Chapter 13
Storage

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1.0 Introduction

Detention storage facilities are used to manage stormwater quantity, attenuating peak flows during flood events. Detention storage is necessary for new development, redevelopment and development expansion to mitigate the effects of increased runoff associated with development. These effects may include increased flooding potential, channel degradation and water quality degradation. In addition to providing flood control benefits, detention facilities can also be designed to enhance stormwater quality by incorporating design components to promote sedimentation, infiltration, and biological uptake.

The City of Woodland Park implemented requirements for detention for low-flows, minor and major events in 1994 via Resolution No. 299. The low-flow criteria is based on retaining (e.g. no discharge) 75% of the 2-year runoff volume based on a 0.8-inch, one-hour storm. The minor event is the 5-year event with a one-hour storm depth of 1.1 inches, and the outlet must be designed to release 5-year flows at or below historic levels. The major event is the 100-year event with a one-hour storm depth of 2.1 inches, and flows from this event must be released at a rate not to exceed the historic discharge rate. The storage volumes from these events must be added together to determine the total detention storage volume.

This chapter provides guidance for the analysis and design of storage facilities that are implemented independently or in combination with stormwater quality facilities. Additionally, this chapter provides guidance on “full-spectrum detention” designs that help to mitigate the effects of increased flow volumes on downstream channels. The UDFCD Water Quality Capture Volume (WQCV) approach and/or the Excess Urban Runoff Volume (EURV) approach that is the core of full spectrum detention may be used to satisfy the intent of City Ordinance No. 299 and may provide additional water quality and stream stability benefits relative to traditional multi-stage detention.

It is notable that the UDFCD WQCV, which corresponds to a rainfall depth of 0.6 inches, is very similar to the 75% of the 2-year, one-hour event that is the basis for the low-flow volume established in Resolution No. 299, Series 1994. The difference between the WQCV and the low-flow volume is that the low-flow volume is a retention volume (e.g. infiltration and/or evaporation of the captured volume without release via an outlet), while the WQCV is released via an outlet over an extended period ranging from 12 to 40 hours depending on BMP type. When soils are favorable for infiltration, the low-flow volume should be used. If soils have poor infiltration characteristics, the WQCV (and/or EURV) may be used as an alternative.

This chapter references the Storage Chapter of the UDFCD Manual for additional background, design parameters, and sizing methods. Criteria presented in the Storage Chapter of the UDFCD Manual shall govern except as modified or added to herein.

In addition to guidance on design of detention storage facilities, this chapter recognizes that detention facilities can require significant land area and be a prominent feature within land development plans. Detention storage planning and design should incorporate features that serve multiple purposes and that are integrated functionally and aesthetically into the land plan.Detention facilities must also be safe and maintainable. When properly designed and maintained, detention facilities can be viewed as community assets rather than liabilities.

1.1 Stormwater Quality Considerations

Detention facilities can be designed to provide both flow control and water quality benefits by providing extended detention and/or infiltration of small, frequently occurring events to enhance stormwater quality as a part of the flood control facility. Water quality treatment may also be provided through runoff reduction techniques thathave the potential to also affect detention storage facility sizing. Early in the planning process, opportunities to provide runoff reduction, stormwater quality management and flood control should be evaluated so that a comprehensive and coordinated approach can be developed. Extended detention and other water quality best management practices and runoff reduction practices are discussed in Volume 2 of the Colorado Springs Manual and Volume 3 of the UDFCD Manual, both of which are resources for stormwater quality planning and design in Woodland Park.

1.2 Stormwater Volume Considerations

In addition to the increase in peak flow rates, stormwater runoff volume increases with urbanization as a result of increased impervious areas, particularly impervious areas that are directly connected to the drainage system. The increase in runoff volume, especially for more frequent storm events, has the potential to disturb the downstream receiving stream's equilibrium and cause channel instability. Therefore, detention basin designs that help to mitigate the effects of increased runoff volumes, including retention and implantation of the low-flow volume, are preferred. Additionally, volume reduction practices upstream of detention facilities can be used in conjunction with flow control facilities to optimize mitigation and reduce costs.

1.3 Downstream Impacts

Even with comprehensive management of stormwater runoff, the effects of urbanization, including excess irrigation, increased snow melt runoff, reduced sediment loads(i.e., "sediment hungry" clear water runoff), and significant increases in stormwater runoff volumes are very difficult to fully mitigate. Therefore, some downstream channel instability can be anticipated due to development. This will require attention to channel improvements and right-of-way that may need to extend downstream beyond project limits.

2.0 Detention Requirements

2.1 General Requirements

Detention storage facilities are critical elements in the management of stormwater and shall be required for all new development, redevelopment, expansion or improvement projects. Detention facilities shall be designed to manage stormwater runoff for storms up to and including the 100-year event. In cases where project-specific conditions cause detention storage to be infeasible or ineffective, variances may be approved on a case-by-case basis through the variance process described in this Manualor through an approved planning process.

2.2 Detention Requirements for Redevelopment

Redevelopment of a site occurs when a change in the property use and/or function is desired, resulting in physical changes to the site. Unless detention is provided via a regional facility, the redevelopment of a site shall require that on-site detention be provided for the entire site, including those areas that previously had not provided detention due to the site being developed prior to the adoption of this Manual.

2.3 Detention Requirements for Expansion of a Developed Site

Expansion of a site occurs when additional area on the site is to be developed. The expansion of a site shall require that the current standards for detention for the entire site are met, where feasible. There are two conditions that may arise for site expansion, depending upon whether or not detention has been provided for the existing site prior to expansion, including:

- Detention has been provided for the existing developed area. The new expansion shall require that additional detention be provided to accommodate the expanded development or that the existing facilities be modified to serve the full site development.

- Detention has not been provided for the existing developed area. Detention will be required for the full expansion and to the extent possible, for the existing site area that has previously been un-detained. A reasonable attempt to provide detention storage will be required for the previously developed, un-detained portion of the site or the release rates from the expansion area must be less than the allowable release rates to compensate for the un-detained area.

3.0 Types of Detention Storage Facilities

Detention storage facility designscan generally be characterized based on scale of implementation and outlet configuration, as discussed below.

3.1 Scale of Implementation

Typical development-related detention facilities can be classified as "regional", "sub-regional" or "on-site." Regional detention facilities typically serve a broad purpose within a watershed and manage flows from multiple parcels and, possibly, multiple development projects. Sub-regional ponds, which by definition serve multiple parcels, may also provide benefits in terms of attenuating flows form developed areas, but typically serve only one development project. Regional and sub-regional detention facilities typically require a commitment for maintenance by a public entity or a legally-binding maintenance agreement. On-site facilities typically only serve a single parcel, have localized benefits, and are maintained by the property owner or private entity.

Regional or sub-regional detention is the preferred approach at a subdivision or project scaleinstead of providing on-site detention at the time each lot is developed. For large subdivisions, regional or sub-regional detention should be implemented by the first sub-divider rather than passing on the responsibility for detention to owners of individual filings. The coordination of development phasing with the construction of detention facilities should be addressed within the basin plans.

Additional information is provided below for regional, sub-regional and onsite facilities. Each of these types may include water quality features or be used in conjunction with separate water quality features or runoff reduction techniques. When water quality treatment is included within a detention facility, its effect on the required flood control storage varies with the type of facility.

3.1.1 Regional Detention

Regional detention typically refers to facilities that are owned and maintained by the City that serve multiple development projects or multiple phases of a development project. A primary function of regional detention facilities is to mitigate the effects of developed runoff so that downstream natural channel features and floodplains can be preserved. The location of these facilities can also differentiate "minor" drainageways from "major" drainageways. Under natural conditions, significant drainageways tend to develop when the contributing area is between 100 to 160 acres. Therefore, regional detention facilities will typically be located with a contributing area of about 130 acres or more. Figure 13-1 illustrates a typical regional detention concept.

The following are required for regional detention facilities:

1. Regional detention facility shall be designed to accommodate the fully developed condition flows from the upstream watershed.

2. Regional detention facilities are required to be owned and maintained by a public entity, with ownership and maintenance responsibilities clearly defined to ensure the proper function of the facility in perpetuity.

3. Drainage easements or tracts for the facility, including access from a public street, shall be provided.

4. An approved Operations and Maintenance Manual is required.

5. The creation of a jurisdictional dam,according to the State Engineer's Office definition, is discouraged.

6. The facility shall be permitted under applicable environmental permits and clearances.

7. Construction of the regional facility must be coordinated with development in the upstream watershed. If the regional facility has not been constructed, temporary on-site detention (and water quality) shall be required to be provided with development projects until the regional facility is available.

8. The drainageways upstream of a regional facility shall be designed to convey fully-developed flows to the regional facility.

9. Roadway embankments may be used to create the storage volume. When this is the case, roadway embankment design should consider the implications of hydrostatic and hydrodynamic forces on the embankment, including the potential for piping and scour. Roadways under the jurisdiction of other agencies, such as CDOT, may be prohibited from being used as detention basin embankments or require special consideration and permission.

3.1.2 Sub-regional Detention

Sub-regional detention refers to facilities located upstream of a major drainageway (generally having a drainage area between 1 and 130 acres) and serving more than one parcel. Like regional facilities, sub-regional detention facilities may be constructed by a public entity such as a municipality or special district to serve several landowners in the upstream watershed or by a single landowner. For a sub-regional facility to be recognized in the determination of flow rates for downstream major drainageways, the facility must be publicly owned and maintained, or the owner must provide easements and a legally binding maintenance agreement. Figure 13-2 illustrates a typical sub-regional detention concept. The conditions listed previously for regional facilities shall be adhered to for sub-regional facilities.

3.1.3 On-site Detention

On-site detention refers to facilities serving one parcel, generally commercial or industrial sites draining areas less than about 20acres. On-site detention is best suited for infill and redevelopment projects and in other areas where regional or sub-regional facilities are not able to be implemented. A primary function of on-site detention facilities is to reduce developed condition flows so that undersized downstream storm drain and/or channel capacities are not exceeded. On-site detention may also provide an opportunity to provide water quality treatment features. Figure 13-3 illustrates a typical on-site detention concept.

On-site detention facilities will not be recognized in the determination of flow rates for downstream major drainageways because of difficulties with ensuring that these facilities are maintained and continue to function in perpetuity on private property.

General guidelines for on-site detention facilities include:

- Integrating Detention and Site Landscaping Requirements. Locating detention basins in areas reserved to meet site landscaping requirements is generally encouraged. Incorporating detention into landscaped areas generally creates detention facilities that are easier to inspect, are relatively easy to maintain, and can enhance the overall aesthetics of a site. Further discussion regarding landscaping improvements in detention facilities is provided later in this chapter. For some small sites, detention and water quality can often be provided using practices such as bioretention that provide for infiltration, storage and regulated outflow.

- Parking Lot Detention. Parking lot detention may be acceptable on commercial and industrial sites and can offset some of the storage volume that needs to be provided on landscaped areas. Parking lot detention will be allowed on a case-by-case basis.

- Underground Detention.Underground detention shall be considered only in cases where other alternatives using surface storage are demonstrated to be infeasible and will only be allowed through the variance process provided in this Manual *(i.e. as approved by the City Engineer).*

- Rooftop Detention. Rooftop detention is prohibited, except as may be allowed through the variance process provided in this Manual *(i.e. as approved by the City Engineer).*

3.2 Outlet Configurations

Detention storage facilities can also be classified by how the outlet structure is configured. Outlet structures that are designed to attenuate specific storm event peak flows, but do not address the full range of stormwater inflows are considered “multi-level” or “multi-stage” outlets. Outlet structures that are designed to better attenuate the full range of storm events are considered “full-spectrum” outlets. These outlets release an outflow hydrograph that more closely represents the undeveloped condition hydrograph. They also provide some mitigation of increased runoff volumes by releasing them over an extended period of time.

3.2.1 Full Spectrum Detention

Full Spectrum Detention (FSD) is a design concept introduced by UDFCD in 2005 (Urbonas and Wulliman 2005) that provides better control of the full range of runoff rates that pass through detention facilities than the conventional multi-stage concept. This concept also provides some mitigation of increased runoff volumes by releasing a portion of the increased runoff volume at a low rate over an extended period of time (up to 72 hours). This concept can be applied for any size drainage basin up to 640 acres and can be integrated into on-site, sub-regional or regional detention facility designs.

By providing an Excess Urban Runoff Volume (EURV) in the lower portion of the facility storage volume with an outlet control device similar to a Water Quality Capture Volume (WQCV), frequent and infrequent inflows are released at rates approximating undeveloped conditions. The EURV is based on the incremental difference between the developed and undeveloped runoff volume for the range of storms that produce runoff from impervious land surfaces. Additional information on FSD is provided in the Storage Chapter of the UDFCD Manual.

Designing a detention basin to capture the EURV and release it slowly (at a rate similar to WQCV release rates) means that the frequent storms, smaller than approximately the 2-year event, will be reduced to very low flows near or below the sediment carrying threshold value for downstream drainageways. Additionally, by incorporating an outlet structure that limits 100-year runoff to the allowable release rate or to the undeveloped condition rate, the discharge hydrograph for storms between the 2-year and 100-year storm event will approximate the hydrograph for undeveloped conditions. This reduces the likelihood that runoff hydrographs from multiple detention facilities will combine to increase downstream discharges above undeveloped conditions and helps to more effectively mitigate the effects of urbanization.

3.2.2 Multi-level Outlet Configurations

Multi-level outlet configurations are most appropriate for on-site facilities to reduce peak flows, and may also be applied to regional or sub-regional facilities if a full spectrum approach (preferred) is not used. If a multi-level outlet configuration is used for a facility, at a minimum, it should be designed to retain the low-flow volume (75% of 2-year, one-hour storm volume) and to limit peak out flow rates for the 5-year and 100-year events to predevelopment levels.

In areas where soils are unfavorable for retention and infiltration of the low-flows volume, a multi-level design with controls for release of the WQCV, 5- and 100-year events may be used with approval of the City Engineer. In these cases, a full spectrum design, including the EURV, should first be considered as this would be expected to provide detention for a broader array of events, while using a simplified outlet structure.

4.0 Sizing Methodology

The detention facility sizing methodology varies depending on the contributing area, type of facility, and its intended function in the drainage system. To determine the appropriate methodology, the following questions should be answered:

1. What is the size of the basin area contributing to the facility?

2. Will the facility be regional, sub-regional or on-site?

3. Will the facility include retention of the low-flow volume or will the WQCV/EURV be provided as an alternative?

4. Will the facility have afull-spectrum or multi-leveloutlet configuration?

Considering these factors, the pond characteristics including location, volume, allowable release rates, multi-use opportunities, and other design features can be determined. Determining final detention storage facility characteristics typically requires an iterative process to achieve the design goals with the minimum storage requirements. The Storage Chapter of the UDFCD Manual describes a design procedure that can be applied for various types of detention storage facilities.

The UDFCD Manual provides approximate, simplified methods (empirical equations) that are adequate for smaller basins. More complex methods are available for larger, regional facilities. Use of the more complex methods may reduce the calculated required volume of the facility.

Table 13-1 summarizes the types of detention facilities and acceptable methods for determining their size and allowable release rates.

Table 13-1. Detention Facility Sizing Methods

Type	Tributary Area	Volume	Allowable Release Rate
Regional	130 to 640 acres	Hydrograph routing required for total volume; empirical equations allowed for EURV (EURV includes WQCV).	Undeveloped runoff rates.
Sub-regional	Less than 130 acres	Hydrograph routing or empirical equations allowed for total volume; empirical equations allowed for EURV (EURV includes WQCV).	Undeveloped runoff rates.
On-site	Less than 20 acres	Empirical equations, simplified FAA or hydrograph routing allowed. Add 50% of WQCV for multi-level facilities. (Do not add WQCV for FSD facilities.)	Undeveloped runoff rates.

4.1 Volume

The required total detention storage volume is based on the type and function of the facilities and may include a combination of these storage elements:

- <u>Flood Control Volume.</u> This storage element is normally the largest portion of the total storage and may be subdivided into separate portions for design purposes depending on the type of storage facility. In FSDs, the flood storage is equal to the entire volume and is inclusive of the EURV and the WQCV. In multi-level facilities, design volumes (and outlet release configurations) must be determined for the 5- and 100-year events. To determine the total flood control volume for a multi-level facility, the low-flow volume should be added to the 100-year flood control volume.

- <u>Excess Urban Runoff Volume (EURV).</u> This storage element is only implemented in an FSD facility and takes the place of the WQCV and low-flow volumes that are used in multi-stage designs. The required volume is based on empirical equations developed by UDFCD. Typically, this volume is about twice as large as the WQCV for Type C or D soils, or slightly larger than the total 2-year runoff volume. It is not necessary to increase the total storage volume by the EURV. The EURV is incorporated into the flood control storage volume.

- <u>Low-Flow Volume</u>. The low-flow volume is define by City Resolution No. 299, Series 1994 as 75% of the 2-year, one-hour runoff volume. The minimum standard for detention design in Woodland Park is retention (and subsequent infiltration) of the low-flow volume and control of the 5- and 100-year peak flow rates to predevelopment levels.

- <u>Water Quality Capture Volume (WQCV).</u> This storage element and methods for determining the WQCV are described in Volume 3 of the UDFCD Manual. The WQCV is intended to capture most runoff events and reduce their pollutant load prior to discharging into drainageways. The WQCV is similar to the low-flow volume in terms of total runoff volume; however, the WQCV is released over an extended period, ranging from 12 to 40 hours (depending on BMP type), while the low-flow volume is a retention volume that infiltrates and/or evaporates. For standalone water quality application (i.e. no minor/major detention), the WQCV is the recommended basis of design. However, in detention storage facilities, providing the low-flow retention volume or the EURV is preferred to using a multi-level WQCV design. The size of this storage element depends primarily on the amount of tributary impervious area and can be reduced by implementing development practices that reduce the effective imperviousness. The WQCV should only be used in multi-level designs when it is infeasible to retain and infiltrate to low-flow volume or to design a FSD with the EURV for water quality. The standard detention requirements for Woodland Park (retain 75% of 2-year, one-hour volume and detain 5- and 100-year events to pre-development levels) or FSD are preferred to a design using the WQCV and 5- and 100-year controls. The City Engineer has the authority to allow for a multi-level WQCV design if other alternatives are found to be infeasible.

- Initial Surcharge Volume. This storage element is calculated as a small percentage of the WQCV, EURV or low-flow volumeand is included within these storage volumes. This small volume is provided within or adjacent to the outlet structure and above the micropool to allow nuisance flows to collect so that the low-flow channel is free to drain and the pond bottom does not become saturated and difficult to maintain.

A single facility may include a combination of these storage elements or the storage elements may be segregated into separate facilities, as shown in Figure 13-4. Table 13-2 shows common configurations of these storage volume components for detention approaches that may be used in Woodland Park. Segregating the storage elements may be beneficial if a project is being phased or when adequate land is not available to combine all of the elements in one facility.

Table 13-2. Detention Volume Configurations

	Allowable Detention Approaches		
Detention Volume Component*	Standard Detention (Per Resolution 299, Series 1994)	WQCV Multi-Stage	Full-Spectrum Detention
Water Quality Capture Volume (WQCV)		X	X (Included in EURV)
Low-Flow (Retain 75% of 2-year, one-hour event)	X		X (Included in EURV)
Excess Urban Runoff Volume			X
Minor Event (5-year, one-hour storm)	X	X	X (Included in EURV and Flood Control Volume)
Major Event (100-year, one-hour storm)	X	X	X (Included in EURV and Flood Control Volume)

*Initial Surcharge Volume to be provided for all approaches as part of low-flow volume, WQCV or EURV to contain nuisance and frequent flows to designated portion of pond bottom.

4.1.1 Flood Control Volume

UDFCD has developed empirical equations for estimating the total required storage volume that can be applied to on-site, multi-level ponds or to on-site or sub-regional FSD ponds. The empirical equations include:

$$V_i = K_i A \qquad \text{Equation 13-1}$$

For NRCS soil types B, C and D.

$$K_{100} = (1.78 \cdot I - 0.002\, I^2 - 3.56) / 900 \qquad \text{Equation 13-2}$$

$$K_5 = (0.77 \cdot I - 2.65) / 1{,}000 \qquad \text{Equation 13-3}$$

For NRCS soil Type A:

$$K_{100A} = (-0.00005501 \cdot I^2 + 0.030148 \cdot I - 0.12) / 12 \qquad \text{Equation 13-4}$$

Where:

V_i = required volume, with i= year storm, acre-feet

K_i = empirical volume coefficient, with i= year storm

i = return period for storm event, years

I = fully developed tributary basin imperviousness, %

A = tributary basin area, acres.

These equations can be applied to calculate the total detention storage for drainage basins up to about 130 acres. When more than one soil type or land use is present in the drainage basin, the storage volume must be weighted by the proportionate areas of each soil type and/or land use. For FSDs, the EURV need not be added to this volume. See the Storage Chapter of the UDFCD Manual for a full description of this method.

4.1.2 EURV

UDFCD has developed empirical equations for estimating the EURV portion of the storage volume that can be applied to on-site, sub-regional or regional FSD ponds.

The empirical equations are as follows:

For NRCS Soil Group A:

$$EURV_A = 1.1\,(2.0491(I/100) - 0.1113) \qquad \text{Equation 13-5}$$

For NRCS Soil Group B:

$$EURV_B = 1.1\,(1.2846(I/100) - 0.0461) \qquad \text{Equation 13-6}$$

For NRCS Soil Group C/D:

$$EURV_{CD} = 1.1\ (1.1381(I/100) - 0.0339)$$ Equation 13-7

Where:

$EURV_K$ = Excess Urban Runoff Volume in watershed inches, K=A, B or C/D soil group

I = basin imperviousness, %.

These equations apply to all FSD facilities, and the EURV need not be added to the flood control volume or to the WQCV. When more than one soil type or land use is present in the drainage basin, the EURV must be weighted by the proportionate areas of each soil type and/or land use. If hydrologic routing is used to size the flood control volume, the EURV remains the same as calculated by these equations and is included in the pond's stage/storage configuration for modeling.

4.1.3 Initial Surcharge Volume

The initial surcharge volume is approximately 0.3 to 0.5 percent of the WQCV and should be approximately 4- to 12-inches deep.

4.1.4 Design Worksheets

The Full Spectrum Worksheet in the UD-Detention Spreadsheet performs all of these calculations for the standard designs. For multi-level ponds, the flood control volumes are calculated for the two design storm frequencies: the major storm (100-year) and the minor storm (5-year).

4.2 Release Rates

Release rates from detention facilities vary with the type of facility and with the storage volume type, as follows:

- WQCV. The WQCV release rate is determined based on a40-hour drain time for extended detention basins. The purpose of this slow release rate is to provide time for pollutants to settle and for the rate of discharge to be less erosive. The method for determining outlet sizing to achieve the necessary drain time is described in Volume 3 of the UDFCD Manual.

- Low-flow Volume.The low-flow volume equivalent to 75% of the 2-year, one-hour storm runoff volume is intended to be retained and subsequently infiltrated and/or evaporated. The low-flow volume is generally similar to the WQCV, but is retained rather than release via an outlet over an extended period.

- EURV. The EURV release rate is determined based on a72-hour drain time. The purpose of this slow release rate is to reduce the potential for downstream erosion and to release flows that more closely mimic undeveloped conditions.

- Flood Storage Volume. The flood storage release is determined by thepeak flow rates for the undeveloped/pre-disturbance site for relevant storm frequencies (5- and 10-year, one-hour event). For multi-level facilities, the design rates are based on specific return frequencies. For FSDs, only the 100-year rate is required for design. In both cases, it has been estimated that intermediate rates will also be released at rates approximately equal to the undeveloped rates.

4.2.1 Allowable Release Rates

The allowable release rates for detention pond design shall be determined based on undeveloped condition rates of runoff calculated using the methods defined in Chapter 6, Hydrology.Only the 100-year rate is used for FSD design, and only the 5- and 100-year are used for multi-level design. The release rates from the proposed pond must be equal to or less than the calculated undeveloped condition release rates.

4.2.2 EURV Release Rate

The EURV is intended to fully drain within a 72-hour period after the end of the storm. This is accomplished by a control plate placed in the outlet structure with the appropriate orifice (hole) sizes and spacing similar to those used for the release of the WQCV.UDFCD has estimated that the area of the holes in the control plate based on Equation 13-8.

$$A_o = 88V^{(0.95/H^{0.085})}/T_D^{(S^{0.09})}H^{(2.6S^{0.3})} \qquad \text{Equation 13-8}$$

Where:

A_o = area per row of orifices spaced on 4-inch centers (in^2)
V = design volume (WQCV or EURV, acre-ft)
T_D = time to drain the prescribed volume (hrs)
(i.e., 40 hours for WQCV or 72 hours for EURV)
H = depth of volume (ft)
S = slope (ft/ft)

The Full Spectrum Worksheet in the UD-Detention Spreadsheet performs these calculations for the standard designs.

5.0 Detention Pond Design Guidelines

In addition to the basic characteristics of location, function, volume, and release rates, several other design aspects must be considered to properly plan, design and maintain detention facilities.

5.1 Pond Location and Configuration

5.1.1 Detention Pond Placement

Detention ponds function best when they are strategically placed according to a plan that identifies proposed land uses, roadway alignments, and topographic features. The preservation of downstream natural features and the floodplain is also an important consideration for the placement of ponds. The placement of ponds adjacent to roadway embankments reduces the cost of pond construction. Using the fewest number of ponds required to accomplish their intended function within a drainage basin also reduces the cost and requires the fewest acres of land. Therefore, detention storage typically functions best if configured in one or a few larger sub-regional or regional ponds. Fewer, larger ponds rather than many small ponds is also advantageous for maintenance.

5.1.2 Detention Ponds in Series

Locating detention ponds in series (one pond draining into another downstream pond) is inherently inefficient and increases the required storage volume of the downstream facilities and is discouraged. This is especially true for FSD ponds because the EURV portion of a downstream FSD facility will collect additional runoff from the upstream pond and may be full when needed to detain runoff from the downstream basin.

If runoff is detained by two or more detention facilities in sequence before leaving the site, hydrograph detention routing analyses must be used to determine the effect of sequential detention and to determine the detention capacity that is needed to reduce runoff peaks to the specified allowable release rates at the end of the system.

5.1.3 Interconnected Ponds

When sequential detention ponds are located in close proximity, separated by a short culvert or pipe at a roadway crossing, or when sequential ponds have similar invert elevations, the ponds may need to be evaluated as interconnected ponds. This situation could also occur if downstream tailwater conditions cause variable backwater effects that influence the discharge of the detention pond outlet. In these situations, the water surface elevation downstream can reduce the discharge rate from the upper pond and, in some cases, reverse flow can occur from downstream into the upstream pond. Analysis of this condition is much more complex because the ponds are hydraulically dependent and the water surface elevations continuously vary and change the discharge characteristics. It is the responsibility of the design engineer to ensure that the appropriate analyses are performed and submitted when ponds are interconnected or affected by downstream tailwater conditions.

5.2 On-site Detention and Off-site Flows

Two approaches are generally acceptable for addressing off-site flows that must be conveyed through a site and the potential impacts to the on-site detention. These approaches include:

- Separate Conveyance Systems. In this approach, off-site runoff is conveyed to a point downstream of the on-site detention pond outfall. The detention pond is sized based only on the tributary area of the site. Off-site flows and the detained runoff can be conveyed in the same system downstream of the detention pond.

- Design for Off-site Flows. An alternative method is to design the detention pond for the entire upstream watershed area, including the future development flows from off-site areas without giving any credit to off-site detention facilities. This method may be appropriate if the off-site tributary area is relatively small, but it becomes less feasible as the off-site tributary increases.

The benefits of detention facilities provided in the off-site area may be considered in some cases, if there is sufficient justification. In those cases, the design engineer shall utilize hydrograph routing methods to size the on-site detention to account for the additional detention facilities on the off-site area and the differences in timing of the various hydrographs.

5.3 Design Features

5.3.1 Discharge Location (Outlets)

Detention ponds shall be designed to discharge into a storm sewer, drainageway, or other designated drainage system that is reasonably available. Analyses must demonstrate that the receiving drainage system (where the pond discharges) has the capacity to convey the detention pond flows.

When a suitable outlet is not available, and with prior approval, detention ponds may discharge into the gutter of a street, such as through a chase section, when the minor storm peak flow from the tributary area is less than 3.5cfs and the street has adequate capacity to convey the excess runoff within the allowable limits. A transition from the outlet to a curb chase will normally be required and the chase section shall be designed to convey the discharge at a low velocity. The location of the outlet shall be designed to minimize potential problems or conflicts with other improvements. Discharge into the gutter will not be allowed on local streets, or in cases where structures along the street have finished floor elevations below the street elevation.

5.3.2 Excavated or Embankment Slopes

All excavated or embankment slopes from the pond bottom to the 100-year water surface elevation shall be no steeper than 4 feet horizontally to 1 foot vertically (4H:1V). Excavated slopes above the 100-year water surface elevation and the slope on the downstream side of embankments must be 3H:1V or flatter. Embankments shall be provided with a top width of at least 10 feet. All earthen slopes shall be covered with topsoil and revegetated as described in Chapter 14, Revegetation.

It is the responsibility of the design engineer to ensure that the design of any earthen embankment is based on specific recommendations determined by a qualified geotechnical engineer. Additionally, the embankment heights and pond size shall not place the structure under the jurisdiction of the Office of the State Engineer, unless specific approval is provided. The potential for piping failure through the embankment or along penetrations of the embankment, such as the outline conduit, shall be mitigated by the design methods consistent with State Engineer dam design criteria.

5.3.3 Freeboard

The minimum required freeboard for detention facilities is 1.0 foot above the computed water surface elevation when the emergency spillway is conveying the design flow.

5.3.4 Low-flow Channels

Detention ponds collect both wet and dry weather flows from the upstream basins, including excess irrigation water that can keep pond bottoms wet and difficult to maintain. Therefore, grassed-bottom detention ponds shall include a low-flow channel sized to convey a minimum of 1 percent of the 100-year peak inflow. The low-flow channel shall be constructed of concrete, concrete with boulder edges, soil riprap, or any combination thereof and shall have a minimum depth of 0.5 feet. The minimum longitudinal slope shall be 0.5 percentto ensure that non-erosive velocities are maintained adjacent to the low-flow channel when the design capacity is exceeded.

Low-flow channels in detention ponds either drain through a WQCV or an EURV to the pond outlet structure where the discharge rate is constrained. This can cause flows to pond at the end of the low-flow channel, deposit sediment, and saturate the surrounding pond bottom. Therefore, the invert elevation of the low-flow channel must be set above the initial surcharge volume near the pond outlet to confine this nuisance ponding to a small area of the pond bottom and reduce maintenance requirements.

Unlined (or wetland) low-flow channels may be allowed on a case-by-case basis. The unlined low-flow channel shall be at least 1.5-feet deep below adjacent grassed benches and shall be vegetated with herbaceous wetland vegetation or riparian grasses, appropriate for the anticipated moisture conditions. The minimum longitudinal slope shall be 0.5 percent and the minimum width of the grassed bench adjacent to the low-flow channel shall be 12 feet on at least one side for equipment access. The side slope below the bench shall be no steeper than 4H:1V and the maximum bottom width of the channel shall be 12 feet if equipment can access one side of the channel or 24 feet if equipment can access both sides.

Typical cross-sections of low-flow channels are shown in Figure 13-5. Typical pond configurations with a concrete low-flow channel and a benched low-flow channelare shown in Figures 13-6 and 13-7.

5.3.5 Bottom Slope

For grassed detention facilities, the pond bottom shall be sloped at least 4 percent for the first 25 feet and at least 1 percent thereafter to drain toward the low-flow channel or outlet, measured perpendicular to the low-flow channel. The benches above unlined low-flow channels, if approved, shall slope at least 1 percent toward the low-flow channel.

5.3.6 Wetland Vegetation (Constructed Wetland Pond)

A soft bottom or constructed wetland pond bottom can be used in place of a dry pond bottom, but special considerations must be made for maintaining an adequate depth of water to allow wetland plants to survive. These types of ponds also require special attention to provide access to the bottom for maintenance. Additionally, the upstream drainage basin must be evaluated to determine whether an adequate amount of flow will be provided to support the vegetation.

5.3.7 Inlet Structures

Runoff shall enter a detention facility via a stabilized drainageway, drop structure, or storm sewer. Riprap rundowns are generally not accepted due to a history of erosion problems.Capturing sediment before it enters the detention facility is important for reducing maintenance requirements inside the facility. Forebays provide locations for debris and coarse sediment to drop out of the flow and accumulate, extending the functionality of the pond features. Forebays shall be sized based on the methods described in Volume 3 of the UDFCD Manual. Figure 13-8 illustrates a concept for storm sewer outfalls entering a forebay at the inlet to a detention facility. Forebay designs must facilitate maintenance by providing adequate access and by having concrete bottoms.

Flows entering ponds often have high energy. Therefore, some form of energy dissipation may be necessary at a pond inlet. To determine the hydraulic characteristics of the inlet structures and energy dissipation devices at an entrance to a pond, the designer may account for tailwater effects of water in the pond during the minor (5-year) and major (100-year) events. The elevation of the low-flow volume, WQCV or the EURV can be used as a minimum tailwater condition for energy dissipation calculations for these events.

A safety barrier, such as a railing of sufficient height, shall be provided around the perimeter of inlet structures whenever the difference in the elevation from the surface to the bottom of the structure is 30 inches or greater.

5.3.8 Outlet Structures

Detention basin outlets shall be designed to control facility discharges at the allowable release rates. Additionally, outlet structures shall be provided with safety/debris grates to reduce the potential for debris plugging, designed for ease of maintenance, equipped with safety features, and designed with favorable aesthetics.

For designs using the WQCV or EURV to drain more effectively, a "micropool" must be located in front of the screen for the outlet control plate. The purpose of a micropool is to create a permanent pool of water on which debris will float, allowing flow to pass through the lower portion of the screen to the control plate. It is preferable to contain the micropool integral to the concrete portion of outlet structures.

Figures 13-9 and 13-10provide examples of integral micropools: one with parallel wingwalls with a flush bar grating and the other with flared wingwalls and handrails, respectively. Extending micropools out into the pond bottom creates areas that may contain standing water for extended periods of time and be difficult to maintain. External micropools (extending beyond the concrete outlet structures) shall only be used if a constant baseflow exists sufficient to maintain the micropool level and will be allowed only on a case-by-case basis. Although there is no volume requirement for micropools, they must have a surface area of 10 square feet or more and be at least 2.5-feet deep.

An “initial surcharge volume” is critical to the proper functioning of a pond outlet and must be provided. This volume provides a limited amount of storage for very low flows passing through the pond and allows the low-flow channel and pond bottom to flow freely and remain drier for maintenance. It is preferable that this volume may be contained within the outlet structure above the micropool, but may extend out beyond it as necessary. When this volume extends beyond the micropool, a concrete curb, rock edge or other feature must separate it from the bottom of the WQCV/EURV volume so that it can be identified and preserved. The bottom of this volume can be lined with concrete or vegetated. This volume is considered part of the WQCV or the EURV and does not need to be added to the other design volumes. A more detailed discussion of this feature is provided in Volume 3 of the UDFCD Manual. An initial surcharge volume is not necessary for Constructed Wetland Ponds or Retention Ponds.

The flood-control outlet shall be sized to discharge the allowable 100-year release rate when the 100-year detention volume is completely full. The outlet structure weir crest (formed by the top of the concrete) shall have adequate capacity to pass design flows so that flow control is maintained at the appropriate control device for the design event.

A safety barrier, such as a railing of sufficient height, shall be provided around the perimeter of outlet structures wherever the difference in the elevation from the top of the structure to the bottom of the structure is 30 inches or greater.

A sealant must be specified behind the orifice plate to prevent leakage around the control plate. All hydraulic sizing, concrete structure dimensions, reinforcing, and metalwork details for outlet structures shall be the responsibility of the design engineer.

5.3.9 Trash Racks

The design of trash racks protecting outlet control devices shall comply with the safety grate criteria discussed in the Culverts Chapterof the UDFCD Manual. The trash rack or screen protecting the control plate orifices must extend to the bottom of the micropool so that flow can pass through the rack below the level of any floating debris and pass through the orifices.

Bar grating may be used on parallel sloping wingwalls, either as the primary debris grate (if orifices are at least 2.5 inches in diameter) or as a coarse screen and safety grate in lieu of handrail. Sloping bar grating shall have a lockable hinged section of at least 2square feet to allow access to the orifice plate or well screen. Manhole steps shall be provided on the side of the wingwall directly under the hinged opening. The bearing bars for the steel bar grating shall be designed to withstand hydrostatic loading up to the spillway crest elevation (assuming the grate is completely clogged and bears the full hydrostatic head), but not be designed for larger loads (like vehicular loads) so that the hinged panels are not excessively heavy. Panels of trash racks or bar grating shall be no more than 3-feet wide and all parts of the grating and support frames shall be hot-dipped galvanized steel. Trash racks or bar grating shall be attached to the outlet structure.

The configuration and dimensions of trash racks and grates should allow debris to be raked off using standard garden tools or other commonly available equipment.

5.3.10 Emergency Spillway and Embankment Protection

Detention storage may be created by a roadway embankment or by a freestanding embankment as conceptually represented by Figures 13-11a and 13-11b. Whenever a detention pond facility uses an embankment to contain water, the embankment shall be protected from catastrophic failure due to overtopping. Overtopping can occur when the pond outlet becomes obstructed or when a storm larger than a 100-year event occurs. Erosion protection for the embankment may be provided in the form of a buried soil-riprap layer at the spillway crest and on the entire downstream face of the embankment or a separate emergency spillway constructed of buried,soil riprap, grouted boulders or concrete. In either case, the protection shall be constructed to convey the 100-year developed condition flow from the upstream watershed without accounting for any flow reduction within the detention facility.

The crest elevation of the emergency spillway shall be set at or above the calculated 100-year water surface elevation. A concrete wall shall be constructed at the emergency spillway crest extending at least to the bottom of the riprap and bedding layers located immediately downstream. The crest wall shall be extended at the sides up to 1 foot above the emergency spillway design water surface as shown in Figure 13-11c.

Riprap embankment protection shall be sized based on methodologies described in *Development of Riprap Testing in Flumes: Phase II Follow-up Investigations* (Abt et al. 1988) to determine the D_{50} dimension. According to this method:

$$D_{50} = 5.23\, S^{0.43}\, (1.35\, C_f\, q)^{0.56} \qquad \text{Equation 13-9}$$

Where:

D_{50} = median rock size (in)

S = longitudinal slope (ft/ft)

C_f = concentration factor (1.0 to 3.0)

q = unit discharge (cfs/ft)

When:

η (porosity) = 0.0 (i.e., for buried soil riprap)

The unit discharge shall be determined by dividing the design flow by the crest width, excluding the side slopes. According to this method, the types of riprap needed for typical embankment slopes and design flows areshown inFigure 13-11d. The riprap types shown were determined assuming that there is no interstitial flow (i.e., no flow between the rocks—soil riprap with filled voids and porosity=0) and that the "concentration factor" (C_f) is equal to 2.0.For plain riprap with interstitial flow, the method requires an interactive process described in Abt et al. (1988). The range for each type shown is based on the D_{50} dimension at the midpoint between the D_{50} for adjacent types. Riprap characteristics such as rock size distributions, thickness, hardness, specific gravity, angle of repose, etc., shall be as described in this Manual. For design conditions outside of the parameters or conditions represented in Figure 13-11d, the designer shall propose an appropriate alternative approach thatmay include grouted boulders or concrete protection.Alternative approaches must be submitted for approval prior to incorporation into designs.

The emergency spillway is also needed to control the location and direction of any overflows. The emergency spillway and the path of the emergency overflow downstream of the spillway and embankment shall be clearly depicted on the drainage plan. Structures shall not be permitted in the path of the emergency spillway or overflow. The emergency overflow water surface shall be shown on the detention facility construction drawings. When emergency overflows will pass over a roadway, the depth of flow shall not be greater than 1 foot over the street crown.

5.3.11 Retaining Walls

The use of retaining walls within detention basins is discouraged due to the potential increase in long-term maintenance costs and concerns regarding the safety of the general public and maintenance personnel. Retaining walls shall only be considered for on-site facilities. If retaining walls are proposed, footings shall be located above the low-flow volume, WQCV or EURV, as applicable. Wall heights not exceeding 30 inches are preferred, and walls shall not be used along more than 50 percent of the pond circumference. If terracing of retaining walls is proposed, adequate horizontal separation shall be provided between adjacent walls. The horizontal separation shall ensure that each wall is loaded by the adjacent soil, based on conservative assumptions regarding the angle of repose. Separation shall consider the proposed anchoring system and equipment and space that would be needed to repair the wall in the event of a failure. The failure and repair of any wall shall not impact or affect loading on adjacent walls. In no case shall the separation be less than 2 times the adjacent wall height, such that a plane extended through the bottom of adjacent walls shall not be steeper than 2H:1V. The maximum ground slope between adjacent walls shall be 4 percent.

Walls shall not be used where live loading or additional surcharge from maintenance equipment or vehicle traffic could occur. The horizontal distance between the top of a retaining wall and any adjacent sidewalk, roadway, or structure shall be at least three times the height of the wall. The horizontal distance to any maintenance access drive not used as a sidewalk or roadway shall be at least 4 feet. Any future outfalls to the pond shall be designed and constructed with the detention basin out to a distance sufficient to avoid disturbing the retaining walls when the future pipeline is connected to the outfall.

Any wall exceeding a height of 30 inches requires perimeter fencing, safety railing, or guardrail, depending on the location of the wall relative to roadways, parking areas, and pedestrian walkways. Walls exceeding a height of 4 feet (measured from the bottom of the footing to the top of the wall) may require a Building Permit. The design engineer is responsible for compliance with any permitting requirements under the Uniform Building Codes.

A Professional Engineer licensed in the State of Colorado shall perform a structural analysis and design the retaining wall for the various loading conditions the wall may encounter, including the differences in hydrostatic pressure between the front and back of the wall. A drain system should be considered behind the wall to ensure that hydrostatic pressures are equalized as the water level changes in the pond. The wall design and calculations shall be stamped by the professional engineer. The structural design details and requirements for the retaining wall(s) shall be included in the construction drawings.

Retaining walls shall not be used within the limits of any impermeable lining of water quality basins or detention ponds.

5.4 Landscaping

The integration of detention facilities and site landscaping requirements is important for making facilities more aesthetically acceptable, consistent with adjacent land uses and compatible with overall stormwater management goals. The type and quantity of landscaping materials should be considered to ensure that the capacity of the pond is maintained and that maintenance activities can be performed with minimal disruption of vegetated areas. Recommendations for pond grading and landscaping include:

1. Wherever possible, involve a landscape architect in the design of detention facilities to provide input regarding layout, grading, and the vegetation plan.

2. Create a pond with a pleasing, curvilinear, natural shape that is characterized by variation in the top, toe, and slopes of banks and avoid boxy, geometrical patterns. A "golf course look" is more attractive than straight lines and straight slopes.

3. Grass selection and plant materials are important considerations in softening the appearance of a detention area and blending it in with the surrounding landscaping and natural features. Selected species should be suitable for the particular hydrologic conditions in the pond. Wetland or riparian species should only be selected for the bottom areas subject to frequent and prolonged inundation. Bluegrass rarely works well in the lowest portion of a pond. Guidelines for revegetation, along with recommended seed mixes, are provided in the Chapter 14, Revegetation.

4. Multi-purpose detention facilities are encouraged that incorporate recreational features such as passive open space areas and pedestrian paths. Active recreational facilities should be located in upland areas to avoid usage conflicts resulting from periodic inundation.

5. To reduce the potential for clogging of debris grates, no straw mulch shall be used within the EURV or WQCV of a detention basin. Instead, erosion control blankets shall be installed for a width of at least 6 feet on either side of concrete low-flow channels or up to a depth of 1 foot in soil riprap or benched low-flow channels. The blankets shall comply with the materials and installation requirements for erosion control blankets (straw coconut or 100 percent coconut). Site-specific conditions may require additional blanket or other erosion control measures.

6. Trees or shrubs consistent with the landscape plan or the surrounding natural environment may be planted within the pond volume above the EURV or the 2-year water surface, whichever is higher. Trees such as Cottonwood, Willow, and Aspen shall not be planted below the 100-year water surface or on the embankment slopes of a detention pond to avoid nuisance spreading of root systems within the facility.

7. Revegetation requirements described in Chapter 14, Revegetation, shall apply to detention facilities. These requirements go beyond plant species selection and include proper soil preparation, irrigation, weed control and other considerations.

5.5 Signage

Two signs, each with a minimum area of 3 square feet, shall be provided around the perimeter of all detention facilities. The signs shall be fabricated of durable materials, such as metal or plastic, using red lettering on a white background with the following message:

WARNING **THIS AREA IS A STORMWATER FACILITY** **AND IS SUBJECT TO PERIODIC FLOODING**

5.6 Access Easements

Easements or tracts shall be provided to ensure access for the maintenance and operation of detention facilities. Access rights shall be granted for inspection, maintenance and reconstruction purposes, and shall be conveyed to the local agency. The boundaries of easements or tracts to be conveyed shall be shown on the drainage plan, final plats and final development plan. All easements shall be conveyed by appropriate legal documents such as plats or grant of easements. Drainage easements and tracts shall be kept clear of obstructions to flow and shall allow unconstrained maintenance access. The minimum easement requirements for detention ponds include the area necessary for storage, including freeboard, associated facilities, excavation and embankment slopes, and adequate maintenance access around the perimeter. Access from public right-of-way to the pond easement or tract shall also be provided in an easement or tract.

5.7 Maintenance

Detention facilities shall be designed to facilitate ongoing maintenance operations. The maintenance of detention facilities shall be performed by the property owner, or as otherwise designated by maintenance agreement. Maintenance operations shall be in accordance with the approved operations and maintenance manual (O&M Manual) for the facility, which is required as a part of the submittal process. Routine maintenance of detention facilities shall include mowing, structural repairs, and sediment and debris removal. Non-routine maintenance may include the repair and/or replacement of outlet structures, trickle channel, outlet pipes, channel slopes, and other related facilities. When appropriate maintenance is not provided, the local government agency may provide the necessary maintenance and shall assess the associated cost to the property owner. All detention facilities, with or without retaining walls, shall be designed in accordance with the maintenance requirements.

5.7.1 Access

A stable access and working bench shall be provided so that equipment can be used to remove accumulated sediment and debris from the detention pond and perform other necessary maintenance activities at all components of the facility. Unless otherwise approved, the horizontal distance from the working bench to the furthest point of removal for the forebay, bottom of the detention basin, or outlet structure shall be no more than 24 feet. The working bench and access drive shall slope no more than 15percent, and be at least 10feet wide for a centerline radius greater than 80 feet and at least 12feet wide for a centerline radius between 50and 80feet. The minimum centerline radius shall be 50feet. Unless otherwise required by a pavement design, the working bench and access drive shall be constructed as follows:

- <u>Below any permanent water surface</u>: A reinforced concrete bottom slab at least 6 inches thick shall be provided as a working platform. The surface of the concrete shall be provided with a grooved finish to improve traction, with grooves oriented to drain water away to one or both sides. Concrete shall be placed on at least 6 inches of gravel base compacted subgrade.

- <u>Below the low-flow, WQCV or EURV water surface</u>: The access ramp shall be reinforced concrete as specified above, or at least a 12-inch thick layer of aggregate base course or crushed gravel over compacted subgrade.

- <u>Above the low-flow, WQCV or EURV and below the 100-year water surface</u>: An access ramp shall be reinforced concrete as specified above or provide at least an 8-inch-thick layer of aggregate base course or crushed gravel over compacted subgrade.Reinforced turf grass, meeting applicable criteria, will be considered in this zone for an access drive on a site-specific basis. If used, a system of marking the edges is required so that its location is evident to maintenance crews. Also, shrubs, trees, sprinkler heads and valve boxes shall not be located in the reinforced turf grass area.

Pavement designs for access drives shall be submitted for review and approval based onsite soil conditions and H-20 loading.

Retaining walls shall be laid out in a manner that avoids access restrictions. Likewise, handrails or fences shall permit vehicular access. The entrance to an access drive from a roadway or parking lot shall be located so that traffic safety is not compromised. A means of limiting public access to the site, such as bollards and a chain or a gate, shall be provided at the entrance to the access drive.

5.7.2 Other Improvements to Facilitate Maintenance

Other improvements that could facilitate future maintenance operations are encouraged. These may include:

1. Providing adequate room for staging the equipment involved in clean-out operations.

2. Providing a power receptacle adjacent to the detention pond to enable dewatering operations using an electric pump. Electric pumps are quieter and require less attention in the event pumps need to operate overnight.

3. For larger, natural sites, it may be worthwhile to reserve a suitable location for disposing of sediment that is cleaned out of the pond. This has to be carefully thought through, however, to make sure it is feasible to dump the material on-site, allow it to dry, then spread it and re-seed and mulch the area, without causing erosion problems. This approach must be approved and adequately described in the O&M Manual, if allowed.

5.8 Construction Phasing

It may be possible to delay the construction of detention ponds if development upstream of the planned pond site is limited relative to the fully-developed land use plan. However, development tends to destabilize downstream channels due to an increase in flows, but also due to a reduction in available sediment (“clear water” discharges). Estimates of the impact of development on downstream channels shows that even a small change in minor storm flowscan begin to change downstream channel characteristics. Therefore, some limited upstream development may occur prior to construction of sub-regional or regional detention facilities. However, improvements to channels between the developed area and the pond site may need to be improved to prevent degradation.

5.9 Downstream Channel Stabilization

Even with the construction of detention ponds that release pre-development flow rates, it is anticipated that downstream channels will tend to become unstable due to the increase in the volume of stormwater released and the reduction in the amount of available sediment. To avoid degradation in downstream channels,channel stabilization improvements should be extended downstream of developed areas or detention facilities. Completing these channel improvements may require the acquisition of offsite right-of-way. Additionally, consideration must be given to the capacity of the channel improvements with respect to future development.

6.0 Parking Lot Detention

Where on-site detention is approved, portions of the site used for parking or landscaping may be inundated to provide some of the storage required.

6.1 Access Requirements

Easements for parking lot detention shall be provided, including the area of the parking lot that is inundated by the 100-year water surface elevation and the outlet structure and conveyance facilities. Easements shall also be provided from public right-of-way to the pond facilities.

6.2 Maintenance Requirements

The property owner shall be required to ensure that the parking lot detention are maintained in accordance with the approved Operations and Maintenance Manual (O&M Manual) for the project.

6.3 Depth Limitation

The 100-year design water surface shall not flood the parking area by more than 9 inches. When FSD is applied, the maximum allowable design depth above pavement surfaces for the EURV is 3 inches. The WQCV shall be located entirely out of the pavement area, possibly in one or more landscaped parking islands or adjacent landscaping.

6.4 Emergency Spillway

An emergency spillway sized for the 100-year peak inflow rate shall be provided with a crest elevation set at the 100-year water surface elevation and a maximum flow depth over the emergency spillway of 6 inches. No freeboard above the emergency spillway 100-year water surface elevation is required. The finished first floor elevation of any adjacent structures shall be at least 1.0 foot above the 100-year emergency overflow water surface elevation (equivalent to 18 inches above the 100-year pond water surface).

The emergency spillway should be integrated into the site plan and landscaping and can be vegetated over stabilization material such as soil riprap or a geotextile. Embankment protection may be eliminated if the depth of flow and velocities for the 100-year flow are low enough to avoid erosion during overtopping.

6.5 Outlet Configuration

The outlet configuration for WQCVs and EURVs shall be designed in accordance with criteria shown in Volume 3 of the UDFCD Manual for the type of facility selected. Outlets for the EURV and 100-year events shall limit peak flows to the allowable release rates.

6.6 Flood Hazard Warning

All parking lot detention areas shall have a minimum of two signs posted identifying the area of potential flooding. The signs shall be fabricated of durable materials, such as metal or plastic, using red lettering on a white background and shall have a minimum area of 1.5 square feet and contain the following message:

WARNING
THIS AREA IS A DETENTION POND
AND IS SUBJECT TO PERIODIC FLOODING
TO A DEPTH OF 9 INCHES OR MORE

Signs shall be located at the edge of the parking area adjacent to where flooding may occur and facing the parking area. Any suitable geometry of the signs is permissible. The property owner shall be responsible to ensure that the sign is provided and maintained at all times.

Figure 13-1. Regional Detention Concept

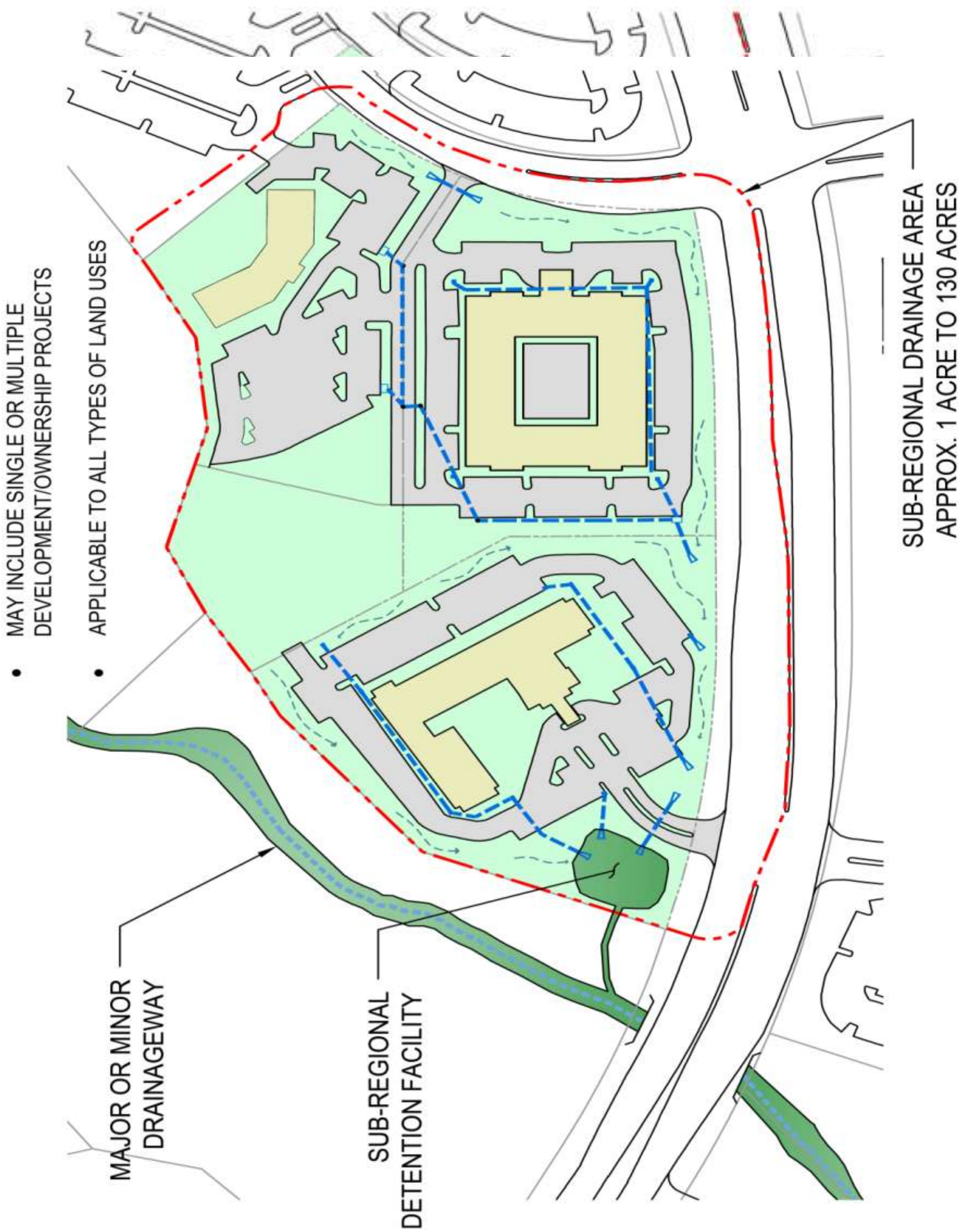


Figure 13-2. Sub-regional Detention Concept

Figure 13-3. On-site Detention Concept

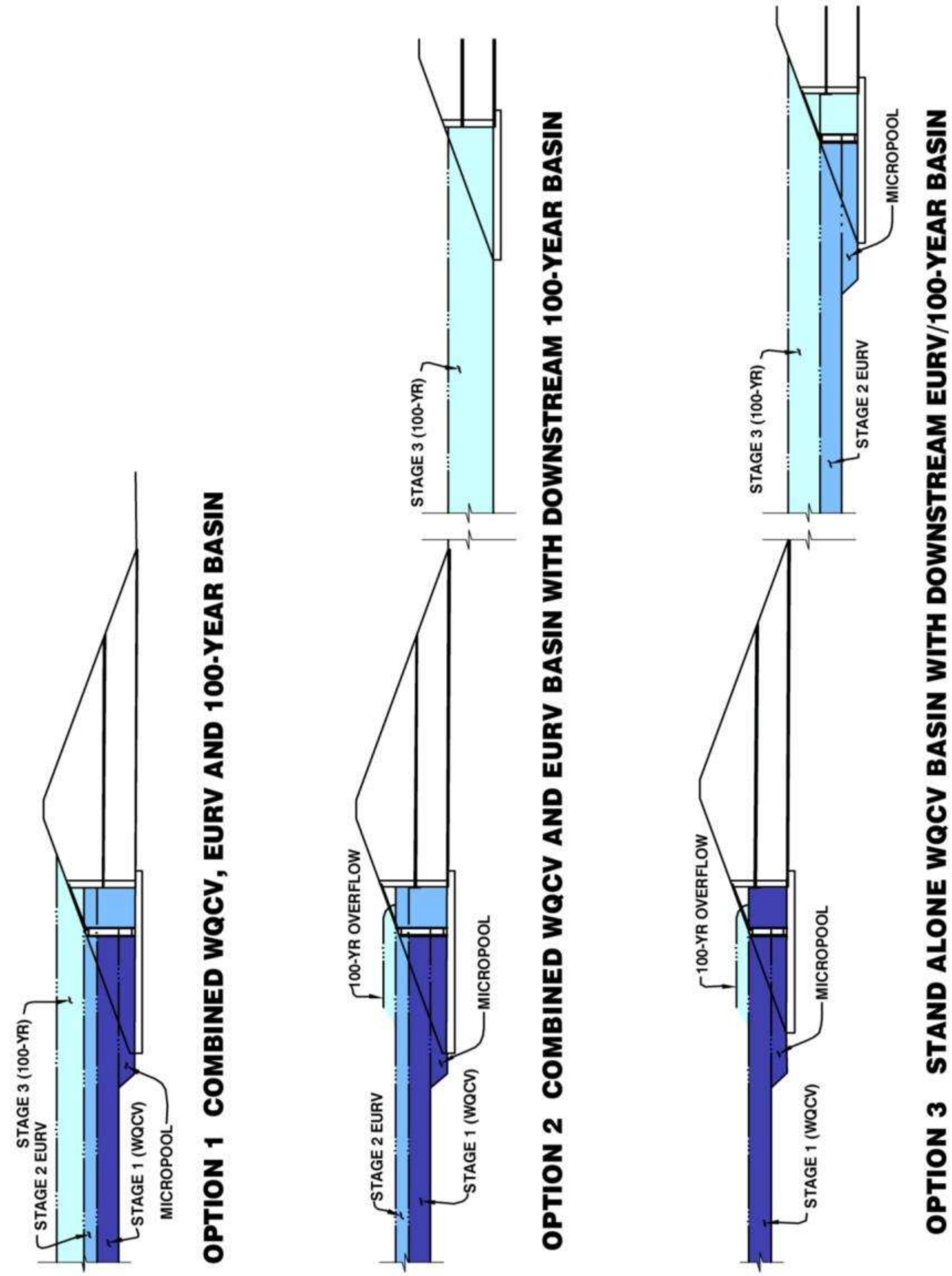


Figure 13-4. Design Options for Detention Basins

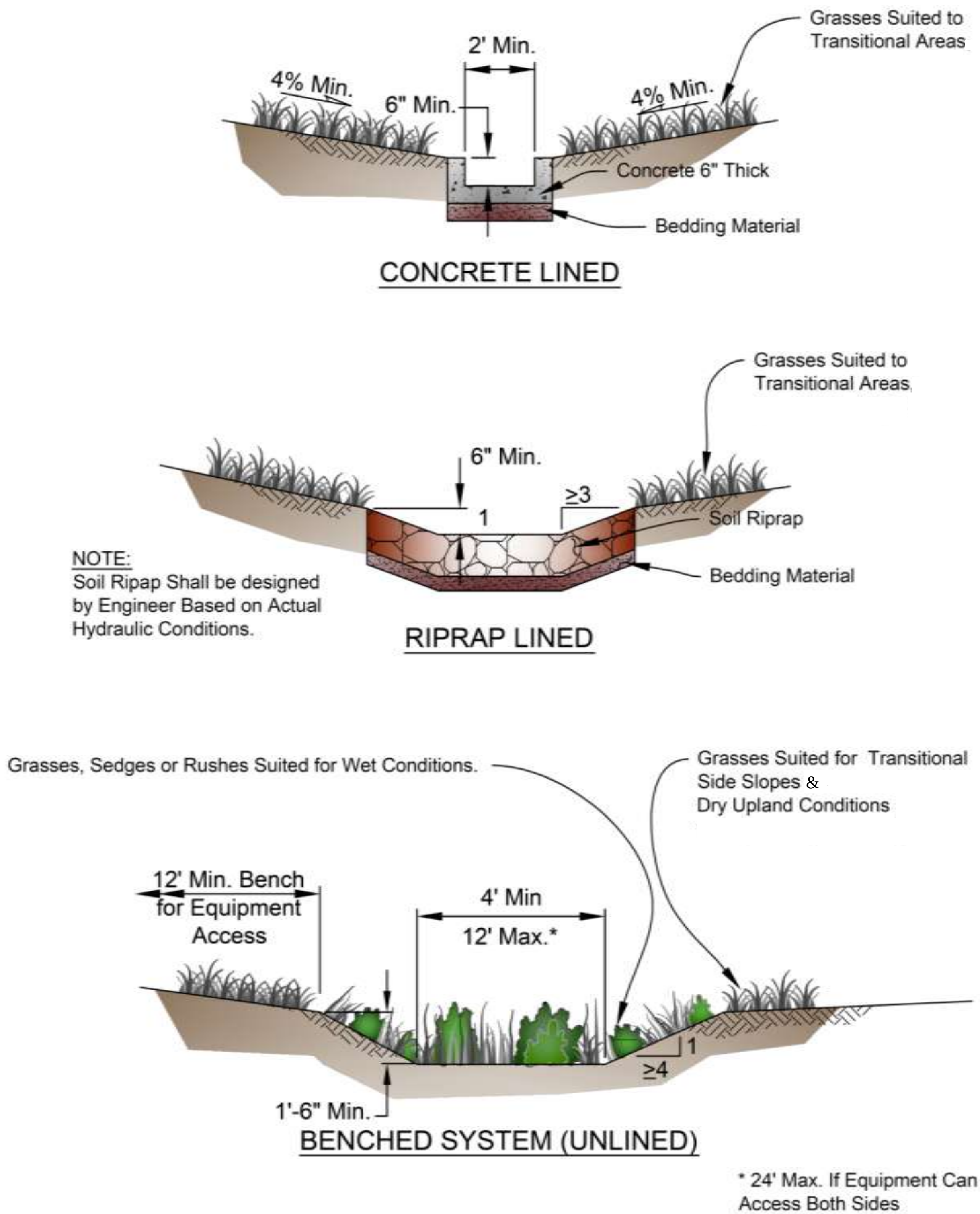


Figure 13-5. Typical Low-flow Channel Details

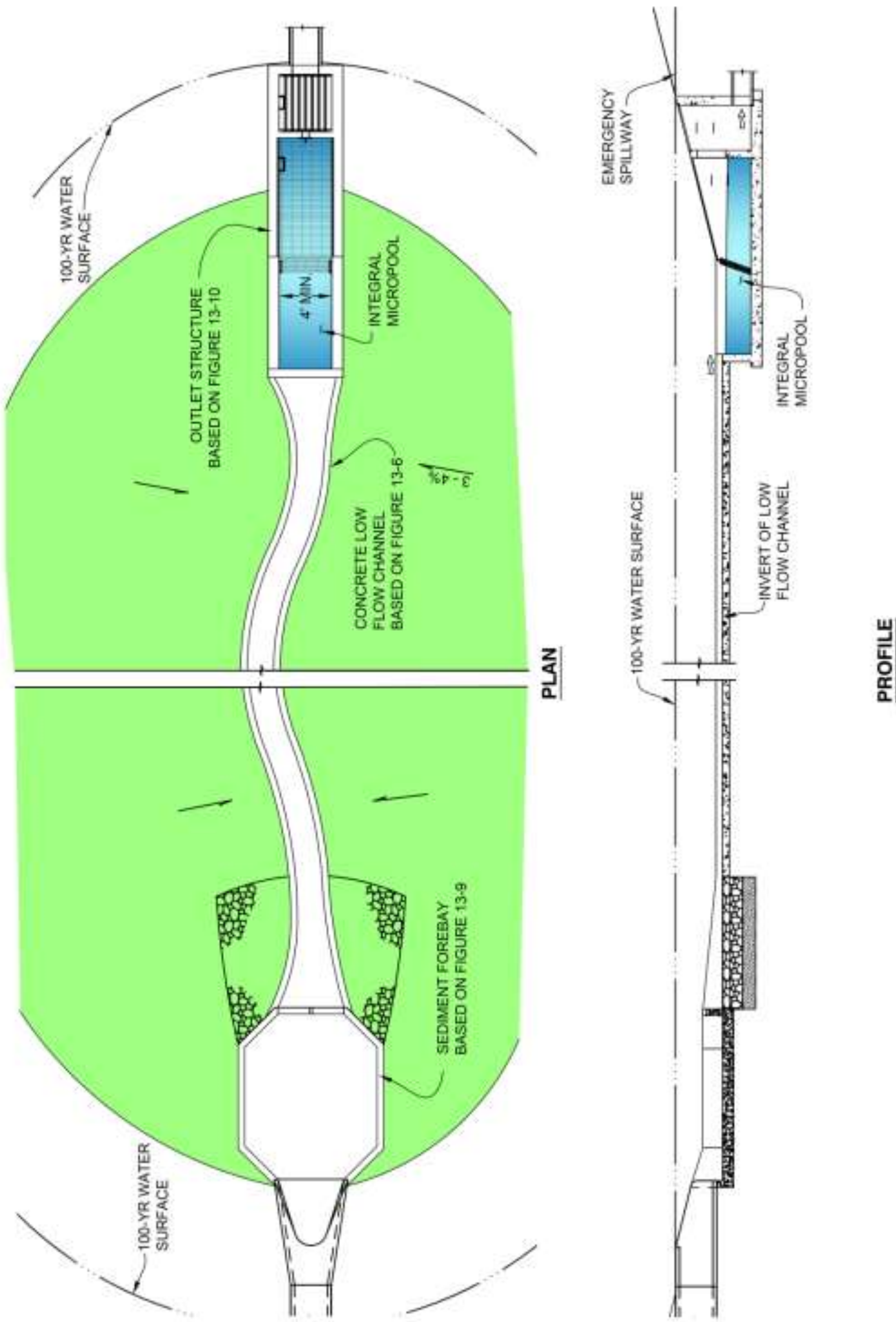


Figure 13-6. Concept for Extended Detention Basin with a Concrete Low-flow Channel

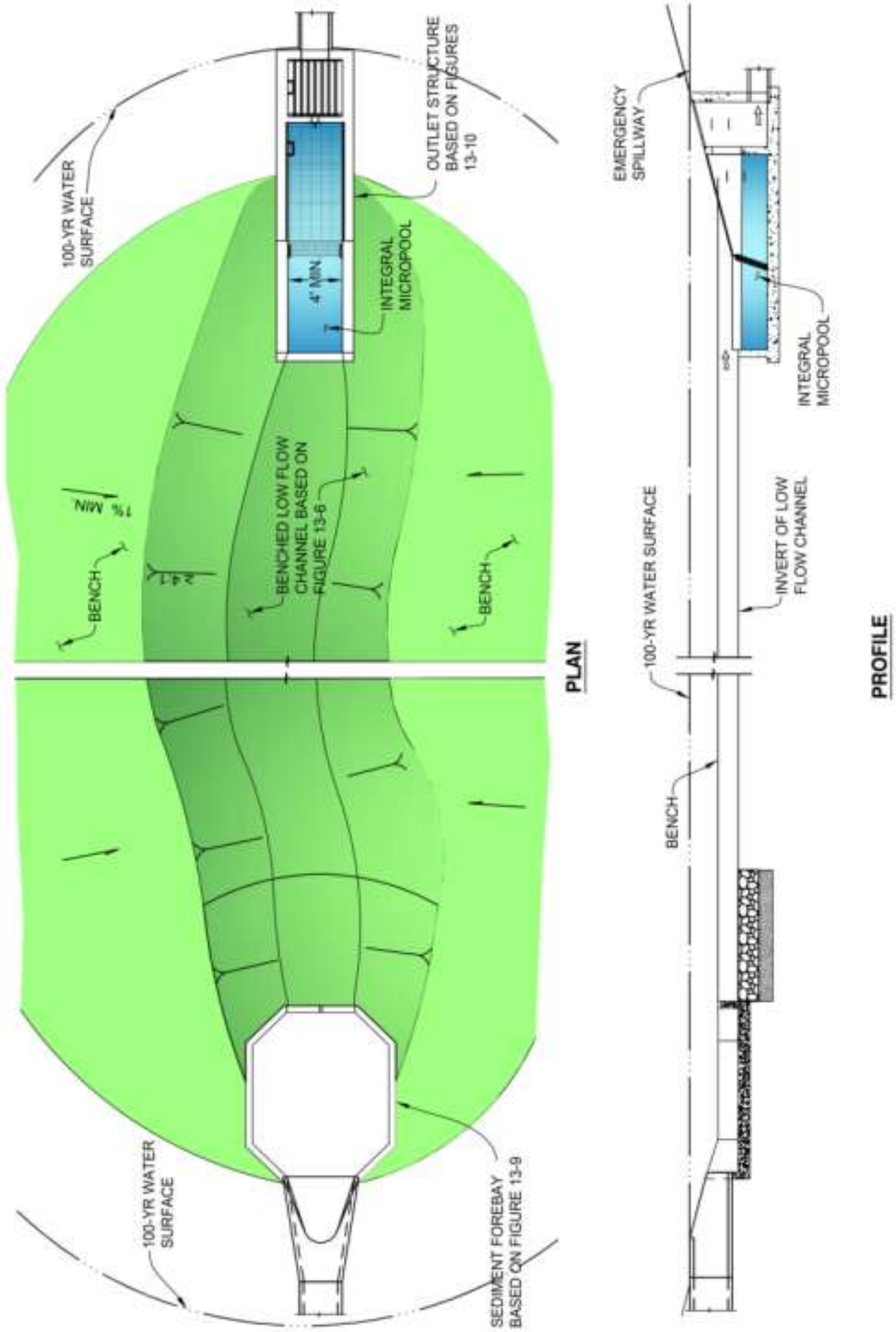

100-YR WATER SURFACE
OUTLET STRUCTURE BASED ON FIGURES 13-10
INTEGRAL MICROPOOL
4' MIN
BENCHED LOW FLOW CHANNEL BASED ON FIGURE 13-6
1% MIN
BENCH
BENCH
100-YR WATER SURFACE
SEDIMENT FOREBAY BASED ON FIGURE 13-9
PLAN
EMERGENCY SPILLWAY
100-YR WATER SURFACE
INTEGRAL MICROPOOL
INVERT OF LOW FLOW CHANNEL
BENCH
PROFILE

Figure 13-7.Concept for Extended Detention Basin with a Benched Low-flow Channel

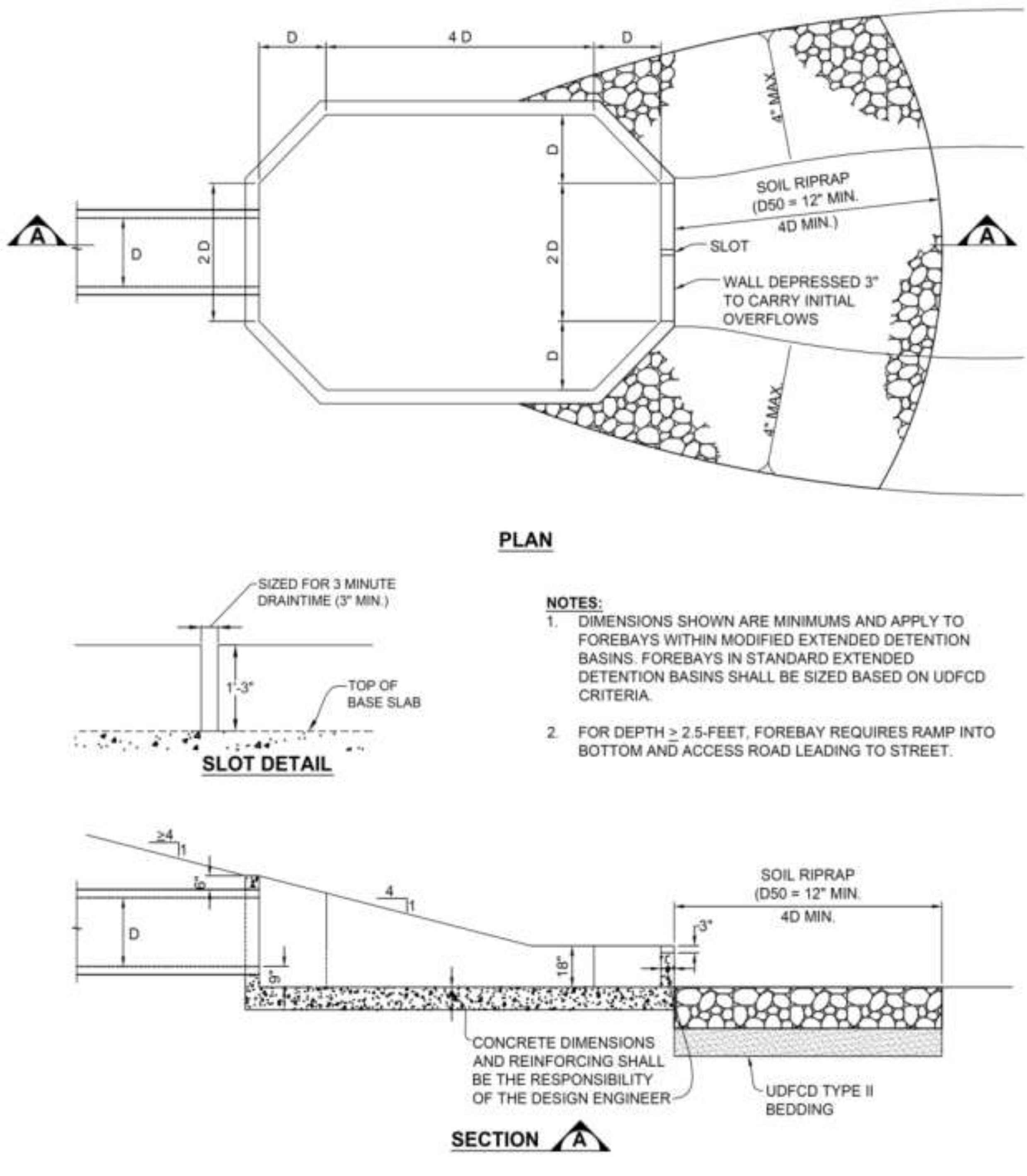
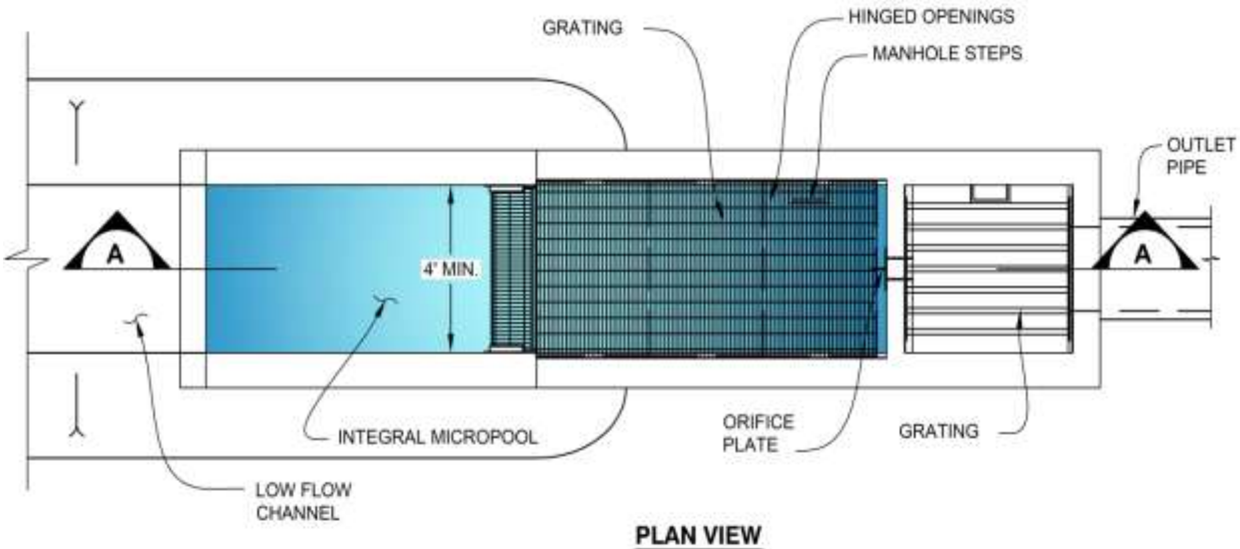


Figure 13-8. Concept for Integral Forebay at Pipe Outfall



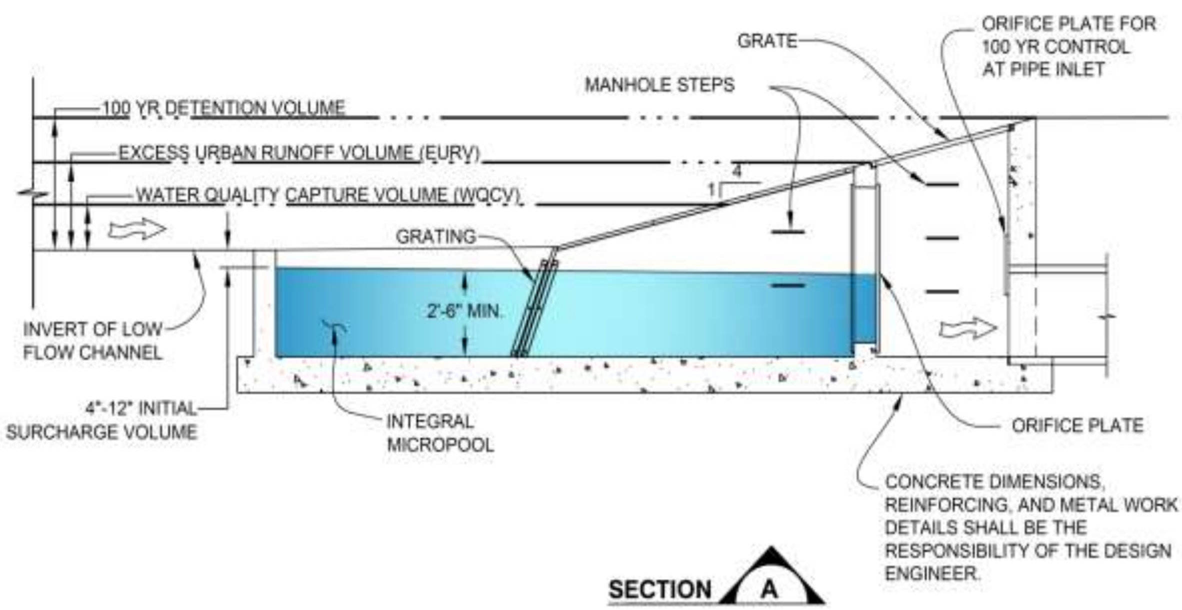


Figure 13-9. Concept for Outlet Structure with Parallel Wingwalls and Flush Bar Grating
(Integral Micropool Shown)

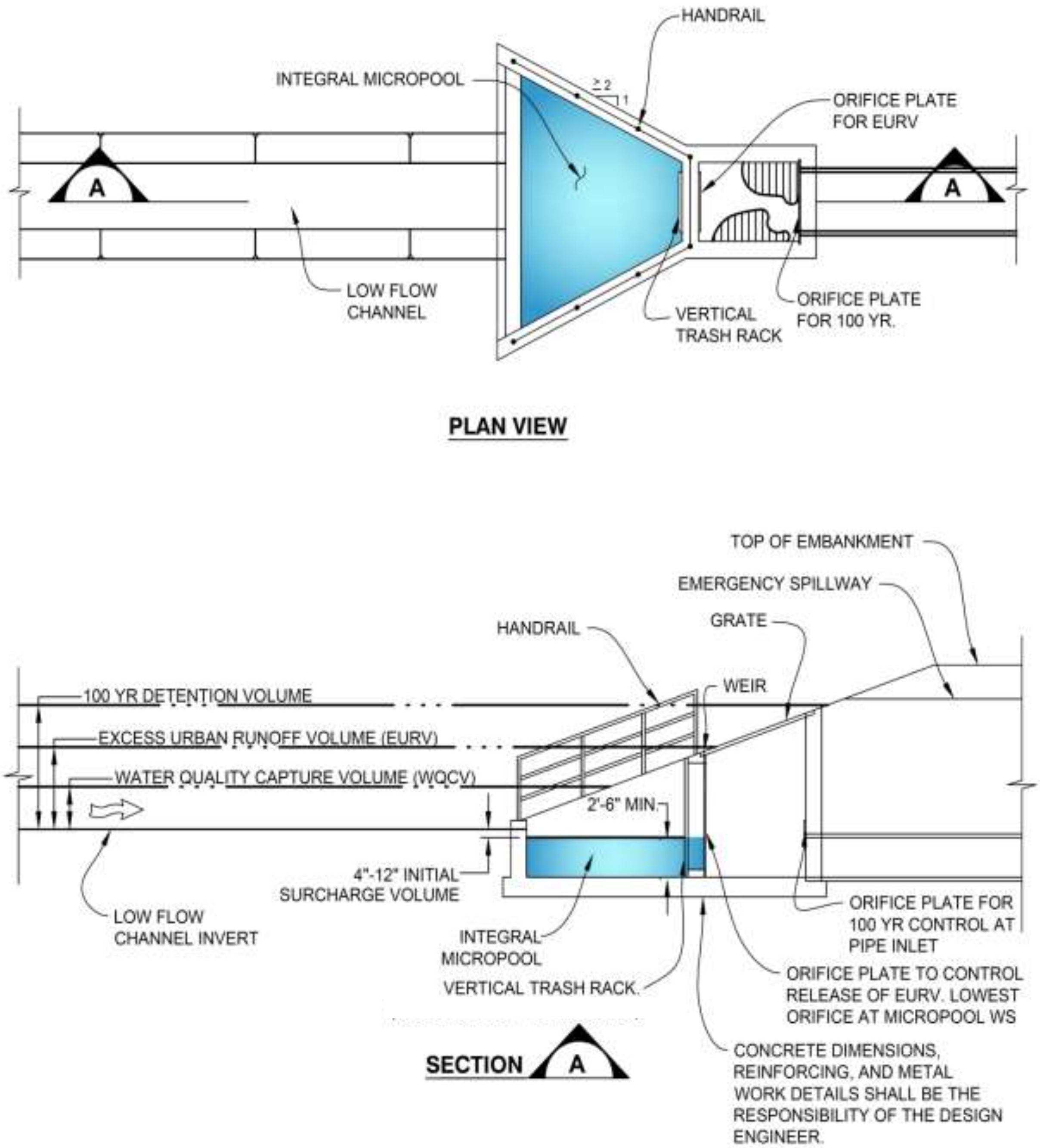


Figure 13-10. Concept for Outlet Structure with Flared Wingwalls and Handrail
(Integral Micropool Shown)

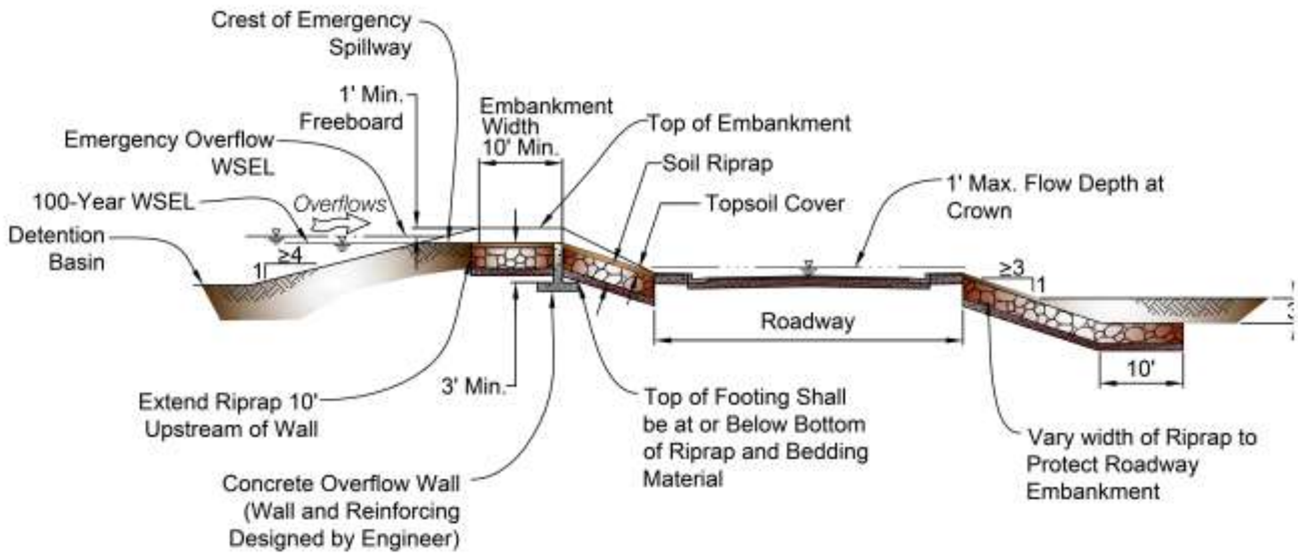


Figure 13-11a. Emergency Spillway Profile at Roadway

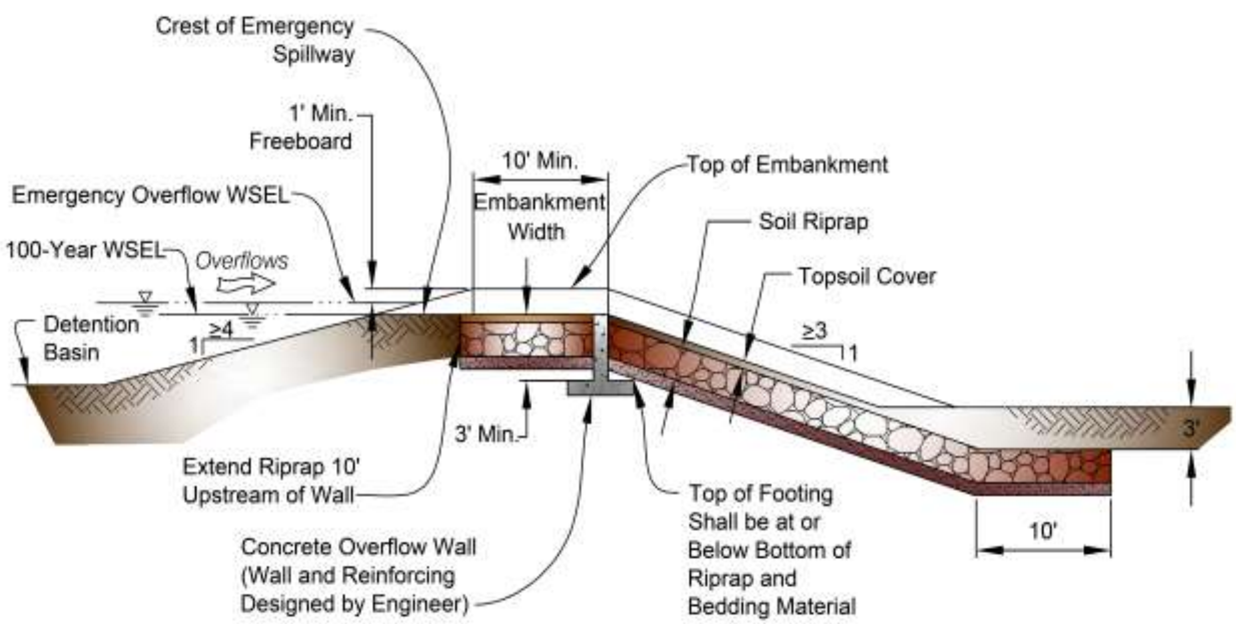


Figure 13-11b. Emergency Spillway Profile at Embankment

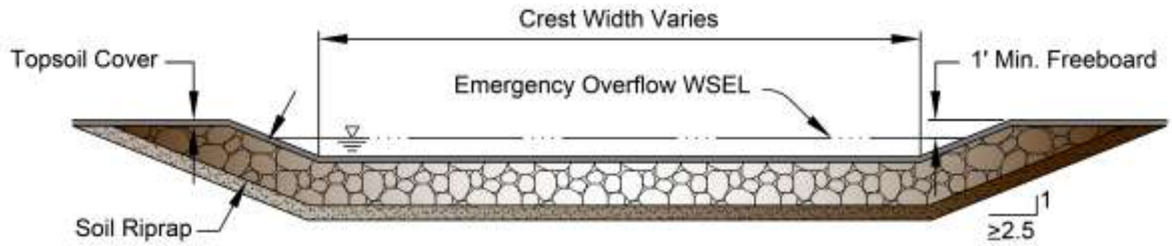


Figure 13-11c. Emergency Spillway Protection

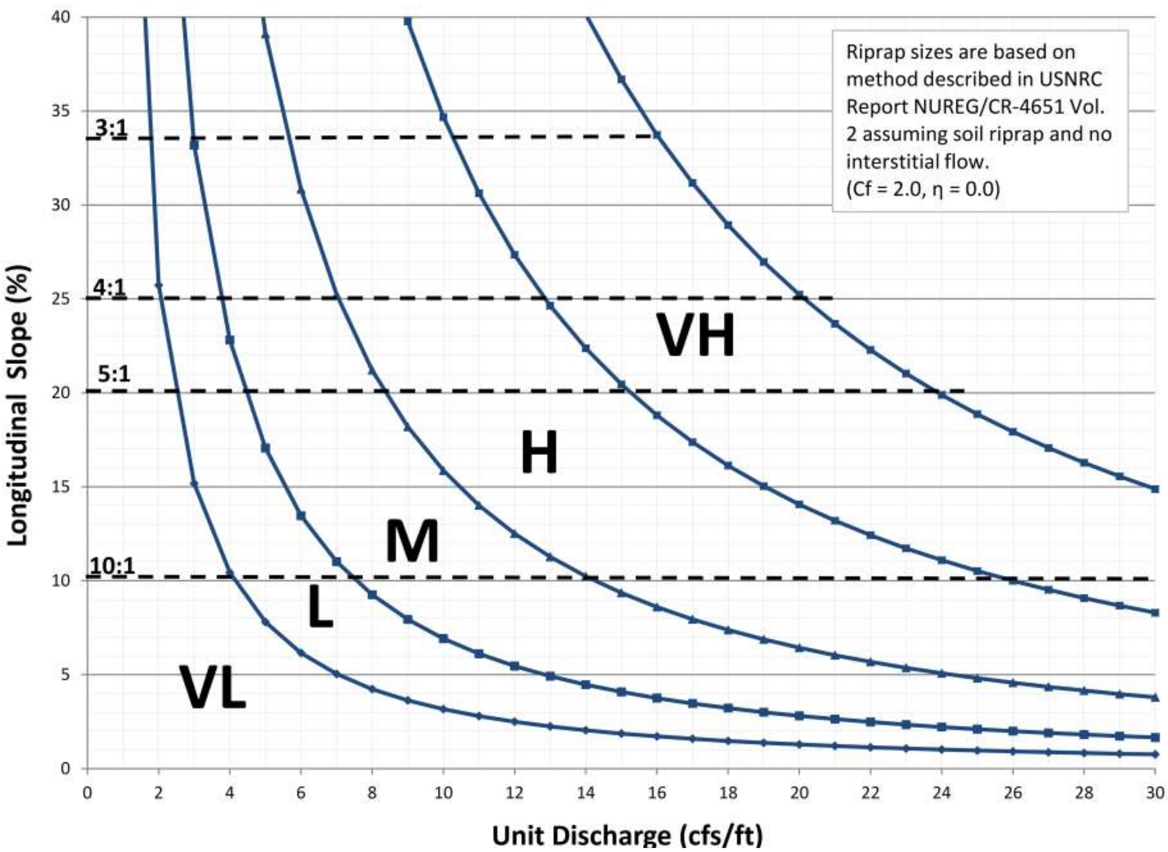


Figure 13-11d. Riprap Types for Emergency Spillway Protection