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STREAM II
Aqueous Transport
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**STREAM II-V5: REVISION OF STREAM II-V4 TO ACCOUNT FOR
THE EFFECTS OF RAINFALL EVENTS**

Author: Kuo-Fu Chen

FEBRUARY 1, 2010

Savannah River National Laboratory
Savannah River Nuclear Solutions
Aiken, SC 29808

**Prepared for the U.S. Department of Energy Under
Contract Number DE-AC09-08SR22470**



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ABSTRACT

STREAM II-V4 is the aqueous transport module currently used by the Savannah River Site emergency response Weather Information Display (WIND) system. The transport model of the Water Quality Analysis Simulation Program (WASP) was used by STREAM II to perform contaminant transport calculations. WASP5 is a US Environmental Protection Agency (EPA) water quality analysis program that simulates contaminant transport and fate through surface water. STREAM II-V4 predicts peak concentration and peak concentration arrival time at downstream locations for releases from the SRS facilities to the Savannah River. The input flows for STREAM II-V4 are derived from the historical flow records measured by the United States Geological Survey (USGS). The stream flow for STREAM II-V4 is fixed and the flow only varies with the month in which the releases are taking place. Therefore, the effects of flow surge due to a severe storm are not accounted for by STREAM II-V4.

STREAM II-V4 has been revised to account for the effects of a storm event. The steps used in this method are: 1) generate rainfall hyetographs as a function of total rainfall in inches (or millimeters) and rainfall duration in hours; 2) generate watershed runoff flow based on the rainfall hyetographs from step 1; 3) calculate the variation of stream segment volume (cross section) as a function of flow from step 2; 4) implement the results from steps 2 and 3 into the STREAM II model. The revised model (STREAM II-V5) will find the proper stream inlet flow based on the total rainfall and rainfall duration as input by the user. STREAM II-V5 adjusts the stream segment volumes (cross sections) based on the stream inlet flow. The rainfall based stream flow and the adjusted stream segment volumes are then used for contaminant transport calculations.

TABLE OF CONTENTS

1. INTRODUCTION	1
2. DESIGN RAINFALL HYETOGRAPH	1
2.1 Derivation of 24-Hour Rainfall Hyetograph	2
2.2 Derivation of 12-Hour Rainfall Hyetograph	2
2.3 Derivation of 6-Hour Rainfall Hyetograph	3
2.4 Derivation of 3-Hour Rainfall Hyetograph	3
3. WATERSHED DELINEATION	4
4. WATERSHED RUNOFF	4
4.1 Upper Three Runs	5
4.2 Beaver Dam Creek	5
4.3 Fourmile Branch	5
4.4 Pen Branch	6
4.5 Steel Creek	6
4.6 Lower Three Runs	6
4.7 Savannah River	7
5. STREAM SEGMENT VOLUME AS A FUNCTION OF RUNOFF FLOW	7
6. CODE MODIFICATIONS	7
7. TEST RESULTS	8
7.1 STREAM II-V4 vs. STREAM II-V5	8
7.2 Rainfall Effects	9
8. CONCLUSION	10
ACKNOWLEDGEMENT	11
REFERENCES	12

LIST OF TABLES

Table 1. 6-Hour Rainfall Distribution as a Function of Return Period	14
Table 2. 24-Hour Rainfall Distribution as a Function of Return Period	15
Table 3. Design Rainfall Events for STREAM II-V5	16
Table 4. HEC-HMS Input Parameters	17
Table 5. Model Comparison between STREAM II-V4 and -V5	18
Table 6. Effects of Rainfall on Contaminant Transport	20

LIST OF FIGURES

Figure 1. 24-Hour Storm Rainfall Distributions	23
Figure 2. 12-Hour Storm Rainfall Distributions	24
Figure 3. 6-Hour Storm Rainfall Distributions	25
Figure 4. 3-Hour Storm Rainfall Distributions	26
Figure 5. Digital Elevation Model for Savannah River Site	27
Figure 6. Streams Delineated by HEC-GeoHMS	28
Figure 7. Watershed Delineated by HEC-GeoHMS	29
Figure 8. Upper Three Runs Watershed	30
Figure 9. Fourmile Branch Watershed	31
Figure 10. Pen Branch Watershed	32
Figure 11. Steel Creek Watershed	33
Figure 12. Lower Three Runs Watershed	34
Figure 13. HEC-HMS Simulation for the Upper Three Runs Watershed Runoff Hydrograph (2.8 Inches of Rainfall in 3 Hours)	35
Figure 14. Upper Three Runs Peak Runoff Flow as a Function of Total Rainfall (Rainfall Duration=1 Hour)	36
Figure 15. Upper Three Runs Peak Runoff Flow as a Function of Total Rainfall (Rainfall Duration=3 Hours)	37
Figure 16. Upper Three Runs Peak Runoff Flow as a Function of Total Rainfall (Rainfall Duration=6 Hours)	38
Figure 17. Upper Three Runs Peak Runoff Flow as a Function of Total Rainfall (Rainfall Duration=12 Hours)	39
Figure 18. Upper Three Runs Peak Runoff Flow as a Function of Total Rainfall (Rainfall Duration=24 Hours)	40
Figure 19. Fourmile Branch Peak Runoff Flow as a Function of Total Rainfall (Rainfall Duration=1 Hour)	41
Figure 20. Fourmile Branch Peak Runoff Flow as a Function of Total Rainfall (Rainfall Duration=3 Hours)	42
Figure 21. Fourmile Branch Peak Runoff Flow as a Function of Total Rainfall (Rainfall Duration=6 Hours)	43
Figure 22. Fourmile Branch Peak Runoff Flow as a Function of Total Rainfall (Rainfall Duration=12 Hours)	44
Figure 23. Fourmile Branch Peak Runoff Flow as a Function of Total Rainfall (Rainfall Duration=24 Hours)	45
Figure 24. Pen Branch Peak Runoff Flow as a Function of Total Rainfall (Rainfall Duration=1 Hour)	46
Figure 25. Pen Branch Peak Runoff Flow as a Function of Total Rainfall (Rainfall Duration=3 Hours)	47
Figure 26. Pen Branch Peak Runoff Flow as a Function of Total Rainfall (Rainfall Duration=6 Hours)	48
Figure 27. Pen Branch Peak Runoff Flow as a Function of Total Rainfall (Rainfall Duration=12 Hours)	49
Figure 28. Pen Branch Peak Runoff Flow as a Function of Total Rainfall (Rainfall Duration=24 Hours)	50

Figure 29. Steel Creek Peak Runoff Flow as a Function of Total Rainfall (Rainfall Duration=1 Hour)	51
Figure 30. Steel Creek Peak Runoff Flow as a Function of Total Rainfall (Rainfall Duration=3 Hours)	52
Figure 31. Steel Creek Peak Runoff Flow as a Function of Total Rainfall (Rainfall Duration=6 Hours)	53
Figure 32. Steel Creek Peak Runoff Flow as a Function of Total Rainfall (Rainfall Duration=12 Hours)	54
Figure 33. Steel Creek Peak Runoff Flow as a Function of Total Rainfall (Rainfall Duration=24 Hours)	55
Figure 34. Lower Three Runs Peak Runoff Flow as a Function of Total Rainfall (Rainfall Duration=1 Hour)	56
Figure 35. Lower Three Runs Peak Runoff Flow as a Function of Total Rainfall (Rainfall Duration=3 Hours)	57
Figure 36. Lower Three Runs Peak Runoff Flow as a Function of Total Rainfall (Rainfall Duration=6 Hours)	58
Figure 37. Lower Three Runs Peak Runoff Flow as a Function of Total Rainfall (Rainfall Duration=12 Hours)	59
Figure 38. Lower Three Runs Peak Runoff Flow as a Function of Total Rainfall (Rainfall Duration=24 Hours)	60
Figure 39. Calculated Upper Three Runs Segment Volume as a Function of Flow (Segment Size: 500 Meters)	61
Figure 40. Calculated McQueen Branch Segment Volume as a Function of Flow (Segment Size: 500 Meters)	62
Figure 41. Calculated Tims Branch Segment Volume as a Function of Flow (Segment Size: 500 Meters)	63
Figure 42. Calculated Fourmile Branch Segment Volume as a Function of Flow (Segment Size: 150 Meters)	64
Figure 43. Calculated Pen Branch Segment Volume as a Function of Flow (Segment Size: 500 Meters)	65
Figure 44. Calculated Steel Creek Segment Volume as a Function of Flow (Segment Size: 500 Meters)	66
Figure 45. Calculated Lower Three Runs Segment Volume as a Function of Flow (Segment Size: 500 Meters)	67
Figure 46. Calculated Savannah River Segment Volume as a Function of Flow (Segment Size: 500 Meters)	68
Figure 47. STREAM II-V5 Graphical User Interface	69
Figure 48. Comparison of Model Predictions for the Peak Concentrations (STREAM II-V5 vs. STREAM II-V4)	70
Figure 49. Comparison of Model Predictions for the Peak Concentration Arrival Time (STREAM II-V5 vs. STREAM II-V4)	71
Figure 50. Effects of Rainfall on the Predicted Peak Concentration Arrival Time (Rainfall 1 inch in 3 Hours vs. No Rainfall)	72
Figure 51. Effects of Rainfall on the Predicted Peak Concentration (Rainfall 1 inch in 3 Hours vs. No rainfall)	73

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1. INTRODUCTION

STREAM II-V4 [1] is the aqueous transport module currently used by the Savannah River Site emergency response Weather Information Display (WIND) system [2]. The transport model of the Water Quality Analysis Simulation Program (WASP) [3] was used by STREAM II to perform contaminant transport calculations. WASP5 is a US Environmental Protection Agency (EPA) water quality analysis program that simulates contaminant transport and fate through surface water. STREAM II-V4 predicts peak concentration and peak concentration arrival time at downstream locations for releases from the SRS facilities to the Savannah River. The input flows for STREAM II-V4 are derived from the historical flow records measured by the United States Geological Survey (USGS). The stream flow for STREAM II-V4 is fixed and the flow only varies with the month in which the releases are taking place. Therefore, the effects of flow surge due to a severe storm are not accounted for by STREAM II-V4.

Recently, STREAM II-V4 has been revised to account for the effects of a storm event. The ideal method to address this concern is to use the real time stream flows as input to the STREAM II. This method requires significant infrastructure investment for setting up a stream gauge network and automatic stream data transmission, collection and storage, and long term network maintenance. Some of the stream monitors at the SRS streams were eliminated in the past several years due to budget constraints. Therefore, an alternate method is pursued. The steps used in this method are: 1) generate rainfall hyetographs as a function of total rainfall in inches (or millimeters) and rainfall duration in hours, 2) generate watershed runoff flow based on the rainfall hyetographs from step 1, 3) calculate the variation of stream segment volume (cross section) as a function of flow from step 2, 4) implement the results from steps 2 and 3 into the STREAM II model. The revised model (STREAM II-V5) will find the proper stream inlet flow based on the total rainfall and rainfall duration as input by the user. STREAM II-V5 adjusts the stream segment volumes (cross sections) based on the stream inlet flow. The rainfall based stream flow and the adjusted stream segment volumes are then used for contaminant transport calculations. This report documents the revisions incorporated into STREAM II-V5.

2. DESIGN RAINFALL HYETOGRAPH

A hyetograph is a graphical representation of the distribution of rainfall over time. This section describes the method to develop design rainfall hyetographs to represent the Savannah River Site (SRS). Table 1 shows the design six-hour extreme precipitation hyetograph obtained from Reference 4, and Table 2 presents the design 24-hour extreme precipitation hyetograph obtained from Reference 5. Both design extreme precipitation hyetographs were developed specifically for SRS based on historical data at or near SRS. Table 3 summarizes the list of rainfall events that were developed for the STREAM II-V5 model. Note that the range of total rainfall shown in Table 3 was chosen to cover possible extreme rainfall events as defined by Tables 1 and 2, and a sufficient number of points were selected to be used to develop functions that represent the watershed peak runoff flow as a function of total rainfall for various rainfall durations. A rainfall duration of 1 hour is

assumed for those rainfall events less than 1 hour, and a rainfall duration of 24 hours is assumed for those rainfall events greater than 24 hours. The watershed peak runoff flow is then interpolated for rainfall events with a duration other than those listed in Table 3. Tables 1 and 2 were used to develop the rainfall distributions for the rainfall events shown in Table 3.

2.1 DERIVATION OF 24-HOUR RAINFALL HYETOGRAPH

The rainfall distributions for 50-, 100- and 500-year return storm events in Table 2 were used to develop a composite rainfall distribution for the 24-hour rainfall events shown in Table 3. The steps are described next.

The normalized composite precipitation distribution for a 24-hour rainfall event is expressed as:

$$C_i^{24} = \frac{A_i^{24}}{B^{24}} \quad i = 1, 2, 3, \dots, 24 \text{ hour} \quad (1)$$

where the superscript of 24 represents a 24-hour rainfall event, and

$$A_i^{24} = \frac{1}{3} (r_i^{24,50} + r_i^{24,100} + r_i^{24,500}). \quad (2)$$

The superscripts 50, 100, 500 represent 50-, 100- and 500-year return period storms, respectively, and the terms $r_i^{24,50}$, $r_i^{24,100}$ and $r_i^{24,500}$ are rainfall increments obtained from Table 2. Also,

$$B^{24} = \frac{1}{24} \sum_{i=1}^{24} A_i^{24}, \quad (3)$$

The precipitation distributions for a total rainfall of X^{24} inches in 24 hours is

$$R_i^{X,24} = X^{24} C_i^{24}. \quad (4)$$

The value of X^{24} varies from 2.4 to 12.0 inches and the values of Eq. 4 are plotted in Figure 1.

2.2 DERIVATION OF 12-HOUR RAINFALL HYETOGRAPH

The normalized composite precipitation distribution for the 12-hour rainfall events is derived from the normalized composite precipitation distribution of 24-hour rainfall, Eq. 1.

$$C_i^{12} = \frac{1}{2} (C_{2i-1}^{24} + C_{2i}^{24}). \quad i = 1, 2, 3, \dots, 12 \text{ hour} \quad (5)$$

The precipitation distributions for a total rainfall of X^{12} inches in 12 hours is

$$R_i^{X,12} = X^{12} C_i^{12} . \quad (6)$$

The value of X^{12} varies from 1.2 to 7.2 inches and the values of Eq. 6 are plotted in Figure 2.

2.3 DERIVATION OF 6-HOUR RAINFALL DISTRIBUTION

The derivation of rainfall distributions for the 6-hour rainfall events is the same method described in Section 2.1, except the distribution data were obtained from Table 1.

The normalized composite precipitation distribution for a 6-hour rainfall event is expressed as:

$$C_i^6 = \frac{A_i^6}{B^6} \quad i = 1, 2, 3, \dots, 6 \text{ hour} \quad (7)$$

where the superscript of 6 represents a 6-hour rainfall event, and

$$A_i^6 = \frac{1}{3} (r_i^{6,50} + r_i^{6,100} + r_i^{6,500}) . \quad (8)$$

The superscripts 50, 100, 500 represent the 50-, 100- and 500-year return period storms, respectively, and the terms $r_i^{6,50}$, $r_i^{6,100}$ and $r_i^{6,500}$ are rainfall increments obtained from Table 1. Also,

$$B^6 = \frac{1}{6} \sum_{i=1}^6 A_i^6 . \quad (9)$$

The precipitation distributions for a total rainfall of X^6 inches in 6 hours is

$$R_i^{X,6} = X^6 C_i^6 . \quad (10)$$

The value of X^6 varies from 0.6 to 4.8 inches and the values of Eq. 10 are plotted in Figure 3.

2.4 DERIVATION OF 3-HOUR RAINFALL HYETOGRAPH

The normalized composite precipitation distribution for a 3-hour rainfall event is derived from the normalized composite precipitation distribution of 6-hour rainfall, Eq. 7.

$$C_i^3 = \frac{1}{2} (C_{2i-1}^6 + C_{2i}^6) \quad i = 1, 2, 3 \text{ hour} \quad (11)$$

The precipitation distributions for a total rainfall of X^3 inches in 3 hours is

$$R_i^{X,3} = X^3 C_i^3. \quad (12)$$

The value of X^3 varies from 0.3 to 3.0 inches and the values of Eq. 12 are plotted in Figure 4.

3. WATERSHED DELINEATION

The basin runoff depends on the watershed characteristics and the soil type, and land cover/land use. This section describes the watershed delineation. The Hydrologic Engineering Center (HEC) of the US Army Corps of Engineers has developed a geospatial hydrologic modeling extension (GeoHMS). The HEC-GeoHMS [6] model delineates the sub-basin watershed based on the Digital Elevation Model (DEM) [7] data and is a tool extension for the Environmental System Research Institute (ESRI) ArcView 3.x, Geographic Information System [8]. HEC-GeoHMS uses ArcView and Spatial Analyst to develop hydrologic modeling input for a hydrologic modeling system developed by HEC, HEC-HMS [9]. HEC-GeoHMS analyzes the digital terrain data, delineates streams and watersheds, and transforms the drainage paths and watershed boundaries into a hydrologic data structure that represents the watershed response to precipitation.

Figure 5 shows a set of DEM data at a 30-by-30-meter resolution which covers the Savannah River Site (SRS). HEC-GeoHMS delineates the streams and watershed boundaries based on the digital elevation data shown in Figure 5. Figure 6 shows the streams delineated by the HEC-GeoHMS model in green. The streams derived by HEC-GeoHMS are in good agreement with the streams (in blue) contained in the SRS Enterprise Geospatial Information Systems (EGIS) data base, as shown in Figure 6. Figure 7 presents the sub-basin watersheds delineated by HEC-GeoHMS. Figure 8 shows the Upper Three Runs watershed which includes the Tinker Creek, McQueen Branch, and Tims Branch sub-basins. Figure 9 to 12 show the watersheds of Fourmile Branch, Pen Branch, Steel Creek and Lower Three Runs, respectively.

4. WATERSHED RUNOFF

This section describes the watershed (basin) runoff as a function of rainfall. HEC-HMS is used to perform the basin runoff calculations. As discussed in Section 3, HEC-HMS is a hydrologic modeling system developed by the US Army Corps of Engineers to model basin runoff hydrology. HEC-HMS performs precipitation-runoff simulations. The HEC-HMS input data are precipitation and model parameters (i.e., losses, runoff transformation and base flow) characterizing the basin properties. The output of HEC-HMS is basin runoff discharge.

4.1 UPPER THREE RUNS

Upper Three Runs is the longest and northernmost system in SRS and has a drainage area of over 204.5 square miles (as determined from HEC-GeoHMS). Three main tributaries of Upper Three Runs are the Tinker Creek, McQueen Branch, and Tims Branch. The HEC-HMS input parameters for the Upper Three Runs, shown in Table 4, are obtained from Reference 4. The rainfall input for the HEC-HMS simulations are from Section 2. For example, Figure 13 is a HEC-HMS simulated hydrograph for the Upper Three Runs watershed in response to a total rainfall of 2.8 inches in a period of 3 hours. Figure 13 shows the runoff flow varies with time and the flow reaches a peak value of 3300 cubic feet per second (cfs) about 30 hours after the start of the rainfall. To model contaminant transport from this runoff transit accurately would require more input parameters from the user such as the rainfall starting time, and the contaminant release time relative to the rainfall starting time. To simplify the user input, it is assumed that the peak runoff flow is used in the transport calculation. This conservative assumption will result in a shorter arrival time for contaminant transport.

Figures 14 to 18 present the calculated Upper Three Runs peak flow as a function of total precipitation for rainfall duration 1, 3, 6, 12, and 24 hours, respectively. The equations shown in the figures are obtained by a least square curve fitting program [10] and are used in the STREAM II-V5.

Tinker Creek, McQueen Branch and Tims Branch are sub-basins of the Upper Three Runs. Therefore, the peak flows for the Tinker Creek, McQueen Branch and Tims Branch are derived from the Upper Three Runs peak flows with the assumption that the sub-basin flow is proportional to the sub-basin area.

4.2 BEAVER DAM CREEK

Beaver Dam Creek was an intermittent stream before SRS operation. The D-area Outfall D-01 is in Beaver Dam Creek, which discharges to the Savannah River. Most of the structures in D-area have been demolished. The only active facility is the power house which will be replaced by a new facility is constructed near F-Area. The Beaver Dam Creek drainage area is 0.73 square miles which is very small. Therefore, the Beaver Dam Creek basin flow runoff was not accounted for in this revision i.e. STREAM II-V5 continues to use monthly average flows.

4.3 FOURMILE BRANCH

The Fourmile Branch basin has about 25.3 square miles of drainage area including much of F-, H, and C-Areas. The stream flows to the southwest into the Savannah River swamp and then into the Savannah River. The HEC-HMS input parameters for the Fourmile Branch watershed, shown in Table 4, are obtained from Reference 4. Figures 19 to 23 present the calculated Fourmile Branch peak flow as a function of total precipitation for rainfall duration

1, 3, 6, 12, and 24 hours, respectively. The equations shown in the figures are obtained by the least square curve fitting and are used in the STREAM II-V5.

4.4 PEN BRANCH

The Pen Branch basin drainage area is about 21.6 square miles. Pen Branch follows a path roughly parallel to Fourmile Branch until it enters the Savannah River swamp. The only significant tributary to Pen Branch is Indian Grave Branch, which flows into Pen Branch about 5 miles upstream from the swamp. Pen Branch enters the swamp about 3 miles from the Savannah River, flows directly toward the river for about 1.5 miles, and then turns and runs parallel to the river for about 5 miles before discharging into Steel Creek at about 0.5 mile from its mouth. The HEC-HMS input parameters for the Pen Branch watershed, shown in Table 4, are obtained from Reference 5. Figures 24 to 28 present the calculated Pen Branch peak flow as a function of total precipitation for rainfall duration 1, 3, 6, 12, and 24 hours, respectively. The equations shown in the figures are obtained by the least square curve fitting and are used in the STREAM II-V5.

4.5 STEEL CREEK

The major tributary of the Steel Creek is Meyers Branch. The L-Lake is at the upper stream of the Steel Creek, as shown in Figure 11. The outlet flow from the L-Lake is controlled by the operation of L-Lake dam. Therefore, the L-Lake outlet flow is less affected by a rainfall event. However, the response of the Steel Creek flow to rainfall events mostly results from the runoff of the Meyers Branch. The HEC-HMS input parameters for the upper stream of the Steel Creek [5] are used for the Meyers Branch sub-basin watershed runoff simulations, as shown in Table 4. Figures 29 to 33 show the calculated peak flow for the Steel Creek watershed as a function of total precipitation for rainfall duration 1, 3, 6, 12, and 24 hours, respectively. The equations shown in the figures are obtained by the least square curve fitting and are used in the STREAM II-V5.

4.6 LOWER THREE RUNS

PAR Pond is at the upstream of Lower Three Runs, as shown in Figure 12. The flow from PAR Pond is controlled by the PAR Pond dam. The effect of rainfall on PAR Pond outlet flow is small compared with the effect of rainfall on the runoff flow from the sub-basin downstream from the PAR Pond dam. Therefore, the runoff flow from the sub-basin downstream of the PAR Pond dam is used in this revised STREAM II code. The input parameters for the Lower Three Runs (downstream of the PAR Pond) are presented in Table 4. The basin area and the Soil Conservation Service (SCS) lag time for the Lower Three Runs sub-basin were calculated by the HEC-GeoHMS. Note that the SCS was renamed the Natural Resources Conservation Services in 1994. The remainder of the input parameters for the Lower Three Runs sub-basin were estimated based on judgment. Figures 34 to 38 present the calculated peak flow for the PAR Pond sub-basin as a function of total precipitation for rainfall duration 1, 3, 6, 12, and 24 hours, respectively. The equations shown in the figures are obtained by the least square curve fitting and are used in the STREAM II-V5.

4.7 SAVANNAH RIVER

The Savannah River flow is strongly influenced by the operations of the upstream dams. The Savannah river watershed runoff is the result of both rainfall and the operations of the upstream dams. The area of the Savannah River basin is large covering 10577 square miles. Most of the rainfall events only cover parts of the basin. Therefore, the Savannah River basin flow runoff was not accounted for in this revision i.e. STREAM II-V5 continues to use monthly average flows. However, the runoff flows from the SRS sub-basins to the Savannah River were included.

5. STREAM SEGMENT VOLUME AS A FUNCTION OF RUNOFF FLOW

The Dynamic Estuary Model Hydrodynamics Program (DYNHYD5) [11] was used to calculate the stream cross-sections as a function of flows. DYNHYD is maintained by the Environmental Protection Agency (EPA) and is in the public domain. DYNHYD, a one-dimensional hydrodynamic model, solves a system of conservation of momentum and mass equations describing the propagation of long waves through a shallow water system. The data required by DYNHYD to perform a simulation for a particular inlet flow and downstream water elevation are channel geometry, slope, and roughness.

The channel geometry, slope, and roughness for the Upper Three Runs, McQueen Branch, Tims Branch and the Savannah River were estimated from the data provided by Timothy H. Lanier of the United States Geological Survey (USGS), Columbia, South Carolina Office [12]. Similarly, these three parameters for Fourmile Branch were estimated from Reference 13, for Pen Branch and Steel Creek were estimated from Reference 14, and for the Lower Three Runs were estimated from Reference 15.

The calculated segment volume as a function of flow for the Upper Three Runs, McQueen Branch, Tims Branch, Fourmile Branch, Pen Branch, Steel Creek, Lower Three Runs, and Savannah River are presented in Figures 39 through 46, respectively. Note that a segment length of 500 meters was used for all the streams except for the Fourmile Branch. A segment length of 150 meters was used for the Fourmile Branch in order to better fit the results from 1995 dye studies and to reduce computing time [16].

6. CODE MODIFICATIONS

The major changes of the code were:

1. provide user a means of inputting the total rainfall and rainfall duration,
2. employ the input to calculate the stream flow based on results in Section 4, and
3. use the stream flow to adjust the stream volume based on the results in Section 5.

The major subroutines modified or added are described below.

Subroutine TALK_VIRTUAL was modified to allow the user to input the total rainfall in inches (or millimeters) and the rainfall period (in hours).

Subroutine BSNFLW was added to calculate watershed peak runoff flow based on the rainfall event input.

Subroutine UPT was added to update the Upper Three Runs input flows.

Subroutine RMQB was added to update the McQueen Branch input flows.

Subroutine TIMSB was added to update the Tims Branch input flows.

Subroutine FMB was added to update the Fourmile Branch input flows.

Subroutine PNB was added to update the Pen Branch input flows.

Subroutine STEEL was added to update the Steel Creek input flows.

Subroutine LTR was added to update the Lower Three Runs input flows.

Subroutine VLMCRT was revised to calculate total flow in each stream segment.

Subroutine VLMF was modified to calculate the stream segment volume based on the flow in the stream segment.

Subroutine DFADJUST was added to adjust the stream segment cross-section area to account for the effect of flow variation.

Figure 47 presents the revised user graphical interface. The inputs for rainfall are shown inside the ellipse.

7. TEST RESULTS

Test cases were run to compare the model predicted results between STREAM II-V4 and STREAM II-V5, and examine the effects of the rainfall runoff on contaminant transport.

7.1 STREAM II-V4 vs. STREAM II-V5

Baseline cases were simulated by STREAM II-V4 with no rainfall. The cases simulated were one-pound hazardous chemical material released from each of the various SRS facilities. Those same cases were also simulated by STREAM II-V5. Figure 48 shows the comparison of peak concentrations predicted by STREAM II-V4 and STREAM II-V5, and

Figure 49 shows the comparison of peak concentration arrival time. The peak concentrations and the peak concentration arrival times predicted by STREAM II-V5 are in good agreement with that predicted by STREAM II-V4, except for a few cases, as noted below.

Note that in Figures 48 and 49, each dot represents a different sampling location downstream of a release. The green dots in Figure 48 represent the simulation results for a release into the Steel Creek, while the blue dots represent the simulation results for a release into the Lower Three Runs. Similarly, in Figure 49, the blue dots represent the simulation results for a release into the Lower Three Runs, while the red dots represent the simulation results for a release into the Pen Branch. In STREAM II-V5, the segment volumes were varied as a function of flow. Likewise, for STREAM II-V4, the segment volumes were also varied as a function of flow except for the Pen Branch, Steel Creek and Lower Three Runs. In STREAM II-V4, the segment volumes for these three streams were kept constant and were independent of the stream flow rate. This was assumed due to relatively small variations in flow rate because rainfall was not accounted for in the model (STREAM II-V4). Therefore, segment volumes for Pen Branch, Steel Creek and Lower Three Runs used in STREAM II-V4 are different from that used in STREAM II-V5. As a result, the predictions of the peak concentration and peak concentration arrival time are not in good agreement between these two versions, as shown in Figures 48 and 49, respectively. For example, the difference in the predicted peak concentration between these two versions is up to 35.7%, and the difference in the predicted peak concentration arrival time is up to 23.7% for the release to the Lower Three Runs. Table 5 shows the model comparison of peak concentration and peak concentration arrival time at various downstream locations between STREAM II-V4 and STREAM II-V5.

7.2 RAINFALL EFFECTS

The baseline cases (one pound of hazardous chemical material was released from all of the various SRS facilities) as described in Section 7.1 were re-run by STREAM II-V5 to include rainfall effects. Two weather conditions were simulated. One weather condition assumed a total rainfall of 1 inch in 3 hours while the other assumed a total rainfall of 10 inches in 24 hours.

Rainfall runoff increases stream flow. Increased stream flow in turn results in increases in flow velocity and the stream volume (cross-section). The concentration in the stream is influenced by the flow velocity and stream volume. Concentration decreases as stream volume increases. The time for contaminant traveling to a downstream location decreases as flow velocity increases. On the other hand, the extent of contaminant dispersion decreases (concentration increases) as traveling time decreases. This is because there is less time available for dispersion. These two competing factors determine the final peak concentration in the stream. This phenomenon is observed in Figures 50 and 51.

The runoff flow for the case of total rainfall of 10 inches in 24 hours is larger than the case of total rainfall of 1 inch in 3 hours. For example, the Upper Three Runs runoff flow is 10.5 m³/s for the case of total rainfall of 1 inch in 3 hours (Fig. 15), and the runoff flow increases to 200.8 m³/s for the case of total rainfall of 10 inches in 24 hours (Fig. 18). Figure 50 shows

the comparison of peak concentration arrival time at downstream locations. The X-axis represents the peak concentration arrival time for the case of no rainfall. The Y-axis represents the corresponding peak concentration arrival time with rainfall effects. The red circles represent the case of total rainfall of 1 inch in 3 hours and the black inverse triangles represent the case of total rainfall of 10 inches in 24 hours. The peak concentration arrival time for the case of total rainfall of 10 inches in 24 hours is less than the case of total rainfall of 1 inch in 3 hours, while the peak concentration arrival time for the case of total rainfall of 1 inch in 3 hours is less than the case of no rainfall, as shown in Figure 50.

Figure 51 presents the comparison of peak concentrations at sampling locations. The X-axis represents the peak concentration for the case of no rainfall. The Y-axis represents the corresponding peak concentration with rainfall effects. The red circles represent the case of total rainfall of 1 inch in 3 hours and the black inverse triangles represent the case of total rainfall of 10 inches in 24 hours. The data in the upper right corner of Figure 51 represent sampling locations near the release points. The peak concentration travel time to the locations near the release location is short. For a short traveling time (less than 600 minutes or roughly one-half day), the influence of the dispersion on the concentration is less important than the influence of the flow volume increase. Therefore, for the sampling location near the release location, the peak concentration decreases as runoff flow increases, as shown in the upper right corner of Figure 51.

The data in the lower left corner of Figure 51 represent peak concentrations at sampling locations far away from the release point. The travel time to those downstream sampling locations are large. However, the travel time for the rainfall cases are much shorter than that of the no rainfall case (Figure 50) due to rainfall runoff. The difference in the travel time can vary up to several thousand minutes (~ 2 to 3 days). The concentrations for the rainfall cases are higher since less time is available for dispersion. The flow volumes for the rainfall cases are larger than the no rainfall case, which results in lower concentration for the rainfall case. For those downstream sampling locations, the influence of the dispersion on the peak concentration could override the influence of the flow volume increase. Therefore, the peak concentration at those downstream sampling locations is actually higher for the cases of higher runoff flow (black triangles), as shown in the lower left corner of Figure 51. Table 6 shows the effects of rainfall on contaminant transport at downstream locations.

8. CONCLUSIONS

STREAM II-V4 is an aqueous transport module of the Savannah River Site emergency response Weather INformation Display (WIND) system. The input flows for the STREAM II-V4 are derived by averaging the historical daily mean flow records by month. The stream flow for the STREAM II-V4 is fixed and the flow only varies with the month in which the releases are taking place. Therefore, the effects of flow surge due to a severe storm are not accounted for by the STREAM II-V4. The STREAM II-V4 was revised to account for the effects of a storm event. The steps used in this revision are: 1) generate design rainfall hyetographs as a function of total rainfall in inches and rainfall duration in hours, 2) generate watershed runoff flow based on the rainfall hyetographs from step 1, 3) calculate the variation of stream cross section as a function of flow from step 2, and 4) implement the

results from steps 2 and 3 into the STREAM II model. The revised model, STREAM II-V5, has an option to account for the effects of rainfall on contaminant transport through the SRS streams and the Savannah River. The effect of rainfall has been shown to impact stream concentration in two competing ways.

This study shows that incorporating rainfall runoff in STREAM II-V5 increases the stream flow. Increased stream flow in turn results in increases in flow velocity and the stream volume (cross-section). The stream concentration is influenced by the flow velocity and stream volume. This concentration decreases as stream volume increases, and the time for contaminant travel to a downstream location decreases as the flow velocity increases. On the other hand, the extent of contaminant dispersion decreases (i.e. concentration increases) as the travel time decreases. This is due to less time being available for dispersion. These two competing factors determine the final peak concentration in the stream. Thus, for the locations near a release point, the effect of the stream volume increase overrides the effect of contaminant travel time. Consequently, the peak concentration for a case with rainfall is lower than a case with no rainfall. Conversely, for locations far away from a release point, the effect of contaminant travel time overrides the effect of the stream volume increase. As a result, the peak concentration for the rainfall case is higher than that of the non-rainfall case.

Note that the loss rate used in the HEC-HMS model determines the amount of infiltration which depends on the soil physical and chemical properties, and initial moisture content. The loss rates used in Section 4 were derived by calibrating the MEC-HMS model with limited measured precipitation and stream flow records, as described in References 4 and 5. The rainfall used in References 4 and 5 occurred in January, March and May. The soil moisture content for those months might be higher than the soil moisture content in the summer months. Therefore, the peak runoff flow derived in Section 4 could be higher than the actual runoff peak flow in the summer months. The recommendation for future improvement is to derive the loss rates using the measured historical records by month.

ACKNOWLEDGEMENT

The graphical user interface (GUI) of the STREAM II-V5 was revised by G. L. Snyder.

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Table 1. Six-Hour Storm Rainfall Distribution as a Function of Return Period

Return Period	Hour 1	Hour 2	Hour 3	Hour 4	Hour 5	Hour 6	Accumulation
	in	in	in	in	in	in	in
50-year	0.13	0.33	1.22	0.71	0.20	0.07	2.65
100-year	0.15	0.37	1.39	0.81	0.22	0.08	3.02
500-year	0.19	0.48	1.80	1.05	0.29	0.11	3.92

Table 2. 24-Hour Storm Rainfall Distributions as a Function of Return Period

	Return Period		
	50-year	100-year	500-year
	in	in	In
Hour 1	0.035	0.039	0.052
Hour 2	0.062	0.070	0.093
Hour 3	0.083	0.094	0.124
Hour 4	0.242	0.273	0.361
Hour 5	0.393	0.445	0.587
Hour 6	0.524	0.593	0.783
Hour 7	0.725	0.819	1.082
Hour 8	1.863	2.106	2.781
Hour 9	1.139	1.287	1.700
Hour 10	0.628	0.710	0.937
Hour 11	0.414	0.468	0.618
Hour 12	0.338	0.382	0.505
Hour 13	0.117	0.133	0.175
Hour 14	0.076	0.086	0.113
Hour 15	0.048	0.055	0.072
Hour 16	0.035	0.039	0.052
Hour 17	0.035	0.039	0.052
Hour 18	0.028	0.031	0.041
Hour 19	0.028	0.031	0.041
Hour 20	0.021	0.023	0.031
Hour 21	0.021	0.023	0.031
Hour 22	0.021	0.023	0.031
Hour 23	0.014	0.016	0.021
Hour 24	0.014	0.016	0.021
Accumulation	6.900	7.800	10.300

Table 3 Design Rainfall Events for STREAM II-V5

Rainfall Duration (hour)	Total Rainfall (inches)						
	1	0.5	1.0	2.0	3.0		
3	0.3	0.6	1.2	1.8	2.4	3.0	
6	0.6	1.2	1.8	2.4	3.0	3.6	4.8
12	1.2	2.4	3.6	4.8	6.0	7.2	
24	2.4	4.8	7.2	9.6	12.0		

Table 4. HEC-HMS Input Parameters

	Upper Three Runs	Fourmile Branch	Pen Branch	Steel Creek*	Lower Three Runs
Basin Area (mi ²)	204.5	25.3	21.6	19.2	123.5
Loss Rate:					
Method	initial/const.	initial/const.	initial/const.	initial/const	initial/const
Initial Loss (in)	0.0	0.0	0.0	0.0	0.0
Constant Rate (in/hr)	0.715	0.5	0.45	0.89	0.45
Imperviousness (%)	2	3	2	0.5	1.0
Transform:					
Method	SCS	SCS	SCS	SCS	SCS
SCS lag (minute)	2000	750	600	250	796
Base Flow:					
Method	recession	recession	recession	recession	recession
Initial Flow (ft ³ /s)	190	27	18	2	2
Recession Constant	0.965	1.0	0.80	0.9	0.9
Thresholds flow (ft ³ /s)	200	39	60	3	3

*Meyers Branch

Table 5 Model Comparison between STREAM II-V4 and STREAM II-V5

Release Location	Monitor Locations	Concentration			Travel time		
		V4	V5	Diff.	V4	V5	Diff.
		(lb/gal)	(lb/gal)	(%)	(min)	(min)	(%)
Release at Road A (Fourmile Creek)	SAVANNAH RIVER:	8.10E-10	7.61E-10	-6.07	1152.00	1152.00	0.00
	US HIGHWAY 301:	5.90E-10	5.64E-10	-4.49	2390.40	2419.20	1.20
	STATE HIGHWAY 119:	4.31E-10	4.16E-10	-3.51	4521.60	4550.40	0.64
	BEAUFORT-JASPER:	4.05E-10	3.94E-10	-2.80	5356.80	5385.60	0.54
	SAV. WATER PLANT:	3.97E-10	3.82E-10	-3.81	5760.00	5731.20	-0.50
Release from A-Area to Tims Branch	ROAD A:	1.79E-08	1.80E-08	0.42	1152.00	1137.60	-1.25
	SAVANNAH RIVER:	5.03E-10	5.07E-10	0.75	1526.40	1526.40	0.00
	US HIGHWAY 301:	4.05E-10	4.05E-10	0.00	2966.40	2966.40	0.00
	STATE HIGHWAY 119:	3.32E-10	3.32E-10	0.00	4982.40	4982.40	0.00
	BEAUFORT-JASPER:	3.19E-10	3.18E-10	-0.24	5788.80	5760.00	-0.50
	SAV. WATER PLANT:	3.13E-10	3.12E-10	-0.36	6134.40	6105.60	-0.47
Release at Road A (Steel Creek)	SAVANNAH RIVER:	2.30E-10	1.78E-10	-22.41	956.40	1085.40	13.49
	US HIGHWAY 301:	2.07E-10	1.61E-10	-22.30	1804.20	1905.60	5.62
	STATE HIGHWAY 119:	1.90E-10	1.48E-10	-21.76	3831.60	3960.60	3.37
	BEAUFORT-JASPER:	1.88E-10	1.48E-10	-21.68	4642.80	4744.20	2.18
	SAV. WATER PLANT:	1.88E-10	1.48E-10	-21.53	4983.60	5112.60	2.59
Release to D-Area Outfall	SAVANNAH RIVER:	2.08E-09	2.02E-09	-2.91	216.00	216.00	0.00
	US HIGHWAY 301:	8.74E-10	8.59E-10	-1.73	1540.80	1540.80	0.00
	STATE HIGHWAY 119:	5.49E-10	5.41E-10	-1.38	3672.00	3672.00	0.00
	BEAUFORT-JASPER:	5.00E-10	4.92E-10	-1.52	4507.20	4507.20	0.00
	SAV. WATER PLANT:	4.81E-10	4.77E-10	-0.79	4881.60	4881.60	0.00
Release at F-Area	ROAD A:	1.68E-07	1.62E-07	-3.39	1267.20	1296.00	2.27
	SAVANNAH RIVER:	5.60E-10	5.34E-10	-4.73	2419.20	2476.80	2.38
	US HIGHWAY 301:	4.54E-10	4.35E-10	-4.17	3686.40	3744.00	1.56
	STATE HIGHWAY 119:	3.59E-10	3.46E-10	-3.59	5817.60	5875.20	0.99
	BEAUFORT-JASPER:	3.44E-10	3.32E-10	-3.41	6652.80	6710.40	0.87
	SAV. WATER PLANT:	3.38E-10	3.27E-10	-3.36	7027.20	7084.80	0.82
Release at Road C (flowing streams)	ROAD A:	2.25E-08	2.25E-08	0.17	662.40	662.40	0.00
	SAVANNAH RIVER:	5.90E-10	5.90E-10	0.00	1051.20	1051.20	0.00
	US HIGHWAY 301:	4.54E-10	4.54E-10	0.00	2476.80	2476.80	0.00
	STATE HIGHWAY 119:	3.62E-10	3.61E-10	-0.21	4521.60	4492.80	-0.64
	BEAUFORT-JASPER:	3.45E-10	3.44E-10	-0.33	5299.20	5299.20	0.00
	SAV. WATER PLANT:	3.38E-10	3.37E-10	-0.45	5644.80	5644.80	0.00
Release at Highway 278 to Upper Three Runs	ROAD A:	1.57E-08	1.57E-08	0.24	1512.00	1512.00	0.00
	SAVANNAH RIVER:	4.58E-10	4.58E-10	0.00	1915.20	1900.80	-0.75
	US HIGHWAY 301:	3.74E-10	3.74E-10	0.10	3340.80	3340.80	0.00
	STATE HIGHWAY 119:	3.12E-10	3.12E-10	-0.12	5356.80	5356.80	0.00
	BEAUFORT-JASPER:	3.01E-10	3.00E-10	-0.25	6163.20	6163.20	0.00
	SAV. WATER PLANT:	2.96E-10	2.96E-10	-0.26	6508.80	6508.80	0.00
Release at H-Area	ROAD A:	1.41E-07	1.37E-07	-3.22	1612.80	1670.40	3.57
	SAVANNAH RIVER:	4.81E-10	4.54E-10	-5.51	2736.00	2793.60	2.11
	US HIGHWAY 301:	4.13E-10	3.94E-10	-4.59	3945.60	4003.20	1.46
	STATE HIGHWAY 119:	3.36E-10	3.24E-10	-3.71	6048.00	6105.60	0.95
	BEAUFORT-JASPER:	3.24E-10	3.12E-10	-3.62	6883.20	6940.80	0.84
	SAV. WATER PLANT:	3.18E-10	3.07E-10	-3.45	7228.80	7286.40	0.80

Release at K-Area Outfall	ROAD A:	3.16E-07	3.07E-07	-2.76	129.60	129.60	0.00
	SAVANNAH RIVER:	7.49E-11	7.23E-11	-3.53	6769.20	7129.20	5.32
	US HIGHWAY 301:	6.81E-11	6.59E-11	-3.33	7777.20	8065.20	3.70
	STATE HIGHWAY 119:	6.28E-11	6.09E-11	-3.01	9649.20	10081.20	4.48
	BEAUFORT-JASPER:	6.28E-11	6.06E-11	-3.61	10513.20	10801.20	2.74
	SAV. WATER PLANT:	6.28E-11	6.06E-11	-3.61	10945.20	11232.60	2.63
Release to the Mouth of Fourmile Branch	US HIGHWAY 301:	9.46E-10	9.35E-10	-1.20	1209.60	1209.60	0.00
	STATE HIGHWAY 119:	5.49E-10	5.45E-10	-0.69	3225.60	3225.60	0.00
	BEAUFORT-JASPER:	4.96E-10	4.92E-10	-0.76	4032.00	4032.00	0.00
	SAV. WATER PLANT:	4.77E-10	4.73E-10	-0.79	4377.60	4377.60	0.00
Release to the Mouth of Beaver Dam Creek	US HIGHWAY 301:	9.80E-10	9.77E-10	-0.39	1353.60	1353.60	0.00
	STATE HIGHWAY 119:	5.49E-10	5.45E-10	-0.69	3484.80	3470.40	-0.41
	BEAUFORT-JASPER:	4.96E-10	4.96E-10	0.00	4305.60	4305.60	0.00
	SAV. WATER PLANT:	4.81E-10	4.77E-10	-0.79	4680.00	4665.60	-0.31
Release to the Mouth of Lower Three Runs	US HIGHWAY 301:	1.90E-09	2.12E-09	11.55	439.80	421.80	-4.09
	STATE HIGHWAY 119:	9.80E-10	1.00E-09	2.31	2467.80	2449.20	-0.75
	BEAUFORT-JASPER:	8.86E-10	8.97E-10	1.28	3269.40	3260.40	-0.28
	SAV. WATER PLANT:	8.52E-10	8.59E-10	0.89	3619.80	3601.20	-0.51
Release from H-Area to McQueen Branch	ROAD A:	1.46E-08	1.46E-08	0.26	1629.00	1647.60	1.14
	SAVANNAH RIVER:	4.39E-10	4.39E-10	0.00	2034.60	2016.00	-0.91
	US HIGHWAY 301:	3.82E-10	3.82E-10	0.00	3463.20	3435.00	-0.81
	STATE HIGHWAY 119:	3.43E-10	3.42E-10	-0.22	5472.00	5472.00	0.00
	BEAUFORT-JASPER:	3.38E-10	3.37E-10	-0.45	6283.20	6283.20	0.00
	SAV. WATER PLANT:	3.36E-10	3.35E-10	-0.34	6624.00	6624.00	0.00
Release to the Mouth of Upper Three Runs	US HIGHWAY 301:	8.33E-10	8.29E-10	-0.45	1468.80	1468.80	0.00
	STATE HIGHWAY 119:	5.22E-10	5.15E-10	-1.45	3484.80	3456.00	-0.83
	BEAUFORT-JASPER:	4.73E-10	4.69E-10	-0.80	4262.40	4262.40	0.00
	SAV. WATER PLANT:	4.58E-10	4.50E-10	-1.65	4636.80	4608.00	-0.62
Release to the Mouth of Steel Creek-Pen Branch	US HIGHWAY 301:	1.31E-09	1.27E-09	-2.89	956.40	956.40	0.00
	STATE HIGHWAY 119:	8.14E-10	7.91E-10	-2.79	3085.20	3075.60	-0.31
	BEAUFORT-JASPER:	7.53E-10	7.31E-10	-3.02	3924.00	3924.00	0.00
	SAV. WATER PLANT:	7.31E-10	7.12E-10	-2.59	4283.40	4283.40	0.00
Release at PAR Pond Dam	SAVANNAH RIVER:	2.65E-10	3.60E-10	35.72	3850.20	2937.60	-23.70
	US HIGHWAY 301:	2.40E-10	3.24E-10	35.23	4227.60	3315.60	-21.57
	STATE HIGHWAY 119:	2.19E-10	2.92E-10	33.16	6255.60	5343.00	-14.59
	BEAUFORT-JASPER:	2.18E-10	2.89E-10	32.63	7075.80	6154.20	-13.02
	SAV. WATER PLANT:	2.17E-10	2.88E-10	32.40	7407.60	6495.00	-12.32
Release to S. River at 6 miles downstream from the Lock & Dam	US HIGHWAY 301:	6.85E-10	6.78E-10	-1.10	2390.40	2361.60	-1.20
	STATE HIGHWAY 119:	4.73E-10	4.73E-10	0.00	4406.40	4406.40	0.00
	BEAUFORT-JASPER:	4.39E-10	4.35E-10	-0.86	5212.80	5212.80	0.00
	SAV. WATER PLANT:	4.24E-10	4.24E-10	0.00	5558.40	5558.40	0.00
Release at Road A (Upper Three Runs)	SAVANNAH RIVER:	9.65E-10	9.65E-10	0.00	388.80	388.80	0.00
	US HIGHWAY 301:	6.13E-10	6.13E-10	0.00	1843.20	1843.20	0.00
	STATE HIGHWAY 119:	4.43E-10	4.39E-10	-0.86	3859.20	3830.40	-0.75
	BEAUFORT-JASPER:	4.13E-10	4.09E-10	-0.92	4636.80	4636.80	0.00
	SAV. WATER PLANT:	4.01E-10	3.97E-10	-0.94	5011.20	4982.40	-0.57

Table 6. Effects of Rainfall on Contaminant Transport

Release Location	Monitor Location	Concentration					travel time				
		No Rain	1" in 3 hr		10" in 24 hr		No Rain	1" in 3 hr		10" in 24 hr	
		(lb/gal)	(lb/gal)	(% Diff)	(lb/gal)	(% Diff)	(min)	(min)	(% Diff)	(min)	(% Diff)
Release at Road A (Fourmile Creek)	SAVANNAH RIVER:	7.61E-10	2.22E-09	191.54	3.29E-09	332.84	1152	490	-57.50	173	-85.00
	US HIGHWAY 301:	5.64E-10	9.01E-10	59.73	6.70E-10	18.79	2419	1728	-28.57	1181	-51.19
	STATE HIGHWAY 119:	4.16E-10	5.41E-10	30.00	3.90E-10	-6.36	4550	3830	-15.82	2938	-35.44
	BEAUFORT-JASPER:	3.94E-10	4.92E-10	25.00	3.49E-10	-11.25	5386	4666	-13.37	3658	-32.09
	SAV. WATER PLANT:	3.82E-10	4.73E-10	23.76	3.36E-10	-12.18	5731	5011	-12.56	3946	-31.16
Release from A-Area to Tims Branch	ROAD A:	1.80E-08	1.76E-08	-1.90	3.13E-09	-82.61	1138	821	-27.85	246	-78.38
	SAVANNAH RIVER:	5.07E-10	6.40E-10	26.12	1.17E-09	131.35	1526	1166	-23.58	360	-76.42
	US HIGHWAY 301:	4.05E-10	4.81E-10	18.69	5.07E-10	25.23	2966	2578	-13.11	1469	-50.47
	STATE HIGHWAY 119:	3.32E-10	3.75E-10	13.01	3.36E-10	1.48	4982	4579	-8.09	3082	-38.14
	BEAUFORT-JASPER:	3.18E-10	3.56E-10	12.02	3.06E-10	-3.69	5760	5386	-6.50	3716	-35.48
SAV. WATER PLANT:	3.12E-10	3.48E-10	11.52	2.95E-10	-5.45	6106	5731	-6.13	4004	-34.42	
Release at Road A (Steel Creek)	SAVANNAH RIVER:	1.78E-10	2.71E-10	51.81	4.24E-10	137.80	1085	799	-26.37	235	-78.39
	US HIGHWAY 301:	1.61E-10	2.44E-10	51.53	3.72E-10	131.06	1906	1620	-14.99	838	-56.05
	STATE HIGHWAY 119:	1.48E-10	2.22E-10	49.75	3.09E-10	108.17	3961	3629	-8.38	2321	-41.40
	BEAUFORT-JASPER:	1.48E-10	2.21E-10	49.49	2.95E-10	99.99	4744	4440	-6.41	2924	-38.36
	SAV. WATER PLANT:	1.48E-10	2.20E-10	48.97	2.90E-10	96.15	5113	4772	-6.67	3184	-37.73
Release to D-Area Outfall	SAVANNAH RIVER:	2.02E-09	2.02E-09	0.00	2.02E-09	0.00	216	216	0.00	216	0.00
	US HIGHWAY 301:	8.59E-10	8.59E-10	0.00	8.59E-10	0.00	1541	1541	0.00	1541	0.00
	STATE HIGHWAY 119:	5.41E-10	5.41E-10	0.00	5.41E-10	0.00	3672	3672	0.00	3672	0.00
	BEAUFORT-JASPER:	4.92E-10	4.92E-10	0.00	4.92E-10	0.00	4507	4507	0.00	4507	0.00
	SAV. WATER PLANT:	4.77E-10	4.77E-10	0.00	4.77E-10	0.00	4882	4882	0.00	4882	0.00
Release at F-Area	ROAD A:	1.62E-07	7.12E-08	-56.08	1.01E-08	-93.74	1296	432	-66.67	144	-88.89
	SAVANNAH RIVER:	5.34E-10	1.73E-09	223.41	2.45E-09	359.57	2477	922	-62.79	317	-87.21
	US HIGHWAY 301:	4.35E-10	8.48E-10	94.78	6.62E-10	52.17	3744	2160	-42.31	1325	-64.62
	STATE HIGHWAY 119:	3.46E-10	5.26E-10	52.08	3.86E-10	11.60	5875	4262	-27.45	3082	-47.55
	BEAUFORT-JASPER:	3.32E-10	4.81E-10	44.65	3.48E-10	4.67	6710	5098	-24.03	3773	-43.78
SAV. WATER PLANT:	3.27E-10	4.66E-10	42.53	3.35E-10	2.43	7085	5443	-23.17	4090	-42.28	

Table 6 (Cont.)

Release Location	Monitor Location	Concentration					travel time				
		No Rain	1" in 3 hr		10" in 24 hr		No Rain	1" in 3 hr		10" in 24 hr	
		(lb/gal)	(lb/gal)	(% Diff)	(lb/gal)	(% Diff)	(min)	(min)	(% Diff)	(min)	(% Diff)
Release at Road C (flowing streams)	ROAD A:	2.25E-08	1.89E-08	-16.14	3.36E-09	-85.09	662	576	-13.04	173	-73.82
	SAVANNAH RIVER:	5.90E-10	6.66E-10	12.82	1.23E-09	107.69	1051	922	-12.33	289	-72.49
	US HIGHWAY 301:	4.54E-10	4.96E-10	9.17	5.11E-10	12.50	2477	2362	-4.65	1397	-43.58
	STATE HIGHWAY 119:	3.61E-10	3.82E-10	5.87	3.37E-10	-6.71	4493	4349	-3.21	2995	-33.33
	BEAUFORT-JASPER:	3.44E-10	3.63E-10	5.39	3.07E-10	-10.78	5299	5155	-2.72	3658	-30.97
	SAV. WATER PLANT:	3.37E-10	3.55E-10	5.28	2.96E-10	-12.25	5645	5501	-2.55	3946	-30.09
Release at Highway 278 to Upper Three Runs	ROAD A:	1.57E-08	1.34E-08	-14.66	2.39E-09	-84.83	1512	1296	-14.29	389	-74.29
	SAVANNAH RIVER:	4.58E-10	5.22E-10	14.05	9.73E-10	112.40	1901	1627	-14.39	505	-73.45
	US HIGHWAY 301:	3.74E-10	4.16E-10	11.22	4.84E-10	29.42	3341	3082	-7.76	1614	-51.69
	STATE HIGHWAY 119:	3.12E-10	3.38E-10	8.50	3.29E-10	5.59	5357	5069	-5.38	3226	-39.77
	BEAUFORT-JASPER:	3.00E-10	3.24E-10	7.95	3.01E-10	0.13	6163	5875	-4.67	3859	-37.38
	SAV. WATER PLANT:	2.96E-10	3.18E-10	7.68	2.90E-10	-1.79	6509	6221	-4.42	4148	-36.26
Release at H-Area	ROAD A:	1.37E-07	5.75E-08	-57.90	7.61E-09	-94.43	1670	576	-65.52	173	-89.66
	SAVANNAH RIVER:	4.54E-10	1.44E-09	216.67	2.29E-09	405.00	2794	1066	-61.86	346	-87.63
	US HIGHWAY 301:	3.94E-10	8.06E-10	104.81	6.47E-10	64.42	4003	2275	-43.17	1354	-66.19
	STATE HIGHWAY 119:	3.24E-10	5.15E-10	58.88	3.82E-10	17.99	6106	4320	-29.25	3082	-49.53
	BEAUFORT-JASPER:	3.12E-10	4.69E-10	50.30	3.44E-10	10.31	6941	5126	-26.14	3773	-45.64
	SAV. WATER PLANT:	3.07E-10	4.54E-10	47.78	3.31E-10	7.64	7286	5501	-24.51	4090	-43.87
Release at K-Area Outfall	ROAD A:	3.07E-07	1.28E-07	-58.20	1.69E-08	-94.49	130	73	-43.52	29	-77.78
	SAVANNAH RIVER:	7.23E-11	1.38E-10	90.57	1.96E-10	171.72	7129	3745	-47.47	1094	-84.65
	US HIGHWAY 301:	6.59E-11	1.25E-10	89.09	1.78E-10	170.12	8065	4537	-43.74	1728	-78.57
	STATE HIGHWAY 119:	6.09E-11	1.14E-10	86.96	1.56E-10	155.27	10081	6553	-35.00	3168	-68.58
	BEAUFORT-JASPER:	6.06E-11	1.13E-10	86.87	1.49E-10	146.25	10801	7345	-32.00	3744	-65.34
	SAV. WATER PLANT:	6.06E-11	1.13E-10	86.25	1.48E-10	144.37	11233	7777	-30.76	4032	-64.10
Release to the Mouth of Fourmile Branch	US HIGHWAY 301:	9.35E-10	9.42E-10	0.81	6.47E-10	-30.77	1210	1181	-2.38	979	-19.05
	STATE HIGHWAY 119:	5.45E-10	5.45E-10	0.00	3.79E-10	-30.56	3226	3197	-0.89	2707	-16.07
	BEAUFORT-JASPER:	4.92E-10	4.92E-10	0.00	3.39E-10	-31.08	4032	3974	-1.43	3398	-15.71
	SAV. WATER PLANT:	4.73E-10	4.69E-10	-0.80	3.26E-10	-31.04	4378	4320	-1.32	3686	-15.79
Release to the Mouth of Beaver Dam Creek	US HIGHWAY 301:	9.77E-10	9.77E-10	0.00	9.77E-10	0.00	1354	1354	0.00	1354	0.00
	STATE HIGHWAY 119:	5.45E-10	5.45E-10	0.00	5.45E-10	0.00	3470	3470	0.00	3470	0.00
	BEAUFORT-JASPER:	4.96E-10	4.96E-10	0.00	4.96E-10	0.00	4306	4306	0.00	4306	0.00
	SAV. WATER PLANT:	4.77E-10	4.77E-10	0.00	4.77E-10	0.00	4666	4666	0.00	4666	0.00

Table 6 (Cont.)

		Concentration					travel time				
		No Rain	1" in 3 hr		10" in 24 hr		No Rain	1" in 3 hr		10" in 24 hr	
		(lb/gal)	(lb/gal)	(% Diff)	(lb/gal)	(% Diff)	(min)	(min)	(% Diff)	(min)	(% Diff)
Release to the Mouth of Lower Three Runs	US HIGHWAY 301:	2.12E-09	2.76E-09	30.18	1.05E-09	-50.54	422	376	-10.95	233	-44.81
	STATE HIGHWAY 119:	1.00E-09	1.12E-09	11.33	4.09E-10	-59.24	2449	2283	-6.79	1444	-41.06
	BEAUFORT-JASPER:	8.97E-10	9.84E-10	9.70	3.54E-10	-60.51	3260	3039	-6.79	1933	-40.71
	SAV. WATER PLANT:	8.59E-10	9.39E-10	9.25	3.36E-10	-60.88	3601	3371	-6.40	2148	-40.35
Release from H-Area to McQueen Branch	ROAD A:	1.46E-08	1.51E-08	3.37	2.37E-09	-83.78	1648	1232	-25.20	376	-77.20
	SAVANNAH RIVER:	4.39E-10	5.90E-10	34.48	9.69E-10	120.69	2016	1574	-21.93	475	-76.43
	US HIGHWAY 301:	3.82E-10	5.00E-10	30.69	4.88E-10	27.72	3435	3002	-12.59	1600	-53.43
	STATE HIGHWAY 119:	3.42E-10	4.35E-10	27.35	3.30E-10	-3.32	5472	5011	-8.42	3198	-41.56
	BEAUFORT-JASPER:	3.37E-10	4.24E-10	25.84	3.02E-10	-10.45	6283	5795	-7.77	3860	-38.56
	SAV. WATER PLANT:	3.35E-10	4.20E-10	25.43	2.91E-10	-12.99	6624	6136	-7.37	4120	-37.81
Release to the Mouth of Upper Three Runs	US HIGHWAY 301:	8.29E-10	8.33E-10	0.46	5.68E-10	-31.51	1469	1454	-0.98	1124	-23.45
	STATE HIGHWAY 119:	5.15E-10	5.15E-10	0.00	3.54E-10	-31.32	3456	3456	0.00	2737	-20.82
	BEAUFORT-JASPER:	4.69E-10	4.69E-10	0.00	3.19E-10	-32.10	4262	4234	-0.68	3370	-20.95
	SAV. WATER PLANT:	4.50E-10	4.50E-10	0.00	3.07E-10	-31.93	4608	4579	-0.63	3658	-20.61
Release to the Mouth of Steel Creek-Pen Branch	US HIGHWAY 301:	1.27E-09	1.15E-09	-9.55	6.66E-10	-47.46	956	883	-7.72	635	-33.56
	STATE HIGHWAY 119:	7.91E-10	7.46E-10	-5.74	4.35E-10	-44.98	3076	2845	-7.49	2107	-31.51
	BEAUFORT-JASPER:	7.31E-10	6.96E-10	-4.66	3.97E-10	-45.60	3924	3601	-8.23	2682	-31.65
	SAV. WATER PLANT:	7.12E-10	6.78E-10	-4.79	3.86E-10	-45.74	4283	3933	-8.18	2941	-31.33
Release at PAR Pond Dam	SAVANNAH RIVER:	3.60E-10	1.67E-09	364.21	8.02E-10	123.15	2938	910	-69.02	304	-89.64
	US HIGHWAY 301:	3.24E-10	1.35E-09	317.04	1.03E-09	218.92	3316	1270	-61.71	520	-84.33
	STATE HIGHWAY 119:	2.92E-10	8.86E-10	203.51	4.09E-10	40.08	5343	3187	-40.36	1730	-67.62
	BEAUFORT-JASPER:	2.89E-10	8.18E-10	182.73	3.54E-10	22.52	6154	3933	-36.09	2220	-63.93
	SAV. WATER PLANT:	2.88E-10	7.91E-10	175.00	3.36E-10	16.84	6495	4265	-34.34	2435	-62.51
Release to S. River at 6 miles downstream from the Lock & Dam	US HIGHWAY 301:	6.78E-10	6.78E-10	0.00	6.78E-10	0.00	2362	2362	0.00	2362	0.00
	STATE HIGHWAY 119:	4.73E-10	4.73E-10	0.00	4.73E-10	0.00	4406	4406	0.00	4406	0.00
	BEAUFORT-JASPER:	4.35E-10	4.35E-10	0.00	4.35E-10	0.00	5213	5213	0.00	5213	0.00
	SAV. WATER PLANT:	4.24E-10	4.24E-10	0.00	4.24E-10	0.00	5558	5558	0.00	5558	0.00
Release at Road A (Upper Three Runs)	SAVANNAH RIVER:	9.65E-10	1.09E-09	12.94	1.93E-09	100.39	389	346	-11.11	116	-70.22
	US HIGHWAY 301:	6.13E-10	6.47E-10	5.56	5.45E-10	-11.11	1843	1786	-3.13	1224	-33.59
	STATE HIGHWAY 119:	4.39E-10	4.54E-10	3.45	3.47E-10	-20.86	3830	3802	-0.75	2838	-25.91
	BEAUFORT-JASPER:	4.09E-10	4.20E-10	2.78	3.14E-10	-23.15	4637	4579	-1.24	3485	-24.83
	SAV. WATER PLANT:	3.97E-10	4.09E-10	2.86	3.02E-10	-24.09	4982	4925	-1.16	3745	-24.83

Figure 1

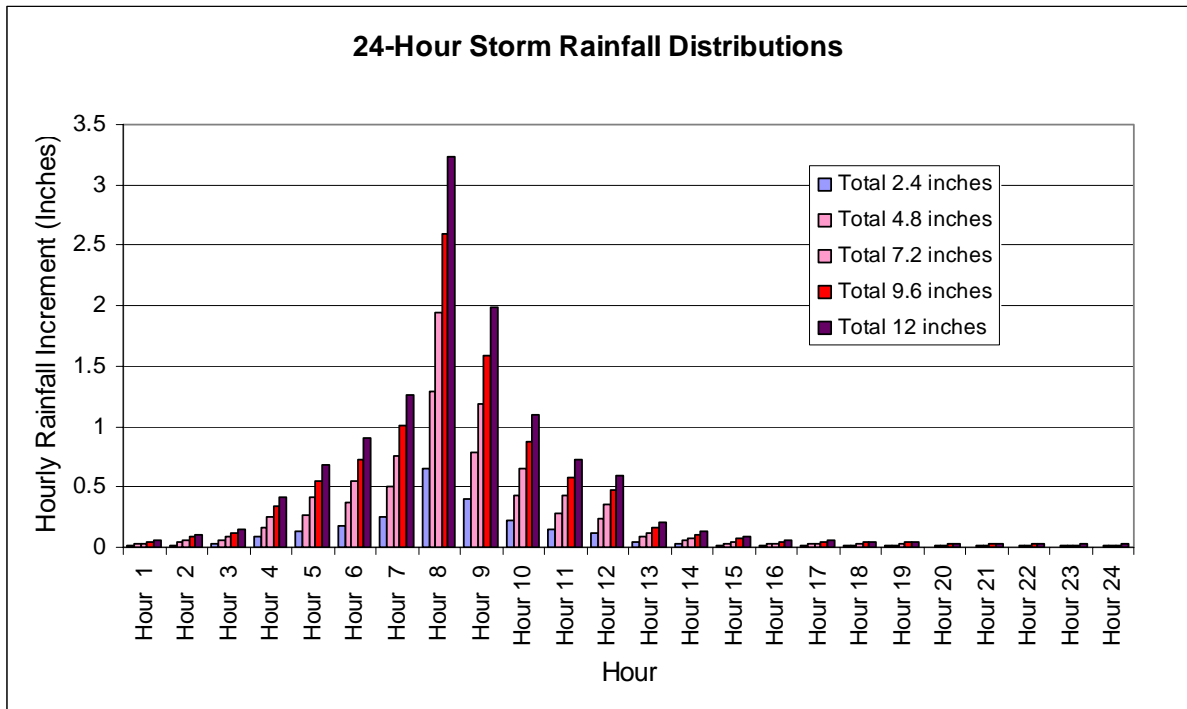


Figure 2

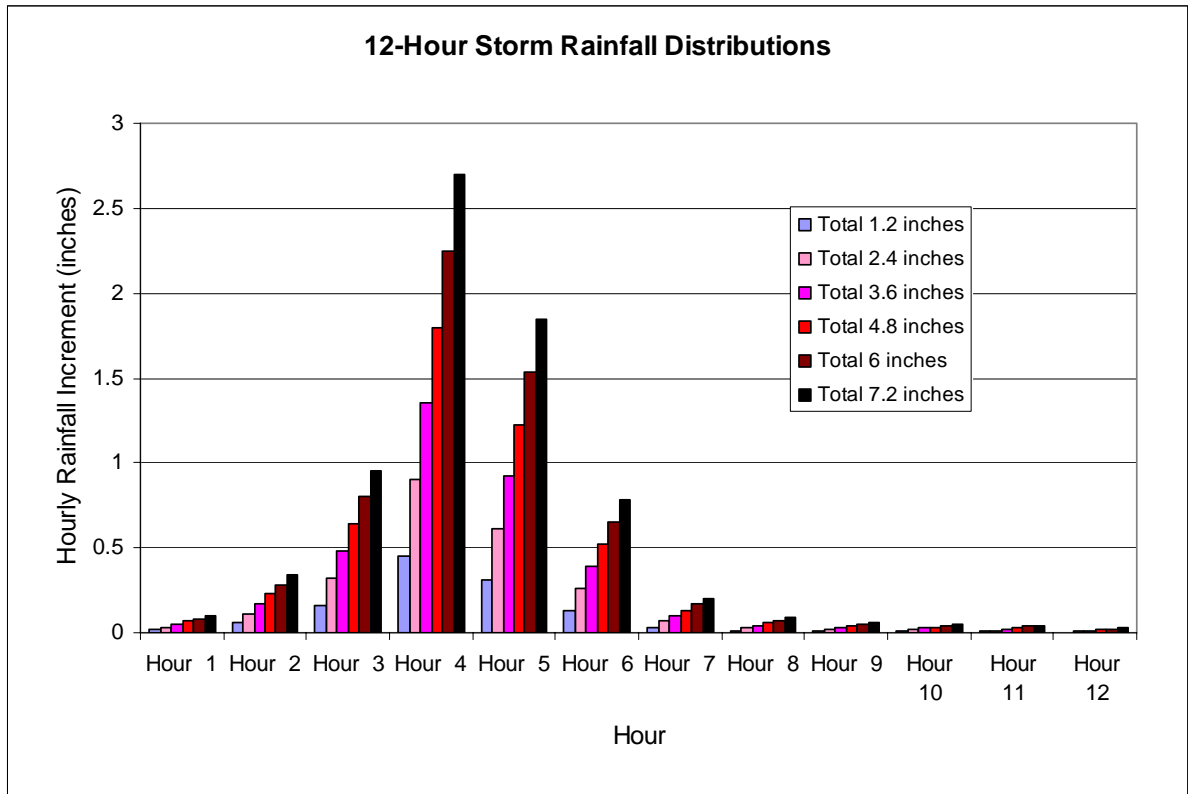


Figure 3

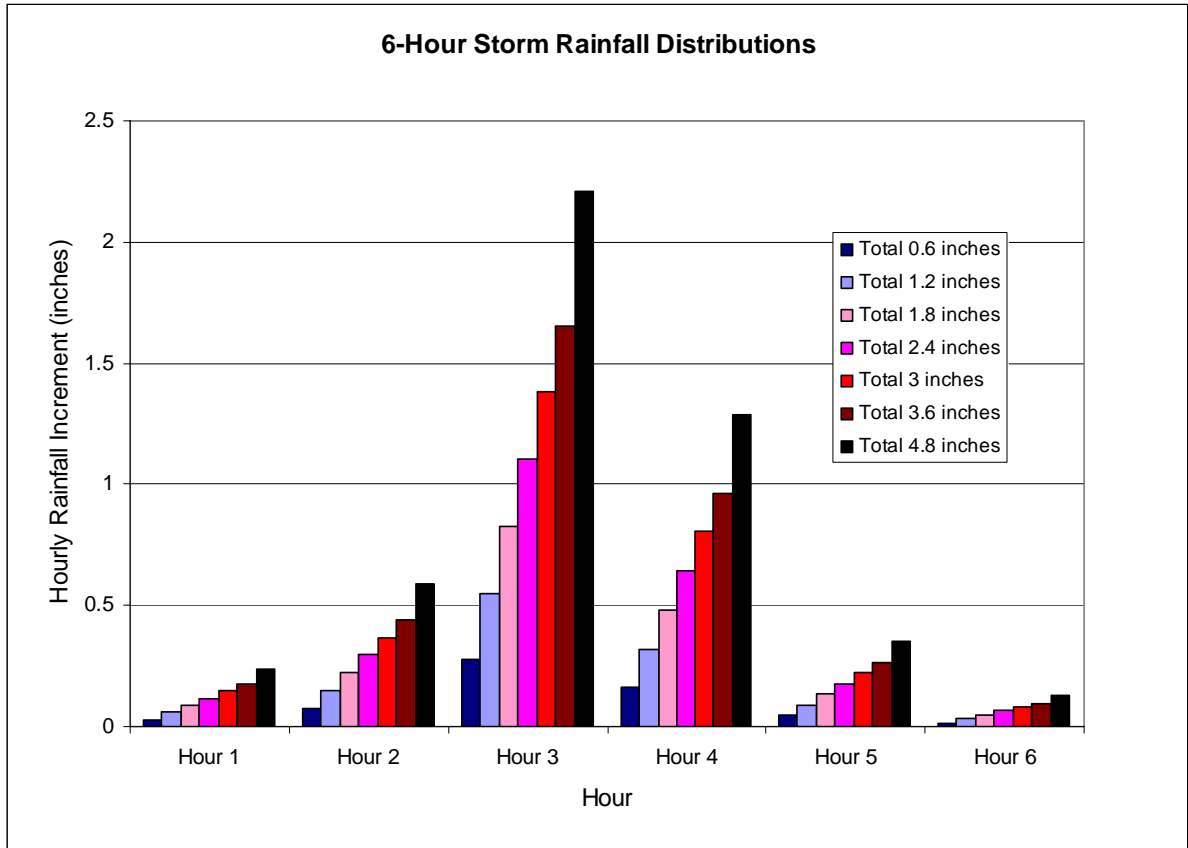


Figure 4

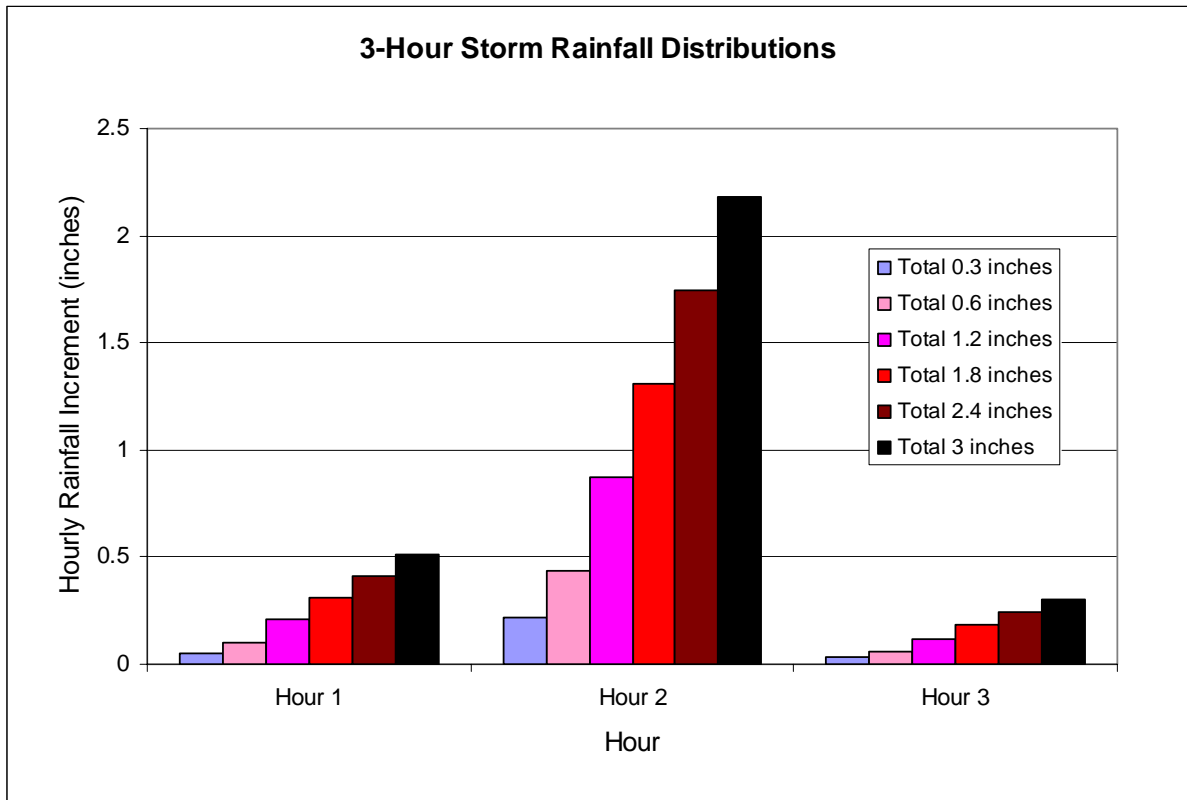


Figure 5

Digital Elevation Model for Savannah River Site

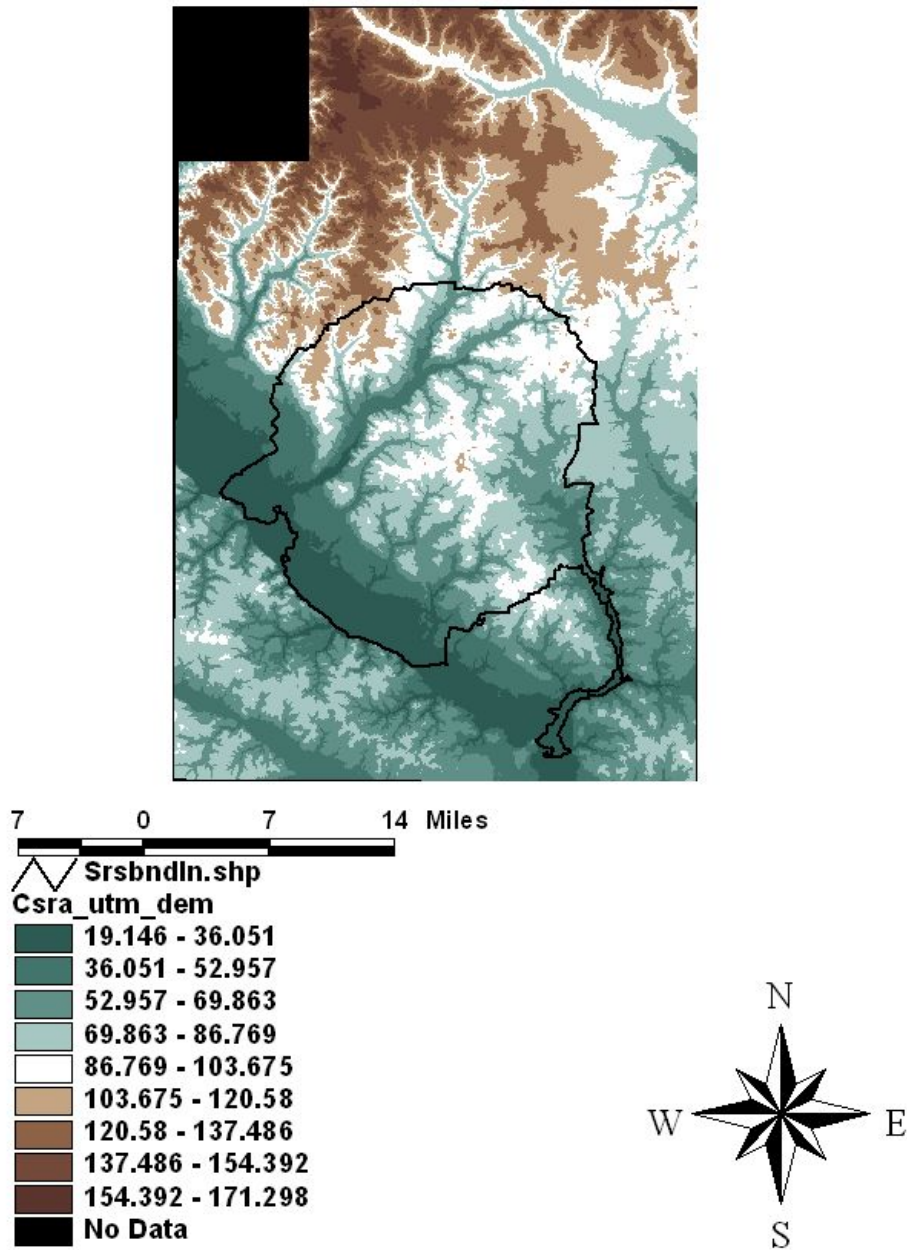


Figure 6

Streams Delineated by HEC-GeoHMS

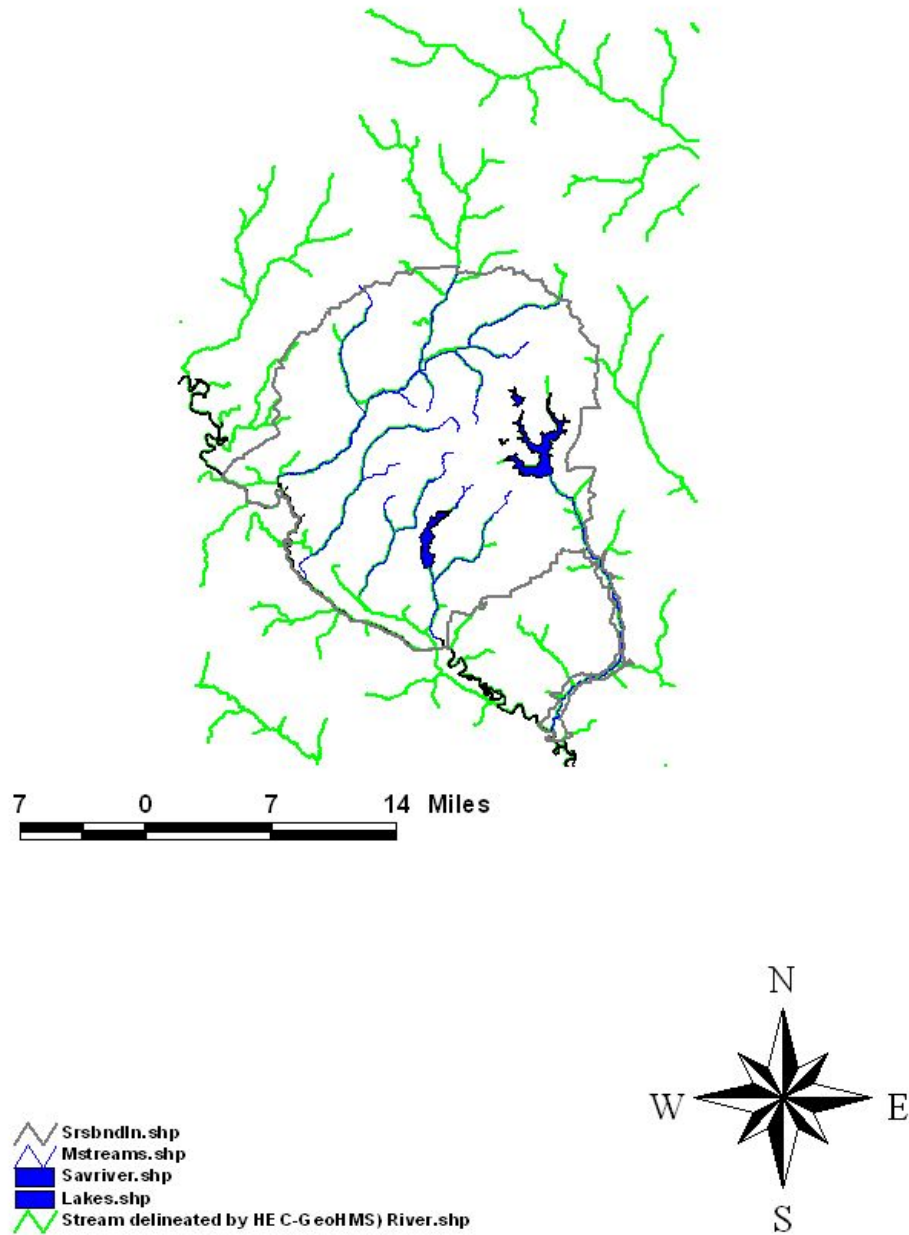
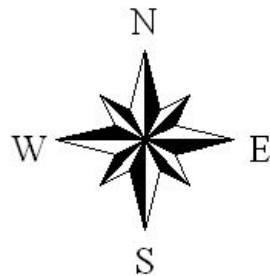
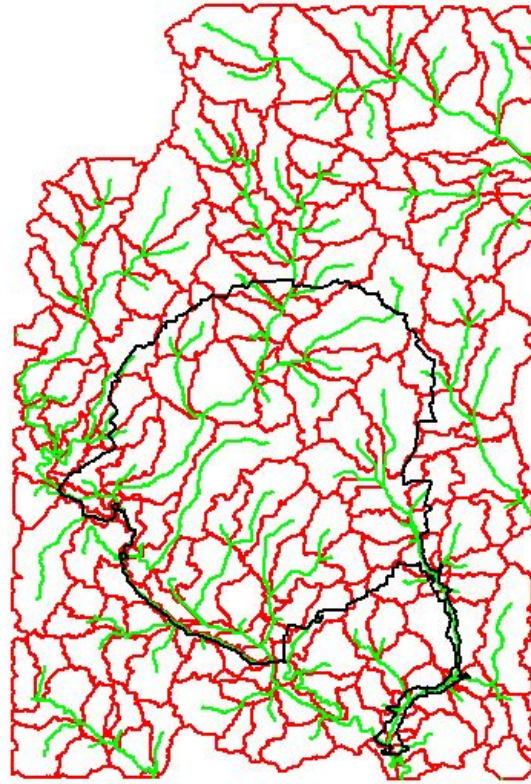


Figure 7

Watershed Delineated by HEC-GeoHMS






-  SrsbndIn.shp
-  Streams Delineated by HEC-GeoHMSRiver.shp
-  Watershed Delineated by HEC-GeoHMSWshedshp.Shp

Figure 8

Upper Three Runs Watershed

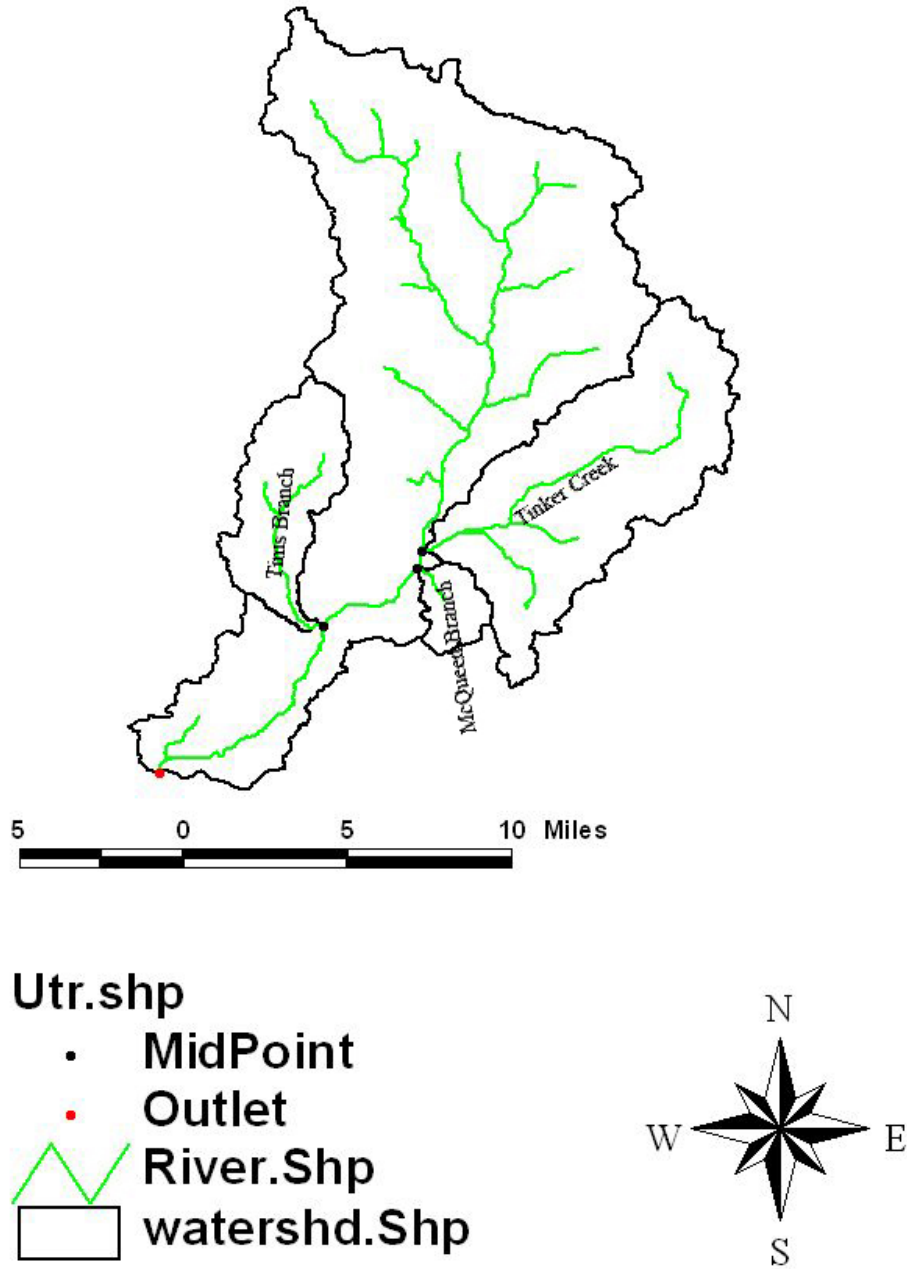


Figure 9

Fourmile Branch Watershed

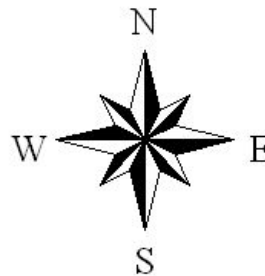
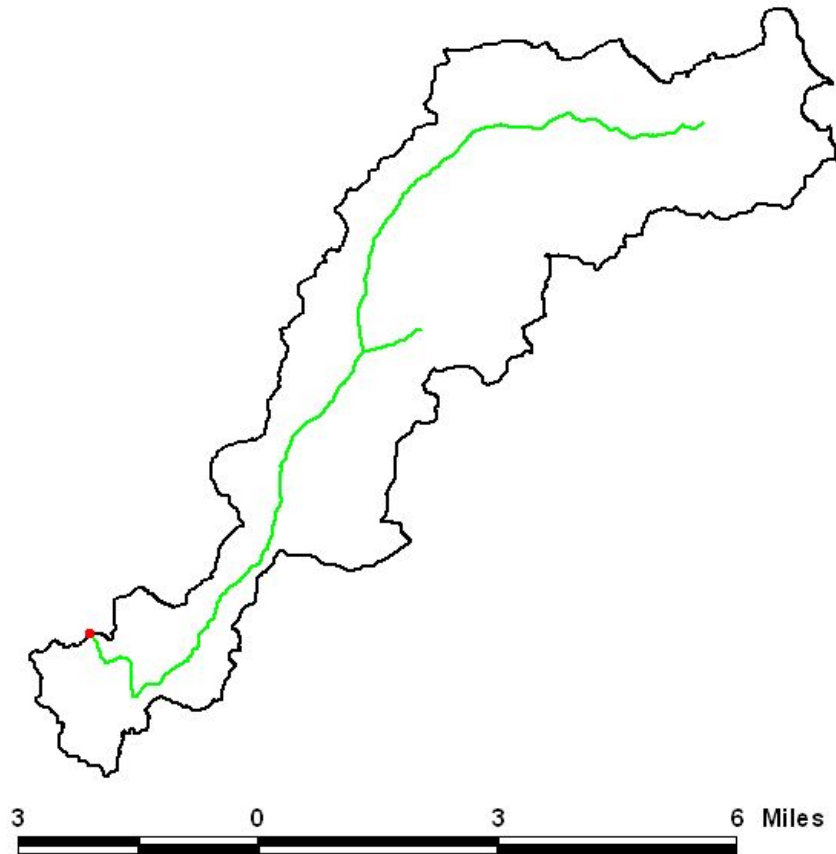


Figure 10

Pen Branch Watershed

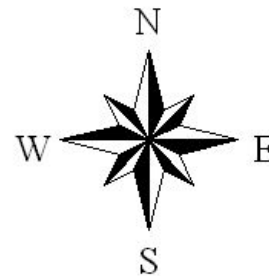
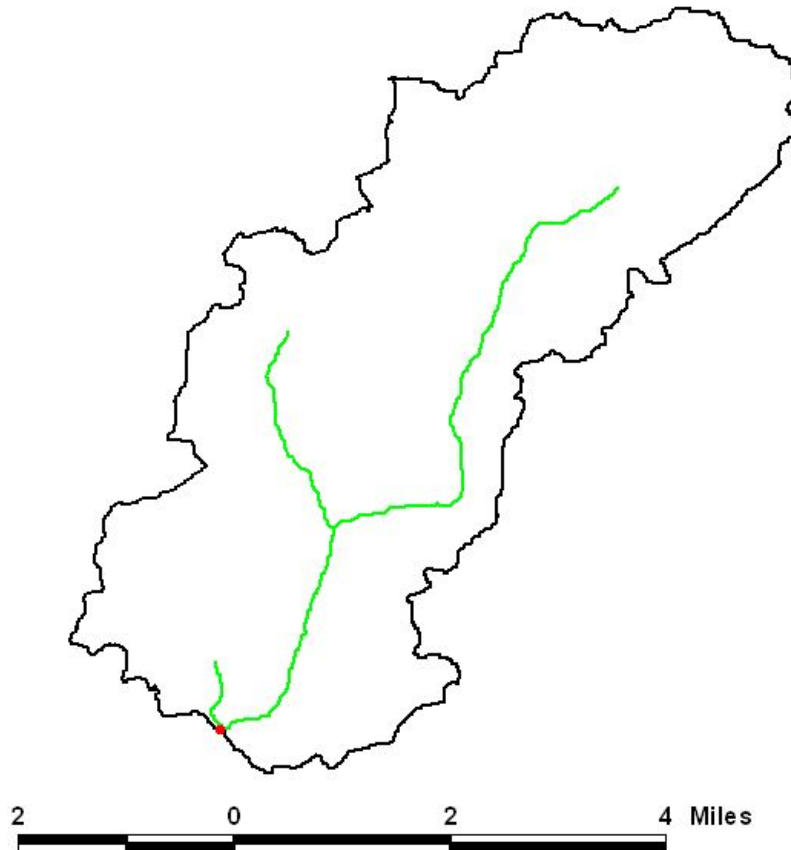


Figure 11

Steel Creek Watershed

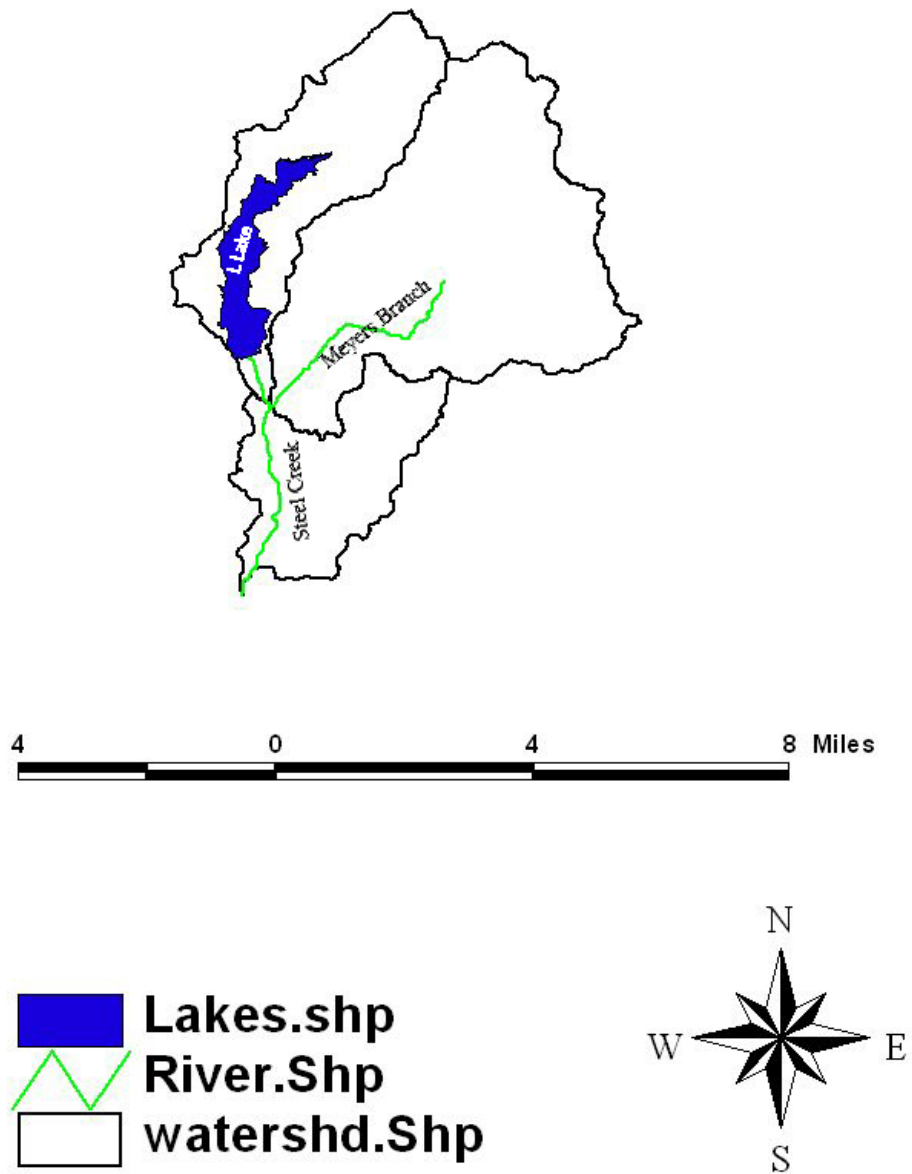


Figure 12

Lower Three Runs Watershed

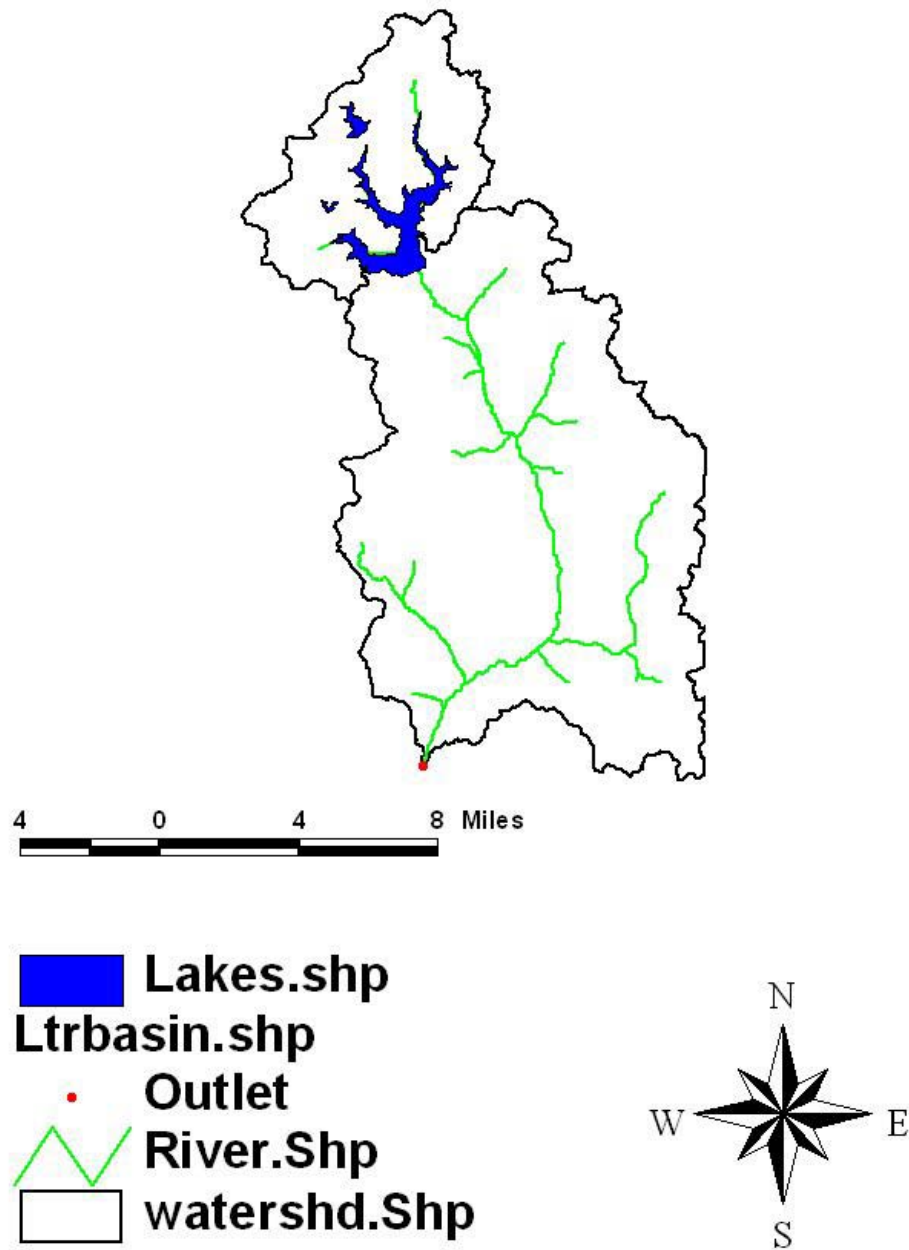


Figure 13. HEC-HMS Simulation for the Upper Three Runs Watershed Runoff Hydrograph (2.8 Inches of Rainfall in 3 Hours)

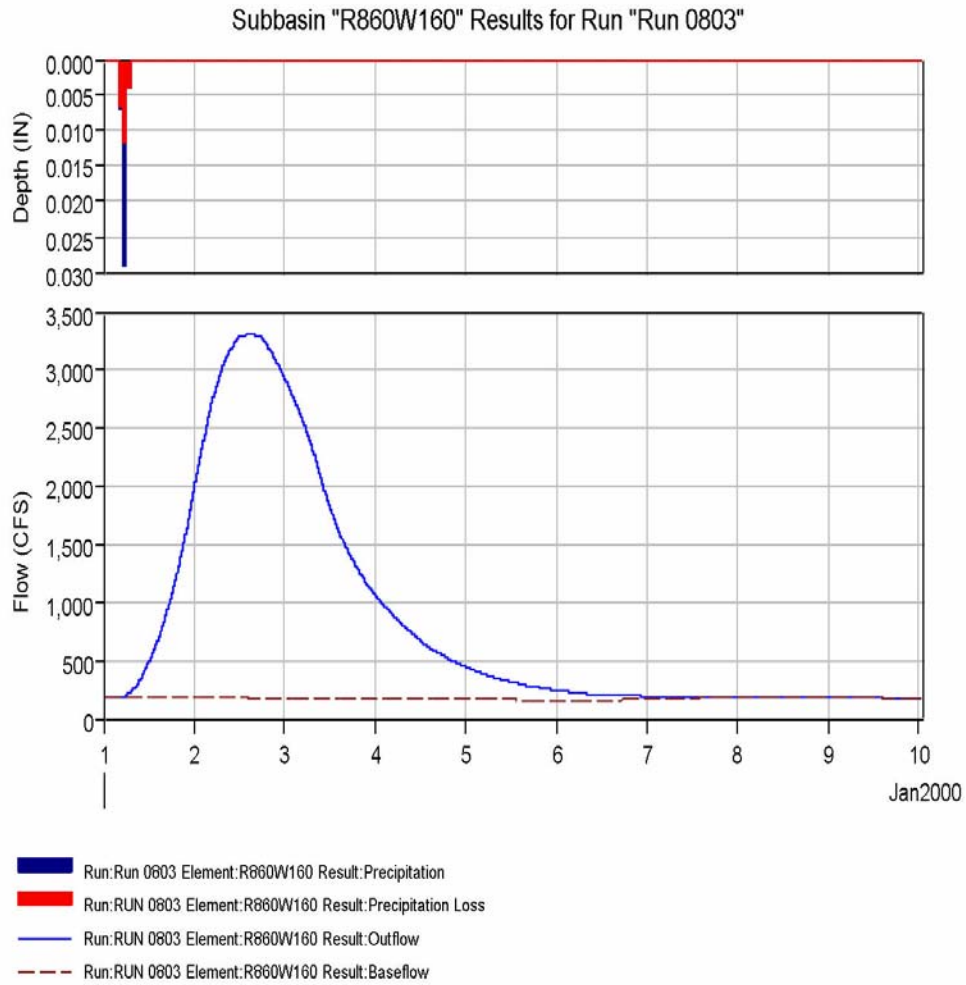


Figure 14
 Upper Three Runs Peak Runoff Flow as a Function of Total Rainfall
 Rainfall Duration = 1 hour

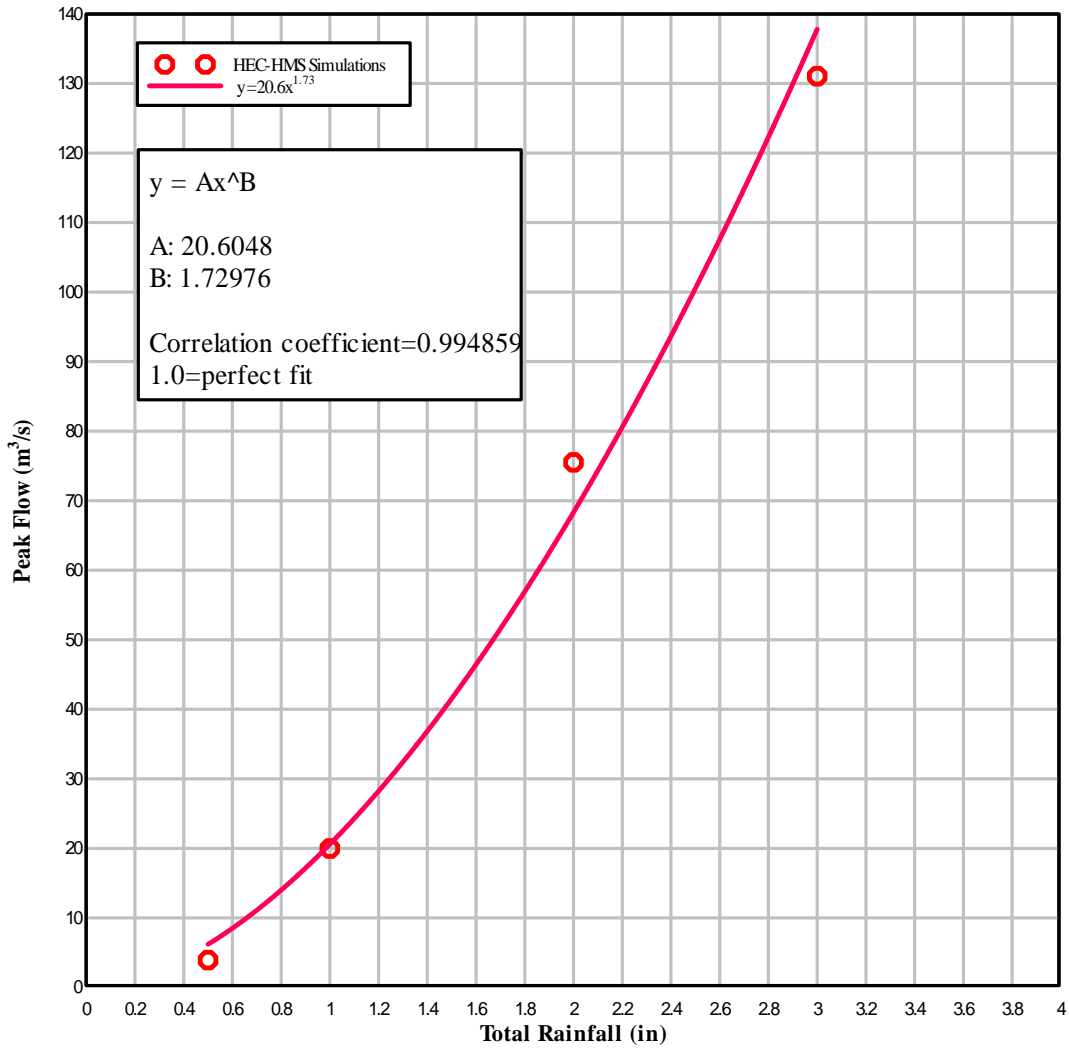


Figure 15
 Upper Three Runs Peak Runoff Flow as a Function of Total Rainfall
 Rainfall Duration = 3 hours

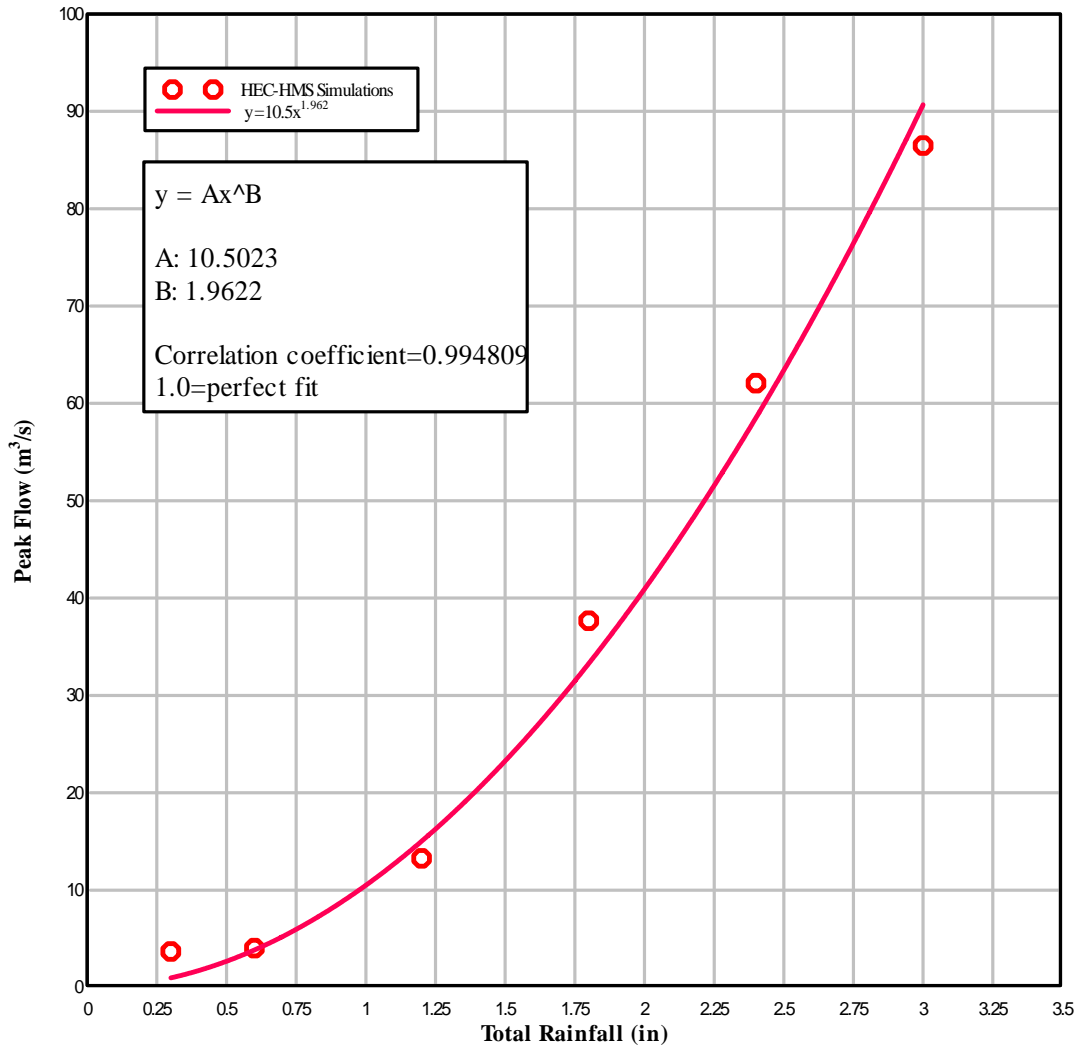


Figure 16
 Upper Three Runs Peak Runoff Flow as a Function of Total Rainfall
 Rainfall Duration = 6 hours

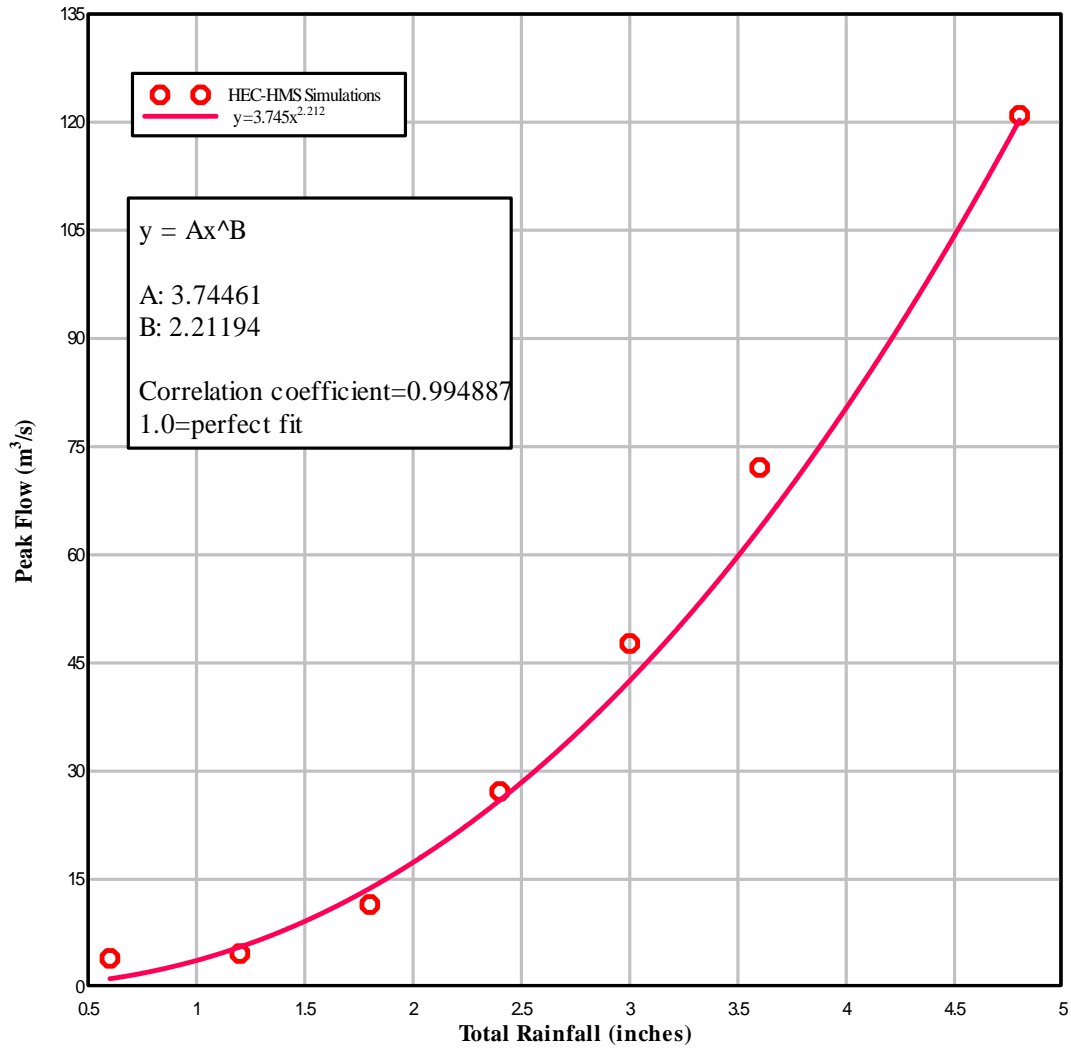


Figure 17
 Upper Three Runs Peak Runoff Flow as a Function of Total Rainfall
 Rainfall Duration = 12 Hours

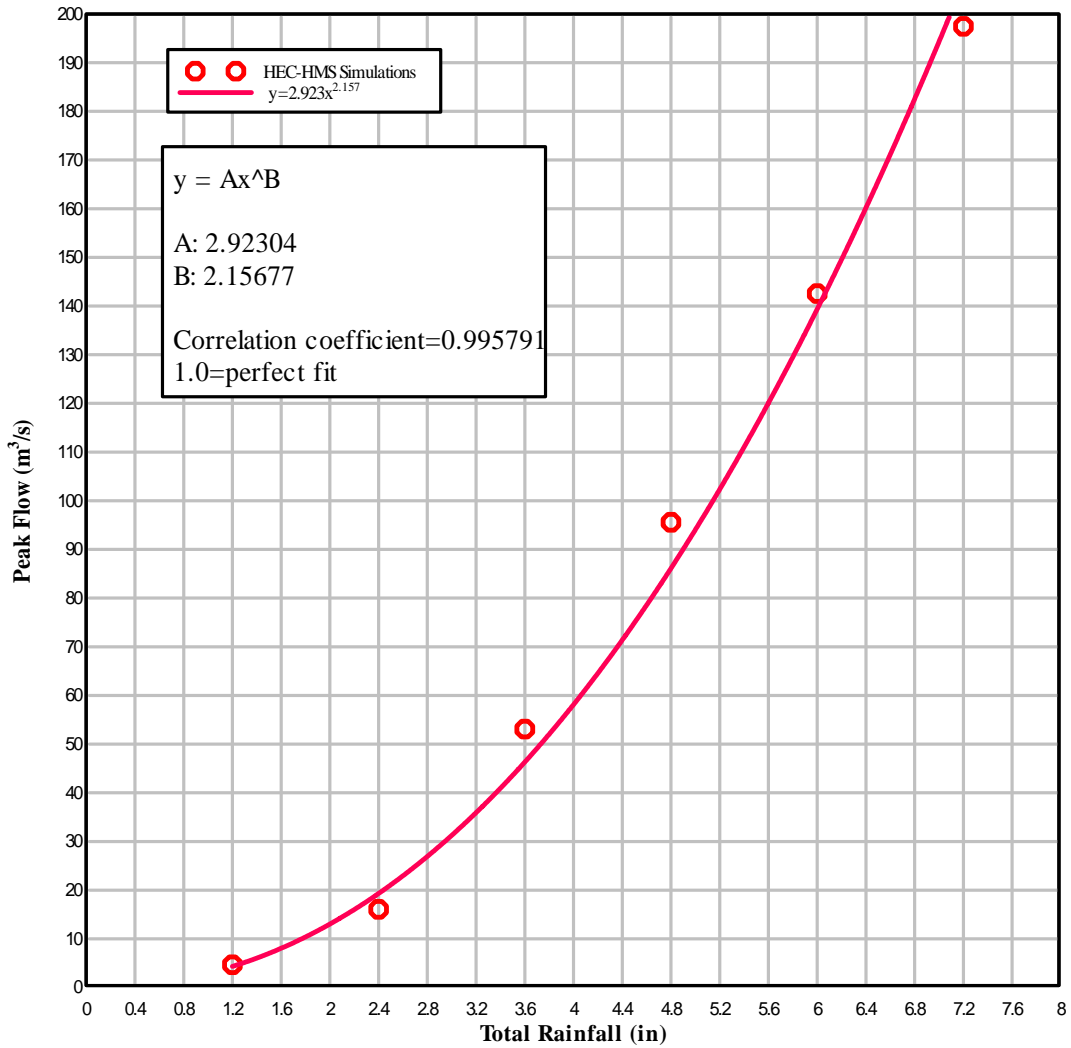


Figure 18
 Upper Three Runs Peak Runoff Flow as a Function of Total Rainfall
 Rainfall Duration = 24 Hours

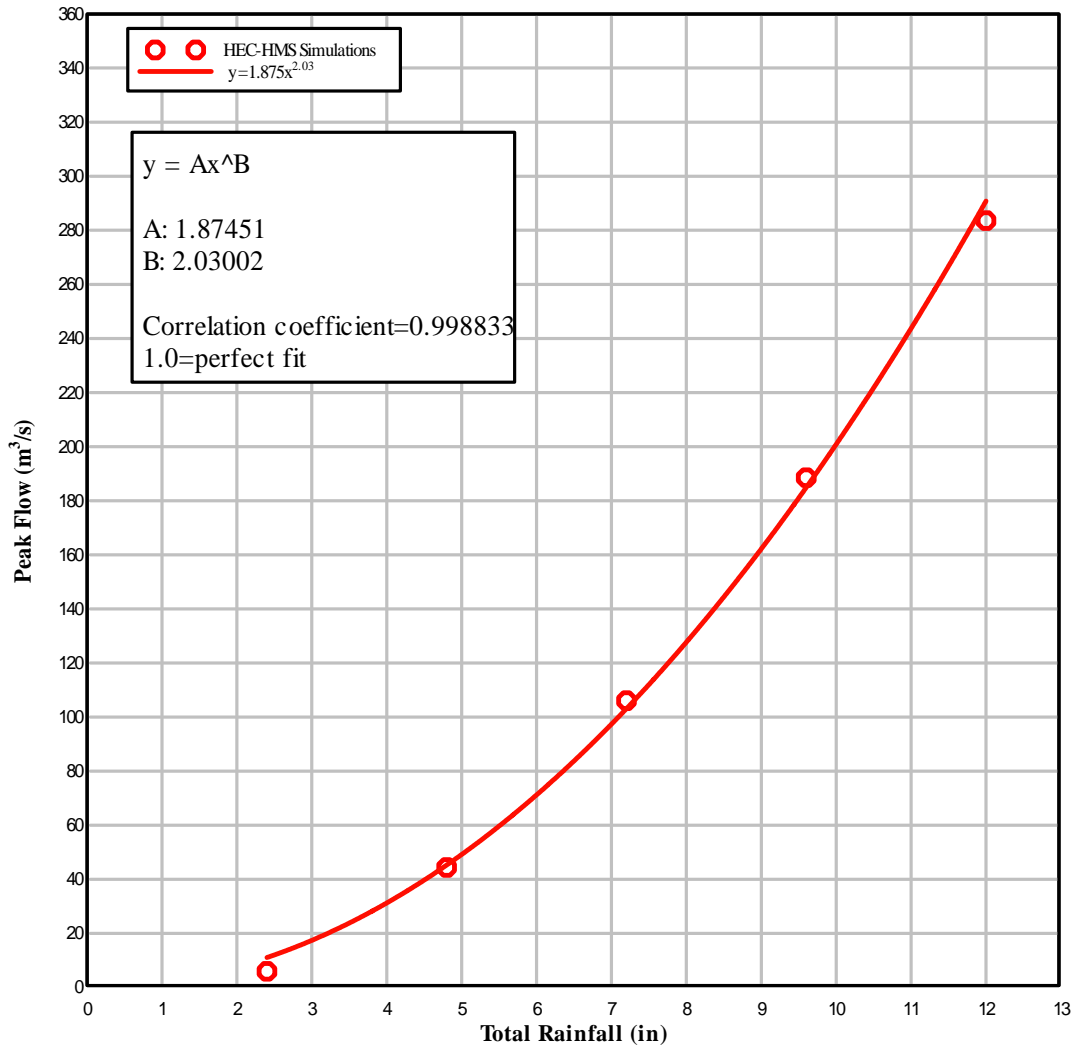


Figure 19
 Fourmile Branch Peak Runoff Flow as a Function of Total Rainfall
 Rainfall Duration = 1 hour

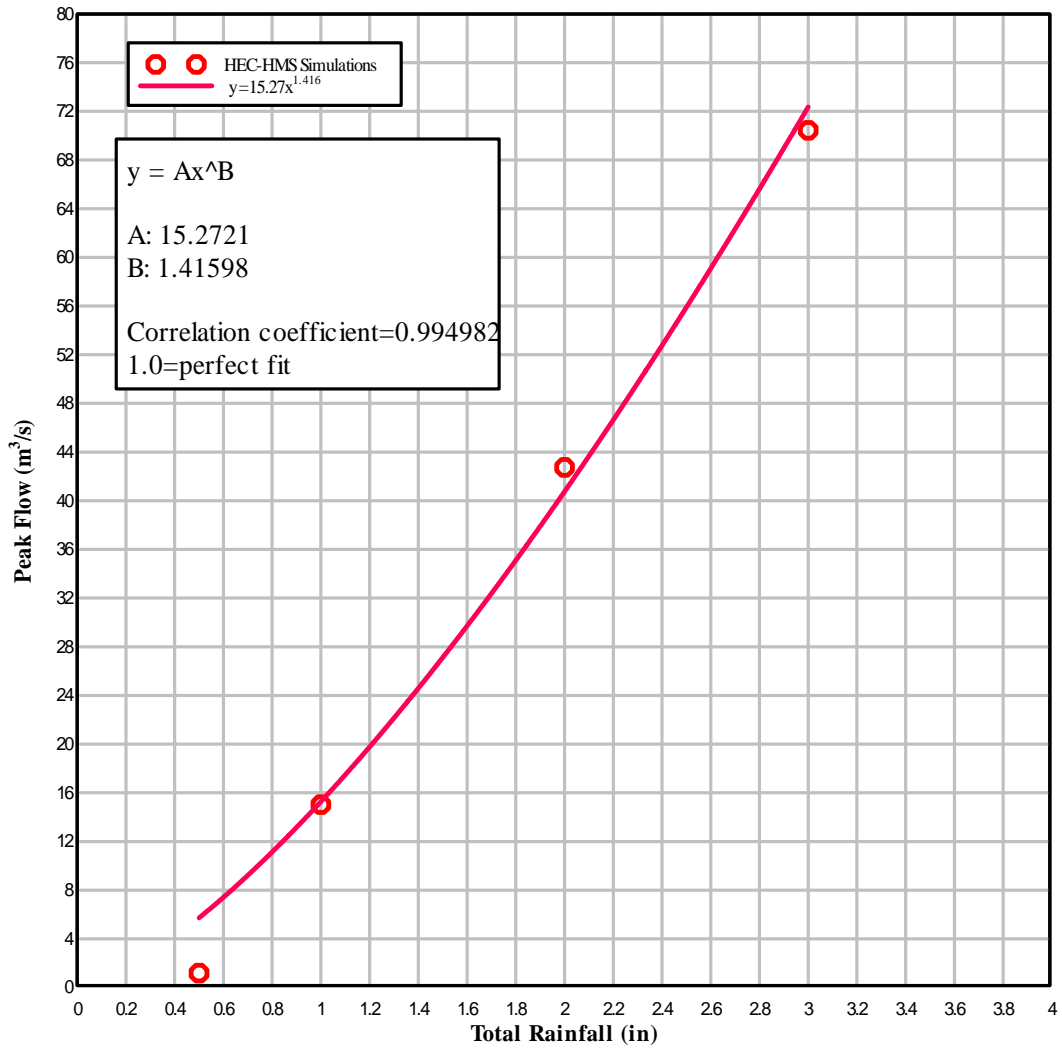


Figure 20
Fourmile Branch Peak Runoff Flow as a Function of Total Rainfall
Rainfall Duration = 3 hour

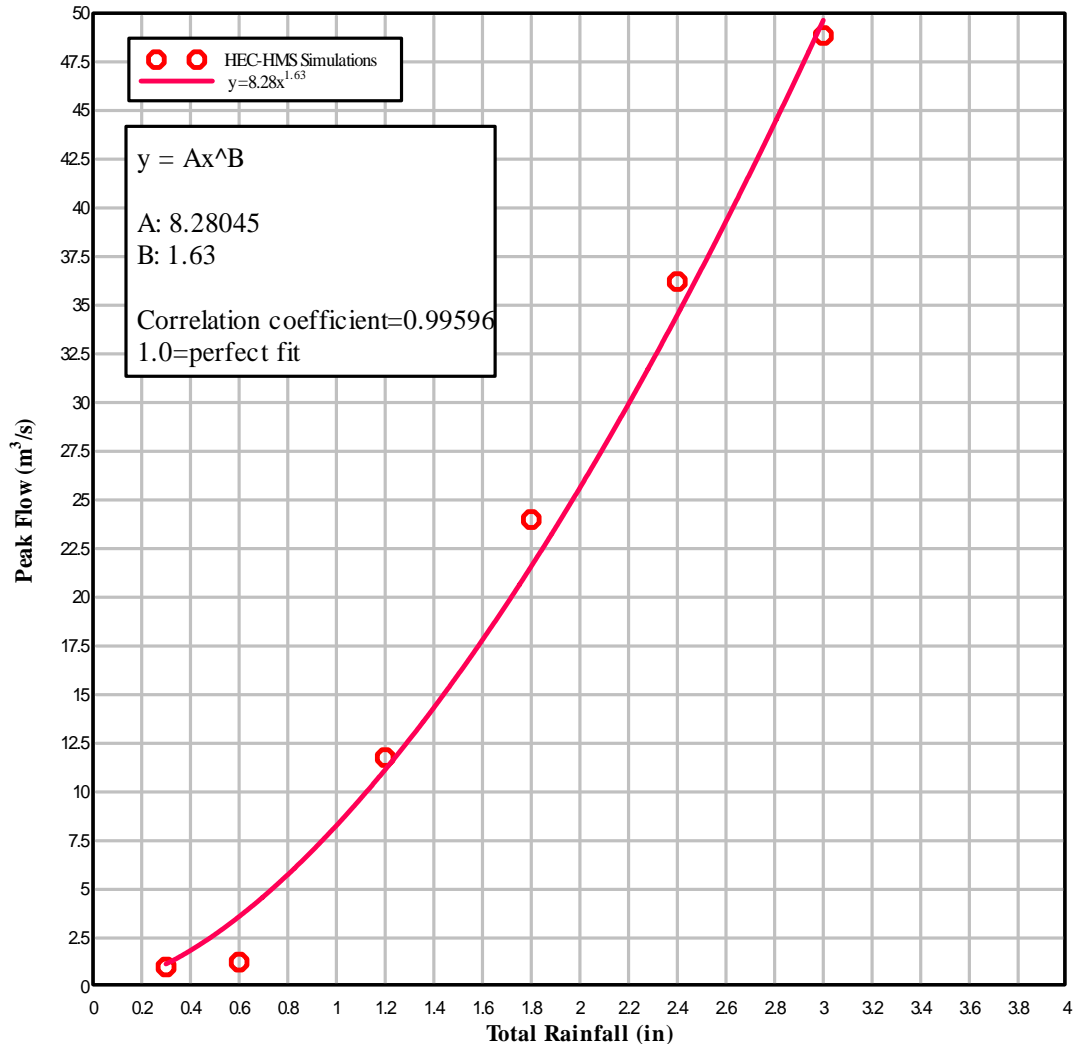


Figure 21
Fourmile Branch Peak Runoff Flow as a Function of Total Rainfall
Rainfall Duration = 6 hours

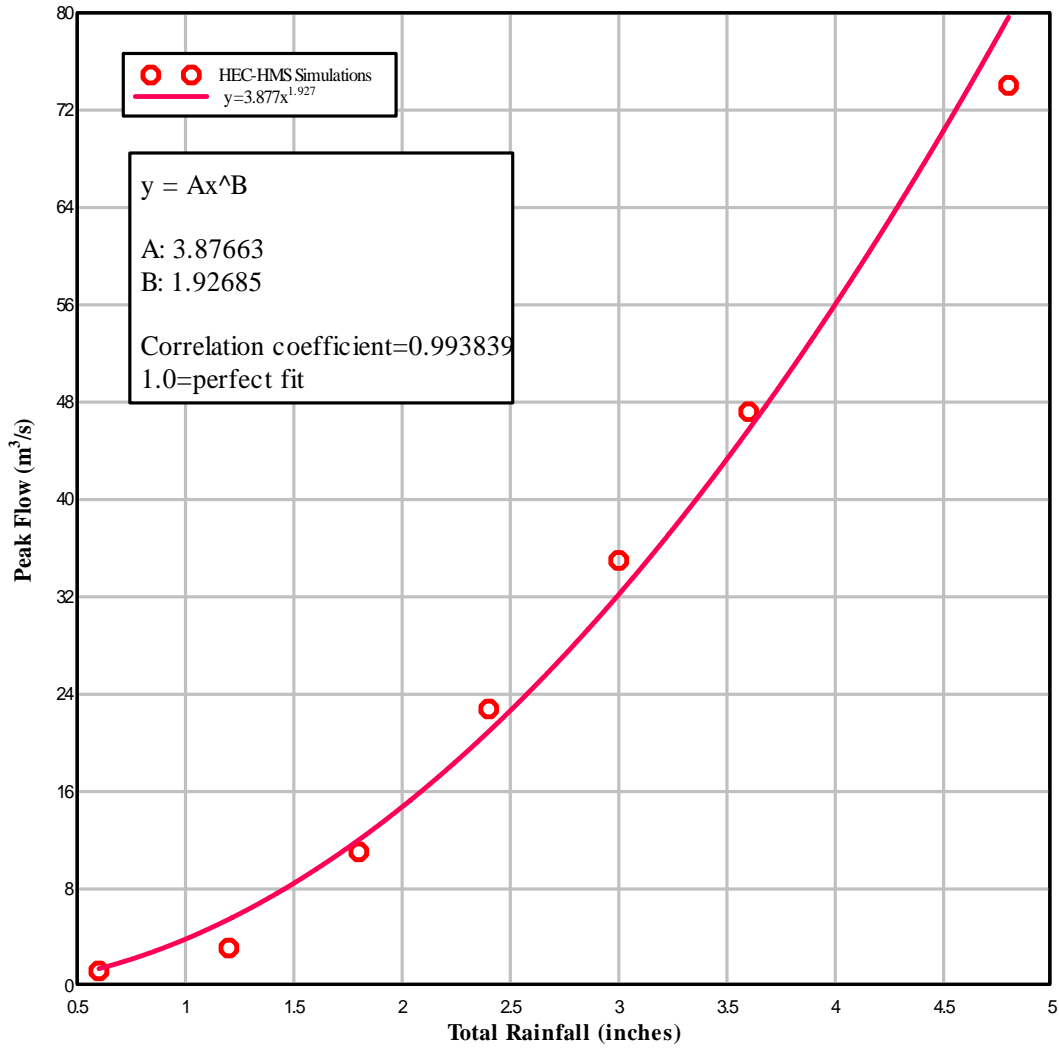


Figure 22
Fourmile Branch Peak Runoff Flow as a Function of Total Rainfall
Rainfall Duration = 12 hour

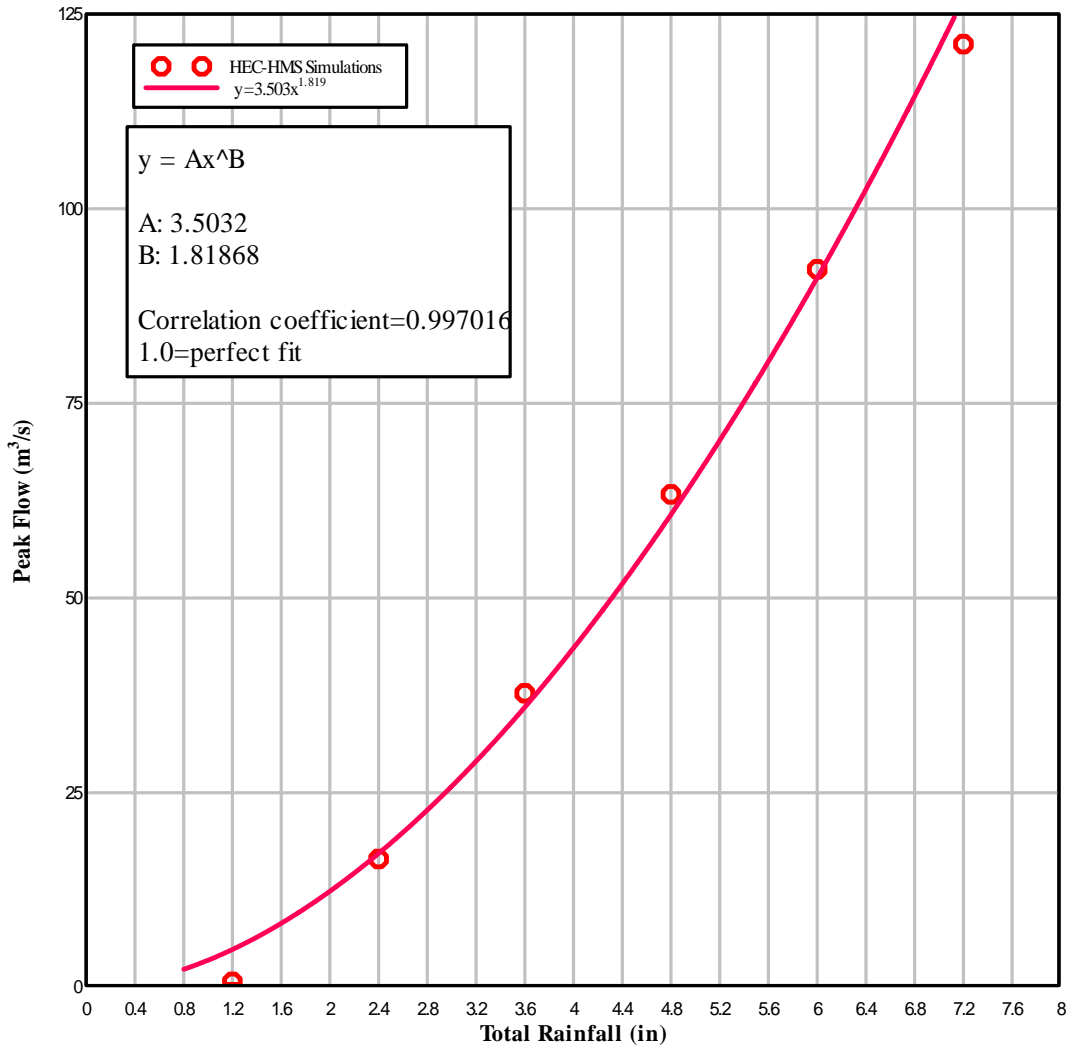


Figure 23
Fourmile Branch Peak Runoff Flow as a Function of Total Rainfall
Rainfall Duration = 24 hours

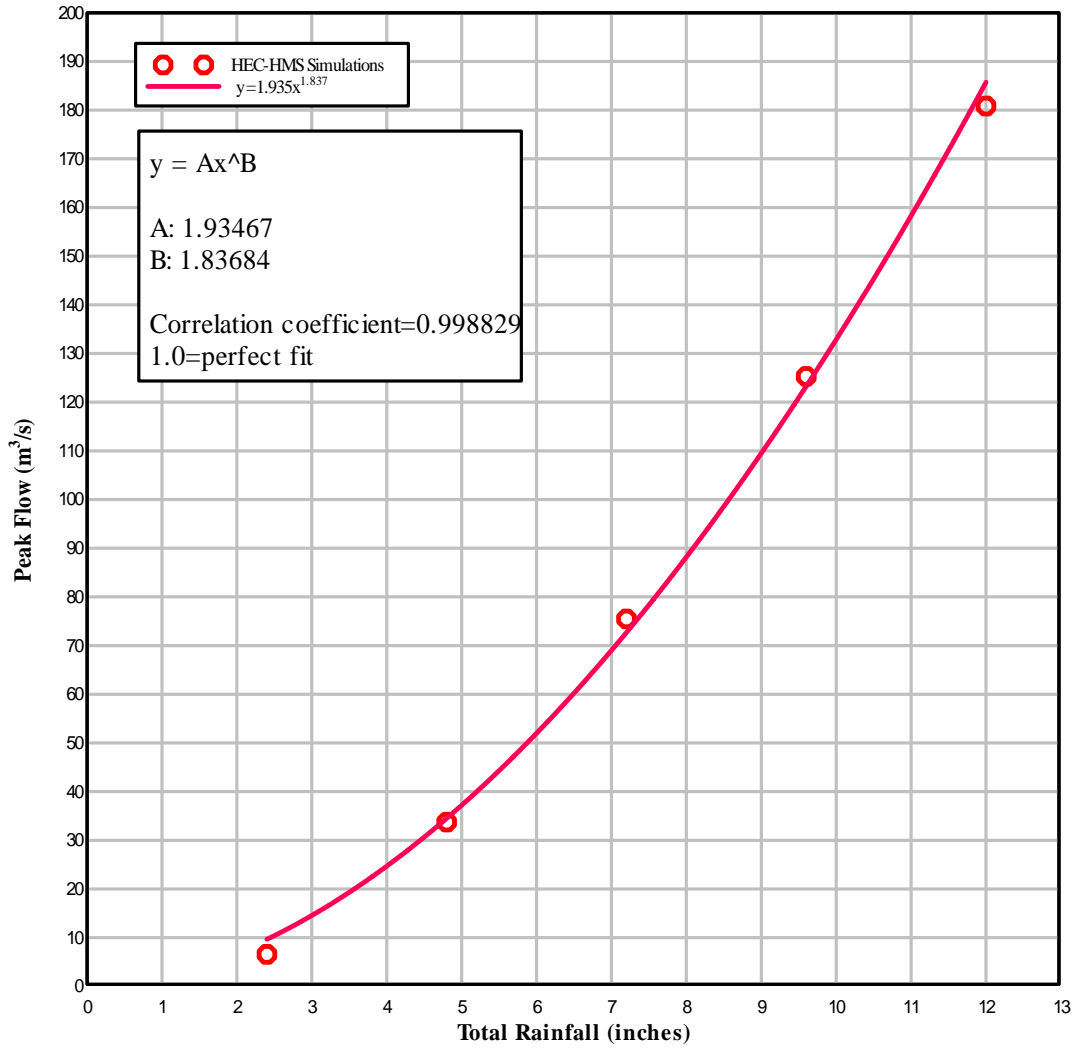


Figure 24
 Pen Branch Peak Runoff Flow as a Function of Total Rainfall
 Rainfall Duration = 1 hour

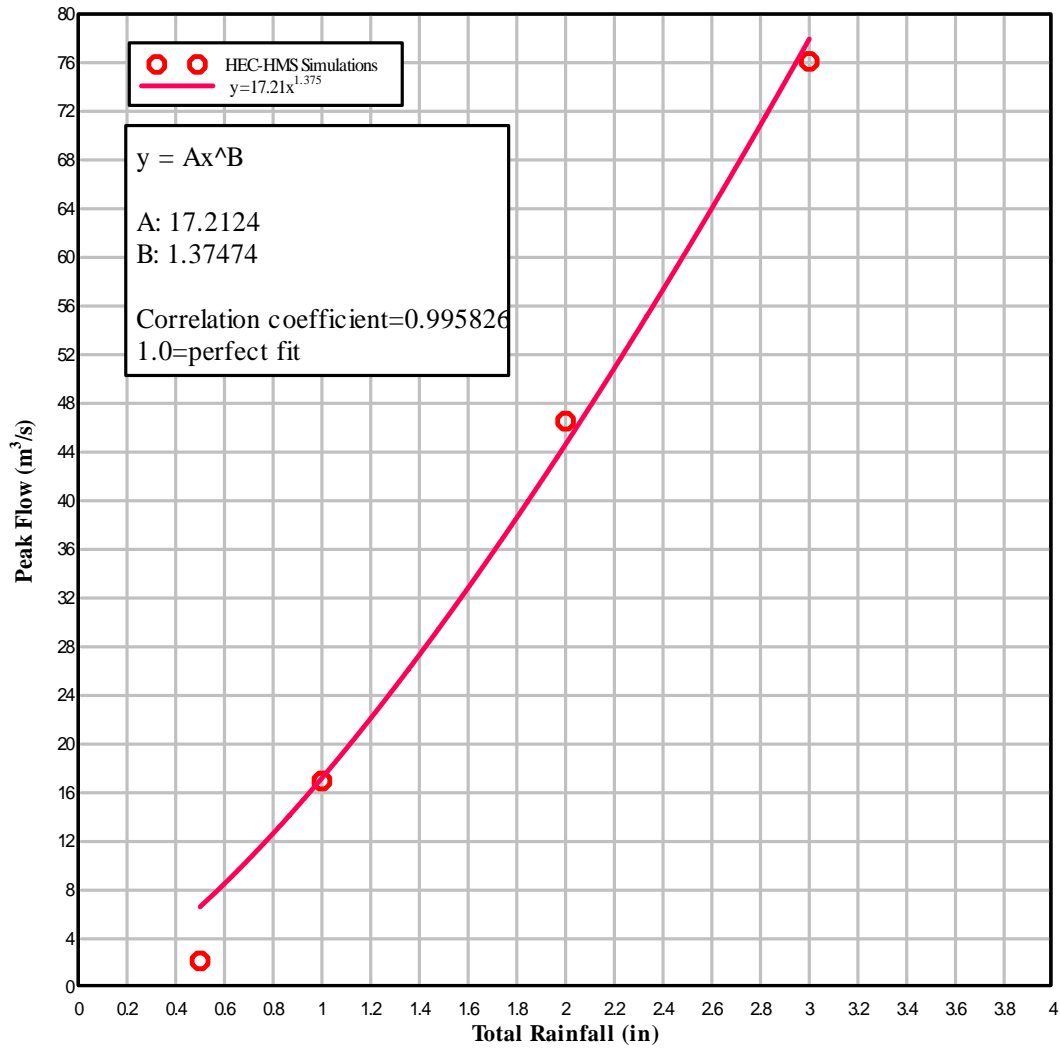


Figure 25
 Pen Branch Peak Runoff Flow as a Function of Total Rainfall
 Rainfall Duration = 3 hour

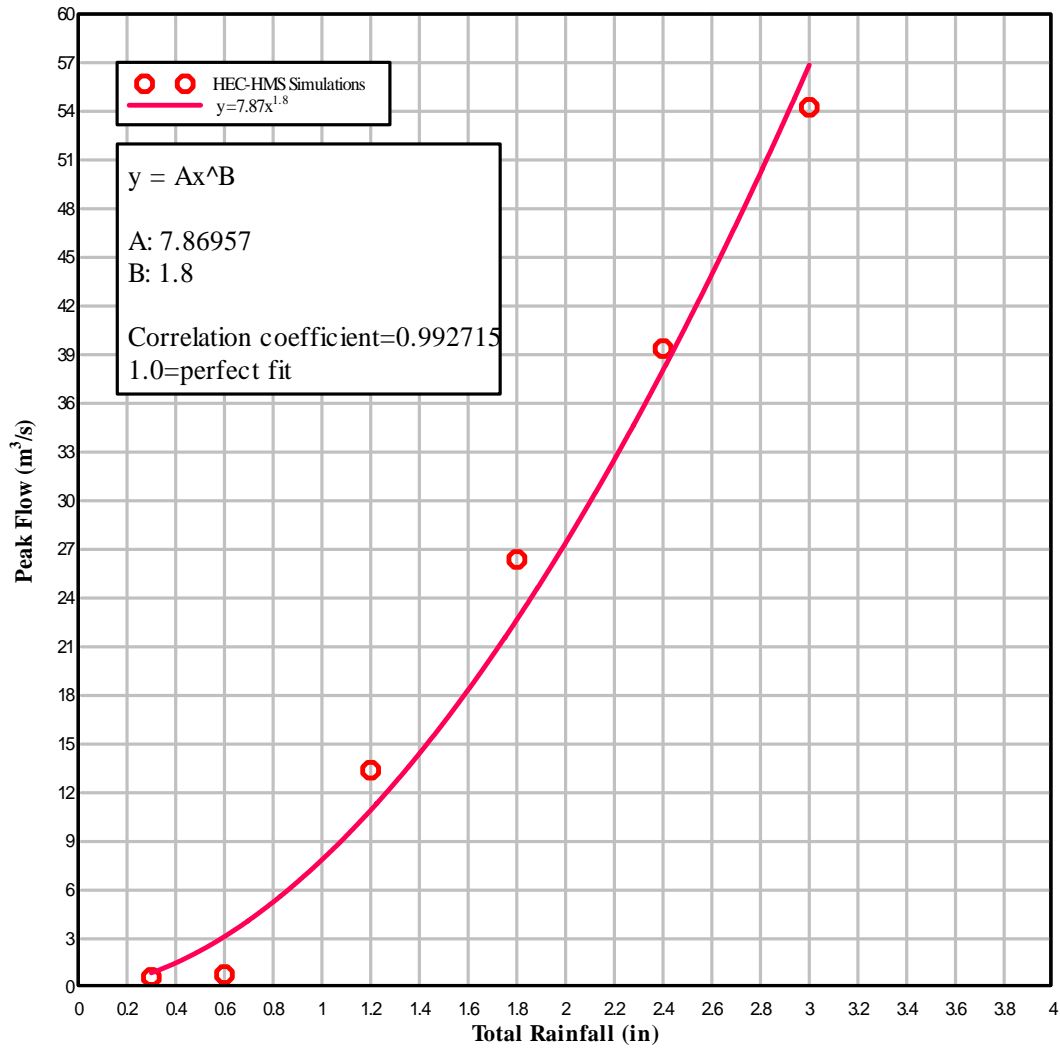


Figure 26
Pen Branch Peak Runoff Flow as a Function of Total Rainfall
Rainfall Duration = 6 hours

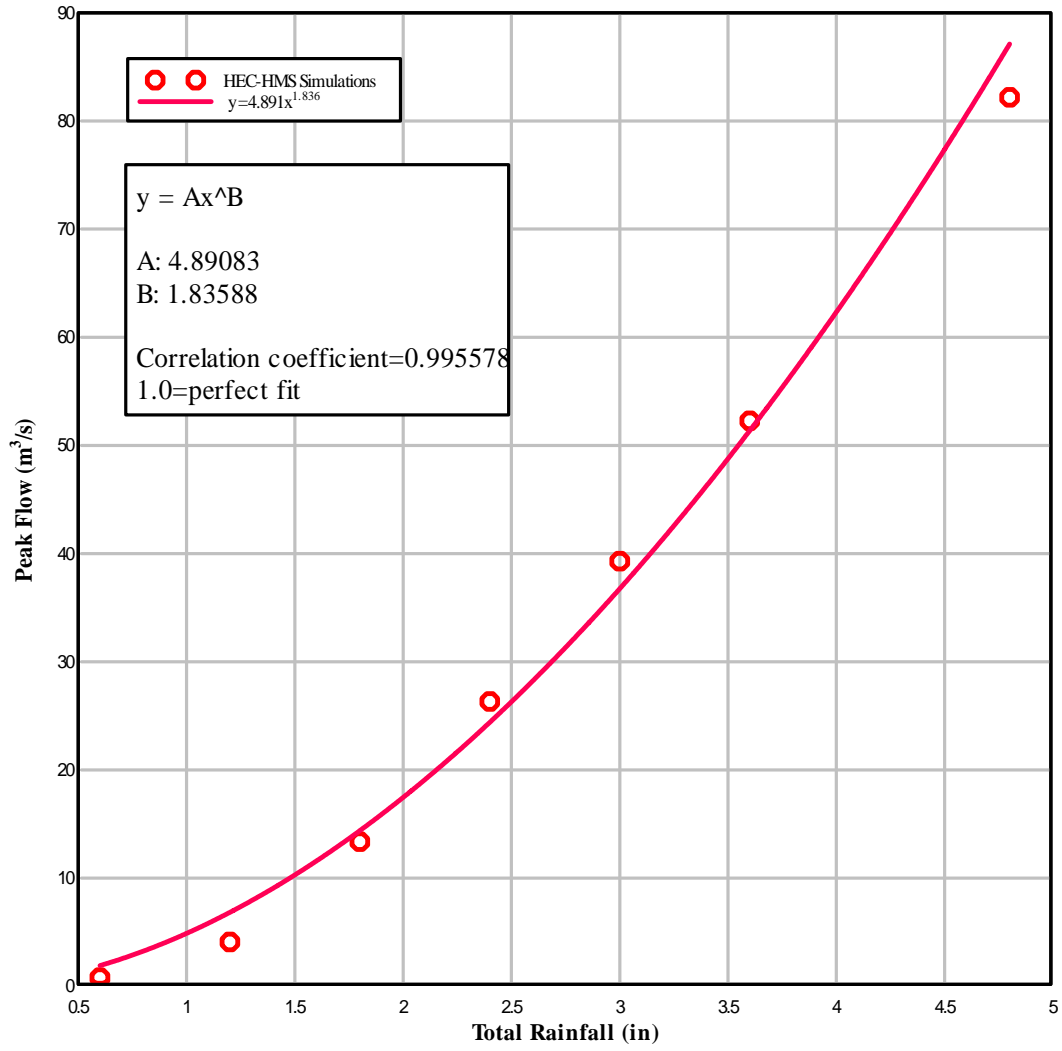


Figure 27
Pen Branch Peak Runoff Flow as a Function of Total Rainfall
Rainfall Duration = 12 hour

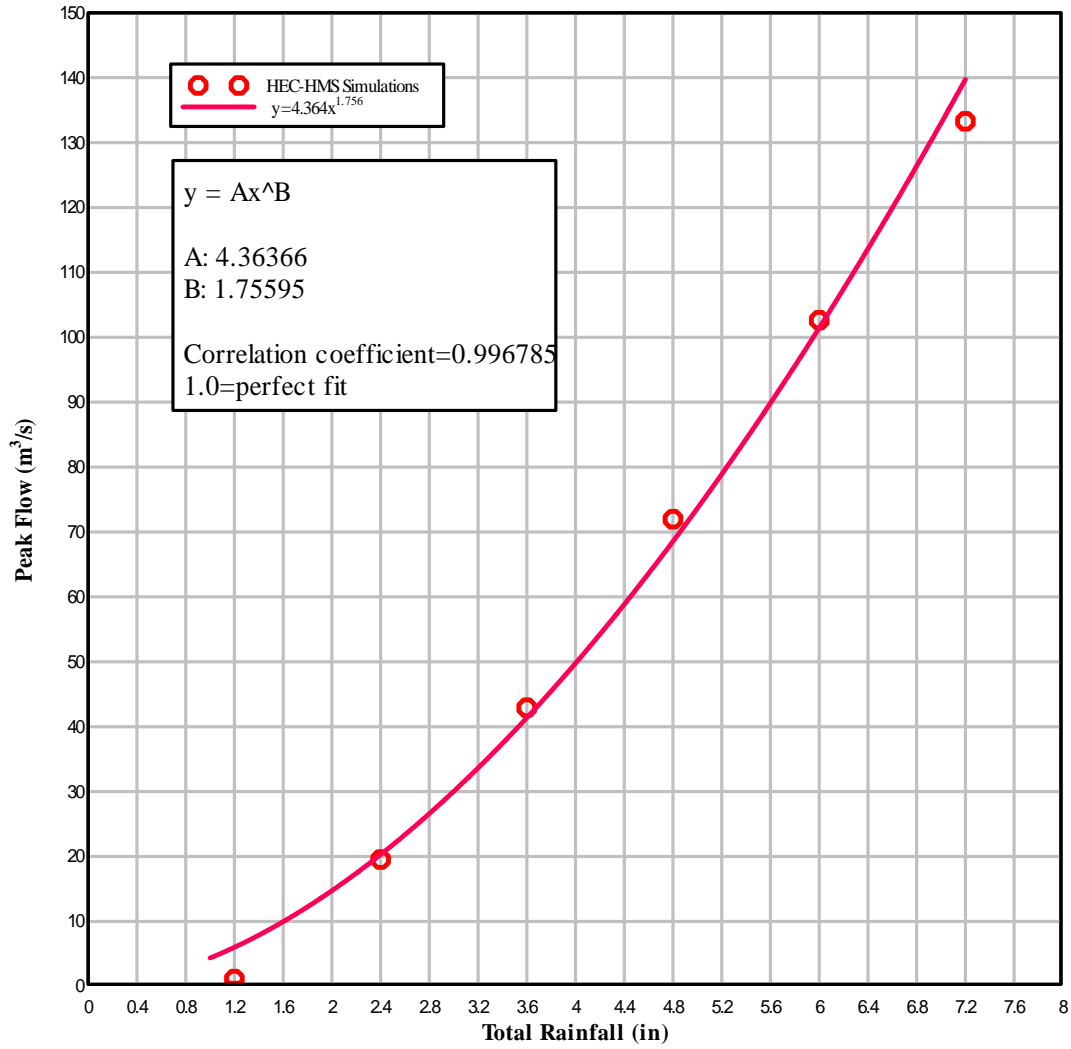


Figure 28
 Pen Branch Peak Runoff Flow as a Function of Total Rainfall
 Rainfall Duration = 24 hours

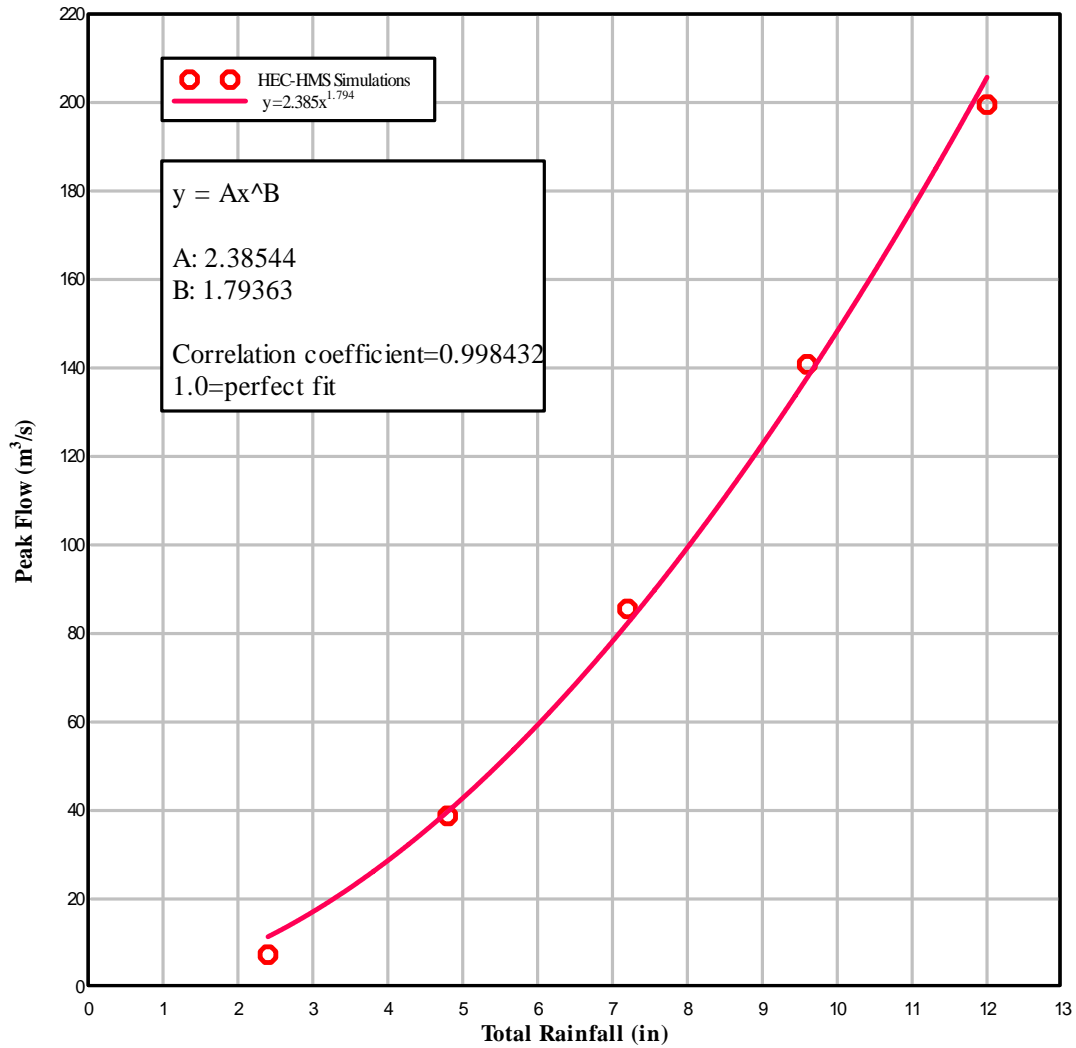


Figure 29
 Steel Creek Peak Runoff Flow as a Function of Total Rainfall
 Rainfall Duration = 1 hour

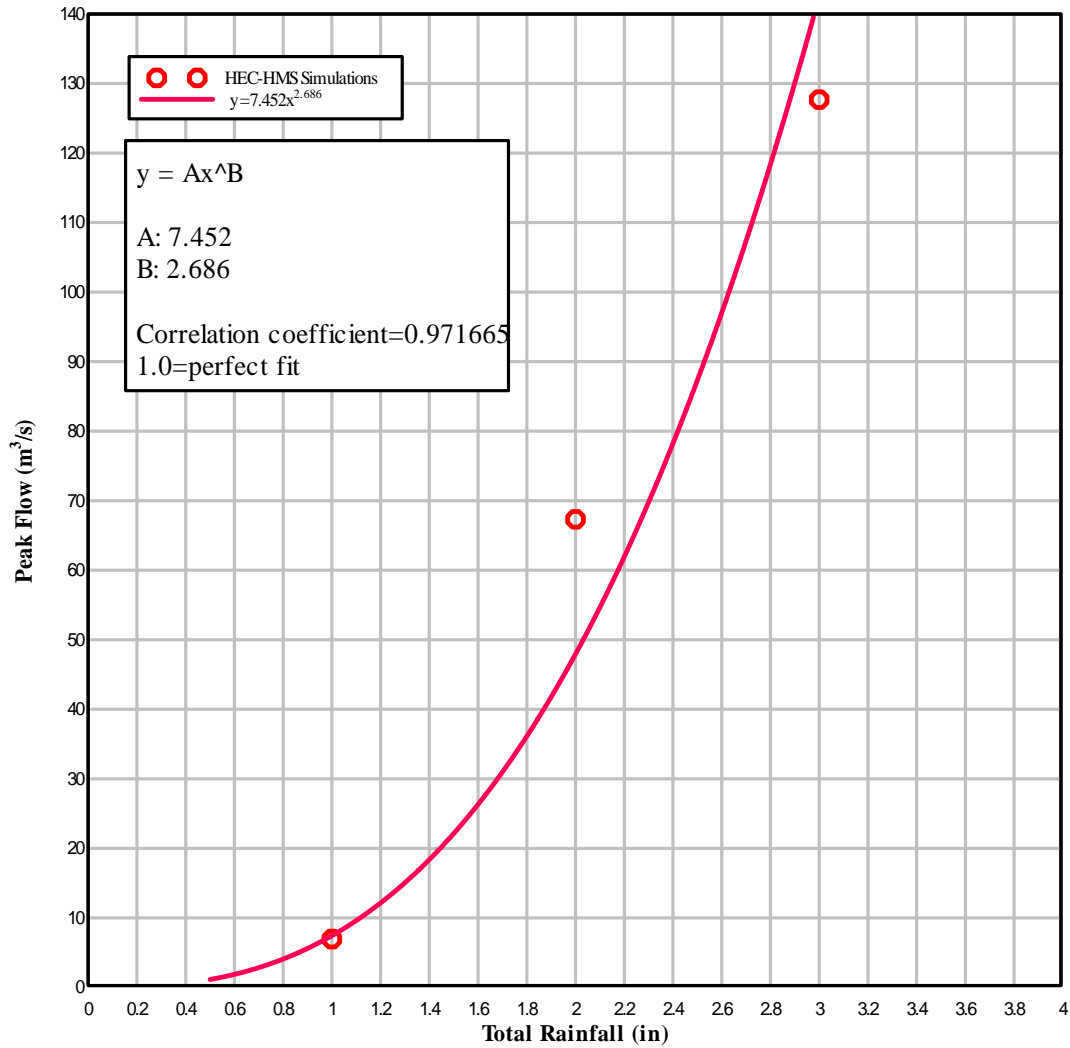


Figure 30
 Steel Creek Peak Runoff Flow as a Function of Total Rainfall
 Rainfall Duration = 3 hour

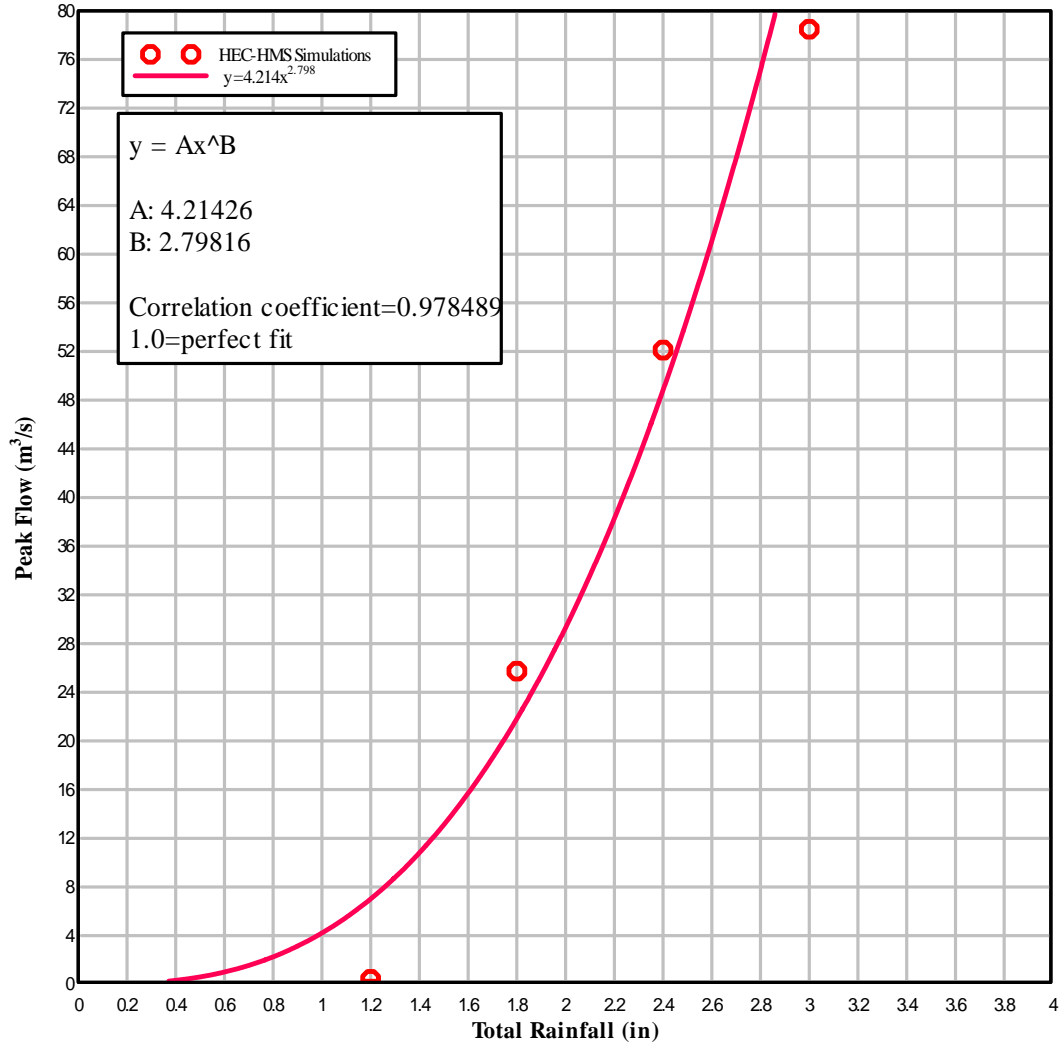


Figure 31
 Steel Creek Peak Runoff Flow as a Function of Total Rainfall
 Rainfall Duration = 6 hours

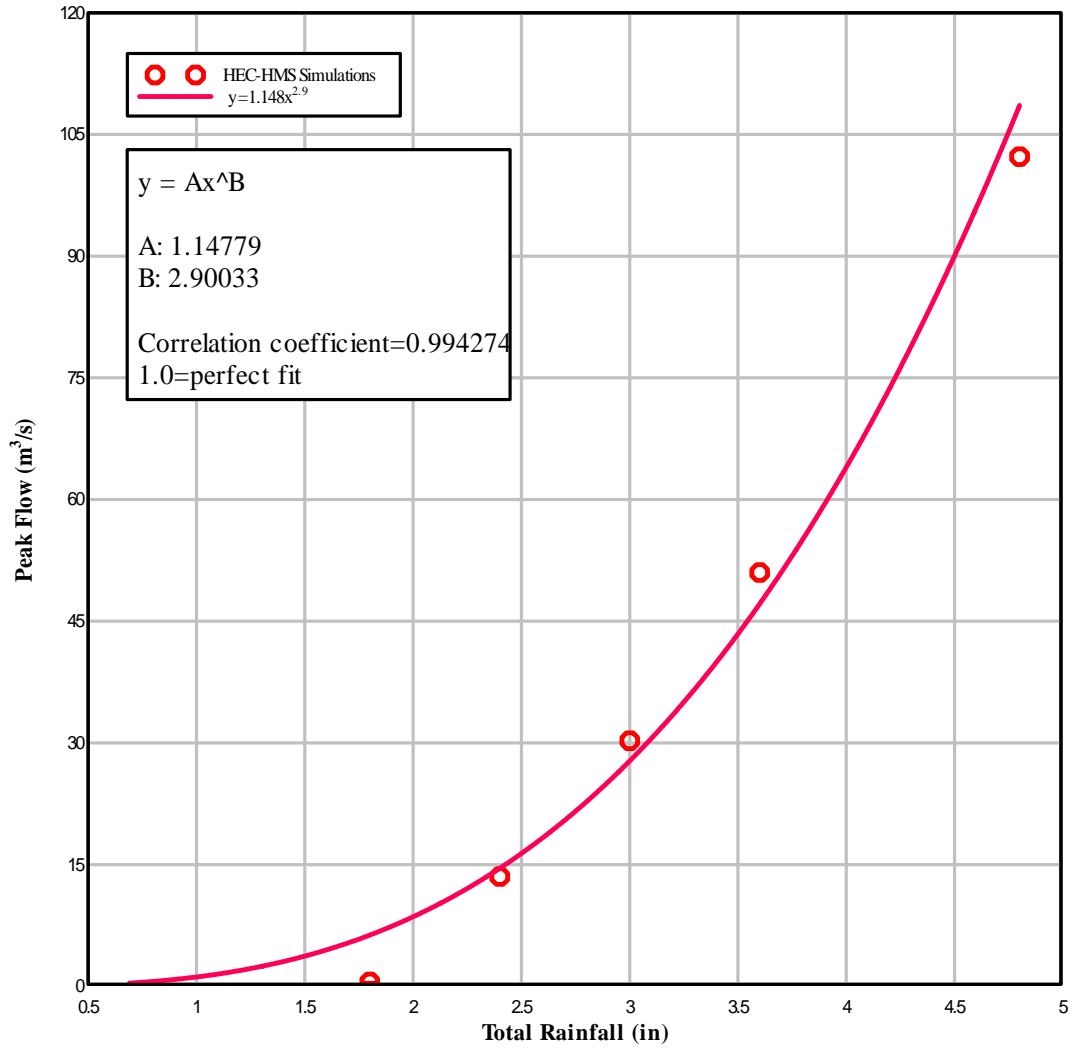


Figure 32
 Steel Creek Peak Runoff Flow as a Function of Total Rainfall
 Rainfall Duration = 12 hour

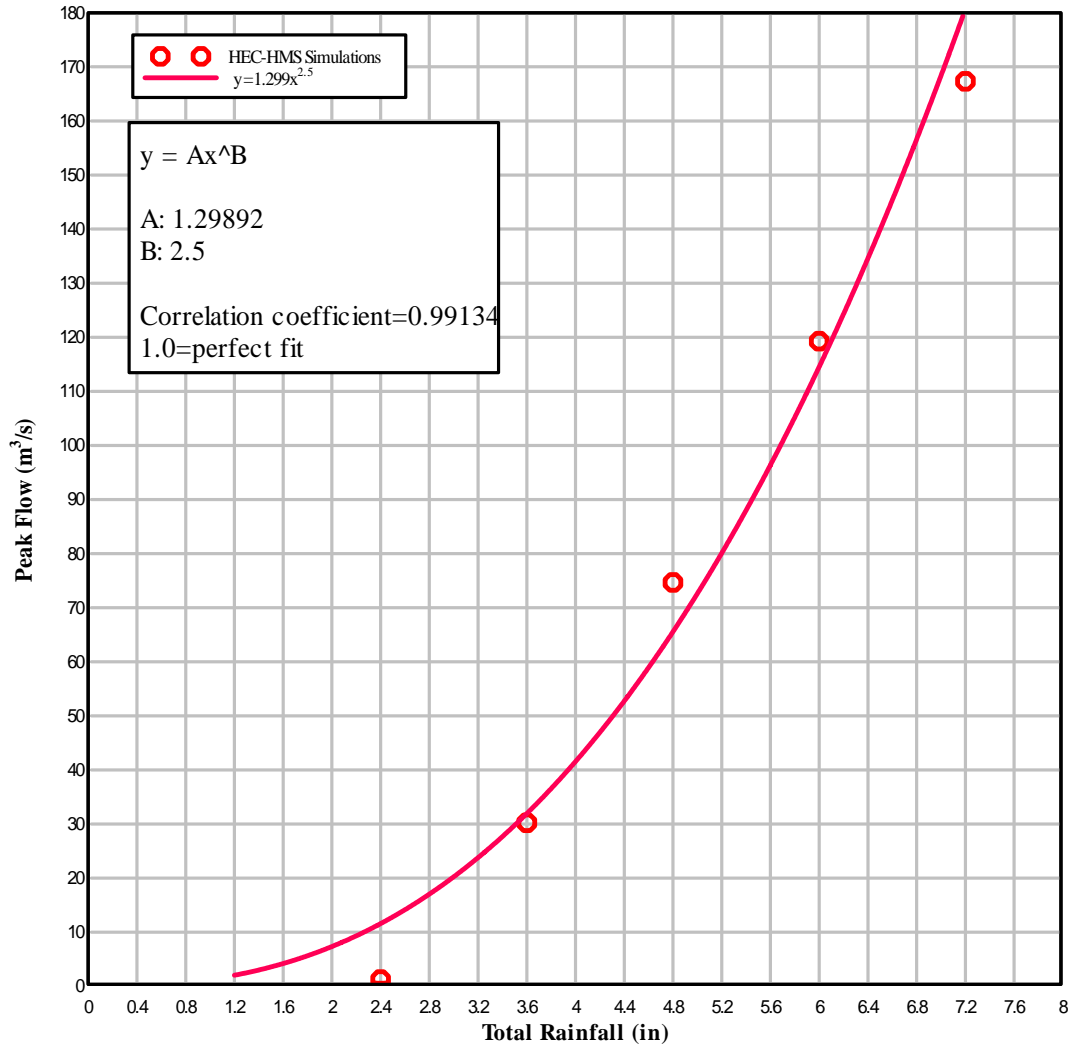


Figure 33
 Steel Creek Peak Runoff Flow as a Function of Total Rainfall
 Rainfall Duration = 24 hours

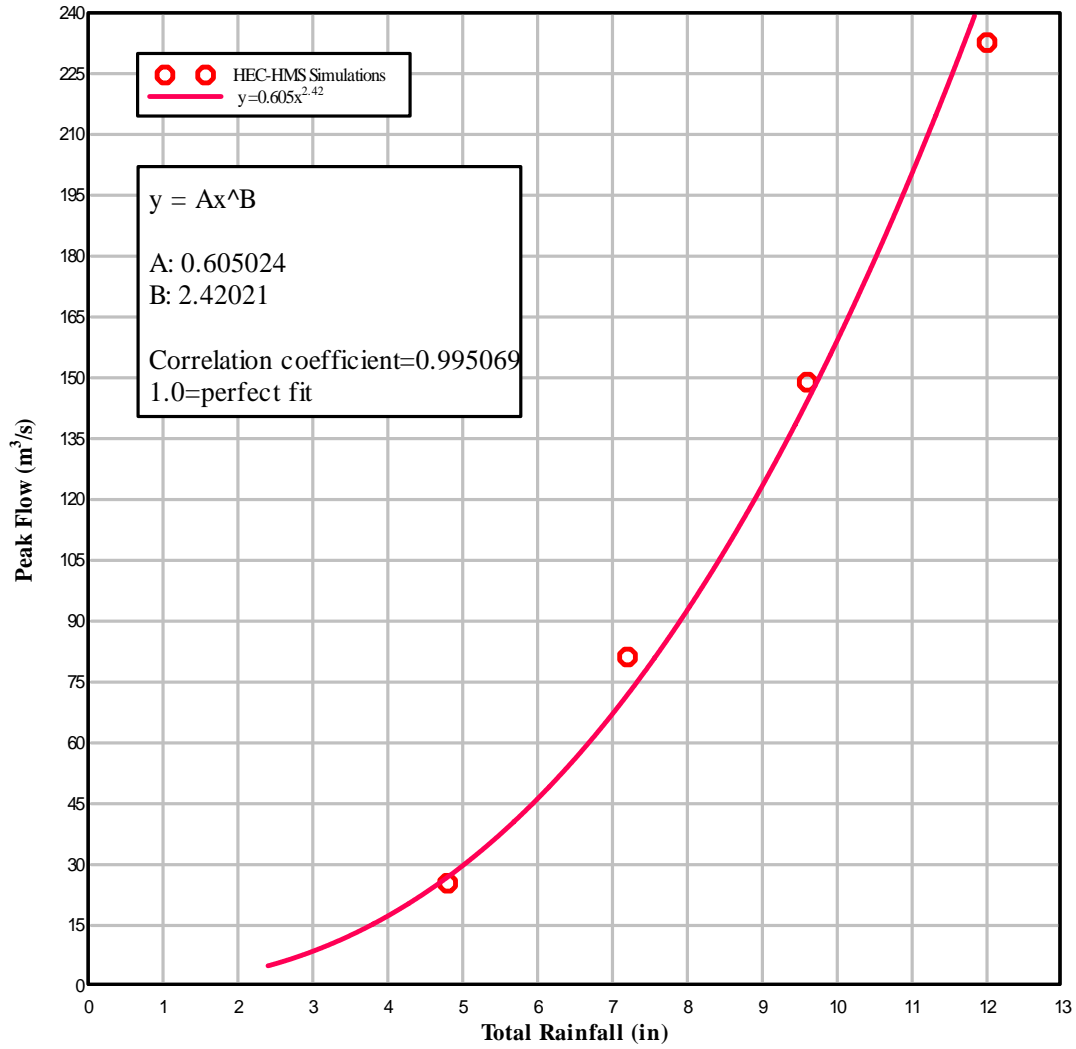


Figure 34
Lower Three Runs Peak Runoff Flow as a Function of Total Rainfall
Rainfall Duration = 1 hour

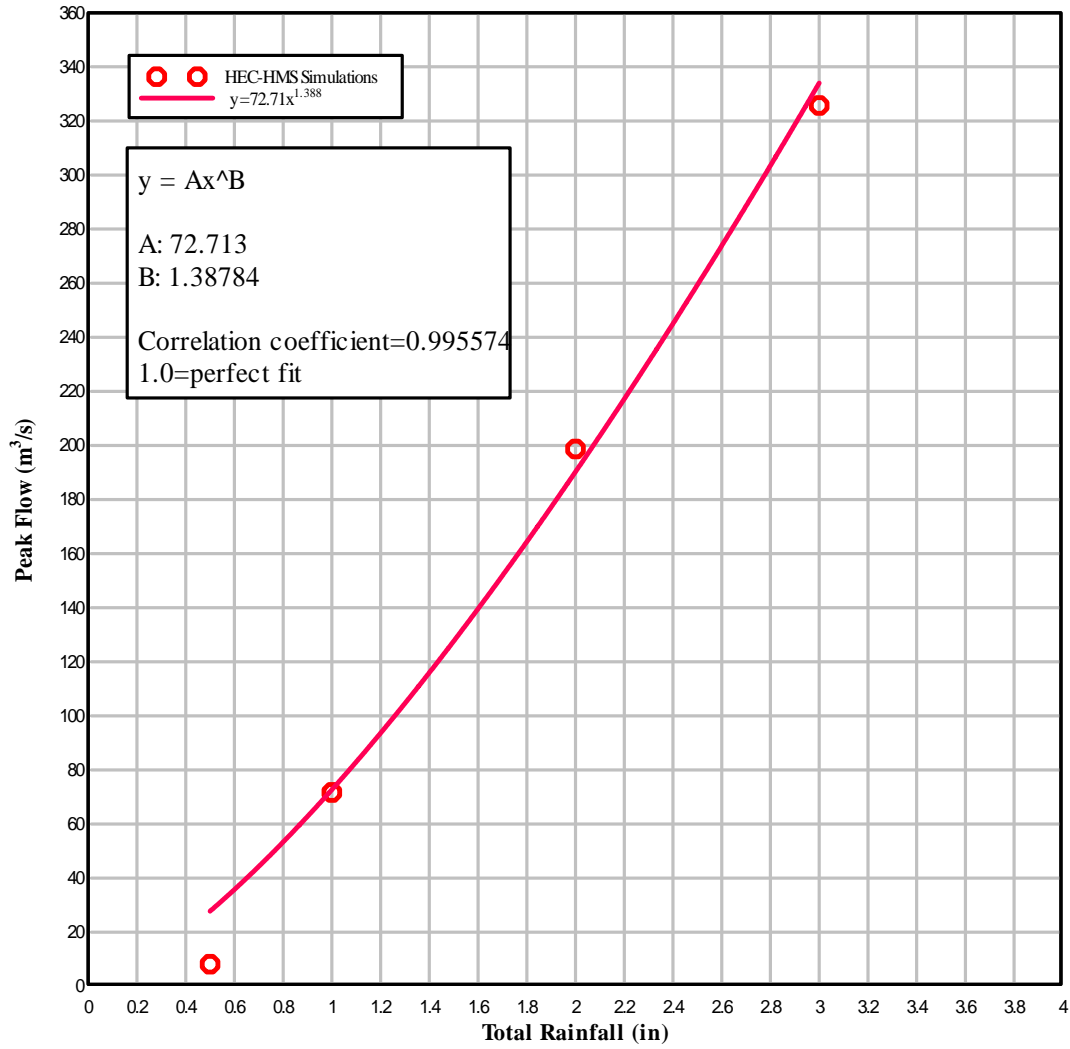


Figure 35
 Lower Three Runs Peak Runoff Flow as a Function of Total Rainfall
 Rainfall Duration = 3 hour

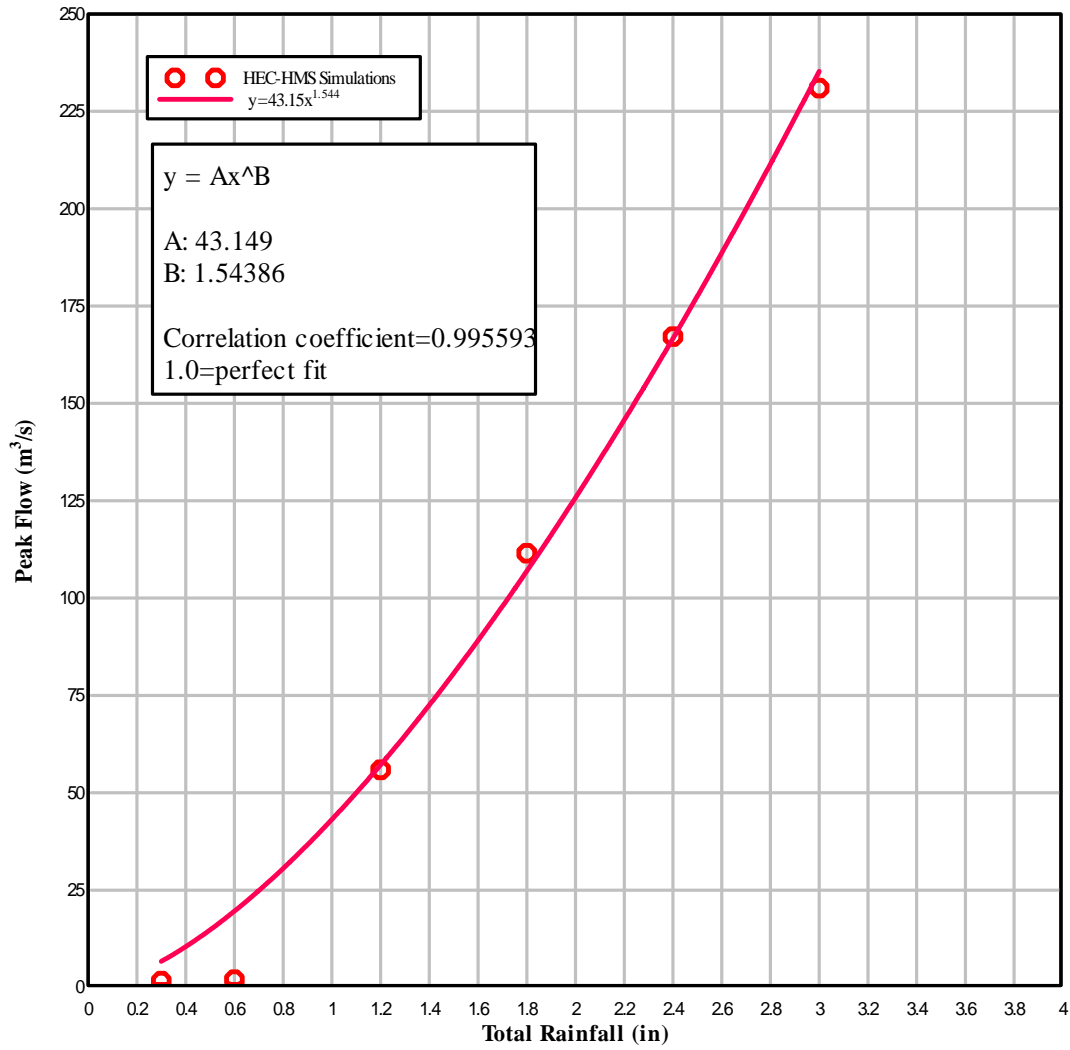


Figure 36
Lower Three Runs Peak Runoff Flow as a Function of Total Rainfall
Rainfall Duration = 6 hours

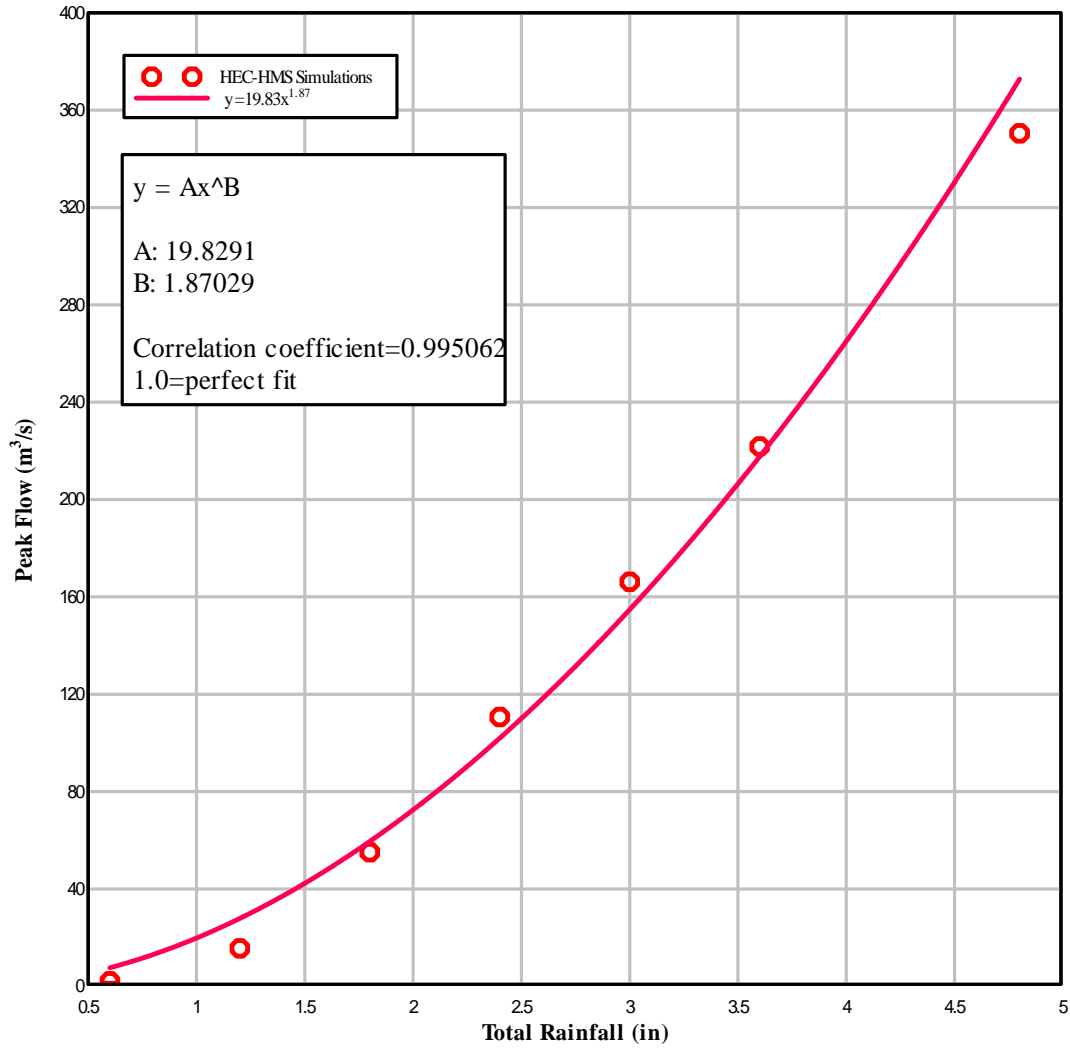


Figure 37
Lower Three Runs Peak Runoff Flow as a Function of Total Rainfall
Rainfall Duration = 12 hour

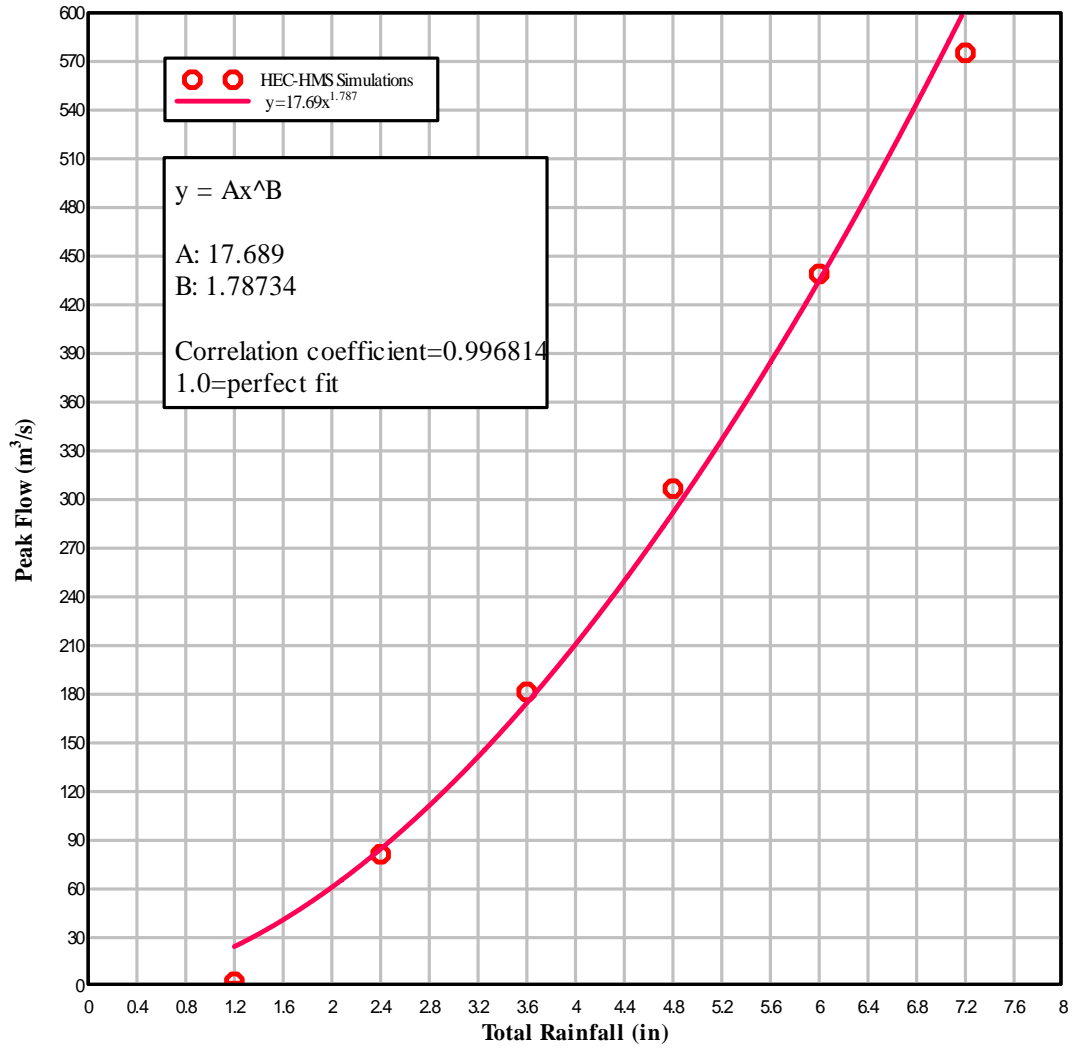


Figure 38
Lower Three Runs Peak Runoff Flow as a Function of Total Rainfall
Rainfall Duration = 24 hours

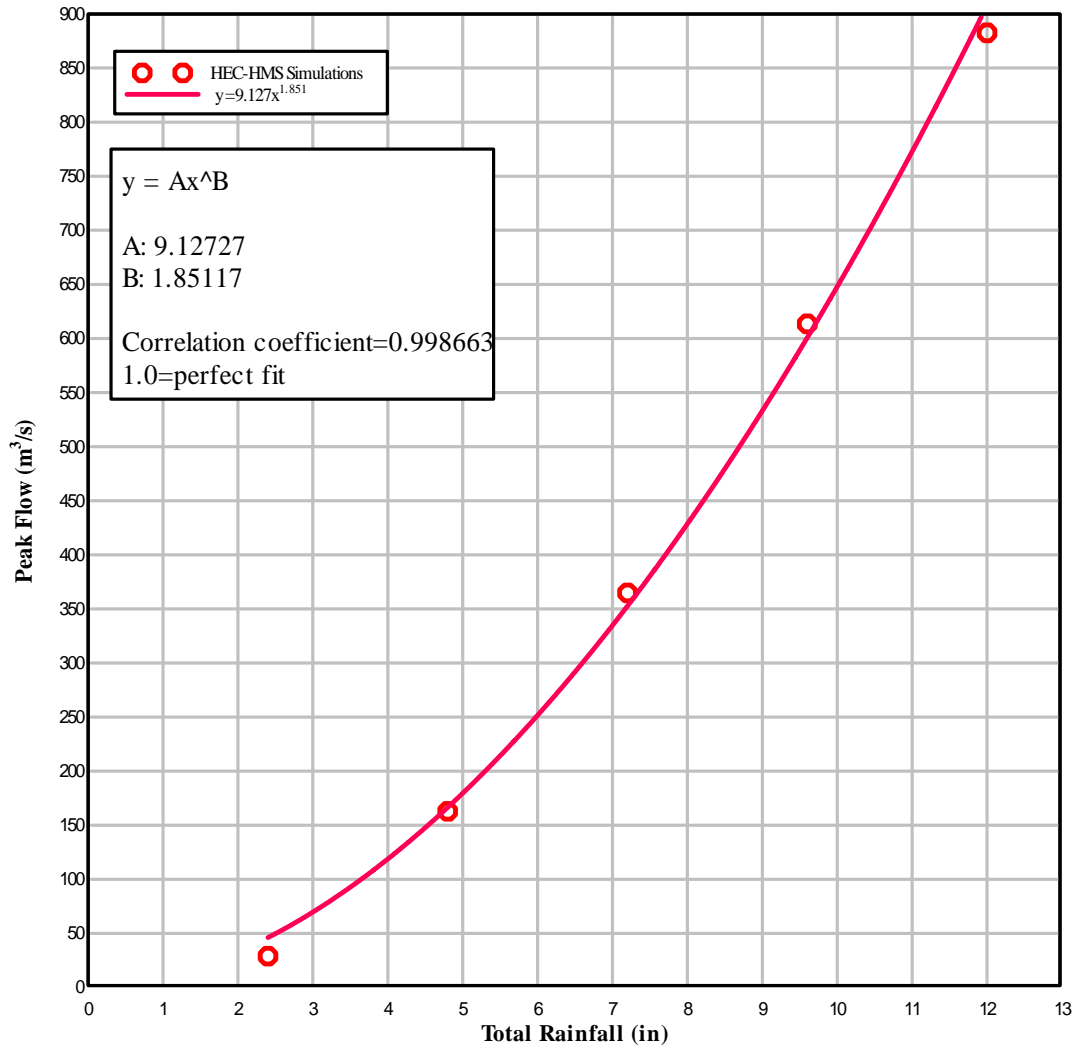


Figure 39
 Calculated Upper Three Runs Segment Volume as a Function of Flow
 Segment Size: 500 Meters

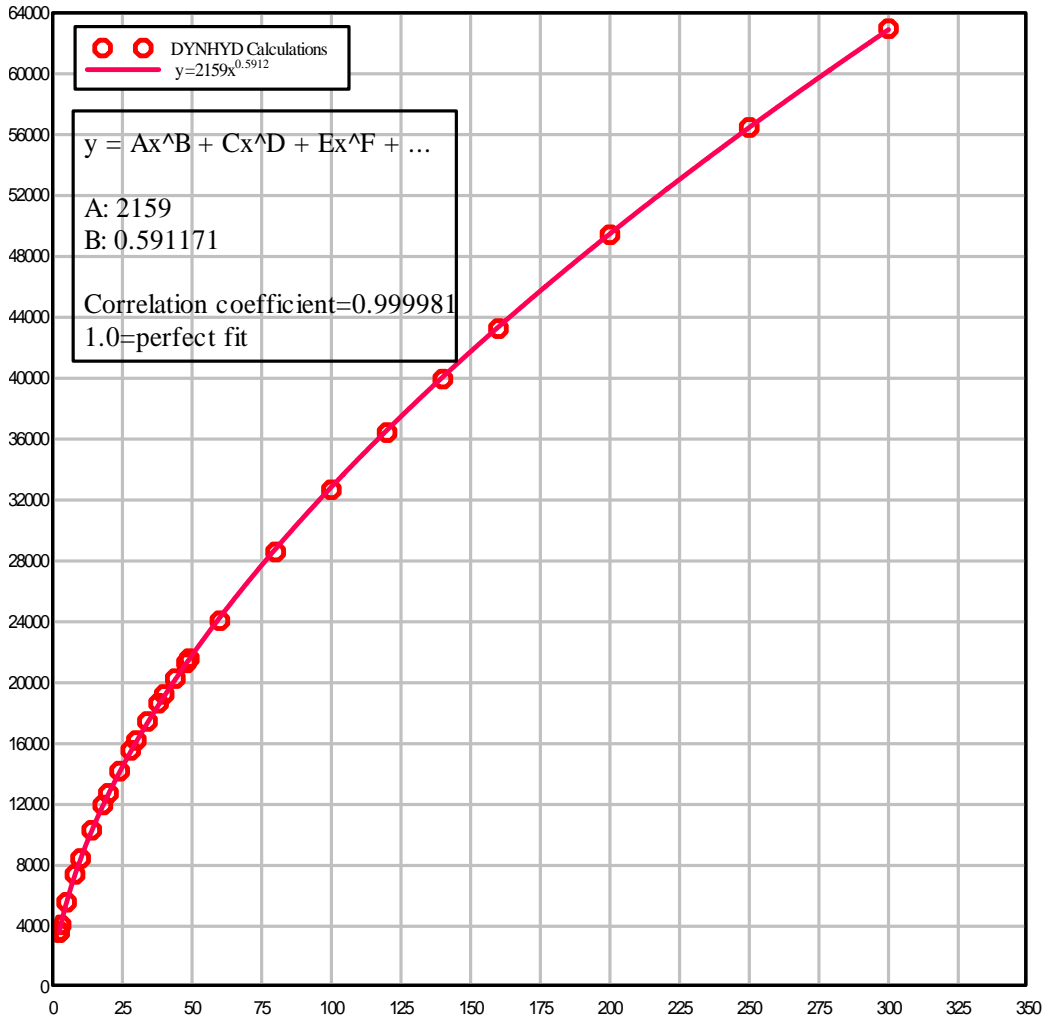


Figure 40
 Calculated McQueen Branch Segment Volume as a Function of Flow
 Segment Size: 500 Meters

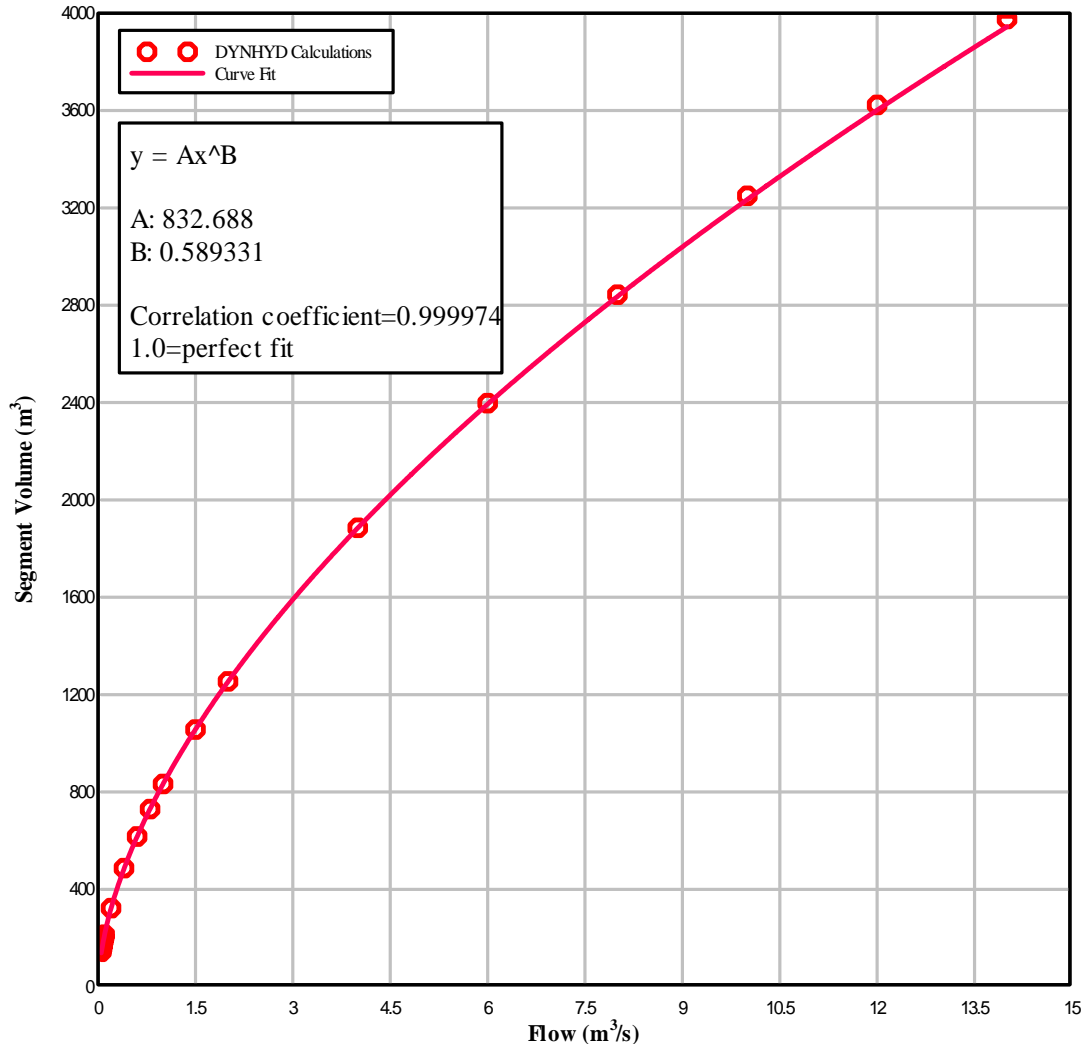


Figure 41
 Calculated Tims Branch Segment Volume as a Function of Flow
 Segment Size: 500 Meters

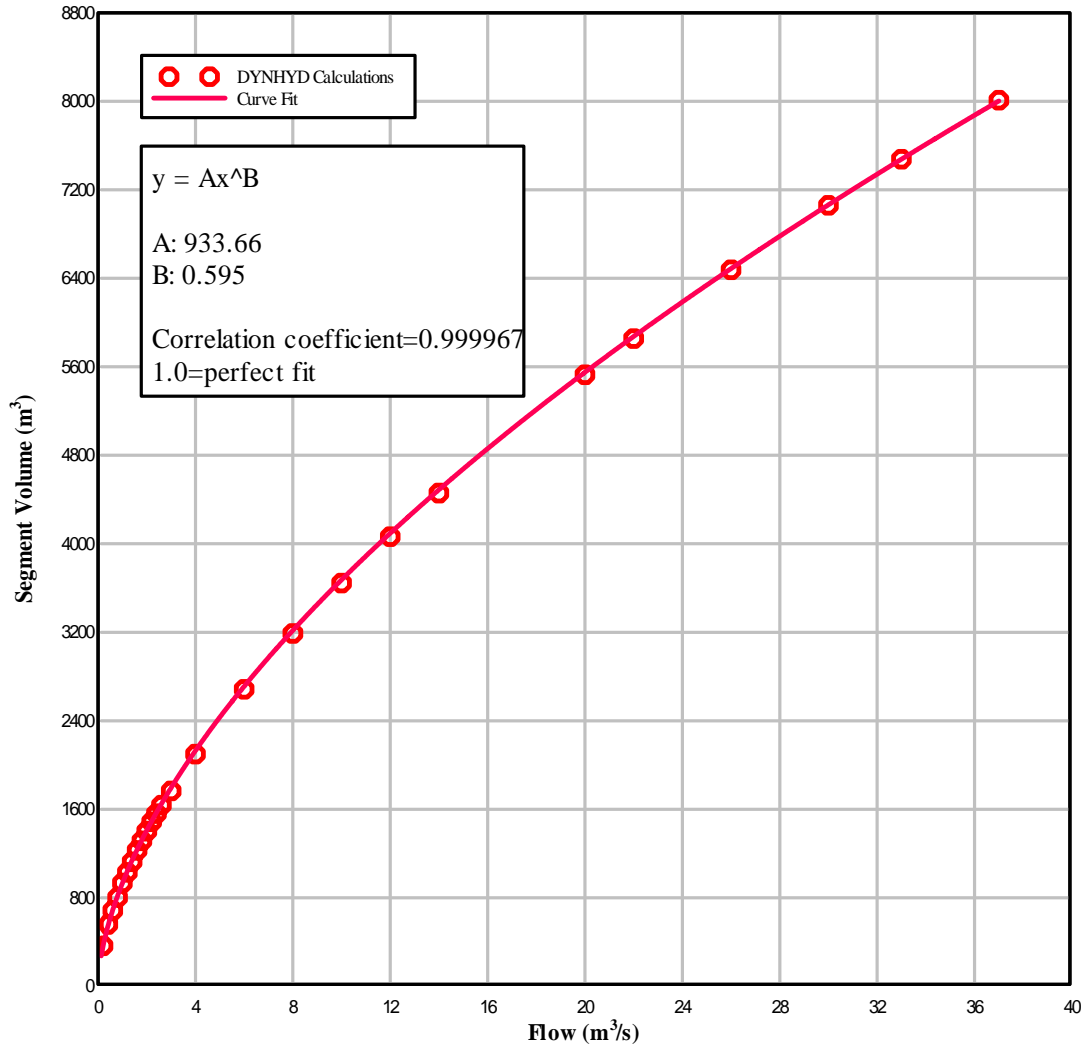


Figure 42
 Calculated Fourmile Branch Segment Volume as a Function of Flow
 Segment Size: 150 Meters

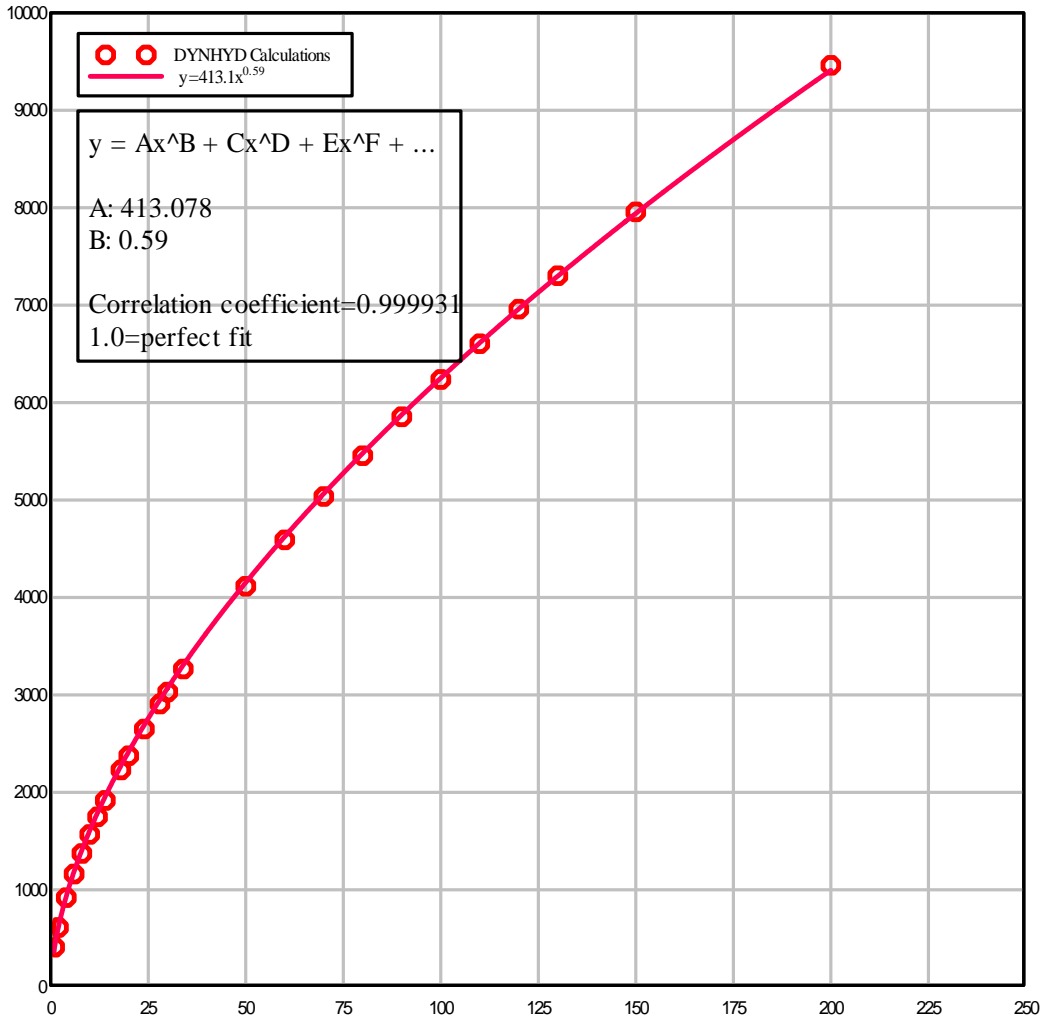


Figure 43
 Calculated Pen Branch Segment Volume as a Function of Flow
 Segment Size: 500 Meters

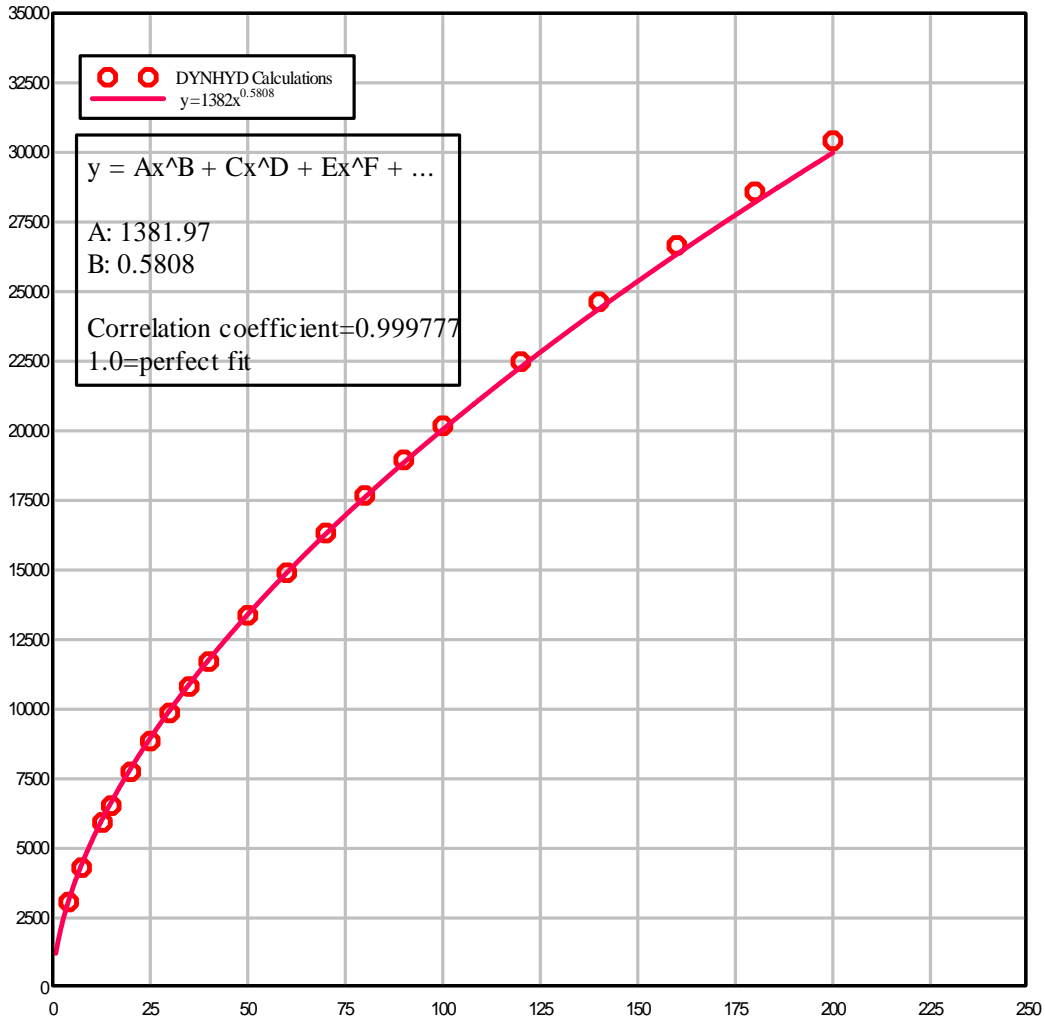


Figure 44
 Calculated Steel Creek Segment Volume as a Function of Flow
 Segment Size: 500 Meters

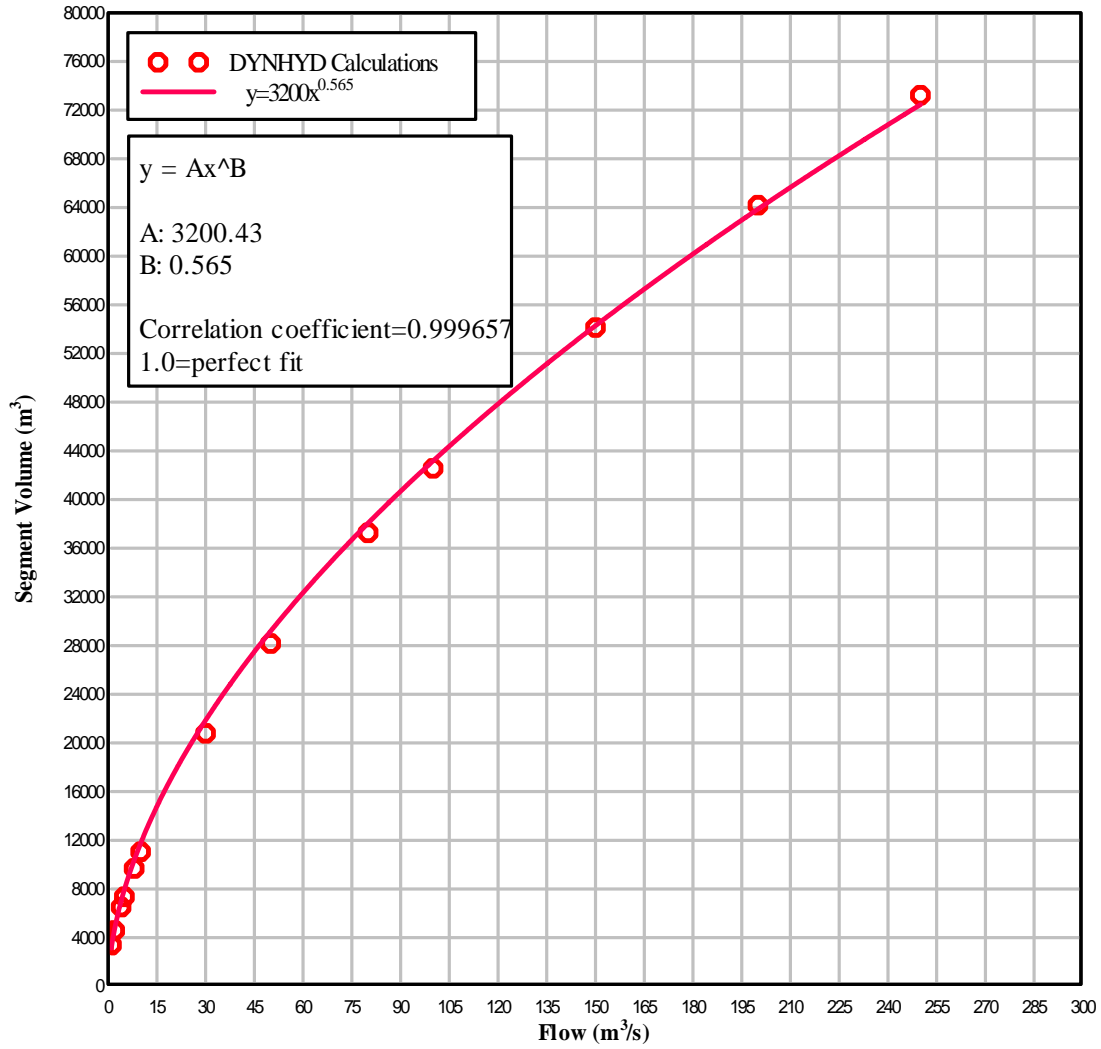


Figure 45
 Calculated Lower Three Runs Segment Volume as a Function of Flow
 Segment Size: 500 Meters

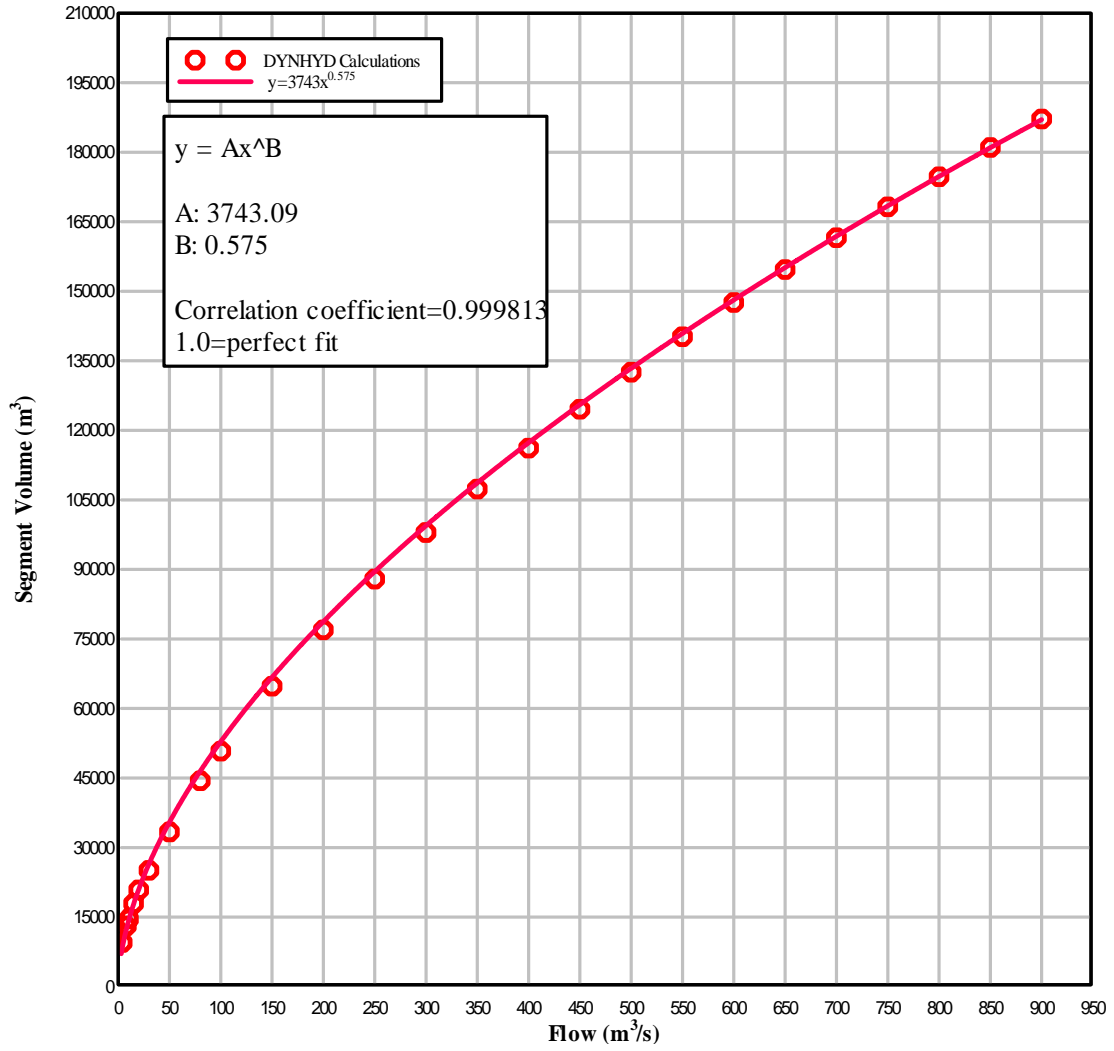


Figure 46
 Calculated Savannah River Segment Volume as a Function of Flow
 Segment Size: 500 meters

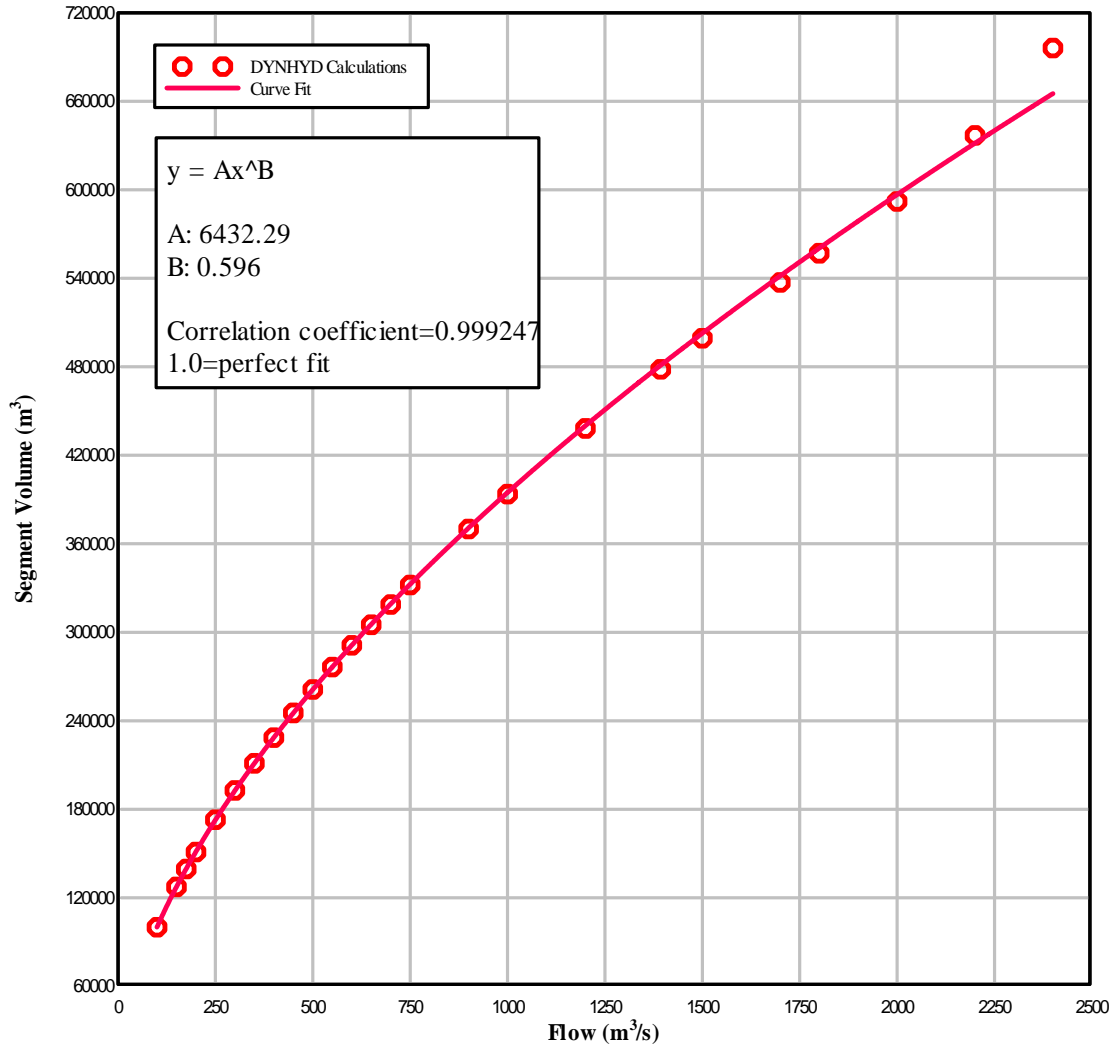


Figure 47 STREAM II-V5 Graphical User Interface

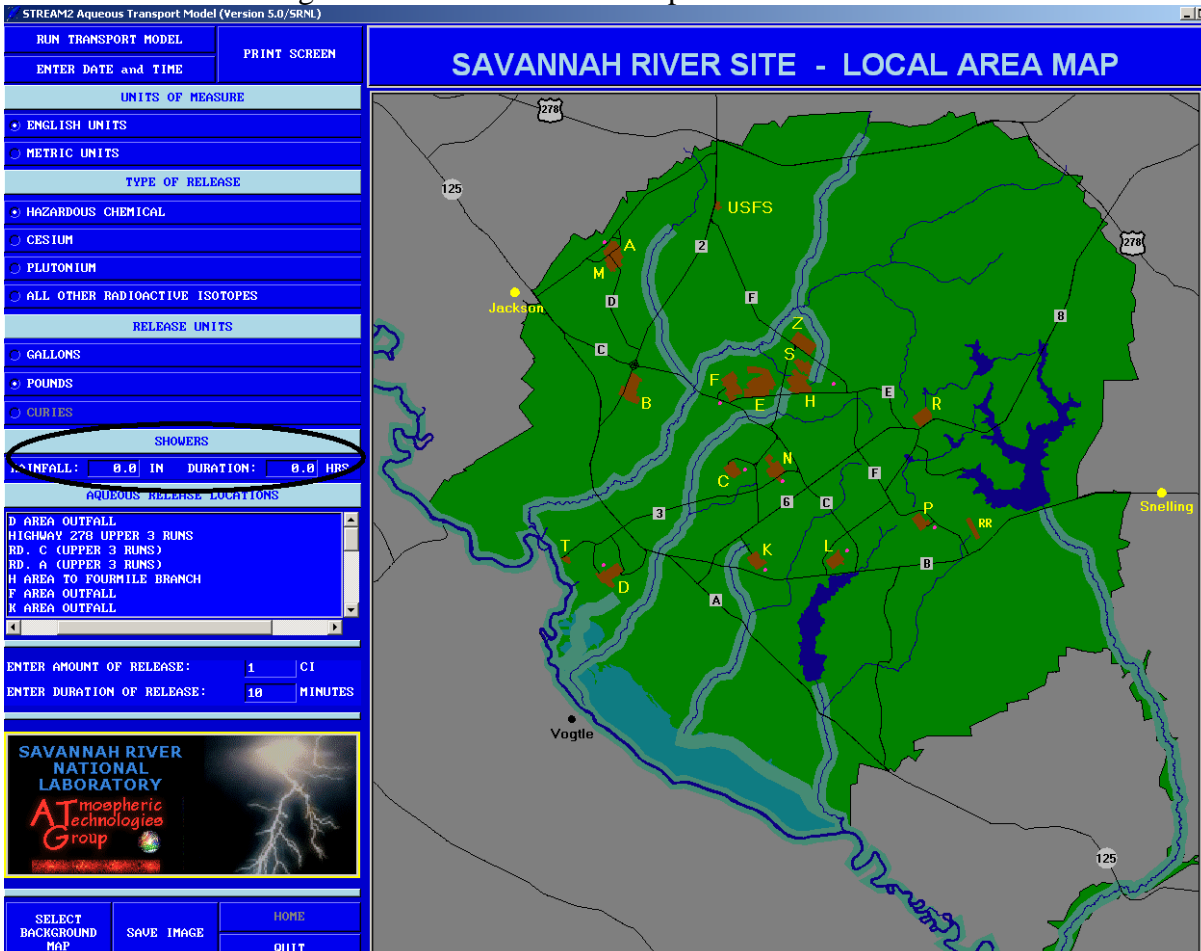
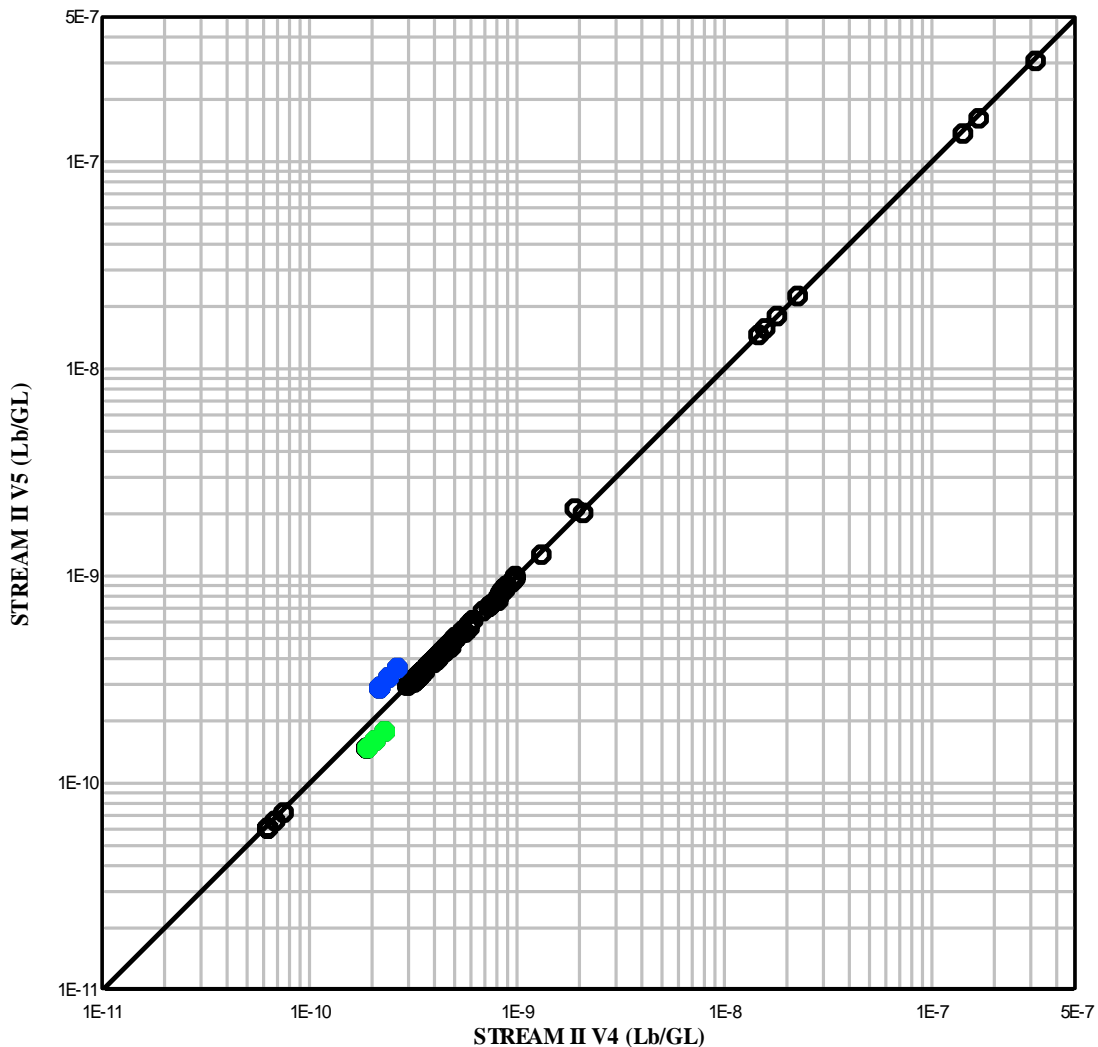


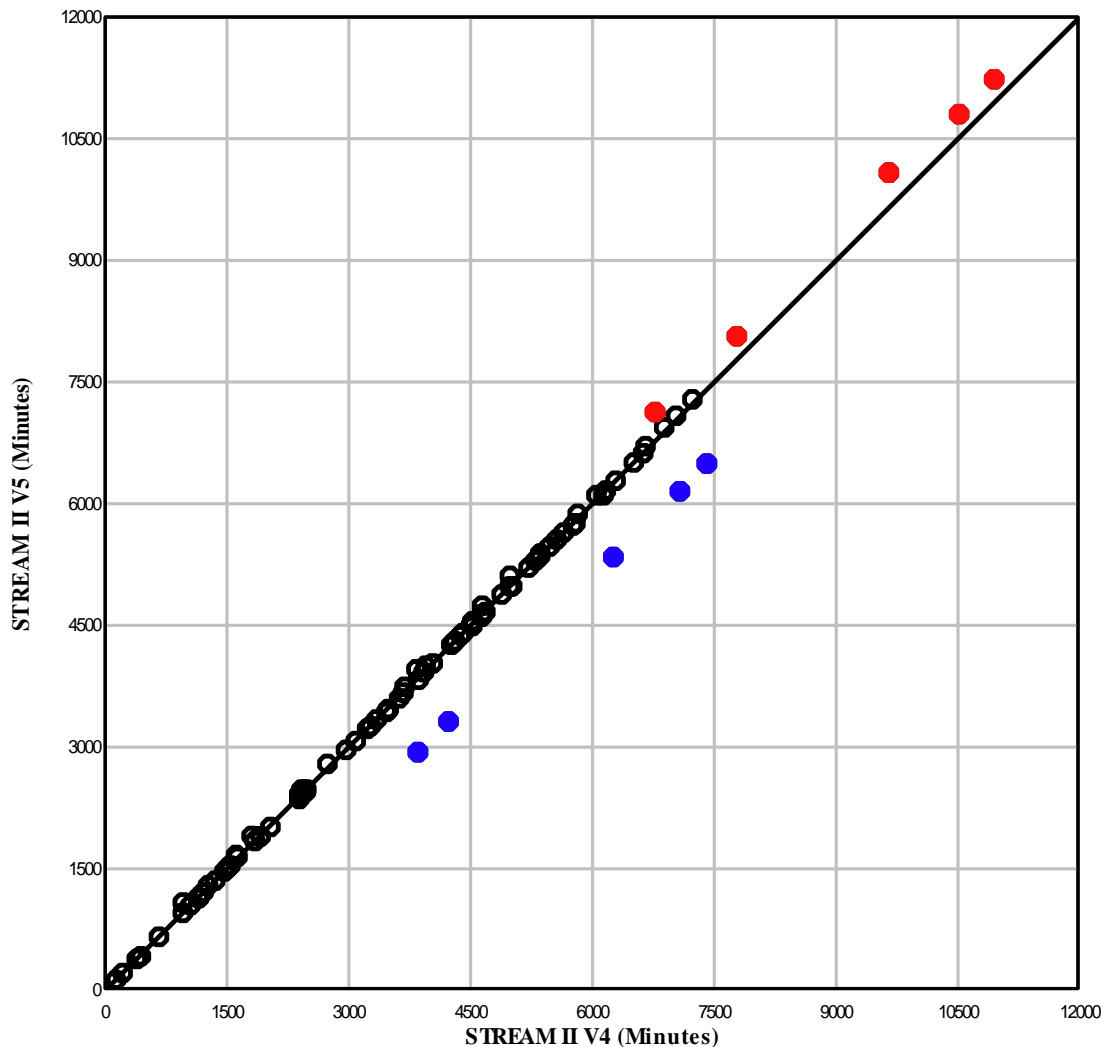
Figure 48
 Comparison of Model Predictions for the Peak Concentrations
 STREAM II-V5 vs STREAM II-V4



Note:

The green dots represent the simulation results for a release into the Steel Creek, and the blue dots represent the simulation results for a release into the Lower Three Runs. In STREAM II-V5, the segment volumes were varied as a function of flow. However, for STREAM II-V4, the segment volumes were also varied as a function of flow except the Pen Branch, Steel Creek and Lower Three Runs. As a result, predictions of the peak concentrations are not in good agreement between these two versions.

Figure 49
 Comparison of Model Predictions for the Peak Concentration Arrival Time
 STREAM II-V5 vs STREAM II-V4



Note:

The blue dots represent the simulation results for a release into the Lower Three Runs, and the red dots represent the simulation results for a release into the Pen Branch. In STREAM II-V5, the segment volumes were varied as a function of flow. However, for STREAM II-V4, the segment volumes were also varied as a function of flow except the Pen Branch, Steel Creek and Lower Three Runs. As a result, predictions of the peak concentration and peak concentration arrival time are not in good agreement between these two versions.

Figure 50
 Effects of Rainfall on the Predicted Peak Concentration Arrival Time
 Rainfall vs No Rainfall

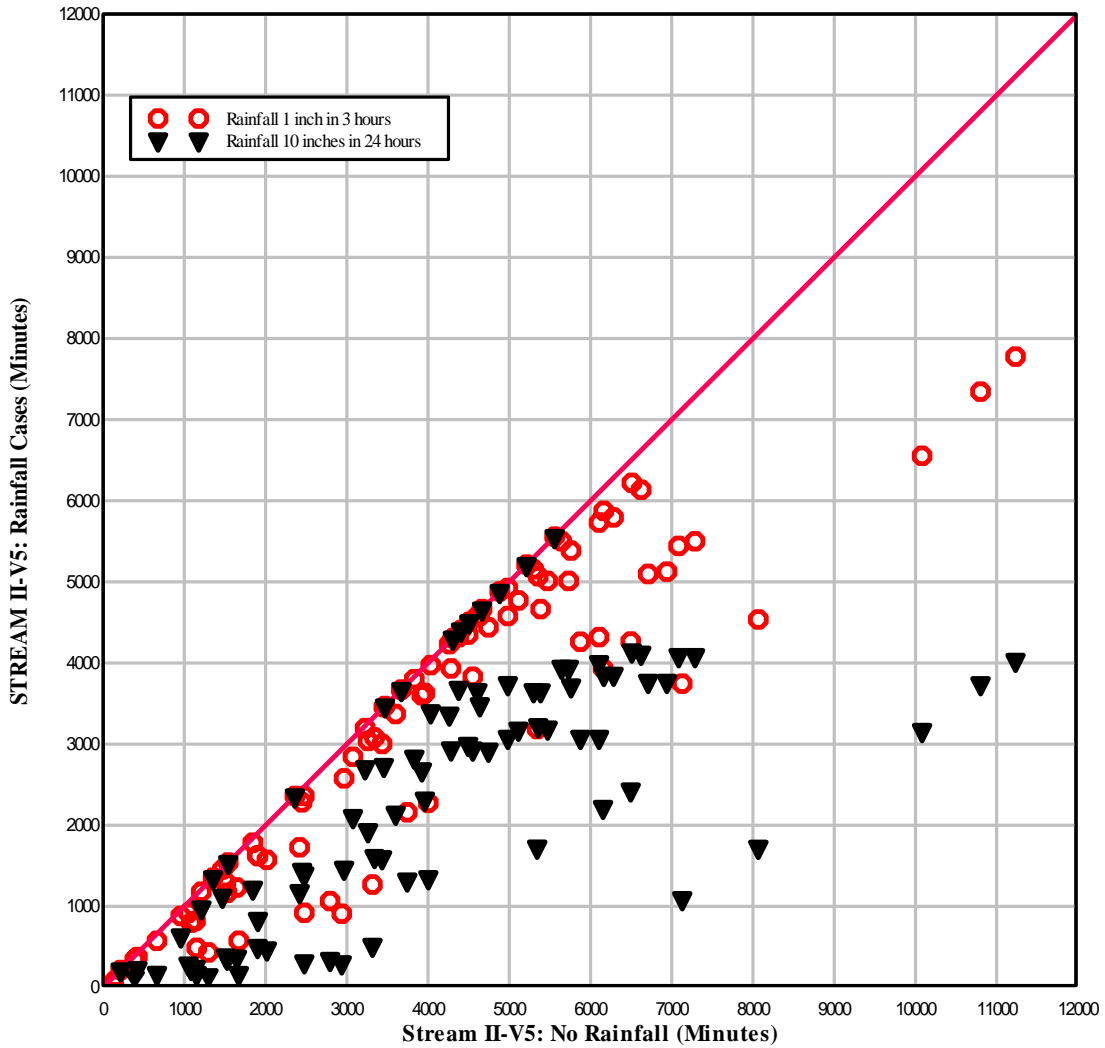
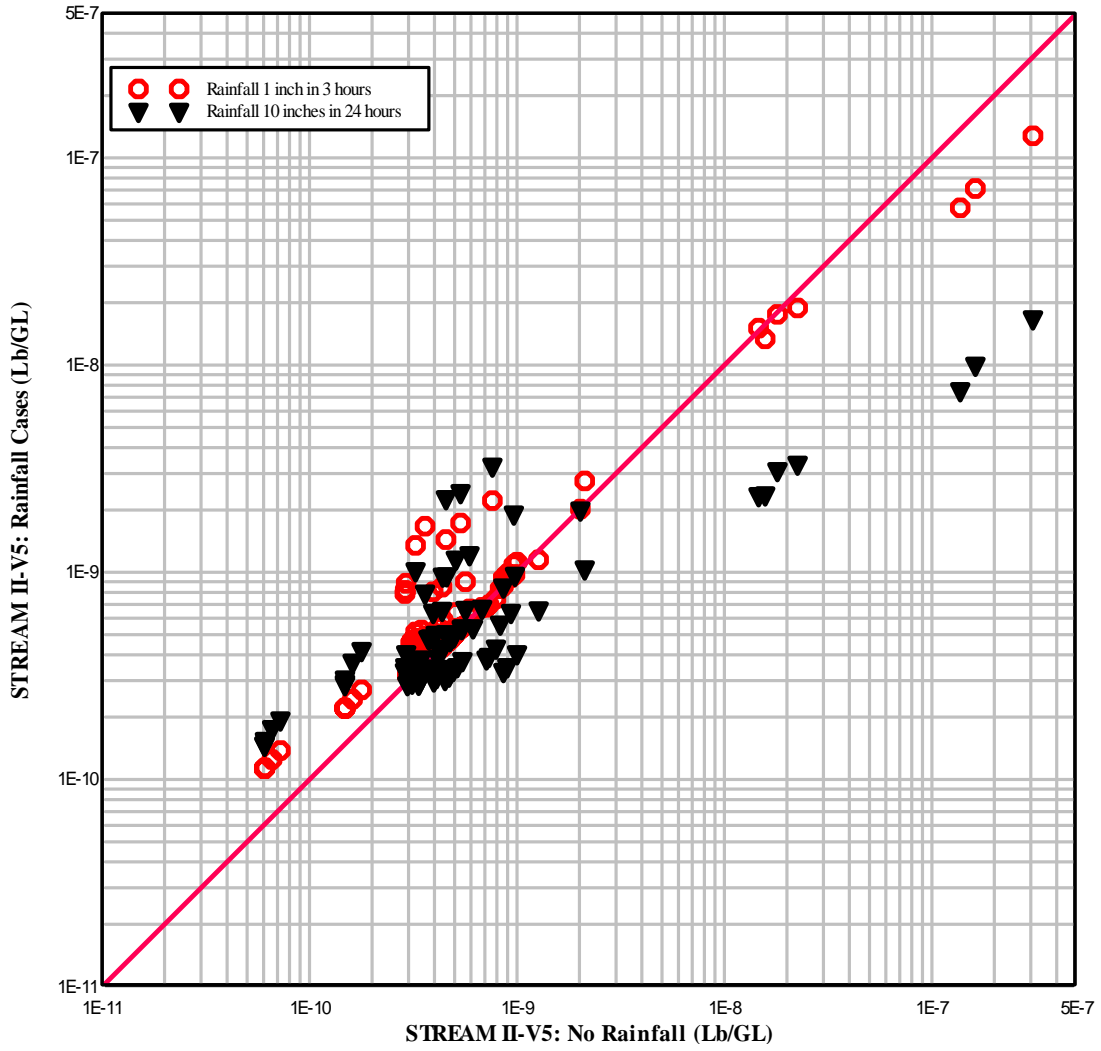


Figure 51
 Effects of Rainfall on the Predicted Peak Concentrations
 Rainfall vs No Rainfall



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