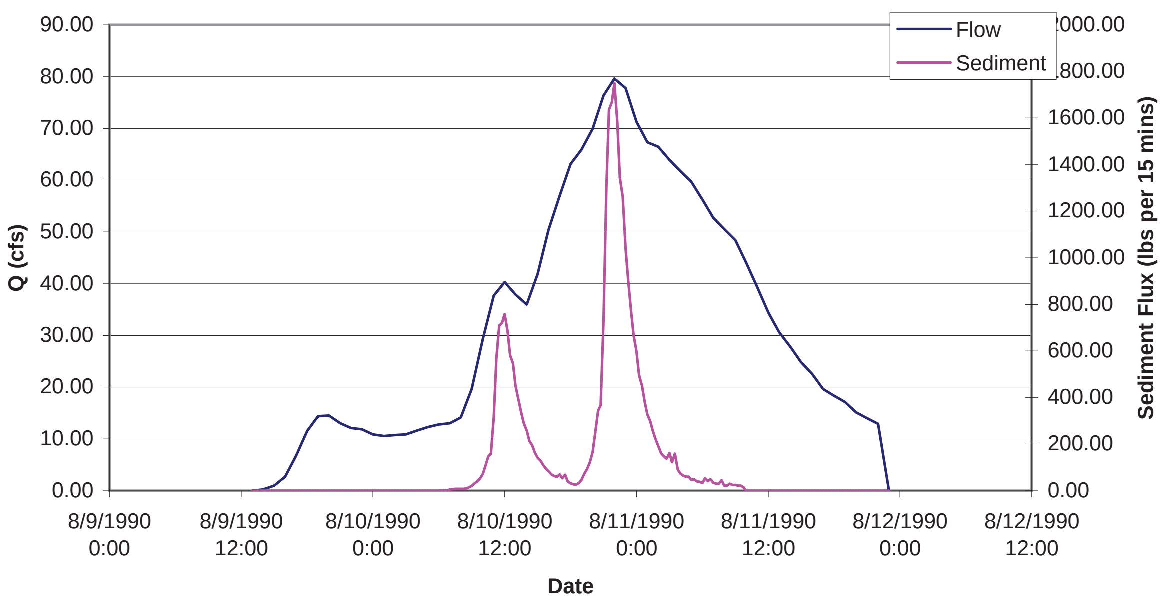


FIGURE 58
10/10/1990 Event - 0.60"

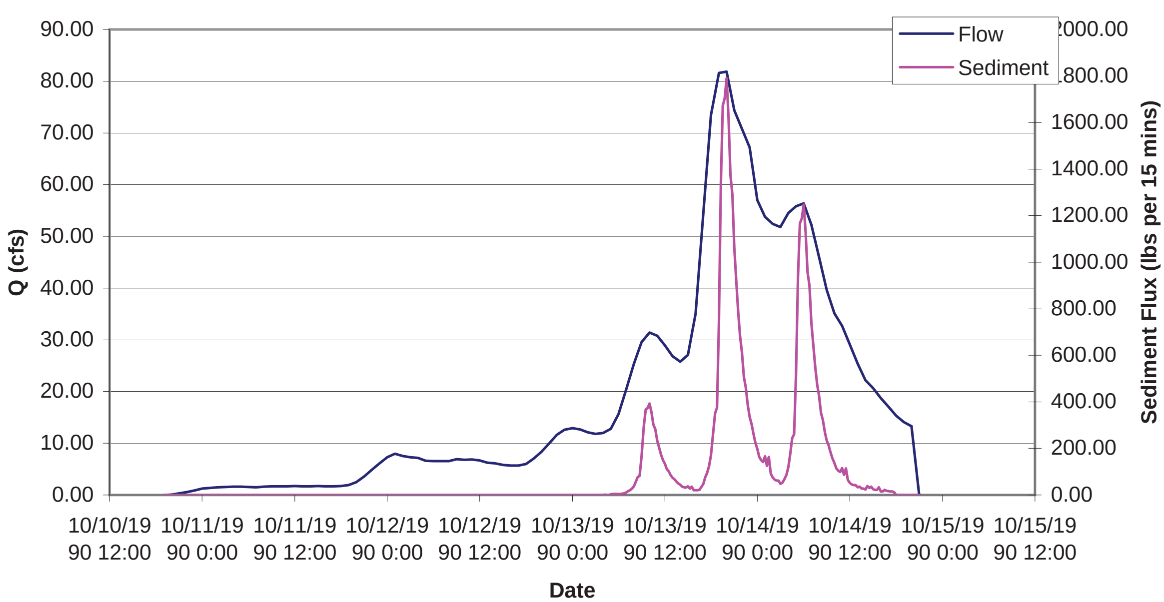


FIGURE 59
2/9/1990 Event - 0.59"

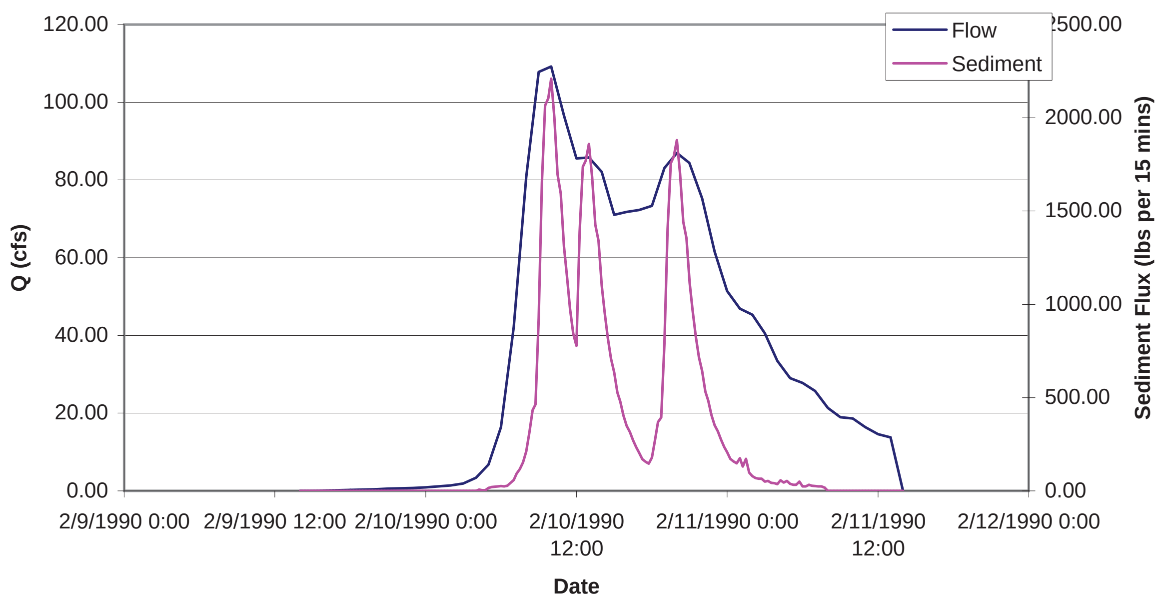


FIGURE 60
12/18/1990 Event - 0.57"

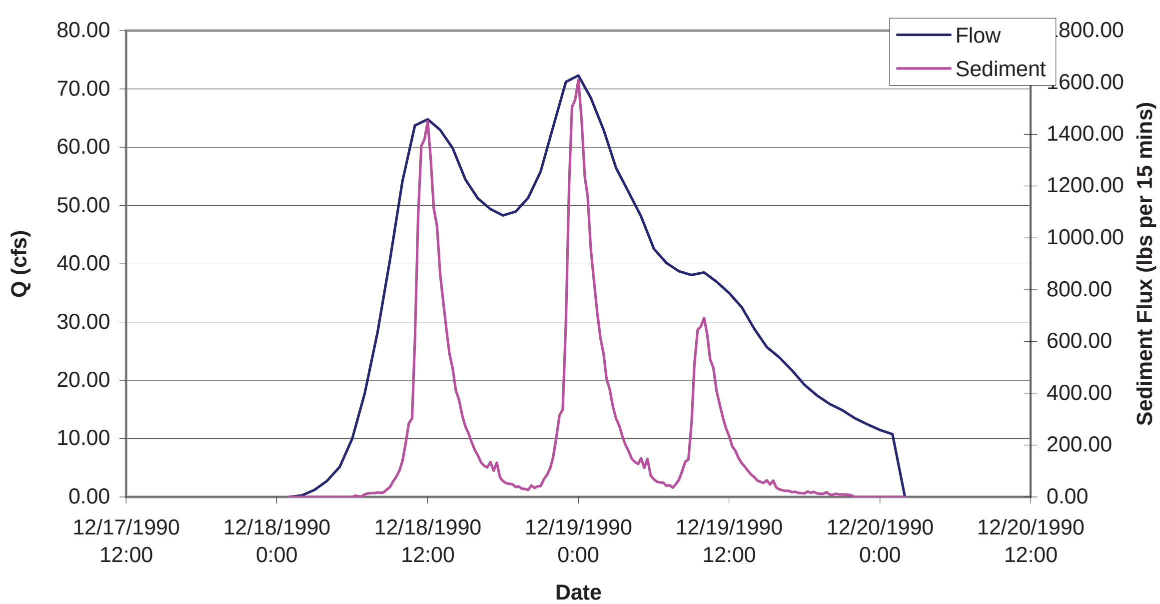


FIGURE 61
12/15/1990 Event - 0.53"

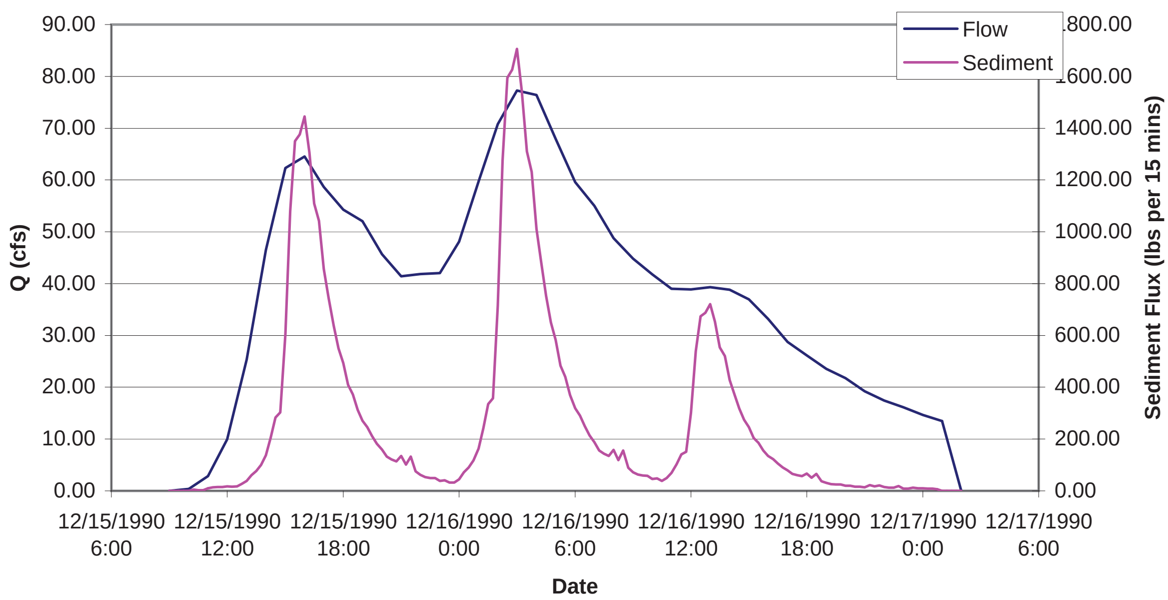


FIGURE 62
6/18/1990 Event - 0.53"

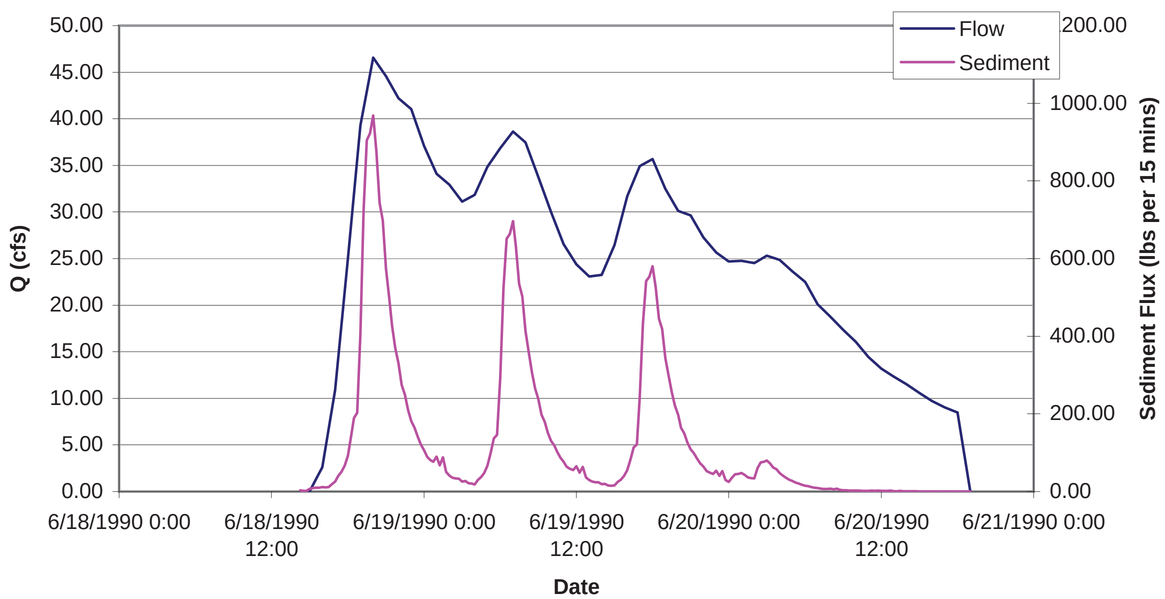


FIGURE 63
6/29/1990 Event - 0.50"

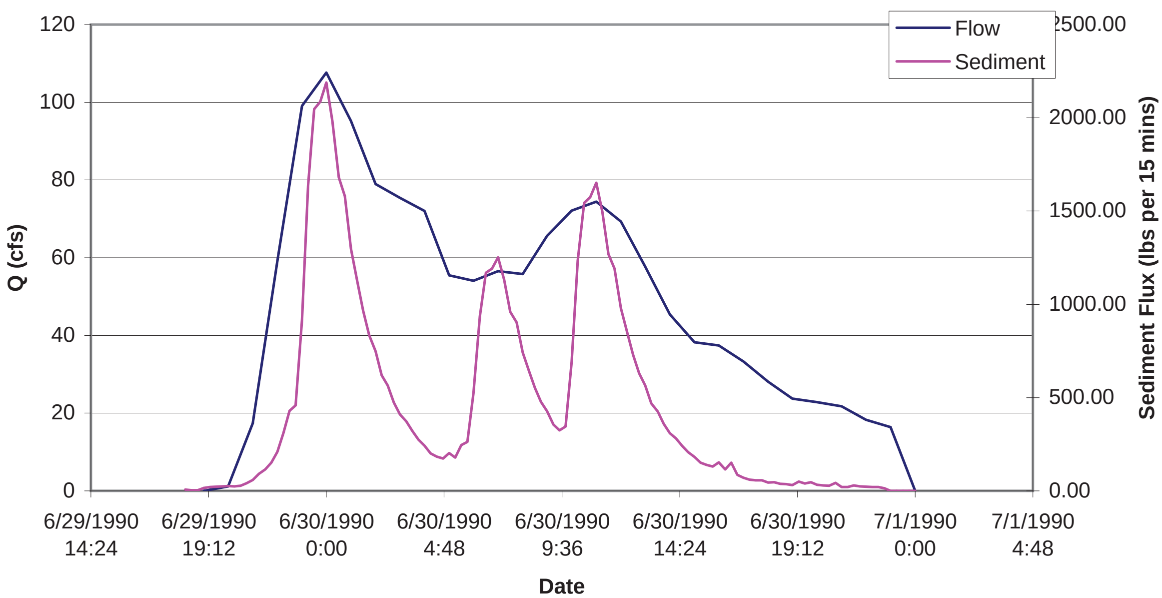


TABLE 1				
1990 Annual Sediment Load Summary				
#	Start Time	End Time	Rainfall (in)	Sediment (lbs)
1	8/5/1990 7:00	8/7/1990 2:00	4.10	314,388
2	5/29/1990 2:00	5/30/1990 5:00	2.93	186,624
3	11/9/1990 20:00	11/10/1990 17:00	2.67	176,204
4	7/11/1990 8:00	7/13/1990 8:00	2.43	192,533
5	12/3/1990 11:00	12/4/1990 11:00	2.23	110,054
6	1/29/1990 7:00	1/30/1990 3:00	1.75	111,843
7	10/22/1990 16:00	10/23/1990 20:00	1.43	84,786
8	5/10/1990 1:00	5/10/1990 19:00	1.37	139,455
9	1/25/1990 4:00	1/26/1990 12:00	1.34	108,561
10	6/8/1990 17:00	6/9/1990 5:00	1.27	141,379
11	5/16/1990 5:00	5/17/1990 1:00	1.09	115,612
12	4/1/1990 10:00	4/3/1990 21:00	1.07	59,735
13	9/22/1990 3:00	9/22/1990 10:00	1.00	68,677
14	2/22/1990 15:00	2/24/1990 1:00	0.97	106,251
15	8/19/1990 18:00	8/24/1990 5:00	0.94	30,541
16	12/27/1990 20:00	12/28/1990 10:00	0.89	62,465
17	12/23/1990 10:00	12/24/1990 6:00	0.83	72,505
18	10/18/1990 14:00	10/18/1990 19:00	0.81	68,212
19	5/4/1990 5:00	5/5/1990 2:00	0.76	64,200
20	3/16/1990 21:00	3/18/1990 2:00	0.75	68,628
21	1/20/1990 7:00	1/21/1990 11:00	0.66	53,594
22	8/13/1990 19:00	8/13/1990 21:00	0.65	80,477
23	8/9/1990 14:00	8/10/1990 22:00	0.61	30,248
24	10/10/1990 20:00	10/13/1990 20:00	0.60	40,901
25	2/9/1990 15:00	2/10/1990 13:00	0.59	62,508
26	12/18/1990 2:00	12/19/1990 1:00	0.57	44,841
27	12/15/1990 10:00	12/16/1990 1:00	0.53	46,137
28	6/18/1990 16:00	6/19/1990 18:00	0.53	27,784
29	6/29/1990 20:00	6/29/1990 23:00	0.50	56,464
Estimated Annual Sediment Load (tons) =				**1,363**
Number of <0.5" storms =				**28**
Estimated Annual Sediment Load for <0.5" storms (tons) =				**10**
Final Revised Estimated Annual Sediment Load (tons) =				**1,643**
AVGWLF Annual Sediment Load (tons) =				**20,688**