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STREAM II-V5: Revision of STREAM II-V4 Aqueous Transport Code to Account for the Effects of Rainfall Events

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ABSTRACT

STREAM II is an aqueous transport model developed by the Savannah River National Laboratory (SRNL) for use in the Savannah River Site (SRS) emergency response program. The transport model of the Water Quality Analysis Simulation Program (WASP) is 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. A recent version of the code (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-V5 is an upgraded version which accounts for the effects of a storm event. The revised model finds the proper stream inlet flow based on the total rainfall and rainfall duration as input by the user. STREAM II-V5 then 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 paper will discuss the required modifications to STREAM II and a comparison of results between the older and newer versions for an example involving a rainfall event.

Key Words: STREAM II, Aqueous Transport

1 INTRODUCTION

STREAM II-V4[1] is the aqueous transport module currently used by the Savannah River Site (SRS) emergency response Weather Information Display (WIND) system[2]. The transport model of the Water Quality Analysis Simulation Program (WASP)[3] is 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 these effects. 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. Since some of the stream monitors at the SRS streams were eliminated in the past several years due to budget constraints, an alternate method was 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, and 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 I shows the design six-hour extreme precipitation hyetograph[4], and Table II presents the design 24-hour extreme precipitation hyetograph[5]. Both design extreme precipitation hyetographs were developed specifically for SRS based on historical data at or near SRS. Table III 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 III was chosen to cover possible extreme rainfall events as defined by Tables I and II, 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 III. Tables I and II were used to develop the rainfall distributions for the rainfall events shown in Table III.

Table I. Six-Hour Storm Rainfall Distribution (in inches) as a Function of Return Period

Return Period	Hour 1	Hour 2	Hour 3	Hour 4	Hour 5	Hour 6	Accumulation
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

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

Table II. 24-Hour Storm Rainfall Distributions (in inches) as a Function of Return Period

	Return Period		
	50-year	**100-year**	**500-year**
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 III 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		

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

$$C_i^{24} = \frac{A_i^{24}}{B^{24}} \qquad i = 1, 2, 3, \ldots, 24 \text{ hour} \tag{1}$$

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

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

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 II. Also,

$$B^{24} = \frac{1}{24}\sum_{i=1}^{24} A_i^{24} . \tag{3}$$

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

$$R_i^{X,24} = X^{24} C_i^{24}, \tag{4}$$

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

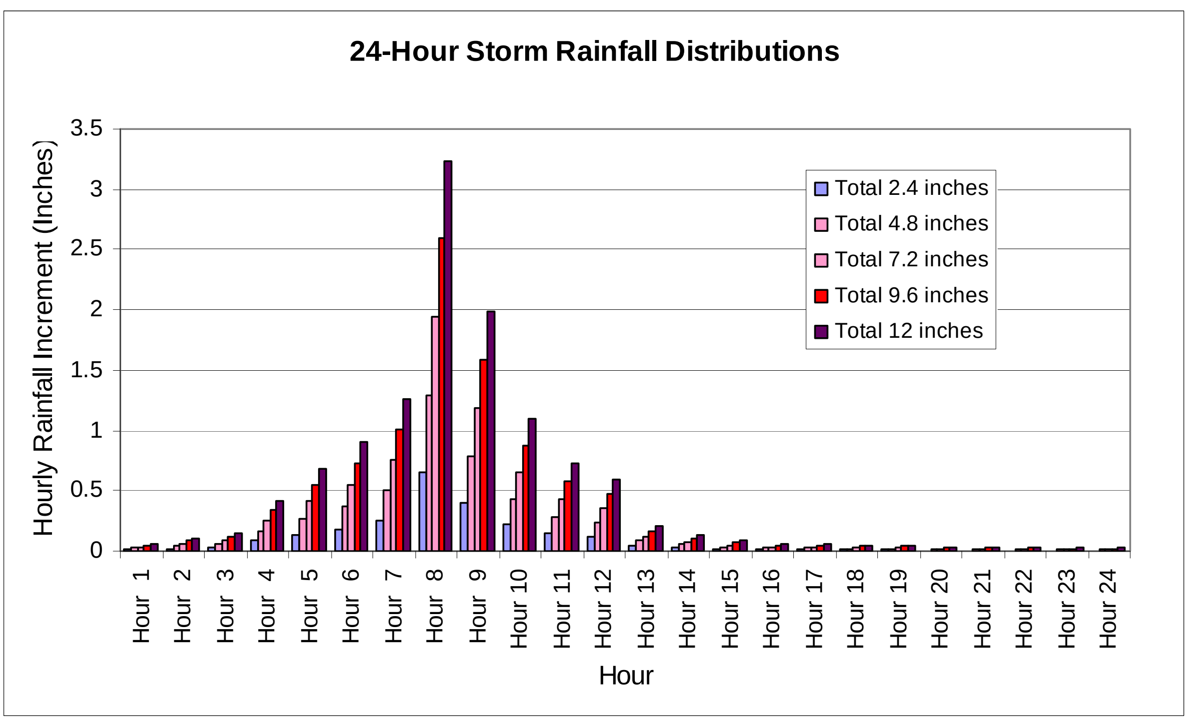

Figure 1. 24-Hour Storm Rainfall Distributions

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.

$$C_i^{12} = \frac{1}{2}\left(C_{2i-1}^{24} + C_{2i}^{24}\right). \qquad \text{i = 1,2,3, …, 12 hour} \tag{5}$$

The precipitation distributions for a total rainfall of X^{12} inches in 12 hours are similar to that given by Equation 4 for 24 hour rainfall events where X^{12} values are given in Table III.

The derivation of rainfall distributions for the 6-hour rainfall events uses the same method described for the 24 hours rainfall events, except the distribution data were obtained from Table I.

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

$$C_i^6 = \frac{A_i^6}{B^6}, \qquad \text{i = 1, 2, 3, …, 6 hour} \tag{6}$$

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

$$A_i^6 = \frac{1}{3}\left(r_i^{6,50} + r_i^{6,100} + r_i^{6,500}\right). \tag{7}$$

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 I. Also,

$$B^6 = \frac{1}{6}\sum_{i=1}^{6} A_i^6 . \tag{8}$$

The precipitation distributions are derived as in Equation 4 using a range of X^6 given in Table III.

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

$$C_i^3 = \frac{1}{2}\left(C_{2i-1}^{6} + C_{2i}^{6}\right). \qquad \text{i = 1, 2, 3 hour} \tag{9}$$

The precipitation distributions are derived as in Equation 4 using a range of X^3 given in Table III.

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. A set of DEM data at a 30-by-30-meter resolution which covers the Savannah River Site (SRS) was used by HEC-GeoHMS to delineate the watersheds of the Upper Three Runs, Fourmile Branch, Pen Branch, Steel Creek, and Lower Three Runs. The Upper Three Runs watershed includes the Tinker Creek, McQueen Branch, and Tims Branch sub-basins, as shown in Figure 2.

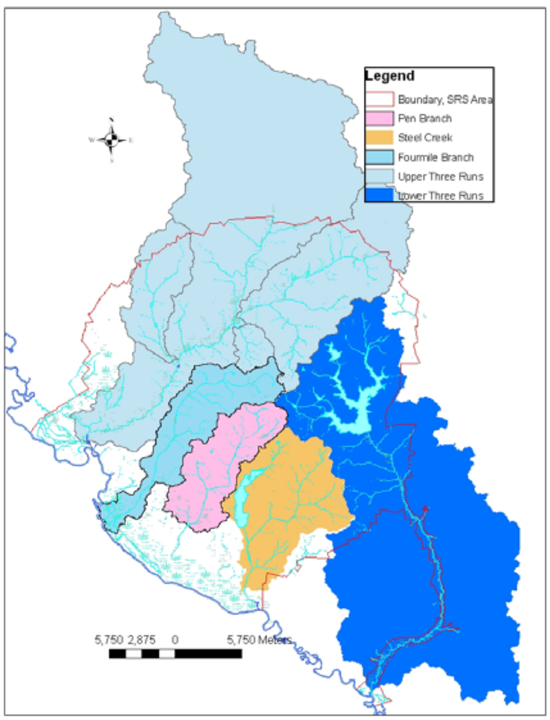

Figure 2. Watershed Delineated by HEC-GeoHMS, the Savannah River is Shown Along the Western Edge of the Map.

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. The HEC-HMS input parameters for all pertinent watersheds are summarized in Table IV[4,5]. Comments related to these inputs follows.

Upper Three Runs is the longest and northernmost system in SRS. Three main tributaries of Upper Three Runs are the Tinker Creek, McQueen Branch, and Tims Branch. The rainfall input for the HEC-HMS simulations are from Section 2. For example, Figure 3 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 3 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.

Table IV. 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 (ft3/s)	190	27	18	2	2
Recession Constant	0.965	1.0	0.80	0.9	0.9
Thresholds flow (ft3/s)	200	39	60	3	3

*Meyers Branch

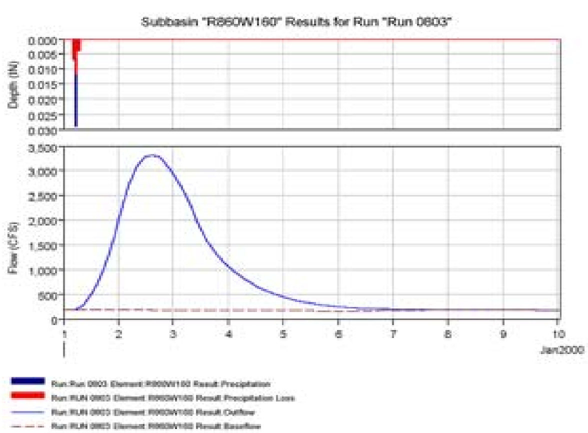

Figure 3. HEC-HMS Simulation for the Upper Three Runs Watershed Runoff Hydrograph (2.8 Inches of Rainfall in 3 Hours)

The hyetographs derived in Section 2 were used by HEC-HMS to calculate the peak flow as a function of total rainfall and rainfall duration. Figures 4 shows an example of the calculated Upper Three Runs peak flow as a function of total precipitation for rainfall duration 24 hours. The equations shown in Figure 4 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.

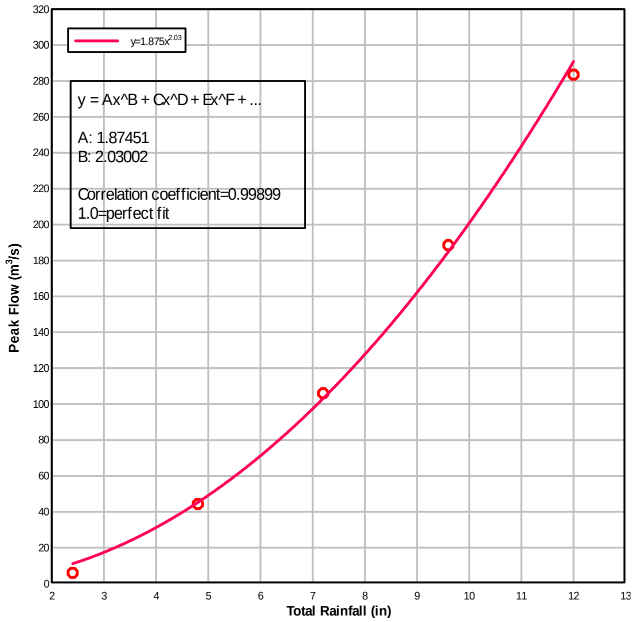

Figure 4. Upper Three Runs Peak Runoff Flow as a Function of Total Rainfall (Rainfall Duration=24 Hours)

Beaver Dam Creek was an intermittent stream before SRS operation. The D-area Outfall D-01 (see site location in Figure 6) 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 being 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.

The Fourmile Branch flows to the southwest into the Savannah River swamp and then into the Savannah River.

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 major tributary of the Steel Creek is Meyers Branch. The L-Lake is at the upper stream of the Steel Creek. 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 IV.

PAR Pond is at the upstream of Lower Three Runs. 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 IV. The basin area and the Soil Conservation Service (SCS) lag time for the Lower Three Runs sub-basin were calculated by the HEC-GeoHMS. The remainder of the input parameters for the Lower Three Runs sub-basin were estimated based on judgment.

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.

As shown in Figure 4, the peak flow is expressed as:

$$F = \alpha Y^{\beta}, \tag{10}$$

where F is the peak flow in cubic meter per second, Y is the total rainfall in inches, and α and β shown in Table V are parameters obtained by fitting the peak flow calculated by HEC-HMS.

Table V. Parameters Used in Peak Flow Determination

	Upper Three Runs		Fourmile Branch		Pen Branch		Steel Creek		Lower Three Runs	
Rain Fall Duration (Hour)	α	β	α	β	α	β	α	β	α	β
1	20.605	1.730	15.272	1.416	17.212	1.375	7.452	2.686	72.713	1.388
3	10.502	1.962	8.280	1.630	7.870	1.800	4.214	2.798	43.149	1.544
6	3.745	2.212	3.877	1.927	4.891	1.836	1.148	2.900	19.826	1.870
12	2.923	2.157	3.503	1.819	4.364	1.756	1.299	2.500	17.689	1.787
24	1.875	2.030	1.935	1.837	2.385	1.794	0.605	2.420	9.127	1.851

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 flow. 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 USGS[12].. Similarly, these three parameters were estimated for Fourmile Branch[13], for Pen Branch and Steel Creek[14], and for the Lower Three Runs were[15].

The 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 were calculated. Figure 5 shows an example of the calculated segment volume as a function of flow for the Upper Three Runs. 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]. Figure 5 also shows a fitted equation

$$V = aF^{b}, \tag{11}$$

where V is the stream segment volume in cubic meters and F is the flow in cubic meters per second. The parameters a and b for various streams are presented in Table VI.

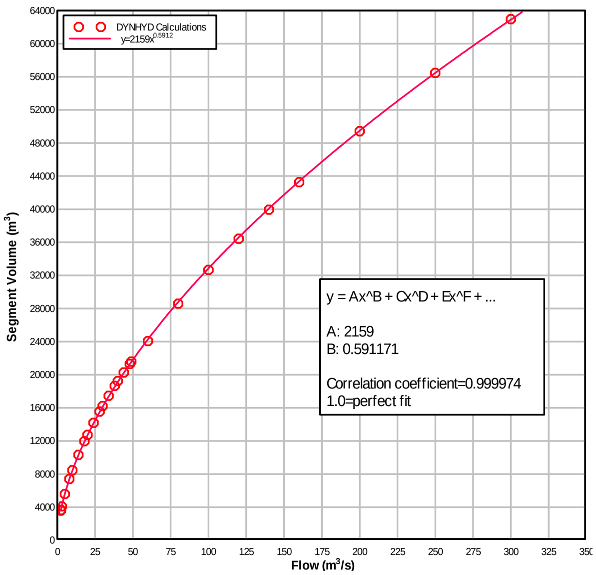

Figure 5. Calculated Upper Three Runs Segment Volume as a Function of Flow (Segment Size=500 meters)

Table VI. Parameters used for Stream Segment Volume

Stream	a	b
Upper Three Runs	2159.0	0.5912
McQueen Branch	832.7	0.5893
Tims Branch	933.7	0.5950
Fourmile Branch	413.1	0.5900
Pen Branch	1382.0	0.5808
Steel Creek	3200.4	0.5650
Lower Three Runs	3743.1	0.5750
Savannah River	6432.3	0.5960

6 CODE MODIFICATIONS

Changes to the STREAM II code as a result of this work include:

1. providing the user a means of inputting the total rainfall and rainfall duration,
2. employing the input to calculate the stream flow based on peak flow determination (described in Section 4), and
3. using the stream flow to adjust the stream segment volume (described in Section 5).

Figure 6 shows the revised graphical user interface where the inputs for rainfall are highlighted inside the ellipse.

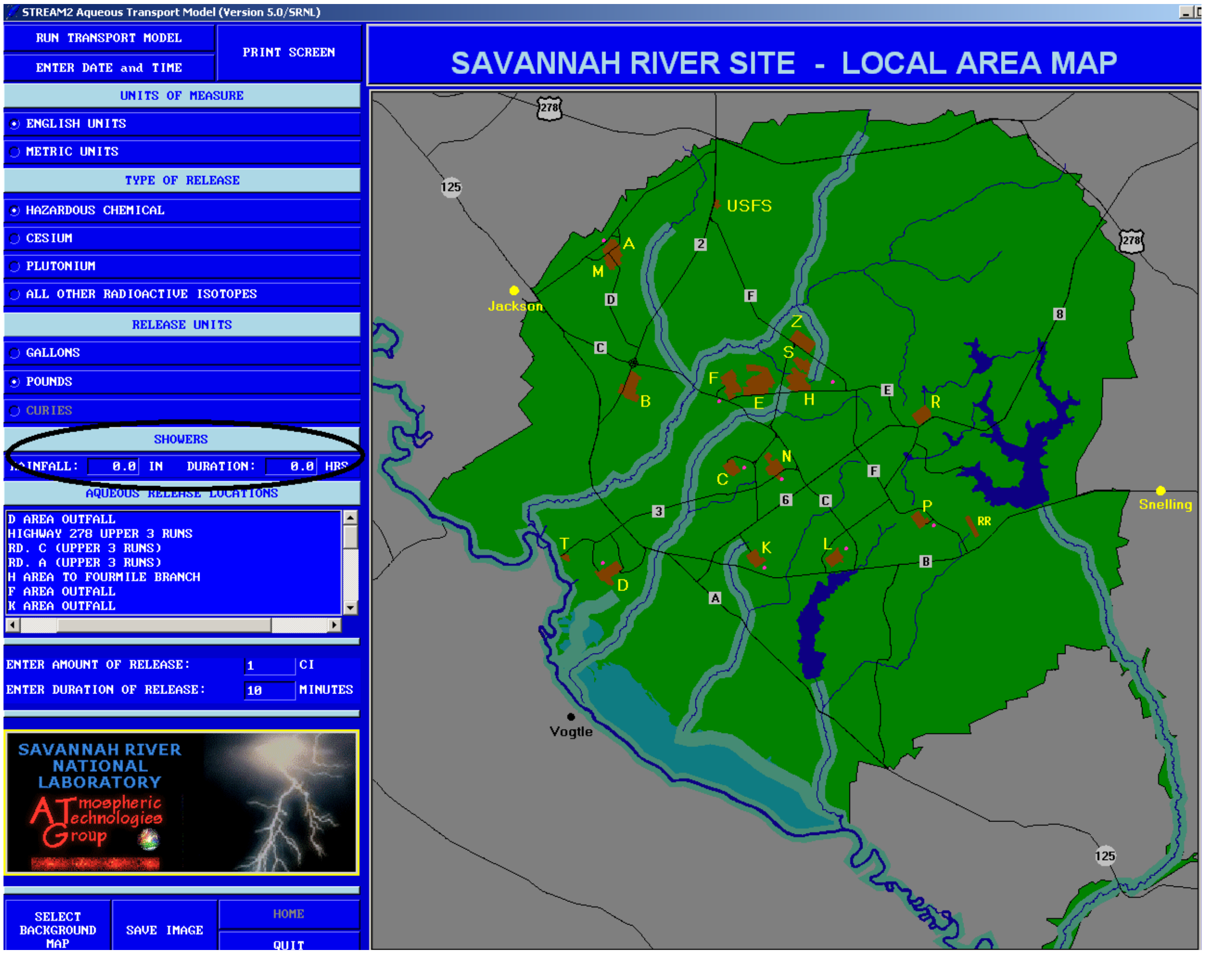

Figure 6. STREAM II-V5 Graphical User Interface (Site locations denoted by yellow letters)

7 TEST RESULTS

Test cases were run to compare the model predicted results between STREAM II-V4 and STREAM II-V5, and to examine the effects of the rainfall runoff on contaminant transport. Simulation comparisons assumed a one-pound hazardous chemical material was released from each of the various SRS facilities (as shown in Figure6).

7.1 STREAM II-V4 vs. STREAM II-V5

Baseline cases were simulated by both STREAM II-V4 and STREAM II-V5 with no rainfall. Figure 7 shows the comparison of peak concentrations, and Figure 8 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 7 and 8, each dot represents a different sampling location downstream of a release. The green dots in Figure 7 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 8, 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 7 and 8, 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.

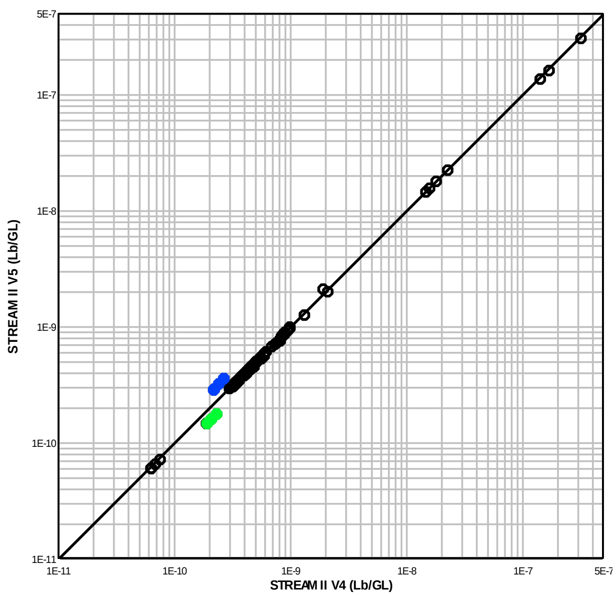

Figure 7 Comparison of Model Predictions for the Peak Concentrations (STREAM II-V5 vs STREAM II-V4)

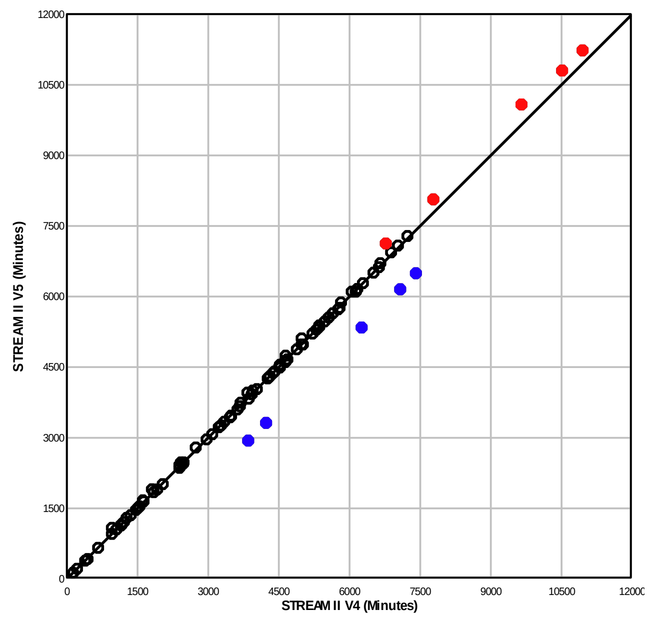

Figure 8 Comparison of Model Predictions for the Peak Concentration Arrival Time (STREAM II-V5 vs STREAM II-V4)

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 9 and 10.

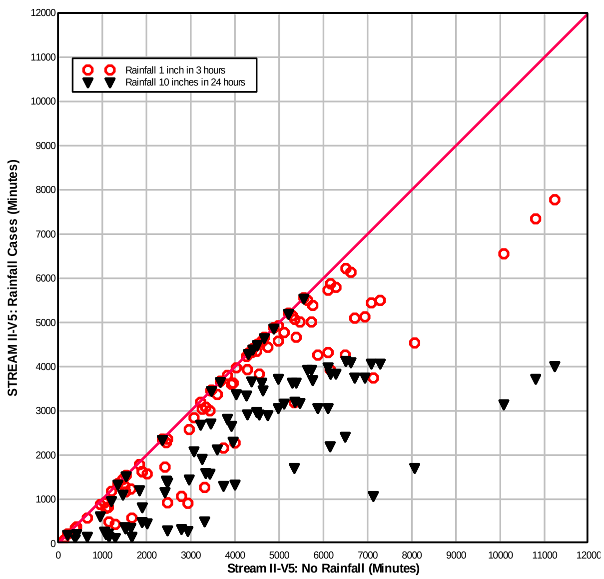

Figure 9 Effects of Rainfall on the Predicted Peak Concentration Arrival Time (Rainfall vs No Rainfall)

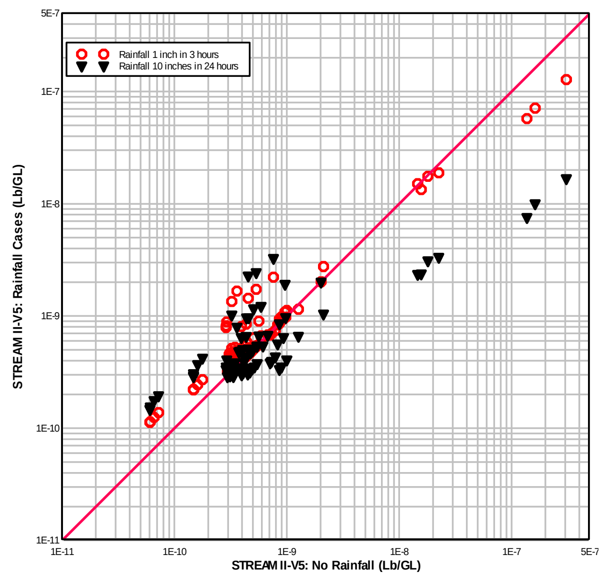

Figure 10 Effects of Rainfall on the Predicted Peak Concentrations (Rainfall vs No Rainfall)

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, and the runoff flow increases to 200.8 m3/s for the case of total rainfall of 10 inches in 24 hours. Figure 9 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 9.

Figure 10 presents the comparison of peak concentrations at sampling locations for the same axis representations. The data in the upper right corner of Figure 10 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 10.

The data in the lower left corner of Figure 10 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 9) 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 10.

8 CONCLUSIONS

An aqueous transport model used for Savannah River Site emergency response has been upgraded to account for effect on contaminant transport through the SRS streams and the Savannah River (STREAM II-V5). 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 leading to decreases in contaminant concentration. 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. 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 were derived by calibrating the HEC-HMS model with limited measured precipitation and stream flow records. The rainfall used for this calibration occurred in January, March and May[4, 5]. The soil moisture content for those months might be higher than the soil moisture content in the summer months. Therefore, the derived peak runoff flow 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.

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

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