CHAPTER 6

STORAGE FACILITIES

6.8 Example Problem

6.8.1 Example

This example demonstrates the application of the methodology presented in this chapter for the design of a typical detention storage facility. Example inflow hydrographs and associated peak discharges for both pre- and post-development conditions are assumed to have been developed using hydrologic methods from the Hydrology Chapter. Note: In this example only the 5- and 25-year hydrographs are used. The 2- and 10-year (and possibly the 100-year) hydrographs should also be checked to determine if the final design is adequate.

6.8.2 Design Discharge And Hydrographs

Storage facilities shall be designed for runoff from the 2-, 5-, 10-, and 25-year design storms and an analysis done using the 100-year design storm runoff to ensure that the structure can accommodate runoff from this storm without damaging adjacent and downstream property and structures. Example peak discharges from the 5- and 25-year design storm events are as follows:

- Pre-developed 5-year peak discharge = 150 cfs
- Pre-developed 25-year peak discharge = 200 cfs
- Post-development 5-year peak discharge = 190 cfs
- Post-development 25-year peak discharge = 250 cfs

Since the post-development peak discharge must not exceed the pre-development peak discharge, the allowable design discharge are 150 and 200 cfs for the 5- and 25-yea storms, respectively.

Example runoff hydrographs are shown in Table 6.8.2-1 below. Inflow durations from the post-development hydrographs are about 1.2 and 1.25 hours, respectively, for runoff from the 5- and 25-year storms.

Table 6.8.2-1 Example Runoff Hydrographs

	Pre-Development Runoff		Post-Development Runoff	
(1) Time (Hrs)	(2) 5-Year (cfs)	(3) 25-Year (cfs)	(4) 5-Year (cfs)	(5) 25-Year (cfs)
0	0	0	0	0
0.1	18	24	38	50
0.2	61	81	125	178
0.3	127	170	190 >150	250 >200
0.4	150	200	125	165
0.5	112	150	70	90
0.6	71	95	39	50
0.7	45	61	22	29
0.8	30	40	12	16
0.9	21	28	7	9
1.0	13	18	4	5
1.1	10	15	2	3
1.2	8	13	0	1

Finally, the 2- and 10-year hydrographs should then be determined for pre-development and post-development conditions to test the storage facility design to be sure they are adequately controlled.

6.8.3 Preliminary Volume Calculations

Preliminary estimates of required storage volumes are obtained using the simplified method outlines in Section 6.6. For runoff from the 5- and 25-year storms, the required storage volumes V_s, are computed using equation EQ-6.6.1-1:

$$V_s = 0.5T_i(Q_i - Q_o)$$

5-year storm: V_s = [0.5(1.2 x 3,600)(190 – 150)]/43,560 = 1.98 acre-feet

25-year storm: V_s, = [0.5(1.25 x 3,600)(250 – 200)]/43,560 = 2.58 acre-ft

6.8.4 Design And Routing Calculations

Stage-discharge and stage-storage characteristics of a storage facility that should provide adequate peak flow attenuation for runoff from both the 5- and 25-year design storms are presented below. The storage-discharge relationship was developed by requiring the preliminary storage volume estimates of runoff for both the 5- and 25-year design storms to be provided when the corresponding allowable peak discharge occurred. Storage values were computed by solving the broad-crested weir equation for head, H, assuming a constant discharge coefficient of 3.1, a weir length of 4 feet, and no tailwater submergence. The capacity of storage relief structures was assumed to be negligible.

Table 6.8.4-1 Stage-Discharge-Storage Data

(1) Stage ft)	(2) Q (cfs)	(3) S (acre-feet)	(4) $S_1 - (O/2)\Delta t$ (acre-feet)	(5) $S_1 + (O/2)\Delta t$ (acre-feet)
0.0	0	0.00	0.00	0.00
0.9	10	0.26	0.30	0.22
1.4	20	0.42	0.50	0.33
1.8	30	0.56	0.68	0.43
2.2	40	0.69	0.85	0.52
2.5	50	0.81	1.02	0.60
2.9	60	0.93	1.18	0.68
3.2	70	1.05	1.34	0.76
3.5	80	1.17	1.50	0.84
3.7	90	1.28	1.66	0.92
4.0	100	1.40	1.81	0.99
4.5	120	1.63	2.13	1.14
4.8	130	1.75	2.29	1.21
5.0	140	1.87	2.44	1.29
5.3	150	1.98	2.60	1.36
5.5	160	2.10	2.76	1.44
5.7	170	2.22	2.92	1.52
6.0	180	2.34	3.08	1.60
6.4	200	2.58	3.41	1.76
6.8	220	2.83	3.74	1.92
7.0	230	2.95	3.90	2.00
7.4	250	3.21	4.24	2.17

Storage routing was conducted for runoff from both the 5- and 25-year design storms to confirm the preliminary storage volume estimates and to establish design water surface elevations. Routing results using the Stage-Discharge-Storage Data given on Table 6.8.4-1 and the Storage Characteristics Curves given on Figures 6.7-1 and 6.7-2, and 0.1 –hour time steps are shown below for runoff from the 5- and 25-year design storms, respectively. The preliminary design provides adequate peak discharge attenuation for both the both the 5- and 25-hear design storms.

Table 6.8.4-2 Storage Routing For The 5-Year Storm

(1) Time (hrs)	(2) Inflow (cfs)	(3) $[I_1+I_2)]/2$ (acre-ft)	(4) H_1 (ft	(5) $S_1-(O_1/2)t$ (acre-feet)	(6) $S_2+(O_2/2)t$ (acre-feet) (3)+(5)	(7) H_2 (ft)	(8) Outflow (cfs)
0.0	0	0.00	0.00	0.00	0.00	0.00	0
0.1	38	0.16	0.00	0.00	0.16	0.43	3
0.2	125	0.67	0.43	0.10	0.77	2.03	36
0.3	190	1.30	2.03	0.50	1.80	4.00	99
0.4	125	1.30	4.00	0.99	2.29	4.80	130<150
0.5	70	0.81	4.80	1.21	2.02	4.40	114
0.6	39	0.45	4.40	1.12	1.57	3.60	85
0.7	22	0.25	3.60	0.87	1.12	2.70	55
0.8	12	0.14	2.70	0.65	0.79	2.02	37
0.9	7	0.08	2.08	0.50	0.58	1.70	27
1.0	4	0.05	1.70	0.42	0.47	1.03	18
1.1	2	0.02	1.30	0.32	0.34	1.00	12
1.2	0	0.01	1.00	0.25	0.26	0.70	7
1.3	0	0.00	0.70	0.15	0.15	0.40	3

Since peak outflow equals 130 cfs which is less than the undeveloped peak flow of 150 cfs, this design will work for the 5-year storm.

Table 6.8.4-3 Storage Routing For The 25-Year Storm

(1) Time (hrs)	(2) Inflow (cfs)	(3) $[I_1+I_2)]/2$ (acre-ft)	(4) H_1 (ft	(5) $S_1-(O_1/2)t$ (acre-feet)	(6) $S_2+(O_2/2)t$ (acre-feet) (3)+(5)	(7) H_2 (ft)	(8) Outflow (cfs)
0.0	0	0.00	0.00	0.00	0.00	0.00	0
0.1	50	0.21	0.21	0.00	0.21	0.40	3
0.2	178	0.94	0.40	0.08	1.02	2.50	49
0.3	250	1.77	2.50	0.60	2.37	4.90	134
0.4	165	1.71	4.90	1.26	2.97	2.97	173<200
0.5	90	1.05	5.80	1.30	2.35	4.00	137
0.6	50	0.58	4.95	1.25	1.83	4.10	103
0.7	29	0.33	4.10	1.00	1.33	3.10	68
0.8	16	0.19	3.10	0.75	0.94	2.40	46
0.9	9	0.10	2.40	0.59	0.69	1.90	32
1.0	5	0.06	1.90	0.44	0.50	1.40	21
1.1	3	0.03	1.40	0.33	0.36	1.20	16
1.2	1	0.02	1.20	0.28	0.30	0.90	11
1.3	0	0.00	0.90	0.22	0.22	0.60	6

Since peak outflow equals 173 cfs which is less than the undeveloped peak flow of 200 cfs, this design will work for the 25-year storm.

For the routing calculations the following equation was used:

$$S_2 + (O_2/S)\ \Delta t = [S_1 - (O_1/2)\ \Delta t] + (I_1 + I_2)/2\ \Delta t]$$

Also, column 6 = column 3 + column 5

Since the routed peak discharge is lower than the maximum allowable peak discharges for both design storm events, the weir length could be increased or the storage decreased. If revisions are desired, routing calculations must be repeated.

Although not shown for this example, runoff from the 100-year storm should be routed through the storage facility and downstream to determine if structures or adjacent land areas will be damaged. If flood damage will result, the storage facility must then be designed to limit the runoff from the 100-year storm to undeveloped conditions. Also, the 100-year routed storm should be used to establish freeboard requirements and to evaluate emergency overflow and stability requirements. In addition, the preliminary design provides hydraulic details only. Final design should consider site constraints such as depth of water, side slope stability and maintenance, grading to prevent standing water, and provisions for public safety. Also, the 2- and 10-year storms should be checked.

END OF SECTION 6.8