SECTION 9
STORAGE

9.01 GENERAL

Storm water management programs aimed at controlling increased stream water runoff generated by development are a top priority in urban watershed planning. More frequent flooding, increased rates and volumes of storm water runoff, increased stream channel erosion and degradation, increased sedimentation, and increased water pollution are all problems intensified by increased storm water runoff resulting from development. Storage of excess Urban storm runoff is one of the most promising methods available in preventing urban flood damage.

Storm runoff storage with reduced release rates can hold downstream flood flows to within the safe conveyance capacity of the storm sewer and stream system. In most cases, it can be shown that storage is more economical than increasing downstream conveyance capacity. Storage facilities should be planned and designed to assure an effective and efficient operation and maintenance program.

Retention and detention are two generalized types of storm runoff storage used to control flooding. Retention storage refers to storm runoff collected and stored for a significant period and released or used after the storm runoff has ended. Retention storage usually consists of "wet reservoirs" which often have agricultural, recreational, and/or aesthetic value. Detention storage consists of reducing the rate of runoff for a short period of time to reduce peak flows by controlling the discharge through an outlet structure and by extending the period of runoff.

Skillful use of the procedures outlined in this section will provide reasonable solutions to Drainage Policy requirements. Individual and community experience in the use of these techniques will evolve into a methodology which will allow urban growth without the attendant drainage problems.

9.02 STORAGE CLASSIFICATION

Storage can be classified by location as follows:

A. Rainfall Storage

The storage of water near the point of rainfall occurrence or before storm runoff accumulates significantly. Rainfall storage is usually accomplished by roof top ponding, parking lot ponding, property line swale ponding, and small onsite ponds.

B. Runoff Storage

Water stored after storm runoff has accumulated significantly and begun to flow in a drainage system. Runoff storage is usually accomplished by offstream storage, channel storage, or onstream storage.

9.03 RAINFALL STORAGE

A. Roof Tops

Building codes require roof load designs for rain and snow. The design load may be converted to equivalent water depth in inches which can be safely contained on flat roofs. The maximum storage allowed for design purposes should not exceed this depth unless a building is designed to withstand a greater roof load. The depth of water can be controlled by proper sizing of downspouts and by constructing scuppers through the parapet walls.

Another method of achieving roof top ponding involves placing loose gravel windrows or dikes a few inches in height so that storm runoff is trapped as it moves toward the drainage outlet. Individual wedge-shaped ponds form behind the small dikes and slowly drain as the storm water filters through the gravel. This solution is of limited value, however, as there is no way to assure its permanence.

The possibility of overflows exist and will occur quite often during major storms. Overflow drains should be used to protect against roof overloading. Periodic inspection and proper maintenance will reduce the possibility and the hazards of overflows.

Special attention must be given to the water tightness of the roof to assure that no leakage occurs due to the accumulation of water.

B. Parking Lots

Considerable area in urban development is occupied by parking lots. If planned correctly, these paved areas can provide adequate detention with minimum inconvenience to the public and without functional interference.

There are two general methods of storm water detention that can be utilized on parking areas. One form involves the storage of runoff in depressions constructed near drains or outfall structures. The second method of storm water detention on parking lots consists of using the paved parking areas to channel storm water to grassed or gravel filled areas for maximum infiltration and a decrease in overland flow.

C. Recreation Areas

Recreation areas, such as sports fields, generally have a substantial area of grass cover which often has a high infiltration rate. Storm runoff from such fields is minimal. A secondary use of such recreation fields can be made by providing for limited detention storage of runoff from adjacent areas.

Since these areas are not used during periods of precipitation, detention ponding should not seriously impede their primary use. To minimize after effects, the recreation area should be designed so that it will thoroughly drain. In addition, the vegetation used on the area should be tolerant of periodic inundation and wetness.

D. Property Line Swales

Subdivision planning and layout requires adequate surface drainage away from buildings. This is obtained by sloping the finished grade in all directions away from the building. The layout often calls for a swale to be located along the back property line, which then drains longitudinally through the block.

Temporary ponding facilities along the rear lot line may include small controlled discharges along the back property line or, if the subsoil conditions are favorable, several inches of rainfall could be expected to percolate into the ground during and after a storm.

Prior to planning for property line swale ponding, the engineer should determine that saturation of the subsoil will not have an adverse effect on building foundations. In cases where significant subsoil problems exist, water should not be ponded or percolated into the ground.

E. Porous Pavements

Porous pavement used in parking and other areas can reduce flood peaks by allowing water to penetrate and flow through it. Porous pavement can be of two types: (1) porous asphalt with a crushed rock base, or (2) lattice-work concrete blocks.

Since the use of porous pavements as a method of storing or attenuating storm runoff is in the development stage, there may be additional design modifications required. Provisions should be made to insure that the surface of the paving does not become clogged, as this will decrease its permeability. When porous asphalt is utilized, storms greater than the design storm may generate excess runoff and provisions should be made for this overflow. Certain soils when saturated, suffer diminished strength, pumping occurs and a general deterioration of the pavement results.

F. Combinations

In many instances, one on-site detention method cannot conveniently or economically satisfy the required or needed amount of storm water storage. Limitations in storage capacities, site development conditions, soils limitations and other related constraints may require that more than one method be utilized. For example, rooftop, parking lot, and surface pond storage might all be required to compensate for increase in runoff due to development of a particular site. Whatever combinations are suitable may be incorporated into a site development plan.

9.04 RUNOFF STORAGE

A. Offstream Storage

The storage of water in depressed open areas, in reservoirs, and on low lying recreation fields.

B. Channel Storage

Although all channels inherently store water, channels can be made to attenuate runoff by altering their hydraulic characteristics in a way that will reduce peak flows. Side channels that run essentially parallel to the main stream channel are also a means of temporarily storing water during excessive rainfall events.

C. Onstream Storage

The construction of an embankment across a channel so that a storage pond is formed represents onstream storage. Spillway considerations are important to pass large floods exceeding the storage capacity. Properly protected roadway embankments are well suited for this purpose.

9.05 MULTIPURPOSE USE

Rainfall storage and runoff storage systems are most practical when designed for multi-purpose use. For maximum land use efficiency the design engineer must consult early with the Planning Department and the Parks and Recreation Department of the City.

Lower Cost Recreation. Making use of detention storage areas as parks and greenbelts, ballfields and playing fields, satisfies two needs and reduces the cost of each. The minipark concept, where small recreational areas are provided in neighborhoods within safe walking distances for children, can be a typical joint effort of the drainage design engineer and the planning and recreational staffs of the City. Provisions must be made for maintenance of such areas.

Multi-Use Criteria. The multiple use of storage areas is a field of endeavor where the different disciplines should develop desirable and acceptable criteria fitting the needs of the local community. It is with storage, including both detention and retention storage that an important potential exists for the reduction of flooding, drainage costs, and to some degree recreation costs.

9.06 HYDRAULIC DESIGN CRITERIA

A. General

Hydraulic and hydrologic design criteria provide the guidelines for design and construction of storm water storage facilities. These criteria are a necessary part of a storm water management program needed to protect low lying areas by preventing unacceptable increases in runoff rates as urban development progresses.

Existing land contours of the property should be a consideration in developing the drainage plan. In many instances, storage can be achieved economically by blocking the overland flow of storm water runoff with various land forms, curbs, walls, terraces, and other means. This amounts to designing a drainage system that will minimize the reduction in the critical time of concentration as the property is developed.

B. Design Factors and Procedures

Before proceeding with engineering design of an onsite storage facility, the physical and technical factors should be identified and the basic design procedures established. A discussion of design factors and procedures follows.

1. Care must be taken to locate, layout, and design the storage facility in a manner to insure safety and ease of maintenance.

2. The rate of inflow to the storage facility (inflow hydrographs) and all hydrologic considerations must assume ultimate development of the site's contributing area. Several inflow hydrographs should be prepared to examine their effect on downstream flooding for the various design storm frequencies. The number of inflow hydrographs to be provided may vary but should always adequately describe the range of flows expected for the design storm frequencies. These various design storm inflow hydrographs and an acceptable flood routing procedure will be necessary in sizing the outlet works for the storage facility. An emergency spillway should be provided to pass runoff that exceeds the design capacity of the detention facility.

3. The maximum allowable release rate from a storage facility is selected after careful review of runoff rates for all pertinent storms. As a minimum, the pertinent design storm frequencies should include the 10, 25, and 100-year events. However, specific site conditions may require that additional consideration be given a particular area. In all cases, the maximum release rate should be calculated using the hydraulic gradient created when the storage area is being utilized at full capacity.

4. The storm water storage volume required is given by the maximum difference, at any time, between cumulative total inflow. The maximum allowable release rate is not to be exceeded by the outflow peak discharge.

5. The outfall or outlet structures should be designed on the basis of inlet or outlet control, whichever is applicable. The structures should be capable of safely and properly passing the flow range of design storm frequencies including the 100-year storm without causing downstream flooding or exceeding the maximum allowable release rate. Outlet works must also pass all of the runoff from the 100-year design storm within a reasonable length of time or a permit may be required from the Texas Water Rights Commission. Wet ponds will in many cases also require a permit from the Texas Water Rights Commission.

6. Special attention should be given to the provision of an emergency or overflow spillway which would pass excess flows greater than those of the 25-year design storm and overflows caused by clogging of the principal outlets. Downstream watershed considerations such as the potential loss of life and damage to property due to overtopping or failure of the structure and the storage facilities, area and capacity dictate the emergency spillway design storm. It is advisable to contact state

agencies such as the Texas Water Development Board and the Texas Water Rights Commission when planning a storage facility in order to meet their criteria.

9.07 HYDRAULIC DESIGN METHODS

A. General

The basic method suggested for predicting the volume of runoff with time and the peak flow rate is the Rational Method.

B. Rational Method Storage Analysis

When designing storage facilities it is often justifiable to use the Rational Method to compute the design inflow hydrographs. This method relies heavily upon personal judgment but it is relatively simple and can give acceptable results if proper procedures are followed. Three different techniques have examples to show their use. These two examples, Example 1 and Example 2, outline the procedure to compute an inflow hydrograph for only one return period flood.

One of the three Rational Method techniques has been utilized by the Federal Aviation agency in designing airport drainage facilities. The procedure is presented in "Airport Drainage", prepared by the Federal Aviation Agency (1966). The FAA technique is basically a graphical procedure which represents the cumulative storm runoff volume and the cumulative volume released from the storage facility through an outlet structure as functions of time. The maximum difference between the two volume curves represents the required storage volume of the storage basin. The procedure will consistently result in underdesigned storage facilities if a constant release rate is assumed from time zero. This is caused by sizing the outlet pipe using the Manning Equation and not recognizing the stage-discharge relationship. A reservoir routing technique utilizing the stage-discharge relationship of the storage facility should be used.

Examples using the FAA technique are not given here as they may be found in the FAA document mentioned above. It is recommended that in most instances the contributing drainage area not be more than 25 acres when using this techinque.

The second technique that employs the Rational Method is referred to as the Modified Rational Method Analysis. This technique manipulates the Rational Method to reflect the fact that storms with durations greater than the normal time of concentration for a basin will result in a larger volume of runoff even though the peak discharge is reduced. Even though rainfall intensities and resulting peak discharges associated with longer duration storms are less than those for short duration storms, the inflow may still be considerably greater than the outflow thus requiring more storage than in the case of shorter, higher intensity storms.

This approach becomes more valid on progressively smaller basins. The technique should, therefore, be limited to relatively small areas such as parking lots, rooftops, or other upstream facilities with contributing areas less than 25 acres.

Example 1 shows the application of the Modified Rational Method to a 10 acre tract of land using 100-year frequency intensities.

Example 1. Computation of Modified Rational Method Hydrographs.

Given: A drainage area, when fully developed, will have the following characteristics:

Drainage area - 10 acres

Type of ultimate development: Industrial C = 0.70

Design rainfall frequency: 100-year

Rainfall intensity-duration-frequency curves: see Section 2, Figure 2-2. Rainfall Curves for Odessa, Texas

Time of concentration(t_c) - 15 minutes (Section 2)

Required: Develop a family of curves representing Modified Rational Method hydrographs for the 15, 30, 60, and 90 minute rainfall durations.

Solution: Solution is shown in Table 9-1 and Fig. 9-1.

TABLE 9-1

HYDROGRAPH DEVELOPMENT BY

MODIFIED RATIONAL METHOD PROCEDURE FOR

100-YEAR RAINFALL INTENSITIES

Rainfall Duration (Min.)	Rainfall Intensity (In/Hr)	Peak Runoff Rate (cfs)
15	8.16	57.1
30	6.10	42.7
60	4.01	28.1
90	3.00	21.0

Figure 9-1 shows the resulting hydrographs. These hydrographs are developed using the basic Rational Method assumptions of constant rainfall intensity (i), time of concentration (t), and the coefficient of runoff (C). The triangular shaped hydrograph with the peak discharge coinciding with the time of concentration for the area is computed using the Rational Method formula, Q = CiA. Following this, a family of trapezoidal shaped hydrographs representing storms of greater duration are developed. The peak discharge for each hydrograph is equal to CiA where (i) is the rainfall intensity for each respective storm duration. The rising and falling limbs of the hydrograph are, in each case, equal to (t) for the drainage area. The basic assumption of this method is that the volume of the developed trapezoidal hydrographs equals the volume of runoff from the theoretical rainfall. The volume under the hydrograph is also equal to the peak discharge rate for that particular rainfall times the rainfall duration.

The Modified Rational Method technique should be used to develop hydrographs over the range of required storm frequencies to evaluate the effect of resultant flooding that might occur. Section 2 of this manual should be consulted to select the appropriate rainfall intensity (i) and coefficient of runoff (C). After developing the hydrographs for various durations and return frequencies, a routing routine should be employed in designing the optimum outlet facilities and required storage capacity.

The third technique utilizing the Rational Method considers a design storm with varying rainfall intensities. The technique beginnings with the intensity ration-frequency is chosen and a design storm is symmetrically arranged such that the storm rainfall pattern will have a average intensities of the same recurrence interval for all durations. The total storm length should be at least one or two hours or until storm intensities are low enough that no appreciable runoff will occur. It is suggested the design storm be built in small time increments of two to five minutes and that the maximum intensity be located near the storm's center.

The basic assumption made in developing the runoff hydrograph is that the runoff rate at any point of time is equal to Q = CiA. The rainfall intensity (i) is taken as the average for the time of concentration immediately preceding the time at which the runoff rate is being computed. This procedure is followed only when computing the ordinates for the rising limb of the hydrograph. The falling limb of the hydrograph is made to be twice as strong as the rising limb which basically characterizes the shape of most hydrographs. The increment of time between any one particular flow (Q) value and the peak time will be twice as long for the falling limb compared to the rising limb. Example 2 and Tables 9-2 and 9-3 outline the procedure.

This technique also provides for anlaysis based on different times of concentrations for any particular drainage area that is being developed. The different (t) values can greatly effect the shape of the flood hydrograph and the resulting amount of storm water to be retained.

Example 2. Rational Method Using Variable Rainfall Intensities

Given: A drainage area, when fully developed, will have the following characteristics:

Drainage area - 3000 acres

Type of development: Residential C - 0.50

Design rainfall frequency: 10-year

Rainfall intensity-duration-frequency curves: see Section 2, Fig. 2. Rainfall Curves for Odessa, Texas

Time of Cencentration = 40 minutes.

Required: Develop a 10-year design storm and resulting flood hydrograph as part of an analysis in planning and designing a storage facility.

Solution: The solution is outlined in Table 9-2 which shows the development of the design 10-year frequency storm and Table 9-3 which shows the computation of the design 10-year flood hydrograph.

Table 9-3 summarizes the procedure to compute the 10-year flood hydrograph for the drainage area described in Example 2. Referring to Table 9-3, the columns are identified and computed as follows:

(1) = Time from beginning of storm in minutes.

(2) = i_{10} is the rainfall intensity in inches per hour for various times during the 10-year design storm.

(3) = Column (3) accumulates the values from column (2).

(4) = Values from column (3) are displaced a time equal to the time of concentration which is 40 minutes in this case.

(5) = Column (4) subtracted from column (3), (5) - (3)·(4).

(6) = Values for this column are compiled from the equation

$$\frac{(5)}{t_c / AT}$$

(5) = values taken from Column (5)

t_c = time of concentration - 40 min. in this case

AT = time increment from column (1) - 5 minutes

Thus column (6) = $\frac{(5)}{40/5} = \frac{(5)}{8}$ in this case which is simply an average intensity over the previous t_c increment.

(7) = The rising limb of a runoff hydrograph from a 300 acre area with a C value of 0.45 is computed with the expression CAq_{40}. This becomes (0.45) x (300) x (q_{40}) in this case.

(8) = The increment of time for the falling limb of the hydrograph is doubled from the time of the peak and thereafter folded back so that the computed runoff figures can be used.

The computations were stopped in column (7) when the rising limb of the hydrograph reached its peak value. At this point the time scale can be folded as shown in column (8). Doubling the time increments for the falling limb serves to double the volume that would have been under that portion of the runoff hydrograph. The volume under the entire discharge hydrograph will be three times that under the rising limb. With this assumption, the volume of runoff expressed as a percentage from an area with a runoff coefficient of 0.45, becomes approximately 67.5% rather than 45% of the rainfall. In this procedure the C value from the Rational Method formula represents the ratio of the peak runoff to the average rainfall intensity rate for a period equal to the time of concentration and not a simple runoff to rainfall ratio.

Having examined the design 10-year storm, other return frequency storms should be converted to flood hydrographs using the same procedure. As in the other Rational Method techniques, a procedure should be used to aid in sizing the outfall structure by routing all pertinent return frequency hydrographs through the planned facility.

TABLE 9-2

DEVELOPMENT OF A 10-YEAR FREQUENCY STORM

Duration (Min)	Accumulated Depth (In)	Incremental Depth (In)	Incremental Intensity (IN/Hr)	Incremental Order
5	0.64	0.64	7.68	13
10		0.38	4.56	14
15	1.40	0.38	4.56	12
20		0.23	2.58	15
25	1.85	0.23	2.58	11
30		0.13	1.56	16
35	2.12	0.13	1.56	10
40		0.10	1.20	17
45	2.32	0.10	1.20	9
50		0.08	0.96	18
55	2.48	0.08	0.96	8
60		0.06	0.72	19
65	2.60	0.06	0.72	7
70		0.05	0.60	20
75	2.70	0.05	0.60	6
80		0.05	0.60	21
85	2.80	0.05	0.60	5
90		0.04	0.48	22
95	2.88	0.04	0.48	4
100		0.03	0.36	23
105	2.94	0.03	0.36	3
110		0.03	0.36	24
115	3.00	0.03	0.36	2
120		0.01	0.12	25
125	3.02	0.01	0.12	1