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STREAM II-V8: Revision for STREAM II-V7 to Include Spatially Variable Radar Derived Rainfall.

G.M. Maze

March 2019

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EXECUTIVE SUMMARY

STREAM II is the aqueous transport model of the Weather Information and Display System (WINDS). It is used to calculate downstream transport in the event of a radiological or chemical spill into the waterways on the Savannah River Site during emergency operations. Improvements were made to the code to include spatially variable radar derived rainfall to improve the accuracy of model estimates of watershed runoff and flow values. In addition, watershed runoff curves for low rainfall values (<1 inch) were improved to provide better stream flow estimates.

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LIST OF ABBREVIATIONS

SRNL	Savannah River National Laboratory
WINDS	Weather Information and Display System
USGS	United States Geological Survey
SRS	Savannah River Site
EPA	Environmental Protection Agency
WASP5	Water Quality Analysis Simulation Program Version 5
HEC-HMS	Hydrologic Engineering Center- Hydrologic Modeling System
NEXRAD	Next Generation Weather Radar

1.0 Introduction

STREAM II-V7 [1] is the aqueous transport module currently used by the Savannah River Site emergency response resource WINDS. STREAMII-V7 models the Savannah River from SRS to a point upstream of the mouth of the Savannah River, as shown in Figure 1-1, and includes all of the site streams as shown in Figure 1-2. In order to represent watershed runoff and river flows more accurately, the STREAM II-V7 code was updated to allow for spatially variable rainfall amount and durations.

NOAAPORT provides the site with hourly Next Generation Weather Radar (NEXRAD) Level-III precipitation calculated for Z-R relationships [3]. This data is then gridded onto a site map and binned into watershed areas (Figure 1-3). For a simulation each watershed area will have an individually calculated total rainfall amount and duration by first calculating the rainfall total and duration over 24 hours at each grid cell, and then by averaging the rainfall totals and durations for each watershed. These rainfall totals and durations are used in rainfall-watershed runoff curve estimates to predict the streamflow under the given rainfall conditions. The rainfall-watershed runoff curve estimates were updated to give better estimates under low rainfall conditions.

Figure 1-1. Savannah River Spanning from Augusta Georgia to Atlantic Ocean

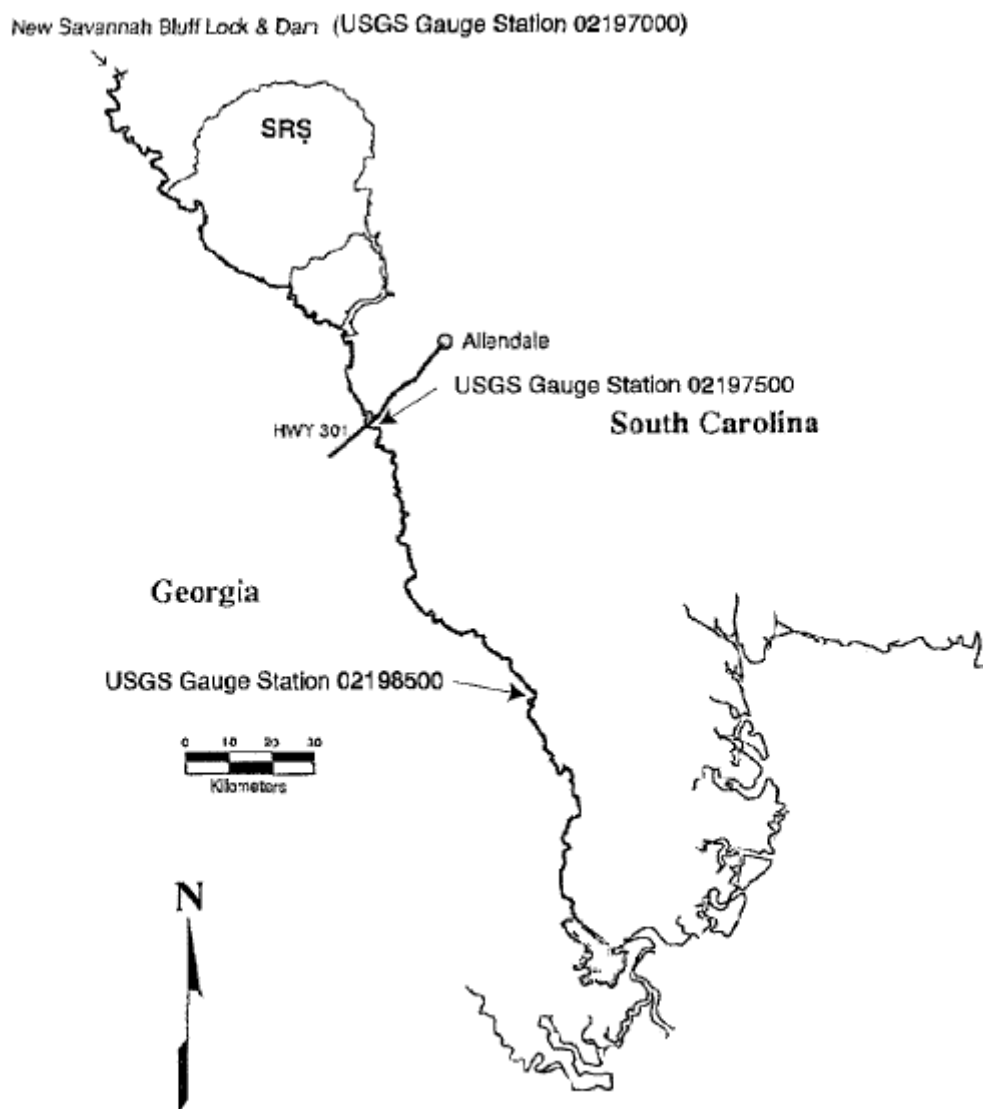
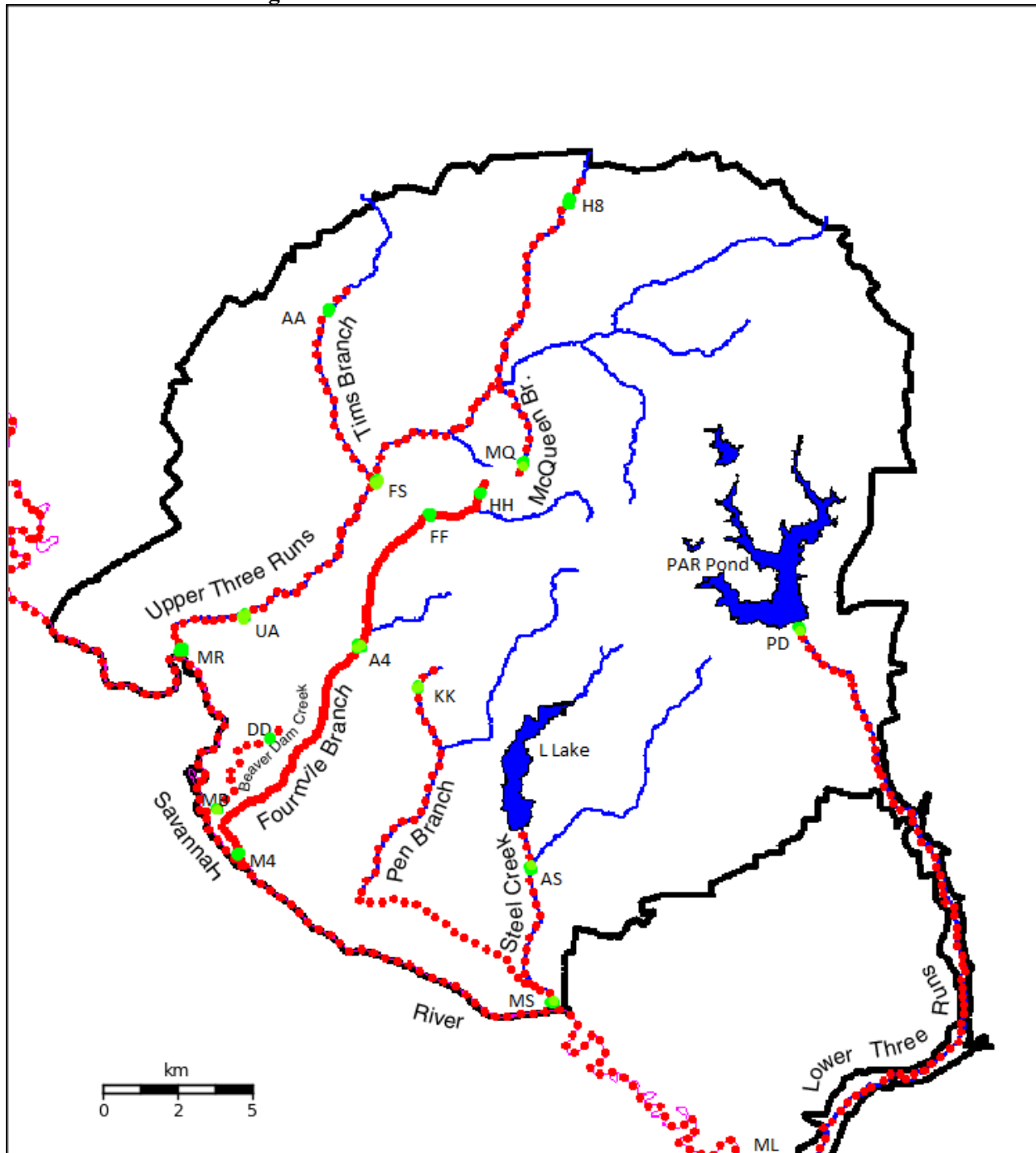
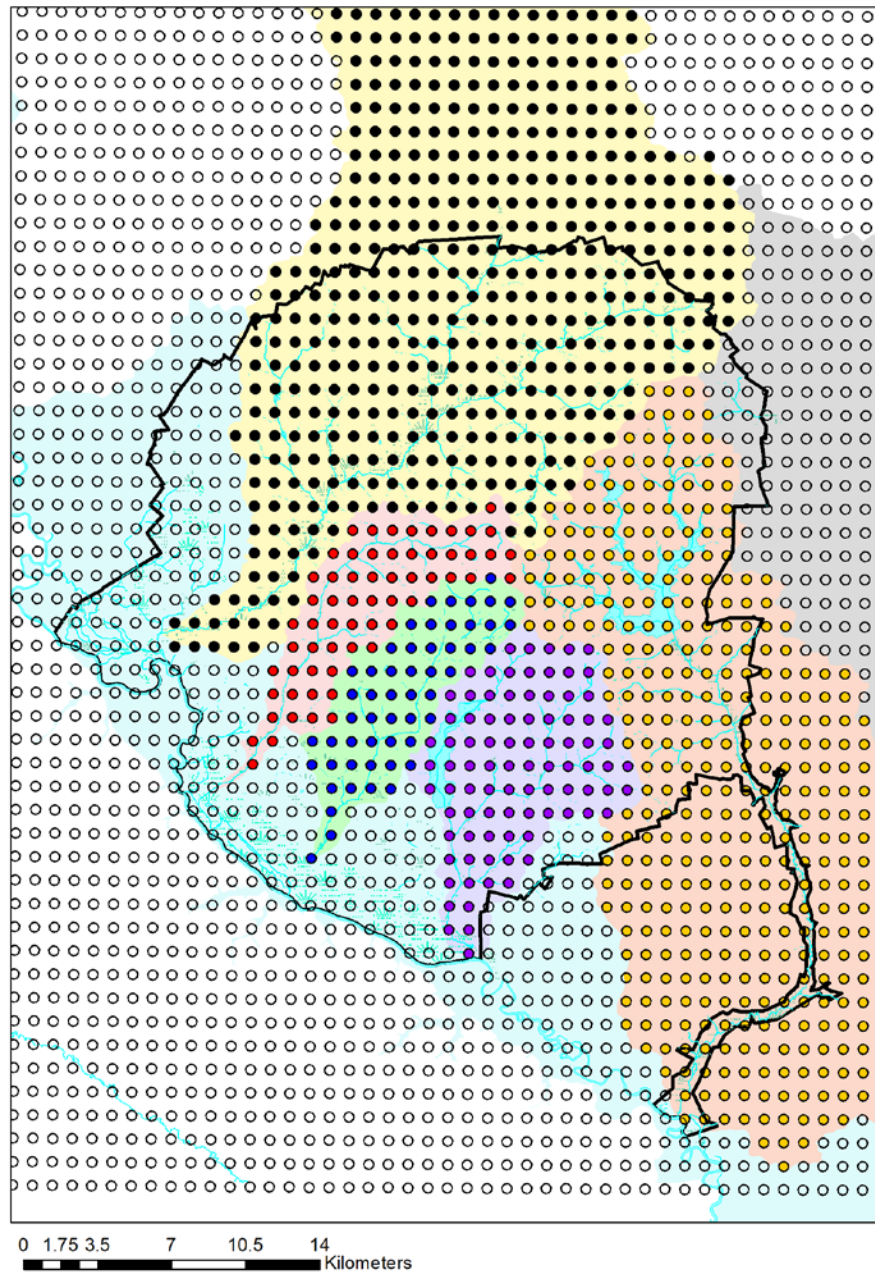


Figure 1-2. Savannah River Site Streams and Creeks



Note: Segment centers are shown in red dots. The spacing between each segment is 500 meters, except for Fourmile Branch, which has a spacing of 150 meters. Release locations are shown with green dots.

Figure 1-3. Radar rainfall grid

Grid of radar derived rainfall. Areas are shaded for Upper Three Runs watershed (yellow), Fourmile Branch watershed (red), Pen Branch (green), Steel Creek watershed (purple), and Lower Three Runs watershed (orange).

2.0 Modifications

New options were added to allow the user to choose single rainfall amount and duration input values or to use the radar derived rainfall. Low total rainfall (<1.0 in) was seen to predict a low flow value (less than if no rain occurred) in STREAM II-V7 so the rainfall watershed runoff curves were recalibrated to give an accurate value for low rainfall periods.

Monthly flow response to rainfall was calibrated using HEC-HMS 4.2.1 using daily data for rainfall and stream flow values from 1995 through 2001. Upper Three Runs was calibrated using USGS gage station 2197315 [3] for the stream flow and rainfall amount from the gage at 200-F. Beaver Creek rainfall response was not calculated. Fourmile Branch was calibrated using USGS gage station 2197344 for the stream flow and rainfall amount from the gage at 200-F. Pen Branch was calibrated using USGS gage station 2197348 for stream flow and rainfall amount from the gage at 100-K. Steel Creek was calibrated using USGS gage 21973565 for stream flow and rainfall amount from the gage at Barricade 5. Lower Three Runs was calibrated using USGS gage 2197400 and rainfall from Barricade 5. To analyze rainfall response from shorter duration events all USGS gage stations were analyzed using 15-minute rainfall data from Central Climatology. Area specific and Central Climatology rain gage measurements are described in [4]. The rainfall runoff response identified by HEC-HMS can be simulated using two different rates for response, a linear response for low rainfall amounts, and a quadratic response for higher rainfall values. The separation between the two equations varies dependently on the rainfall duration.

Rainfall response was analyzed for 0.01 inch to 2.0 inch rainfall in 1 hour, 0.01 inch to 3.0 inch rainfall in 3 hours, 0.5 inch to 3.0 inch rainfall in 6 hours, 0.5 inch to 3.0 inch rainfall in 12 hours, and 1.0 inch to 3.0 inch rainfall in 24 hours for each month on each stream. Low rainfall response curves were bounded to ensure that a low rainfall event does not give a stream flow lower than the base stream flow (no rainfall).

Hourly gridded radar rainfall totals are available for SRS and have been binned into watershed areas (Figure 1-3). Each watershed area now has an individually calculated total rainfall and duration by first calculating the rainfall total and duration over 24 hours at each grid cell, and then by averaging the rainfall totals and durations for each watershed. These rainfall totals and durations are used in rainfall-watershed runoff curve estimates to predict the streamflow under the given rainfall conditions.

3.0 Results and Discussion

Releases were simulated on a random sampling of days using the radar derived rainfall. For each case simulated, the transport times and concentrations were compared with the results obtained using manually input rainfall of the average for the values for the watershed in which the release occurs. No difference was seen in the transport time and concentrations within the main watershed of the release; however, small differences (<0.5%) were seen downstream on the Savannah River as the rainfall rates are variable across the watersheds with the radar derived rainfall which is not captured using the manually entered rainfall.

Constants for rainfall response curves are shown in Table 3-1 to Table 3-5. The rainfall curves are a piecewise equation with the lower end being a liner response and the upper end a quadratic equation with the separation rainfall between the two denoted by S.

$$Q = \begin{cases} A * r + b & \text{for } r \leq S \\ C * r^3 + D * r^2 + E * r + F & \text{for } r > S \end{cases} \quad r = \text{rainfall in inches}$$

Each watershed has a different rainfall response curve for each month and each rainfall duration bin (1 hour, 3 hours, 6 hours, 12 hours, and 24 hours) for a total of 60 curves per watershed.

A	1h	3h	6h	12h	24h	C	1h	3h	6h	12h	24h
---	----	----	----	-----	-----	---	----	----	----	-----	-----

Jan	13.7842	13.7536	13.8824	13.8508	13.6701
Feb	4.7086	4.6072	4.7087	4.7043	4.6641
Mar	6.6707	6.5239	6.6654	6.6564	9.0857
Apr	4.6319	4.5297	4.6270	4.6191	7.4273
May	3.6247	3.5446	3.6259	3.6169	5.8425
Jun	4.1700	4.0759	4.1635	4.1555	4.1096
Jul	4.1701	4.0759	4.1635	4.1548	4.1096
Aug	2.5007	2.4457	2.5019	2.4959	2.4565
Sep	5.8326	5.7085	5.8299	5.8237	5.7555
Oct	6.6648	6.5194	6.6599	6.6356	6.5040
Nov	4.1700	4.0759	4.1635	4.1555	4.1096
Dec	5.0013	4.8936	4.9970	4.9938	4.9292
B	1h	3h	6h	12h	24h
Jan	8.8176	8.9291	8.8093	8.8162	8.8115
Feb	7.5876	7.6359	7.5879	7.5874	7.5871
Mar	7.8960	7.9641	7.8960	7.8955	7.3952
Apr	6.4627	6.5106	6.4629	6.4624	5.8878
May	5.5077	5.5452	5.5070	5.5082	5.0573
Jun	6.1256	6.1690	6.1263	6.1264	6.1267
Jul	6.1537	6.1971	6.1544	6.1539	6.1548
Aug	7.1375	7.1632	7.1368	7.1374	7.1377
Sep	5.9297	5.9887	5.9301	5.9292	5.9294
Oct	7.6433	7.7116	7.6433	7.6421	7.6437
Nov	7.0248	7.0682	7.0255	7.0256	7.0259
Dec	7.1095	7.1599	7.1097	7.1087	7.1102
S (in.)	1h	3h	6h	12h	24h
Jan	0.5	1.2	2.4	2.4	2.4
Feb	0.5	0.6	1.2	1.2	1.2
Mar	0.5	0.6	0.6	0.5	1.2
Apr	0.5	0.6	0.6	0.5	1.2
May	0.5	0.6	0.6	0.5	1.2
Jun	0.5	0.6	0.6	0.5	0.5
Jul	0.5	0.6	0.6	0.5	0.5
Aug	0.5	0.6	0.6	1.2	1.2
Sep	0.5	0.6	0.6	1.2	1.2
Oct	0.5	0.6	0.6	0.5	0.5
Nov	0.5	0.6	0.6	0.5	0.5
Dec	0.5	0.6	0.6	0.5	0.5

Jan	-5.1946	-20.1102	-8.6409	-1.2151	-0.2527
Feb	-11.0150	-0.6016	-2.2594	-0.8245	-0.1031
Mar	-12.4658	-9.2648	-2.7054	-0.8735	-0.0744
Apr	-14.3042	-10.6275	-2.9409	-1.0020	-0.0842
May	-11.1950	-8.3183	-2.3016	-0.7844	-0.0664
Jun	-12.8726	-9.5672	-2.6467	-0.9022	-0.2547
Jul	-12.8726	-9.5672	-2.6467	-0.9018	-0.2547
Aug	0.0000	-0.0011	-0.0001	0.0000	-0.0007
Sep	0.0021	0.0011	0.0002	0.0000	0.0000
Oct	-16.9803	-14.3557	-3.4921	-1.1898	-0.3350
Nov	-12.8726	-9.5672	-2.6467	-0.9022	-0.2547
Dec	-12.7375	-9.4664	-2.6187	-0.8925	-0.2522
D	1h	3h	6h	12h	24h
Jan	45.3986	150.0971	97.9685	23.7780	7.7629
Feb	67.0385	14.6418	27.5558	14.4552	4.3776
Mar	75.8665	60.6519	26.5725	12.3757	2.0077
Apr	87.0518	69.5745	29.1736	14.1975	2.2752
May	68.1313	54.4580	22.8338	11.1136	1.7999
Jun	78.3414	62.6309	26.2561	12.7804	5.9455
Jul	78.3414	62.6309	26.2561	12.7774	5.9455
Aug	0.0000	0.0047	0.0010	0.0005	0.0135
Sep	-0.0110	-0.0053	-0.0019	-0.0006	0.0080
Oct	103.3400	92.4345	34.6383	16.8516	7.7984
Nov	78.3414	62.6309	26.2561	12.7804	5.9455
Dec	77.5183	61.9717	25.9785	12.6447	5.8859
E	1h	3h	6h	12h	24h
Jan	-45.1148	-295.512	-312.488	-90.9056	-31.176
Feb	-54.3616	-1.6564	-57.2533	-31.2621	-9.0775
Mar	-60.1923	-44.6484	-0.1710	24.8572	60.5289
Apr	-72.0895	-54.2265	-0.3916	25.5042	66.5638
May	-56.4220	-42.4486	-0.3060	19.9636	52.0605
Jun	-68.8731	-48.8223	-0.3481	22.9538	35.4586
Jul	-64.8731	-48.8223	-0.3482	22.9612	35.4586
Aug	2.5009	2.4948	2.4969	2.4936	2.4030
Sep	5.8520	5.8412	5.8363	5.8246	5.7103
Oct	-84.3978	-79.2062	0.6964	31.4440	47.9638
Nov	-64.8731	-48.8223	-0.3482	22.9538	35.4586
Dec	-63.3129	-47.4324	0.5351	23.5888	35.9389
F	1h	3h	6h	12h	24h
Jan	27.6134	198.7043	347.2520	140.2359	75.1423
Feb	21.7398	4.2528	45.6688	30.4015	17.4506
Mar	23.9193	18.5319	0.9749	-8.9745	-58.220
Apr	24.8483	18.6584	-2.8828	-12.8946	-69.512
May	19.8976	15.0554	-1.8054	-9.6422	-53.899
Jun	22.6711	17.1078	-2.2884	-11.2960	-22.257
Jul	22.6992	17.1359	-2.2602	-11.2717	-22.229
Aug	7.1374	7.1369	7.1391	7.1402	7.2081
Sep	5.9224	5.9274	5.9260	5.9291	5.9887
Oct	29.4623	28.4243	-3.4496	-15.3432	-29.855
Nov	23.5703	18.0070	-1.3891	-10.3968	-21.358
Dec	23.4792	17.9767	-1.2172	-10.1276	-20.965

Table 3-1. Rainfall Response Curve Constants for Upper Three Runs

A	1h	3h	6h	12h	24h
Jan	1.9503	1.9044	1.9247	1.9297	1.8541
Feb	2.2988	2.2436	2.2853	2.2593	2.1493
Mar	1.9328	1.8919	1.9303	1.9131	1.8399
Apr	1.1465	1.1236	1.1437	1.1316	1.0747
May	1.1465	1.1236	1.1437	1.1316	1.0747
Jun	0.6920	0.6738	0.6828	0.6791	0.6440
Jul	1.1465	1.1236	1.1437	1.1316	1.0747
Aug	2.2988	2.2436	2.2853	2.2593	2.1493
Sep	1.1690	1.1402	1.1653	1.1587	1.1240
Oct	1.6068	1.5707	1.5979	1.5826	1.5054
Nov	0.6128	0.5963	0.6088	0.6088	0.5996
Dec	1.1465	1.1236	1.1437	1.1316	1.0747
B	1h	3h	6h	12h	24h
Jan	1.0816	1.1025	1.0829	1.0814	1.0834
Feb	1.1802	1.2042	1.1801	1.1807	1.1812
Mar	1.2845	1.3036	1.2835	1.2842	1.2855
Apr	0.8150	0.8262	0.8143	0.8141	0.8154
May	0.5846	0.5958	0.5839	0.5836	0.5850
Jun	0.6939	0.7013	0.6946	0.6941	0.6948
Jul	0.8375	0.8487	0.8368	0.8365	0.8379
Aug	0.9750	0.9991	0.9750	0.9755	0.9761
Sep	0.7055	0.7180	0.7054	0.7058	0.7053
Oct	0.8965	0.9136	0.8963	0.8964	0.8974
Nov	0.7531	0.7590	0.7531	0.7531	0.7526
Dec	0.8403	0.8515	0.8396	0.8394	0.8407
S (in.)	1h	3h	6h	12h	24h
Jan	0.5	0.6	0.6	1.2	1.2
Feb	0.5	0.6	0.6	1.2	1.2
Mar	0.5	0.6	0.6	1.2	1.2
Apr	0.5	0.6	0.6	1.2	1.2
May	0.5	0.6	0.6	1.2	1.2
Jun	0.5	0.6	0.6	1.2	1.2
Jul	0.5	0.6	0.6	1.2	1.2
Aug	0.5	0.6	0.6	1.2	1.2
Sep	0.5	0.6	0.6	1.2	1.2
Oct	0.5	0.6	0.6	1.2	1.2
Nov	0.5	0.6	0.6	1.2	1.2
Dec	0.5	0.6	0.6	1.2	1.2

C	1h	3h	6h	12h	24h
Jan	-0.0013	0.0000	-0.0002	0.0000	-0.0003
Feb	0.0013	-0.0011	-0.0002	-0.0001	-0.0002
Mar	0.0021	-0.0011	-0.0001	0.0000	-0.0003
Apr	0.0007	0.0000	0.0002	0.0000	-0.0001
May	0.0007	0.0000	0.0002	0.0000	-0.0001
Jun	-0.0021	0.0000	0.0001	0.0000	-0.0001
Jul	0.0007	0.0000	0.0002	0.0000	-0.0001
Aug	0.0013	-0.0018	-0.0002	-0.0008	-0.0025
Sep	0.0013	-0.0011	-0.0002	0.0001	-0.0002
Oct	-0.0013	0.0011	-0.0001	0.0001	-0.0002
Nov	-0.0021	0.0022	0.0001	-0.0001	-0.0002
Dec	0.0007	0.0000	0.0002	0.0000	-0.0001
D	1h	3h	6h	12h	24h
Jan	0.0065	-0.0006	0.0014	-0.0004	0.0045
Feb	-0.0065	0.0053	0.0019	0.0006	0.0035
Mar	-0.0110	0.0047	0.0010	-0.0001	0.0051
Apr	-0.0045	0.0000	-0.0014	0.0004	0.0018
May	-0.0045	0.0000	-0.0014	0.0004	0.0018
Jun	0.0110	0.0000	-0.0010	-0.0004	0.0010
Jul	-0.0045	0.0000	-0.0014	0.0004	0.0018
Aug	-0.0065	0.0053	0.1860	0.0057	0.0035
Sep	-0.0065	0.0053	0.0019	-0.0011	0.0041
Oct	0.0065	-0.0047	0.0005	-0.0009	0.0027
Nov	0.0110	-0.0117	-0.0009	0.0008	0.0028
Dec	-0.0045	0.0000	-0.0014	0.0004	0.0018
E	1h	3h	6h	12h	24h
Jan	1.9427	1.9526	1.9404	1.9307	1.8389
Feb	2.3060	2.2890	2.2799	2.2578	2.1432
Mar	1.9517	1.9281	1.9256	1.9147	1.8240
Apr	1.1575	1.1474	1.1443	1.1282	1.0711
May	1.1575	1.1474	1.1443	1.1282	1.0711
Jun	0.6728	0.6884	0.6877	0.6786	0.6431
Jul	1.1575	1.1474	1.1443	1.1282	1.0711
Aug	2.3060	2.2890	2.2799	2.2578	2.1432
Sep	1.1764	1.1604	1.1606	1.1626	1.1078
Oct	1.5999	1.6125	1.5991	1.5845	1.4991
Nov	0.5941	0.6291	0.6125	0.6065	0.5858
Dec	1.1575	1.1474	1.1443	1.1282	1.0711
F	1h	3h	6h	12h	24h
Jan	1.0841	1.0796	1.0835	1.0809	1.0991
Feb	1.1780	1.1819	1.1833	1.1821	1.1873
Mar	1.2774	1.2864	1.2859	1.2823	1.3023
Apr	0.8104	0.8149	0.8146	0.8177	0.8187
May	0.5800	0.5845	0.5841	0.5873	0.5883
Jun	0.7008	0.6941	0.6924	0.6950	0.6951
Jul	0.8329	0.8374	0.8370	0.8402	0.8412
Aug	0.9728	0.9768	0.9782	0.9769	0.9822
Sep	0.7031	0.7070	0.7084	0.7025	0.7230
Oct	0.8986	0.8941	0.8954	0.8955	0.9027
Nov	0.7598	0.7447	0.7517	0.7550	0.7681
Dec	0.8357	0.8402	0.8398	0.8430	0.8440

Table 3-2. Rainfall Response Curve Constants for Fourmile Branch

A	1h	3h	6h	12h	24h
Jan	0.2710	0.2678	0.2729	0.2701	0.2631
Feb	0.6812	0.6639	0.6800	0.6740	0.6557
Mar	1.7657	1.7267	1.7586	1.7452	1.8670
Apr	1.4691	1.4370	1.4463	1.4158	1.2981
May	1.4720	1.4331	1.4466	1.4136	1.2993
Jun	1.4693	1.4328	1.4464	1.4159	1.2991
Jul	2.3560	2.2966	2.3151	2.2653	2.0794
Aug	1.4739	1.4332	1.4639	1.4147	1.3000
Sep	2.3553	2.2944	2.3121	2.2640	2.0789
Oct	2.3553	2.2944	2.3153	2.2640	2.0789
Nov	0.8833	0.8613	0.8688	0.8482	0.7796
Dec	1.4720	1.4331	1.4466	1.4136	1.2993
B	1h	3h	6h	12h	24h
Jan	1.4688	1.4713	1.4684	1.4688	1.4689
Feb	1.2386	1.2469	1.2382	1.2396	1.2392
Mar	1.2501	1.2683	1.2495	1.2498	1.2512
Apr	0.7267	0.7406	0.7259	0.7259	0.7274
May	1.1132	1.1286	1.1135	1.1139	1.1138
Jun	0.4934	0.5077	0.4926	0.4925	0.4929
Jul	0.4660	0.4893	0.4657	0.4649	0.4679
Aug	0.3954	0.4112	0.3705	0.3955	0.3966
Sep	0.2977	0.3225	0.2985	0.2976	0.2997
Oct	0.4551	0.4798	0.4553	0.4549	0.4571
Nov	0.2523	0.2617	0.2526	0.2524	0.2538
Dec	0.2168	0.2322	0.2171	0.2175	0.2174
S (in.)	1h	3h	6h	12h	24h
Jan	0.5	0.6	1.2	1.2	1.2
Feb	0.5	0.6	1.2	1.2	1.2
Mar	0.5	0.6	0.6	1.2	1.2
Apr	0.5	0.6	1.2	1.2	1.2
May	0.5	0.6	0.6	1.2	1.2
Jun	0.5	0.6	1.2	1.2	1.2
Jul	0.5	0.6	0.6	1.2	1.2
Aug	0.5	0.6	1.8	1.2	1.2
Sep	0.5	0.6	0.6	1.2	1.2
Oct	0.5	0.6	1.2	1.2	1.2
Nov	0.5	0.6	1.2	1.8	1.2
Dec	0.5	0.6	0.6	1.2	1.2

C	1h	3h	6h	12h	24h
Jan	-1.4899	-1.2088	-0.7636	-0.1165	-0.0243
Feb	-1.5549	-1.1708	-0.6729	-0.1291	-0.0234
Mar	0.0021	0.0000	0.0004	-0.0001	-0.0003
Apr	-3.3366	-2.5314	-1.4701	-0.2750	-0.0537
May	-2.8795	-2.4956	-1.1775	-0.2124	-0.0538
Jun	-3.4859	-2.9054	-1.0737	-0.3702	-0.0453
Jul	-3.7373	-4.2616	-0.5632	-0.3112	-0.0439
Aug	-0.5395	-0.2960	-1.3449	-0.4360	-0.0453
Sep	-3.8055	-4.1727	-0.5579	-0.3115	-0.0439
Oct	-3.8055	-4.1727	-0.9038	-0.3112	-0.0439
Nov	-4.0123	-4.4004	-0.9531	-0.3279	-0.0463
Dec	3.9299	-4.3093	-0.5762	-0.3213	-0.0453
D	1h	3h	6h	12h	24h
Jan	9.7780	8.6154	7.8845	2.1920	0.9480
Feb	10.2677	8.4779	7.2455	2.3091	0.9165
Mar	-0.0110	0.0000	-0.0028	0.0015	0.0041
Apr	22.0133	18.2954	15.7328	4.9173	2.0086
May	18.7480	17.4962	12.2526	4.1874	2.0087
Jun	23.3601	21.1452	13.0373	6.2474	1.8491
Jul	23.8485	27.2930	7.7321	5.5040	1.7905
Aug	9.2224	7.4813	17.6690	7.6308	1.8487
Sep	24.0778	26.5771	7.6860	5.5039	1.7904
Oct	24.0778	26.5771	10.9407	5.5039	1.7904
Nov	25.3861	28.0267	11.5368	5.8009	1.8879
Dec	24.8634	27.4457	7.9379	5.6832	1.8491
E	1h	3h	6h	12h	24h
Jan	-7.8278	-8.9467	-15.6164	-2.5930	-1.5029
Feb	-9.1400	-9.0803	-14.2947	-2.6475	-0.9621
Mar	1.7831	1.7656	1.7657	1.7382	1.6581
Apr	-19.2342	-19.3821	-30.8746	-5.4269	-2.2628
May	-11.0674	-15.3504	-18.6959	-2.8839	-2.2639
Jun	-23.5783	-27.1384	-29.5994	-13.8599	-4.3239
Jul	-20.2292	-32.7403	-12.4896	-10.7231	-3.3626
Aug	-11.4227	-12.1569	-53.7000	-21.9584	-4.3219
Sep	-19.8974	-31.1552	-12.3786	-10.7225	-3.3613
Oct	-19.8974	-31.1552	-21.7127	-10.7225	-3.3613
Nov	-22.5770	-34.4513	-24.4691	-12.8336	-4.9635
Dec	-21.5046	-33.1279	-13.7288	-11.9927	-4.3239
F	1h	3h	6h	12h	24h
Jan	3.2602	4.1329	10.5553	1.6092	1.8469
Feb	3.7766	4.2718	9.9636	1.7581	1.5024
Mar	1.2437	1.2504	1.2456	1.2561	1.2628
Apr	5.9920	7.1447	19.4571	1.5399	1.3401
May	3.0556	5.3817	9.2187	0.0600	1.7283
Jun	7.6129	10.6128	20.8943	9.9867	4.3928
Jul	6.2635	12.5304	7.0467	8.2483	4.2400
Aug	4.6056	6.0488	50.3776	18.2809	4.2954
Sep	5.8802	11.6098	6.8223	8.0797	4.0698
Oct	6.0376	11.7672	14.9574	8.2370	4.2272
Nov	6.1376	12.1836	15.5449	8.4469	4.2375
Dec	5.9802	11.8964	6.9556	8.2483	4.1174

Table 3-3. Rainfall Response Curve Constants for Pen Branch

A	1h	3h	6h	12h	24h
Jan	3.8810	3.7812	3.8155	3.7312	3.4239
Feb	1.9384	1.8926	1.9079	1.8659	1.7134
Mar	1.9394	1.8932	1.9073	1.9073	1.7124
Apr	1.9392	1.8929	1.9085	1.8648	1.7161
May	1.9379	1.8920	1.9071	1.8652	1.7131
Jun	1.9384	1.8926	1.9079	1.8659	1.7134
Jul	1.9387	1.8919	1.9060	1.8661	1.7111
Aug	1.9381	1.8923	1.9078	1.8658	1.7133
Sep	1.9389	1.8922	1.9054	1.8662	1.7121
Oct	1.9428	1.8434	1.9064	1.8640	1.7124
Nov	1.9384	1.8926	1.9079	1.8659	1.7134
Dec	1.9346	1.8929	1.9065	1.8625	1.7150
B	1h	3h	6h	12h	24h
Jan	2.1932	2.2328	2.1933	2.1928	2.1961
Feb	2.1920	2.2117	2.1919	2.1915	2.1935
Mar	2.8744	2.8931	2.8734	2.8734	2.8751
Apr	2.5570	2.5757	2.5564	2.5560	2.5563
May	2.0349	2.0546	2.0355	2.0351	2.0364
Jun	2.1246	2.1443	2.1245	2.1241	2.1260
Jul	1.9671	1.9865	1.9674	1.9666	1.9690
Aug	1.5262	1.5459	1.5261	1.5256	1.5276
Sep	1.4331	1.4525	1.4330	1.4326	1.4339
Oct	1.7587	1.7823	1.7579	1.7580	1.7595
Nov	1.7593	1.7790	1.7592	1.7588	1.7607
Dec	1.7356	1.7523	1.7347	1.7346	1.7349
S (in.)	1h	3h	6h	12h	24h
Jan	0.5	0.6	1.2	1.2	1.2
Feb	0.5	0.6	1.2	1.2	1.2
Mar	0.5	0.6	1.2	1.2	1.2
Apr	0.5	0.6	1.2	1.2	2.4
May	0.5	0.6	1.2	1.2	1.2
Jun	0.5	0.6	1.2	1.2	1.2
Jul	0.5	0.6	0.6	1.2	1.2
Aug	0.5	0.6	1.2	1.2	1.2
Sep	0.5	0.6	0.6	1.2	1.2
Oct	0.1	0.3	0.3	0.48	1.2
Nov	0.5	0.6	1.2	1.2	1.2
Dec	0.5	0.6	1.2	1.2	2.4

C	1h	3h	6h	12h	24h
Jan	-4.9078	-5.3804	-1.0003	-0.4015	-0.0566
Feb	-5.1798	-5.6796	-1.2306	-0.4235	-0.0598
Mar	-5.1803	-5.6818	-1.2305	-1.2305	-0.0597
Apr	-5.1803	-5.6818	-1.2309	-0.4236	-0.0474
May	-5.1798	-5.6796	-1.2312	-0.4269	-0.0597
Jun	-5.8281	-3.5916	-0.6151	-0.5429	-0.0426
Jul	-2.8874	-3.1526	-1.3156	-0.2795	-0.0703
Aug	-5.0925	-5.7945	-1.2423	-0.4233	-0.0598
Sep	-2.8698	-3.8555	-1.4519	-0.2227	-0.0739
Oct	-3.5850	-2.9363	-1.0573	-0.4426	-0.1074
Nov	-5.1798	-5.6796	-1.2306	-0.4235	-0.0598
Dec	-5.1803	-5.6818	-1.2309	-0.4236	-0.0474
D	1h	3h	6h	12h	24h
Jan	31.0511	34.2700	12.6975	7.1004	2.3087
Feb	32.7730	36.1757	14.8950	7.4922	2.4378
Mar	32.7750	36.1891	14.8944	14.8944	2.4374
Apr	32.7750	36.1880	14.8987	7.4927	2.1518
May	32.7730	36.1757	14.9002	7.5358	2.4374
Jun	38.0640	27.5662	10.0198	9.2235	1.9993
Jul	18.3597	19.4710	13.8843	5.5003	2.6368
Aug	32.4769	37.0912	15.0010	7.4896	2.4378
Sep	18.5772	23.6992	14.7889	4.6677	2.7193
Oct	21.2883	17.4447	10.7171	6.7023	3.0903
Nov	32.7730	36.1757	14.8950	7.4922	2.4378
Dec	32.7750	36.1880	14.8987	7.4927	2.1518
E	1h	3h	6h	12h	24h
Jan	-24.8147	-39.3304	-23.6871	-13.0268	-3.5854
Feb	-28.3435	-43.6665	-30.8048	-15.8106	-5.7011
Mar	-28.3455	-43.6905	-30.8023	-30.8023	-5.6986
Apr	-28.3455	-43.6865	-30.8159	-15.8126	-3.7176
May	-28.3435	-43.6665	-30.8177	-15.9679	-5.6986
Jun	-43.8788	-38.6343	-23.7547	-26.0741	-5.3626
Jul	0.8251	-8.6509	-18.3191	-3.2134	-2.6673
Aug	-28.7489	-45.6798	-31.0823	-15.8020	-5.7006
Sep	-0.9201	-15.1955	-18.3568	1.5624	-1.8699
Oct	-0.6896	-0.3227	-2.0911	1.7177	3.5489
Nov	-28.3435	-43.6665	-30.8048	-15.8106	-5.7011
Dec	-28.3455	-43.6865	-30.8159	-15.8126	-3.7176
F	1h	3h	6h	12h	24h
Jan	9.3916	16.7779	18.3926	12.2375	7.0507
Feb	9.7823	17.5889	21.9355	12.7827	7.3365
Mar	10.4706	18.2819	22.6131	22.6131	8.0136
Apr	10.1531	17.9621	22.3091	13.1471	3.7592
May	9.6299	17.4316	21.7875	12.7453	7.1762
Jun	16.2457	17.3175	19.4704	23.3445	7.8648
Jul	-1.7051	1.8591	9.1595	0.1330	2.4364
Aug	9.3871	17.8755	21.4589	12.1092	6.6698
Sep	-1.4230	3.9839	8.0911	-4.7498	1.0610
Oct	1.2985	0.2433	1.0028	-1.1639	-5.1127
Nov	9.3545	17.1562	21.5028	12.3500	6.9037
Dec	9.3298	17.1388	21.4858	12.3237	2.9359

Table 3-4. Rainfall Response Curve Constants for Steel Creek

A	1h	3h	6h	12h	24h
Jan	8.4425	8.2285	8.2952	8.1158	7.4498
Feb	8.4347	8.2316	8.2961	8.1171	7.4512
Mar	8.4388	8.2276	8.2958	8.1149	7.4515
Apr	4.2231	4.1297	4.2130	4.1893	4.0568
May	8.4371	8.2319	8.2958	8.1170	7.4510
Jun	3.3741	3.2919	3.3210	3.2460	2.9813
Jul	5.0603	4.9392	4.9778	4.8709	4.4687
Aug	3.3790	3.2889	3.3212	3.2471	2.9806
Sep	3.3771	3.2924	3.3190	3.2460	2.9791
Oct	3.4033	3.2916	3.3207	3.2459	2.9811
Nov	5.0652	4.9358	4.9796	4.8692	4.4706
Dec	5.0649	4.9351	4.9801	4.8719	4.4731
B	1h	3h	6h	12h	24h
Jan	2.8199	2.9053	2.8198	2.8188	2.8259
Feb	2.8704	2.9520	2.8675	2.8657	2.8725
Mar	3.0394	3.1248	3.0396	3.0385	3.0448
Apr	2.0627	2.1055	2.0623	2.0618	2.0633
May	1.5662	1.6503	1.5659	1.5640	1.5708
Jun	1.6382	1.6711	1.6370	1.6373	1.6400
Jul	1.4461	1.4962	1.4447	1.4436	1.4496
Aug	1.9129	1.9482	1.9126	1.9128	1.9152
Sep	1.8095	1.8435	1.8099	1.8093	1.8122
Oct	1.8496	1.8835	1.8499	1.8497	1.8524
Nov	1.8652	1.9166	1.8653	1.8651	1.8686
Dec	1.9587	2.0107	1.9590	1.9597	1.9633
S (in.)	1h	3h	6h	12h	24h
Jan	0.5	0.6	0.6	1.2	1.2
Feb	0.5	0.6	0.6	1.2	1.2
Mar	0.5	0.6	0.6	1.2	1.2
Apr	0.5	0.6	0.6	1.2	1.2
May	0.5	0.6	0.6	1.2	1.2
Jun	0.5	0.6	1.2	1.2	1.2
Jul	0.5	0.6	0.6	1.2	1.2
Aug	0.5	0.6	0.6	1.2	1.2
Sep	0.5	0.6	1.2	1.2	1.2
Oct	0.5	0.6	1.2	1.2	1.2
Nov	0.5	0.6	1.2	1.2	1.2
Dec	0.5	0.6	1.2	1.2	1.2

C	1h	3h	6h	12h	24h
Jan	-13.0652	-16.7802	-6.1861	-1.4690	-0.3020
Feb	-22.5360	-24.7166	-3.3044	-1.8427	-0.2599
Mar	-22.5360	-24.7221	-3.3056	-1.8425	-0.2599
Apr	-11.2753	-12.3649	-1.6513	-0.9153	-0.1250
May	-15.1292	-12.3103	-7.5375	-0.9744	-0.3633
Jun	-23.2492	-25.4940	-5.5232	-1.9001	-0.2680
Jul	-13.5887	-14.9962	-5.7528	-1.2630	-0.3147
Aug	-13.4416	-16.1972	-6.1439	-1.1873	-0.3104
Sep	-22.7311	-26.1611	-5.5921	-1.8986	-0.2680
Oct	-23.2539	-25.4940	-5.5229	-1.8997	-0.2680
Nov	-23.0117	-25.2331	-5.4669	-1.8808	-0.2653
Dec	-23.0117	-25.2331	11.1477	-1.8820	-0.2655
D	1h	3h	6h	12h	24h
Jan	84.2689	103.5019	63.7288	27.2381	11.4330
Feb	142.5870	157.4244	45.5248	32.5973	10.6042
Mar	142.5870	157.4460	45.5335	32.5949	10.6046
Apr	71.3406	78.7551	22.7834	16.2555	5.2535
May	98.4076	86.7538	75.1391	19.9754	12.6076
Jun	147.0980	162.3797	66.8504	33.6177	10.9396
Jul	86.3843	92.6609	61.3284	24.8421	11.7643
Aug	86.2259	99.7218	64.0440	23.7938	11.7471
Sep	145.3451	167.7390	67.4699	33.6005	10.9387
Oct	147.1277	162.3786	66.8487	33.6140	10.9395
Nov	145.5950	160.7173	66.1702	33.2760	10.8275
Dec	145.5950	160.7173	-50.6072	33.2971	10.8344
E	1h	3h	6h	12h	24h
Jan	-10.1889	-69.1884	-82.6655	-24.269	-8.7606
Feb	-123.321	-190.038	-78.7399	-68.793	-24.793
Mar	-123.321	-190.061	-78.7570	-68.784	-24.796
Apr	-61.7073	-95.0546	-39.3688	-34.120	-11.917
May	-43.4122	-57.0698	-104.524	11.2708	-9.1013
Jun	-132.558	-201.327	-143.490	-76.049	-30.303
Jul	-9.7913	-53.8841	-86.3436	-21.011	-16.385
Aug	-12.5166	-64.8838	-89.4081	-14.930	-15.138
Sep	-134.990	-213.176	-145.109	-75.995	-30.298
Oct	-132.617	-201.323	-143.486	-76.039	-30.303
Nov	-129.480	-197.546	-140.339	-73.628	-28.466
Dec	-129.480	-197.546	113.4376	-73.676	-28.485
F	1h	3h	6h	12h	24h
Jan	-7.2986	15.4926	34.1951	9.1909	1.8698
Feb	35.9172	69.8784	41.5226	48.9486	25.2333
Mar	36.0899	70.0555	41.6995	49.1099	25.4087
Apr	18.6022	35.5844	21.4227	24.9691	13.1189
May	4.7799	11.9879	43.4432	30.7074	0.7995
Jun	35.7361	70.7534	90.2371	49.1316	24.7317
Jul	-11.0257	6.0602	34.7395	-3.5696	5.0384
Aug	-10.0154	9.9814	34.5686	-10.329	2.3791
Sep	37.4981	76.5441	91.5099	49.2590	24.8973
Oct	35.9851	70.9634	90.4469	49.3382	24.9440
Nov	35.6156	70.2712	89.5666	48.8873	24.7155
Dec	35.7089	70.3646	-78.2943	49.0136	24.8258

Table 3-5. Rainfall Response Curve Constants for Lower Three Runs

4.0 Conclusions

The use of real time radar derived rainfall allows for a more accurate prediction of stream flow values following a rainfall event and prevent one source of human error in predictions by automatically calculating rainfall rates. More accurate stream flow values will correlate to more accurate transport predictions. Additionally, the revised rainfall watershed runoff curves capture the response to low rainfall events more accurately.

5.0 Recommendations, Path Forward or Future Work

It is recommended that real time stream flow values are used for the stream flow modeling. This will capture the variance in watershed conditions during abnormally high or low flow conditions. USGS ended the stream gage network onsite in 2002, however the Environmental Compliance Group has developed a stream gage network.

6.0 References

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