10.9 Routing Procedure

The most commonly used method for routing inflow hydrograph through a detention pond is the Storage Indication or modified Puls method. This method begins with the continuity equation which states that the inflow minus the outflow equals the change in storage $(I - 0 = \Delta S)$. By taking the average of two closely spaced inflows and two closely spaced outflows, the method is expressed by equation 10.29. This relationship is illustrated graphically in Figure 10-19.

$$\frac{\Delta S}{\Delta t} = \frac{I_1 + I_2}{2} - \frac{O_1 + O_2}{2} \qquad \textbf{(10.29)}$$

where: ΔS = change in storage, m^3 (ft^3)
Δt = time interval, min
I = inflow, m^3 (ft^3)
O = outflow, m^3 (ft^3)

In equation 10.29, subscript 1 refers to the beginning and subscript 2 refers to the end of the time interval.

Equation 10.29 can be rearranged so that all the known values are on the left side of the equation and all the unknown values are located on the right hand side of the equation, as shown in equation 10.30. Now, the equation with two unknowns, S_2 and O_2, can be solved with one equation. The following procedure can be used to perform routing through a reservoir or storage facility using equation 10.30.

$$\frac{I_1 + I_2}{2} + \left(\frac{S_1}{\Delta t} + \frac{O_1}{2}\right) - O_1 = \left(\frac{S_2}{\Delta t} + \frac{O_2}{2}\right) \qquad \textbf{(10.30)}$$

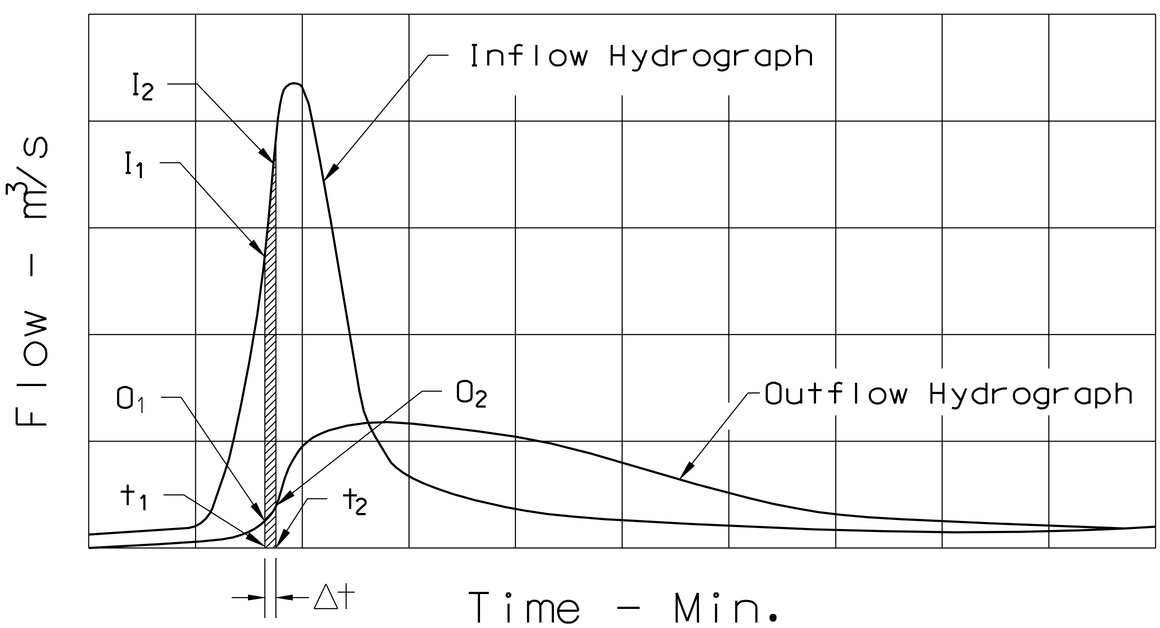

Figure 10-19 Routing hydrograph schematic

Step 1. Develop an inflow hydrograph, stage-discharge curve, and stage-storage curve for the proposed storage facility.

Step 2. Select a routing time period, Δt, to provide a minimum of five points on the rising limb of the inflow hydrograph.

Step 3. Use the stage-storage and stage-discharge data from Step 1 to develop a storage indicator numbers table that provides storage indicator values, $S/(\Delta t) + O/2$, versus stage. A typical storage indicator numbers table contains the following column headings:

(1) Stage (m)	(2) Discharge (O) (m^3/s)	(3) Storage (S) (m^3)	(4) $O_2/2$ (m^3/s)	(5) $S_2/\Delta t$ (m^3/s)	(6) $S_2/\Delta t + O_2/2$

a. The discharge (O) and storage (S) are obtained from the stage-discharge and stage-storage curves, respectively.

b. The subscript 2 is arbitrarily assigned at this time.

c. The time interval (Δt) must be the same as the time interval used in the tabulated inflow hydrograph.

Step 4. Develop a storage indicator numbers curve by plotting the outflow (column 2) vertically against the storage indicator numbers in column (6). An equal value line plotted as $O_2 = S_2/\Delta t + 0_2/2$ should also be plotted. If the storage indicator curve crosses the equal value line, a smaller time increment (Δt) is needed (refer to Figure 10-20).

Step 5. A supplementary curve of storage (column 3) vs. $S_2/\Delta t + O_2/2$ (column 4) can also be constructed. This curve does not enter into the mainstream of the routing; however, it is useful for identifying storage for any given value of $S_2/\Delta t + O_2/2$. A plot of storage vs. time can be developed from this curve.

Step 6. The routing can now be performed by developing a routing table (see Example 10-9) for the solution of equation 10.30 as follows:

a. Columns (1) and (2) are obtained from the inflow hydrograph.

b. Column (3) is the average inflow over the time interval.

c. The initial vales for columns (4) and (5) are generally assumed to be zero since there is no storage or discharge at the beginning of the hydrograph when there is no inflow into the basin.

d. The left side of equation 10.30 is determined algebraically as columns (3) + (4) - (5). This value equals the right side of equation 10.30 or $S_2/\Delta t + 0_2/2$ and is placed in column (6).

e. Enter the storage indicator curve with $S_2/\Delta t + O_2/2$ (column 6) to obtain O_2 (column 7).

f. Column (6) ($S_2/\Delta t + O_2/2$) and column (7) (O_2) are transported to the next line and become $S_1/\Delta t + O_1/2$ and O_1 in columns (4) and (5), respectively. Because ($S_2/\Delta t + O_2/2$) and O_2 are the ending values for the first time step, they can also be said to be the beginning values for the second time step.

g. Columns (3), (4), and (5) are again combined and the process is continued until the storm is routed.

h. Peak storage depth and discharge (O_2 in column (7)) will occur when column (6) reaches a maximum. The storage indicator numbers table developed in Step 3 is entered with the maximum value of $S_2/\Delta t + O_2/2$ to obtain the maximum amount of storage required. This table can also be used to determine the corresponding elevation of the depth of stored water.

i. The designer needs to make sure that the peak value in column (7) does not exceed the allowable discharge as prescribed by the stormwater management criteria.

Step. 7. Plot O_2 (column (7)) versus time (column (1)) to obtain the outflow hydrograph.

The above procedure is illustrated in the following example.

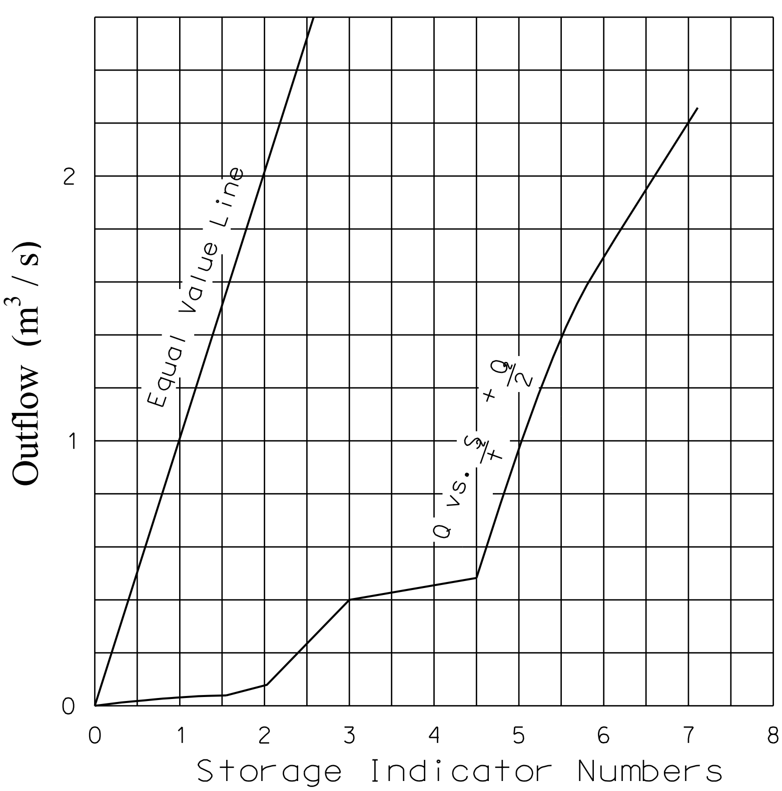

Figure 10-20 Storage Indicator Curve

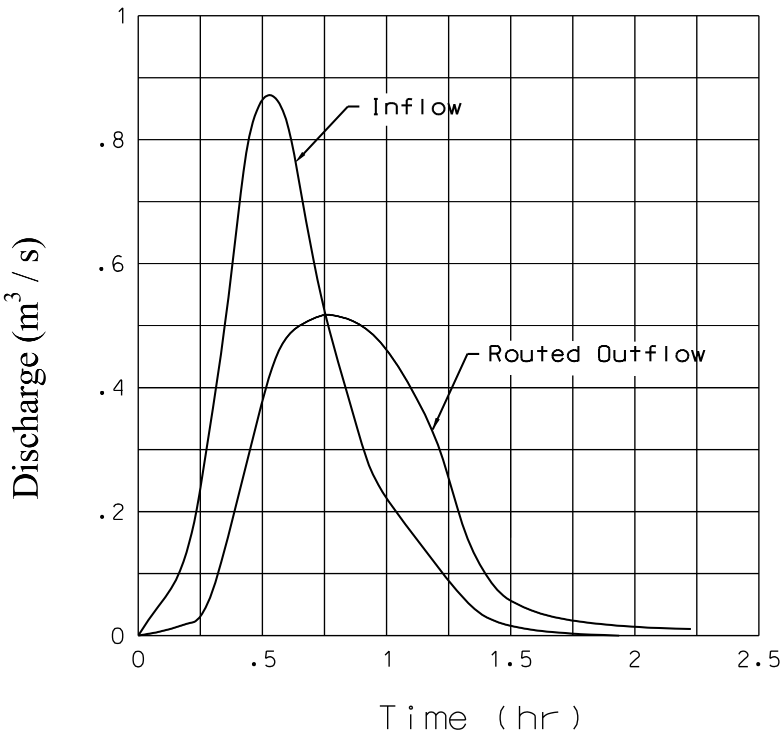

Figure 10-21 Example hydrographs

Example 10-9

Given: *The inflow hydrograph from Figure 10-21, the storage basin, and a discharge control structure comprised of the components in examples 10-5 through 10-8 having a composite stage-discharge relationship defined in Table 10.4.*

Find: *The outflow hydrograph.*

Solution: *Use the generalized routing procedure outlined above.*

Step 1. The inflow hydrograph is tabulated in the final routing table to follow and illustrated in Figure 10-19. The stage-storage curve for the basin in example 10-2 is illustrated in Figure 10-5. The composite stage-discharge curve tabulated in Table 10-4 is illustrated in Figure 10-18.

Step 2. A routing time interval of 0.057 hrs is selected to match the interval used in the inflow hydrograph. This interval provides 9 points on the rising limb of the hydrograph.

Step 3. Using the given stage-storage and stage-discharge curve data, and a time step of 0.057 hr, storage indicator numbers table can be developed as illustrated in the table on page 10.9-6.

Step 4. A storage indicator curve is constructed by plotting the outflow (column 2 from the table below) against the storage indicator numbers (column 6). This curve is illustrated in Figure 10-20. Note that an equal value line is also plotted in Figure 10-20, and since the storage indicator numbers curve does not cross the equal value line, the time step selected is adequate.

Step 5. (The supplementary curve of storage (column 3) vs. the storage indicator numbers (column 6) is not required for this example.)

Step 6. The final routing is shown in the final routing table below.

Step 7. The inflow and outflow hydrographs are plotted in Figure 10-21.

As indicated in the final routing table, the peak routed outflow is 0.52 m^3/s (18.4 ft^3/s). This peak outflow is less than the maximum allowable value of 0.55 m^3/s (19.4 ft^3/s). Using the table below, it can be determined that the outflow of 0.52 m^3/s (18.4 ft^3/s) corresponds to an approximate basin stage of 11.46 m (37.6 ft) which is less than the maximum available stage of 11.6 m (38.1 ft) established in example 10-2, and a storage volume of 794 m^3 (28,020 ft^3) which is less than the estimated storage requirement of 850 m^3 (30,000 ft^3) estimated in example 10-2. At the peak stage of 11.46 m (37.6 ft), the water is not flowing over the emergency spillway. Only the riser pipe and the low flow orifice are functioning.

Storage Indicator Numbers Table

(1) Stage (m)	(2) Discharge (O_2) (m^3/s)	(3) Storage (S_2) (m^3)	(4) $O_2/2$ (m^3/s)	(5) $S_2/\Delta t$ (m^3/s)	(6) $S_2/t + O_2/2$ (m^3/s)
10.0	0.000	0	0.000	0.000	0.000
10.1	0.006	35	0.003	0.171	0.174
10.2	0.011	72	0.006	0.351	0.357
10.3	0.018	109	0.009	0.531	0.540
10.4	0.024	155	0.012	0.755	0.767
10.5	0.028	199	0.014	0.970	0.984
10.6	0.032	248	0.016	1.209	1.225
10.7	0.035	299	0.018	1.457	1.475
10.8	0.038	353	0.019	1.720	1.739
10.9	0.171	414	0.086	2.018	2.104
11.0	0.303	470	0.152	2.290	2.442
11.1	0.378	540	0.189	2.632	2.821
11.2	0.418	600	0.209	2.924	3.133
11.3	0.464	672	0.235	3.275	3.510
11.4	0.503	744	0.252	3.626	3.878
11.5	0.530	824	0.265	4.016	4.281
11.6	0.587	902	0.294	4.396	4.690
11.7	1.150	986	0.575	4.805	5.380
11.8	1.771	1075	0.886	5.239	6.125
11.9	2.069	1160	1.035	5.653	6.688
12.0	2.284	1264	1.142	6.160	7.302

As a last check, it must be determined that the discharge pipe will carry the peak discharge at a head equal to or less than the final stage in the basin. At the peak discharge indicated in the Final Routing Table, the head on the discharge pipe is 1.46 m (4.8 ft). In example 10-7, it was determined that a 750 mm (30 in) discharge pipe would carry a discharge greater than 0.55 m^3/s (19.4 ft^3/s) at a stage of 0.75 m (2.51 ft). Therefore, the discharge pipe capacity is adequate, and the pipe will not control the flow of water from the basin.

Final Routing Table.

(1) Time (hr)	(2) Inflow (m^3/s)	(3) $(I_1+I_2)/2$ (m^3/s)	(4) $(S_1/t+O_1/2)$ (m^3/s)	(5) O_1 (m^3/s)	(6) $(S_2/t+O_2/2)$ (m^3/s)	(7) O_2 (m^3/s)	(8) O_2 (ft^3/s)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
0.06	0.04	0.02	0.00	0.00	0.02	0.00	0.0
0.11	0.07	0.06	0.02	0.00	0.08	0.00	0.0
0.17	0.12	0.10	0.08	0.00	0.17	0.01	0.4
0.23	0.18	0.15	0.17	0.01	0.31	0.01	0.4
0.29	0.33	0.26	0.31	0.01	0.56	0.02	0.7
0.34	0.49	0.41	0.56	0.02	0.95	0.03	1.1
0.40	0.67	0.58	0.95	0.03	1.50	0.04	1.4
0.46	0.81	0.74	1.50	0.04	2.20	0.21	7.4
0.51	0.88	0.85	2.20	0.21	2.83	0.38	13.4
0.57	0.86	0.87	2.83	0.38	3.32	0.45	15.9
0.63	0.79	0.83	3.32	0.45	3.70	0.49	17.3
0.68	0.69	0.74	3.70	0.49	3.95	0.51	18.0
0.74	0.57	0.63	3.95	0.51	4.07	0.52	18.3
0.80	0.48	0.53	4.07	0.52	4.07	0.52	18.3
0.86	0.39	0.44	4.07	0.52	3.99	0.51	18.0
0.91	0.32	0.36	3.99	0.51	3.83	0.50	17.6
0.97	0.26	0.29	3.83	0.50	3.62	0.48	16.9
1.03	0.22	0.24	3.62	0.48	3.38	0.45	15.9
1.08	0.18	0.20	3.38	0.45	3.13	0.42	14.8
1.14	0.15	0.17	3.13	0.42	2.88	0.39	13.8
1.20	0.11	0.13	2.88	0.39	2.62	0.34	12.0
1.25	0.09	0.10	2.62	0.34	2.38	0.28	9.9
1.31	0.05	0.07	2.38	0.28	2.17	0.20	7.1
1.37	0.03	0.04	2.17	0.20	2.01	0.14	4.9
1.43	0.00	0.02	2.01	0.14	1.88	0.07	2.5
1.48	0.00	0.00	1.88	0.07	1.81	0.06	2.1
1.54	0.00	0.00	1.81	0.06	1.75	0.05	1.8
1.60	0.00	0.00	1.75	0.05	1.70	0.04	1.4
1.65	0.00	0.00	1.70	0.04	1.66	0.04	1.4
1.71	0.00	0.00	1.66	0.04	1.62	0.04	1.4
1.77	0.00	0.00	1.62	0.04	1.58	0.04	1.4
1.82	0.00	0.00	1.58	0.04	1.54	0.04	1.4
1.88	0.00	0.00	1.54	0.04	1.50	0.04	1.4
1.94	0.00	0.00	1.50	0.04	1.46	0.03	1.1
1.99	0.00	0.00	1.46	0.03	1.43	0.03	1.1
2.05	0.00	0.00	1.43	0.03	1.40	0.03	1.1
2.11	0.00	0.00	1.40	0.03	1.37	0.03	1.1
2.17	0.00	0.00	1.37	0.03	1.34	0.03	1.1