

Appendix C - Santa Barbara Urban Hydrograph Example

2.3.3 Hydrograph Synthesis – Santa Barbara Urban Hydrograph

The Santa Barbara Urban Hydrograph (SBUH) method is described below. It is given here as a guideline only, as it is only one of the many SCS-based hydrograph methods that are available for use.

The SBUH method, like the Soil Conservation Service Unit Hydrograph (SCSUH) method, is based on the curve number (CN) approach, and also uses SCS equations for computing soil absorption and precipitation excess. The SCSUH method works by converting the incremental runoff depths (precipitation excess) for a given basin and design storm into a runoff hydrograph via application of a dimensionless unit hydrograph. The shape of the SCS unit hydrograph (time to peak, time base, and peak) are determined by a single parameter - the basin time of concentration. The SBUH method, on the other hand, converts the incremental runoff depths into instantaneous hydrographs that are then routed through an imaginary reservoir with a time delay equal to the basin time of concentration.

The SBUH method was developed by the Santa Barbara County Flood Control and Water Conservation District, California. The SBUH method directly computes a runoff hydrograph without going through an intermediate process (unit hydrograph) as the SCSUH method does. By comparison, the calculation steps of the SBUH method are much simpler and can be programmed on a calculator or a spreadsheet program.

The SBUH method uses two steps to synthesize the runoff hydrograph:

- Step one - computing the instantaneous hydrograph, and
- Step two - computing the runoff hydrograph.

The instantaneous hydrograph, $I(t)$, in cfs, at each time step, dt , is computed as follows:

$$I_t = 60.5 R_t A / d_t$$

Where R_t = total runoff depth (both impervious and pervious runoffs) at time increment dt , in inches (also known as precipitation excess)

A = area in acres

d_t = time interval in minutes*

*NOTE: A maximum time interval of 10 minutes should be used for all design storms of 24-hour duration. A maximum time interval of 60 minutes should be used for the 100-year, 7-day design storm.

The runoff hydrograph, Q_t , is then obtained by routing the instantaneous hydrograph I_t , through an imaginary reservoir with a time delay equal to the time of concentration, T_c , of the drainage basin. The following equation estimates the routed flow, Q_t :

$$Q_{t+1} = Q_t + w[I_t + I_{t+1} - 2Q_t]$$

$$\text{Where: } w = d_t / (2T_c + d_t)$$

$$d_t = \text{time interval in minutes}$$

Example: To illustrate the SBUH method, Tables 2.6 and 2.7 show runoff hydrograph values computed by this method for both existing and developed conditions. Figure 2.3 illustrates the hydrographs for existing and developed conditions. Note, this example was prepared using the Excel 5.0 spreadsheet program and illustrates how the method can be used with a personal computer. Copies of this program and a Fortran version are available (with minimal documentation) from King County Surface Water Management Division.

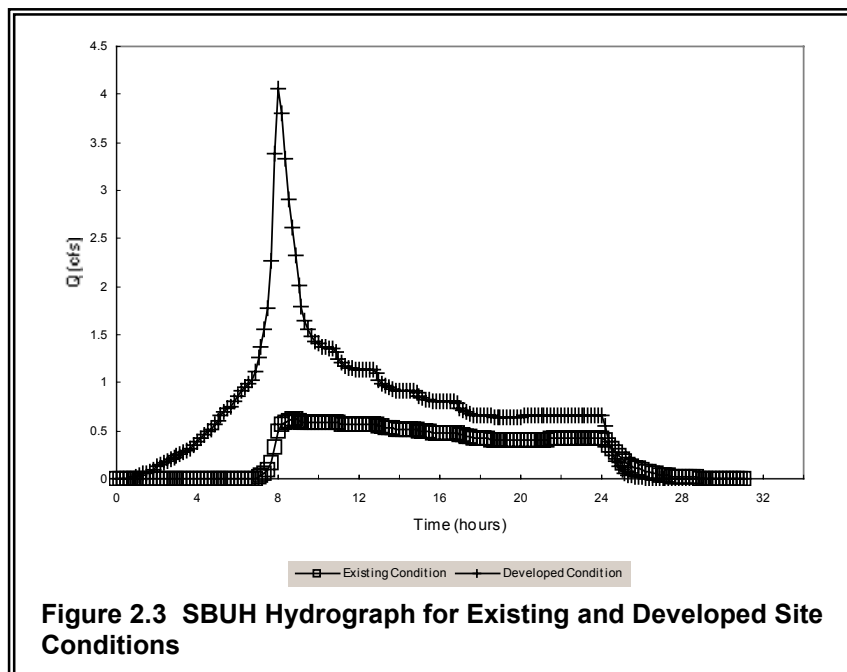


Table 2.6
SBUH Values for Existing Site Condition

Given: Area = 10 acres P = 2.9 inches (10-yr, 24-hr. event) dt = 10 minutes
 PERVIOUS AREA: Area = 10 acres CN = 74 S = 3.513514 0.2S = 0.70
 IMPERVIOUS AREA: Area = 0 acres CN = 98 S = 0.204082 0.2S = 0.04
 Tc = 73 minutes w = 0.064103 where S = potential maximum natural detention (as defined earlier)

Column (1) = Time Increment
 Column (2) = Time (min)
 Column (3) = Type IA Storm Distribution
 Column (4) = Column (3) * P
 Column (5) = Accumulated sum of Column (4)
 Column (6) = If (P < 0.2S) = 0, If (P > 0.2S) = (Column (5) - 0.2S)^2/(Column (5) + 0.8S), where the PERVIOUS AREA S value is used
 Column (7) = Column (6) of the present step - Column (6) of the previous step
 Column (8) = Same as Column (6) except use IMPERVIOUS AREA S value
 Column (9) = Column (8) of the present step - Column (8) of the previous step
 Column (10) = (PERVIOUS AREA/TOTAL AREA)*Column (7)+(IMPERVIOUS AREA/TOTAL AREA)*Column (9)
 Column (11) = (60.5*Column (10)*Total Area)/dt, where dt = 10 or 60 minutes
 Column (12) = Column (12) of previous time step + w * [(Column (11) of previous time step + Column (11) of present time step) - (2 * Column (12) of previous time step)] where w = routing constant = dt/(2Tc + dt) = 0.0641

(1) Time Increment	(2) Time (minute)	(3) Rainfall Distrib. (fraction)	(4) Incre. Rainfall (inches)	(5) Accumul. Rainfall (inches)	(6) PERVIOUS Accum. Runoff (inches)	(7) Incre. Runoff (inches)	(8) IMPERVIOUS Accum. Runoff (inches)	(9) Incre. Runoff (inches)	(10) Total Runoff (inches)	(11) Instant Flowrate (cfs)	(12) Design Flowrate (cfs)
1	0	0	0	0	0	0	0	0	0	0.0	0.0
2	10	0.004	0.012	0.012	0.000	0.000	0.000	0.000	0.000	0.0	0.0
3	20	0.004	0.012	0.023	0.000	0.000	0.000	0.000	0.000	0.0	0.0
4	30	0.004	0.012	0.035	0.000	0.000	0.000	0.000	0.000	0.0	0.0
5	40	0.004	0.012	0.046	0.000	0.000	0.000	0.000	0.000	0.0	0.0
6	50	0.004	0.012	0.058	0.000	0.000	0.001	0.001	0.000	0.0	0.0
7	60	0.004	0.012	0.070	0.000	0.000	0.004	0.002	0.000	0.0	0.0
8	70	0.004	0.012	0.081	0.000	0.000	0.007	0.003	0.000	0.0	0.0
9	80	0.004	0.012	0.093	0.000	0.000	0.011	0.004	0.000	0.0	0.0
10	90	0.004	0.012	0.104	0.000	0.000	0.015	0.005	0.000	0.0	0.0
11	100	0.004	0.012	0.116	0.000	0.000	0.020	0.005	0.000	0.0	0.0
12	110	0.005	0.015	0.131	0.000	0.000	0.027	0.007	0.000	0.0	0.0
13	120	0.005	0.015	0.145	0.000	0.000	0.035	0.008	0.000	0.0	0.0
14	130	0.005	0.015	0.160	0.000	0.000	0.044	0.008	0.000	0.0	0.0
15	140	0.005	0.015	0.174	0.000	0.000	0.053	0.009	0.000	0.0	0.0
16	150	0.005	0.015	0.189	0.000	0.000	0.062	0.009	0.000	0.0	0.0
17	160	0.005	0.015	0.203	0.000	0.000	0.072	0.010	0.000	0.0	0.0
18	170	0.006	0.017	0.220	0.000	0.000	0.084	0.012	0.000	0.0	0.0
19	180	0.006	0.017	0.238	0.000	0.000	0.097	0.013	0.000	0.0	0.0
20	190	0.006	0.017	0.255	0.000	0.000	0.110	0.013	0.000	0.0	0.0
21	200	0.006	0.017	0.273	0.000	0.000	0.123	0.013	0.000	0.0	0.0
22	210	0.006	0.017	0.290	0.000	0.000	0.137	0.014	0.000	0.0	0.0
23	220	0.006	0.017	0.307	0.000	0.000	0.151	0.014	0.000	0.0	0.0
24	230	0.007	0.020	0.328	0.000	0.000	0.168	0.017	0.000	0.0	0.0
25	240	0.007	0.020	0.348	0.000	0.000	0.185	0.017	0.000	0.0	0.0
26	250	0.007	0.020	0.368	0.000	0.000	0.202	0.017	0.000	0.0	0.0
27	260	0.007	0.020	0.389	0.000	0.000	0.219	0.017	0.000	0.0	0.0
28	270	0.007	0.020	0.409	0.000	0.000	0.237	0.018	0.000	0.0	0.0
29	280	0.007	0.020	0.429	0.000	0.000	0.255	0.018	0.000	0.0	0.0
30	290	0.008	0.024	0.453	0.000	0.000	0.276	0.021	0.000	0.0	0.0
31	300	0.008	0.024	0.477	0.000	0.000	0.297	0.021	0.000	0.0	0.0
32	310	0.008	0.024	0.501	0.000	0.000	0.318	0.021	0.000	0.0	0.0
33	320	0.008	0.024	0.524	0.000	0.000	0.340	0.022	0.000	0.0	0.0
34	330	0.008	0.024	0.548	0.000	0.000	0.362	0.022	0.000	0.0	0.0
35	340	0.008	0.024	0.572	0.000	0.000	0.384	0.022	0.000	0.0	0.0
36	350	0.010	0.028	0.599	0.000	0.000	0.409	0.026	0.000	0.0	0.0
37	360	0.010	0.028	0.627	0.000	0.000	0.435	0.026	0.000	0.0	0.0
38	370	0.010	0.028	0.655	0.000	0.000	0.461	0.026	0.000	0.0	0.0

(1) Time Increment	(2) Time (minute)	(3) Rainfall Distrib. (fraction)	(4) Incre. Rainfall (inches)	(5) Accumul. Rainfall (inches)	(6) PERVIOUS		(7) IMPERVIOUS		(10) Total Runoff (inches)	(11) Instant Flowrate (cfs)	(12) Design Flowrate (cfs)
					Accum. Runoff (inches)	Incre. Runoff (inches)	Accum. Runoff (inches)	Incre. Runoff (inches)			
39	380	0.010	0.028	0.682	0.000	0.000	0.486	0.026	0.000	0.0	0.0
40	390	0.010	0.028	0.710	0.000	0.000	0.512	0.026	0.000	0.0	0.0
41	400	0.010	0.028	0.737	0.000	0.000	0.539	0.026	0.000	0.0	0.0
42	410	0.013	0.039	0.776	0.001	0.001	0.575	0.037	0.001	0.1	0.0
43	420	0.013	0.039	0.815	0.003	0.002	0.613	0.037	0.002	0.1	0.0
44	430	0.013	0.039	0.854	0.006	0.003	0.650	0.037	0.003	0.2	0.0
45	440	0.018	0.052	0.906	0.011	0.005	0.700	0.050	0.005	0.3	0.1
46	450	0.018	0.052	0.958	0.017	0.006	0.750	0.050	0.006	0.4	0.1
47	460	0.034	0.099	1.057	0.032	0.015	0.846	0.096	0.015	0.9	0.2
48	470	0.054	0.157	1.213	0.065	0.032	0.999	0.153	0.032	2.0	0.3
49	480	0.027	0.078	1.292	0.085	0.020	1.075	0.077	0.020	1.2	0.5
50	490	0.018	0.052	1.344	0.099	0.014	1.127	0.051	0.014	0.9	0.6
51	500	0.013	0.039	1.383	0.110	0.011	1.165	0.038	0.011	0.7	0.6
52	510	0.013	0.039	1.422	0.122	0.012	1.203	0.038	0.012	0.7	0.6
53	520	0.013	0.039	1.460	0.134	0.012	1.241	0.038	0.012	0.7	0.6
54	530	0.009	0.026	1.486	0.143	0.008	1.266	0.025	0.008	0.5	0.6
55	540	0.009	0.026	1.511	0.151	0.009	1.291	0.025	0.009	0.5	0.6
56	550	0.009	0.026	1.537	0.160	0.009	1.317	0.025	0.009	0.5	0.6
57	560	0.009	0.026	1.563	0.169	0.009	1.342	0.025	0.009	0.5	0.6
58	570	0.009	0.026	1.588	0.178	0.009	1.367	0.025	0.009	0.6	0.6
59	580	0.009	0.026	1.614	0.188	0.009	1.392	0.025	0.009	0.6	0.6
60	590	0.009	0.026	1.639	0.197	0.010	1.417	0.025	0.010	0.6	0.6
61	600	0.009	0.026	1.665	0.207	0.010	1.442	0.025	0.010	0.6	0.6
62	610	0.009	0.026	1.690	0.217	0.010	1.468	0.025	0.010	0.6	0.6
63	620	0.009	0.026	1.716	0.227	0.010	1.493	0.025	0.010	0.6	0.6
64	630	0.009	0.026	1.741	0.237	0.010	1.518	0.025	0.010	0.6	0.6
65	640	0.009	0.026	1.767	0.247	0.010	1.543	0.025	0.010	0.6	0.6
66	650	0.007	0.021	1.788	0.256	0.009	1.564	0.021	0.009	0.5	0.6
67	660	0.007	0.021	1.808	0.265	0.009	1.585	0.021	0.009	0.5	0.6
68	670	0.007	0.021	1.829	0.274	0.009	1.605	0.021	0.009	0.5	0.6
69	680	0.007	0.021	1.850	0.283	0.009	1.626	0.021	0.009	0.5	0.6
70	690	0.007	0.021	1.871	0.292	0.009	1.647	0.021	0.009	0.5	0.6
71	700	0.007	0.021	1.892	0.301	0.009	1.667	0.021	0.009	0.6	0.6
72	710	0.007	0.021	1.913	0.310	0.009	1.688	0.021	0.009	0.6	0.6
73	720	0.007	0.021	1.934	0.319	0.009	1.709	0.021	0.009	0.6	0.6
74	730	0.007	0.021	1.955	0.329	0.009	1.729	0.021	0.009	0.6	0.6
75	740	0.007	0.021	1.975	0.338	0.010	1.750	0.021	0.010	0.6	0.6
76	750	0.007	0.021	1.996	0.348	0.010	1.771	0.021	0.010	0.6	0.6
77	760	0.007	0.021	2.017	0.358	0.010	1.791	0.021	0.010	0.6	0.6
78	770	0.006	0.017	2.034	0.366	0.008	1.808	0.016	0.008	0.5	0.6
79	780	0.006	0.017	2.050	0.374	0.008	1.824	0.016	0.008	0.5	0.6
80	790	0.006	0.017	2.067	0.382	0.008	1.841	0.016	0.008	0.5	0.5
81	800	0.006	0.017	2.083	0.389	0.008	1.857	0.016	0.008	0.5	0.5
82	810	0.006	0.017	2.100	0.398	0.008	1.873	0.016	0.008	0.5	0.5
83	820	0.006	0.017	2.116	0.406	0.008	1.890	0.016	0.008	0.5	0.5
84	830	0.006	0.017	2.133	0.414	0.008	1.906	0.016	0.008	0.5	0.5
85	840	0.006	0.017	2.149	0.422	0.008	1.923	0.016	0.008	0.5	0.5
86	850	0.006	0.017	2.166	0.430	0.008	1.939	0.016	0.008	0.5	0.5
87	860	0.006	0.017	2.183	0.439	0.008	1.955	0.016	0.008	0.5	0.5
88	870	0.006	0.017	2.199	0.447	0.008	1.972	0.016	0.008	0.5	0.5
89	880	0.006	0.017	2.216	0.455	0.008	1.988	0.016	0.008	0.5	0.5
90	890	0.005	0.015	2.230	0.463	0.007	2.003	0.014	0.007	0.4	0.5
91	900	0.005	0.015	2.245	0.470	0.007	2.017	0.014	0.007	0.5	0.5
92	910	0.005	0.015	2.259	0.478	0.008	2.031	0.014	0.008	0.5	0.5
93	920	0.005	0.015	2.274	0.485	0.008	2.046	0.014	0.008	0.5	0.5
94	930	0.005	0.015	2.288	0.493	0.008	2.060	0.014	0.008	0.5	0.5
95	940	0.005	0.015	2.303	0.501	0.008	2.075	0.014	0.008	0.5	0.5

(1) Time Increment	(2) Time (minute)	(3) Rainfall Distrib. (fraction)	(4) Incre. Rainfall (inches)	(5) Accumul. Rainfall (inches)	(6) PERVIOUS		(7) IMPERVIOUS		(10) Total Runoff (inches)	(11) Instant Flowrate (cfs)	(12) Design Flowrate (cfs)
					Accum. Runoff (inches)	Incre. Runoff (inches)	Accum. Runoff (inches)	Incre. Runoff (inches)			
96	950	0.005	0.015	2.317	0.508	0.008	2.089	0.014	0.008	0.5	0.5
97	960	0.005	0.015	2.332	0.516	0.008	2.103	0.014	0.008	0.5	0.5
98	970	0.005	0.015	2.346	0.524	0.008	2.118	0.014	0.008	0.5	0.5
99	980	0.005	0.015	2.361	0.532	0.008	2.132	0.014	0.008	0.5	0.5
100	990	0.005	0.015	2.375	0.539	0.008	2.147	0.014	0.008	0.5	0.5
101	1000	0.005	0.015	2.390	0.547	0.008	2.161	0.014	0.008	0.5	0.5
102	1010	0.004	0.012	2.401	0.554	0.006	2.173	0.012	0.006	0.4	0.5
103	1020	0.004	0.012	2.413	0.560	0.006	2.184	0.012	0.006	0.4	0.5
104	1030	0.004	0.012	2.424	0.566	0.006	2.196	0.012	0.006	0.4	0.4
105	1040	0.004	0.012	2.436	0.573	0.006	2.207	0.012	0.006	0.4	0.4
106	1050	0.004	0.012	2.448	0.579	0.006	2.219	0.012	0.006	0.4	0.4
107	1060	0.004	0.012	2.459	0.585	0.006	2.230	0.012	0.006	0.4	0.4
108	1070	0.004	0.012	2.471	0.592	0.006	2.242	0.012	0.006	0.4	0.4
109	1080	0.004	0.012	2.482	0.598	0.006	2.253	0.012	0.006	0.4	0.4
110	1090	0.004	0.012	2.494	0.605	0.007	2.265	0.012	0.007	0.4	0.4
111	1100	0.004	0.012	2.506	0.611	0.007	2.276	0.012	0.007	0.4	0.4
112	1110	0.004	0.012	2.517	0.618	0.007	2.288	0.012	0.007	0.4	0.4
113	1120	0.004	0.012	2.529	0.625	0.007	2.299	0.012	0.007	0.4	0.4
114	1130	0.004	0.012	2.540	0.631	0.007	2.311	0.012	0.007	0.4	0.4
115	1140	0.004	0.012	2.552	0.638	0.007	2.322	0.012	0.007	0.4	0.4
116	1150	0.004	0.012	2.564	0.644	0.007	2.334	0.012	0.007	0.4	0.4
117	1160	0.004	0.012	2.575	0.651	0.007	2.346	0.012	0.007	0.4	0.4
118	1170	0.004	0.012	2.587	0.658	0.007	2.357	0.012	0.007	0.4	0.4
119	1180	0.004	0.012	2.598	0.664	0.007	2.369	0.012	0.007	0.4	0.4
120	1190	0.004	0.012	2.610	0.671	0.007	2.380	0.012	0.007	0.4	0.4
121	1200	0.004	0.012	2.622	0.678	0.007	2.392	0.012	0.007	0.4	0.4
122	1210	0.004	0.012	2.633	0.685	0.007	2.403	0.012	0.007	0.4	0.4
123	1220	0.004	0.012	2.645	0.691	0.007	2.415	0.012	0.007	0.4	0.4
124	1230	0.004	0.012	2.656	0.698	0.007	2.426	0.012	0.007	0.4	0.4
125	1240	0.004	0.012	2.668	0.705	0.007	2.438	0.012	0.007	0.4	0.4
126	1250	0.004	0.012	2.680	0.712	0.007	2.449	0.012	0.007	0.4	0.4
127	1260	0.004	0.012	2.691	0.719	0.007	2.461	0.012	0.007	0.4	0.4
128	1270	0.004	0.012	2.703	0.726	0.007	2.472	0.012	0.007	0.4	0.4
129	1280	0.004	0.012	2.714	0.732	0.007	2.484	0.012	0.007	0.4	0.4
130	1290	0.004	0.012	2.726	0.739	0.007	2.496	0.012	0.007	0.4	0.4
131	1300	0.004	0.012	2.738	0.746	0.007	2.507	0.012	0.007	0.4	0.4
132	1310	0.004	0.012	2.749	0.753	0.007	2.519	0.012	0.007	0.4	0.4
133	1320	0.004	0.012	2.761	0.760	0.007	2.530	0.012	0.007	0.4	0.4
134	1330	0.004	0.012	2.772	0.767	0.007	2.542	0.012	0.007	0.4	0.4
135	1340	0.004	0.012	2.784	0.774	0.007	2.553	0.012	0.007	0.4	0.4
136	1350	0.004	0.012	2.796	0.781	0.007	2.565	0.012	0.007	0.4	0.4
137	1360	0.004	0.012	2.807	0.788	0.007	2.576	0.012	0.007	0.4	0.4
138	1370	0.004	0.012	2.819	0.795	0.007	2.588	0.012	0.007	0.4	0.4
139	1380	0.004	0.012	2.830	0.803	0.007	2.599	0.012	0.007	0.4	0.4
140	1390	0.004	0.012	2.842	0.810	0.007	2.611	0.012	0.007	0.4	0.4
141	1400	0.004	0.012	2.854	0.817	0.007	2.623	0.012	0.007	0.4	0.4
142	1410	0.004	0.012	2.865	0.824	0.007	2.634	0.012	0.007	0.4	0.4
143	1420	0.004	0.012	2.877	0.831	0.007	2.646	0.012	0.007	0.4	0.4
144	1430	0.004	0.012	2.888	0.838	0.007	2.657	0.012	0.007	0.4	0.4
145	1440	0.004	0.012	2.900	0.845	0.007	2.669	0.012	0.007	0.4	0.4

Table 2.7
SBUH Values for Developed Site Condition

Given: Area = 10 acres P = 2.9 inches (10-yr., 24-hr. event) dt = 10 minutes
 PERVIOUS AREA: Area = 6.1 acres CN = 89 S = 1.235955 0.2S = 0.25
 IMPERVIOUS AREA: Area = 3.9 acres CN = 98 S = 0.204082 0.2S = 0.04
 Tc = 28 minutes w = 0.151515 where S = potential maximum natural detention (as defined earlier)
 Column (1) = Time Increment Column (2) = Time (min)
 Column (3) = Type IA Storm Distribution
 Column (4) = Column (3) * P
 Column (5) = Accumulated sum of Column (4)
 Column (6) = If (P < 0.2S) = 0, If (P > 0.2S) = (Column (5) - 0.2S)² / (Column (5) + 0.8S), where the PERVIOUS AREA S value is used
 Column (7) = Column (6) of the present step - Column (6) of the previous step
 Column (8) = Same as Column (6) except use IMPERVIOUS AREA S value
 Column (9) = Column (8) of the present step - Column (8) of the previous step
 Column (10) = (PERVIOUS AREA/TOTAL AREA)*Column (7)+(IMPERVIOUS AREA/TOTAL AREA)*Column (9)
 Column (11) = (60.5*Column (10)*Total Area)/dt, where dt = 10 or 60 minutes
 Column (12) = Column (12) of previous time step + w * [(Column (11) of previous time step + Column (11) of present time step) - (2 * Column (12) of previous time step)] where w = routing constant = dt/(2Tc + dt) = 0.0641

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
					PERVIOUS		IMPERVIOUS				
Time Increment	Time (minute)	Rainfall Distrib. (fraction)	Incr. Rainfall (inches)	Accumul. Rainfall (inches)	Accum. Runoff (inches)	Incr. Runoff (inches)	Accum. Runoff (inches)	Incr. Runoff (inches)	Total Runoff (inches)	Instant Flowrate (cfs)	Design Flowrate (cfs)
1	0	0	0	0	0	0	0	0	0	0.0	0.0
2	10	0.004	0.012	0.012	0.000	0.000	0.000	0.000	0.000	0.0	0.0
3	20	0.004	0.012	0.023	0.000	0.000	0.000	0.000	0.000	0.0	0.0
4	30	0.004	0.012	0.035	0.000	0.000	0.000	0.000	0.000	0.0	0.0
5	40	0.004	0.012	0.046	0.000	0.000	0.000	0.000	0.000	0.0	0.0
6	50	0.004	0.012	0.058	0.000	0.000	0.001	0.001	0.000	0.0	0.0
7	60	0.004	0.012	0.070	0.000	0.000	0.004	0.002	0.001	0.1	0.0
8	70	0.004	0.012	0.081	0.000	0.000	0.007	0.003	0.001	0.1	0.0
9	80	0.004	0.012	0.093	0.000	0.000	0.011	0.004	0.002	0.1	0.0
10	90	0.004	0.012	0.104	0.000	0.000	0.015	0.005	0.002	0.1	0.1
11	100	0.004	0.012	0.116	0.000	0.000	0.020	0.005	0.002	0.1	0.1
12	110	0.005	0.015	0.131	0.000	0.000	0.027	0.007	0.003	0.2	0.1
13	120	0.005	0.015	0.145	0.000	0.000	0.035	0.008	0.003	0.2	0.1
14	130	0.005	0.015	0.160	0.000	0.000	0.044	0.008	0.003	0.2	0.1
15	140	0.005	0.015	0.174	0.000	0.000	0.053	0.009	0.003	0.2	0.2
16	150	0.005	0.015	0.189	0.000	0.000	0.062	0.009	0.004	0.2	0.2
17	160	0.005	0.015	0.203	0.000	0.000	0.072	0.010	0.004	0.2	0.2
18	170	0.006	0.017	0.220	0.000	0.000	0.084	0.012	0.005	0.3	0.2
19	180	0.006	0.017	0.238	0.000	0.000	0.097	0.013	0.005	0.3	0.2
20	190	0.006	0.017	0.255	0.000	0.000	0.110	0.013	0.005	0.3	0.3
21	200	0.006	0.017	0.273	0.001	0.000	0.123	0.013	0.006	0.3	0.3
22	210	0.006	0.017	0.290	0.001	0.001	0.137	0.014	0.006	0.4	0.3
23	220	0.006	0.017	0.307	0.003	0.001	0.151	0.014	0.006	0.4	0.3
24	230	0.007	0.020	0.328	0.005	0.002	0.168	0.017	0.008	0.5	0.4
25	240	0.007	0.020	0.348	0.008	0.003	0.185	0.017	0.008	0.5	0.4
26	250	0.007	0.020	0.368	0.011	0.003	0.202	0.017	0.009	0.5	0.4
27	260	0.007	0.020	0.389	0.015	0.004	0.219	0.017	0.009	0.5	0.5
28	270	0.007	0.020	0.409	0.019	0.004	0.237	0.018	0.009	0.6	0.5
29	280	0.007	0.020	0.429	0.023	0.005	0.255	0.018	0.010	0.6	0.5
30	290	0.008	0.024	0.453	0.029	0.006	0.276	0.021	0.012	0.7	0.6
31	300	0.008	0.024	0.477	0.036	0.007	0.297	0.021	0.012	0.7	0.6
32	310	0.008	0.024	0.501	0.043	0.007	0.318	0.021	0.013	0.8	0.7
33	320	0.008	0.024	0.524	0.051	0.008	0.340	0.022	0.013	0.8	0.7
34	330	0.008	0.024	0.548	0.059	0.008	0.362	0.022	0.013	0.8	0.7
35	340	0.008	0.024	0.572	0.068	0.009	0.384	0.022	0.014	0.8	0.8
36	350	0.010	0.028	0.599	0.078	0.011	0.409	0.026	0.016	1.0	0.8
37	360	0.010	0.028	0.627	0.089	0.011	0.435	0.026	0.017	1.0	0.9
38	370	0.010	0.028	0.655	0.101	0.012	0.461	0.026	0.017	1.0	0.9

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Time Increment	Time (minute)	Rainfall Distrib. (fraction)	Incre. Rainfall (inches)	Accumul. Rainfall (inches)	PERVIOUS		IMPERVIOUS		Total Runoff (inches)	Instant Flowrate (cfs)	Design Flowrate (cfs)
					Accum. Runoff (inches)	Incre. Runoff (inches)	Accum. Runoff (inches)	Incre. Runoff (inches)			
39	380	0.010	0.028	0.682	0.113	0.012	0.486	0.026	0.018	1.1	1.0
40	390	0.010	0.028	0.710	0.126	0.013	0.512	0.026	0.018	1.1	1.0
41	400	0.010	0.028	0.737	0.139	0.013	0.539	0.026	0.018	1.1	1.0
42	410	0.013	0.039	0.776	0.158	0.019	0.575	0.037	0.026	1.6	1.1
43	420	0.013	0.039	0.815	0.179	0.020	0.613	0.037	0.027	1.6	1.3
44	430	0.013	0.039	0.854	0.200	0.021	0.650	0.037	0.027	1.7	1.4
45	440	0.018	0.052	0.906	0.229	0.029	0.700	0.050	0.037	2.3	1.6
46	450	0.018	0.052	0.958	0.260	0.031	0.750	0.050	0.038	2.3	1.8
47	460	0.034	0.099	1.057	0.320	0.061	0.846	0.096	0.074	4.5	2.3
48	470	0.054	0.157	1.213	0.424	0.103	0.999	0.153	0.123	7.4	3.4
49	480	0.027	0.078	1.292	0.478	0.054	1.075	0.077	0.063	3.8	4.1
50	490	0.018	0.052	1.344	0.516	0.037	1.127	0.051	0.043	2.6	3.8
51	500	0.013	0.039	1.383	0.544	0.028	1.165	0.038	0.032	1.9	3.3
52	510	0.013	0.039	1.422	0.572	0.028	1.203	0.038	0.032	2.0	2.9
53	520	0.013	0.039	1.460	0.601	0.029	1.241	0.038	0.032	2.0	2.6
54	530	0.009	0.026	1.486	0.620	0.019	1.266	0.025	0.021	1.3	2.3
55	540	0.009	0.026	1.511	0.639	0.019	1.291	0.025	0.022	1.3	2.0
56	550	0.009	0.026	1.537	0.659	0.019	1.317	0.025	0.022	1.3	1.8
57	560	0.009	0.026	1.563	0.678	0.019	1.342	0.025	0.022	1.3	1.7
58	570	0.009	0.026	1.588	0.698	0.020	1.367	0.025	0.022	1.3	1.5
59	580	0.009	0.026	1.614	0.717	0.020	1.392	0.025	0.022	1.3	1.5
60	590	0.009	0.026	1.639	0.737	0.020	1.417	0.025	0.022	1.3	1.4
61	600	0.009	0.026	1.665	0.757	0.020	1.442	0.025	0.022	1.3	1.4
62	610	0.009	0.026	1.690	0.777	0.020	1.468	0.025	0.022	1.3	1.4
63	620	0.009	0.026	1.716	0.797	0.020	1.493	0.025	0.022	1.3	1.4
64	630	0.009	0.026	1.741	0.818	0.020	1.518	0.025	0.022	1.3	1.4
65	640	0.009	0.026	1.767	0.838	0.020	1.543	0.025	0.022	1.3	1.4
66	650	0.007	0.021	1.788	0.855	0.017	1.564	0.021	0.018	1.1	1.3
67	660	0.007	0.021	1.808	0.871	0.017	1.585	0.021	0.018	1.1	1.3
68	670	0.007	0.021	1.829	0.888	0.017	1.605	0.021	0.018	1.1	1.2
69	680	0.007	0.021	1.850	0.905	0.017	1.626	0.021	0.018	1.1	1.2
70	690	0.007	0.021	1.871	0.922	0.017	1.647	0.021	0.018	1.1	1.2
71	700	0.007	0.021	1.892	0.939	0.017	1.667	0.021	0.018	1.1	1.1
72	710	0.007	0.021	1.913	0.956	0.017	1.688	0.021	0.018	1.1	1.1
73	720	0.007	0.021	1.934	0.973	0.017	1.709	0.021	0.019	1.1	1.1
74	730	0.007	0.021	1.955	0.990	0.017	1.729	0.021	0.019	1.1	1.1
75	740	0.007	0.021	1.975	1.008	0.017	1.750	0.021	0.019	1.1	1.1
76	750	0.007	0.021	1.996	1.025	0.017	1.771	0.021	0.019	1.1	1.1
77	760	0.007	0.021	2.017	1.042	0.017	1.791	0.021	0.019	1.1	1.1
78	770	0.006	0.017	2.034	1.056	0.014	1.808	0.016	0.015	0.9	1.1
79	780	0.006	0.017	2.050	1.070	0.014	1.824	0.016	0.015	0.9	1.0
80	790	0.006	0.017	2.067	1.084	0.014	1.841	0.016	0.015	0.9	1.0
81	800	0.006	0.017	2.083	1.097	0.014	1.857	0.016	0.015	0.9	1.0
82	810	0.006	0.017	2.100	1.111	0.014	1.873	0.016	0.015	0.9	0.9
83	820	0.006	0.017	2.116	1.125	0.014	1.890	0.016	0.015	0.9	0.9
84	830	0.006	0.017	2.133	1.139	0.014	1.906	0.016	0.015	0.9	0.9
85	840	0.006	0.017	2.149	1.153	0.014	1.923	0.016	0.015	0.9	0.9
86	850	0.006	0.017	2.166	1.167	0.014	1.939	0.016	0.015	0.9	0.9
87	860	0.006	0.017	2.183	1.181	0.014	1.955	0.016	0.015	0.9	0.9
88	870	0.006	0.017	2.199	1.195	0.014	1.972	0.016	0.015	0.9	0.9
89	880	0.006	0.017	2.216	1.209	0.014	1.988	0.016	0.015	0.9	0.9
90	890	0.005	0.015	2.230	1.222	0.012	2.003	0.014	0.013	0.8	0.9
91	900	0.005	0.015	2.245	1.234	0.012	2.017	0.014	0.013	0.8	0.9
92	910	0.005	0.015	2.259	1.246	0.012	2.031	0.014	0.013	0.8	0.8
93	920	0.005	0.015	2.274	1.259	0.012	2.046	0.014	0.013	0.8	0.8
94	930	0.005	0.015	2.288	1.271	0.012	2.060	0.014	0.013	0.8	0.8
95	940	0.005	0.015	2.303	1.284	0.012	2.075	0.014	0.013	0.8	0.8

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Time Increment	Time (minute)	Rainfall Distrib. (fraction)	Incre. Rainfall (inches)	Accumul. Rainfall (inches)	PERVIOUS		IMPERVIOUS		Total Runoff (inches)	Instant Flowrate (cfs)	Design Flowrate (cfs)
					Accum. Runoff (inches)	Incre. Runoff (inches)	Accum. Runoff (inches)	Incre. Runoff (inches)			
96	950	0.005	0.015	2.317	1.296	0.012	2.089	0.014	0.013	0.8	0.8
97	960	0.005	0.015	2.332	1.309	0.012	2.103	0.014	0.013	0.8	0.8
98	970	0.005	0.015	2.346	1.321	0.012	2.118	0.014	0.013	0.8	0.8
99	980	0.005	0.015	2.361	1.334	0.013	2.132	0.014	0.013	0.8	0.8
100	990	0.005	0.015	2.375	1.346	0.013	2.147	0.014	0.013	0.8	0.8
101	1000	0.005	0.015	2.390	1.359	0.013	2.161	0.014	0.013	0.8	0.8
102	1010	0.004	0.012	2.401	1.369	0.010	2.173	0.012	0.011	0.6	0.8
103	1020	0.004	0.012	2.413	1.379	0.010	2.184	0.012	0.011	0.6	0.7
104	1030	0.004	0.012	2.424	1.389	0.010	2.196	0.012	0.011	0.6	0.7
105	1040	0.004	0.012	2.436	1.399	0.010	2.207	0.012	0.011	0.6	0.7
106	1050	0.004	0.012	2.448	1.409	0.010	2.219	0.012	0.011	0.6	0.7
107	1060	0.004	0.012	2.459	1.419	0.010	2.230	0.012	0.011	0.6	0.7
108	1070	0.004	0.012	2.471	1.429	0.010	2.242	0.012	0.011	0.6	0.7
109	1080	0.004	0.012	2.482	1.439	0.010	2.253	0.012	0.011	0.6	0.7
110	1090	0.004	0.012	2.494	1.449	0.010	2.265	0.012	0.011	0.6	0.7
111	1100	0.004	0.012	2.506	1.460	0.010	2.276	0.012	0.011	0.6	0.7
112	1110	0.004	0.012	2.517	1.470	0.010	2.288	0.012	0.011	0.6	0.6
113	1120	0.004	0.012	2.529	1.480	0.010	2.299	0.012	0.011	0.6	0.6
114	1130	0.004	0.012	2.540	1.490	0.010	2.311	0.012	0.011	0.6	0.6
115	1140	0.004	0.012	2.552	1.500	0.010	2.322	0.012	0.011	0.6	0.6
116	1150	0.004	0.012	2.564	1.510	0.010	2.334	0.012	0.011	0.6	0.6
117	1160	0.004	0.012	2.575	1.521	0.010	2.346	0.012	0.011	0.6	0.6
118	1170	0.004	0.012	2.587	1.531	0.010	2.357	0.012	0.011	0.6	0.6
119	1180	0.004	0.012	2.598	1.541	0.010	2.369	0.012	0.011	0.6	0.6
120	1190	0.004	0.012	2.610	1.551	0.010	2.380	0.012	0.011	0.6	0.6
121	1200	0.004	0.012	2.622	1.562	0.010	2.392	0.012	0.011	0.6	0.6
122	1210	0.004	0.012	2.633	1.572	0.010	2.403	0.012	0.011	0.7	0.6
123	1220	0.004	0.012	2.645	1.582	0.010	2.415	0.012	0.011	0.7	0.6
124	1230	0.004	0.012	2.656	1.592	0.010	2.426	0.012	0.011	0.7	0.7
125	1240	0.004	0.012	2.668	1.603	0.010	2.438	0.012	0.011	0.7	0.7
126	1250	0.004	0.012	2.680	1.613	0.010	2.449	0.012	0.011	0.7	0.7
127	1260	0.004	0.012	2.691	1.623	0.010	2.461	0.012	0.011	0.7	0.7
128	1270	0.004	0.012	2.703	1.633	0.010	2.472	0.012	0.011	0.7	0.7
129	1280	0.004	0.012	2.714	1.644	0.010	2.484	0.012	0.011	0.7	0.7
130	1290	0.004	0.012	2.726	1.654	0.010	2.496	0.012	0.011	0.7	0.7
131	1300	0.004	0.012	2.738	1.664	0.010	2.507	0.012	0.011	0.7	0.7
132	1310	0.004	0.012	2.749	1.675	0.010	2.519	0.012	0.011	0.7	0.7
133	1320	0.004	0.012	2.761	1.685	0.010	2.530	0.012	0.011	0.7	0.7
134	1330	0.004	0.012	2.772	1.695	0.010	2.542	0.012	0.011	0.7	0.7
135	1340	0.004	0.012	2.784	1.706	0.010	2.553	0.012	0.011	0.7	0.7
136	1350	0.004	0.012	2.796	1.716	0.010	2.565	0.012	0.011	0.7	0.7
137	1360	0.004	0.012	2.807	1.726	0.010	2.576	0.012	0.011	0.7	0.7
138	1370	0.004	0.012	2.819	1.737	0.010	2.588	0.012	0.011	0.7	0.7
139	1380	0.004	0.012	2.830	1.747	0.010	2.599	0.012	0.011	0.7	0.7
140	1390	0.004	0.012	2.842	1.758	0.010	2.611	0.012	0.011	0.7	0.7
141	1400	0.004	0.012	2.854	1.768	0.010	2.623	0.012	0.011	0.7	0.7
142	1410	0.004	0.012	2.865	1.778	0.010	2.634	0.012	0.011	0.7	0.7
143	1420	0.004	0.012	2.877	1.789	0.010	2.646	0.012	0.011	0.7	0.7
144	1430	0.004	0.012	2.888	1.799	0.010	2.657	0.012	0.011	0.7	0.7
145	1440	0.004	0.012	2.900	1.810	0.010	2.669	0.012	0.011	0.7	0.7

2.3.4 Hydrograph Routing (Sizing Detention Facilities)

A methodology is presented here for routing a hydrograph through an existing retention/detention facility or closed depression, and for sizing a new retention/detention facility using hydrograph analysis.

Storage Routing Technique: The “level pool routing” technique presented here is one of the simplest and most commonly used hydrograph routing methods. This method is described in “Handbook of Applied Hydrology,” Chow, V. Te, 1964, and elsewhere, and is based on the continuity equation:

Inflow - Outflow = Change in Storage

$$\left[\frac{I_1 + I_2}{2} - \frac{O_1 + O_2}{2} \right] = \frac{\Delta S}{\Delta t} = \frac{S_2 - S_1}{\Delta t}$$

Where I = Inflow at time 1 and time 2

O = Outflow at time 1 and time 2

S = Storage at time 1 and time 2

Δt = Time interval, 2-1

The time interval, Δt , must be consistent with the time interval used in developing the inflow hydrograph. The time interval used for a 24-hour storm is 10 minutes while the time interval used for a 7-day storm is 60 minutes. The Δt variable can be eliminated by dividing it into the storage variables to obtain the following rearranged equation:

$$I_1 + I_2 + 2S_1 - O_1 = O_2 + 2S_2$$

If the time interval, Δt , is in minutes and the units of storage (S) are in cubic feet (cf), this can be converted to cubic feet per second (cfs) by dividing by 60.

The terms I_1 , I_2 , O_1 , and S_1 are known from the inflow hydrograph and from the storage and outflow values of the previous time step. The unknowns O_2 and S_2 can be solved interactively from the given stage-storage and stage-discharge curves.