10

DETENTION/RETENTION

10
DETENTION/RETENTION

As part of a total system of urban stormwater management, detention and retention facilities are man-made storage measures intended to mitigate the negative impacts of urbanization, which include:

- Increased peak flow rates.
- Loss of natural depression storage.
- Reduction of infiltration capacity in a drainage basin.
- Reduction of natural vegetation.
- Increased pollutant load in surface runoff.

This section presents the methods associated with the planning, analysis and design of detention and retention facilities. The guidelines herein are intended to achieve the following goals:

1. Design of detention/retention facilities that satisfy the ordinance provisions of the City;
2. Design of detention/retention facilities that are amenities and, where possible, incorporate multiple-use concepts; and
3. Design of facilities that will not jeopardize the quality of surface water or groundwater resources.

10.1 LIMITATIONS ON USE OF DETENTION/RETENTION FACILITIES

The requirements for a development to provide storage of excess runoff by detention or retention facilities shall not be waived unless determined otherwise by the Director of Public Works on a case-by-case basis.

In general, storage facilities are to be located so they can intercept the flow from the entire development area. The objective is to provide storage for excess runoff with a minimum number of detention/retention facilities located at optimum points within a developed area. Whenever possible, the facilities shall be designed for multiple uses, such as parks or other recreational facilities, to offset the cost of open space and to encourage improved maintenance.

10.1.1 Regional Detention/Retention Facilities

Regional detention/retention facilities are large storage sites within a drainage basin provided to control excess runoff and to achieve the most cost-effective drainage system. Advantages of this type of facility include the following:

- The siting and design of regional storage facilities are normally incorporated as part of an overall drainage master plan.

- Operation and maintenance costs are reduced.

- Regional facilities are more effective and reliable because they are planned, designed and maintained as part of a total drainage system.

10.2 DESIGN CRITERIA

10.2.1 Criteria for Detention/Retention Facilities

Design Frequency: All detention/retention facilities incorporated within new developments shall be designed to retain the peak flow and volume of runoff from the 100-year, 3-hour duration storm event. Stormwater detention facilities for watershed areas larger than 100 acres shall be designed to ensure that, at a minimum, the post-development 100-year, 3-hour duration peak discharge does not exceed the pre-development condition.

Hydrology: Procedures for development of inflow hydrographs for detention/retention facilities are introduced in Section 5 of this Manual and in the Riverside County Flood Control and Water Conservation District *Hydrology Manual.*

In cases where detention/retention facilities are being evaluated for extremely small watersheds, areas less than 100 to 200 acres with lag times less than 7 to 8 minutes, a short-cut Unit Hydrograph Method may be useful. The method is based on the assumption that in a small watershed, which has a high percentage of impervious area, response time to effective rainfall is very short. Therefore, runoff rates for given periods of time can be assumed to be directly proportional to effective rain. It should be emphasized that this method yields conservative results and should only be used for watersheds which meet the limitations noted above.

When designing a typical stormwater detention facility, there are three variables to be considered:

1. Inflow to the facility, which varies as a function of time;
2. Outflow from the facility, which varies as a function of time; and,
3. Storage which is the result of the difference between the inflow and the outflow for period of time or time interval.

As illustrated in Figure 10.1.

The outflow hydrograph from a proposed stormwater detention facility shall be determined using the "Storage Indication" or "Modified Puls" method of flood routing. Section 10.6 offers a detailed description of this routing procedure.

If a computer program is to be used, City staff shall be consulted on the applicability of the program being proposed.

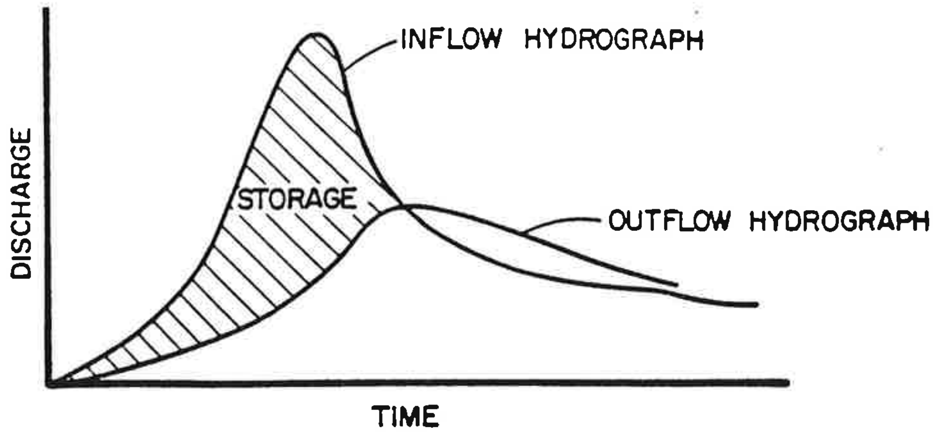


Figure 10.1
Flood Routing (Inflow and Outflow Hydrograph)

Geometry: Basic requirements regarding facility shape, side slopes, depth and bottom configuration are provided below.

- Shape: As a general rule, curvilinear, irregularly shaped facilities will have the most natural character. A wide range of shapes can be considered and utilized to integrate the detention facility with the surrounding site development.

- Side Slopes: Where grass is intended to be established, side slopes shall not be steeper than 4 horizontal to 1 vertical. Where other protection measures are intended, such as shrub planting, rock riprap and other structural measures, slopes shall not exceed 3 horizontal to 1 vertical unless approved by the City Engineer. Where slopes abut the street right-of-way, the minimum slope shall be 4 horizontal to 1 vertical regardless of surface treatment.

- Depth and Bottom Configuration: With respect to grading, deep facilities should be avoided, if possible. For facilities in excess of eight feet deep, consideration should be given to the use of flatter side slopes or the provision of intermediate benches along the side slopes.

  The bottom shall be designed to drain to a low flow channel for a detention facility.

Drain Time: The design of all detention/retention facilities shall be such that the stored runoff shall be discharged completely from the facility within 72 hours of the storm event.

Lining/Surface Treatment: As a general rule, grass and plant species used for landscape development and revegetation should be native to Riverside County.

Permanent irrigation systems are required for grass areas and most types of basin revegetation and landscaping. However, use of native and drought tolerant species may only require a temporary system to obtain effective germination and establishment.

The use of inert materials is appropriate for stabilization and erosion control where steep slopes are unavoidable, along channels, at points of inflow, at the outlet control structure and any other location where flowing water may threaten stability. Inert materials for erosion control include:

- Loose rock riprap with a specific, engineered gradation.
- Loose or grouted boulders (minimum dimension 18 inches or larger).
- River stone.

Low Flow Channels: A low flow channel is required in the bottom of a detention facility to provide positive routing of drainage to the primary outlet structure. An example of a rectangular concrete low flow channel is provided in Figure 10.2. The channel shall have a 0.5 percent maximum longitudinal slope.

Inlet and Outlet Structures: The design of an inlet structure shall be such that inflow is directed into the facility in a non-erosive manner and without adverse impacts to the retention facility or to upstream areas.

Outlet structures are classified as: 1) primary outlet structures that provide hydraulic control for the specific design event(s), and 2) emergency spillways that provide safe routes, typically via surface overflow, for storm events in excess of the design frequency or in the case of debris blockage or malfunction of the primary outlet structure.

The minimum allowable pipe size for primary outlet structures shall be 18 inches in diameter.

If the capacity of an outlet pipe must be further reduced, an orifice plate may be installed, as shown on Figure 10.3(a). The orifice plate may be constructed of heavy, galvanized steel and attached with tamper-proof bolts or by forming a smaller diameter opening in the concrete headwall at the outlet structure.

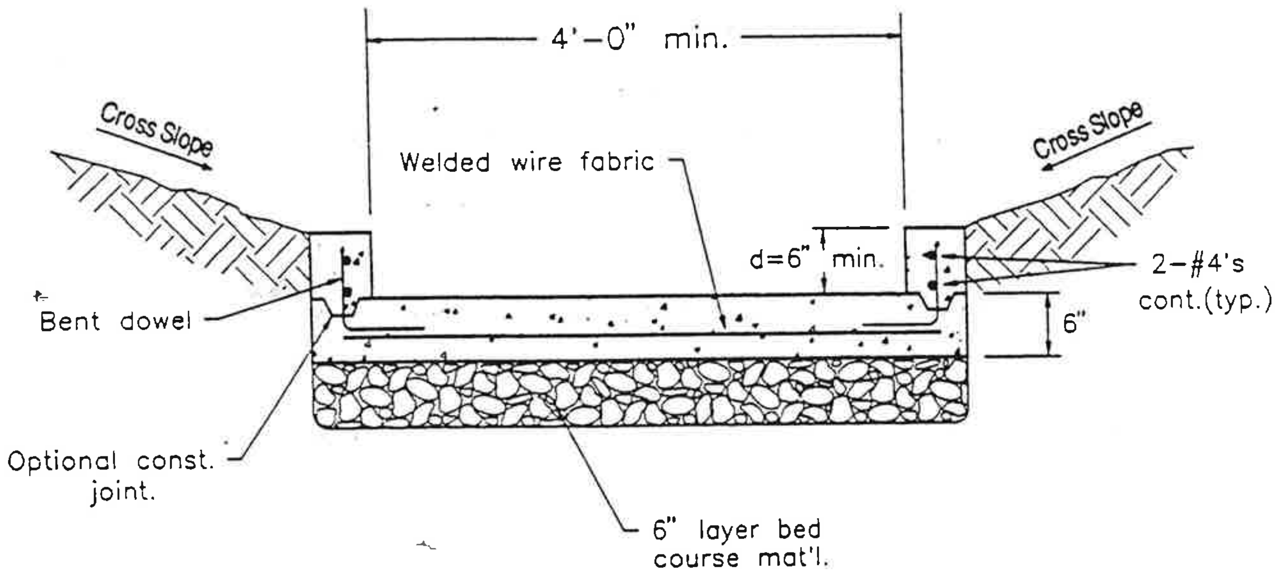


Figure 10.2
Rectangular Concrete Channel Section
(Adapted from: WRC Engineering, Inc. 1985)

Energy Dissipation at Outlet: Adequate energy dissipation measures shall be provided at the downstream end of primary outlet structures. Such measures shall be designed to control local scour at the pipe outlet and to reduce velocities to pre-development conditions prior to exiting onto downstream properties.

Emergency Spillways: Emergency spillways are normally surface overflow weirs, channels, or combinations thereof, provided for the safe overflow and routing of floodwaters under unusual circumstances.

Consideration must be given to the layout of the emergency spillway so that excess flow is routed in the same manner and direction as would have occurred under pre-development or historic conditions. Emergency spillways must be designed to convey the unattenuated 100-year peak discharge at non-erosive velocities.

10.2.2 Criteria for Special Detention/Retention Methods

Special methods for stormwater detention/retention include, roadway embankment storage and storage in parking lots and greenbelt areas.

The use of underground storage facilities, for detention/retention of excess runoff is permitted, subject to review and approval by the City Engineer.

The use of rooftop areas for storage of runoff is not permitted in the City of Hemet.

Since the following methods often result in facilities near buildings, it should be emphasized that the pad elevations adjacent these structures shall be a minimum of one foot above the 100-year water surface of the detention/retention facility.

Conveyance Storage: During the period that channels and floodplains are filling with runoff, the stormwater is being stored in transient form. This type of storage is known as conveyance storage. Construction of low velocity channels with large cross sectional areas assists in the accomplishment of such storage. Conveyance storage systems are usually feasible only on large projects, and require detailed dynamic modeling for analysis.

Roadway Embankment Storage: When feasible, use of roadway fill slopes as an embankment for a detention basin provides an economical means of stormwater storage. Special considerations must be given both to the stability of the embankment and to the protection of the embankment from erosion. Additionally, State of California, Division of Dam Safety requirements may need to be addressed if the embankment height and/or the potential storage volume exceed certain limits.

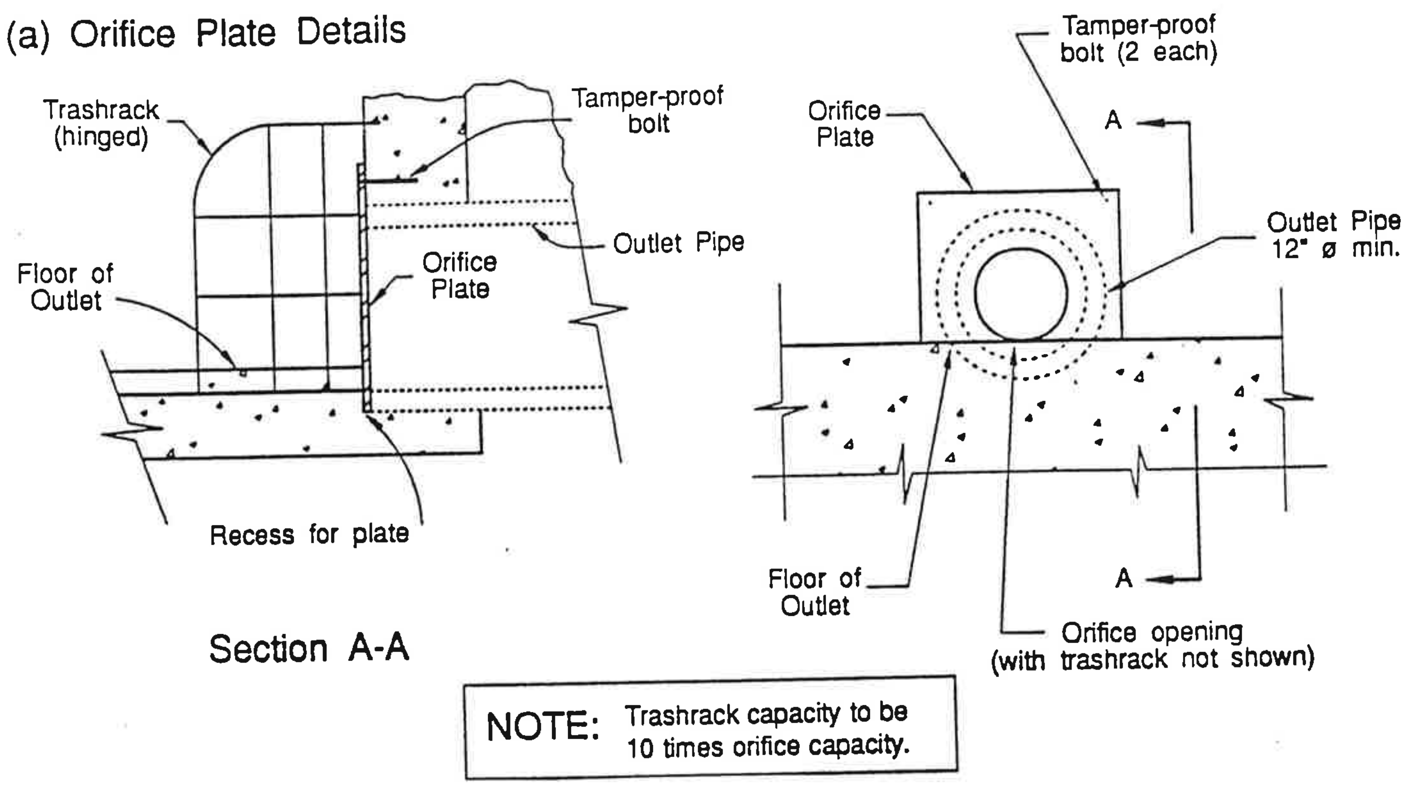


Figure 10.3
Detention Facility Outlet Details
(Adapted from: WRC Engineering 1987)

STATE OF CALIFORNIA
The Resources Agency
Department of Water Resources
Division of Safety of Dams

STATUTES AND REGULATIONS PERTAINING TO SUPERVISION OF DAMS AND RESERVOIRS 1970*

CALIFORNIA ADMINISTRATIVE CODE

Title 23. Waters

Chapter 2. Department of Water Resources

Subchapter 1. Dams and Reservoirs

Article 1. General Provisions

301. Definitions. As used in these regulations, the terms listed below shall have the meanings noted:

(a) Department. "Department" means the Department of Water Resources of the State of California.

(b) Dam. "Dam" means any artificial barrier, together with appurtenant works, which does or may impound or divert water, and which either (a) is or will be 25 feet or more in height from the natural bed of the stream or watercourse at the downstream toe of the barrier, as determined by the department, or from the lowest elevation of the outside limit of the barrier, as determined by the department, if it is not across a stream channel or watercourse, to the maximum possible water storage elevation or (b) has or will have an impounding capacity of 50 acre-feet or more.

Any such barrier which is or will not be in excess of 6 feet in height, regardless of storage capacity, or which has or will have a storage capacity not in excess of 15 acre-feet, regardless of height, shall not be considered a dam.

No obstruction in a canal used to raise or lower water therein or divert water therefrom, no levee, including but not limited to a levee on the bed of a natural lake the primary purpose of which levee is to control floodwaters, no railroad fill or structure, and no road or highway fill or structure, no circular tank constructed of steel or concrete or of a combination thereof, no tank elevated above the ground, and no barrier which is not across a stream channel, watercourse, or natural drainage area and which has the principal purpose of impounding water for agricultural use shall be considered a dam. In addition, no obstruction in the channel of a stream or watercourse which is 15 feet or less in height from the lowest elevation of the obstruction and which has the single purpose of spreading water within the bed of the stream or watercourse upstream from the obstruction for percolation underground shall be considered a dam.

(c) Reservoir. "Reservoir" means any reservoir which contains or will contain the water impounded by a dam.

(d) Owner. "Owner" includes any of the following who own, control, operate, maintain, manage, or propose to construct a dam or reservoir:

(1) The State and its departments, institutions, agencies, and political subdivisions.

(2) Every municipal or quasi-municipal corporation.

(3) Every public utility.

(4) Every district.

(5) Every person.

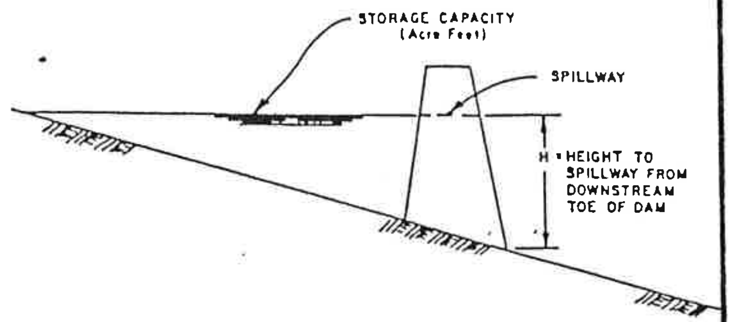
(6) The duly authorized agents, lessees, or trustees of any of the foregoing.

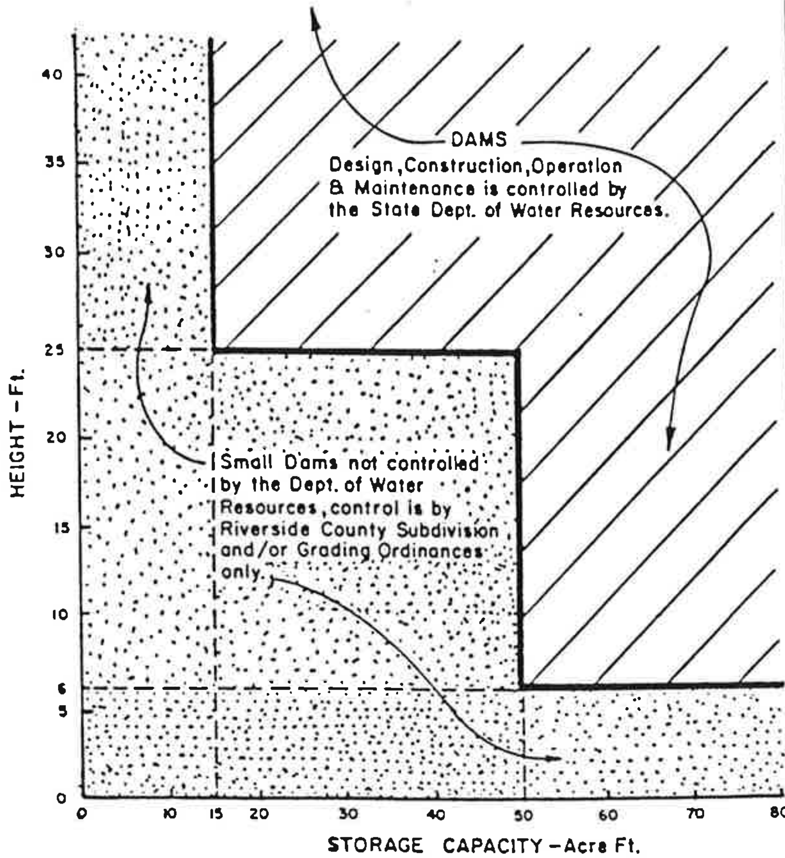
(7) Receivers or trustees appointed by any court for any of the foregoing.

"Owner" does not include the United States. (Sections 6002-6005, Water Code)

302. Purpose and Effect of Regulations. These regulations are adopted for the purpose of carrying out the provisions of Part 1 of Division 3 of the Water Code. Under no circumstances, and in no particular case, shall these regulations, or any of them, be construed as a limitation or restriction upon the exercise of any proper discretion that is vested in the department, nor shall they in any event be construed to deprive the department of any exercise of powers, duties and jurisdiction conferred by law, nor to limit or restrict the amount or character of data or information which may be required for the proper administration of the law. (Section 6078, Water Code)

* USERS SHOULD ASCERTAIN IF STATUTES HAVE BEEN REVISED.





RCFC & WCD
HYDROLOGY MANUAL

DAMS & IMPOUNDMENT RESERVOIRS UNDER STATE CONTROL

Figure 10.4
Jurisdictional Dam Definition

Parking Lot Storage: Using parking lots for detention/retention is a special case of surface storage. It is an economical option for meeting detention/retention requirements in high density commercial and industrial developments. Planning of areas within a parking lot which will accept ponding should be such that pedestrians are inconvenienced as little as possible.

The following criteria shall be considered when developing parking lot storage:

- The maximum depth of ponded water within any parking lot location shall be eight inches.

- The minimum longitudinal slope permitted within parking lot storage facilities is 0.01 ft/ft, unless concrete valley gutters are provided. With concrete valley gutters, a minimum longitudinal slope of 0.005 ft/ft may be permitted.

Drainage of parking lots can be accomplished by means of curb openings, weirs, storm drains or orifices in walls.

10.2.3 Embankment Design Criteria

Whenever possible, detention/retention facilities should be constructed with the storage volume located entirely below the natural ground surface adjacent to the basin. However, in some instances this may not be possible, and embankments may be necessary to provide the required storage volume. Since the use of embankments may create a potential downstream flood hazard due to failure of the embankment, the following design considerations must be addressed in conjunction with their use. For additional information and guidelines for the design of detention/retention facilities, refer to *Design of Small Dams* (USBR 1987).

State Dam Safety Requirements: The State of California, Division of Dam Safety (DSD) has legal jurisdiction over all dams (embankments) which exceed certain height and storage limits. The DSD defines a jurisdictional dam as either 25 feet or more in height or stores more than 50 acre-feet. If it is less than six feet in height regardless of storage capacity or does not store more than 15 acre-feet regardless of height, it is not jurisdictional."

Figure 10.4 illustrates the difference between a jurisdictional and non-jurisdictional dam.

Geotechnical Engineering Studies: Analyses shall be conducted to evaluate conditions such as embankment slope, foundation stability, embankment and foundation seepage, internal and external erosion potential and embankment settlements. The results of these analyses are used to develop criteria for economic and safe design and construction of embankment dams. These criteria include the types and zones of embankment fill materials based on using available borrow materials, upstream and downstream embankment slopes, and recommended measures for control of seepage.

Emergency Spillway: All embankment dams for detention/retention facilities shall incorporate an emergency spillway for the safe overflow and routing of flood waters under unusual circumstances. Such conditions include the blockage or malfunction of the primary outlet structure or the occurrence of a storm event larger than that for which the facility was designed.

The design of emergency spillways shall incorporate adequate erosion control and energy dissipation measures to insure the stability of the embankment. The minimum design standard for emergency spillways shall be as indicated in Table 10.1.

Primary Outlet Structure: The primary outlet structure is the main outlet structure by which stormwater is discharged from the detention/retention facility. It is typically a closed conduit structure with an inlet specifically designed to control a single frequency storm or multiple events.

Table 10.1
Emergency Spillway Design Capacity Requirements

Dam Height	Spillway Design Capacity
$H \leq 6$ ft	Unattenuated 100-year inflow
6 ft $< H <$ 25 ft	1/2 Probable Maximum Flood

10.3 DESIGN CONSIDERATIONS

The following is an outline of design considerations and recommendations which facilitate specific maintenance activities.

10.3.1 Access

Access roads for service and maintenance vehicles should be maintained to allow for equipment access to the facility, whenever needed. Access control gates should be provided if restricted access is required.

Design Recommendations:

- Access ramps into the facility shall be graded at 10 percent or less. Turning radii shall be 50 feet or greater.
- Service drives and gates shall be located in readily accessible locations.

- Access control gates and adjacent areas shall be as secure as economically feasible.

10.3.2 Sediment Removal

Sediment will inevitably be deposited in the detention/retention facility. Conditions will be worst during years when construction activity in the watershed is greatest.

Design Recommendations:

- Provide stilling basins or fore-basin collection points where most sediment will be deposited.
- Provide controlled vehicular access into the facility for trucks and front-end loaders.

10.3.3 Maintenance of Low Flow Channels and Drainage Structures

In-basin drainage structures and facilities must be maintained to insure their proper operation. Structure design can influence maintenance requirements.

Design Recommendations:

- Provide energy dissipators to prevent damage to the channel or drainage structures during high inflow conditions.
- Design structures so that they will not collect debris which could impact proper operation.

10.4 MULTIPLE-USE CONCEPTS

Flood control functions and other uses in detention/retention facilities are generally compatible. Rationale for multiple-use facilities includes decreased facility maintenance costs and an increased community acceptance. Combining flood storage with recreation use or other community facilities on a single site decreases total costs for land acquisition and site development. The development of detention/retention facilities as parks or urban green space increases the acceptance by area residents and encourages better overall maintenance.

10.4.1 Potential Uses

Appropriate uses for detention/retention facilities include active and passive recreation and urban green space. Uses in addition to flood control should address specific community needs and be clearly identified before the facility is designed.

Active Recreation: Active recreation includes a wide range of activities that involves some type of physical movement. This type of recreational activity - both individual and group - generally requires larger areas than passive recreation uses. Because of their size, regional detention/retention facilities can provide more opportunities for group sports with large space requirements.

Passive Recreation: Passive recreation generally involves individuals or small groups and a minimal amount of physical activity. Typically, passive recreation does not require large open space and is, therefore, appropriate for both large and small detention/retention facilities.

Urban Green Space: Urban green space provides a visual resource within the community. As urbanization continues, the value of green space will increase. Green space provides visual breaks from the urban environment, acts as a filter to clean air and can reduce erosion from wind and rain. Landscape materials in a detention/retention facility should respond to the recessed nature of the land form, the scale of the facility and the occurrence of frequent flooding.

The use of native and non-native species for landscape planting is highly recommended. The following basic zones should be considered in the landscape design for a detention/retention facility.

- Channels: Planting in these areas should be limited to grasses, groundcovers and low growing shrubs, with preference given to vegetation with flexible branching and resilient growth habits.

- Basin Areas: There may be inundation and standing water in basin areas at some time during the year. Choice of plant materials should reflect these conditions. Trees, shrubs and grasses can be planted judiciously in these areas.

- Elevated Areas: These areas may be occasionally inundated. The choice of plant material will depend on the use assigned to the area. Trees, shrubs and grasses can be planted and more easily maintained in areas of higher ground elevation.

10.5 WATER QUALITY

Urban runoff is distinguished from undeveloped area runoff in two principal ways: it occurs at greater discharge rates and volumes, and it contains varying but commonly higher concentrations of toxic substances, bacteria, and dissolved organic matter. Detention/Retention facilities can play a significant role in mitigating the pollution problems associated with urban runoff.

10.5.1 Method for Control of Sedimentation

Sediment removal within a detention/retention facility may be facilitated by the use of a "sediment trap" at the inlet, which will concentrate the majority of the incoming sediment bed load to a small portion of the facility. Sediment traps should be provided in conjunction with all detention/retention facilities which are intended as multi-use facilities. The following list provides guidelines for the design of efficient sediment traps.

1. An additional sedimentation volume should be provided within the sediment trap at an elevation below the invert of the inflow channel.

2. The length/width ratio of the sediment trap should be a minimum of 2:1, with the length measured along a line between the inlet and outlet.

3. The basin should be wedge-shaped, with the narrow end located at the inlet to the basin.

4. Provisions for total drainage and accumulated sediment removal of the sediment trap must be provided. Maintenance access should also be provided and designed to accommodate heavy trucks and other equipment necessary for removal of accumulated sediment.

10.6 FLOOD ROUTING

Characteristically, the storage of a reservoir is closely related to its outflow rate. In reservoir routing methods, the storage-discharge relation is used for repeatedly solving the continuity equation; each solution is a step delineating the outflow hydrograph.

10.6.1 Flood Routing through Detention Facilities by the Storage-Indication Method

$$\frac{ds}{dt} = I(t) - O(t) \qquad \textbf{(10.1)}$$

The continuity equation used in reservoir routing methods is concerned with conservation of mass: for a given time interval, the volume of inflow minus the volume of outflow equals the change in volume of storage. The continuity equation for reservoir routing is:

where:

S	=	Storage volume in the system, in cubic feet,
t	=	Time, in hours,
I(t)	=	Inflow to the system, in cubic feet per second, and
O(t)	=	Outflow from the system, in cubic feet per second.

If the time is broken into intervals of duration "Δt" and indexed by j, Equation 10.1 can be rewritten for the change in storage over the interval:

$$S_{j+1} - S_j = \frac{I_j + I_{j+1}}{2}\Delta t - \frac{O_j + O_{j+1}}{2}\Delta_i \qquad \textbf{(10.2)}$$

The values of I_j and I_{j+1} are obtained at the jth time interval from calculation during the previous time interval. Equation 10.3 results from multiplying Equation 10.2 through by $2/\Delta t$ and then isolating the unknowns O_{j+1} and S_{j+1}.

$$\left(\frac{2S_{j+1}}{\Delta t} + O_{j+1}\right) = (I_1 + I_{j+1}) + \left(\frac{2S_j}{\Delta t} - O_j\right) \quad \textbf{(10.3)}$$

Equation 10.3 can be used to facilitate the storage-outflow function solution in tabular form (see sample problem, Section 10.6.2). In order to calculate the outflow (O_{j+1}) from Equation 10.3, a storage-outflow function relating $2S/\Delta t + O$ and O is needed. The method for developing this relationship using elevation-storage and elevation-outflow data is shown in Figure 10.5.

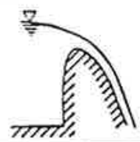
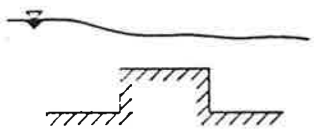
The following steps are used in the Storage-Indication Method of flood routing:

1. Develop the inflow hydrograph as directed in Section 5.

2. Develop an elevation-storage relationship (Figure 10.5a) for the structure. The storage will normally be developed in acre-feet which will then be converted to cubic feet in the working table (see Table 10.3, page 10-21).

Table 10.2
Spillway Discharge Equations

(from *Applied Hydrology*, Chow et al 1988)

Spillway Type	Equation	Notation
Uncontrolled overflow ogee crest 	$O = CLH^{3/2}$	O = Discharge, cfs C = Discharge coefficient[1] L = Effective length of crest H = Total head on the crest including velocity of approach head
Broad-crested weir 	$O = C_oLH^{3/2}$	C_o = Discharge coefficient[2] L = Effective length of crest H = Total head on the crest including velocity of approach head
Culvert (submerged inlet control)	$O = C_dA\sqrt{2gH}$	A = Cross-sectional area C_d = Discharge coefficient[3]

Source: *Handbook of Hydraulics*, 6th Edition, Brater and King 1982.

(1) C value for ogee crest varies from 3.1 to 3.9 depending upon the head, the depth of approach, the slope of upstream face, and the configuration of the downstream apron.

(2) C_o value for broad-crested weir varies from 2.3 to 3.3 depending upon the head, the breadth of weir crest, and the shape of the upstream corner.

(3) C_d value for culvert varies from 0.2 to 0.9 depending upon the head, pipe size, pipe length, material of the pipe, and the shape of the inlet edge.

3. Develop an elevation-discharge relationship (Figure 10.5b) for the structure from hydraulic equations relating head and discharge for various types of spillways and outlet works. Table 10.2 lists various equations that can be used. For values of C, C_o, and C_d, see *Design of Small Dams* (USBR 1987).

4. Select the routing interval, "Δt". The shorter the interval selected, the more precise the results will be.

5. Using the results of steps 2 and 3, make a four-column table with the following headings: 1) Elevation H, ft; 2) Storage S,ft^3) Discharge Q, cfs; and, 4) $2S/\Delta t + O$ For an example, see Table 10.4, page 10-22.

6. Plot the values of $2S/\Delta t + O$ on the horizontal axis of a graph with the value of the outflow, O, on the vertical axis (see Figure 10.6).

7. Compute the value of $2S_{j+1}/\Delta t + O_{j+1}$ using Equation 10.3. All the terms on the right side of Equation 10.3 are known for the time interval j. Obtain the values of I_j and I_{j+1} from the inflow hydrograph (Step 1), as done in Table 10.5.

8. Determine the corresponding value of O_{j+1} to $2S_{j+1}/\Delta t + O_{j+1}$ from the storage-outflow relationship $2S/\Delta t + O$ versus O. This can be done by either using the plot of step 6 or by linear interpolation of tabular values from step 5.

9. Calculate the value of $2S_{j+1}/\Delta t - O_{j+1}$ to set the data required for the next time interval by:

$$\left(\frac{2S_{J+1}}{\Delta t} - O_{J+1}\right) = \left(\frac{2S_{J+1}}{\Delta t} + O_{J+1}\right) - 2O_{J+1} \qquad \textbf{(10.4)}$$

10. Repeat the computation for subsequent routing periods and plot the inflow and outflow hydrographs.

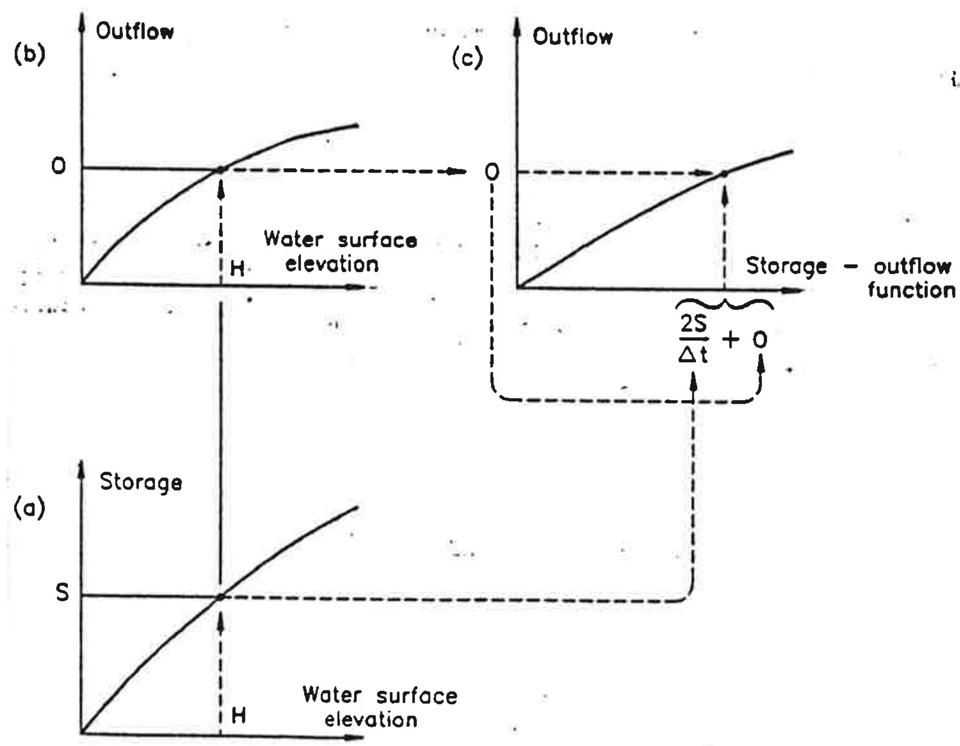


Figure 10.5
Development of the Storage-Outflow Function
for Level Pool Routing on the Basis of
Storage-Elevation and Elevation-Outflow Curves
(from: Applied Hydrology, Chow et al 1988)

Steps 7, 8 and 9 are demonstrated in Table 10.5. With the exception of Step 8, all of these steps can be easily performed using a spreadsheet.

10.6.2 Flood Routing Sample Problem

A detention basin is proposed. Determine the peak outflow and the peak water surface elevation in the basin.

10.6.2.1 Given:

1. Inflow Hydrograph

Time, hrs	Inflow, cfs	Time, hrs	Inflow, cfs
0.00	0	2.00	250
0.225	10	2.25	160
0.50	25	2.50	110
0.75	50	2.75	70
1.00	100	3.00	40
1.25	220	3.25	20
1.50	610	3.50	10
1.75	450	3.75	0

2. Stage-Surface Area Relationship

Elevation, ft	Surface Area, Acres
1100	4.6
1100.5	4.8
1101	5.2
1101.5	5.4
1102	5.6
1103	5.8
1104	6.2
1105	6.6
1106	7.0
1107	7.5
1108	7.8

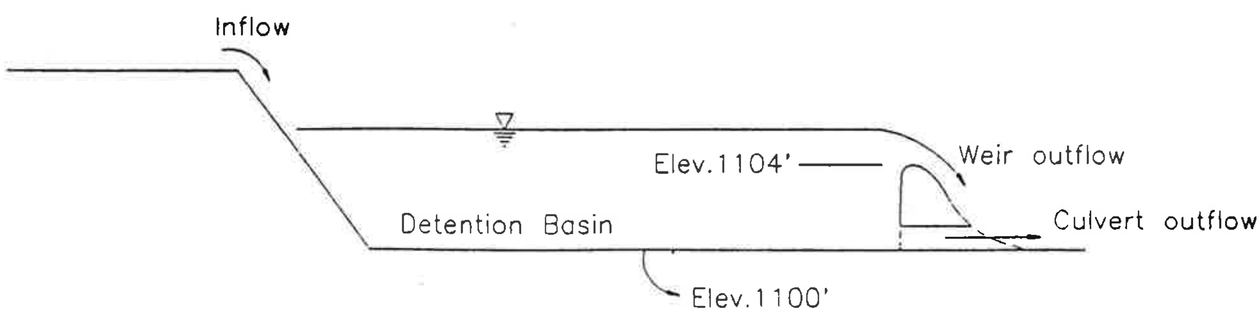
3. Outflow Structures

a. Principal Spillway, ogee crest

Discharge coefficient = 3.5
Width of weir = 20 ft
Elevation of weir crest = 1104 ft

b. Low Flow Structure, culvert (corrugated metal pipe)

Discharge coefficient = 0.5
Diameter = 15 inches = 1.25 ft
Elevation of culvert inlet = 1100 ft
Elevation of culvert center = 1100.63 ft (used to determine H_2)



10.6.2.2 **Solution:**

An inflow hydrograph for this sample problem is given, so the solution procedure begins with Step 2. However, for a practical problem, the inflow hydrograph needs to be developed for Step 1.

Step 2. Develop a Water Surface Elevation-Storage Relationship, as in Table 10.3

Step 3. Develop a Water Surface Elevation-Discharge Relationship, as in Table 10.4.

$$\begin{aligned} &\textit{Weir Flow} && O_1 = C_1 L H_1^{3/2} = 3.5 \times 20 \times H_1^{3/2} \\ &\textit{Culvert Flow} && O_2 = C_2 A \sqrt{2_g H_2} = 0.5 \times \frac{\pi \times 1.25^2}{4} \sqrt{2 \times 32.2 \times H_2} \\ &\textit{Total Outflow} && O = O_1 + O_2 \end{aligned} \qquad \textbf{(10.5)}$$

Step 4. Δt = 0.25 hrs = 900 seconds

Step 5. Develop a Storage-Outflow Relationship for a detention reservoir, as in Table 10.5.

Step 6. Plot the value of $2S/\Delta t + O$ on the horizontal axis of a graph with the value of the outflow O on the vertical axis. See Figure 10.6.

Table 10.3
Water Surface Elevation-Storage Relationship

Elevation	Surface Area, Acres	Average Surface Area, Acres	Difference in Elevation, ft	Interval Storage, Acre-ft	Storage, Acre-ft	Storage, ft^3*
1100.0	4.6				0	0
		4.7	0.5	2.35		
1100.5	4.8				2.35	102,370
		5.0	0.5	2.5		
1101.0	5.2				4.85	211,270
		5.3	0.5	2.65		
1101.5	5.4				7.5	326,700
		5.5	0.5	2.75		
1102.0	5.6				10.25	446,490
		5.7	1.0	5.7		
1103.0	5.8				15.95	694,780
		6.0	1.0	6.0		
1104.0	6.2				21.95	956,140
		6.4	1.0	6.4		
1105.0	6.6				28.35	1,234,930
		6.8	1.0	6.8		
1106.0	7.0				35.15	1,531,130
		7.25	1.0	7.25		
1107.0	7.5				42.4	1,846,940
		7.65	1.0	7.65		
1108.0	7.8				50.05	2,180,180

*1 Acre-ft = 43,560 ft^3

Table 10.4
Storage-Outflow Relationship for a Detention Reservoir

Elevation H, ft	Storage S, ft^3	Discharge O, cfs	$(2S/\Delta t) + O$, cfs
1100.0	0	0	0
1100.5	102,370	0	227
1101.0	211,270	3	472
1101.5	326,700	5	731
1102.0	446,490	6	998
1103.0	694,780	8	1,552
1104.0	956,140	9	2,134
1105.0	1,234,930	80	2,824
1106.0	1,531,130	209	3,612
1107.0	1,846,940	376	4,480
1108.0	2,180,180	573	5,418

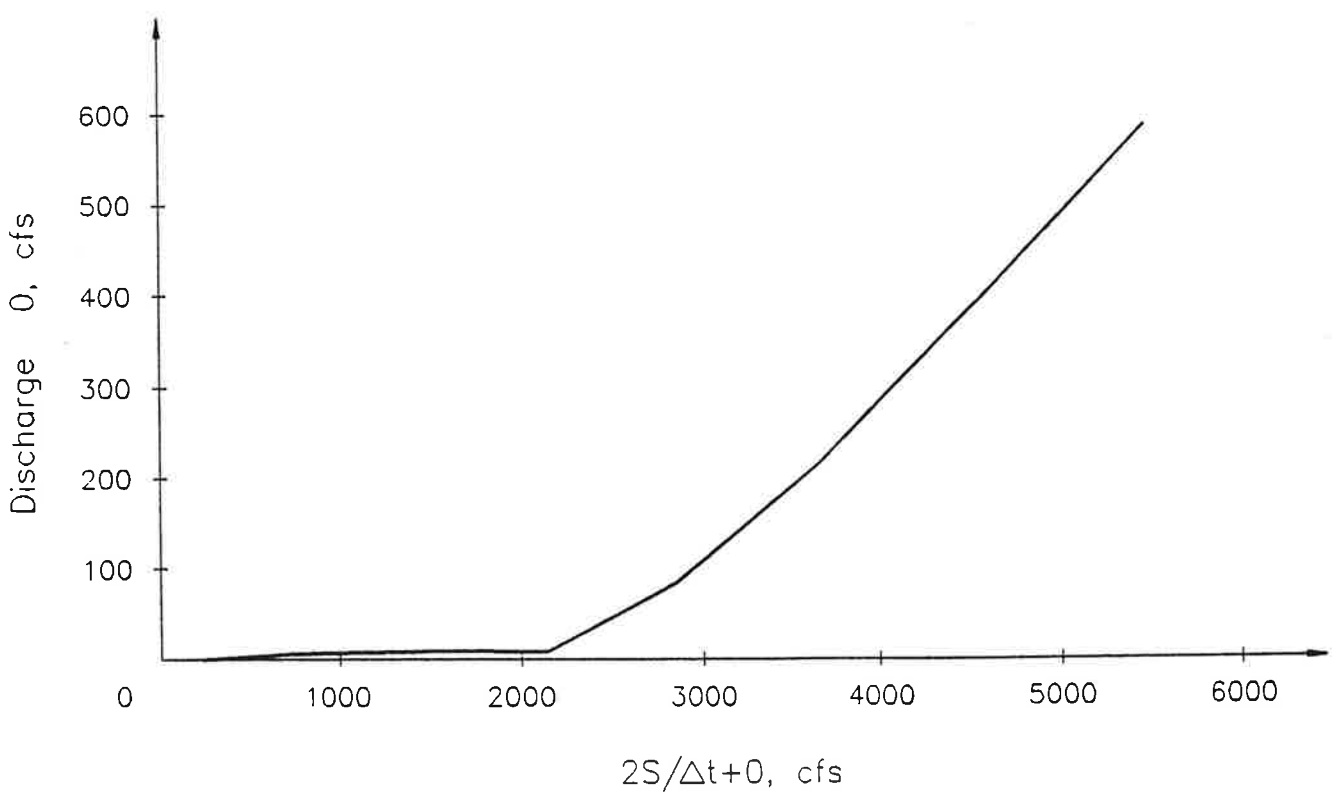


Figure 10.6
Storage-Outflow Function for Sample Problem

Steps 7 through 9:

Table 10.5
Routing of Flow through Detention Basin

Time, hrs	Inflow, cfs	$I_j + I_{j+1}$, cfs	$\frac{2S_j}{\Delta t} - O_j$, cfs	$\frac{2S_{j+1}}{\Delta t} + O_{j+1}$, cfs	Outflow, cfs
0.00	0		0		
0.25	10	10	10	10	0
0.50	25	35	45	45	0
0.75	50	75	120	120	0
1.00	100	150	268	270	1
1.25	220	320	580	588	4
1.50	610	830	1,394	1,410	8
1.75	450	1,060	2,370	2,454	42
2.00	250	700	2,830	3,070	120
2.25	160	410	2,942	3,240	149
2.50	110	270	2,928	3,212	142
2.75	70	180	2,858	3,108	125
3.00	40	110	2,762	2,968	103
3.25	20	60	2,662	2,822	80
3.50	10	30	2,556	2,692	68
3.75	0	10	2,450	2,566	53
4.00		0	2,368	2,450	41
4.25			2,304	2,368	32
4.50				2,304	26

Step 7 · Step 8 · -2x · Step 9

Step 10. Plot the inflow and outflow hydrographs.

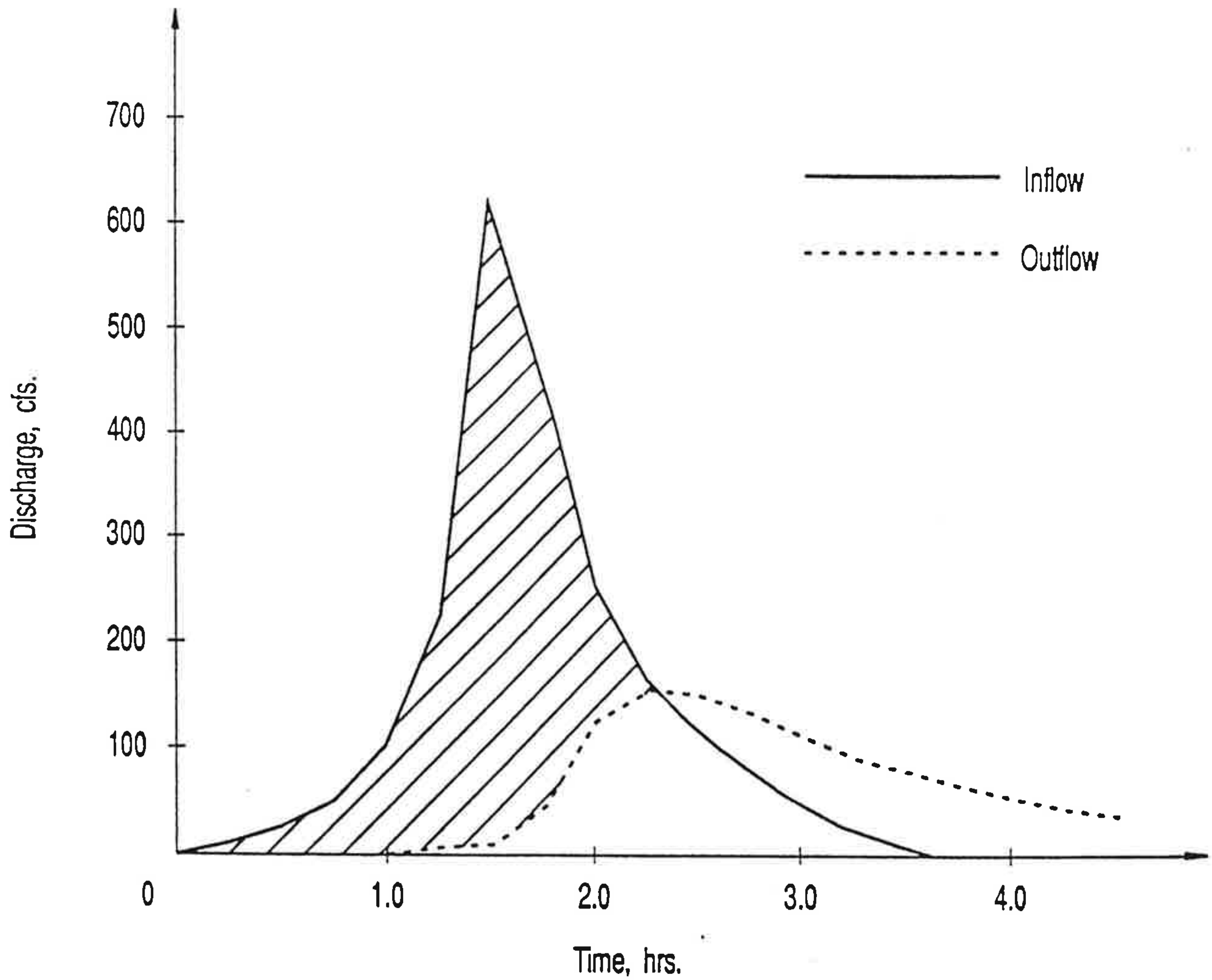


Figure 10.7
Comparison of Inflow and Outflow Hydrographs

Peak Outflow Discharge: O_{peak} = 149 cfs (from Table 10.6).

Peak Water Surface Elevation: By linear interpolation of values in Table 10.5 and Using O_{peak}.

(10.6)

$$H_{peak} = 1105 + \frac{(149-80)}{(209-80)} \times (1106 - 1105) = 1105.53 ft$$

The shaded area in Figure 10.13 is the required storage volume capacity for the detention basin.

10.7 LIST OF VARIABLES

$^{ds}/dt$ = Change in storage as a function of time

I = Inflow in cubic feet per second

I(f) = Inflow at time interval t.

O = Outflow in cubic feet per second

O(t) = Outflow at time interval t.

S = Storage volume in cubic feet

t = Time, in hours

10.8 REFERENCES

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