Drainage	Chapter: Storage
	Subject: General

DR 901-1 STORAGE CONSIDERATIONS

Generally drainage structures are designed to convey project runoff in a manner that will not pond significant amounts of water. However, if there is adequate right of way or drainage easement available, drainage systems can be designed to impound water and make use of storage, thereby reducing peak flows. The basic principal in stormwater storage is based on the concept of continuity. If the flow rate into a point is larger than the flow rate leaving this point, storage will develop in the form of ponding water. The use of storage is a practical method of alleviating the adverse effects of urbanization (i.e., highway construction) upon the existing drainage facilities. The method utilized to provide storage for storm water can vary from sizing a culvert under a roadway embankment to allow for ponding at the inlet, to large excavated basins with multistage outflow devices.

Urbanization increases peak flows from watersheds in two primary ways. First, the increase in impervious surfaces allows more water to flow off the surface of the watershed and not infiltrate into the soil. Second, the runoff moves more rapidly across the watershed. This is due to the presence of more impervious surfaces and the replacement of natural channels with pipe systems, both of which allows water to be conveyed from the watershed more rapidly. These two factors combine to increase peak flow rates. By providing storage in a drainage system and properly sizing an outflow structure, the peak flow can be reduced and the timing of the peak flow delayed. This is illustrated in Figure 901-1 below:

DR 901-2 Hydrographs and Routing

Because storage design involves analysis of the timing of a watershed's response to runoff, hydrograph analysis is necessary to evaluate the design. Inflow hydrographs have to be developed for the runoff leaving the watershed, which represents the inflow into the storage facility. These hydrographs are then routed though the facility to determine the outflow hydrograph leaving the storage facility. Details for developing these hydrographs are given later in this chapter and Chapter 4 of this manual.

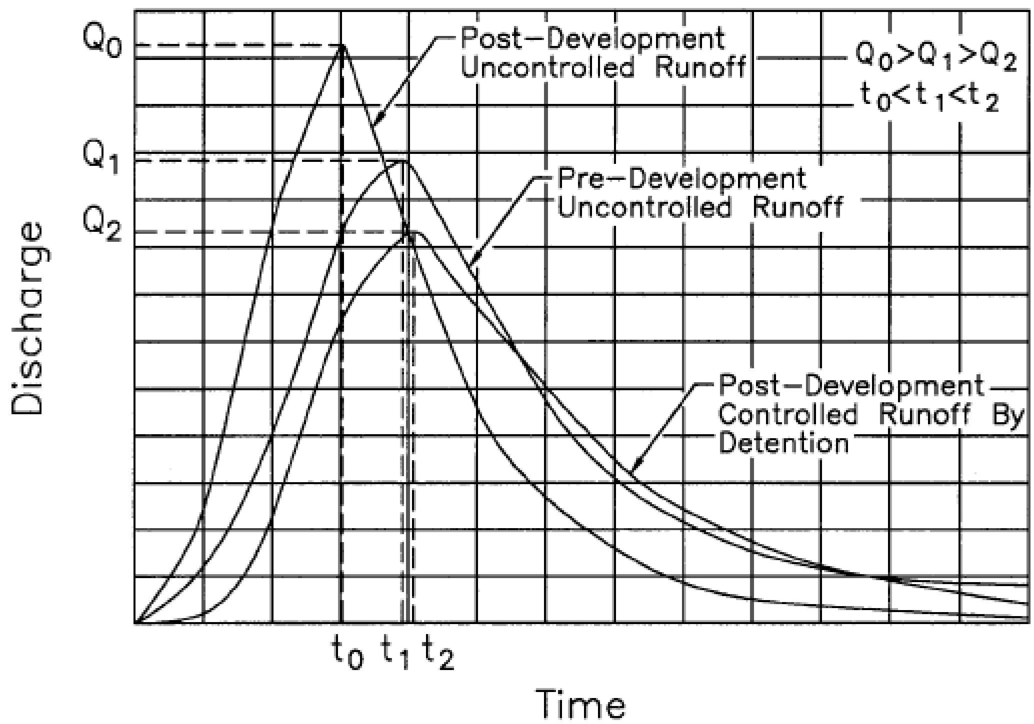

Figure 901-1 Attenuation of Peak Flow

DR 901-3 Culvert Sizing

Conventional culvert design is based upon the principle that the inflow for a design storm is allowed to flow through the culvert with the outflow equal to the inflow and with no use of the available storage. The culvert is sized so there is an insignificant increase in stage at the inlet of the culvert. For areas with open space available at the inlet of the culvert, the use of storage could allow the use of a smaller culvert than one sized conventionally. Allowing a significant increase in the stage at the inlet of a culvert could reduce the outflow from the culvert. Storage created by culvert sizing should follow the principals of detention basin design.

DR 901-4 Dams

Kentucky law defines dams as any artificial barrier, including appurtenant works, which does or can impound or divert water, and which either:

- Is or will be twenty-five (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 Environmental and Public Protection Cabinet; or,
- Has or will have an impounding capacity at maximum water storage elevation of fifty (50) acre-feet or more.

Dams fall under the jurisdiction of the Environmental and Public Protection Cabinet, Division of Water. Construction of dams with KYTC projects is strongly discouraged.

KYTC policy as it pertains to dams is to follow the guidelines recommended by the Division of Water. These guidelines are presented in the Division of Water's, "Engineering Memorandum No. 5." In the event that an impoundment of this size is proposed on a KYTC project, close coordination with the Division of Water will be required.

DR 901-5 Detention/Retention Basins

Generally detention and/or retention basins consist of an impoundment with a controlled outflow structure. This impoundment can be constructed by excavating a basin, constructing a berm above the ground or a combination of both. The outflow structure is designed to create a balance between the inflow, outflow and storage in the basin that will meet the hydraulic needs for the project.

Detention basins are designed to reduce the peak flows from a watershed and to detain runoff for only a short time. These facilities are designed to completely drain after a storm event. Detention basins have minimal effect on water quality.

Retention Basins are very similar to detention basins, except that they maintain a permanent pool of water or have a much slower release rate. The area above the permanent pool in a retention basin is used for stormwater storage; the area below the permanent pool is used for water quality purposes. Some definitions of retention facilities include the provision of infiltration as a means of removing water from the basin. Retention basins provide many water quality benefits. This manual discusses retention basins only as it pertains to their ability to reduce peak flows from a watershed.

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Drainage	Chapter: Storage
	Subject: Detention/Retention Basins

DR 902-1 Local Criteria

Local criteria should be considered when designing a storage facility such as a detention or retention basin. The project manager must identify any local criteria that may apply to a basin. This identification should take place early in the project development process.

These criteria may vary from what is outlined in this manual. If the project team decides it is feasible, local criteria can be used in the design of storage facilities. In the absence of any local criteria, detention and retention basins should be designed as outlined here.

DR 902-2 Design Storm

The design storm is a major component to the design of a detention basin. Local municipalities have developed specific guidance in this area due to their experience with historical flooding. Typically local design criteria will dictate the use of several design storms.

Most often this criterion will require that the post construction (proposed) peak discharges from the basin will be less than or equal to the pre-construction (existing) peak discharge for all applicable design storms.

The selection of a design storm must consider the amount, intensity and time distribution for the rainfall event. As mentioned earlier, local municipalities often will have specific guidelines on these design storms. As an example, the Lexington Fayette Urban County Government (LFUCG) requires that two historical storms be used to analyze detention basins. The amount and time distribution for these storms are given in LFUCG's stormwater manual. In the absence of any other guidance, KYTC recommends the use of the SCS Type II rainfall distribution for detention / retention basin analysis. The SCS distributions are based on a 24 hour storms. More information concerning design storms is given in DR 400 of this guidance manual.

DR 902-3 Inflow Hydrograph

Using the design storm mentioned in the previous section, and the appropriate method to transform this rainfall into runoff, a hydrograph is developed that represents the flow into the basin for the both the pre-construction and post-construction conditions. The development of hydrographs is discussed in Chapter 4 of this manual.

DR 902-4 Basin Outlet

The outlet configuration from a detention or retention basin can have a multitude of configurations. Generally each basin contains a principal outlet and emergency outlet. These outlets are commonly referred to as spillways. Exhibit DR-900-1 shows a typical detention basin schematic.

Principal Spillway

The principal spillway usually consists of a pipe that exits the basin. Principal spillways are used to carry the primary flows from the basin.

Hydraulic Control Structure

Often principal spillways will have a hydraulic control structure at the upstream end of the spillway pipe. This device is used to control the flows leaving the basin.

A hydraulic control device could be composed of a headwall attached to the end of the principal spillway pipe. In this configuration, the headwall and the spillway pipe itself serve as the only control from the basin. This is referred to as a single stage outlet.

It is often necessary to construct a hydraulic control structure as a multiple stage structure. This means that there are multiple orifices and weirs that will allow the various storm events to pass through the spillway pipe.

Figure 902-1 shows a 3 stage hydraulic control structure consisting of a concrete riser box with multiple orifices. The top of the box acts as the third stage.

The number of stages needed for an outlet structure depends on numerous factors and will generally be determined through trial and error.

Emergency Spillway

Constructing berms above existing ground to impound water carries more risk that excavating basins into existing ground. In cases where berms have been constructed above the existing ground, it is highly recommended to have an additional exit for larger flows from the basin. This can be accomplished with an emergency spillway. The emergency spillway’s primary function is to allow the controlled passage of large storm events and to prevent the sudden failure of the basin’s berm by providing a controlled overflow.

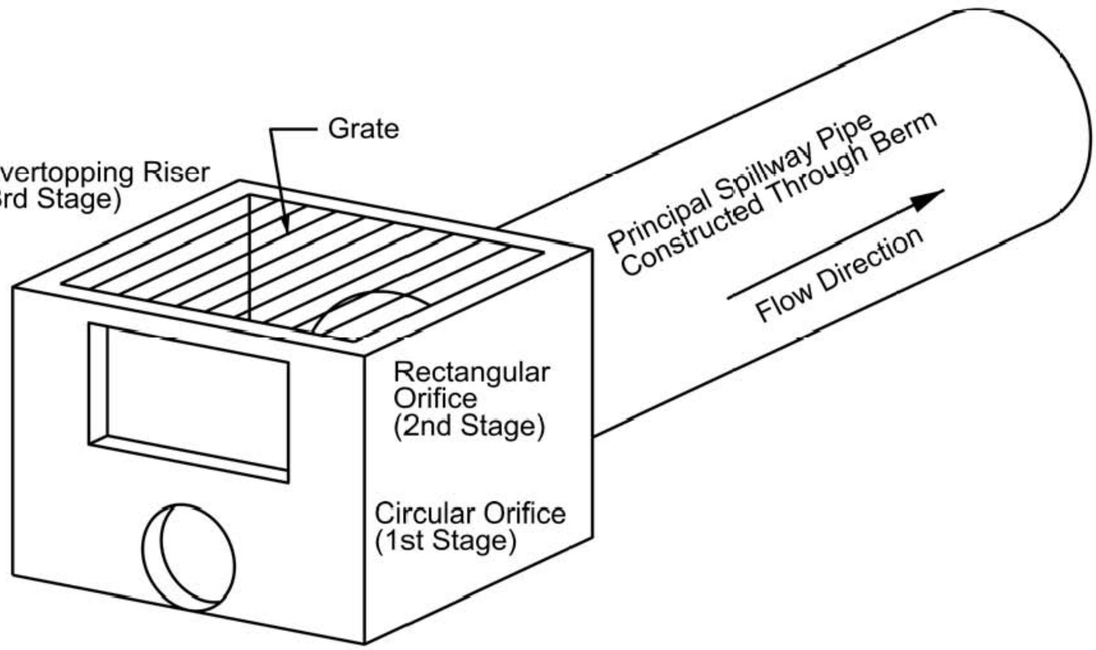


Figure 902-1
Hydraulic Control Structure

Channels cut into the top of the berm are an effective way to provide an emergency spillway. Ensure that the proper amount of erosion protection is included to protect the emergency spillway channel and receiving stream from erosion.

Single Spillway Basins

When it is not practically feasible to provide a separate emergency spillway for the basin, the basin can be designed to have a single spillway. This option should only be used when it is impractical to provide a separate emergency spillway, and where the ramifications of a failure of the basin from overtopping are insignificant.

In this case, it is extremely important to provide measures that will prevent clogging to the principal spillway pipe. All hydraulic control structures attached to the principal spillway pipe must be designed such that debris large enough to clog the principal spillway pipe is prevented from entering the principal spillway pipe. This can be done by ensuring that any orifice or weir in the outlet control structure is smaller than the principal spillway pipe or that these openings have a trash rack or grate to prevent the entry of debris into the principal spillway pipe.

Additionally an overflow control spillway should be provided to protect the berm from sudden failure. Whereas an emergency spillway is designed to convey storm discharges, the overflow control spillway is simply a means to control the overtopping of the berm should the principal spillway fail or a catastrophic storm occurs. Unlike a principal and emergency spillway, the overflow control spillway does not require a defined flow path below the spillway.

Grates and Trash Racks

Figure 902-1 shows a grate over the top of the control structure riser. As mentioned above, this is a requirement when there is not a separate emergency spillway.

It is possible for a flat grate to collect debris with the rise and fall of water above the structure. A solution to this is to provide a pyramid or cone shaped trash rack on top of the riser. This forces the debris to the side of the control structure as water levels recede in the basin.

Outlet Protection

The receiving waters downstream of the emergency and principal spillways must be analyzed for erosion potential. See DR 1000 "Erosion Control" for more information on

DR 902-5 Basin Volume

The hydraulic performance of the outlet structure, which works in concert with the design volume of the basin, controls flow rates leaving the basin. This basin volume can be obtained by excavating into existing ground or constructing a berm to impound water.

The process of designing detention and retention basins is a trial and error solution. The outlet control structure hydraulics and basin volume are adjusted until the project requirements for peak flow leaving the basin are met. Some municipalities have additional basin volume requirements that are separate from the peak flow limitations. Designers should consult the municipality they are working in to determine if there is a volume requirement.

Methods are available for assisting the Designer in making initial estimates for the requirements for detention volume. These methods are simplified procedures that estimate inflow and outflow hydrograph and are intended to give the designer a starting point for the design. See section 8.4 of FHWA's Hydraulic Engineering Circular No. 22, "Urban Drainage Design (2001)" for more information.

Underground Storage

In areas with right of way restrictions underground storage systems may be used. Underground storage systems range from large underground vaults, to systems of pipes. Generally, underground storage systems are very expensive, but they may be considered when there are right of way restrictions.

DR 902-6 Basin Routing

Basin Routing is the process of taking an inflow hydrograph representing the flow from the watershed, routing it through the storage facility, and developing an outflow hydrograph representing the flow from the facility. This process takes into consideration the storage of the basin and the hydraulic performance of the outflow device from the basin.

The routing procedure most commonly used for this type of routing is commonly referred to as the Storage Indication method or the Modified Puls method. The basic premise of this method is to mathematically relate the stage, storage and discharge for the facility. With these relationships, the inflow, storage and basin outflow can be analyzed for small increments of time.

The stage (or water level in the basin) can be directly related to the storage in the facility using the geometric properties of the basin. From this relationship a stage-storage curve is developed. Since the flow rates through an orifice or weir are related to the depth of water above them, a relationship can be developed between the stage in the basin and outflow rate from the basin. This relationship is commonly referred to as the stage-discharge curve (also called performance curve). The derivation of the Storage Indication method begins with the continuity equation which states:

Equation 902-1 Continuity Equation

$$\frac{\Delta S}{\Delta t} = \frac{I_1 + I_2}{2} - \frac{O_1 + O_2}{2}$$

Where:

ΔS = change in storage volume over Δt (ft^3)
Δt = time interval (seconds)
I_1 = inflow at beginning of time interval (ft^3/s)
I_2 = inflow at end of time interval (ft^3/s)
O_1 = outflow at beginning of time interval (ft^3/s)
O_2 = outflow at end of time interval (ft^3/s)

By substituting $\Delta S = S_1 – S_2$
S_1 = storage volume at beginning of time interval (ft^3)
S_2 = storage volume at end of time interval (ft^3)

The continuity equation becomes:

Equation 902-2 Continuity Equation

$$\frac{S_2 - S_1}{\Delta t} = \frac{I_1 + I_2}{2} - \frac{O_1 + O_2}{2}$$

Since we are doing a time step calculation, we will know information about the storage facility at the beginning of the analysis and from the inflow hydrograph we will know the inflow at both the beginning and the end of the time interval. Therefore, we want to re-arrange the terms in the continuity equation to solve for the unknowns, which are the storage and outflow at the end of the time interval.

Equation 902-3 Storage Routing Equation

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

Using the storage routing equation we solve for storage and outflow at the end of the first time interval. These values are then used for the beginning of the next time interval and the process is repeated throughout each successive time interval.

DR 902-7 Seepage

A pipe placed in an embankment that impounds water introduces discontinuities in the fill material in the embankment. Seepage of water along the exterior surface of a principal spillway conduit causes the progressive internal erosion of embankment material (piping) from around the pipe. This can lead to failure of the embankment.

Seepage is generally not a problem for standard detention basins. However, retention basins and extended detention basins may be susceptible to piping. All detention and retention basins shall consider the use of anti seep collars to prevent piping.

DR 902-8 Construction Requirements

Berms

Because berms for detention and retention basins impound water, they require special construction considerations. Berms should be composed of impervious soil that is free of large rocks and debris. Specify embankment material for the berms that meets the requirements for soil structural backfill as specified in Section 603.03.04 of the Standard Specifications for Road and Bridge Construction.

Berms should have a slope of 3:1 or flatter and should be vegetated as soon as possible after construction. Rip rap protected embankments may use 2:1 or flatter.

A geotechnical slope stability analysis is recommended for berms with heights greater than 10'.

Spillway Pipes Through Berms

Spillway pipes constructed through berms shall not have aggregate bedding or granular backfill. Specify the following criteria for all spillway pipes constructed through a detention or retention basin berm (the applicable specification number from the Standard Specifications for Road and Bridge Construction is show in parentheses)

- Reinforced Concrete Pipe (701.02)
- Type 1 Installation (701)
- Fine aggregate for pipe bedding and initial backfill up ½ of the diameter of the pipe (804.08 and 701.03.06–A-1)
- Soil embankment material rest for backfill to an elevation of 1 foot above the pipe (701.03.06-A-1)

DR 902-9 Maintenance Considerations

Maintenance is a primary consideration when locating and designing storage facilities. According to the location of the facility, the maintenance may be handled by another government agency, KYTC or possibly both. KYTC has maintenance agreements with many local governments throughout the state. Responsibility for the maintenance of these facilities must be determined in early in the design process to ensure the long term performance of these facilities. The Division of Maintenance should be consulted during this process.

The following maintenance problems are typical with urban detention facilities:

- weed growth,
- grass and vegetation maintenance,
- sedimentation control,
- bank deterioration,
- standing water or soggy surfaces,
- mosquito control,
- blockage of outlet structures,
- litter accumulation, and
- maintenance of fences and perimeter plantings.

Proper design procedures can alleviate some of the above problems. These design techniques include:

- Both weed growth and grass maintenance may be addressed by constructing side slopes that can be maintained using available power-driven equipment (e.g., tractor mowers).

- Sedimentation may be controlled by constructing traps to contain sediment for easy removal or low-flow channels to reduce erosion and sediment transport.

- Bank deterioration can be controlled with protective lining or by limiting bank slopes.

- Standing water or soggy surfaces may be eliminated by sloping basin bottoms toward the outlet, constructing low-flow pilot channels across basin bottoms from the inlet to the outlet, or constructing underdrain facilities to lower water tables.

- In general, when the above problems are addressed, mosquito control will not be a major problem.
- Outlet structures should be selected to minimize the possibility of blockage (i.e., very small pipes tend to block quite easily and should be avoided).
- Finally, one way to address the maintenance associated with litter and damage to fences and perimeter plantings is to locate the facility for easy access where maintenance can be conducted on a regular basis.

DR 902-10 Design Procedure

A general procedure for the design of storage facilities is presented below:

1. Compute inflow hydrograph for runoff from the 2, 10, and 100-year design storms using the procedures outlined in the DR 400. Both pre- and post development hydrographs are required for all storms.

2. Perform preliminary calculations to evaluate detention storage requirements for the hydrographs from Step 1. See section 8.4 of FHWA's Hydraulic Engineering Circular No. 22, "Urban Drainage Design (2001)" for more information.

3. Determine the physical dimensions necessary to hold the estimated volume from Step 2, including freeboard. The maximum storage requirement calculated from Step 2 should be used.

4. Size the outlet structure. Estimate the peak stage using the estimated volume from Step 2. The outlet structure should be sized to convey the allowable discharge at this stage.

5. Perform routing calculations using inflow hydrographs from Step 1 to check the preliminary design using the storage routing equations. If the routed post development peak discharges from the 2,10 and 100-year design storms exceed the pre-development peak discharges, or if the peak stage varies significantly from the estimated peak stage from Step 4, then revise the estimated volume and/or outlet structure then return to Step 3.

6. Consider emergency overflow from runoff due to the 100-year storm and established freeboard requirement in DR 902-8.

7. Evaluate the downstream effects of detention outflow to ensure that the routed hydrograph does not cause downstream flooding problems.

8. Evaluate the control structure outlet velocity and provide channel and bank stabilization if the velocity will cause erosion problems downstream. This procedure can involve a significant number of reservoir routing calculations to obtain the desired results.

DR 902-11 Design Criteria

Where no local guidance is available, permanent detention and/or retention basins should be designed to these guidelines. Chapter DR 1000 gives guidance for temporary sediment basins.

Requirements that apply to all basin types:

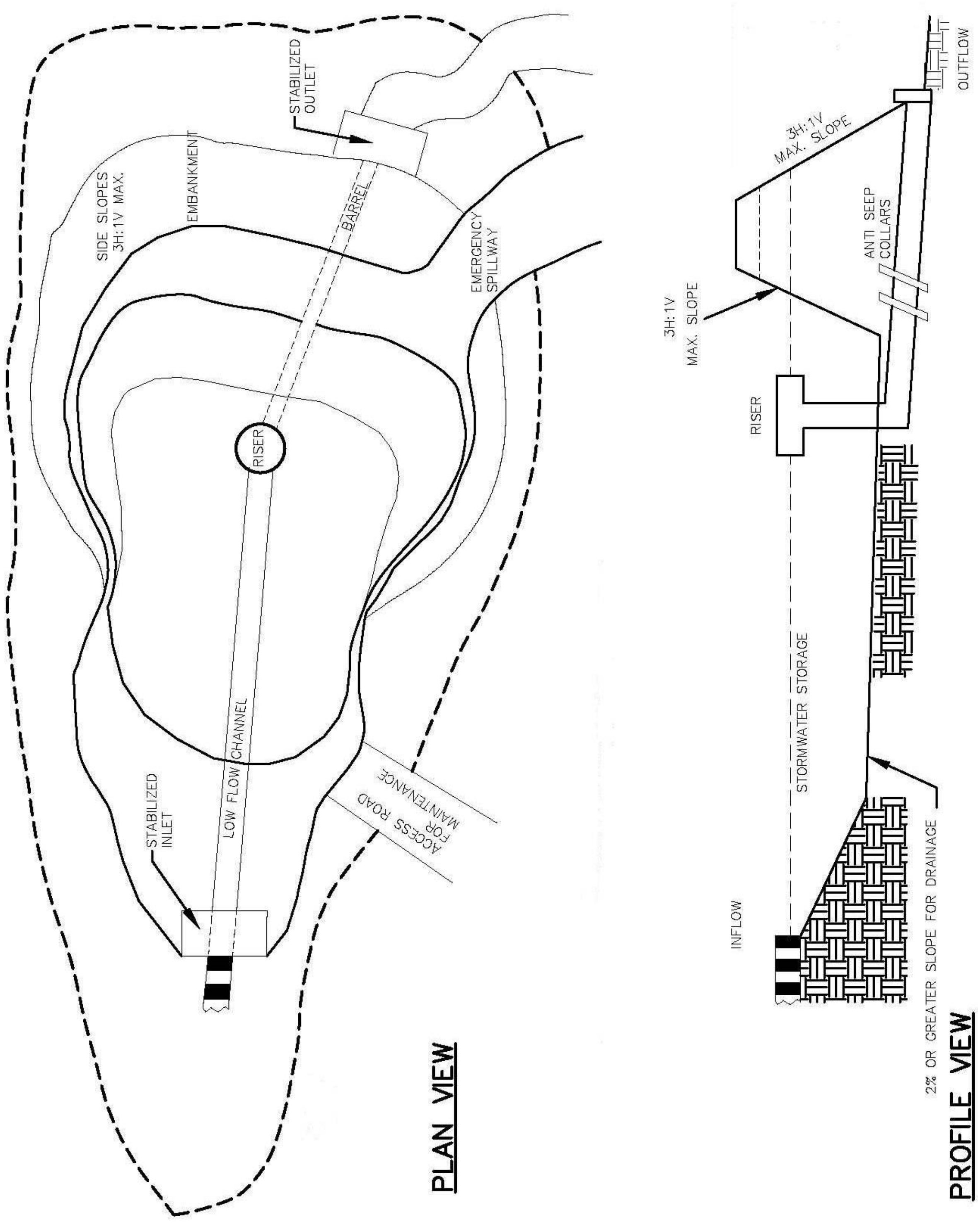
- Limit post construction peak discharges from the basin to the pre-construction (existing) peak discharges for the 2 year, 10 year and 100 year, 24 hour SCS Type II design storms.
- The water surface elevation in the basin resulting from the 100 year storm shall be at an elevation that provides a minimum of one foot of freeboard below the top of the basin when assuming all spillways and/or outlets are functional.
- Design outlet structures so that all water is discharged from the basin within 24 hours after the design storm.
- Design the basin and place notes in the plan set that address the construction requirement set forth in DR 902-8.
- Avoid designing any basin that qualifies as a dam as specified in DR 901-4 “Dams.” If it becomes necessary to propose a basin of this size, it shall be designed according to Division of Water requirements.

Additional requirements that apply to basins with a separate emergency spillway:

- Size the emergency spillway to convey the 100 year flow, without overtopping the basin, by assuming the principal spillway is clogged. This includes analyzing the spillway for erosion potential.

Additional requirements that apply to basins without a separate emergency spillway:

- Ensure that clogging of the principal spillway pipe is addressed by designing a hydraulic control structure that has openings that are either smaller than the principal spillway pipe, or are protected by grates.
- Provide an overflow control spillway to protect the berm from overtopping as discussed in DR 902-4 under the sub topic heading “Singe Spillway Basins.” Size the overflow control spillway to convey the 100 year flow, without overtopping the basin, by assuming the principal spillway is clogged. This includes analyzing the spillway for erosion potential. When an overflow control spillway is provided, the flowline of the spillway is considered the top of the basin for the freeboard considerations mentioned above.


STABILIZED OUTLET
SIDE SLOPES 3H:1V MAX.
EMBANKMENT
BARREL
EMERGENCY SPILLWAY
RISER
LOW FLOW CHANNEL
STABILIZED INLET
ACCESS ROAD FOR MAINTENANCE
PLAN VIEW
OUTFLOW
3H:1V MAX. SLOPE
ANTI SEEP COLLARS
3H:1V MAX. SLOPE
RISER
STORMWATER STORAGE
INFLOW
2% OR GREATER SLOPE FOR DRAINAGE
PROFILE VIEW