Chapter 6. BMPs for Stormwater

This chapter provides designers, permitting agencies, and airports operators in the state of Washington with guidance on design and operations & maintenance of stormwater management techniques to comply with federal, state, and local stormwater management regulations while meeting airport safety requirements. Chapter 4 presents guidelines for BMP selection, depending on treatment goals, flow control requirements, and wildlife of concern.

6-1. BMPs for Stormwater Source Control

Source controls are methods to decrease the amount of pollutants entering stormwater runoff by preventing the contact of pollutants with rainfall and runoff. It is usually more cost-effective to prevent pollution than to treat it after pollutants enter stormwater. Volume IV of the SMMWW (Ecology 2005) has a detailed description of operational, structural and treatment source control BMPs recommended for a variety of land uses and potential pollutants. Applicable source control measures must be implemented to comply with Ecology's Minimum Requirement 3, "all known, available, and reasonable source control BMPs shall be applied to all projects." Source Control BMPs that are particularly relevant to airport operations include deicing facilities that collect deicer and prevent it from entering the stormwater system, fueling facilities, landscaping/vegetation management and parking areas, all of which are described in the Ecology manual.

6-2. BMP Design Criteria

This chapter provides design criteria for flow control and runoff treatment BMPs. Design criteria for some of the BMPs, such as the underground facilities, have not been modified from the criteria presented in the original Ecology or HRM sources as they are not likely to attract hazardous wildlife or pose safety concerns to aircraft. However, they are included in this manual to show the full range of BMPs available. For many of the BMPs, their configurations were modified for this manual, such as detention-type BMPs. In this case, the revised design maintains the characteristics influencing the BMP's effectiveness, such as the same volume requirements and locating the inlet(s) and outlet at opposite ends of the facility. The modifications were made using published information on wildlife attractants and deterrents as listed in the technical memorandum published as a precursor to this manual (Herrera 2007b).

6-2.1. AR.01 – Natural Dispersion

N*atural dispersion along highway.*

Eastern Washington	Yes
Western Washington	Yes
Landside Areas	Yes

Object Free Area (OFA)	Yes
Runway Safety Area (RSA)	No
Taxiway Safety Area (TSA)	No
Clearway (CWY)	Yes

Introduction

General Description

Natural dispersion is the simplest method of flow control and runoff treatment. This BMP can be used for impervious or pervious surfaces that are graded to avoid concentrating flows. Natural dispersion uses the existing vegetation, soils, and topography to effectively provide flow control and runoff treatment. It requires little or no construction activity. Site selection is very important to the success of this BMP. The pollutant-removal processes include infiltration into the existing soils and through vegetation root zones; evaporation; and uptake and transpiration by the vegetation.

The key to natural dispersion is that flows from the impervious area enter the natural dispersion area as sheet flow. Because stormwater enters the dispersion area as sheet flow, it only needs to traverse a narrow band of contiguous vegetation for effective attenuation and treatment. The goal is to have the flows dispersed into the surrounding landscape, such that there is a low probability that any surface runoff will reach a flowing body of water.

Using natural dispersion on projects will result in benefits when determining applicable minimum requirements and thresholds. New impervious surfaces that drain to dispersion areas should be accounted for when determining the project's total new impervious surface area, but the area should be counted as a noneffective impervious surface. When modeling the hydrology of the project site and threshold discharge area, the designer should treat natural dispersion areas and their tributary drainage areas as disconnected from the project site because they do not contribute flow to other flow control or runoff treatment BMPs.

Applications and Limitations

Applications

- Natural dispersion is ideal for roadways, runways, and other linear projects.
- There are two types of natural dispersion: sheet flow dispersion and channelized dispersion.
- Natural dispersion helps maintain the temperature norms of stormwater because it promotes infiltration, evaporation, and transpiration and should not have a surface discharge to a lake or stream.
- Natural dispersion areas meet basic and enhanced runoff treatment criteria as required by Ecology.
- Natural dispersion areas meet flow control criteria.
- Natural dispersion designed in accordance with these guidelines will not have standing ponded water.

Limitations

- The effectiveness of natural dispersion relies on maintaining sheet flow to the dispersion area, which maximizes soil and vegetation contact and prevents short-circuiting due to channelized flow. If sheet flow cannot be maintained, natural dispersion will not be effective.
- Natural dispersion areas must be protected from future development. (See the *Site Design Elements* section of this BMP.)

- Refer to the Glossary for "noneffective impervious surfaces" to see how dispersion meets thresholds for existing impervious surfaces and thresholds.

The following are additional limitations for sites where runoff is channelized upstream of the dispersion area:

- The channelized flow must be redispersed before entering the natural dispersion area. Dispersal BMPs create sheet flow conditions.
- Energy dissipaters in conjunction with dispersal BMPs may be needed to prevent high velocities through the natural dispersion areas. The HRM has design guidance for dispersal BMPs and energy dissipaters.
- Channelized flows are limited to on-site flows. Parallel conveyance systems may be needed to separate off-site flows. There may be situations where it might be more beneficial to disperse off-site flows.

Site Design Elements

Siting Criteria

The key to natural dispersions is having vegetative land cover with a good established root zone where the roots, organic matter, and soil macroorganisms provide macropores to reduce surface compaction and prevent soil pore sealing. The vegetative cover also provides filtration and maintains sheet flow, reducing the chance for erosion. The following areas are considered appropriate candidates for natural dispersion because they are likely to retain these vegetative conditions over the long term:

- WSDOT rights-of-way
- Protected beautification areas
- Agricultural areas
- State parks
- Commercial or government-owned forest lands
- Rural areas with zoned densities of less than one dwelling unit per 5 acres
- Vegetated areas adjacent to runways and taxiways but outside of the RSA and TSA, as long as there are no future plans to pave or otherwise change these areas.

Note: Though natural dispersion areas should be adjacent to the project area, they do not have to be immediately adjacent to the paved area.

Natural dispersion areas should have the following attributes:

- Be well vegetated with grass or other vegetation meeting height requirements of AOA
- Have an average longitudinal slope of 15 percent or flatter
- Have an average lateral slope of 15 percent or flatter
- Have infiltrative soil properties that are verified by a geotechnical engineer using the testing methods in Section 5-4.

Natural dispersion areas that have impervious areas (e.g., abandoned roads with compacted subgrades) within them should have those areas tilled and restored using the soil amendments described in Section 5-4.2.

Natural dispersion areas that are within a landslide hazard area must be evaluated by a geotechnical engineer or qualified geologist.

Natural dispersion areas should have a separation of at least 3 feet between the existing ground elevation and the average annual maximum groundwater elevation. There should be no discernible continuous flow paths through the dispersion area.

When selecting natural dispersion areas, the designer should determine if there are groundwater management plans for the area and contact the local water purveyors to determine if the project lies within a wellhead or groundwater protection zone, septic drain fields, or aquifer recharge area. These areas typically restrict stormwater infiltration; however, the local jurisdiction may waive this requirement.

Intent: Natural dispersion areas are not likely to have a uniform slope across their entire area. As a result, there are ponding areas and uneven terrain. Minor channelization of flow within the dispersion area is expected. However, a continuous flow path through the entire dispersion area disqualifies its use as a BMP because channelized flow promotes erosion of the channel that carries the flow and greatly reduces the potential for effective pollutant removal and peak flow attenuation.

Sizing Criteria

Figure AR.01.1 illustrates the configuration of a typical natural dispersion area relative to the roadway.

Sheet Flow

Sheet flow dispersion criteria for Type A, B, C, and D soils are as follows:

- The sheet flow path leading to the natural dispersion area should not be longer than 75 feet for impervious surfaces and 150 feet for pervious surfaces. The sheet flow path is measured in the direction of flow and generally represents the width of the pavement area.

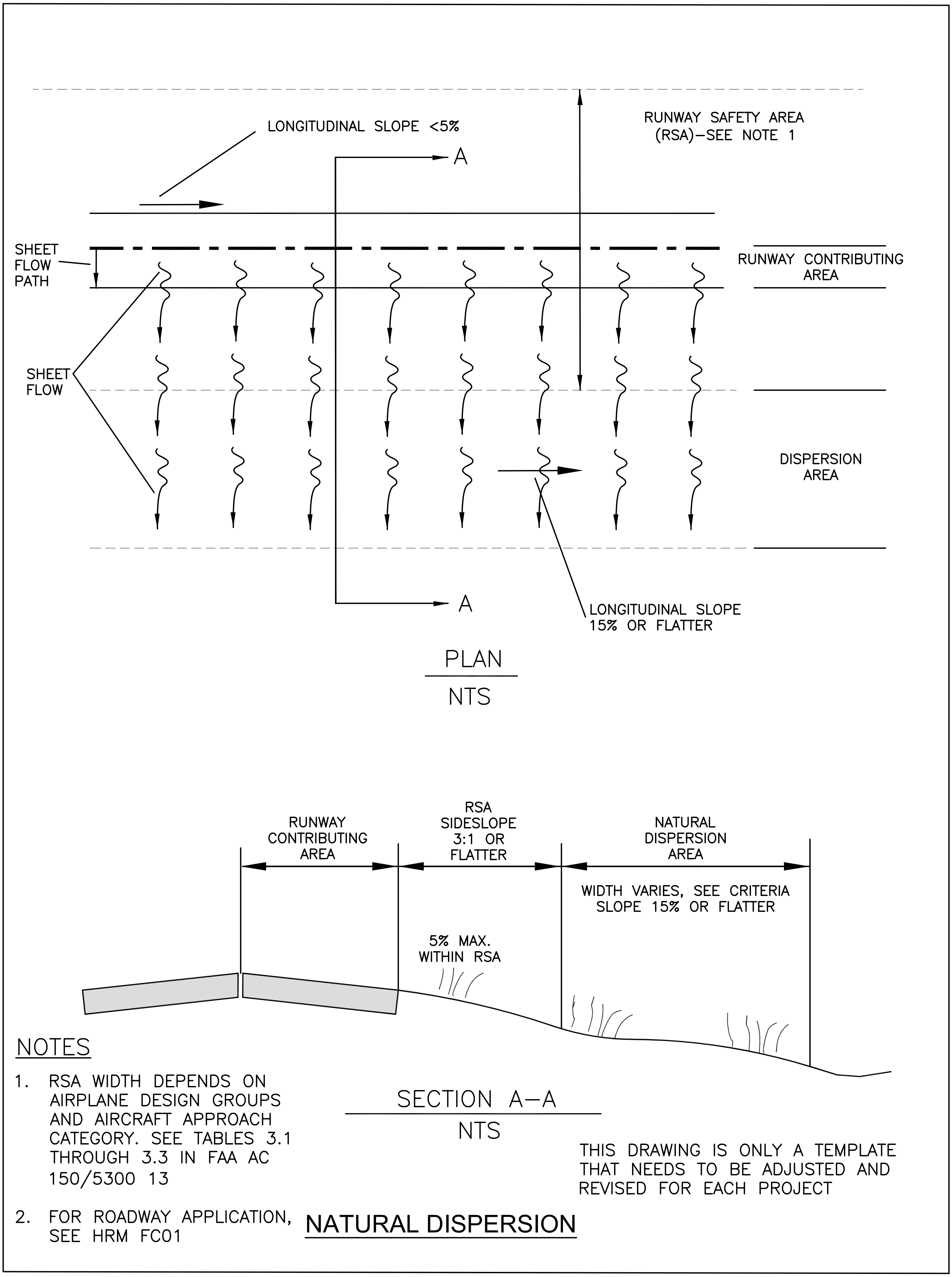

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Figure AR.01.1 Natural Dispersion Area

- The longitudinal length of the dispersion area should be equivalent to the longitudinal length of the roadway that is contributing sheet flow.
- Roadway or runway side slopes leading to natural dispersion areas should be 25 percent (4H:1V) or flatter. Side slopes that are 25 to 15 percent (7H:1V) should not be considered part of the dispersion area. Slopes steeper than 25 percent are allowed if the existing side slopes are well vegetated and show no signs of erosion problems.
- For any existing slope that will lead to a natural dispersion area, if evidence of channelized flow (rills or gullies) is present, a flow-spreading device should be used before those flows are allowed to enter the dispersion area.
- Side slopes adjacent to paved areas that are 15 percent or flatter are considered part of the dispersion area if engineered dispersion practices are applied to the slope (6.5 feet of compost-amended side slope width mitigates for 1 foot of impervious surface width).
- The longitudinal slope of the contributing area (perpendicular to the direction of sheet flow) should be less than 5 percent. Contributing drainage areas with slopes steeper than 5 percent should follow the guidance below under *Channelized Flow*, or engineered dispersion should be used.
- Pervious shoulders and side slopes are not counted in determining the sheet flow path.

The following criteria are specific to sheet flow dispersion on all Type A and some Type B soils (depending on saturated hydraulic conductivity rates):

- For saturated hydraulic conductivity rates of 4 inches per hour or greater and for the first 20 feet (along the sheet flow path) of impervious surface that drains to the dispersion area, there must be 10 lateral feet of dispersion area width. For each additional foot of impervious surface (along the sheet flow path) that drains to the dispersion area, 0.25 lateral feet of dispersion area should be provided.
- For dispersion areas that receive sheet flow from only disturbed pervious areas (i.e., bare soil and non-native landscaping), for every 6 feet (along the sheet flow path) of disturbed pervious area, 1 lateral foot of dispersion area width is required.

The following criteria are specific to sheet flow dispersion on all Type C and D soils and some Type B soils (depending on saturated hydraulic conductivity rates):

- For every 1 foot of contributing pavement width, 6.5 feet of dispersion area width is needed.

- The dispersion area should have a minimum width of native vegetation of 100 feet (measured in the direction of the flow path).

Channelized Flow

Channelized flow dispersion criteria for Type A, B, C, and D soils are as follows:

- Concentrated runoff from the roadway and adjacent upstream areas (e.g., in a ditch or cut slope) must be incrementally discharged from the conveyance system (ditch, gutter, or storm sewer) via cross culverts or at the ends of cut sections. These incremental discharges of newly concentrated flows must not exceed 0.5 cubic feet per second (cfs) at any single discharge point from the conveyance system for the 100-year runoff event (determined by an approved continuous flow model as described in Chapter 5). Where flows at a particular discharge point are already concentrated under existing site conditions (e.g., in a natural channel that crosses the roadway alignment), the 0.5-cfs limit would be in addition to the existing concentrated peak flows.
- Discharge points with up to 0.2 cfs discharge for the peak 100-year flow may use rock pads or dispersion trenches to disperse flows. Discharge points with between 0.2 and 0.5 cfs discharge for the 100-year peak flow must use only dispersion trenches to disperse flows.
- Dispersion trenches must be designed to accept surface flows (free discharge) from a pipe, culvert, or ditch end; aligned perpendicular to the flow path; a minimum of 2 feet by 2 feet in section, 50 feet in length; filled with ¾- to 1½-inch washed rock; and provided with a level notched grade board. Manifolds may be used to split flows up to 2 cfs discharge for the 100-year peak flow between four trenches (maximum). Dispersion trenches must have a minimum spacing of 50 feet.
- After being dispersed with rock pads or trenches, flows from discharge points must traverse the required flow path length of the dispersion area before entering an existing on-site channel carrying existing concentrated flows away from the roadway alignment.

Note: To provide the required flow path length to an existing channel, some roadway runoff may unavoidably enter the channel undispersed.

- Flow paths from adjacent discharge points must not intersect within the required flow path lengths, and dispersed flow from a discharge point must not be intercepted by another discharge point.
- Ditch discharge points must be located a minimum of 100 feet upgradient of steep slopes (i.e., slopes steeper than 40 percent within a vertical elevation change of at least 10 feet), wetlands, and streams.

- Where the local jurisdiction determines that there is a potential for significant adverse impacts downstream (e.g., erosive steep slopes, existing downstream drainage problems), dispersion of roadway runoff may not be allowed, or other measures may be required.

The following criterion is specific to channelized flow dispersion on all Type A and some Type B soils (depending on saturated hydraulic conductivity rates):

- For saturated hydraulic conductivity rates of 4 inches per hour or greater, the dispersion area should be at least 50 percent of the tributary drainage area.

The following criteria are specific to channelized flow dispersion on all Type C and D soils and some Type B soils (depending on saturated hydraulic conductivity rates):

- For every 1 foot of contributing pavement width, 6.5 feet of dispersion area width is needed.
- The dispersion area should have a minimum width of native vegetation of 100 feet (measured in the direction of the flow path).

Pipe or Ditch Conveyance System

Flows collected in a pipe or ditch conveyance system require energy dissipation and dispersal at the end of the conveyance system before entering the dispersion area.

Setback Requirements

- Natural dispersion areas should be set back at least 100 feet from drinking water wells; septic tanks or drain fields; and springs used for public drinking water supplies. Natural dispersion areas upgradient of drinking water supplies and within the 1-, 5-, and 10-year time of travel zones must comply with health department requirements (Washington Wellhead Protection Program, DOH, 12/93).
- The designer should check with the local jurisdiction for additional setback requirements.
- If the project significantly increases flows to off-site properties, a drainage easement may be required or additional right-of-way may be purchased.

Signage

- The limits of the natural dispersion area should be marked as a stormwater management facility and also should be physically marked in the field (during and after construction). Signage ensures that the natural dispersion area is protected from construction activity disturbance and is adequately protected by measures shown in the temporary erosion and sedimentation control (TESC) plan.

- Signage helps ensure that the natural dispersion area is not cleared or disturbed after the construction project.

Construction Considerations

- For installation of dispersal BMPs and conveyance systems near dispersion areas, the area that needs to be cleared or grubbed should be minimized. Maintaining plant root systems is important for dispersion areas.
- The area around dispersion areas should not be compacted.
- To the maximum extent practicable, low-ground-pressure vehicles and equipment should be used during construction.

Maintenance Considerations

- Maintenance pullout areas should be considered to promote successful maintenance practices at dispersion areas. Pullout areas should be large enough to accommodate a typical maintenance vehicle. Please contact the local maintenance office to determine the typical size of maintenance vehicle used in the project area.

6-2.2. AR.02 – Engineered Dispersion

Engineered Dispersion Area Along I-5.

Eastern Washington	Yes
Western Washington	Yes
Landside Areas	Yes

Object Free Area (OFA)	Yes
Runway Safety Area (RSA)	No
Taxiway Safety Area (TSA)	No
Clearway (CWY)	Yes

Introduction

General Description

Engineered dispersion is similar to natural dispersion. This BMP can be used for impervious or pervious surfaces that are graded to drain via sheet flow or are graded to collect and convey stormwater to engineered dispersion areas after going through a flow spreading or energy dissipater device. Engineered dispersion uses the existing vegetation or landscaped areas, existing soils or engineered compost-amended soils, and topography to effectively provide flow control and runoff treatment. This type of dispersion may require major or minor construction activity depending on the existing site conditions. Site selection is very important to the success of this BMP. The pollutant-removal processes include infiltration to the existing or engineered soils and through vegetation root zones; evaporation; and uptake and transpiration by the existing vegetation or landscaped areas.

The key to effective engineered dispersion is that flows from the impervious area enter the dispersion area as sheet flow. Because stormwater enters as sheet flows to the dispersion area, it need only traverse a band of contiguous vegetation and compost-amended soils for effective attenuation and treatment. This differs from natural dispersion in that flows may not have previously (preproject) been directed to the selected engineered dispersion area. Absorption capacity can be gained by using compost-amended soils to disperse and absorb contributing flows to the dispersion area. The goal is to have the flows dispersed into the surrounding landscape such that there is a low probability that any surface runoff will reach a flowing body of water.

Applications and Limitations

Applications

- Engineered dispersion is ideal for runways, taxiways, highways and linear projects of paved surfaces that collect and convey stormwater to discrete discharge points along the project.
- Engineered dispersion maintains temperature norms of stormwater because it promotes infiltration, evaporation, and transpiration and should not have a surface discharge to a lake or stream.
- Engineered dispersion areas meet basic and enhanced runoff treatment criteria set forth in the Ecology manuals.
- Engineered dispersion areas meet flow control criteria set forth in Minimum Requirement 7 (Flow Control) in the Ecology manuals.

Limitations

- The effectiveness of engineered dispersion relies on maintaining sheet flow to the dispersion area, which maximizes soil and vegetated contact and prevents short-circuiting due to channelized flow. If sheet flow cannot be maintained, engineered dispersion will not be effective.
- The airport operator must ensure that the engineered dispersion area is not developed with future airport projects.

Design Flow Elements

Flows to Be Dispersed

The required size of the engineered dispersion area depends on the area contributing flow and the predicted rates of water loss through the dispersion system. The designer should ensure that the dispersion area is able to dispose of (through infiltration, evaporation, transpiration, and soil absorption) stormwater flows predicted by an approved continuous runoff model.

Because a water balance model has not yet been developed for designing engineered dispersion areas, a set of conservative guidelines similar to those given for natural dispersion have been agreed upon by WSDOT and Ecology. Designers should check with WSDOT region or HQ Hydraulics Office staff for updates to the engineered dispersion criteria.

Structural Design Considerations

Geometry

- The average longitudinal slope of the dispersion area should not exceed 15 percent.
- The average lateral slope of the dispersion area should not exceed 15 percent.
- There should be no discernible flow paths through the dispersion area.
- There should be no surface water discharge from the dispersion area to a conveyance system or Category I and II wetlands (as defined by Ecology's Wetland Rating Systems for western and eastern Washington).

Materials

- Compost-amended soils should be generously applied to the dispersion areas. The final organic content of the soil in the dispersion areas should be 10 percent. Design information for determining the amount and type of compost needed and the necessary planted vegetation to meet those requirements is given in Section 5-4.

Site Design Elements

Siting Criteria

The following areas are appropriate engineered dispersion areas because they are likely to remain in their existing condition over the long term:

- WSDOT rights-of-way
- Protected beautification areas
- Agricultural areas
- State parks
- Commercial or government-owned forestlands
- Rural areas with zoned densities of less than one dwelling unit per 5 acres
- Vegetated areas adjacent to runways and taxiways but outside of the RSA and TSA, as long as there are no future plans to pave or otherwise change these areas.

Engineered dispersion areas should have infiltrative soil properties that are verified by a geotechnical engineer using the testing methods in Chapter 5.

Engineered dispersion areas that have impervious areas (e.g., former roads with compacted subgrades) within them should have those areas tilled and reverted using the soil amendments described in the *Soil Amendments BMP* section in the HRM.

Engineered dispersion areas that are within a landslide hazard area must be evaluated by a geotechnical engineer or qualified geologist. Engineered dispersion areas should not be sited above slopes greater than 20 percent or above erosion hazard areas without evaluation by a geotechnical engineer or qualified geologist and approval by the local jurisdiction.

Engineered dispersion areas should have a separation of at least 3 feet between the existing ground elevation and the average annual maximum groundwater elevation.

When selecting engineered dispersion areas, the designer should determine if there are groundwater management plans for the area, and contact the local water purveyors to determine if the project lies within a wellhead or groundwater protection zone, septic drain fields, or aquifer recharge area. These areas typically restrict stormwater infiltration; however, the local jurisdiction may waive this requirement. The WSDOT GIS Workbench (WSDOT 2008b) may be a source of initial information about wells within the project limits.

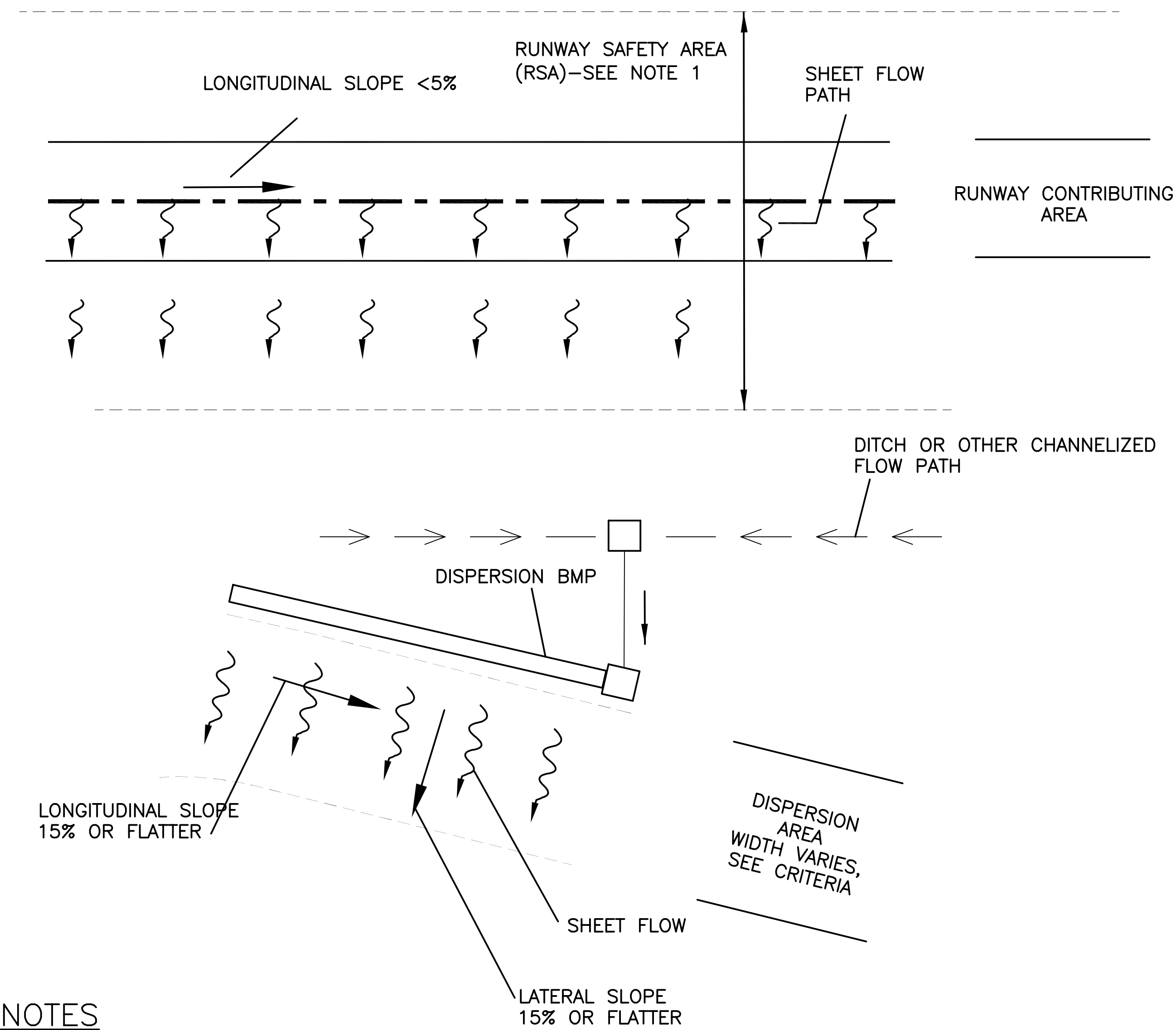
Sizing Criteria

Figure AR.02.1 illustrates a typical engineered dispersion area relative to the adjacent roadway.

Sheet Flow

Sheet flow dispersion criteria for Type A, B, C, and D soils are as follows:

- The sheet flow path leading to the engineered dispersion area should not be longer than 75 feet for impervious surfaces and 150 feet for pervious surfaces. The sheet flow path is measured in the direction of flow and generally represents the width of the pavement area.
- The longitudinal length of the dispersion area should be equivalent to the longitudinal length of the roadway that is contributing sheet flow.
- The side slopes leading to engineered dispersion areas should be 25 percent (4H:1V) or flatter. Side slopes that are 25 to 15 percent (7H:1V) should not be considered part of the dispersion area. Slopes steeper than 25 percent are allowed if the existing side slopes are well vegetated and show no signs of erosion problems. For any existing slope that will lead to an engineered dispersion area, if evidence of channelized flow (rills or gullies) is present, a flow-spreading device should be used before those flows are allowed to enter the dispersion area.



NOTES

1. RSA WIDTH DEPENDS ON AIRPLANE DESIGN GROUPS AND AIRCRAFT APPROACH CATEGORY. SEE TABLES 3.1 THROUGH 3.3 IN FAA AC 150/5300 13

2. FOR ROADWAY APPLICATION, SEE HRM FC01

PLAN

NTS

THIS DRAWING IS ONLY A TEMPLATE THAT NEEDS TO BE ADJUSTED AND REVISED FOR EACH PROJECT

ENGINEERED DISPERSION

Figure AR.02.1 Engineered Dispersion Area

- Side slopes that are 15 percent or flatter are considered part of the dispersion area if engineered dispersion practices are applied to the slope (6.5 feet of compost-amended side slope width mitigates for 1 foot of impervious surface). The use of natural and engineered dispersion concepts within one threshold discharge area is acceptable.
- The longitudinal slope of the contributing area (perpendicular to the direction of sheet flow) should be less than 5 percent. Contributing drainage areas with slopes steeper than 5 percent should follow the guidance below under *Channelized Flow*.
- Pervious shoulders and side slopes are not counted in determining the sheet flow path.

The following criteria are specific to sheet flow dispersion on all Type A and some Type B soils (depending on saturated hydraulic conductivity rates):

- For saturated hydraulic conductivity rates of 4 inches per hour or greater, and for the first 20 feet (along the sheet flow path) of impervious surface that drains to the dispersion area, there must be 10 lateral feet of dispersion area width. For each additional foot of impervious surface (along the sheet flow path) that drains to the dispersion area, 0.25 lateral feet of dispersion area should be provided.
- For dispersion areas that receive sheet flow only from disturbed pervious areas (i.e., bare soil and non-native landscaping), for every 6 feet (along the sheet flow path) of disturbed pervious area, 1 lateral foot width of dispersion area is required.

The following criteria are specific to sheet flow dispersion on all Type C and D soils and some Type B soils (depending on saturated hydraulic conductivity rates):

- For every 1 foot of contributing pavement width, 6.5 feet of dispersion area width is needed.
- The dispersion area should have a minimum width of 100 feet (measured in the direction of the flow path).

Channelized Flow

Channelized flow dispersion criteria for Type A, B, C, and D soils are as follows:

- Concentrated runoff from the pavement and adjacent upstream areas (e.g., in a ditch or cut slope) must be incrementally discharged from the conveyance system (ditch, gutter, or storm sewer) via cross culverts or at the ends of cut sections. These incremental discharges of newly concentrated flows must not exceed 0.5 cfs at any single discharge point from the conveyance system for the 100-year runoff event (determined by an approved continuous flow model as described in Chapter 4). Where flows at a particular discharge point are already concentrated under existing site conditions (e.g., in a natural channel that crosses the roadway alignment), the 0.5-cfs limit would be in addition to the existing concentrated peak flows.

- Discharge points with up to 0.2 cfs discharge for the peak 100-year flow may use rock pads or dispersion trenches to disperse flows. Discharge points with between 0.2 and 0.5 cfs discharge for the 100-year peak flow must use only dispersion trenches to disperse flows.
- Dispersion trenches must be designed to accept surface flows (free discharge) from a pipe, culvert, or ditch end; aligned perpendicular to the flow path; a minimum of 2 feet by 2 feet in section; 50 feet in length; filled with ¾- to 1½-inch washed rock; and provided with a level notched grade board. Manifolds may be used to split flows up to 2 cfs discharge for the 100-year peak flow between four trenches (maximum). Dispersion trenches must have a minimum spacing of 50 feet.
- After being dispersed with rock pads or trenches, flows from discharge points must traverse the required flow path length of the dispersion area before entering an existing on-site channel carrying existing concentrated flows away from the paved area.

Note: To provide the required flow path length to an existing channel, some runoff may unavoidably enter the channel undispersed.

- Flow paths from adjacent discharge points must not intersect within the required flow path lengths, and dispersed flow from a discharge point must not be intercepted by another discharge point.
- Discharge points must be located a minimum of 100 feet upgradient of steep slopes (i.e., slopes steeper than 40 percent within a vertical elevation change of at least 10 feet), wetlands, and streams.
- Where the local jurisdiction determines that there is a potential for significant adverse impacts downstream (e.g., erosive steep slopes or existing downstream drainage problems), dispersion of roadway runoff may not be allowed, or other measures may be required.

The following criterion is specific to channelized flow dispersion on all Type A and some Type B soils (depending on saturated hydraulic conductivity rates):

- For saturated hydraulic conductivity rates of 4 inches per hour or greater, and for the first 20 feet (along the sheet flow path) of impervious surface that drains to the dispersion area, there must be 10 lateral feet of dispersion area width. For each additional foot of impervious surface (along the sheet flow path) that drains to the dispersion area, 0.25 lateral feet of dispersion area should be provided.

The following criteria are specific to channelized flow dispersion on Type C and D soils and some Type B soils (depending on saturated hydraulic conductivity rates):

- For every 1 foot of contributing pavement width, 6.5 feet of dispersion area width is needed.
- The dispersion area should have a minimum width of 100 feet (measured in the direction of the flow path).

Pipe or Ditch Conveyance System

- Flows collected in a pipe or ditch conveyance system require energy dissipation and dispersal at the end of the conveyance system before entering the dispersion area. For flow dispersal BMPs (e.g., gravel-filled trenches, level spreaders) and techniques and energy dissipater designs and considerations, see the HRM.

Setback Requirements

- Engineered dispersion areas should be set back at least 100 feet from drinking water wells, septic tanks or drain fields, and springs used for public drinking water supplies. Engineered dispersion areas upgradient of drinking water supplies and within the 1-, 5-, and 10-year time of travel zones must comply with health department requirements (Washington Wellhead Protection Program, DOH, 12/93).
- The designer should check with the local jurisdiction for additional setback requirements.
- If the project significantly increases flows to off-site properties, a drainage easement may be required or right-of-way purchased.

Signage

- The limits of the engineered dispersion area should be physically be marked in the field (during and after construction). Signage ensures that the engineered dispersion area is protected from construction activity disturbance and is adequately protected by measures shown in the TESC plan.
- Signage helps ensure that the engineered dispersion area is not cleared or disturbed after the construction project.

Construction Considerations

- For installation of dispersal BMPs and conveyance systems near dispersion areas, the area that needs to be cleared or grubbed should be minimized. Maintaining plant root systems is important for dispersion areas.
- The area around dispersion areas should not be compacted.
- To the maximum extent practicable, low-ground-pressure vehicles and equipment should be used during construction.

Maintenance Considerations

- Maintenance pullout areas should be considered to promote successful maintenance practices of dispersion areas. Pullout areas should be large enough to accommodate a typical maintenance vehicle. Please contact the local maintenance office to determine the typical size of maintenance vehicle used in the project area.
- General maintenance criteria should follow Table 6-1 (presented at the end of this chapter).

6-2.3. AR.03 – Bioinfiltration Pond (Eastern Washington Only)

Bioinfiltration pond with Bioswale.

Eastern Washington	Yes
Western Washington	No
Landside Areas	Yes

Object Free Area (OFA)	No
Runway Safety Area (RSA)	No
Taxiway Safety Area (TSA)	No
Clearway (CWY)	No

Introduction

General Description

Bioinfiltration ponds, also known as bioinfiltration swales or grass percolation areas, combine grassy vegetation and soils to remove stormwater pollutants as the water percolates into the ground. Their pollutant-removal mechanisms include infiltration, soil sorption, and uptake by vegetative root zones. Bioinfiltration ponds have been used in Spokane County for many years to treat urban stormwater and recharge the groundwater.

In general, bioinfiltration ponds are used for treating stormwater runoff from pollution generating impervious surfaces such as roads and parking lots. In order to avoid standing water associated with bioinfiltration ponds, it is also important that an overflow system be provided. Overflows shall be routed through an appropriate conveyance system to a higher permeability (flow control) infiltration BMP such as a drywell or infiltration pond, or to a surface water discharge point with flow control as necessary (see Figure AR.03.1).

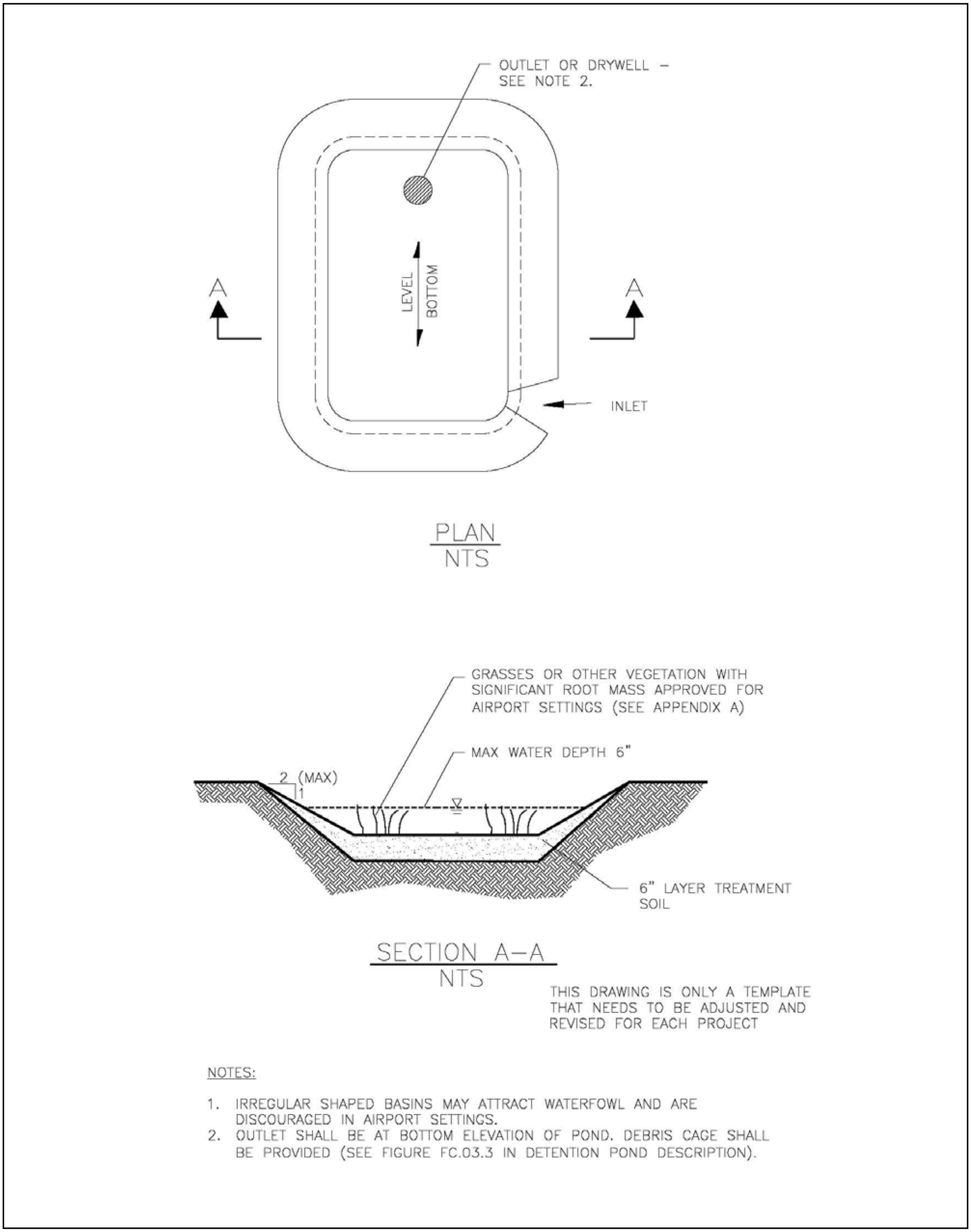


Figure AR.03.1. Bioinfiltration pond.

Applications and Limitations

Bioinfiltration ponds can be used to meet basic runoff treatment objectives (see Section 4-5.10). Although bioinfiltration ponds treat runoff by infiltration through soil, the infiltration capacity of these facilities is usually not sufficient to provide flow control to meet the criteria of Minimum Requirement 7 (see Section 1-3.4). Unless a very large area is available for the shallow water depth required of a bioinfiltration pond, flow control must be implemented using a separate facility.

Bioinfiltration ponds require moderately permeable soil (with an infiltration rate of 0.5 – 1.0 inch/hour) for proper function. For general site suitability criteria for infiltration facilities, see BMP AR.04, Infiltration Pond. Additional criteria for runoff treatment are presented in Section 5-2. Airport-specific modifications to hydrologic site suitability criteria are presented in Chapter 5 of this manual.

Bioinfiltration ponds are not suitable for airside locations at airports, such as within the runway safety area (RSA), taxiway safety area (TSA) or clearway. The standard bioinfiltration pond design includes a 6 inch layer of treatment soil, which does not meet FAA compaction requirements (FAA 2005a) for these airside locations.

On a case-by-case basis, reinforcement through the use of a plastic matrix or other suitable soil reinforcement technique may be used to meet FAA requirements. The proposed structural reinforcement in these restricted areas must be approved by a geotechnical engineer prior to construction.

Alternatively, a bioinfiltration pond with a 4 inch layer of treatment soil could be proposed for an airside location at an airport. However, this would require approval from Ecology, which would likely require establishment of a monitoring program to demonstrate that the alternative design would meet Ecology requirements. The project proponent would need to coordinate with Ecology to set up a monitoring program to demonstrate that the project will not adversely affect water quality.

There are several design modifications from the bioinfiltration pond design presented in the HRM and the bio-infiltration swale design in the SMMEW to make these facilities suitable for airport applications. Additional information on the specific modifications and the reason for the modified design are summarized in this section:

- Pretreatment is required
- Plantings must be suitable for airport settings (Appendix A)
- A debris cage is required on the outlet structure.

Presettling and/or Pretreatment

Pretreatment is required for bioinfiltration ponds in airport settings. If adequate pretreatment were not provided, clogging of treatment soils could result in ponding for extended periods of time, presenting an attractant to waterfowl and other wildlife and thereby becoming a hazard to aircraft. The following are acceptable pretreatment methods for stormwater facilities at airports:

- Vegetated Filter Strip (AR.12)
- Biofiltration Swale (AR.13)
- **Proprietary presettling devices**. These devices are designed to remove debris, sediment, and large oil droplets. They are considered "emerging technologies". Emerging technologies that have been evaluated by Ecology have one of three designations; general use level designation (GULD), conditional use level designation (CUD), or pilot level designation (PLD). Technologies with a GULD may be used without additional approval for the designated treatment category (pretreatment in this case), while Ecology approval would be required for technologies that are designated as PLD or CUD. Additional information on proprietary presettling devices may be found at the following Washington State Department of Ecology website: <http://www.ecy.wa.gov/programs/wq/stormwater/newtech/vortex_enhanced_sedimentation.html>.

Design Flow Elements

Flows to Be Treated

Bioinfiltration ponds are designed as volume-based, infiltration treatment facilities. The runoff volume to be treated by a bioinfiltration pond is dependent on the method used to size the facility. Hydrologic analysis methods are presented in Section 5-2 of this manual.

Structural Design Considerations

Geometry

Bioinfiltration pond sizing methods are the same as those for infiltration ponds (see BMP AR.04) designed for runoff treatment, except for the following:

- Maximum drawdown time for the treated volume shall be 48 hours following the design storm event.
- The maximum (temporary) ponded depth shall be 6 inches.
- Maximizing distance between the inlet and outlet is encouraged to promote sediment trapping and to ensure a long narrow facility that discourages use by waterfowl. The length to width ratio of the pond

should be 3:1 or greater. Irregular shaped basins (emulating natural water bodies) may attract waterfowl and are discouraged in airport settings.

- The pond bottom shall be flat.
- Interior pond side slopes shall be 2:1 or steeper.
- The treatment soil shall be at least 6 inches thick with a cation exchange capacity (CEC) of at least 5 milliequivalents per 100 grams of dry soil, organic content of at least 1 percent, and sufficient target pollutant loading capacity (see *Criteria for Assessing the Trace Element Removal Capacity of Bio-filtration Systems* (Miller 2000).
- Other combinations of treatment soil thickness, CEC, and organic content design factors can be considered if it is demonstrated that the soil and vegetation will provide an acceptable target pollutant loading capacity and performance level.
- The treatment zone soil depth of 6 inches or more should contain sufficient organics and texture to ensure good vegetation growth.

Site Design Elements

Groundwater Issues

Infiltration facilities should not be located where pollutants in contributing stormwater could cause a violation of the Washington State groundwater quality standards (WAC 173-200). Local jurisdictions should be consulted for applicable pollutant-removal requirements upstream of the infiltration facility, and available information must be reviewed to determine whether the site overlies a sensitive groundwater recharge area, sole-source aquifer, or a wellhead protection zone.

Consider the potential impact of pollutants on potable water wells when siting the infiltration facility. Mitigation measures, such as diligent pollutant source control and additional pretreatment must be implemented to ensure that infiltration of pollutants does not result in a violation of groundwater quality standards.

Infiltration rates, depths to groundwater and other hydrologic considerations are included in Chapter 5 of this manual.

Site Design Elements

Infiltration Rates

The average infiltration rate of the 6-inch-thick layer of treatment soil should not exceed 1 inch per hour for a system relying on the root zone to enhance pollutant removal. Furthermore, the site suitability criteria in Section 5-3.1 must also be applied.

Landscaping (Planting Considerations)

Native grasses, adapted grasses, or other vegetation with significant root mass should be used. Since this BMP applies to eastern Washington only, grasses should be drought tolerant. Appendix A contains lists of plants recommended as generally suitable for vegetation and landscaping in airport settings. Guidance for planting methods is also provided below. For plant species lists and planting methods specific to local site conditions, consult a qualified landscape architect, biologist, and/or other specialist.

- Plants must be selected that encourage filtering and settling of suspended solids and that are not attractive to wildlife potentially hazardous to aircraft. Select fine, turf-forming grasses where moisture is appropriate for growth.
- If possible, perform seeding of the BMP during the seeding windows specified in the WSDOT Standard Specifications section 8-01.3(2)F, Dates for Application of Final Seed, Fertilizer, and Mulch. To the greatest extent possible, seeding should be conducted at a time when wildlife are not as prevalent and/or are less likely to be attracted to seed. Perform planting of the BMP during the planting windows specified in the WSDOT Standard Specifications section 8-03.3(8) Planting. Supplemental irrigation may be required depending on seeding and planting times.
- Stabilize soil areas upslope of the BMP to prevent erosion and excessive sediment deposition.
- Apply seed using methods and timing that limits the attractiveness of the seeded area to hazardous wildlife. Seeding should be coordinated with a qualified airport wildlife biologist to make sure seeds or young plant shoots are not available when migratory wildlife are expected.
- Plant BMPs with species that can withstand periodic saturation as well as extended dry periods.

Materials

For runoff treatment, soils must meet the criteria described for BMP AR.04, Infiltration Pond, and satisfy the *Site Suitability Criteria* in Section 5-3.1.

Pond Excavation

Conduct initial excavation to within 1 foot of the final elevation of the floor of the bioinfiltration pond. Defer final excavation to the finished grade until all disturbed areas in the upgradient drainage area have been stabilized or protected. After construction is completed, prevent sediment from entering the bioinfiltration pond by first conveying the runoff water through an appropriate pretreatment system (see above). Bioinfiltration ponds, as with all types of infiltration facilities, should generally not be used as temporary sediment traps during construction. The final phase of excavation should remove all accumulated sediment.

Relatively light-tracked equipment is recommended for excavation to avoid compacting the floor of the bioinfiltration pond. Consider the use of draglines and trackhoes. The bioinfiltration pond area should be flagged or marked to keep equipment away.

Setback Requirements

Setback requirements for bioinfiltration ponds are the same as those for infiltration ponds (BMP AR.04).

Access Requirements

Access requirements for bioinfiltration ponds are the same as those for infiltration ponds (BMP AR.04).

6-2.4. AR.04 – Infiltration Pond

Eastern Washington	Yes
Western Washington	Yes
Landside Areas	Yes

Object Free Area (OFA)	No
Runway Safety Area (RSA)	No
Taxiway Safety Area (TSA)	No
Clearway (CWY)	No

Introduction

General Description

Infiltration ponds for flow control are earthen impoundments used for the collection, temporary storage, and infiltration of incoming stormwater runoff to groundwater (see Figure AR.04.1). Infiltration ponds can also be designed to provide runoff treatment (see the *Runoff Treatment* section below).

Applications and Limitations

Infiltration of runoff is the preferred method of flow control where soils and site conditions are suitable. Infiltration trenches (AR.05) are generally preferred over ponds in the airport environment. Runoff in excess of the infiltration capacity must be detained and released in compliance with the flow control requirement described under Minimum Requirement 7 in Section 1-3.4.

Where site conditions are appropriate for infiltration, infiltration ponds are a good option for airports, which often have a large amount of open space. Infiltration ponds typically have lower cost and easier maintenance requirements than underground facilities, such as infiltration vaults (AR.06). However, if infiltration ponds are to be constructed in the airport environment, **wildlife deterrence must be a top priority to assure that the stormwater facility does not present a safety hazard to aircraft**. For airport applications, there are several design modifications from the infiltration pond design presented in the HRM, SMMEW, and SMMWW. Additional information on the specific modifications and the reason for the modified design are summarized in this section:

- Modifications to infiltration design guidance (see *Design Flow Elements* in this section)
- Clearance from seasonal high-water mark, bedrock, or other low-permeability layer (see *Design Flow Elements* in this section)
- Steeper interior pond side slopes

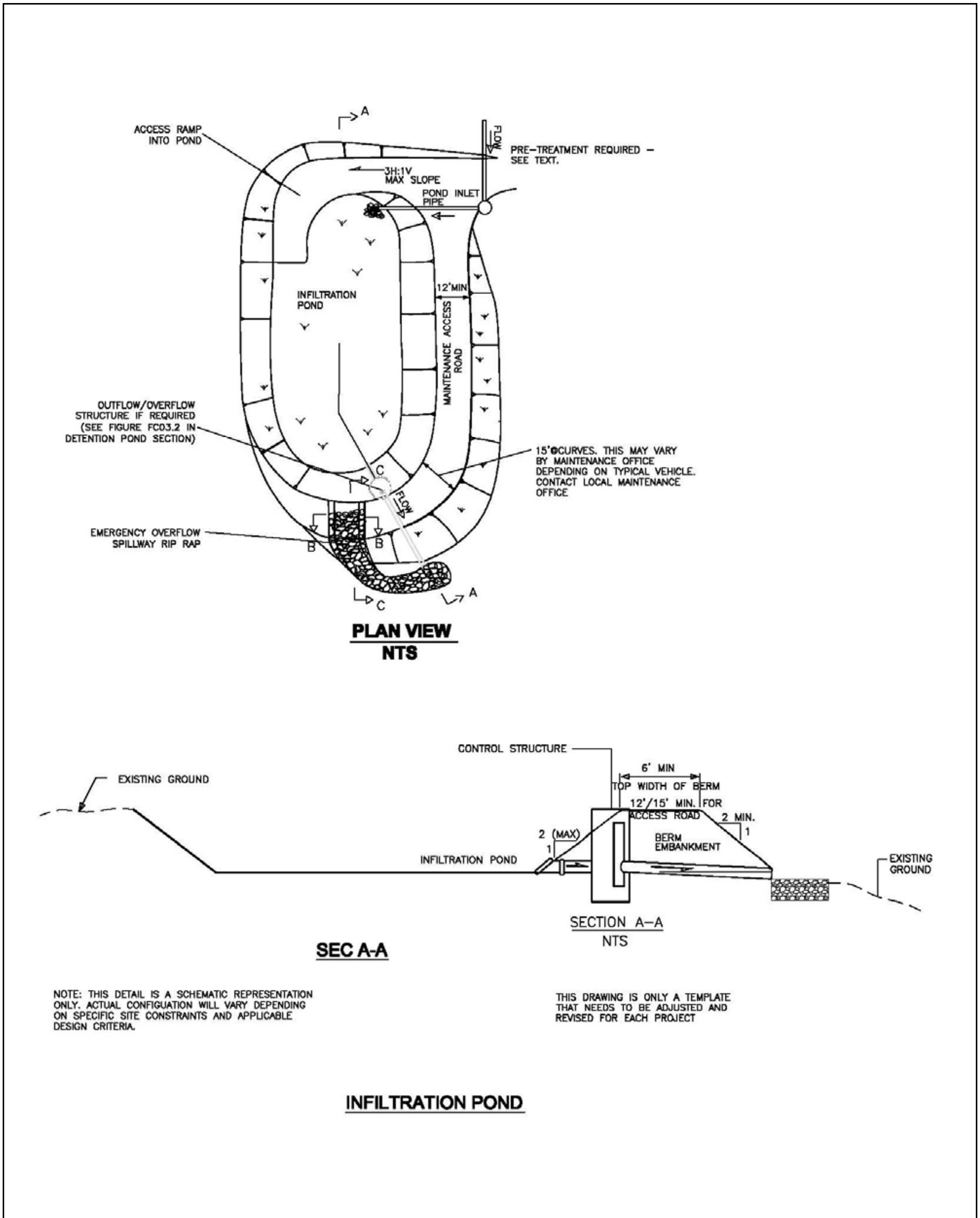


Figure AR.04.1. Infiltration pond.

- Pond width restrictions to reduce wildlife site lines.
- Vegetation recommendations.
- Additional setbacks.

Presettling and/or Pretreatment

Infiltration ponds should follow a runoff treatment or pretreatment facility to prevent sediment buildup and clogging of the infiltrative soils. Basic treatment facilities that are recommended for pretreatment in the airport setting include the following:

- Biofiltration swale (AR.13)
- Vegetated filter strip (AR.12)
- **Proprietary presettling devices.** These devices are designed to remove debris, sediment, and large oil droplets, and should be followed by a basic or enhanced treatment facility. They are considered "emerging technologies". Emerging technologies that have been evaluated by Ecology have one of three designations; general use level designation (GULD), conditional use level designation (CUD), or pilot level designation (PLD). Technologies with a GULD may be used without additional approval for the designated treatment category (pretreatment in this case), while Ecology approval would be required for technologies that are designated as PLD or CUD. Additional information on proprietary presettling devices may be found at the following Washington State Department of Ecology website: <http://www.ecy.wa.gov/programs/wq/stormwater/newtech/vortex_enhanced_sedimentation.html>.

Design Flow Elements

Flows to Be Infiltrated

Site runoff should be infiltrated to the extent that occurred before the site was developed. Runoff in excess of the infiltration pond's capacity must be detained and released in compliance with the flow control requirement described under Minimum Requirement 7 in Section 1-3.4. (See Section 5-2 of this manual for hydrologic analysis methods applicable to flow control for surface discharges.)

For a site to be considered suitable for an infiltration pond, the design infiltration rate must be at least 1.0 inch/hour. Infiltration can still be considered in flow control facility design if the infiltration rate is less than this, but infiltration must be considered to be a secondary function in that case. A pond must be designed to a desirable depth of 3 feet and a maximum depth of 6 feet, with a minimum freeboard of 1 foot above the design water level (1 foot above the 50-year water surface elevation for western Washington, and 1 foot above the 25-year water surface elevation for eastern Washington). For guidance on design of infiltration facilities in eastern and western Washington, see Section 5.4.1.

1. For western Washington, an infiltration flow control pond must be designed using a continuous hydrograph model to infiltrate sufficient volume so that the overflow matches the duration standard (or 100 percent of the runoff volume).
2. For eastern Washington, an infiltration flow control pond must be designed using a single-event hydrograph model to infiltrate the runoff treatment volume out of the pond within 48 hours. An infiltration flow control pond must be designed using a single-event hydrograph model to infiltrate the 25-year storm, with an overflow for the higher events or infiltrate 100 percent of the storm runoff volume.

Outlet Control Structure

If the pond will not have capacity to infiltrate all inflows up to the required flow control performance level, an outlet control structure will be needed to regulate the release of excess flows. Outlet control structure design guidance is provided in BMP AR.09, Detention Pond, in this manual.

Infiltration Design Guidance

Chapter 5 presents hydrologic design guidance for infiltration facilities.

Flow Splitters

For an infiltration pond designed only to serve as a runoff treatment facility, the pond may be located off-line by installing a flow splitter upstream of the infiltration facility. The splitter must direct all flows up to the water quality design flow rate into the infiltration facility. The facility must be designed to infiltrate all water directed to it while satisfying the duration of ponding criterion. All bypassed flow must be conveyed to a flow control facility unless it is directly discharged to an exempt water body. (See the HRM or SMMWW for flow splitter design guidance.)

Infiltration ponds designed for flow control must be located on-line.

Emergency Overflow Spillway

A nonerodible outlet or spillway must be constructed to discharge overflow to the downstream conveyance system, as described in BMP AR.09, Detention Pond, in this manual. Ponding depth, drawdown time, and storage volume are calculated from the overflow elevation.

Structural Design Considerations

Geometry

For detailed guidance on sizing infiltration facilities, see Section 5-2 of this manual as well as the airport-specific modifications discussed under *Design Flow Elements* above. Infiltration ponds should meet the following geometry criteria:

- The slope of the floor of an infiltration pond must not exceed 3 percent in any direction.
- Interior pond side slopes should be 2H:1V or steeper.
- The pond width at the overflow elevation should be no greater than 30 feet. If the open chamber of the pond is greater than 30 feet in length, one of the *Adaptive Stormwater Facility Design* measures from Section 3-4 should be incorporated to reduce wildlife site lines.

Eastern Washington

For cold climate infiltration pond design criteria, refer to Ecology's SMMEW (Ecology 2004).

Embankments

Requirements for infiltration pond embankments are the same as those for BMP AR.09, Detention Pond, described in this manual. In addition, the site geotechnical investigation must include the following:

- Stability analysis of the proposed side slopes of the pond and the potential to activate landslides in the vicinity of the facility during construction or during service.
- Seepage analysis of any berms or dams required by the facility to retain stormwater.

Liners

The floor of infiltration ponds can be covered with a 6- to 12-inch layer of filter material such as coarse sand, or a suitable filter fabric liner may be used to help prevent buildup of low-permeability sediment deposits on the soil surface. A nonwoven geotextile that functions sufficiently without plugging should be selected (see underground drainage geotextile specifications in Section 9-33 of the WSDOT Standard Specifications). The underlying geotextile helps to maintain separation between the filter material and the underlying soils.

Groundwater Issues

Infiltration facilities should not be located where pollutants in contributing stormwater could cause a violation of the Washington State groundwater quality standards (WAC 173-200). Local jurisdictions should be consulted for applicable pollutant-removal requirements upstream of the infiltration facility, and available information must be reviewed to determine whether the site overlies a sensitive groundwater recharge area, sole-source aquifer, or a wellhead protection zone.

Consider the potential impact of pollutants on potable water wells when siting the infiltration facility. Mitigation measures, such as diligent pollutant source control and additional pretreatment must be implemented to ensure that infiltration of pollutants does not result in a violation of groundwater quality standards.

Infiltration rates, depths to groundwater and other hydrologic considerations are included in Chapter 5 of this manual.

Runoff Treatment

Infiltration ponds can also be used for runoff treatment. See Section 5-3.1 for restrictions and requirements related to runoff treatment for highway facilities. These restrictions also apply for infiltration facilities at airports. Specifically, the following requirements must be met:

- Treatment soils must have the physical and chemical characteristics specified in SSC 6, *Soil Physical and Chemical Suitability for Treatment* (Section 5-3.1), including the minimum cation exchange capacity (CEC) and depth, the maximum sodium adsorption ratio (SAR), and the appropriate organic content for treatment.
- The short-term soil infiltration rate must be 2.4 inches per hour or less, as stipulated in SSC 4, *Soil Infiltration Rate* (Section 5-3.1).

Site Design Elements

Initial excavation should be conducted to within 1 foot of the final elevation of the infiltration pond floor. Final excavation to the finished grade should be deferred until all disturbed areas in the upgradient drainage area have been stabilized or protected. The final phase of excavation should remove all accumulated sediment.

Infiltration ponds, as with all types of infiltration facilities, should generally not be used as temporary sediment traps during construction. If an infiltration pond is to be used as a sediment trap, it must not be excavated to final grade until after the upgradient drainage area has been stabilized. Any accumulation of silt in the pond must be removed before the pond is put into service.

Low-ground-pressure equipment is recommended for excavation to avoid compacting the floor of the infiltration pond. The use of draglines and trackhoes should be considered. The infiltration area should be flagged or marked to keep equipment away.

Setback Requirements

Setback requirements for infiltration ponds are generally required by local regulations, Uniform Building Code requirements, or other state regulations. The following setback criteria are provided as guidance:

- Infiltration ponds and other infiltration facilities must be located outside of the RSA and TSA.
- Infiltration facilities must be located far enough from runways or buildings to avoid threatening the structural stability. A professional engineer should be consulted for this analysis. In addition, adequate distance for vegetative treatment must be allowed between receiving water and runways, taxiways, and other areas treated with de-icing chemicals, if they are not treated with a designed system. Distances between 30 feet and 600 feet have been reported for effects related to deicers, depending on the type of deicer (NCHRP 2005).
- For infiltration facilities, a geotechnical report should be prepared by a qualified professional for the project that evaluates any potential structural site instability due to extended subgrade saturation and/or head loading of the permeable soil layer, including the potential impacts to downgradient properties, especially on hills with known side-hill seeps. The geotechnical report should address the adequacy of the proposed infiltration pond location(s) and recommend the necessary setbacks from any steep slopes and building foundations.
- Infiltration facilities should be set back at least 100 feet from drinking water wells, septic tanks or drain fields, and springs used for public drinking water supplies. Infiltration facilities upgradient of drinking water supplies and within 1-, 5-, and 10-year time of travel zones must comply with health department requirements (Washington Wellhead Protection Program, WAC 246-290-135).
- Infiltration facilities must be located at least 20 feet downslope and 100 feet upslope from building foundations.
- Infiltration facilities must be located at least 20 feet from a native growth protection easement (NGPE).
- Infiltration facilities must be a minimum of 5 feet from any property line and/or vegetative buffer. This distance may need to be increased based on permit conditions required by regulations of the local jurisdiction.

Landscaping (Planting Considerations)

Without healthy vegetation, the surface soil pores quickly plug The interior of the infiltration pond, as well as surrounding berms, spoil areas, borrow areas, and other disturbed areas, should be stabilized and planted, preferably with plants that with limited attraction potential for wildlife. The use of slow-growing, stoloniferous grasses permits long intervals between mowing (see the *Operation and Maintenance* section, below, for additional recommendations related to mowing).

Appendix A contains lists of plants recommended as generally suitable for revegetation and landscaping in airport settings. Guidance for planting methods is also provided below. For plant species lists and planting methods specific to local site conditions, consult a qualified landscape architect, biologist, and/or other specialist.

- Plants must be selected that encourage filtering and settling of suspended solids and that are not attractive to hazardous wildlife. Select fine, turf-forming grasses where moisture is appropriate for growth.
- If possible, perform seeding of the BMP during the seeding windows specified in the WSDOT Standard Specifications section 8-01.3(2)F, Dates for Application of Final Seed, Fertilizer, and Mulch. To the greatest extent possible, seeding should be conducted at a time when wildlife are not as prevalent and/or are less likely to be attracted to seed. Perform planting of the BMP during the planting windows specified in the WSDOT Standard Specifications section 8-03.3(8) Planting. Supplemental irrigation may be required depending on seeding and planting times.
- Stabilize soil areas upslope of the BMP to prevent erosion and excessive sediment deposition.
- Apply seed using methods and timing that limits the attractiveness of the seeded area to wildlife. Seeding should be coordinated with a qualified airport wildlife biologist to make sure seeds or young plant shoots are not available when migratory wildlife are expected.
- Plant BMPs with species that can withstand periodic saturation as well as extended dry periods.

Fencing

If the pond is located in a landside area that is accessible to the public, fencing is recommended due to the steep interior side slopes. Fencing would not typically be necessary in airside locations due to the limited public access.

Signage

The local jurisdiction may require that the infiltration pond have a sign. The sign should be placed for maximum visibility from adjacent airport areas. Any signs must conform to FAA restrictions on objects non-essential for air navigation (FAA AC 150/5300-13).

Maintenance Access Roads (Access Requirements)

Vehicle access must be provided to maintain the facility, such as periodic retiling of the infiltration surface without disturbing side slope vegetation or resuspending sediment.

Operation and Maintenance

Infiltration ponds, as is the case with all BMPs, must be designed to accommodate routine inspection and maintenance to enable the facility to perform effectively for its intended design life. (See Section 6-3 for more details.) Operations and maintenance of the infiltration pond cannot conflict with regular airport activities. Therefore, the infiltration facility must be located outside of critical areas where routine maintenance could interfere with airport operations. See Chapter 2 of this manual for restrictions within specific airport operations zones.

Mowing should be done with a push mower or small tractor to avoid compaction of soils. Mowing at night has been used at many airports to decrease the likelihood of birds following the mower to eat insects or rodents that have been exposed by shorter grass.

6-2.5. AR.05 – Infiltration Trench

Infiltration trench along SR 539.

Eastern Washington	Yes
Western Washington	Yes
Landside Areas	Yes

Object Free Area (OFA)	Yes*
Runway Safety Area (RSA)	No
Taxiway Safety Area (TSA)	No
Clearway (CWY)	Yes*

* Contact FAA Seattle ADO for approval.

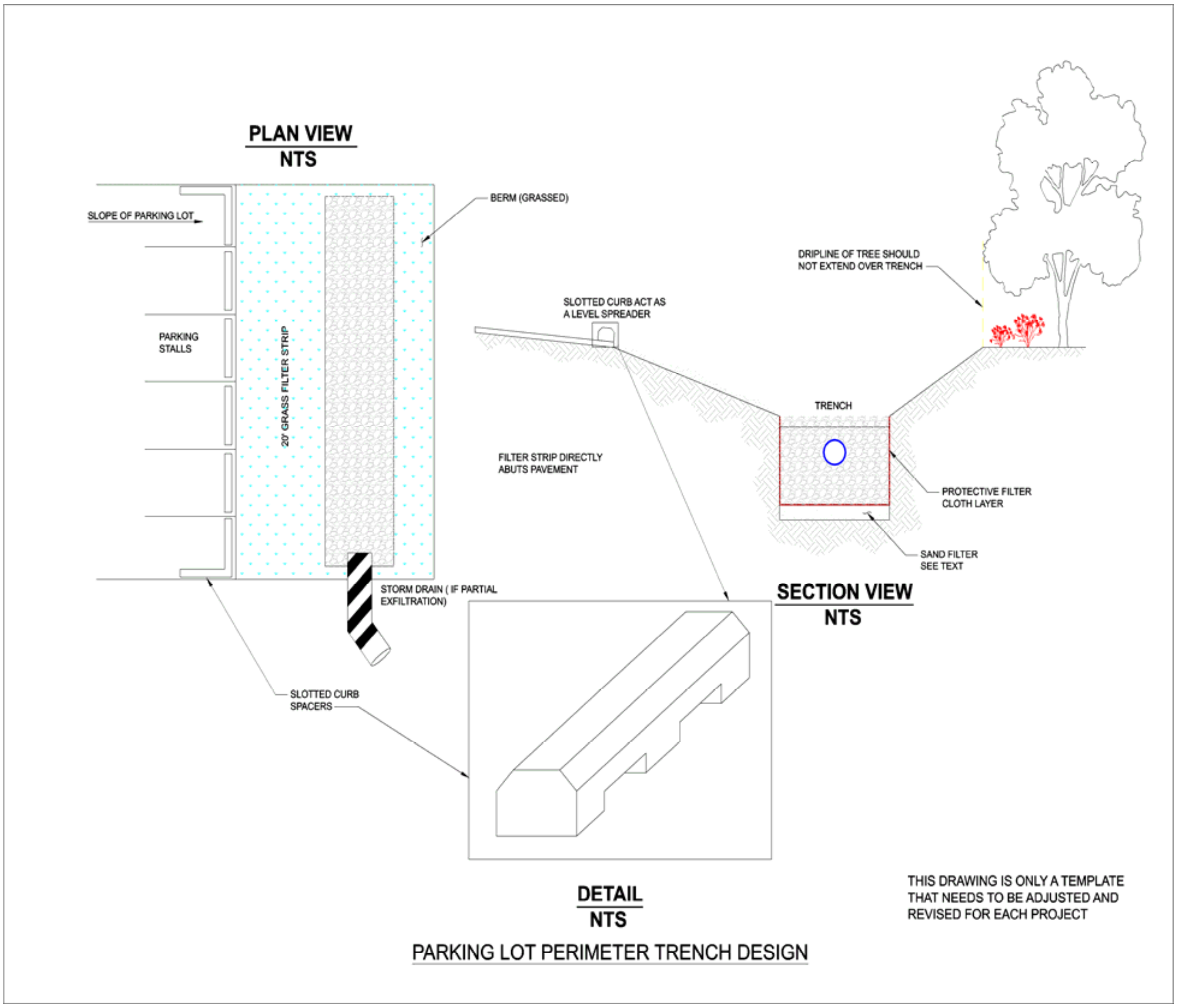
Introduction

General Description

Infiltration trenches are long, narrow, stone-filled trenches used for the collection, temporary storage, and infiltration of stormwater runoff to groundwater. Being linear facilities, they are less likely to attract hazardous wildlife and are therefore generally preferable to infiltration ponds in the airport environment. Infiltration trenches may be placed beneath parking areas, along the site periphery, or in other suitable linear areas. They may also be designed for runoff treatment (see Site Suitability Criteria in Chapter 5). For infiltration trench concept details, see Figures AR.05.1 through AR.05.5.

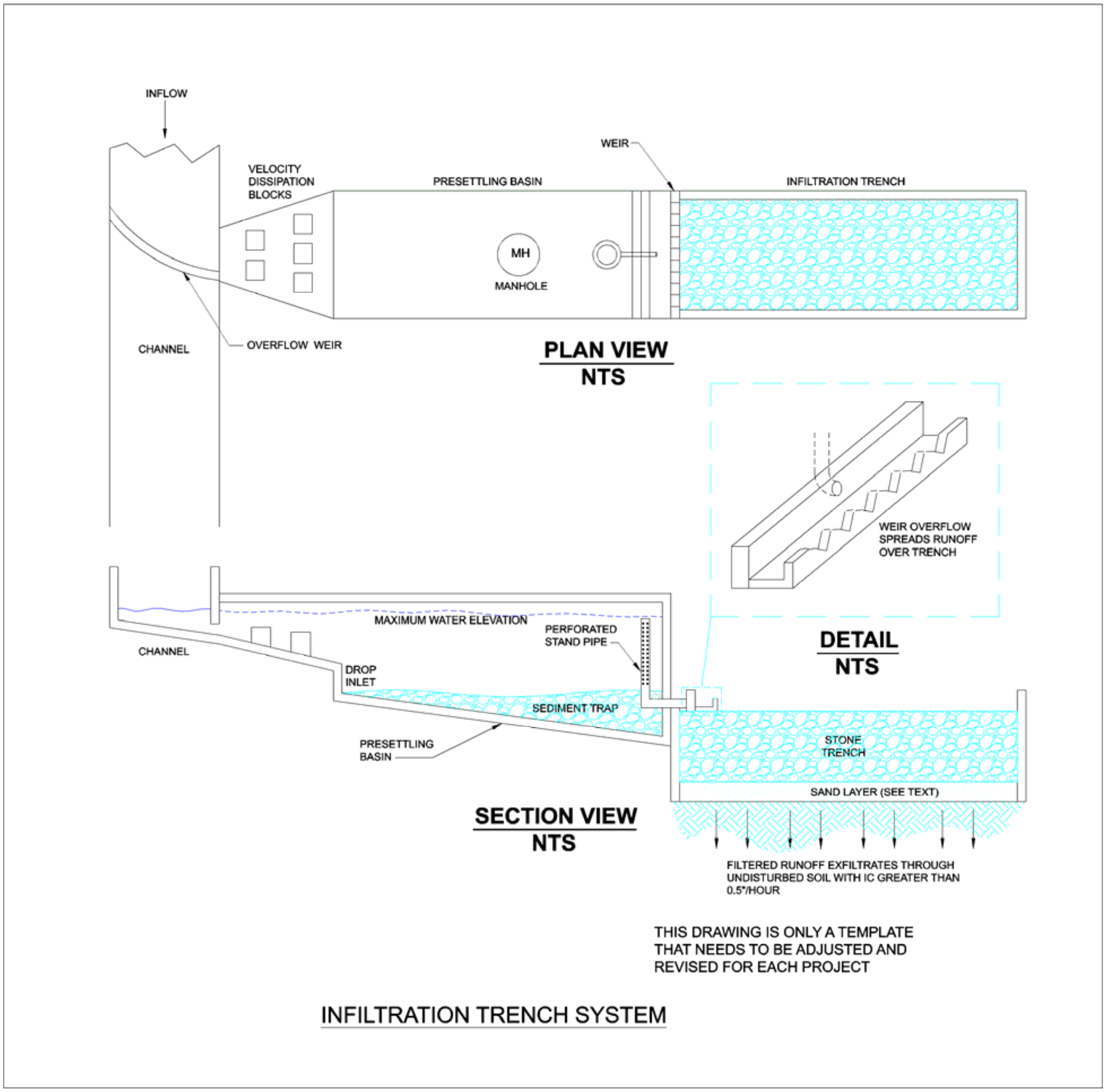
Applications and Limitations

Infiltration of runoff is the preferred method of flow control following appropriate runoff treatment. Runoff in excess of the infiltration capacity must be detained and released in compliance with the flow control requirements under Minimum Requirement 7.



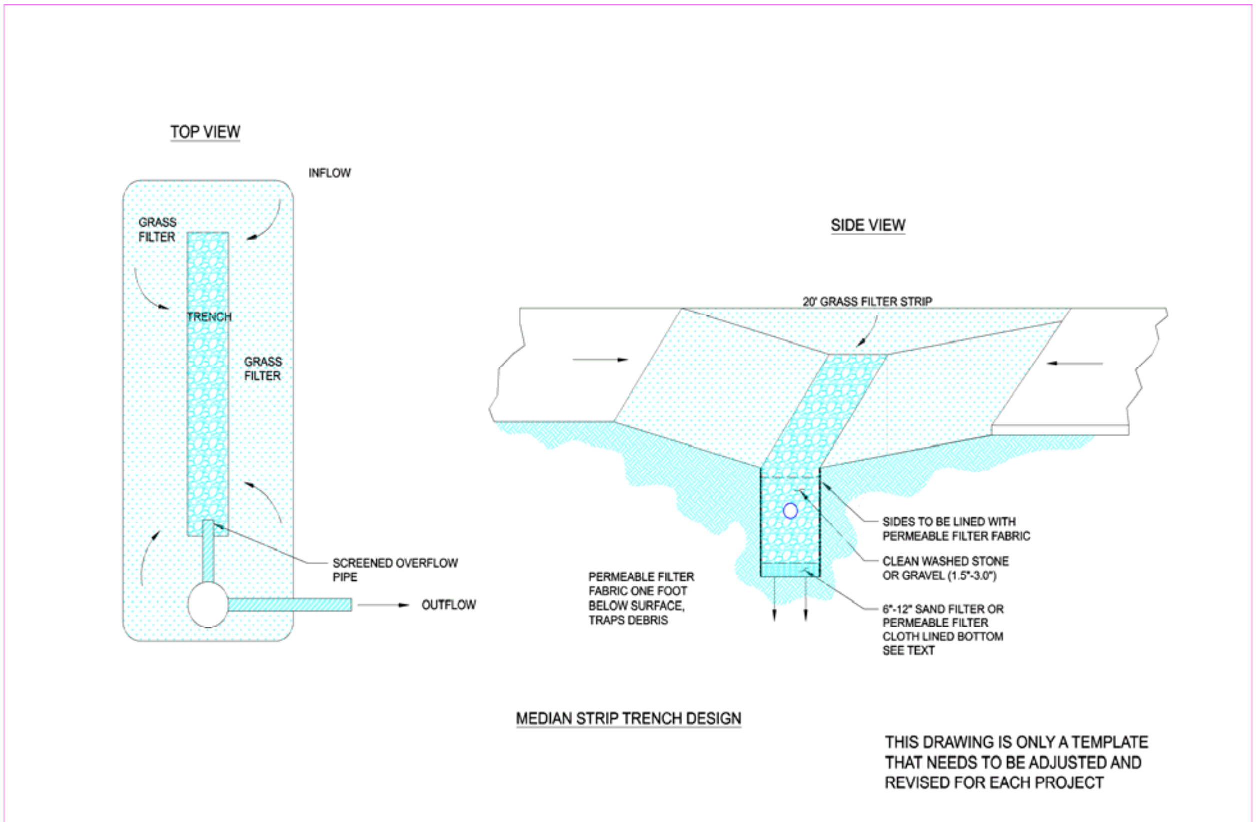
Source: Schueler.

Figure AR.05.1. Parking lot perimeter trench design.



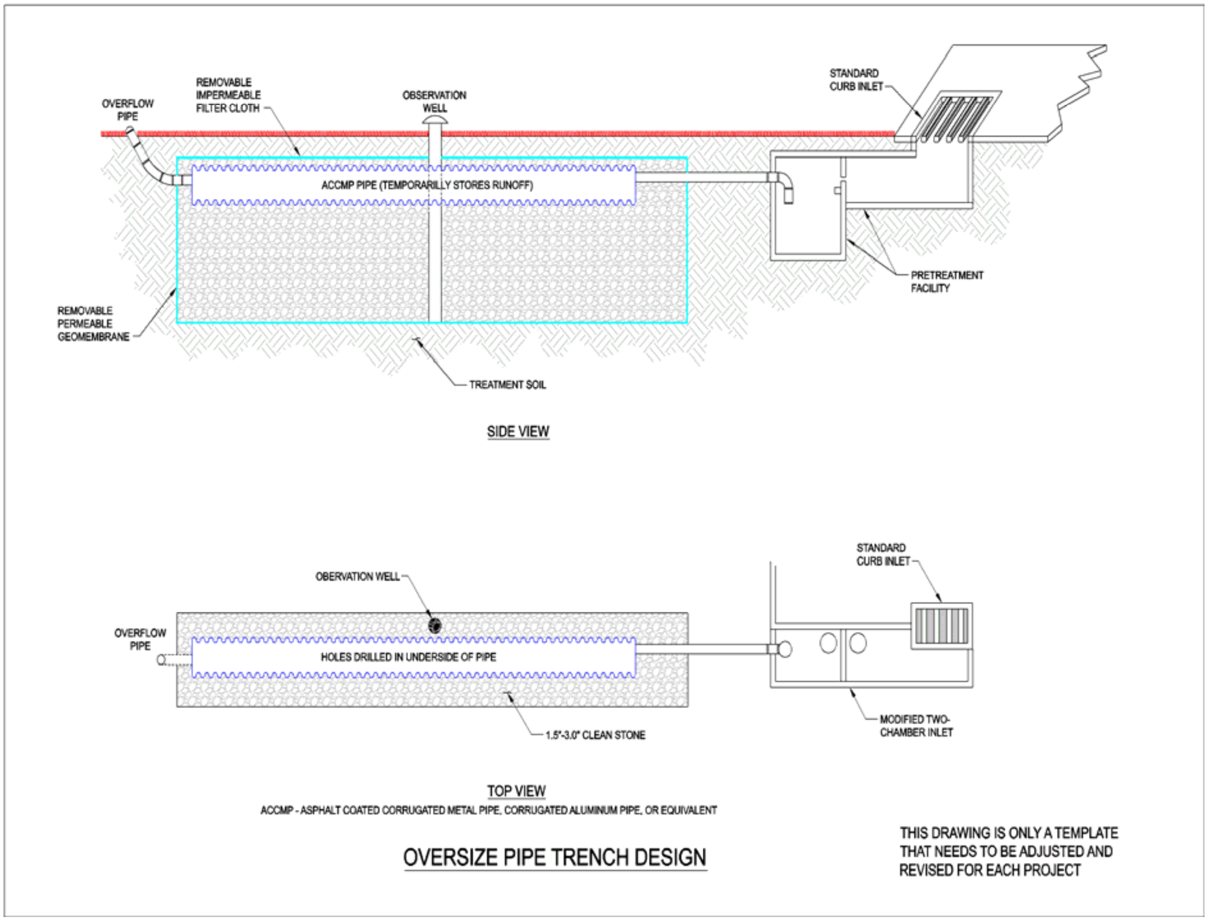
Source: Schueler.

Figure AR.05.2. Infiltration trench system.



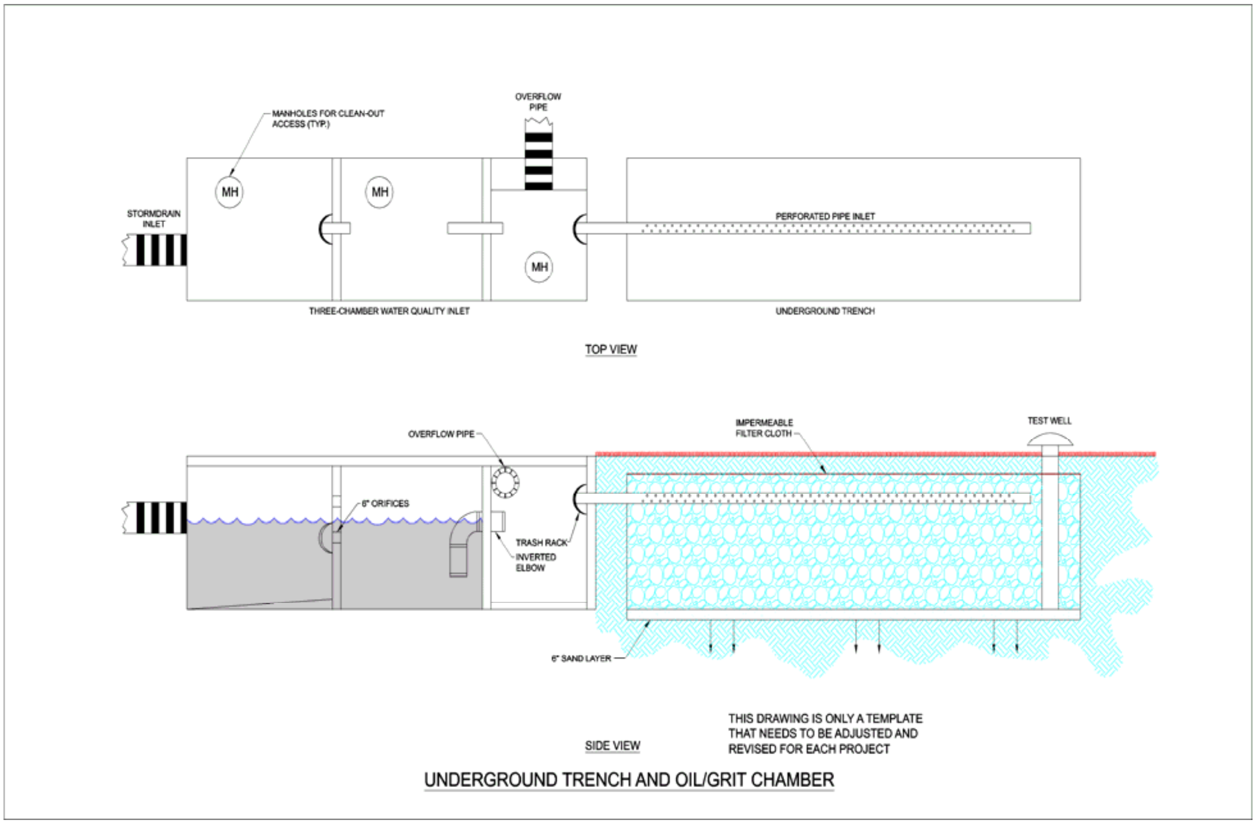
Source: Schueler.

Figure AR.05.3. Median strip trench design.



Source: Schueler et al. 1992.

Figure AR.05.4. Oversize pipe trench design.



Source: Schueler.

Figure AR.05.5. Underground trench and oil/grit chamber.

This BMP is considered a subsurface infiltration facility and its use may be subject to the rules governing Class V underground injection wells, but only if it includes the use of a perforated pipe. This type of stormwater facility must be registered through Ecology's UIC (Underground Injection Control) Program. For more information on UIC requirements, see the SMMWW, SMMEW, or HRM.

Site Suitability Criteria

Site suitability criteria for infiltration facilities are described in Section 5-3.1.

Presettling and/or Pretreatment

Infiltration trenches should follow a runoff treatment or pretreatment facility to prevent sediment buildup and clogging of the trench.

Design Flow Elements

Flows to Be Infiltrated

The flows to be treated by an infiltration trench are identical to those for BMP AR.04, Infiltration Pond. (See Section 5-4.1 for additional design guidance.)

Overflow or Bypass

Because infiltration trenches are generally used for small drainage areas, an emergency spillway is not necessary. However, a nonerosive overflow channel leading to a stabilized watercourse should be provided.

Outlet Control Structure

If the pond will not have capacity to infiltrate all inflows up to the required flow control performance level, an outlet control structure will be needed to regulate the release of excess flows. Outlet control structure design guidance is provided in BMP AR.09, Detention Pond, in this manual.

Flow Splitters

For an infiltration trench designed only to serve as a runoff treatment facility, the pond may be located off-line by installing a flow splitter upstream of the infiltration facility. The splitter must direct all flows up to the water quality design flow rate into the infiltration facility. The facility must be designed to infiltrate all water directed to it while satisfying the duration of ponding criterion. All bypassed flow must be conveyed to a flow control facility unless it is directly discharged to an exempt water body. (See the HRM or SMMWW for flow splitter design guidance.)

Infiltration trenches designed for flow control must be located on-line.

Structural Design Considerations

Geometry

Infiltration trench sizing methods are the same as those for BMP AR.04, Infiltration Pond.

Materials

Backfill Material

The backfill material for the infiltration trench should consist of clean aggregate with a maximum diameter of 3 inches and a minimum diameter of 1.5 inches. Void space for the aggregate should be in the range of 30 to 40 percent.

Geotextile Fabric Liner

An engineering geotextile material must encase all of the aggregate fill material, except for the top 1 foot of the trench where an aggregate surface is the final ground condition. Geotextile fabric with acceptable properties must be carefully selected to avoid plugging (see geotextile for underground drainage in Section 9-33 of the WSDOT Standard Specifications). The bottom sand or geotextile fabric shown in Figures AR.05.1 through AR.05.3 is optional.

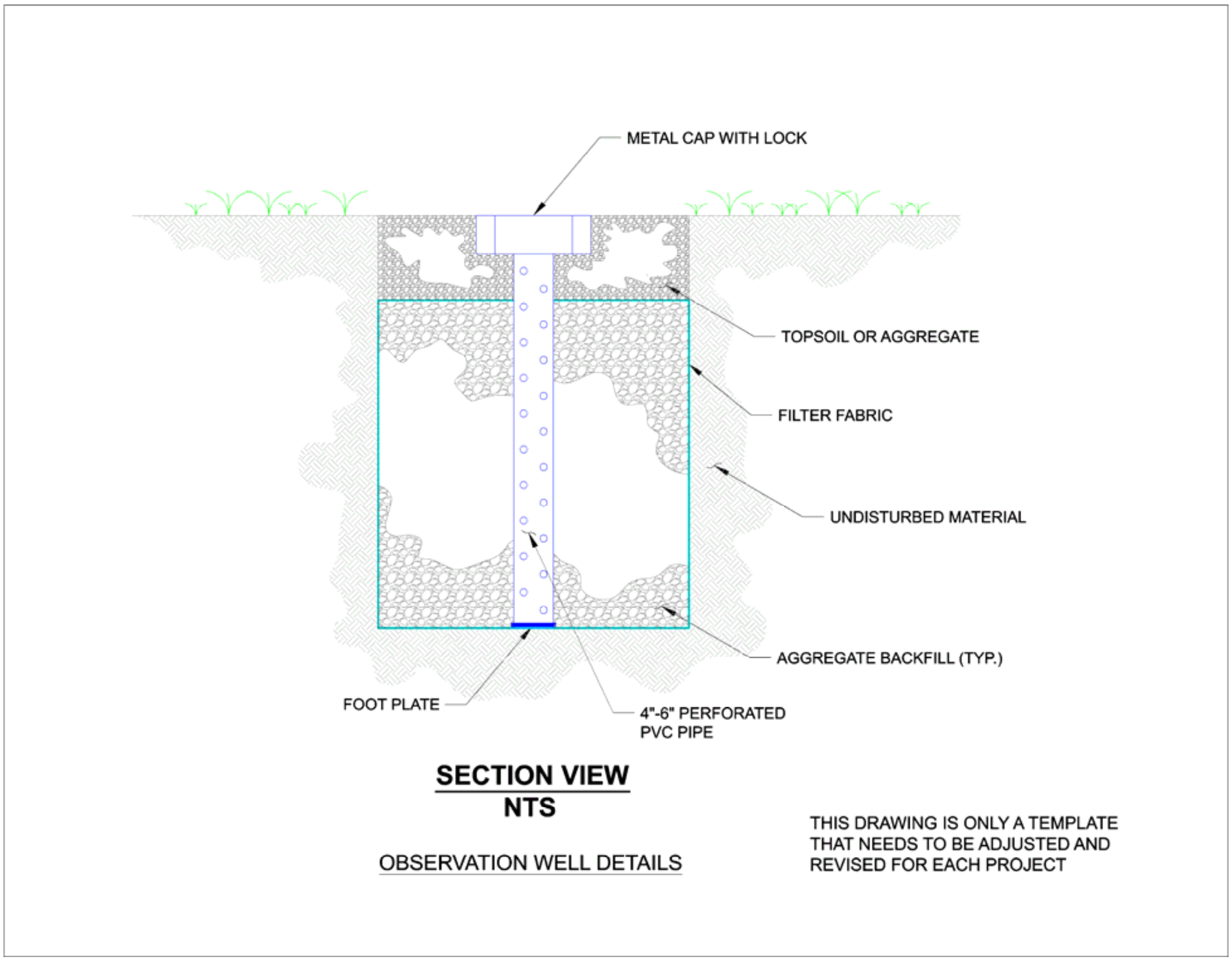
See the *References* section (at the end of this manual) for publications by the Federal Highway Administration (FHWA) (1995) for design guidance on geotextiles in drainage applications, and the National Cooperative Highway Research Program (NCHRP) (1994) for long-term performance data and background on the potential for geotextiles to clog or blind, for piping to be incorporated, and how to design for these issues.

Observation Well

An observation well should be installed at the lower end of the infiltration trench to check water levels, drawdown time, and sediment accumulation, and to allow for water quality monitoring. The well should consist of a perforated PVC pipe 4 to 6 inches in diameter, constructed flush with the ground elevation. For larger trenches, a 12- to 36-inch-diameter well can be installed to facilitate maintenance operations such as pumping out trapped sediment. The top of the well should be capped to discourage vandalism and tampering. (See Figure AR.05.6 for more details.)

Groundwater Issues

Infiltration facilities should not be located where pollutants in contributing stormwater could cause a violation of the Washington State groundwater quality standards (WAC 173-200). Local jurisdictions should be consulted for applicable pollutant-removal requirements upstream of the infiltration facility, and available information must be reviewed to determine whether the site



Source: King County.

Figure AR.05.6. Observation well detail.

overlies a sensitive groundwater recharge area, sole-source aquifer, or a wellhead protection zone.

Consider the potential impact of pollutants on potable water wells when siting the infiltration facility. Mitigation measures, such as diligent pollutant source control and additional pretreatment must be implemented to ensure that infiltration of pollutants does not result in a violation of groundwater quality standards.

Infiltration rates, depths to groundwater and other hydrologic considerations are included in Chapter 5 of this manual.

Site Design Elements

Setback Requirements

Setback requirements for an infiltration trench are identical to those for BMP AR.04, Infiltration Pond.

Planting Considerations

See Appendix A for planting recommendations. For additional general planting and seeding recommendations for infiltration facilities, see BMP AR.04, Infiltration Pond.

Access Requirements

Because of accessibility and maintenance limitations, infiltration trenches must be carefully designed and constructed. The local jurisdiction should be contacted for additional specifications.

An access port, or an open or grated top should be considered to permit access for inspections and maintenance.

Construction Criteria

Trench Preparation

Excavated materials must be placed away from the trench sides to enhance trench wall stability. Care should be taken to keep this material away from slopes, neighboring property, sidewalks, and streets. It is recommended that this material be covered with plastic.

Stone Aggregate Placement and Compaction

The stone aggregate should be placed in lifts and compacted using plate compactors. As a rule of thumb, a maximum loose lift thickness of 12 inches is recommended. The compaction process ensures geotextile conformity to the excavation sides, thereby reducing potential piping and geotextile clogging, as well as settlement problems.

Separation of Aggregate from Surrounding Soil

Natural or fill soils must not intermix with the stone aggregate. If the stone aggregate becomes mixed with the soil, the stone aggregate must be removed and replaced with uncontaminated stone aggregate.

Overlapping and Covering

Following the stone aggregate placement and compaction, the geotextile must be folded over the stone aggregate to form a 12-inch-minimum longitudinal overlap. When overlaps are required between rolls, the upstream roll should overlap a minimum of 2 feet over the downstream roll to provide a shingled effect.

Voids Behind Geotextile

Voids between the geotextile and excavation sides must be avoided. The space left by boulders or other obstacles removed from the trench walls is one source of such voids. Natural soils should be placed in these voids at the most convenient time during construction to ensure geotextile conformity to the excavation sides. Soil piping, geotextile clogging, and possible surface subsidence can be avoided by this remedial process.

Unstable Excavation Sites

Vertically excavated walls may be difficult to maintain in areas where the soil moisture is high or where soft or cohesion less soils predominate. Trapezoidal, rather than rectangular, cross sections may be needed.

Initial excavation should be conducted to within 1 foot of the final elevation of the infiltration pond floor. Final excavation to the finished grade should be deferred until all disturbed areas in the upgradient drainage area have been stabilized or protected. The final phase of excavation should remove all accumulated sediment.

Infiltration trenches, as with all types of infiltration facilities, should generally not be used as temporary sediment traps during construction. If an infiltration trench is to be used as a sediment trap, it must not be excavated to final grade until after the upgradient drainage area has been stabilized. Any accumulation of silt in the trench must be removed before the trench is put into service.

Operation and Maintenance

Infiltration trenches, as with all BMPs, must have routine inspection and maintenance designed into the life performance of the facility. (See Section 6-3 for more details.)

6-2.6. AR.06 – Infiltration Vault

Underground infiltration installation at Arlington airport.

Eastern Washington	Yes
Western Washington	Yes
Landside Areas	Yes

Object Free Area (OFA)	No
Runway Safety Area (RSA)	No
Taxiway Safety Area (TSA)	No
Clearway (CWY)	Yes

Introduction

General Description

Infiltration vaults are typically bottomless underground structures used for temporary storage and infiltration of stormwater runoff to groundwater. Infiltration tanks are large-diameter cylindrical structures with perforations in the base. These types of underground infiltration facilities can be a useful alternative for sites with constraints that make siting an infiltration pond difficult. They may also be modified for runoff treatment.

Applications and Limitations

Infiltration of runoff is the preferred method of flow control following appropriate runoff treatment. Runoff in excess of the infiltration capacity must be detained and released in compliance with the flow control requirement described in Section 1-3.4 under Minimum Requirement 7.

Site Suitability Criteria

Site suitability criteria are described in Section 5-3.1.

Infiltration vaults are not allowed on slopes greater than 25 percent (4H:1V). On slopes over 15 percent, a geotechnical report may be required for evaluation by a professional engineer with geotechnical expertise or a qualified geologist with jurisdiction approval. A geotechnical report may also be required if the proposed vault is located within 200 feet of the top of a steep slope or landslide hazard area.

Presettling and/or Pretreatment

Infiltration vaults should follow a runoff treatment or pretreatment facility to prevent sediment accumulation and clogging of the basin. (See Section 6-2.4, BMP AR.04, Infiltration Pond, for pretreatment design guidance.)

Design Flow Elements

Flows to Be Infiltrated

Site runoff should be infiltrated to the extent that occurred before the site was developed. Runoff in excess of the infiltration vault's capacity must be detained and released in compliance with the flow control requirement described under Minimum Requirement 7 in Section 1-3.4. (See Section 5-2 of this manual for hydrologic analysis methods applicable to flow control for surface discharges.)

Outlet Control Structure

If the pond will not have capacity to infiltrate all inflows up to the required flow control performance level, an outlet control structure will be needed to regulate the release of excess flows. Outlet control structure design guidance is provided in BMP AR.09, Detention Pond, in this manual.

Overflow or Bypass

A primary overflow must be provided to bypass flows over the 100-year postdeveloped peak flow to the infiltration vault. (See BMP AR.09, Detention Pond, for overflow structure types.)

Flow Splitters

For an infiltration vault designed only to serve as a runoff treatment facility, the vault may be located off-line by installing a flow splitter upstream of the infiltration facility. The splitter must direct all flows up to the water quality design flow rate into the infiltration facility. The facility must be designed to infiltrate all water directed to it while satisfying the duration of ponding criterion. All bypassed flow must be conveyed to a flow control facility unless it is directly discharged to an exempt water body. (See the HRM or SMMWW for flow splitter design guidance.)

Infiltration vaults designed for flow control must be located on-line.

Structural Design Considerations

Materials

All vaults must meet structural requirements for overburden support and H-20 vehicle loading. Vaults located under roadways must meet the live load requirements of the WSDOT Standard Specifications. Cast-in-place wall sections must be designed as retaining walls. Structural designs for cast-in-place vaults must be stamped by a licensed structural civil engineer. Bottomless vaults must be provided with footings placed on stable, well-consolidated native material and sized considering overburden support, traffic loading (assume maintenance traffic, if vault is placed outside right-of-way), and lateral soil pressures when the vault is dry. Infiltration vaults are not allowed in fill slopes unless a geotechnical analysis approves fill stability. The infiltration medium at the bottom of the vault must be native soil.

Infiltration vaults may be constructed using material other than reinforced concrete, such as large, perforated, corrugated metal pipe (see Figure AR.06.1), provided that the following additional criteria are met:

- Bedding and backfill material for the structure must be washed drain rock extending at least 1 foot below the bottom of the structure, at least 2 feet beyond the sides, and up to the top of the structure.
- Drain rock (3 to 1½ inches nominal diameter) must be completely covered with construction geotextile for separation (per the WSDOT Standard Specifications) prior to backfilling. If the drain rock becomes mixed with soil, the affected rock material must be removed and replaced with washed drain rock to provide maximum infiltration effectiveness.

  The perforations (holes) in the bottom half of the pipe must be 1 inch in diameter and start at an elevation of 6 inches above the invert. The nonperforated portion of the pipe in the lower 6 inches is intended for sediment storage to protect clogging of the native soil beneath the structure. The number and spacing of the perforations should be sufficient

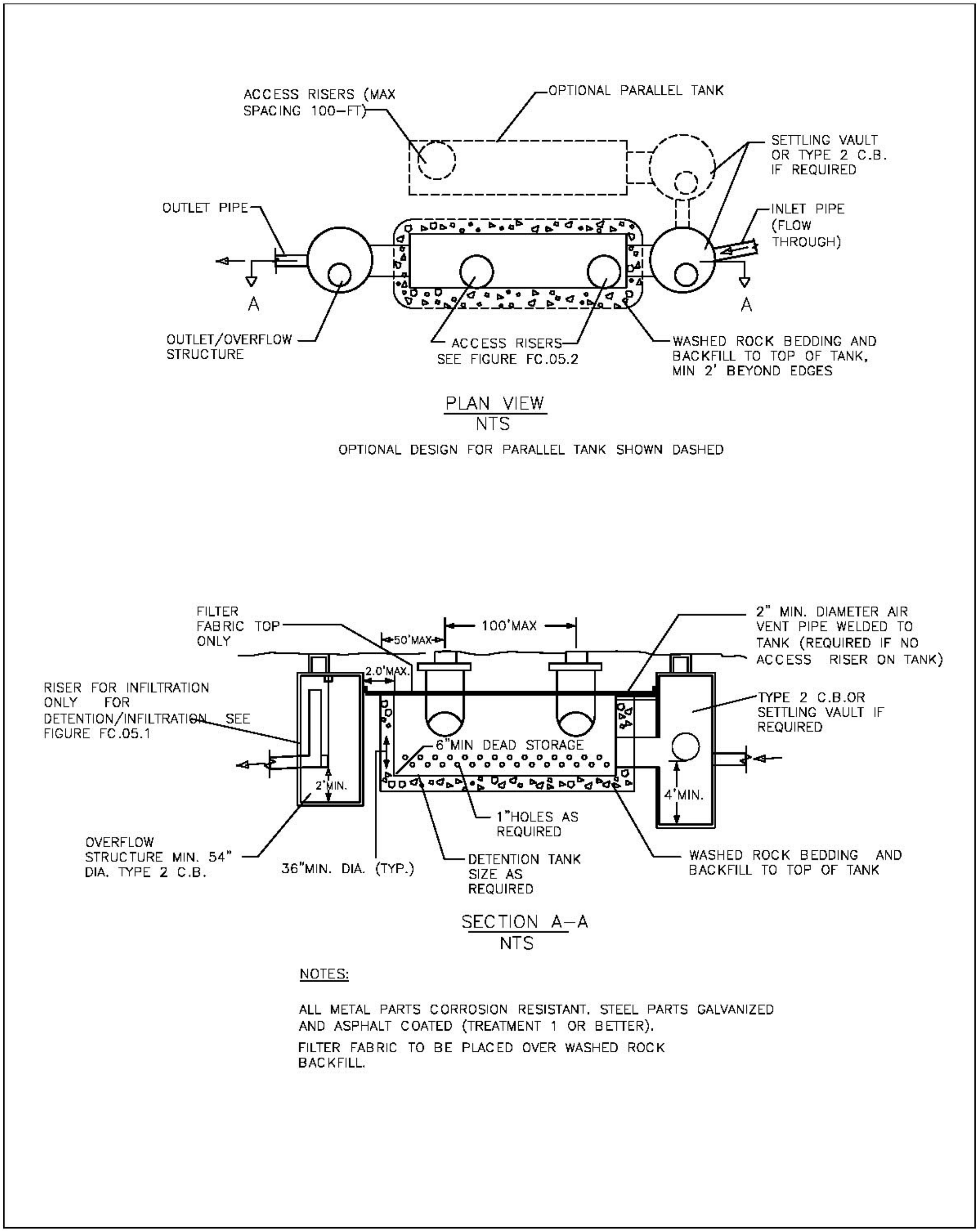


Figure AR.06.1. Infiltration vault constructed with corrugated pipe.

to allow complete infiltration of the soils with a safety factor of 2.0 without jeopardizing the structural integrity of the pipe.

- The criteria for general design**,** materials, structural stability, buoyancy, maintenance access, access roads, and right-of-way are the same as those for detention tanks (BMP AR.11), except for features needed to facilitate infiltration.

Groundwater Issues

Infiltration facilities should not be located where pollutants in contributing stormwater could cause a violation of the Washington State groundwater quality standards (WAC 173-200). Local jurisdictions should be consulted for applicable pollutant-removal requirements upstream of the infiltration facility, and available information must be reviewed to determine whether the site overlies a sensitive groundwater recharge area, sole-source aquifer, or a wellhead protection zone.

Consider the potential impact of pollutants on potable water wells when siting the infiltration facility. Mitigation measures, such as diligent pollutant source control and additional pretreatment must be implemented to ensure that infiltration of pollutants does not result in a violation of groundwater quality standards.

Infiltration rates, depths to groundwater and other hydrologic considerations are included in Chapter 5 of this manual.

Maintenance Access Roads (Access Requirements)

For General maintenance requirements, see Section 6-3.

Construction Criteria

Initial excavation should be conducted to within 1 foot of the final elevation of the infiltration vault base. Final excavation to the finished grade should be deferred until all disturbed areas in the upgradient drainage area have been stabilized or protected. The final phase of excavation should remove all accumulated sediment.

Infiltration vaults, as with all types of infiltration facilities, should generally not be used as temporary sediment traps during construction. If an infiltration vault is to be used as a sediment trap, it must not be excavated to final grade until after the upgradient drainage area has been stabilized. Any accumulation of silt in the vault must be removed before the vault is put into service.

Relatively light-tracked equipment is recommended for excavation to avoid compacting the soil beneath the base of the infiltration vault. The use of draglines and trackhoes should be considered. The infiltration area should be flagged or marked to keep equipment away.

Operation and Maintenance

Infiltration vaults, as with all BMPs, must have routine inspection and maintenance designed into the life performance of the facility. (See Section 6-3 for more details.)

6-2.7. AR.07 – Drywell

Drywell installation.

Eastern Washington	Yes
Western Washington	Yes
Landside Areas	Yes

Object Free Area (OFA)	Yes*
Runway Safety Area (RSA)	No
Taxiway Safety Area (TSA)	No
Clearway (CWY)	Yes*

* Contact FAA Seattle ADO for approval.

Introduction

General Description

Drywells are subsurface concrete structures, typically precast, that convey stormwater runoff into the soil matrix. They can be used as stand-alone structures or as part of a larger drainage system (e.g., the overflow for a bioinfiltration pond).

Applications and Limitations

Drywells may be used for flow control where runoff treatment is not required, for flows greater than the runoff treatment design storm, or where runoff is treated before it is discharged.

This BMP is considered a subsurface infiltration facility and its use would be subject to the rules governing Class V underground injection wells. This type of stormwater facility must be registered through Ecology's UIC (Underground Injection Control) Program.

Uncontaminated or properly treated stormwater must be discharged to drywells in accordance with Ecology's UIC Program (see WAC 173-218).

Presettling and/or Pretreatment

Treatment for removal of TSS, oil, and soluble pollutants may be necessary before the stormwater is conveyed to a drywell. Companion practices, such as street sweeping and catch basin inserts, can provide additional benefits and reduce the cleaning and maintenance needs for the infiltration facility.

Design Flow Elements

Inflow to infiltration facilities is calculated according to the methods described in Chapter 5. The storage volume in the drywell is used to detain runoff prior to infiltration. The infiltration rate is used in conjunction with the size of the storage area to design the facility. To prevent the onset of anaerobic conditions, the infiltration facility must be designed to drain completely 72 hours after the flow to it has stopped.

In general, an infiltration facility should have two discharge modes. The primary mode of discharge is infiltration into the ground. However, when the infiltration capacity of the facility is reached, a secondary discharge mode is needed to prevent overflow. Overflows from an infiltration facility must comply with the requirements of the local jurisdiction.

Flows to Be Infiltrated

Site runoff should be infiltrated to the extent that occurred before the site was developed. Runoff in excess of the drywell's capacity must be detained and released in compliance with the flow control requirement described under Minimum Requirement 7 in Section 1-3.4. (See Section 5-2 of this manual for hydrologic analysis methods applicable to flow control for surface discharges.)

Overflow or Bypass

A primary overflow must be provided to bypass the 100-year postdeveloped peak flow over or around the flow restrictor system.

Structural Design Considerations

Geometry

WSDOT Standard Plans B-25a, B-27, B-27a, and B-27b show typical details for drywell systems. These systems are designed as specified below.

- Drywell bottoms should be a minimum of 5 feet above seasonal high ground-water level or impermeable soil layers. Refer to the *Setback Requirements* below.
- Typically, drywells are 48 inches in diameter (minimum) and are approximately 5 to 10 feet deep or more.
- Filter fabric (geotextile) may need to be placed on top of the drain rock and on trench or drywell sides before the drywell is backfilled to prevent migration of fines into the drain rock, depending on local soil conditions and local jurisdiction requirements.
- Drywells should be spaced no closer than 30 feet center-to-center or twice the structure depth in free-flowing soils, whichever is greater.
- Drywells should not be built on slopes greater than 25 percent (4H:1V).
- Drywells may not be placed on or above a landslide hazard area or slopes greater than 15 percent without evaluation by a professional engineer with geotechnical expertise or a qualified geologist, and approval by the local jurisdiction.

Groundwater Issues

Infiltration facilities should not be located where pollutants in contributing stormwater could cause a violation of the Washington State groundwater quality standards (WAC 173-200). Local jurisdictions should be consulted for applicable pollutant-removal requirements upstream of the infiltration facility, and available information must be reviewed to determine whether the site overlies a sensitive groundwater recharge area, sole-source aquifer, or a wellhead protection zone.

Consider the potential impact of pollutants on potable water wells when siting the infiltration facility. Mitigation measures, such as diligent pollutant source control and additional pretreatment must be implemented to ensure that infiltration of pollutants does not result in a violation of groundwater quality standards.

Infiltration rates, depths to groundwater and other hydrologic considerations are included in Chapter 5 of this manual.

Vadose Zone Requirements

As mentioned under *Geometry*, the base of all infiltration systems should be at least 5 feet above the seasonal high-water level, bedrock (or hardpan), or other low-permeability layer. The base of the facility may be within 3 feet if the groundwater mounding analysis, volumetric receptor capacity, and design of the overflow or bypass structures are judged by the designer to be adequate to prevent overtopping and meet the site suitability criteria.

The designer should investigate whether the soil under the proposed infiltration facility contains contaminants that could be transported by infiltration from the facility. If so, measures should be taken for remediation of the site before the facility is constructed, or an alternative location should be chosen. The designer should also determine whether the soil beneath the proposed infiltration facility is unstable due to improper placement of fill, subsurface geologic features, or other reasons. If so, further investigation and planning should be undertaken before siting the facility.

Site Design Elements

Setback Requirements

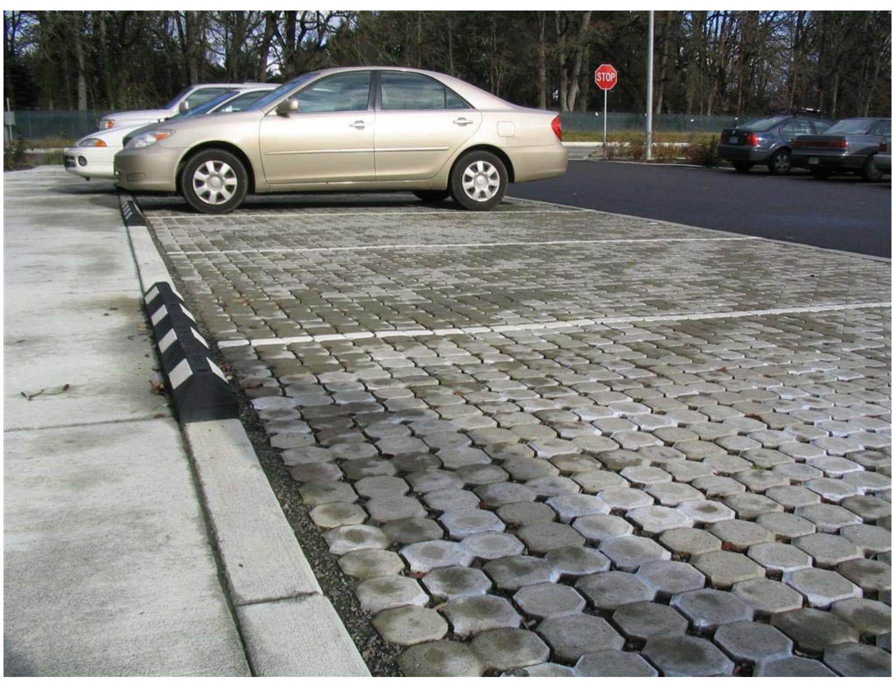
Setback requirements for drywells are the same as those for infiltration ponds (see BMP AR.04).

Signage

The local jurisdiction may require that the drywell have a sign. The sign should be placed for maximum visibility from adjacent airport areas. Any signs must conform to FAA restrictions on objects non-essential for air navigation (FAA AC 150/5300-13).

6-2.8. AR.08 – Permeable Pavement Surfaces

Porous concrete showing rapid infiltration.



Use of porous pavers in parking lot.

Eastern Washington	Yes
Western Washington	Yes
Landside Areas	Yes

Object Free Area (OFA)	No
Runway Safety Area (RSA)	No
Taxiway Safety Area (TSA)	No
Clearway (CWY)	No

Introduction

General Description

Currently, this BMP cannot be considered a stand-alone runoff treatment or flow control BMP. However, when used as part of a project surface, it can reduce the total runoff, thereby providing an overall reduction to the size and placement of other acceptable runoff treatment and flow control BMPs.

Permeable (porous or pervious) *surfaces* can be applied to nonpollution-generating surfaces such as pedestrian/bike paths, raised traffic islands, and sidewalks. Permeable surfaces with a media filtration sublayer (such as sand or an amended soil) could be applied to pollution-generating surfaces (such as parking lots) for calculating runoff treatment. Permeable surfaces allow stormwater to pass through and infiltrate the soil below, thereby reducing the rate and volume of runoff associated with conventional surfacing, and fostering groundwater recharge.

The permeable concrete or asphalt pavement surface is an open-graded mix placed in a manner that results in a high degree of interstitial spaces or voids within the cemented aggregate. This technique demonstrates a high degree of absorption or storage within the voids and infiltration to subsoils. The pavement may be permeable concrete, permeable asphalt, or manufactured systems such as interlocking brick or a combination of sand and brick lattice. Geo-Cell with geotextile and aggregate material may also be considered for limited applications.

Applications and Limitations

Applications

Possible areas for use of these permeable surface materials include:

- Sidewalks, bicycle trails, community trail/pedestrian path systems, or any pedestrian-accessible paved areas (such as traffic islands).
- Vehicle access areas, including emergency stopping lanes, maintenance/enforcement areas on divided highways, and facility maintenance access roads.
- Public and municipal parking lots, including perimeter and overflow parking areas.

Permeable surface systems function as stormwater infiltration areas and temporary stormwater retention areas that can accommodate pedestrians and light- to medium-load parking areas. They are applicable to both residential and commercial applications, with the exception of heavy truck traffic. This combination of functions offers the following benefits:

- Captures and retains precipitation on-site
- Mimics natural soils filtration throughout the pavement depth, underlying sub-base reservoir, and native soils for improved groundwater quality
- Eliminates surface runoff, depending on existing soil conditions
- Greatly reduces or eliminates the need for an on-site stormwater management system
- Reduces drainage water runoff temperatures
- Increases recharge of groundwater
- Provides runoff treatment with a media filtration layer
- Thaws quicker when covered by ice and/or snow.

Handling and placement practices for permeable surfaces are different from conventional pavement placement. Unlike conventional pavement construction, it is important that the underlying native or subgrade soils be nominally consolidated to prevent settling and minimize the effect of intentional or inadvertent heavy compaction due to heavy equipment operation during construction. Consolidation can be accomplished using static dual-wheel small mechanical rollers or plate vibration machines. If heavy compaction does occur, then tilling may be necessary to a depth of 2 feet below the material placement. This would occur prior to subsequent application of the separation and base layers.

Contractors shall have prior experience with constructing permeable surfaces. If a contractor does not have this experience, the contractor shall be required to construct test panels before placement of the main surfacing to demonstrate application competency.

Permeable surfaces are vulnerable to clogging from sediment in runoff and the following techniques will reduce this potential:

- Surface runoff – Permeable surfaces should not be located where turbid runoff from adjacent areas can introduce sediments onto the permeable surface. Designs should slope impervious runoff away from permeable pavement installations to the maximum extent possible.
- Diversion – French drains, or other diversion structures, may be designed into the system to avoid unintended off-site runoff. Permeable systems can be separated using edge drain systems, turnpikes, and 0.15-foot-high tapered bumps.
- Cold climates – Snow removal activities (plowing) and the use of salt and abrasives can increase the risk of clogging.

- Slopes – Off-site drainage slopes immediately adjacent to the permeable surface should be less than 5 percent to reduce the chance of soil loss that would cause clogging.

Limitations

Suitable grades, subsoil drainage characteristics, and groundwater table conditions require good multidisciplinary analysis and design. Proper construction techniques and diligent field inspection during the placement of permeable surfaces are also essential to a successful installation.

- Installation works best with level, adjacent slopes (1 to 2 percent) and on upland soils. Permeable surface installations are not appropriate when adjacent draining slopes are 5 percent or greater.
- An extended period of saturation of the base material underlying the surface is undesirable. Therefore, the subsurface reservoir layer should fully drain in a period of less than 36 hours.
- The minimum depth from the bottom of the base course to bedrock and seasonally high water table should be 3 feet, unless it is possible to engineer a groundwater bypass into the system.
- Sanding or repeated snow removal can lead to a reduction in surface permeability. Permeable surfaces should not be used in traffic areas where sanding or extensive snow removal is carried out in the winter.

Examples of situations where the use of permeable surfaces is not currently recommended include the following:

- Roadway lanes. Because of a number of considerations (e.g., dynamic loading, safety, clogging, heavy loads), more study and experience are needed before using permeable surfaces in these situations. Use of any type of shoulder application whereby the retained moisture drains away from the main line requires coordinated approval from materials, roadway design, hydraulics, and maintenance support staff.
- Areas where the permeable surface will be routinely exposed to heavy sediment loading.
- Areas where the risk of groundwater contamination from organic compounds is high (e.g., fueling stations, commercial truck parking areas, and maintenance and storage yards).
- Within 100 feet of a drinking water well and within areas designated as sole-source aquifers.
- Areas with a high water table or impermeable soil layer.

- Within 100 feet upgradient or 10 feet downgradient from building foundations. Closer upgradient distances may be considered where the minimum seasonal depth to groundwater lies below the foundation, or where it can be demonstrated that infiltrating water from the permeable surface will not affect the foundation.

General Design Criteria

- As long as runoff is not directed to the permeable asphalt from adjacent surfaces, the estimated long-term infiltration rate may be as low as 0.1 inch/hour. Soils with lower infiltration rates should have underdrains to prevent prolonged saturated soil conditions at or near the ground surface within the pavement section (PSAT 2005).
- For initial planning purposes, permeable surface systems will work well on Hydrologic Soil Groups A and B, and can be considered for Group C soils. Standard three-layer placement sections for Group D soils may not be applicable.
- For projects constructed upon Group C and D soils, a minimum of three soil gradation analyses or three infiltration tests should be conducted to establish on-site soil permeability (see SMMWW for Design Procedure). Otherwise, a minimum of one such test should be conducted for Group A and B soils to verify adequate permeability.
- Ideally, the base layer should be designed with sufficient depth to meet flow control requirements (taking into account infiltration). If the infiltration rate and base layer's recharge bed storage does not meet flow control requirements, an underdrain system may be required. The underdrain could be discharged to a bioretention area, dispersion system, or a stormwater detention facility.
- Turbid runoff to the permeable surface from off-site areas is not allowed. Designs may incorporate infiltration trenches or other options to ensure long-term infiltration through the permeable surface.
- Any necessary boreholes must be installed to a depth of 10 feet below the base of the reservoir layer, and the water table must be monitored at least monthly for a year.
- Infiltration systems perform best on upland soils.

On-site soils should be tested for porosity, permeability, organic content, and potential for cation exchange. These properties should be reviewed when designing the recharge bed of pervious surfaces.

Once a permeable surface site is identified, a geotechnical investigation should be performed to determine the quantity and depth of borings/test pits required and any groundwater monitoring needed to characterize the soil infiltration characteristics of the site. Table AR.08.1 provides general guidance on the overall composition of permeable surfaces based on various soil conditions.

In site locations where subgrade materials are marginal, the use of a heavy-duty geogrid placed directly on subgrade may be necessary. A sand layer is placed above the heavy geogrid, followed by geotextile for drainage.

For determining a final design-level infiltration rate, refer to the design guidance provided in Chapter 5. (Note that this guidance applies primarily to infiltration basins and may therefore exclude slower-percolating soils such as loams, which are potentially suitable for permeable surfaces.)

Table AR.08.1. Permeable surface application matrix.

Soil Characterization Chart for Design of Permeable Surface Layers					
Soil Type	**A**	**B**	**C**	**D**	**Notes**
Surface Layer	1 – 4 [(B)]	1 – 4 [(B)]	1 – 4 [(B)]	1 – 4 [(B)]	4-inch depth (min.).
Base Layer	5	5	5	5	6-inch depth (min.). Aggregate base depths of 18 to 36 inches are common depending on storage needs (PSAT 2005).
Separation Layer	7	7	7	7	The separation layer provides a permeable barrier to prevent fine soil particles from migrating up into the base aggregate.
Water Quality Treatment Layer	Not Required [(C)]	Not Required [(C)]	6 or 8	6 or 8	The treatment media can consist of a sand layer or an engineered amended soil (PSAT 2005).
Subgrade Soil	9	9	9	9	If subgrade is overly compacted prior to constructing pavement, till soil 2 feet below the material placement to maintain the soil's permeability.
Underdrain System	No	No	To be determined	To be determined	6-inch-diameter (min.); discharged to bioretention area, natural dispersion, or a detention facility.
Edge Treatment	To be considered	To be considered	To be considered	To be considered	6-inch-diameter (min.); discharged to bioretention area, natural dispersion, or a detention facility.
Subgrade Slope	To be considered	To be considered	To be considered	To be considered	Consider slopes from 1.0% to 2.0%.
Placement Application	10 – 15	10 – 15	10 – 15	11 – 15	

Numbers Referenced in Table AR.08.1:

Surface Type
1) Portland Cement-Based Pervious Pavement Materials
2) Asphalt-Based Pervious Pavement Materials
3) Paving or Lattice Stone
4) Geo-Cell

Base Type
5) BARB (Base Aggregate for Recharge Bed)

Separation
6) Sand
7) Geotextile [(E)]
8) Engineered Amended Soil

Miscellaneous
9) Minimum Consolidation Required

Placements
10) Residential or Access Driveways
11) Sidewalks
12) Bike Paths
13) Traffic Islands
14) Median Turn-Around
15) Parking Lots

Notes Referenced in Table AR.08.1:

(B) The separation of permeable surface installations from impermeable surface runoff may be necessary by installing an edge drain or a similar system.

(C) A treatment layer is not required where the subgrade soil has a long-term infiltration rate < 2.4 inches/hour and a cation exchange capacity greater than or equal to 5-milliequivalents/100 grams of dry soil.

(E) Permeable geotextile must be used to keep the surface layer stable and fines from migrating up through base and surface layers. To obtain geotextile classification, use Geotextile for Underground Drainage, WSDOT Standard Specification Section 9-33, as specified in the special provision Base Aggregate for Recharge Bed and WSDOT *Design Manual,* Section 530.

Design Flow Elements

Flows to Be Infiltrated

The design guidance below assumes that it is feasible to meet the flow control requirements by sizing a storage volume within the subsurface layers. This needs to be explored further for viability. It is possible that the design criteria for an infiltration trench may be more comprehensive and applicable than the general guidelines provided below. There has been discussion in the past that using permeable pavement surfaces is a part of low-impact development (LID) practices and would result only in some form of credit being applied to flow control mitigation.

For western Washington, use an acceptable continuous runoff simulation model to size an infiltration basin, as described in Chapter 5, Infiltration Design Guidelines. For eastern Washington, use an appropriate single event-based model consistent with the Section 5-2 guidelines. For sizing purposes, use the following guidelines:

- The bottom area of an "infiltration basin" will typically be equivalent to the area below the surrounding grade underlying the permeable surface. Adjust the depth of this "infiltration basin" so that it is sufficient to store the required design volume.
- Multiply this depth by a factor of 5. This will determine the depth of the gravel base underlying the permeable surface. This assumes a void ratio of 0.20, a conservative assumption. When a base material that has a different porosity will be used, that value may be substituted to determine the depth of the base. The minimum base depth is 6 inches, which allows for adequate structural support of the permeable surface.
- For a large, contiguous area of permeable surface, such as a parking lot, the area may be designed with a level surface grade and a sloped subgrade to prevent water buildup on the surface, except under extreme conditions. Rare instances of shallow ponding in a parking lot are normally acceptable.
- For projects where ponding is unacceptable under any condition, the surface of the parking lot may be graded at a 1 percent slope leading to a shallow swale, which would function to ensure emergency drainage (similar to an emergency overflow from a conventional infiltration pond). However, the design depth of the base material must be maintained at all locations.

Facility Design Considerations

Geometry

The Special Provisions referenced below are still under development. Until these provisions have been completed, designers should coordinate directly with the WSDOT HQ Materials Laboratory for further guidance on project application requirements.

The following Special Provisions for permeable surfaces can be used to assist with final Plans, Specifications, and Estimates (PS&E) development:

- GSP XXX, Subgrade Preparation for Pervious Surfacing
- GSP XXX, Recharge Bed for Pervious Surfacing
- GSP XXX, Pervious Asphalt
- GSP XXX, Pervious Cement Concrete

Maintenance Considerations

Permeable surfaces require more maintenance than conventional pavement installations. The primary concern in maintaining the continued effectiveness of a permeable surface system is to prevent the surface from clogging with fine sediments and debris. (See Section 6-3 for operation and maintenance guidelines.)

Materials

Permeable surfaces consist of a number of components: the surface pavement, an underlying base layer, a separation layer, and the native soil or subgrade soil (see Figure AR.08.1). An overflow or underdrain system may need to be considered as part of the pavement's overall design.

Surface Layer

The surface layer is the first component of a permeable system's design that creates the ability for water to infiltrate through the surface. Permeable paving systems allow infiltration of storm flows; however, the wearing course should not be allowed to become saturated from excessive water volume stored in the aggregate base layer (PSAT 2005).

Portland Cement-Based Pervious Pavement Materials

The surface layer consists of specially formulated mixtures of Portland cement, uniform open-graded coarse aggregate, and potable water. The depth of the surface layer may increase from a minimum of 4 inches, depending on the required bearing strength and pavement design requirements. The gradation required to obtain a pervious concrete pavement is of the open graded or coarse type (AASHTO Grading No. 67: ¾ inch and lower). For additional information, refer to the pervious pavement specifications.

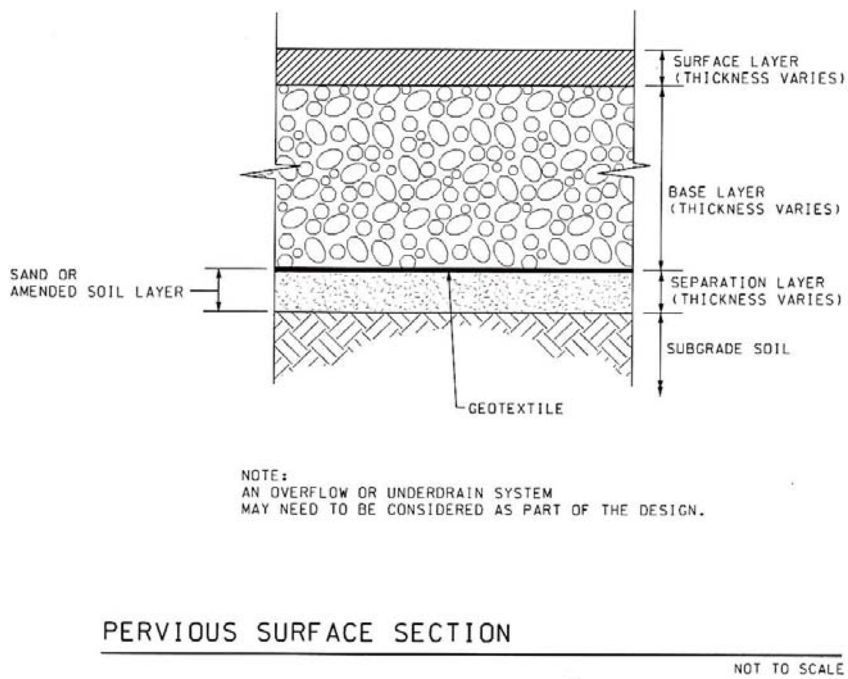


Figure AR.08.1. Permeable pavement surface detail.

Due to the relatively low water content of the concrete mix, an agent may be added to retard concrete setup time**.** When properly handled and installed, pervious pavement has a higher percentage of void space than conventional pavement (approximately 12 to 21 percent), which allows rapid percolation of stormwater through the pavement. The initial permeability can commonly exceed 200 inches per hour (Chollack et al. 2001; Mollick et al. 2000).

Asphalt-Based Pervious Pavement Materials

The surface asphalt layer consists of an open-graded asphalt mixture. The depth of the surface layer may increase from a minimum of 4 inches, depending on the required bearing strength and pavement design requirements.

Pervious asphalt pavement consists of an open-graded coarse aggregate. The pervious asphalt creates a surface layer with interconnected voids that provide a high rate of permeability.

Paving and Lattice Stone

Paving and lattice stones consist of a high-compressive-strength stone that may increase from a minimum depth of 4 inches, depending on the required bearing strength and pavement design requirements. When placed together, these paving stones create a reinforced surface layer. An open-graded fine aggregate fills the voids, which creates a system that provides infiltration into a permeable base layer. This system can be used in parking lots, bike paths, or areas that receive common local traffic.

The Ashway Park and Ride in Marysville utilized paving stones with a peat treatment layer (see photos below).

Geo-Cell (PVC Containment Cell)

A Geo-Cell surface stabilization system consists of a high-strength, UV-resistant, PVC-celled panel that is 4 inches thick. The celled panels can be filled with soil and covered with turf by installing sod. Base gravel may also be used to fill the celled panels. Both applications create a surface layer.

The Geo-Cell creates an interlock layer with interconnected voids that provide a high rate of permeability of water to an infiltrative base layer. The common application for this system is on slopes, pedestrian/bike paths, parking areas, and low-traffic areas.

Base Layer

The underlying base material is the second component of a permeable surface's design. The base material is a crushed aggregate and provides:

- A stable base for the pavement.
- A high degree of permeability to disperse water downward through the underlying layer to the separation layer.
- A temporary reservoir that slows the migration of water prior to infiltration into the underlying soil.
- Base material is often composed of larger aggregate (1.5 to 2.5 inches) with smaller stone (leveling or choker course) between the larger stone and the wearing course. Typical void space in base layers ranges from 20 to 40 percent (WSDOT 2001; Cahill et al. 2003).
- Depending on the target flow control standard and physical setting, retention or detention requirements can be partially or entirely met in the aggregate base (PSAT 2005).
- Aggregate base depths of 18 to 36 inches are common depending on storage needs, and they provide the additional benefit of increasing the strength of the wearing course by isolating underlying soil movement and imperfections that may be transmitted to the wearing course (Cahill et al. 2003).

Separation Layer

The third component of permeable systems is the separation layer. This layer consists of a non-woven geotextile fabric and possibly a treatment media base material. A geotextile fabric layer is placed between the base material and the native soil to prevent migration of fine soil particles into the base material, followed by a runoff treatment media layer if required.

- For geotextile, see WSDOT Standard Specification 9-33.

- For separation base material, see the FHWA manual, *Construction of Pavement Subsurface Drainage Systems* (2002), for aggregate gradation separation base guidance.
- A treatment media layer is not required where subgrade soil is determined to have a long-term infiltration rate less than 2.4 inches per hour and a CEC of the subgrade soil that is at least 5 milliequivalents/100 grams of dry soil or greater (Ecology 2005).
- If a treatment media layer is used, it must be distributed below the geotextile layer and above the subgrade soil. The media can consist of a sand filter layer or amended soil. Engineered amended soil layers should be a minimum of 18 inches and incorporate compost, sphagnum peat moss, or other organic material to provide a cation exchange capacity of greater than or equal to 5 milliequivalents/100 grams dry soil (Ecology 2005). Gradations of the treatment media should follow base sizing.

Subgrade Soil

The underlying subgrade soil is the fourth component of pervious pavement. Runoff infiltrates into the soil and moves to the local interflow or groundwater layer. Compaction of the subgrade must be kept to an absolute minimum to ensure that the soil maintains a high rate of permeability, while maintaining the structural integrity of the pavement.

Liners

The primary purpose of a permeable pavement system is to promote infiltration. An impervious liner will discontinue infiltration; therefore, a flow control credit is not allowed and the surface is modeled as impervious.

Cost

- Materials and mixing costs for permeable asphalt are similar to conventional asphalt. In general, local contractors are currently not familiar with permeable asphalt installation, and additional costs for handling and installation should be anticipated. Estimates for porous pavement material and installation are approximately $.60 to $.70/square foot and will likely be comparable to standard pavement as contractors become more familiar with the product. Due to the lack of experience regionally, this is a rough estimate. The cost for base aggregate will vary significantly depending on base depth for stormwater storage and is not included in the cost estimate (PSAT 2005).

6-2.9. AR.09 – Detention Pond

Detention pond Along SR 18 in King County.

Eastern Washington	Yes
Western Washington	Yes
Landside Areas	Yes

Object Free Area (OFA)	No
Runway Safety Area (RSA)	No
Taxiway Safety Area (TSA)	No
Clearway (CWY)	No

Introduction

General Description

Detention ponds are open basins that provide live storage volume to enable reduction of stormwater runoff flow rates and matching of predeveloped flow durations discharged from a project site (see Figures AR.09.1 and AR.09.2). Detention ponds are commonly used for flow control in locations where space is available for an aboveground stormwater facility but where infiltration of runoff is infeasible. Detention ponds are not a preferred method of flow control due to wildlife concerns. If detention ponds are to be constructed in the airport environment, wildlife deterrence must be a top priority to ensure that the stormwater facility does not present a safety hazard to aircraft. They should also be monitored in accordance with the recommendations in Chapter 3. Detention ponds used for flow control do not have a permanent pool of water.

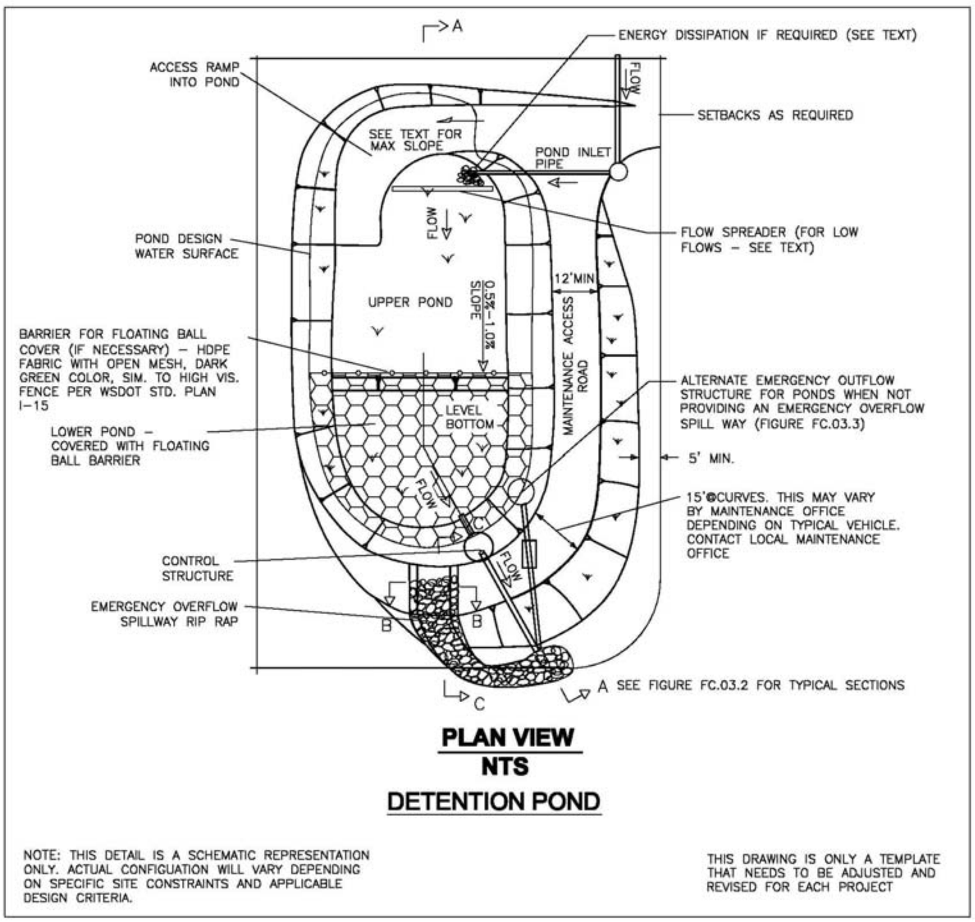


Figure AR.09.1. Detention pond.

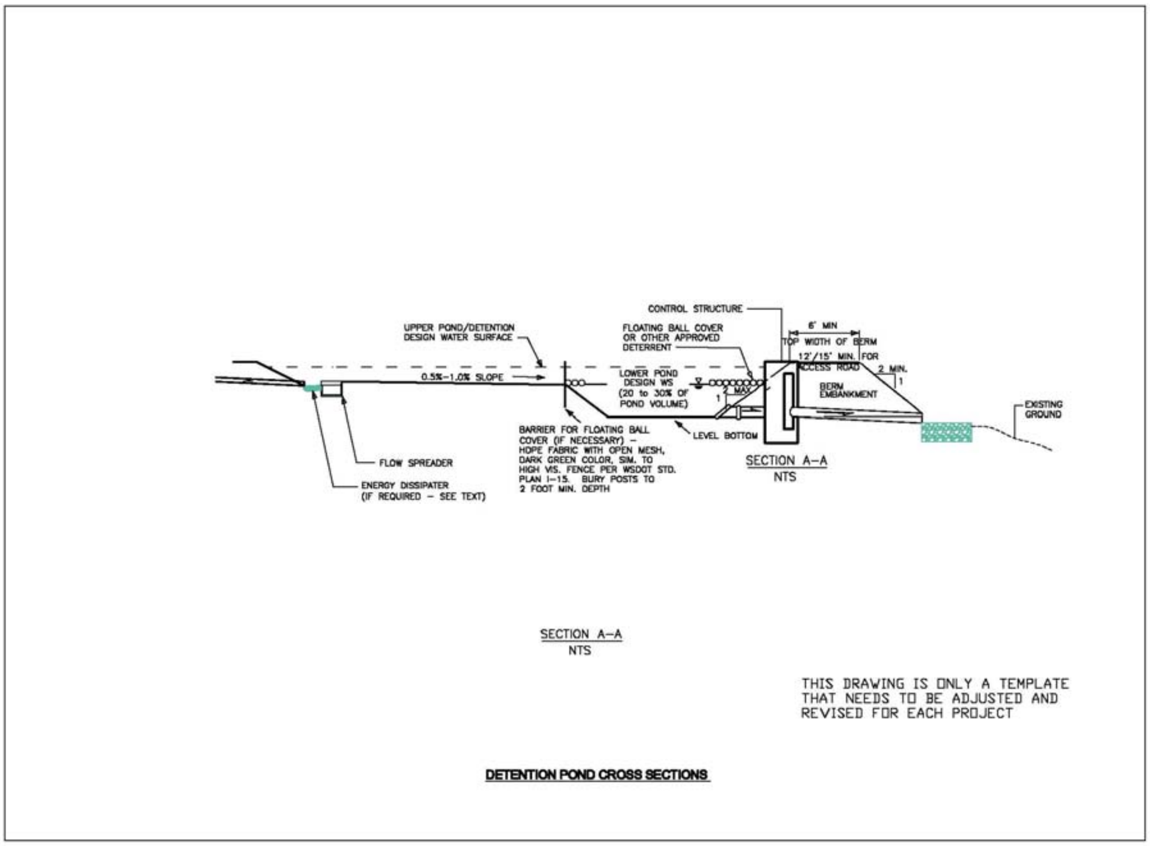


Figure AR.09.2. Detention pond: cross sections.

Detention ponds designed using continuous runoff simulation are expected to have adequate live storage volume for multiple day rain events and still meet discharge performance objectives.

Airport Specific Design Considerations

Infiltration of runoff is the preferred method of flow control following appropriate runoff treatment. However, in areas where infiltration is not feasible, runoff detention must be implemented.

Airports often have a large amount of open space, so detention ponds can be an attractive choice for a flow control facility, given the relative low cost and ease of construction and maintenance (as compared to underground vaults, for example). However, if detention ponds are to be constructed in the airport environment, wildlife deterrence must be a top priority to assure that the stormwater facility does not present a safety hazard to aircraft. There are several design modifications from the detention pond design from the HRM, SMMWW, and SMMEW.

- Alternate pretreatment required (proprietary hydrodynamic separator, filter strip or swale)
- Two-cell configuration
- Avoid irregular-shaped ponds and maximize length to width ratio (ideally, a 3:1 minimum length to width ratio)
- Steeper side slopes (2 maximum horizontal: 1 vertical)
- Vegetation restrictions
- Planting of bottom of upstream cell required (see Appendix A)
- Flow spreader required at inlet
- Elimination of sediment storage depth to reduce hazard associated with standing water.

Detention ponds are designed to drain completely between storm events or have enough available storage so that they perform adequately in multiple day rain events.

Additional information on the specific modifications and the reason for the modified design are included in the following sections.

Design Flow Elements

Pretreatment

As shown in Figure AR.09.2, the detention pond design modified for airports eliminates the 6 inches of sediment storage typically included in detention ponds. The reason for this change is to eliminate any permanent pool of water that could attract waterfowl or other hazardous wildlife. Due to the lack of sediment storage, pretreatment is required to avoid frequent pond maintenance. Pretreatment can be accomplished by one of the following:

- Vegetated filter strip (AR.12)
- Biofiltration swale (AR.13)
- **Proprietary presettling devices.** These hydrodynamic separators are designed to remove debris, sediment, and large oil droplets. They are considered "emerging technologies". Emerging technologies that have been evaluated by Ecology have one of three designations; general use level designation (GULD), conditional use level designation (CUD), or pilot level designation (PLD). Technologies with a GULD may be used without additional approval for the designated treatment category (pretreatment in this case), while Ecology approval would be required for technologies that are designated as PLD or CUD. Additional information on proprietary presettling devices may be found at the following Washington State Department of Ecology website: <http://www.ecy.wa.gov/programs/wq/stormwater/newtech/vortex_enhanced_sedimentation.html>.

Flows to Be Detained

The volume and outflow design for detention ponds must be determined in accordance with the flow control criteria presented in Section 1-3.4 under Minimum Requirement 7. Hydrologic analysis and design methods are presented in Chapter 5.

Note: The design water surface elevation is the elevation of the riser, or the highest water surface elevation that is projected in order to satisfy the outflow criteria.

Detention Ponds in Infiltrative Soils

Detention ponds may occasionally be sited on soils that are sufficiently permeable for a properly functioning infiltration system. These detention ponds have both a surface discharge and a subsurface discharge. If infiltration is accounted for in the detention pond sizing calculations, the pond design process and corresponding site conditions must meet all the requirements for infiltration ponds (BMP AR.04), including a soils report, soil infiltration testing, groundwater protection, presettling, and construction techniques.

Standing Water Duration

The Federal Aviation Administration (FAA) recommends that open stormwater management facilities at airports be designed to drain within 48 hours of the conclusion of a storm event to eliminate the attraction to waterfowl presented by an open pool of water (FAA 2004a). Particularly in western Washington, multiple storm events over a short period time are not uncommon. The detention pond design presented in this section therefore is a two-cell design.

The lower part of the pond may contain water for extended periods following a storm event, due to consecutive storm events. This lower pond is to be designed with additional wildlife deterrence measures so that it does not become a hazard to aircraft.

The continuous simulation models commonly used in Washington (WWHM and MGSFlood) do not allow the user to readily confirm the drawdown time of detention facilities. Therefore, rather than requiring a specific drawdown time, the deeper cell was sized to minimize the time that there is an exposed water surface, without confirming that the drawdown time meets the FAA criteria. Based on hydrologic modeling of historic average daily pond volume, sizing the lower pond to contain 30 percent of the detention volume will minimize the exposed water surface (and potential attractant to wildlife) in the upper pond during most years (Parametrix 2007 [included in Appendix B]).

Flow Spreader

A flow spreader is required immediately downstream of the inlet to the upstream cell to prevent erosion of the sloped bottom of the upstream cell. See Figure AR.09.1 and the HRM for details on design and placement of flow spreaders.

Overflow or Bypass

A primary overflow (usually a riser pipe within the outlet control structure) must be provided for the detention pond system to bypass the 100-year post developed peak flow over or around the flow restrictor system. Overflow can occur when the facility is full of water due to plugging of the outlet control structure or high inflows; the primary overflow is intended to protect against breaching of the pond embankment (or overflows of the upstream conveyance system). The design must provide controlled discharge of pond overflows directly into the downstream conveyance system or another acceptable discharge point.

As shown in Figure AR.09.2, the detention pond design modified for airports eliminates the 6 inches of sediment storage typically included in detention ponds. The reason for this is to eliminate any permanent pool of water that could attract waterfowl or other hazardous wildlife (e.g., great blue herons). Due to the lack of sediment storage, the primary inlet pipe to the control structure may be at risk of clogging.

A secondary inlet to the pond discharge control structure is recommended in airport settings as protection against overflows should the primary inlet pipe to the control structure become plugged. In these situations, the designer should first determine if a secondary inlet to the control structure would be appropriate. One option for the secondary inlet is a grated opening (called a jailhouse window) in the control structure that functions as a weir when used as a secondary inlet. Contact a professional design engineer for the specific structural design modification requirements on this design option.

Another common option for a secondary inlet is to allow flow to spill into the top of the discharge control structure, or another structure linked to the discharge control structure, that is fitted with a debris cage (called a debris cage; details may be found in the HRM). Other options can be used for secondary inlets, subject to assurance that they would not be plugged by the same mechanism that plugged the primary inlet pipe. The maximum circumferential length of a jailhouse window weir opening must not exceed one-half the control structure circumference.

Outlet Control Structure

Control structures are catch basins or manholes with a restrictor device for controlling outflow from a facility to meet the desired performance. Riser-type restrictor devices (tees or FROP-Ts) also provide some incidental oil/water separation to temporarily detain oil or other floatable pollutants in runoff due to accidental spill.

The restrictor device usually consists of two or more orifices and/or a weir section sized to meet performance requirements.

Standard control structure details are shown in WSDOT Standard Plan B-10.40-00 and WSDOT Standard Plan B-10.60-00 (baffle type flow restrictor).

Multiple Orifice Restrictor

In most cases, control structures need only two orifices, one at the bottom and one near the top of the riser (although additional orifices may optimize the detention storage volume). Several orifices may be located at the same elevation if necessary to meet performance requirements.

- The minimum circular orifice diameter is 0.5 inches. For orifices that have a diameter of less than 1 inch, the designer should use a flow screen that fits over the orifice to help prevent plugging. Consult a professional design engineer for more details on orifice screens.
- The minimum vertical rectangular orifice length is 0.25 inches.
- Orifices may be constructed on a tee section as shown in WSDOT Standard Plan B-10.40-00.
- In some cases, performance requirements may require the top orifice or elbow to be located too high on the riser to be physically constructed (e.g., a 13-inch-diameter orifice cannot be positioned 6 inches from the top of the riser). In these cases, a notch weir in the riser pipe may be used to meet performance requirements.
- Consideration must be given to the backwater effect of water surface elevations in the downstream conveyance system. High tailwater elevations may affect performance of the restrictor system and reduce live storage volumes.

Riser and Weir Restrictor

- Properly designed weirs may be used as flow restrictors. However, they must be designed to provide for primary overflow of the developed 100-year peak flow discharging to the detention facility.
- The combined orifice and riser (or weir) overflow may be used to meet performance requirements; however, the design must still provide for primary overflow of the developed 100-year peak flow, assuming all orifices are plugged.
- For different orifice, weir, and riser configurations and design equations and assumptions, see the MGSFlood or Western Washington Highways Hydrology Analysis Model (WHAM) training manual (🖰 http://www.wsdot.wa.gov/eesc/design/hydraulics/training.htm).

Emergency Overflow Spillway

In addition to the overflow provisions described above, detention ponds must have an emergency overflow spillway. For impoundments of 10 acre-feet or greater, the emergency overflow spillway must meet the state's dam safety requirements (see discussion on dam safety later in this section). For impoundments with less than 10 acre-feet of storage, ponds must have an emergency overflow spillway that is sized to pass the 100-year postdeveloped peak flow in the event of total control structure failure (e.g., blockage of the control structure outlet pipe) or extreme inflows. Emergency overflow spillways are intended to control the location where flows overtop the pond perimeter and to direct overflows into the downstream conveyance system or other acceptable discharge point.

Emergency overflow spillways must be provided for ponds with constructed berms more than 2 feet high or for ponds located on grades more than 5 percent. (As an option, emergency overflow may be provided by a Type II manhole fitted with a debris cage.) The emergency overflow structure must be designed to pass the 100-year postdeveloped peak flow directly to the downstream conveyance system or to another acceptable discharge point. Where an emergency overflow spillway would discharge to a steep slope, consideration should be given to providing an emergency overflow structure *in addition to* the spillway.

The emergency overflow spillway must be armored with riprap that is sized in conformance with Ecology's Outlet Protection BMP guidance (BMP C209 in Volume II of the SMMWW) or its equivalent. The spillway must be armored across its full width, beginning at a point midway in the cross section of the berm embankment and extending downstream to where emergency overflows reenter the conveyance system (see Figure AR.09.3).

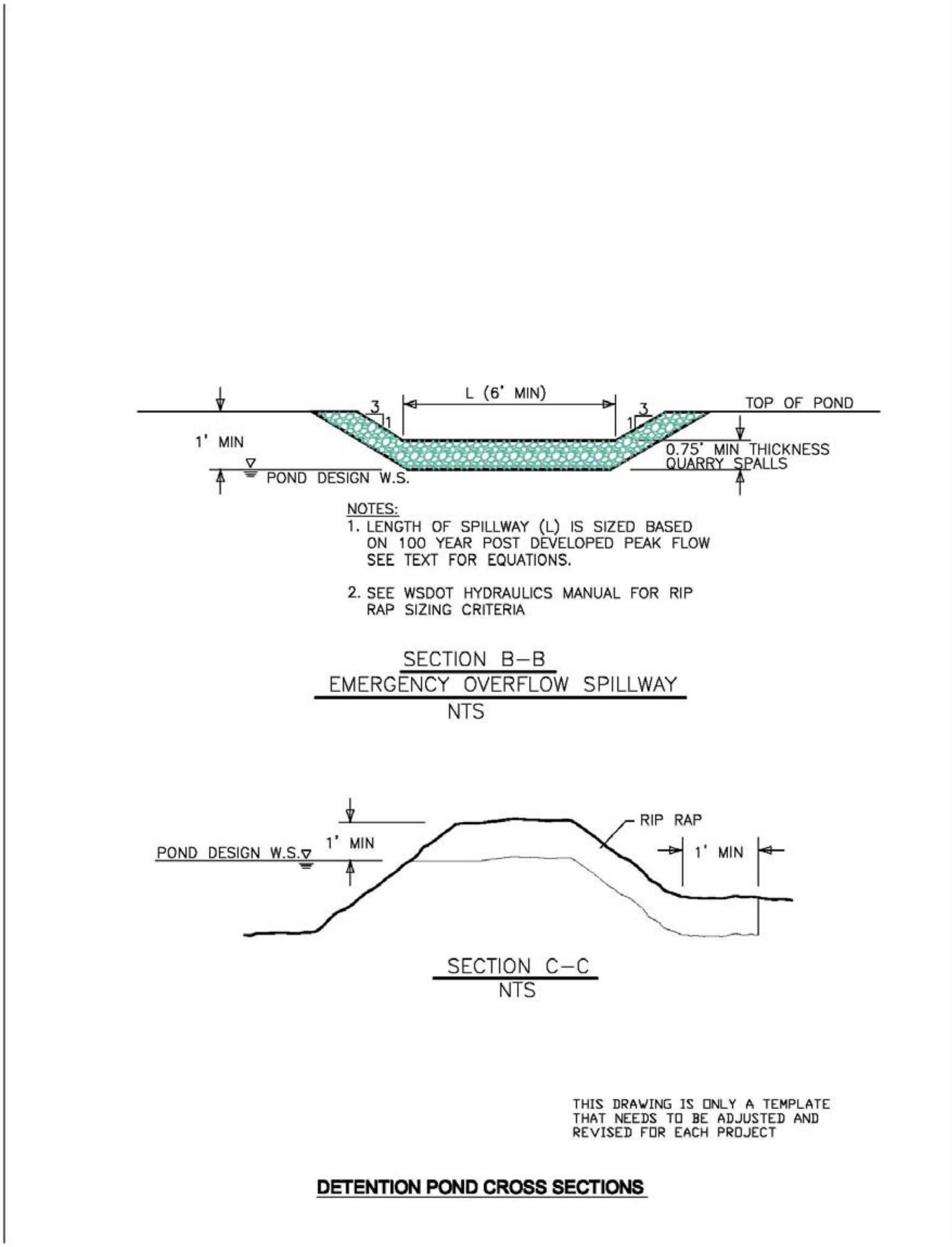


Figure AR.09.3. Overflow spillway cross section.

Emergency overflow spillway designs must be analyzed as broad-crested trapezoidal weirs using the following equation (either one of the weir sections shown in Figure AR.09.3 may be used):

$$Q_{100} = C\,(2g)^{1/2}\left[\frac{2}{3}LH^{3/2} + \frac{8}{15}(\operatorname{Tan}\theta)\,H^{5/2}\right] \qquad \textbf{(AR.09-11)}$$

where: Q_{100} = peak flow for the 100-year runoff event (cfs)
C = discharge coefficient (0.6)
g = gravity (32.2 ft/sec^2)
L = length of weir (ft)
H = height of water over weir (ft)
θ = angle of side slopes.

Assuming C = 0.6 and Tan θ = 3 (for 3H:1V slopes), the equation becomes:

$$Q_{100} = 3.21[LH^{3/2} + 2.4\,H^{5/2}] \qquad \textbf{(AR.09-12)}$$

To find the width *L* for the weir section, the equation is rearranged to use the computed Q_{100} and trial values of H (0.2 feet minimum):

$$L = [Q_{100}/(3.21H^{3/2})] - 2.4\,H \text{ or 6 feet minimum} \qquad \textbf{(AR.09-13)}$$

Structural Design Considerations

Geometry

Pond inflows must enter through a conveyance system separate from the outlet control structure and outflow conveyance system. Maximizing distance between the inlet and outlet is encouraged to produce a long narrow facility that discourages use by waterfowl (FAA 2004a). It may also help promote sediment trapping, but that is not the main purpose of the detention pond. The following are guidelines for the detention pond geometry:

- The maximum width at the design water surface elevation (riser elevation) should be 30 feet (WDFW 2005). If a wider pond is needed, one of the *Adaptive Stormwater Facility Design* measures from Section 3-4 should be incorporated to reduce wildlife site lines.
- Detention ponds at airports should be designed with two cells, sized as described in the *Design Flow Elements/ Standing Water Duration* section.
- Pond bottoms must have gradient ≥ 0.5 to 1.0 percent slope, making sure that the outlet/control structure is at the absolute lowest point (and the pond actually drains down) and located in the enclosed or covered, downstream cell of the pond.
- Pond length to width ratio should be 3:1 or greater when possible. Implementing this for larger pond volumes may result in unreasonably long facilities that are difficult to patrol. If a wider pond is needed, one of

the *Adaptive Stormwater Facility Design* measures from Section 3-4 should be incorporated to reduce wildlife site lines.

- Interior pond side slopes should be 2:1 or steeper. Material used to construct the interior pond slopes 2:1 or steeper must be evaluated for stability and approved by a licensed geotechnical engineer.

Unless the pond is completely covered by a wildlife deterrent Section 3-4 it must be designed with upper and lower cells as described. Sizing of cells is described under Design Flow Elements.

Berms, Baffles, and Slopes

- Interior side slopes up to the emergency overflow water surface should be 2H:1V. If the detention pond is located in an area that is accessible to the public (landside applications), a fence should be provided due to the steep interior side slopes.
- Exterior side slopes must not be steeper than 2H:1V unless analyzed for stability by a geotechnical engineer.
- Pond walls may be vertical retaining walls subject to the following:
    - They are constructed of minimum 3,000-psi structural reinforced concrete.
    - All construction joints must be provided with water stops.
    - Cast-in-place wall sections must be designed as retaining walls. A licensed civil engineer with structural expertise must stamp structural designs for cast-in-place walls.
    - Walls must be placed on stable, well-consolidated native material with suitable bedding per the WSDOT Standard Specifications. Walls must not be placed in fill slopes unless the slopes have been analyzed in a geotechnical report for stability and constructability.
    - A fence is provided along the top of the wall if the detention pond is located in an area that is accessible to the public, such as adjacent to landside parking lots.
    - The designer discusses the design of the pond with the local maintenance office to determine if there are maintenance access issues.
    - The design is stamped by a licensed civil engineer with structural expertise.

- Other retaining walls such as rockeries, concrete, masonry unit walls, and keystone-type walls may be used if designed under the direction of a geotechnical engineer or a civil engineer with structural expertise. If the entire pond perimeter is to be retaining walls, ladders should be provided on the full height of the walls for safe access by maintenance staff.

Embankments

- Pond berm embankments must be constructed in accordance with Section 2-03.3(14)C Method C of the WSDOT Standard Specifications.
- For berm embankments 6 feet high or less, the minimum top width should be 6 feet or as recommended by a geotechnical engineer.
- Pond berm embankments must be constructed on native consolidated soil (or adequately compacted and stable fill soils analyzed by a geotechnical engineer), free of loose surface soil materials, roots, and other organic debris.
- Pond berm embankments greater than 4 feet high must be constructed by excavating a key trench equal to 50 percent of the berm embankment cross-sectional height and width, unless specified otherwise by a geotechnical engineer.
- Antiseepage filter-drain diaphragms must be placed on outflow pipes in berm embankments impounding water with depths greater than 8 feet at the design water surface. Additional guidance on filter-drain diaphragms is given in Ecology's Dam Safety Guidelines, Part IV, Dam Construction and Design (Section 3.3B, pages 70–72): http://www.ecy.wa.gov/programs/wr/dams/Images/pdfs/guidelines_part_4.pdf

Dam Safety for Detention BMPs

Stormwater detention facilities that can impound 10 acre-feet (435,600 cubic feet, or 3.26 million gallons) or more of runoff with the water level at the embankment crest are subject to state dam safety requirements, even if water storage is intermittent and infrequent (WAC 173-175-020[1]). The principal safety concern is for the downstream population at risk if the embankment or other impoundment structure should breach and allow an uncontrolled release of the pond contents. Peak flows from impoundment failures are typically much larger than the 100-year flows, which these ponds are typically designed to accommodate.

Ecology's Dam Safety Office uses consequence-dependent design levels for critical project elements. There are eight design levels with storm recurrence intervals ranging from 1 in 500 years for design step 1, and to 1 in 1,000,000 years for design step 8. The specific design step for a particular project depends on the downstream population and other resources that would be at risk from a failure of the impoundment. Precipitation events more extreme than the

100-year event may be rare at any one location, but have historically occurred somewhere within Washington State every few years (on average).

With regard to the engineering design of stormwater detention facilities, the primary effect of the state's dam safety requirements is in sizing the emergency spillway to accommodate the runoff from the dam safety design storm without overtopping the impoundment structure (typically a berm or other embankment). The hydrologic computation procedures are the same as those for the original pond design, except that the computations must use more extreme precipitation values and the appropriate dam safety design storm hyetographs. This information is described in detail within guidance documents developed by and available from Ecology's Dam Safety Office (contact information is provided below). In addition to the other design requirements for stormwater detention BMPs described elsewhere in this manual, dam safety requirements should be an integral part of planning and design for stormwater detention ponds. It is most cost effective to consider these requirements at the beginning of the project.

In addition to the hydrologic and hydraulic issues related to precipitation and runoff, other dam safety requirements relate to geotechnical issues; construction inspection and documentation; dam breach analysis; inundation mapping; emergency action planning; and periodic inspections by project owners and by engineers from the Dam Safety Office. All of these requirements, plus procedural requirements for plan review, approval, and payment of construction permit fees are described in detail in guidance documents developed by and available from the Dam Safety Office.

In addition to the written guidance documents, engineers from the Dam Safety Office are available to provide technical assistance to project owners and design engineers in understanding and addressing the dam safety requirements for their specific project. In the interest of providing a smooth integration of dam safety requirements into the stormwater detention project and streamlining the Dam Safety Office engineering review and issuance of the construction permit, it is recommended and requested that the Dam Safety Office be contacted early in the project planning process. The Dam Safety Office is located in the Ecology Headquarters building in Lacey. Electronic versions of the guidance documents in PDF format are available on the Ecology web site (🖰 http://www.ecy.wa.gov/programs/wr/dams/dss.html).

Wildlife Deterrents

The downstream cell of the pond should be covered with a wildlife deterrent. One option for a deterrent is a floating ball cover which minimizes or eliminates access to and visibility of open water from the air and land, is long lived, and allows access for pond maintenance. Section 3-4 contains additional information on options for wildlife deterrents. A barrier for the floating ball cover must be included that separates the upstream and downstream cells (see Figures AR.09.1 and AR.09.2).

Ponds should not be greater than 30 feet in width due to the potential for attracting wildlife. If a wider pond is needed, one of the *Adaptive Stormwater Facility Design* measures from Section 3-4 should be incorporated to reduce wildlife site lines.

Full vegetation is also a deterrent (Stevens et al. 2005). For more information on vegetation, including planting considerations and plants recommended for use in airport settings, see Appendix A.

Groundwater Issues

Identification and Avoidance

Flow control BMPs must be constructed above the seasonal high groundwater table. Storage capacity and proper flow attenuation are compromised if groundwater levels are allowed to fluctuate above the limits of live storage. High groundwater may also cause seepage into the detention facility resulting in a permanent pool of water that attracts hazardous wildlife. The project should locate flow control pond, vault, and tank locations such that there is a separation between the local groundwater table elevation and the bottom of the proposed BMP. In some cases, this may require that a much shallower pond be constructed in order to function properly.

The groundwater table elevation in and around the flow control facility needs to be determined early on in the project. This can be done by installing piezometers at the BMP location and taking water table readings over at least one wet season. The wet season is generally defined as October 1 through April 30. Where it has been determined that site conditions within the project limits are not conducive to constructing flow control facilities due to high groundwater levels, another type of flow control should be identified or the project proponent must consult with Ecology on an alternative.

Seeps and Springs

Intermittent seeps along cut slopes are typically fed by a shallow groundwater source (interflow) flowing along a relatively impermeable soil stratum. These flows are storm-driven and should discontinue after a few weeks of dry weather. However, if the site exhibits other more continuous seeps and springs, extending through longer dry periods, they are likely from a deeper groundwater source. An open detention pond is not recommended in locations subject to continuous base flow from seeps or springs.

Site Design Elements

Setback Requirements

Detention ponds with open water are a known hazardous wildlife attractant. The measures described above should reduce many of the hazards and attraction commonly associated with detention facilities. Therefore, construction of these facilities on and around airports is not specifically prohibited as long as standing water duration is minimized (less than 48 hours).

However, detention facilities should not be placed in certain operational areas of the airport, including the object free area (OFA), runway safety area (RSA), taxiway safety area (TSA), Clearway (CWY) or Stopway (SWY).

Section 3-4 provides a detailed discussion on additional siting considerations for stormwater facilities, including detention ponds. In the event that the design modifications cannot be implemented, the FAA recommends that these detention ponds be located beyond the following distances from an airport's aircraft movement areas, loading ramps, or aircraft parking areas:

- 5,000 feet for airports serving piston-powered aircraft.
- 10,000 feet for airports serving turbine-powered aircraft.
- 5 statute miles if the attractant causes hazardous wildlife movement into or across the approach or departure airspace.

Detention ponds must be a minimum of 5 feet from any property line or vegetative buffer. This distance may need to be increased based on the permit requirements of the local jurisdiction.

Detention ponds must be 100 feet from any septic tank or drain field.

For proposed detention ponds within 200 feet of a building, runway or taxiway or on hills with known side-hill seeps, a geotechnical report should be prepared for the project that evaluates any potential structural site instability due to extended subgrade saturation and/or head loading of the permeable layer, including the potential impacts to downgradient properties. The report should address the adequacy of the proposed detention pond locations and recommend the necessary setbacks from any steep slopes, building foundations, and runway/taxiway subgrade.

Landscaping (Planting Considerations)

The project should revegetate the side slopes of the flow control pond to the maximum extent practicable (unless a synthetic liners is used). The interior of the pond's upstream cell should be hydroseeded to prevent erosion and promote settling of solids with fine, turf-forming grasses recommended in the airport setting. The downstream cell should, at minimum, be hydroseeded above the 100-year water surface elevation and on the exterior side slopes before completion of the project to prevent erosion. Planting a continuous, dense strip of small shrubs along the lip of a pond may also deter waterfowl. Hydroseeding should be coordinated with a qualified airport wildlife biologist to make sure seeds or young plant shoots are not available when hazardous migratory wildlife are expected.

Appendix A contains lists of plants recommended as generally suitable for revegetation and landscaping in airport settings. Guidance for planting methods is also provided below. For plant species lists and planting methods specific to local site conditions, consult a qualified landscape architect, biologist, and/or other specialist.

- Plants must be selected that encourage filtering and settling of suspended solids and that are not attractive to hazardous wildlife. Select fine, turf-forming grasses where moisture is appropriate for growth.
- If possible, perform seeding of the BMP during the seeding windows specified in the WSDOT Standard Specifications section 8-01.3(2)F, Dates for Application of Final Seed, Fertilizer, and Mulch. To the greatest extent possible, seeding should be conducted at a time when wildlife are not as prevalent and/or are less likely to be attracted to seed. Perform planting of the BMP during the planting windows specified in the WSDOT Standard Specifications section 8-03.3(8) Planting. Supplemental irrigation during establishment of vegetation may be required depending on seeding and planting times.
- Stabilize soil areas upslope of the BMP to prevent erosion and excessive sediment deposition.
- Apply seed using methods and timing that limits the attractiveness of the seeded area to hazardous wildlife. Seeding should be coordinated with a qualified airport wildlife biologist to make sure seeds or young plant shoots are not available when hazardous migratory wildlife are expected.
- Plant BMPs with species that can withstand periodic saturation as well as extended dry periods.

Fencing

If the pond is located in an area that is accessible to the public, such as a facility located on the landside, fencing is recommended due to the steep interior slopes (and/or retaining walls).

Signage

The local jurisdiction may require that the detention pond have a sign. The sign should be placed for maximum visibility from adjacent streets, sidewalks, and paths.

General Maintenance Requirements

Maintenance access to facilities must be available without interfering with daily airport operations. For general maintenance requirements, see Section 6-3.

6-2.10. AR.10 – Detention Vault

Detention vault during construction at Bellingham.

Eastern Washington	Yes
Western Washington	Yes
Landside Areas	Yes

Object Free Area (OFA)	Yes*
Runway Safety Area (RSA)	No
Taxiway Safety Area (TSA)	No
Clearway (CWY)	Yes*

* Contact FAA Seattle ADO for approval.

Introduction

General Description

Detention vaults are underground storage facilities, typically constructed with reinforced concrete, that provide live storage volume to enable reduction of stormwater runoff flow rates and matching of predeveloped flow durations discharged from a project site, where necessary (see Figure AR.10.1). Detention vaults are commonly used for flow control when infiltration is infeasible and space is not available for surface detention facilities. Detention vaults are designed to drain completely after a storm event so that the live storage volume is available for the next event.

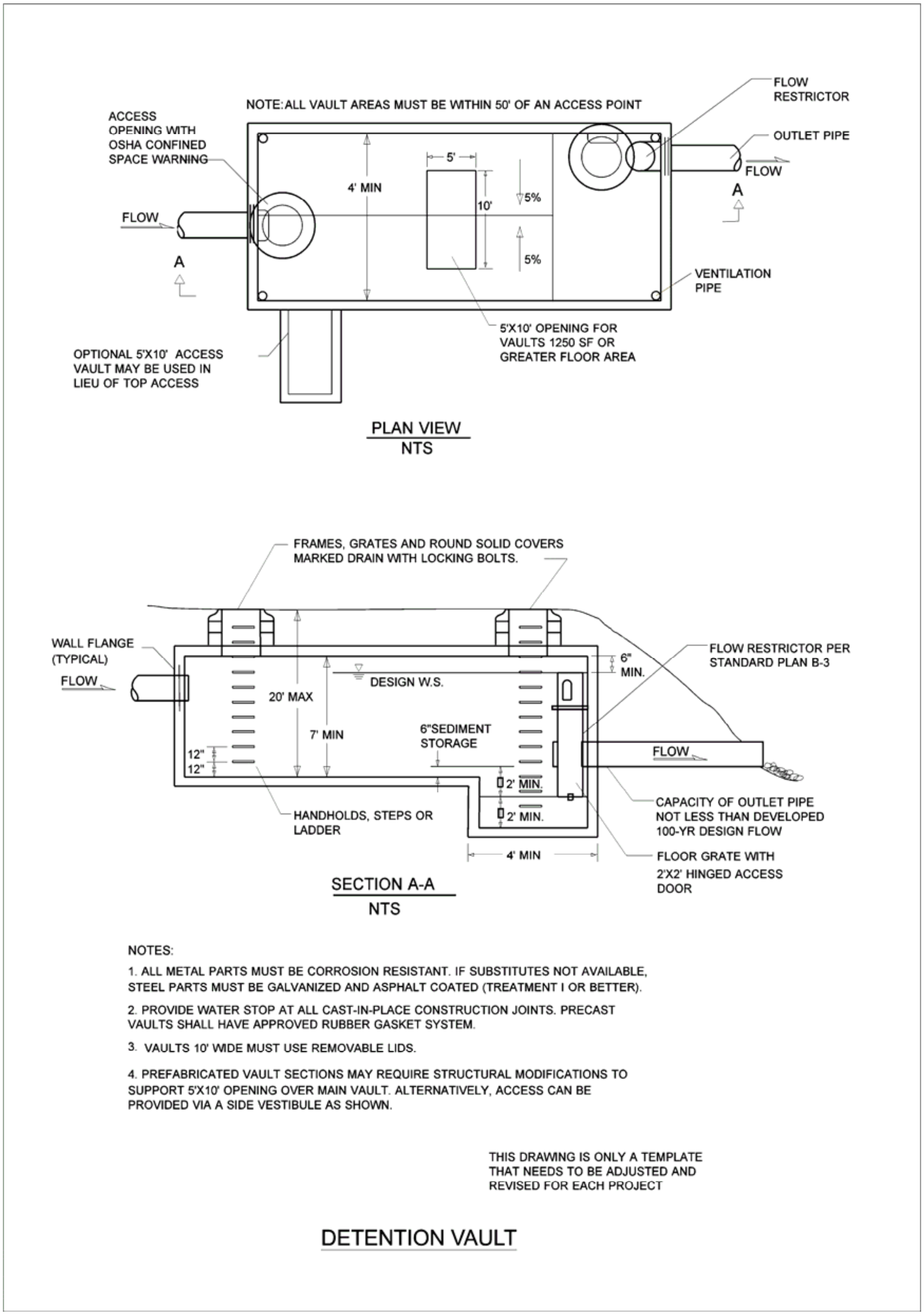


Figure AR.10.1. Detention vault.

Applications and Limitations

Detention vaults are commonly used for projects that have limited space and thus have no room for a pond. Detention tanks (see BMP AR.11) are a similar option for these situations. Although underground facilities are appealing because of their minimal right of way requirements and lack of attraction for wildlife, they typically do not function as well as ponds. Due to their lack of visibility, care must be taken with vaults and tanks to determine when maintenance is necessary. Adequate access for maintenance must also be provided.

Detention vaults may be designed as flow-through systems with bottoms level (longitudinally) or sloped toward the inlet to facilitate sediment removal. The distance between the inlet and outlet should be maximized, as feasible. Detention vaults can be constructed to include dead storage in the bottom for runoff treatment.

Design Flow Elements

Flows to Be Detained

The volume and outflow design for detention vaults must be in accordance with flow control criteria presented in Section 1-3.4, under Minimum Requirement 7. Hydrologic analysis and design methods are presented in Sections 5-1 and 5-2 in this manual. Note: The design water surface elevation is the highest water surface elevation projected in order to satisfy the outflow criteria.

Overflow or Bypass

A primary overflow, which is usually a riser pipe within the control structure (see BMP AR.09), must be provided to bypass the 100-year postdeveloped peak flow over or around the flow restrictor system.

Outlet Control Structure

Control structures are catch basins or manholes with a restrictor device for controlling outflow from a facility to meet the desired performance. Riser-type restrictor devices (tees or FROP-Ts) also provide some incidental oil/water separation to temporarily detain oil or other floatable pollutants in runoff due to accidental spill.

The restrictor device usually consists of two or more orifices and/or a weir section sized to meet performance requirements.

Standard control structure details are shown in WSDOT Standard Plan B-10.40-00 and WSDOT Standard Plan B-10.60-00 (baffle type flow restrictor).

Structural Design Considerations

Geometry

Detention vaults may be designed with bottoms level (longitudinally) or sloped toward the inlet to facilitate sediment removal. The distance between the inlet and outlet should be maximized, as feasible.

The detention vault bottom may slope at least 5 percent from each side toward the center, forming a broad V to facilitate sediment removal. More than one V may be used to minimize vault depth. However, the vault bottom may be flat with a minimum of 6 inches of sediment storage if removable panels are provided over the entire vault. It is recommended that the removable panels be at grade, have stainless steel lifting eyes, and weigh no more than five tons per panel.

The invert elevation of the outlet should be elevated above the bottom of the vault to provide an average 6 inches (or greater) of sediment storage over the entire bottom. The outlet should also be elevated a minimum of 2 feet above the orifice to retain oil within the vault. To accomplish this, a sump can be constructed in the vicinity of the outlet (see Figure AR.10.1).

For maintenance access, the maximum depth from finished grade to the vault invert should be 20 feet. The minimum internal height should be 7 feet from the highest point of the vault floor (not sump), and the minimum width should be 4 feet. The minimum internal height requirement may not be needed for any areas covered by removable panels.

Note: If a vault is over 20 feet in width, it must be designed by a professional engineer and regularly inspected.

Materials

Minimum 3,000-psi structural reinforced concrete may be used for detention vaults. All construction joints must be provided with water stops.

All vaults must meet structural requirements for overburden support and H-20 traffic loading. Refer to WSDOT's *Standard Specifications for Road, Bridge, and Municipal Construction* (*Standard Specifications*; WSDOT 2006d) for more information. Vaults located under roadways must meet any live load requirements of the local jurisdiction. Cast-in-place wall sections must be designed as retaining walls. A licensed civil engineer with structural expertise must stamp structural designs for cast-in-place vaults. Vaults must be placed on stable, well-consolidated native material with suitable bedding per the WSDOT Standard Specifications. Vaults must not be placed in fill slopes unless the slopes have been analyzed in a geotechnical report for stability and constructability.

Groundwater Issues

Criteria are the same as for detention ponds (see BMP AR.09).

Site Design Elements

Setback Requirements

Detention vaults must be a minimum of 5 feet from any property line or vegetative buffer. This distance may need to be increased based on the permit requirements of the local jurisdiction.

Detention vaults must be 100 feet from any septic tank or drain field, except wet vaults, which must be a minimum of 20 feet.

The designer should obtain a geotechnical report for the project that evaluates any potential structural site instability due to extended subgrade saturation or head loading of the permeable layer, including the potential impacts to downgradient properties (especially on hills with known side-hill seeps). The report should address the adequacy of the proposed detention vault locations and recommend the necessary setbacks from any steep slopes and building foundations.

General Maintenance Requirements

Maintenance access to facilities must be available without interfering with daily airport operations. For general maintenance requirements, see Section 6-3.

6-2.11. AR.11 – Detention Tank

Eastern Washington	Yes
Western Washington	Yes
Landside Areas	Yes

Object Free Area (OFA)	Yes*
Runway Safety Area (RSA)	No
Taxiway Safety Area (TSA)	No
Clearway (CWY)	Yes*

* Contact FAA Seattle ADO for approval.

Introduction

General Description

Detention tanks are underground storage facilities, typically constructed with large-diameter corrugated metal pipe, that provide live storage volume to enable reduction of stormwater runoff flow rates and matching of predeveloped flow durations discharged from a project site (see Figure AR.11.1). Detention tanks are commonly used for flow control where infiltration is infeasible and space is not available for surface detention facilities and where costs may be lower compared to an underground detention vault (see BMP AR.10). Detention tanks are designed to drain completely after a storm event so that the live storage volume is available for the next event.

Applications and Limitations

Detention tanks are commonly used for projects that have limited space and thus have no room for a pond. Although underground facilities are appealing because of their minimal right of way requirements and lack of attraction for wildlife, they typically do not function as well as ponds. Due to their lack of visibility, care must be taken with vaults and tanks to determine when maintenance is necessary. Adequate access for maintenance must also be provided

Detention tanks may be designed as flow-through systems with manholes in line to promote sediment removal and facilitate maintenance. Tanks may also be designed as backup systems if preceded by runoff treatment facilities because little sediment should reach the inlet/control structure, and low head losses can be expected because of the proximity of the inlet/control structure to the tank. (See the optional parallel tank in Figure AR.11.1.)

Design Flow Elements

Flows to Be Detained

The volume and outflow design for detention tanks must be in accordance with flow control criteria presented in Section 1-3.4, under Minimum Requirement 6. Hydrologic analysis and design methods are presented in Sections 5-1 and 5-2 in this manual.

Note: The design water surface elevation is the highest water surface elevation projected in order to satisfy the outflow criteria.

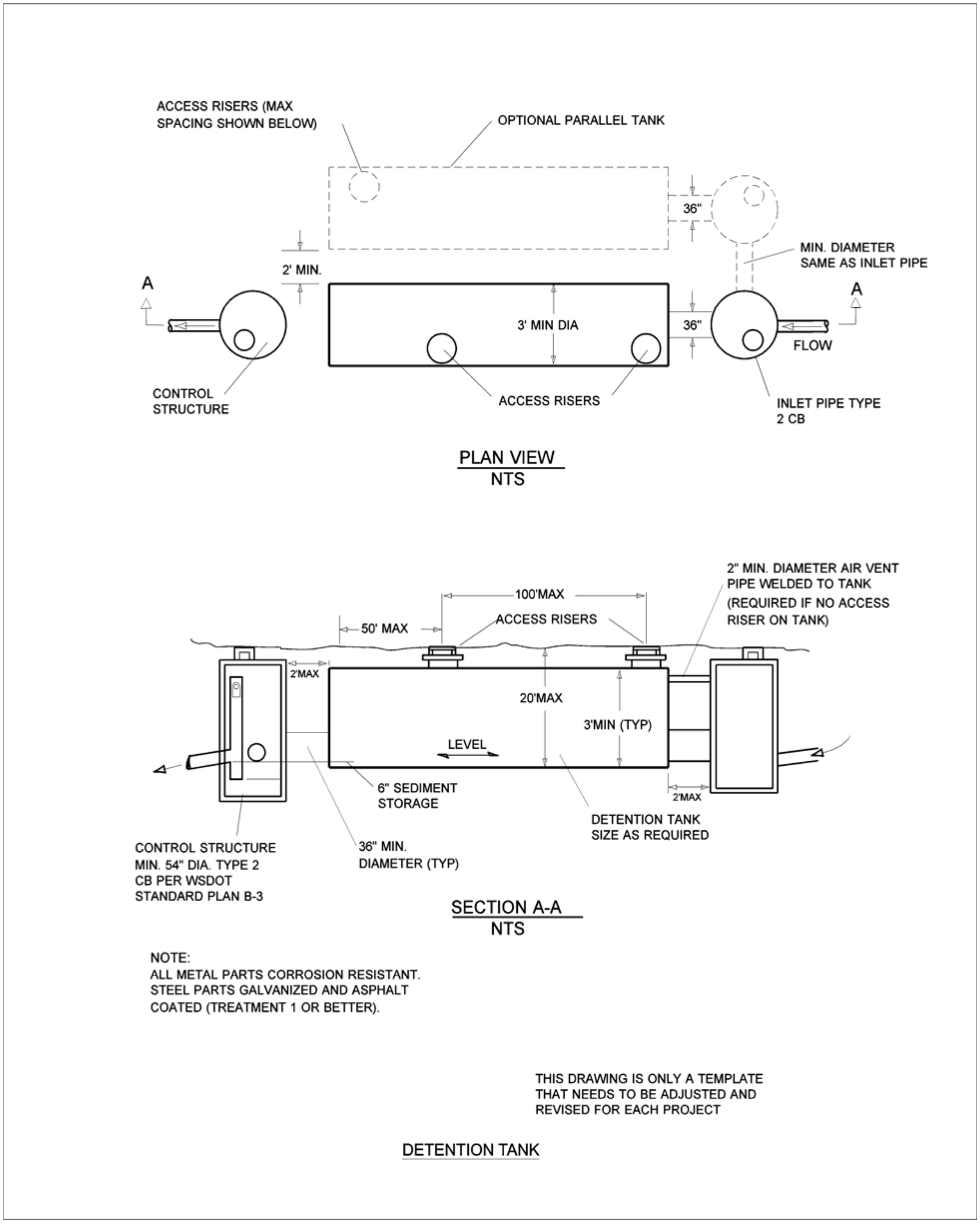


Figure AR.11.1. Detention tank.

Overflow or Bypass

A primary overflow, which is usually a riser pipe within the control structure (see BMP AR.09), must be provided to bypass the 100-year postdeveloped peak flow over or around the flow restrictor system.

Outlet Control Structure

Control structures are catch basins or manholes with a restrictor device for controlling outflow from a facility to meet the desired performance. Riser-type restrictor devices (tees or FROP-Ts) also provide some incidental oil/water separation to temporarily detain oil or other floatable pollutants in runoff due to accidental spill.

The restrictor device usually consists of two or more orifices and/or a weir section sized to meet performance requirements.

Standard control structure details are shown in WSDOT Standard Plan B-10.40-00 and WSDOT Standard Plan B-10.60-00 (baffle type flow restrictor).

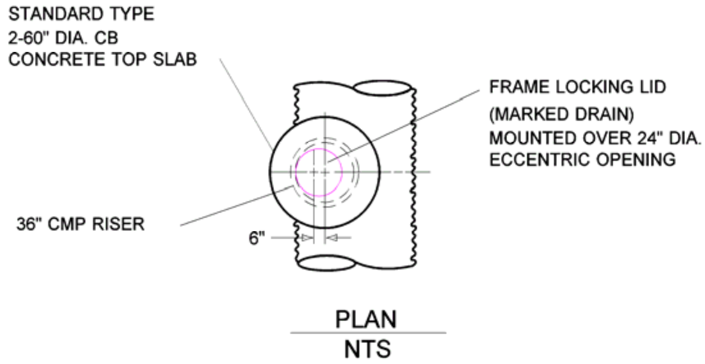
Structural Design Considerations

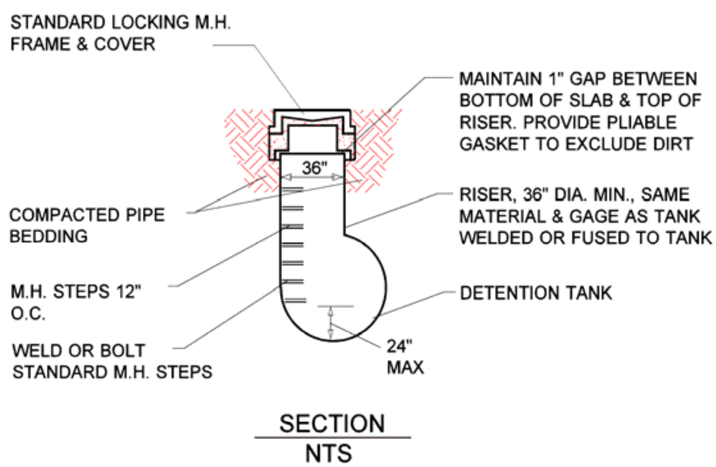
Geometry

- The detention tank bottom should be located 6 inches below the inlet and outlet to provide dead storage for sediment.
- The minimum pipe diameter for a detention tank is 36 inches.
- Tanks larger than 36 inches in diameter may be connected to adjoining tanks in a manifold arrangement with a short section—2-foot maximum length—of 36-inch-minimum-diameter pipe.
- For maintenance access, the maximum depth from finished grade to the tank invert should be 20 feet.

Note: Control structures and access risers should have additional ladder rungs to allow ready access to all tank inlet and outlet pipes, regardless of water level (see Figures AR.11.1 and AR.11.2).

- In moderately pervious soils where seasonal groundwater may induce flotation, buoyancy tendencies must be balanced either by ballasting with backfill or concrete backfill, providing concrete anchors, increasing the total weight, or providing subsurface drains to permanently lower the groundwater table. Calculations that demonstrate stability must be documented.





NOTES:

1. USE ADJUSTING BLOCKS AS REQUIRED TO BRING FRAME TO GRADE.
2. ALL MATERIALS TO BE ALUMINUM OR GALVANIZED AND ASPHALT COATED (TREATMENT 1 OR BETTER).
3. MUST BE LOCATED FOR ACCESS BY MAINTENANCE VEHICLES.
4. MAY SUBSTITUTE WSDOT SPECIAL TYPE IV MANHOLE (RCP ONLY).

THIS DRAWING IS ONLY A TEMPLATE THAT NEEDS TO BE ADJUSTED AND REVISED FOR EACH PROJECT

DETENTION TANK ACCESS RISER DETAIL

Figure AR.11.2. Detention tank access riser detail.

Materials

Galvanized metals leach zinc into the environment, especially in standing water situations. Leaching can result in zinc concentrations toxic to aquatic life. Therefore, use of galvanized materials in stormwater facilities and conveyance systems is discouraged. Where other metals, such as aluminum or stainless steel; or plastics, are available, they should be used.

Pipe material, joints, and protective treatment for tanks should be in accordance with Section 9.05 of the WSDOT *Standard Specifications*.

Tanks must meet structural requirements for overburden support and traffic loading, if appropriate. H-20 live traffic loads must be accommodated for tanks lying under parking areas and access roads. Metal tank end plates must be designed for structural stability at maximum hydrostatic loading conditions. Flat end plates generally require thicker-gage material than the pipe or require reinforcing ribs. Tanks must be placed on stable, well-consolidated native material with suitable bedding. Tanks must not be placed in fill slopes unless the slopes have been analyzed in a geotechnical report for stability and constructability.

Note: If a tank is over 20 feet in width, it must be designed by a professional engineer and regularly inspected.

Groundwater Issues

Criteria are the same as for detention ponds (see BMP AR.09).

Site Design Elements

Setback Requirements

Detention tanks must be a minimum of 5 feet from any property line or vegetative buffer. This distance may need to be increased based on the permit requirements of the local jurisdiction.

Detention tanks must be 100 feet from any septic tank and drain field, except wet vaults, which must be a minimum of 20 feet.

The designer should obtain a geotechnical report for the project that evaluates any potential structural site instability due to extended subgrade saturation or head loading of the permeable layer, including the potential impacts to downgradient properties (especially on hills with known side-hill seeps). The report should address the adequacy of the proposed detention tank locations and recommend the necessary setbacks from any steep slopes and building foundations.

General Maintenance Requirements

Maintenance access to facilities must be available without interfering with daily airport operations. For general maintenance requirements, see Chapter 5.

6-2.12. AR.12 – Vegetated Filter Strip

Vegetated filter strip in along airport runway.

Eastern Washington	Yes
Western Washington	Yes
Landside Areas	Yes

Object Free Area (OFA)	Yes*
Runway Safety Area (RSA)	No
Taxiway Safety Area (TSA)	No
Clearway (CWY)	Yes

* Contact FAA Seattle ADO for approval.

Introduction

General Description

Vegetated filter strips are land areas of planted vegetation and amended soils situated between the pavement surface and a surface water collection system, pond, wetland, stream, or river. (See Figure AR.12.1 for an illustration of a typical vegetated filter strip.)

Vegetated filter strips accept overland sheet flow runoff from adjacent impervious areas. They rely on their flat cross slope and dense vegetation to maintain sheet flows. Their primary purpose is to remove sediments and other pollutants coming directly off the pavement. Vegetated filter strips function by slowing runoff velocities, trapping sediment and other

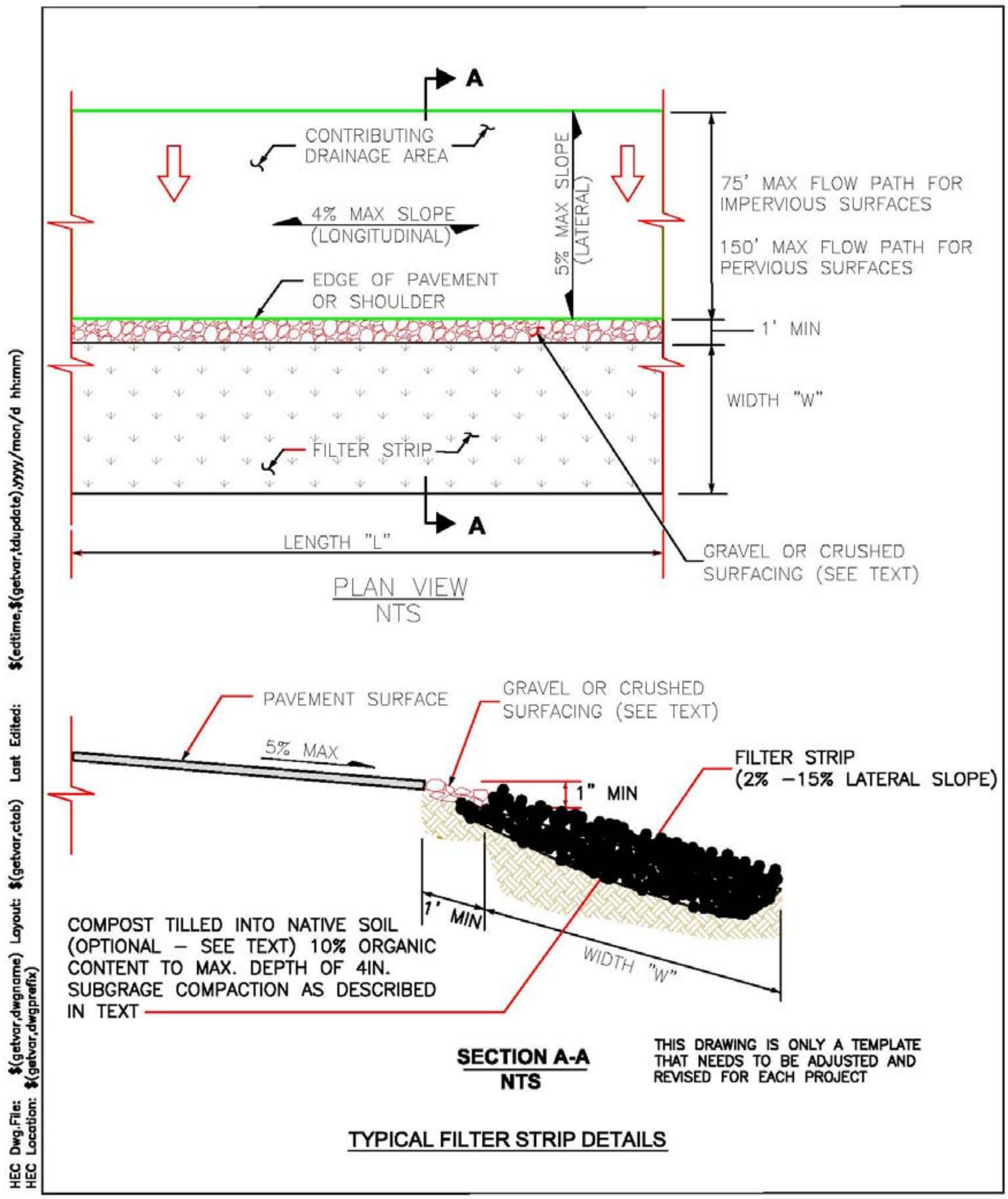


Figure AR.12.1. Typical vegetated filter strip.

pollutants, and providing some infiltration and biologic uptake. Frequently planted with turf grasses, the strips may also incorporate native vegetation such as small herbaceous shrubs to Effective BMP planting design makes the system more effective in treating runoff and providing root penetration into subsoils, thereby enhancing infiltration. As with all vegetated stormwater management systems in the airport setting, plantings should be selected with limited attractiveness to hazardous wildlife. Examples of plantings suitable for use in airport settings are included in plant lists provided in Appendix A.

Timing of planting is also a critical component. Hydroseeding can become a significant attractant if done such that new growth develops during periods when hazardous migratory birds can be present. A qualified airport wildlife biologist should be consulted when hydroseeding is planned.

The design approach for vegetated filter strips involves site design techniques to maintain prescribed maximum sheet flow distances, as well as to ensure adequate temporary storage, so that the design storm runoff is treated. Vegetated filter strips are particularly suited to providing treatment for linear contributing areas. In the airport setting, filter strips would most likely be associated with runways or taxiways. If filter strips are adjacent to critical airport facilities, ponding or storage of runoff is prohibited, due to the potential to attract hazardous wildlife.

Vegetated filter strips can also be used as a pretreatment BMP in conjunction with bioretention, biofiltration, media filtration, or infiltration BMPs. The sediment and particulate pollutant load that could reach the primary BMP is reduced by the pretreatment, which in turn reduces maintenance costs and enhances the pollutant-removal capabilities of the primary BMP.

There are three methods described in this section for designing vegetated filter strips: *basic* vegetated filter strips, *compost-amended* vegetated filter strips (CAVFS), and *narrow area* vegetated filter strips. The narrow area vegetated filter strip is the simplest method to design; however, its use is limited to impervious flow paths less than 30 feet, such as some taxiways or service roads. If space is available to use the basic vegetated filter strip design or the CAVFS, either of the two designs should be used in preference to the narrow area vegetated filter strip. For flow paths greater than 30 feet, designers should follow the design method for the basic vegetated filter strip or the CAVFS.

The basic vegetated filter strip is a compacted embankment adjacent to a paved surface that is subsequently hydroseeded. The CAVFS is a variation of the basic vegetated filter strip that adds soil amendments to the embankment. The soil amendments improve infiltration characteristics, increase surface roughness, and improve plant sustainability. If located within the Runway Safety Area or other critical airport operation zone, soil below the 4 inches of amended soil must meet the compaction and weight-bearing requirements of the airport (see *Structural Design Considerations*).

The CAVFS design incorporates compost into the native soils per the guidance in Section 5-4.2. The CAVFS bed should have a final organic content of 10 percent. Once permanent vegetation is established, the advantages of the CAVFS are higher surface roughness; greater retention and infiltration capacity; improved removal of soluble cationic contaminants through sorption; improved overall vegetative health; and a reduction of invasive weeds. Compost-amended systems have somewhat higher construction costs due to more expensive materials, but require less land area for runoff treatment, which can reduce overall costs. Recent comparative field monitoring of CAVFS and standard vegetated filter strip installations show similar pollutant concentrations from the two BMP types (Herrera 2007a). However, the CAVFS-type also removed a considerable volume, leading to lower pollutant loads.

Airport Specific Design Considerations

The following are airport-specific design modifications from the filter strips from the SMMEW, SMMWW, and HRM:

- CAVFS limited to top 4 inches in airside applications
- CAVFS use within 100 feet of airfield operations areas should include measures to control worms that may attract wildlife
- If a gravel flow spreader is used, gravel should be outside of the runway shoulder and should meet the specifications for shoulder ballast listed in Section 9-03.9(2) of the WSDOT Standard Specifications.

Additional information on the specific modifications and the reason for the modified design are summarized in the next section.

Vegetated filter strips (*narrow area* and *basic*) can be used to meet basic runoff treatment objectives or as part of a treatment train to provide additional removal of phosphorus or dissolved metals.

CAVFS can be used to meet basic runoff treatment and enhanced runoff treatment (dissolved metals only) objectives.

Applications

- Vegetated filter strips can be effective in reducing sediments and pollutants associated with sediments, such as phosphorus, pesticides, or insoluble metallic salts.
- Because they do not pond water on the surface for long periods, vegetated filter strips help maintain the temperature norms of the water, deter creating habitat for disease vectors such as mosquitoes, and decrease attractiveness to hazardous wildlife.
- In the airport environment, vegetated filter strips can generally be located adjacent to the runways, taxiways, and access roads within the airside and anywhere on the landside.

- Designs can be modified to reduce runoff volumes and peak flows when needed or desired so long as they do not increase ponding.

Limitations

- If sheet flow cannot be maintained, vegetated filter strips will not be effective.
- Vegetated filter strips generally are not suitable for steep slopes or large impervious areas that can generate high-velocity runoff.
- Use of vegetated filter strips in airside locations must meet compaction requirements (see *Structural Design Considerations)*.
- For most project applications where less than 10 feet of roadside embankment or available side slope is available for water quality treatment, the media filter drain (see BMP AR.14) is a more suitable BMP option.
- Improper grading can render this BMP ineffective.
- The flow attenuation properties of vegetated filter strips and amended vegetated filter strips are only beginning to be studied. Monitoring studies are being conducted to evaluate the peak flow, runoff volume and flow duration reductions achieved by vegetated filters strips along roadways and ultimately give designers the ability to model water losses in vegetated filter strips.
- Design methodology for sizing CAVFS in western Washington uses a continuous flow model and is different from the design methodology for sizing basic vegetated filter strips in western Washington. See Chapter 5.
- Design methodology for sizing CAVFS in eastern Washington is identical to the design methodology for sizing basic vegetated filter strips in eastern Washington. Both use a more traditional design storm.
- Worms on runways could attract birds, thereby creating an aircraft hazard. If compost amendment is used in the vicinity of runways, the designer should consult with airport officials regarding earthworm management. If the airport does not have routine worm control measures in place (sweeping worms off impervious surfaces following heavy rains, applying worm repellent along the edge of impervious surfaces, physically blocking worms from tarmac) then compost amendment should not be used within 100 feet of runways.

Design Flow Elements

Flows to Be Treated

Vegetated filter strips must be designed to treat the runoff treatment flow rate to meet Minimum Requirement 6. Hydrologic methods are presented in Sections 5-1 and 5-2.

Structural Design Considerations

Note: Following compaction and gravel design criteria subject to confirmation that it meets FAA requirements.

If located within the Runway Safety Area or Taxiway Safety Area, filter strips must meet the following structural design criteria:

Compaction:

- Compaction of the filter strip subgrade shall be in accordance with WSDOT standard specification 2-03.3(14)C.
- Compaction is not required on the top 4 inches of the filter strip (FAA Advisory Circular 150/5370-10, P-152-2.6).

Gravel:

- If a gravel flow spreader is used, gravel should be outside of the runway shoulder and should meet the specifications for shoulder ballast listed in Section 9-03.9(2) of the WSDOT Standard Specifications.

Geometry

Design Criteria and Specifications

The key design elements of vegetated filter strip systems follow.

Drainage Area Limitations

- Vegetated filter strips are used to treat small drainage areas. Flow must enter the vegetated filter strip as sheet flow spread out over the length (long dimension perpendicular to flow) of the strip, generally no deeper than 1 inch. For basic vegetated filter strips and CAVFS, the greatest flow path from the contributing area delivering sheet flow to the vegetated filter strip should not exceed 75 feet for impervious surfaces and 150 feet for pervious surfaces. For greater flow paths, special provisions such as check dams or other devices must be incorporated to ensure that the design flows spread evenly across the vegetated filter strip. For the narrow area vegetated filter strip, the maximum contributing flow path should not exceed 30 feet.

- The longitudinal slope of the contributing drainage area parallel to the edge of pavement should be 4 percent or less.
- The lateral slope of the contributing drainage area perpendicular to the pavement edge should be 5 percent or less.
- Vegetated filter strips should be fully integrated within site designs.
- Vegetated filter strips should be constructed outside the natural stream buffer area whenever possible to maintain a more natural buffer along the stream bank.

Vegetated Filter Strip Geometry

- Applicable for basic vegetated filter strips in eastern and western Washington and CAVFS in eastern Washington.
- Vegetated filter strips must provide a minimum residence time of 9 minutes for full water quality treatment in eastern Washington. In western Washington, a flow rate adjustment (described below) is needed to use the 9-minute criterion.
- Vegetated filter strips can be used for pretreatment to another water quality BMP. Wherever a basic vegetated filter strip or CAVFS system cannot fit within the available space, a narrow area vegetated filter strip system can be used solely as a pretreatment device. A narrow area design should have a minimum width of 4 feet and should take advantage of all available space.
- Basic vegetated filter strips should be designed for lateral slopes (along the direction of flow) between 2 and 15 percent. Steeper slopes encourage the development of concentrated flow; flatter slopes encourage standing water. Vegetated filter strips should not be used on soils that cannot sustain a dense grass cover with high flow retardance. Ponding or storage of run-off is prohibited due to the potential to attract hazardous wildlife.
- In areas where lateral grades are between 15 and 25 percent, designers should consider using CAVFS or a media filter drain (see BMP AR.14) in lieu of a basic vegetated filter strip because at these intermediate slopes, CAVFS or a media filter drain will usually require less treatment area to achieve the water quality treatment objectives.
- The minimum width of the grass filter strip generally is dictated by the design method.
- Both the top and toe of the slope should be as flat as possible to encourage sheet flow and prevent erosion.

- The Manning's *n* to be used in the vegetated filter strip design calculations depends on the type of soil amendment and vegetation conditions used in the construction of the vegetated filter strip (see Table AR.12.1).
- When the runoff treatment peak flow rate Q_{WQ} has been established, the design flow velocity can be estimated using Manning's Equation to calculate the width of the vegetated filter strip parallel to the direction of flow.
- Geometry guidance above is applicable for CAVFS in western Washington except for the following clarifications:
- CAVFS design in western Washington does not have a residence time component or Manning's "*n*" component. (See Section 5-4.2 for design sizing guidance.)
- The CAVFS lateral slope (along direction of flow) can be up to 25 percent (4:1).

Table AR.12.1. Surface roughness/Manning's *n* for vegetated filter strip design calculations.

Option	Soil and Vegetation Conditions	Manning's *n*
1	Fully compacted and hydroseeded	0.20
2	Compaction minimized and soils amended, hydroseeded	0.35
3	Compaction minimized; soils amended to a minimum 10% organic content; hydroseeded; grass maintained at 95% density and 4-inch length via mowing; periodic reseeding; possible landscaping with herbaceous shrubs	0.40*
4	Compost-amended vegetated filter strip: compaction minimized, soils amended to a minimum 10% organic content, vegetated filter strip top-dressed with 3 to 4 inches vegetated compost or compost/mulch (seeded and/or landscaped)	0.55*

* These values were estimated using the NRCS TR-55 Peak Discharge and Runoff Calculator (http://www.lmnoeng.com/Hydrology/hydrology.htm). This tool lists the Manning's *n* values for woods–light underbrush at 0.4, and woods–dense underbrush at 0.8. The intent of Option 3 is to amend the soils so that they have surface roughness characteristics equivalent to forested conditions with light underbrush. Option 4 adds a 3-inch top dressing of compost or compost/mulch to simulate a thick forest duff layer, which warrants a higher Manning's *n*, estimated at 0.55.

Water Depth and Velocity

- The maximum depth of sheet flow through a vegetated filter strip for the runoff treatment design flow rate is 1.0 inch.
- The maximum flow velocity for the runoff treatment design flow velocity is 0.5 feet per second.

Maintain Sheet Flow Conditions

- Sheet flow conditions from the pavement into the vegetated filter strip should be maintained. A no-vegetation zone may help establish and maintain this condition.
- Periodic edge dam (gravel or crushed surfacing adjacent to paved surface as shown on Figure AR.12.1) inspection and removal of accumulated edge dam sediment required to maintain sheet flow.
- In areas where it may be difficult to maintain sheet flow conditions, consider using gravel as a flow spreader. It would be placed between the pavement surface and the vegetated filter strip. The gravel should be outside of the runway shoulder, see AC 150/5300-13 (FAA 2006b) and should meet the specifications for shoulder ballast listed in Section 9-03.9(2) of the WSDOT Standard Specifications.
- If there are concerns that water percolated within the gravel flow spreader may exfiltrate into the runway subgrade, impervious geotextiles can be used to line the bottom of the gravel layer.

Vegetated Filter Strip (eastern and western Washington basic vegetated filter strip, and eastern Washington CAVFS)

Design Method

1. **Determine the runoff treatment design flow (Q_{WQ}).** In western Washington, the design flow for runoff treatment is the flow rate derived from a continuous model (such as MGSFlood or WWHM) that calculates the flow rate from the drainage basin below which 91 percent of the average annual runoff volume occurs. In eastern Washington, the design flow rate is determined based on the peak 5-minute interval for the short duration design storm, which is the 6-month, 3-hour event. (See Chapter 4 for criteria and hydrologic methods.)

   Western Washington flow rate adjustment. In western Washington, design flow rates are calculated using a continuous simulation model. Most of the performance research on vegetated filter strips and biofiltration BMPs has been conducted on vegetated filter strips that used event-based designs. The 91st percentile flow event (as calculated by the continuous model) tends to be less than the estimated 6-month, 24-hour event flow rate in most cases.

   The ratio between the 91st percentile flow event and the estimated 6-month, 24-hour flow rate varies with location and percent of impervious area in the modeled drainage basin. When designing vegetated filter strips in western

Washington, multiply the on-line water quality design flow rate by the coefficient k[1] given below to apply the 9-minute residence time criterion.

Western Washington Design Flow Coefficient for Biofilters

$$k = 1.41\,(P_{72\%,\ 2\text{-yr.}}) - 0.052 \qquad \textbf{(AR.12-1)}$$

where: $P_{72\%,\ 2\text{-yr}}$ = 72% of the 2-year, 24-hour precipitation depth (in.)

Note: The 6-month, 24-hour precipitation event can be estimated at 72 percent of the 2-year, 24-hour precipitation event if 6-month, 24-hour precipitation data are not available.

In eastern Washington, no design flow rate adjustment is needed, since the 6 month, 24 hour flow rate is calculated directly using SBUH-based models such as StormSHED.

The vegetated filter strip design flow rate then becomes:

$$Q_{vfs} = kQ_{wq} \qquad \textbf{(AR.12-2)}$$

2. **Calculate the design flow depth at Q_{vfs}.** The design flow depth is calculated based on the length of the vegetated filter strip (same as the length of the pavement edge contributing runoff to the vegetated filter strip) and the lateral slope of the vegetated filter strip parallel to the direction of flow. Design flow depth is calculated using a form of Manning's Equation:

$$Q_{vfs} = \frac{1.49}{n} L y^{5/3} s^{1/2} \qquad \textbf{(AR.12-3)}$$

where: Q_{vfs} = vegetated filter strip design flow rate (cfs)

n = Manning's roughness coefficient. Manning's n can be adjusted by specifying soil and vegetation conditions at the project site, as specified in Table AR.12.1

y = design flow depth (ft), also assumed to be the hydraulic radius = 1.0 inch maximum = 0.083 feet

L = length of the vegetated filter strip parallel to the pavement edge (ft)

s = slope of the vegetated filter strip parallel to the direction of flow (ft/ft). Vegetated filter strip slopes should be greater than 2% and less than 15%. Vegetated filter strip slopes should be made as shallow as is feasible by site constraints. Gently sloping vegetated filter strips can produce the required residence time for runoff treatment using less space than steeper vegetated filter strips.

Rearranging Equation AR.12-1 to solve for y yields:

[1] Derived by calculating the linear regression of the ratios of the 91st percentile flow event at 15-minute intervals (determined by MGSFlood) vs. 72% of the 2-year, 24-hour event (determined by the rational method) at each of the major continuously-operating rain gages in western Washington.

$$y = \left[\frac{nQ_{vfs}}{1.49 L s^{1/2}} \right]^{3/5} \quad \textbf{(AR.12-4)}$$

If the calculated depth *y* is greater than 1 inch, either adjust the vegetated filter strip geometry or use other runoff treatment BMPs.

3. **Calculate the design flow velocity passing through the vegetated filter strip at the vegetated filter strip design flow rate.** The design flow velocity (V_{WQ}) is based on the vegetated filter strip design flow rate, the length of the vegetated filter strip, and the calculated design flow depth from Step 2:

$$V_{WQ} = \frac{Q_{vfs}}{Ly} \quad \textbf{(AR.12-5)}$$

where: V_{WQ} = design flow velocity (ft/sec)
y = design flow depth (ft, from Equation AR.12-2)

4. **Calculate the vegetated filter strip width.** The width of the vegetated filter strip is determined by the residence time of the flow through the vegetated filter strip. A 9-minute (540-second) residence time is used to calculate vegetated filter strip width:

$$W = TV_{WQ} = 540V_{WQ} \quad \textbf{(AR.12-6)}$$

where: W = vegetated filter strip width (ft)
T = time (sec)
V_{WQ} = design flow velocity (ft/sec, from Equation AR.12-3)

A minimum width of 8 feet is recommended in order to ensure that the long-term effectiveness of the vegetated filter strip will occur.

Narrow Area Vegetated Filter Strip

As previously mentioned, narrow area vegetated filter strips are limited to impervious flow paths less than 30 feet. For flow paths greater than 30 feet, designers should follow the basic vegetated filter strip guidelines. The sizing of a narrow area vegetated filter strip is based on the width of the roadway surface parallel to the flow path of the vegetated filter strip and the lateral slope of the vegetated filter strip.

5. Determine width of paved surface parallel to flow path draining to vegetated filter strip:

   Determine the width of the paved surface parallel to the flow path from the upstream to the downstream edge of the impervious area draining to the vegetated filter strip.

6. Determine average lateral slope of the vegetated filter strip:

Calculate the lateral slope of the vegetated filter strip (parallel to the flow path), averaged over the total length of the vegetated filter strip. If the slope is less than 2 percent, use 2 percent for sizing purposes. The maximum lateral slope allowed is 15 percent.

7. Determine required width of the vegetated filter strip:

Use Figure AR.12.2 to size the narrow area vegetated filter strip; locate the width of the impervious surface parallel with the flow path on one of the curves (interpolate between curves as necessary). Next, move along the curve to the point where the design lateral slope of the vegetated filter strip is directly below. Read the vegetated filter strip width to the left on the y-axis. The vegetated filter strip must be designed to provide this minimum width "W" along the entire stretch of pavement draining to it.

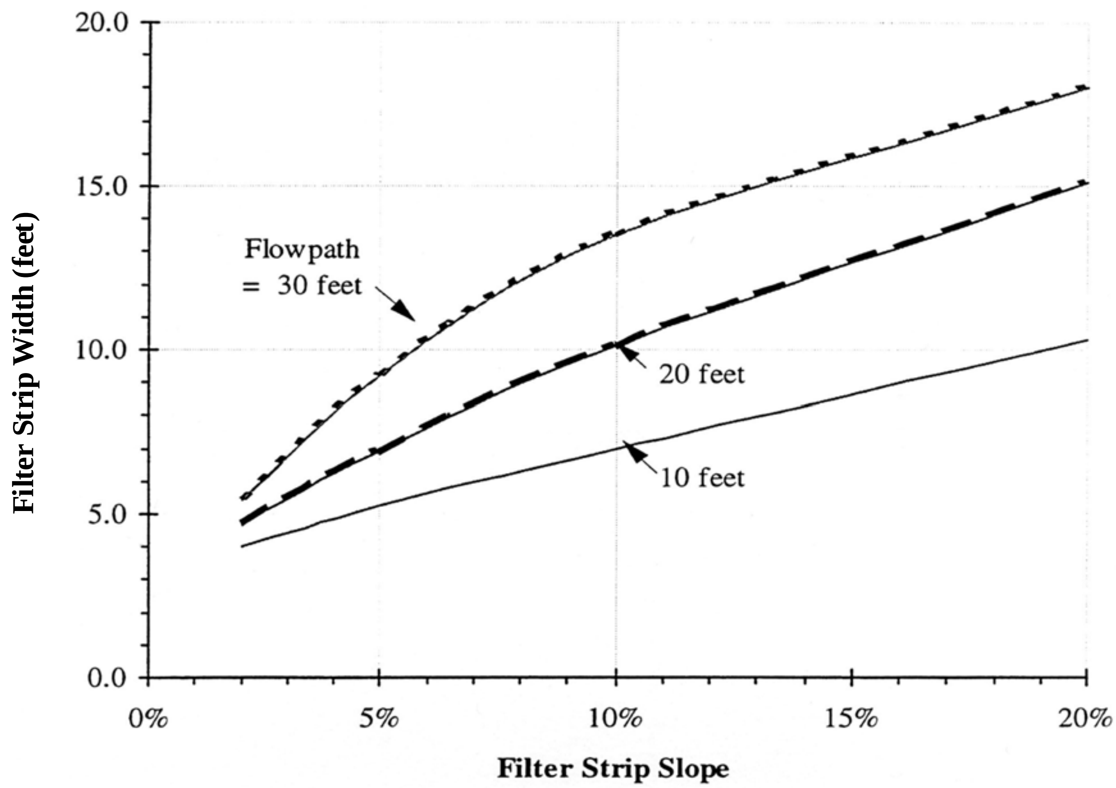


Figure AR.12.2. Narrow area vegetated filter strip design graph.

Materials

Vegetation

Vegetated filter strips should be planted with grass that can remain upright and withstand relatively high velocity flows as well as wet and dry periods. Appendix A lists plants, including grasses, which represent species suitable for use airports.

Soil Amendments

See Soil Amendments BMP 5-3.5.1 in the HRM.

Compost used as an amendment, such as in the compost-amended vegetated filter strip, can also provide runoff storage through its water-holding capacity. The University of Washington College of Forest Resources reported in *Field Test of Compost Amendment to Reduce Nutrient Runoff* (UW 1994) that soils amended with 2:1 compost exhibited 35 and 37 percent field capacities by weight and volume, respectively, over eight simulated rainstorms. The field tests showed that a 4-inch-minimum compost top layer has some semipermanent storage and also slowly releases stored runoff to subsoils, where it can infiltrate to provide interflow or groundwater recharge, depending on the local geology. Recent field monitoring (Herrera 2007a) showed that CAVFS reduced runoff volumes to half that of regular vegetated filter strip when comparing soils of equivalent, 11 inch total depth. Because CAVFS thickness is limited to 4 inches in the airport environment, a significant reduction in available storage volume is anticipated.

Compost source materials should not include any moderate risk wastes (put rescible wastes that could attract scavenging wildlife) or any regulated hazardous or dangerous wastes as defined in *Washington Administrative Code* (WAC) 173-303. Soils contaminated with petroleum should not be included as a source material in the composting process and should not be blended with finished compost products.

Vegetation

Vegetated filter strips should be planted with grass that can withstand relatively high velocity flows as well as wet and dry periods. For examples of plants appropriate for use in airport settings when planting BMPs, refer to Appendix A.

Site Design Elements

Maintenance Access Roads (Access Requirements)

Access should be provided at the upper edge of all vegetated filter strips to enable maintenance of the gravel flow spreader and permit lawnmower entry to the vegetated filter strip.

Other Maintenance Considerations

Mowing at night has been used at many airports to decrease the likelihood of birds following the mower to eat insects or rodents that have been exposed by mowing operations and the new presence of shorter grass.

6-2.13. AR.13 – Biofiltration Swale

Bioinfiltration swale along taxiway.

Bioinfiltration swale at industrial facility.

Eastern Washington	Yes
Western Washington	Yes
Landside Areas	Yes

Object Free Area (OFA)	Maybe*
Runway Safety Area (RSA)	No
Taxiway Safety Area (TSA)	No
Clearway (CWY)	No

* Contact FAA Seattle ADO for approval.

Introduction

General Description

Biofiltration swales are vegetation-lined channels designed to remove suspended solids from stormwater. The shallow, concentrated flow within these systems is filtered and slowed by the dense vegetation, removing pollutants by filtration and settling. Biological uptake, biotransformation, sorption, and ion exchange are potential secondary pollutant-removal processes (see Figures AR.13.1 and AR.13.2).

If biofiltration swales are to be constructed in the airport environment, wildlife deterrence must be a top priority to assure that the stormwater facility does not present a safety hazard to aircraft. This does not mean only grassed swales can be used, however. Several design modifications from the traditional biofiltration swale design presented in the SMMWW, SMMEW, and HRM are recommended in the airport environment:

- No surficial base flow or standing water is allowed in the biofiltration swale for more than 24 hours after a storm. Wet Biofiltration Swales, a variation of basic biofiltration swales included in the SMMWW and HRM, are not appropriate in the airport environment due to wildlife attractant concerns.
- Vegetation must not be particularly attractive to potentially hazardous wildlife. For examples of plant species suitable for use in airport settings, see Appendix A.

Two design procedures are described below; the first is for eastern and western Washington and the second is applicable only in eastern Washington.

Design Flow Elements

Flows to Be Treated

Biofiltration swales must be designed to treat the biofiltration design flow rate outlined below.

Where the longitudinal slope is slight, water tables are high, or continuous base flow is likely to result in saturated soil conditions, underdrains will be required to prevent standing water that may attract wildlife that could potentially be hazardous to aircraft.

Structural Design Considerations

Geometry

The following sizing procedure can be used in both eastern and western Washington:

Sizing Procedure

Preliminary Steps (P)

P-1 Determine the runoff treatment design flow rate (Q_{wq}) (see Section 5-2 of this manual).

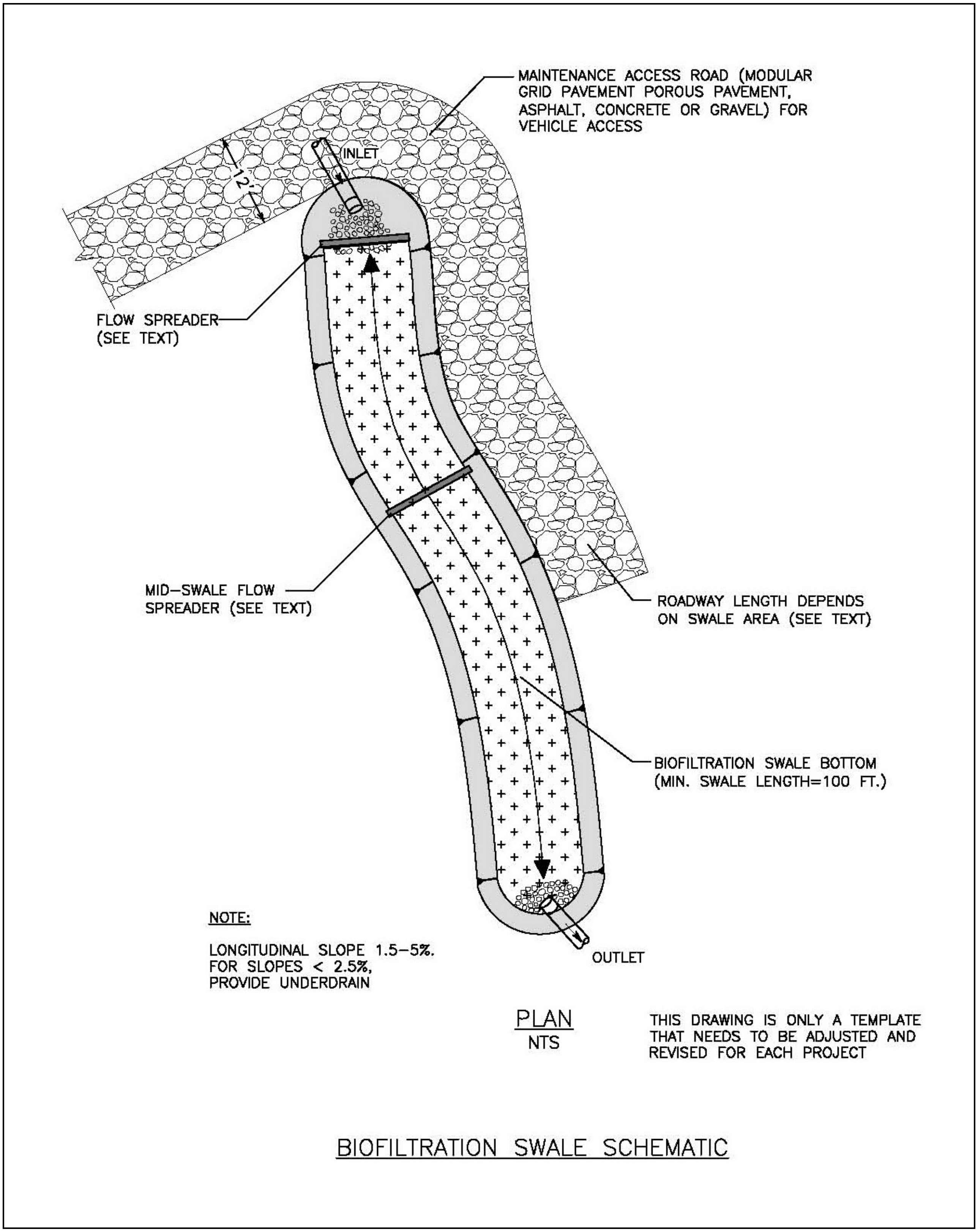


Figure AR.13.1. Biofiltration swale: plan view.

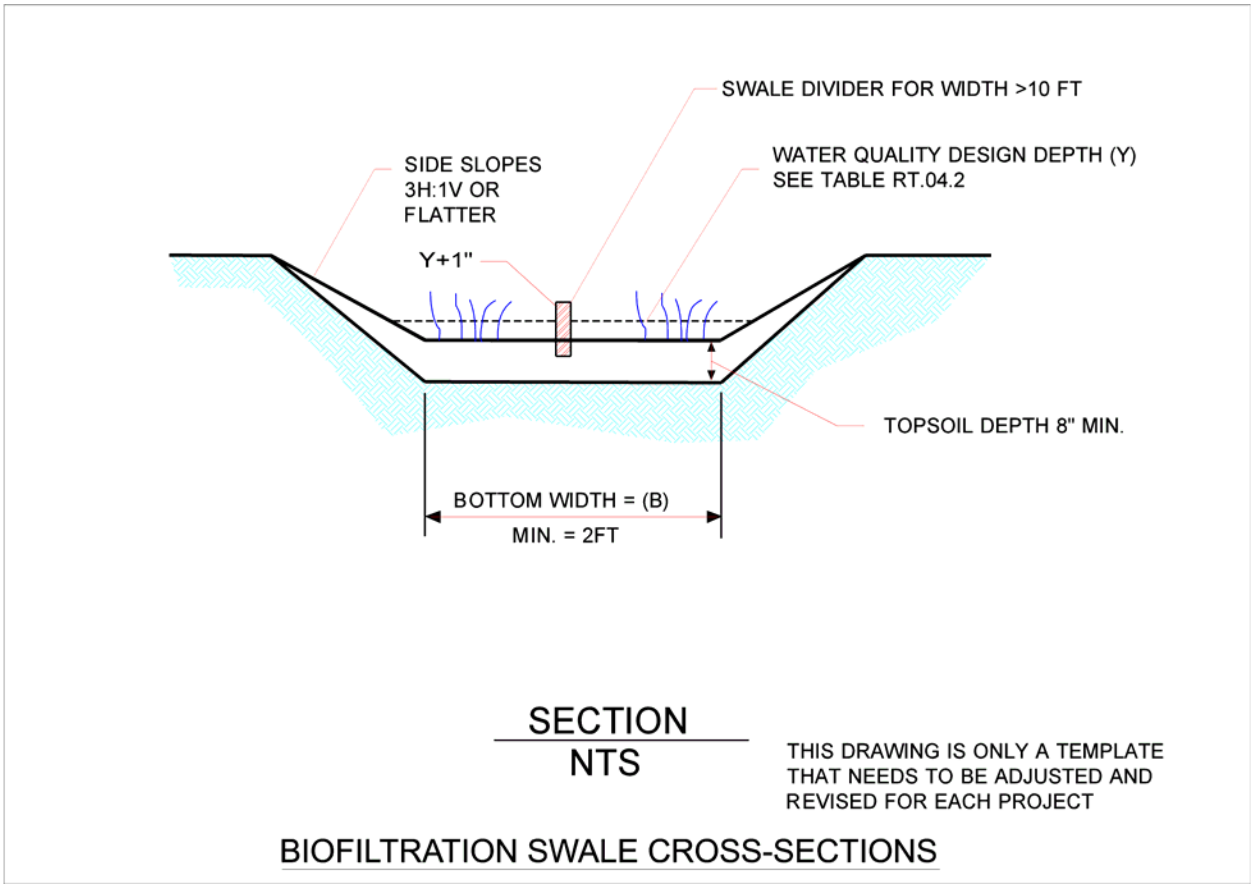


Figure AR.13.2. Biofiltration swale: cross section.

P-2 Determine the biofiltration design flow rate (Qbiofil):

$$Q_{biofil} = kQ_{wq}$$

For western Washington:[1]

$$k = 1.41\ (P_{72\%,\ 2\text{-yr.}}) - 0.052$$

where: $P_{72\%,\ 2\text{-yr}}$ = 72 percent of the 2-year, 24-hour precipitation depth (in.)

Note: If the 6-month, 24-hour precipitation depth (in.) is known for the project area, that value can be used instead of $P_{72\%,\ 2\text{-yr}}$

For eastern Washington:

$$k = 1.0$$

P-3 Establish the longitudinal slope of the proposed biofiltration swale (see Table AR.13.1 for criteria).

Table AR.13.1. Biofiltration swale design criteria.

Parameter	Criteria
Longitudinal slope	0.015–0.050[a] feet per foot
Maximum velocity	1 foot per second at Q_{biofil}
Maximum water depth at Q_{biofil}, y	2 inches if swale mowed frequently; 4 inches if mowed infrequently or inconsistently. For dryland grasses in eastern Washington, set depth to 3 inches. Flow depth shall be less than the grass height.
Manning coefficient at Q_{biofil}	See Table AR.13.2
Bed width	2–10 feet [b]
Freeboard height	1 foot for the peak conveyance flow rate (Q_{convey}) [c]
Minimum length	100 feet
Maximum side slope (for trapezoidal cross section) [d]	3H:1V
Low flow drain [e]	Install the low-flow drain 6 inches deep in the soil (see Figure AR.13.4).

[a] For basic biofiltration swale on slopes less than 1.5 percent, install an underdrain system (see Figure AR.13.3). Underdrain backfill shall be covered by at least 4 inches of amended soil or topsoil. For slopes greater than 5 percent, install energy dissipaters.
[b] Multiple parallel swales can be constructed when the calculated swale bottom width exceeds 10 feet.
[c] Q_{convey} shall be based on the design flow rate of the conveyance system downstream of the biofiltration swale. In general, this is the peak $Q_{25\text{-}year}$.
[d] From swale bed to top of water surface at Q_{biofil}.
[e] Required for swales receiving base flow (max. 0.01 cfs/acre)

[1] The coefficient k is derived by calculating the linear regression of the ratios of the 91st percentile flow event at 15-minute intervals (determined by MGSFlood) vs. 72 percent of the 2-year, 24-hour event (determined by the rational method) at each of the major continuously-operating rain gages in western Washington and applied to the design flow rate in order to meet the 9-minute residence time criteria.

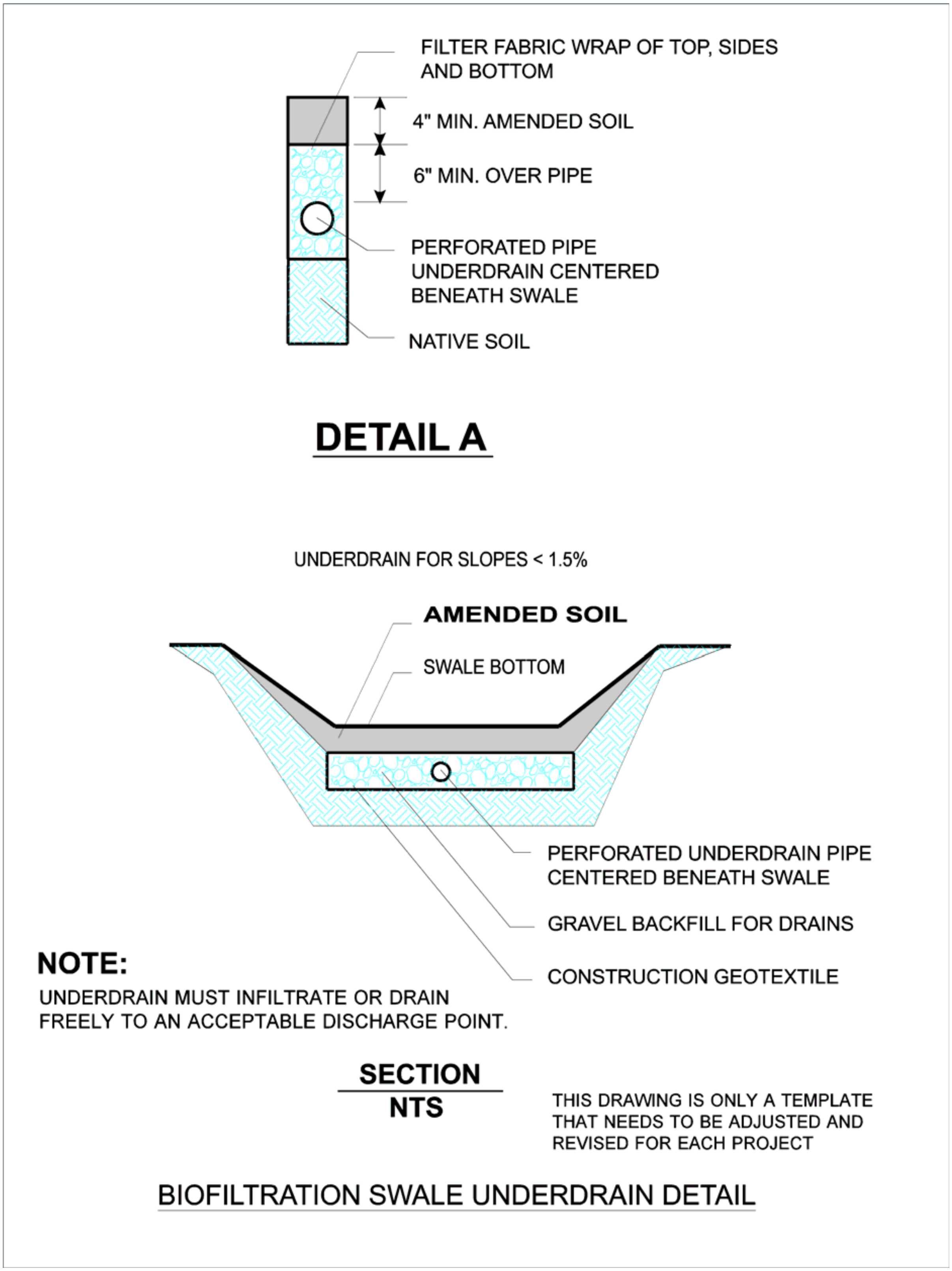


Figure AR.13.3. Biofiltration swale: underdrain detail.

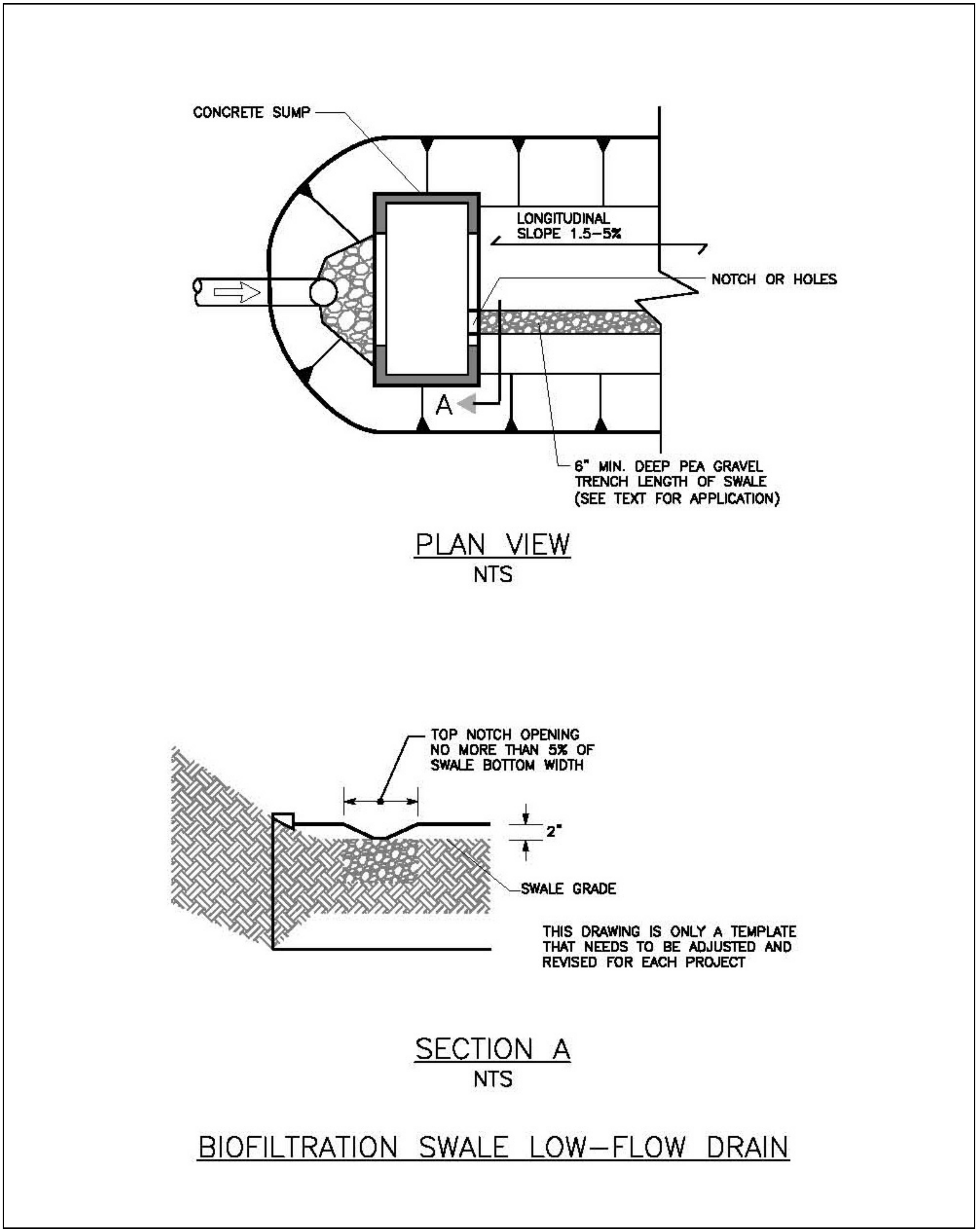


Figure AR.13.4. Biofiltration swale: low-flow drain detail.

P-4 Select a soil and vegetation cover suitable for the biofiltration swale (see Table AR.13.2 and example of recommended plant species provided in Appendix A).

Table AR.13.2. Flow resistance coefficient in basic and continuous inflow biofiltration swales.

Soil and Cover	Manning's Coefficient
Grass mix [a] on compacted native soil	0.20
Grass mix on lightly compacted, compost-amended [b] soil	0.22
Grass mix on lightly compacted, compost-amended [b] soil with surface roughness features [c]	0.35

[a] See Appendix A for examples of grass species suitable for use in airport settings.
[b] For information on compost-amended soils, refer to Section 5-4.2. (Note that swales do not require a mulch layer and that compost amendments are incorporated into the soil.)
[c] Acceptable surface roughness features are wattle check dams (WSDOT Std. Spec. 8-01.3(6)D), gravel filter berms (WSDOT Std. Spec. 8-01.3(9)B), or compost berms (WSDOT Std. Plan I-14). These features must be placed every 50 feet (or closer) and shall not exceed 1.5 feet in height above finished swale bottom. These features must not be used in place of level spreaders or energy dissipaters.

Design Steps (D)

D-1 Select the design depth of flow, y (see Table AR.13.1).

D-2 Select a swale cross-sectional shape (trapezoidal is preferred, but rectangular or parabolic cross sections can be used if site-specific constraints so dictate).

D-3 Use Manning's equation (AR.13-1) and first approximations relating hydraulic radius and dimensions for the selected swale shape to obtain a value for the width of the biofiltration swale:

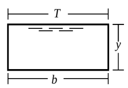
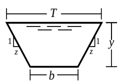
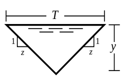
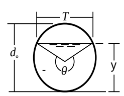
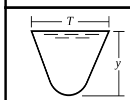
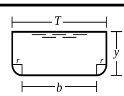
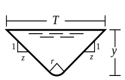
$$Q_{biofil} = \frac{1.49 A R^{2/3} s^{1/2}}{n} \qquad \textbf{(AR.13-1)}$$

where: Q_{biofi} = runoff treatment design flow rate (cfs)
A = wetted area (ft^2)
R = hydraulic radius (ft)
s = longitudinal slope of swale (ft/ft)
n = Manning's coefficient (see Table AR.13.2).

To solve for the cross-sectional shape of the swale, use one of the following methods:

Method 1:

Solve the implicit equation $AR^{0.67} = Q_{biofil}\, n / (1.49 s^{0.5})$ to determine bed width, *b*, or width of water surface, *T* (for parabolic or triangular cross sections), for the selected cross-sectional geometry. Use Figure AR.13.5 to substitute for *A* and *R* for the selected cross-sectional geometry. The variables Q_{biofil}, *y*, *s*, and *n* are all known values. The equation should then contain only a single unknown (*b* or *T*).

Section	Area A	Wetted perimeter P	Hydraulic radius R	Top width W	Hydraulic depth D	Section factor Z
 Rectangle	by	$b + 2y$	$\frac{by}{b + 2y}$	b	y	$by^{1.5}$
 Trapezoid	$(b + zy)y$	$b + 2y\sqrt{1 + z^2}$	$\frac{(b + zy)y}{b + 2y\sqrt{1 + z^2}}$	$b + 2zy$	$\frac{(b + zy)y}{b + 2zy}$	$\frac{[(b + zy)y]^{1.5}}{\sqrt{b + 2zy}}$
 Triangle	zy^2	$2y\sqrt{1 + z^2}$	$\frac{zy}{2\sqrt{1 + z^2}}$	$2zy$	$^1/_2 y$	$\frac{\sqrt{2}}{2} zy^{2.5}$
 Circle	$^1/_8(\theta - \sin\theta)d_\circ^2$	$^1/_2\theta d_\circ$	$^1/_4\left(1 - \frac{\sin\theta}{\theta}\right)d_\circ$	$(\sin(^1/_2\theta)d_\circ)$ *or* $2\sqrt{y(d_\circ - y)}$	$^1/_8\left(\frac{\theta - \sin\theta}{\sin{^1/_2}\theta}\right)d_\circ$	$\frac{\sqrt{2}}{32}\frac{(\theta - \sin\theta)^{1.5}}{(\sin{^1/_2}\theta)^{0.5}}d_\circ^{2.5}$
 Parabola	$^2/_3 Ty$	$T + \frac{8y^2}{3T}$ *	$\frac{2T^2y}{3T^2 + 8y^2}$ *	$\frac{3A}{2y}$	$^2/_3 y$	$^2/_9\sqrt{6}Ty^{1.5}$
 Round-cornered Rectangle ($y>r$)	$(\frac{\pi}{2} - 2)r^2 + (b + 2r)y$	$(\pi - 2)r + b + 2y$	$\frac{(\frac{\pi}{2} - 2)r^2 + (b + 2r)y}{(\pi - 2)r + b + 2y}$	$b + 2r$	$\frac{(\frac{\pi}{2} - 2)r^2}{(b + 2r)} + y$	$\frac{[(\frac{\pi}{2} - 2)r^2 + (b + 2r)y]^{1.5}}{\sqrt{b + 2y}}$
 Round-bottomed Triangle	$\frac{T^2}{4z} - \frac{r^2}{z}(1 - z\cot^{-1}z)$	$\frac{T}{z}\sqrt{1 + z^2} - \frac{2r}{z}(1 - z\cot^{-1}z)$	$\frac{A}{P}$	$2[z(y - r) + r\sqrt{1 + z^2}]$	$\frac{A}{T}$	$A\sqrt{\frac{A}{T}}$

*Satisfactory approximation for the interval 0<x≤1, where x=4y/T. When x>1, use the exact expression $P = (^T/_2)\left[\sqrt{1 + x^2} + {^1/_x}\ln\left(x + \sqrt{1 + x^2}\right)\right]$

Figure AR.13.5. Geometric elements of common cross sections.

Method 2:

Use nomographs relating $(Q_{biofil}\, n) / (1.49s^{0.5})$ for trapezoidal channels with known side slopes (z) to determine b for a given y (see Figure AR.13.6 for z=3 and Figure AR.13.7 for z=4).

Method 3:

For a trapezoidal swale that is flowing very shallow, the hydraulic radius, R, can be set equal to the depth of flow. Using this assumption, the equation in Method 1 can be changed to:

$$b = [(Q_{biofil}\, n) / (1.49y^{1.67}s^{0.5})] - zy$$

Note: If any of these methods produce a value for b or T of less than 2 feet, then set bed width to 2 feet.

D-4 Compute A at Q_{biofil} by using the equations in Figure AR.13.5.

D-5 Compute the flow velocity at Q_{biofil}:

$$V_{biofil} = \frac{Q_{biofil}}{A} \qquad \textbf{(AR.13-2)}$$

where: V_{biofil} = flow velocity at Q_{biofil} (ft/sec).

If $V_{biofil} > 1.0$ ft/sec, increase width (b or T) or investigate ways to reduce Q_{WQ} and then repeat Steps D-3, D-4, and D-5 until $V_{biofil} \leq 1.0$ ft/sec. A velocity greater than 1.0 ft/sec was found to flatten grasses, thus reducing filtration.

D-6 Compute the swale length, L (ft):

$$L = V_{biofil}\, t \text{ (60 sec/min)}$$

where: t = hydraulic residence time (9 minutes for basic biofiltration swales).

D-7 If there is not sufficient space for the biofiltration swale, consider the following solutions:

1. Divide the site drainage to flow to multiple biofiltration swales.
2. Use infiltration or dispersion to provide lower Q_{biofil}.
3. Alter the design depth of flow (y), if possible (see Table AR.13.1). The depth of flow shall remain less than the height of the grass in the swale, however.
4. Reduce the developed surface area to gain space for the biofiltration swale.

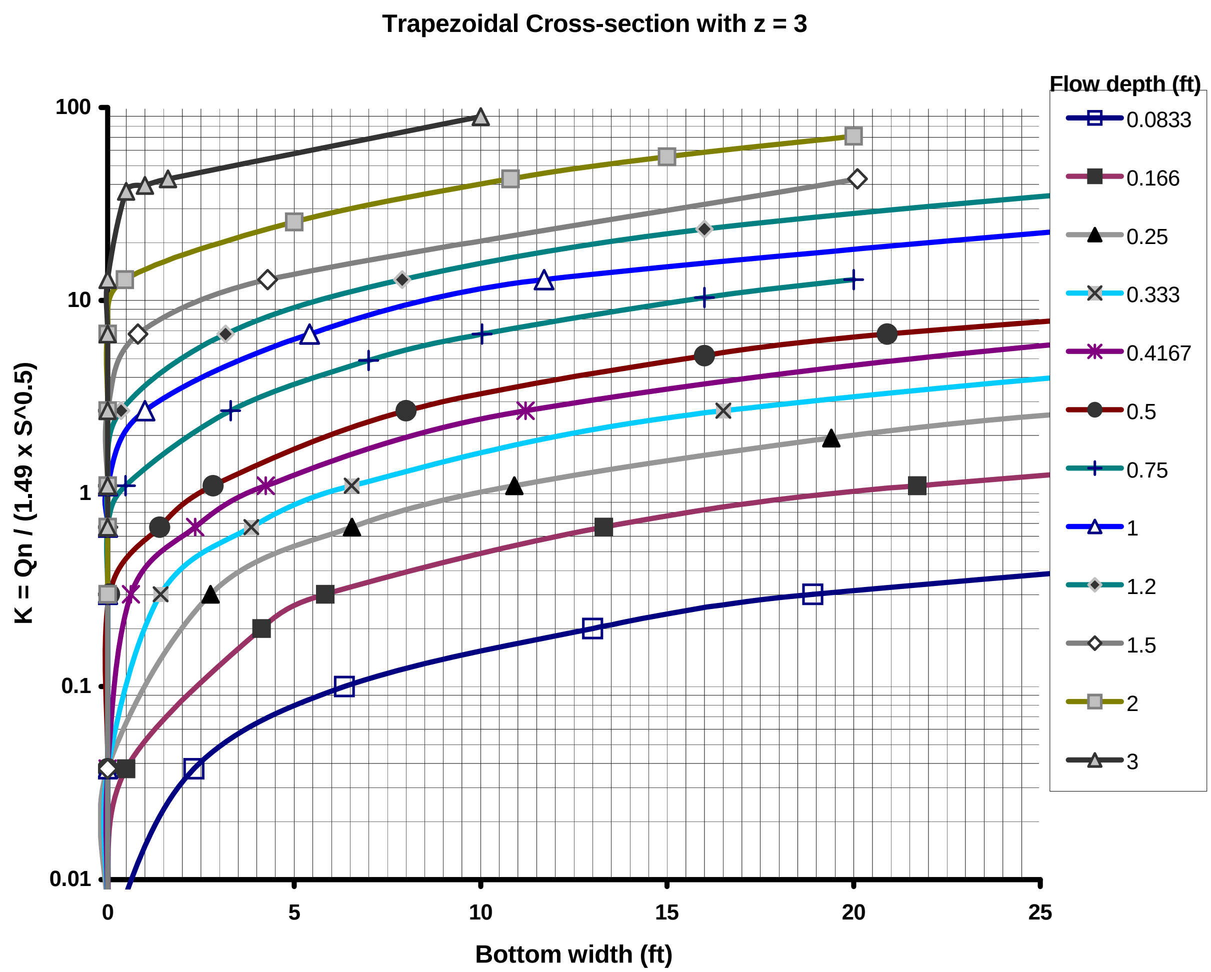


Figure AR.13.6. Open channel flow parameter, Qn/(1.49 $s^{0.5}$), versus bottom width (b) at different flow depths (z=3).

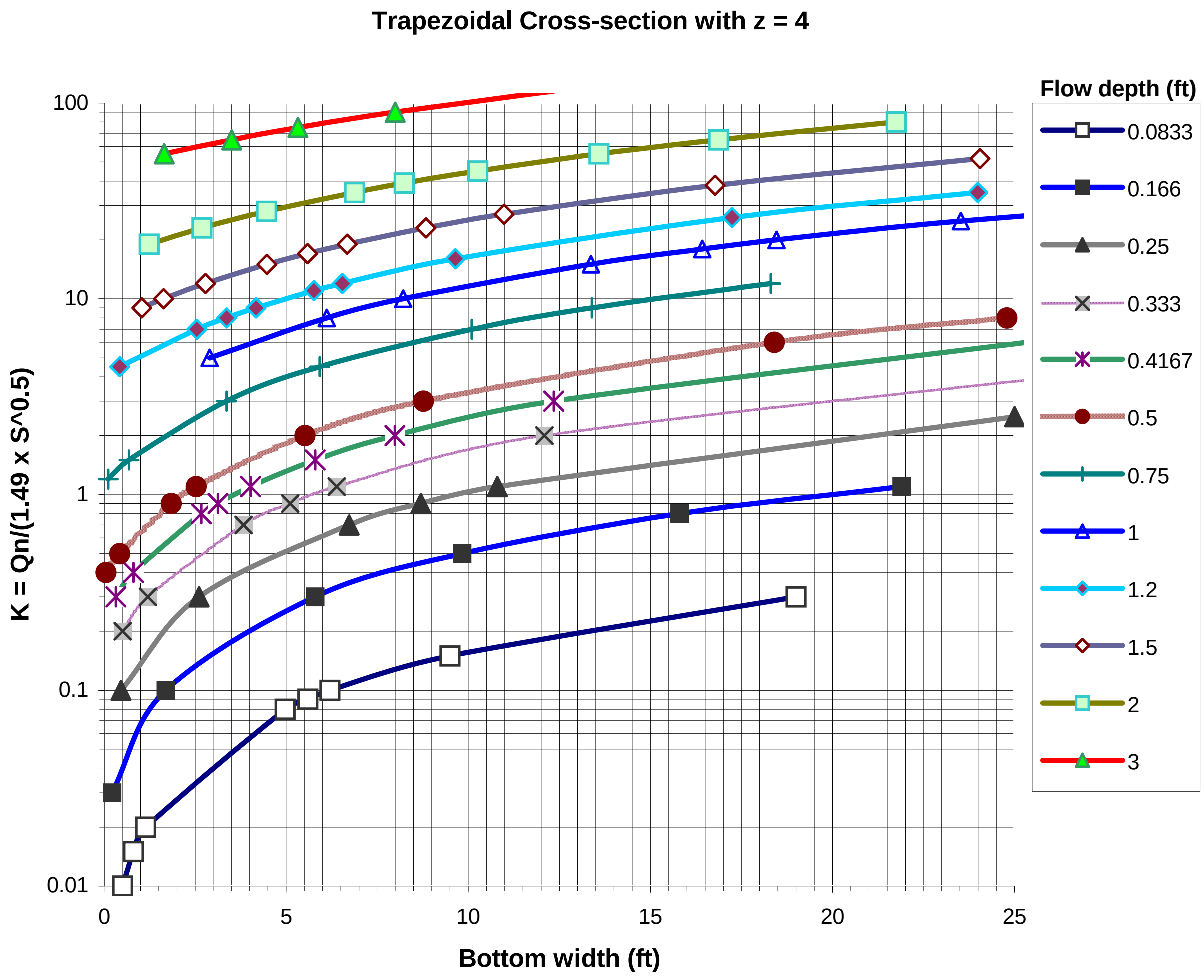


Figure AR.13.7. Open channel flow parameter, Qn/(1.49 $s^{0.5}$), versus bottom width (b) at different flow depths (z=4).

1. Reduce the longitudinal slope by meandering the biofiltration swale. This should not be considered as a preferred solution. In general, straight swale configurations are thought to be less attractive to hazardous wildlife and are therefore preferred in the airport environment.

2. Nest the biofiltration swale within or around another stormwater BMP.

Freeboard Check (FC)

A freeboard check must be performed for the combination of highest expected flow and least vegetation coverage and height. The highest expected flow rate (Q_{convey}) is the design flow rate of the conveyance system that discharges to the swale. The freeboard check is not necessary for biofiltration swales that are located off-line from the primary conveyance and detention system; that is, when flows in excess of Q_{biofil} bypass the biofiltration swale. Off-line is the preferred configuration of biofiltration swales.

Note: Use the same units as in the biofiltration swale design steps.

FC-1 Unless runoff at rates higher than Q_{biofil} will bypass the biofiltration swale, perform a freeboard check for Q_{convey}.

FC-2 Select the lowest possible roughness coefficient for the biofiltration swale (assume n=0.03).

FC-3 Again, use the implicit equation $AR^{0.67} = Q_{convey}\, n / (1.49s^{0.5})$ (Figure AR.13.5) and with a known b (or T), solve for depth, y. Select the lowest y that provides a solution. For trapezoidal swales, Figures AR.13.6 and AR.13.7 can be used directly. (Note that in the case of a parabola, the equation must be solved implicitly for two unknowns.)

FC-4 Ensure that swale depth exceeds flow depth at Q_{convey} by a minimum of 1 foot (1-foot-minimum freeboard).

The following procedure can only be used in eastern Washington:

Sizing Procedure

Preliminary Steps (P)

P-1 Determine the runoff treatment design flow rate (Q_{wq}); this is also the biofiltration design flow rate (Q_{biofil}) (see Section 5-2).

P-2 Determine the slope of the biofiltration swale (this will be somewhat dependent on where the swale is placed). The slope shall be at least 1.5 percent and shall be no steeper than 5 percent. When slopes less than 2.5 percent are used, underdrains shall be provided. See Table AR.13.1, footnote a, and Figure AR.13.4.

P-3 Select a swale shape. Trapezoidal is the most desirable shape; however, rectangular and triangular shapes can be used. The remainder of the design process assumes that a trapezoidal shape has been selected.

P-4 Use Manning's Equation to estimate the bottom width of the biofiltration swale. Manning's Equation for English units is as follows:

$$Q_{biofil} = (1.486\ AR^{0.667}s^{0.5})\ /\ n$$

where: Q_{biofil} = runoff treatment design flow rate (cfs)
A = cross-sectional area of flow (ft^2)
R = hydraulic radius of flow cross section (ft)
s = longitudinal slope of biofiltration swale (ft/ft)
n = Manning's roughness coefficient (use n=0.20 for typical biofiltration swale with turf/lawn vegetation, and n=0.30 for biofiltration swale with less dense vegetation such as meadow or pasture).

For a trapezoid, this equation cannot be directly solved for bottom width. However, for trapezoidal channels that are flowing very shallow, the hydraulic radius can be set equal to the depth of flow. Using this assumption, the equation can be altered to:

$$B = (((n/1.486)\ Q_{biofil})\ /\ (y^{1.667}\ s^{0.5}))\ -\ zy$$

where: B = bottom width of the swale
y = depth of flow
z = the side slope of the biofiltration swale in the form of z:1

Typically, the depth of flow for turf grass is selected to be 4 inches. (The depth of flow shall be less than the height of the grass.) For dryland grasses, the depth of flow shall be set to 3 inches. It can be set lower, but doing so will increase the bottom width. Sometimes when the flow rate is very low, the equation listed above will generate a negative value for B. Since it is not possible to have a negative bottom width, the bottom width should be set to 1 foot when this occurs.

Biofiltration swales are limited to a maximum bottom width of 10 feet. If the required bottom width is greater than 10 feet, parallel swales shall be used in conjunction with a device that splits the flow and directs the proper amount to each swale.

P-5 Calculate the cross-sectional area of flow for the given channel using the calculated bottom width and the selected side slopes and depth.

P-6 Calculate the velocity of flow in the channel using:

$$V = Q_{biofil}/A$$

If *V* is less than or equal to 1 ft/sec, the biofiltration swale will function correctly with the selected bottom width. Proceed to P-7.

If *V* is greater than 1 ft/sec, the biofiltration swale will not function correctly. Increase the bottom width, recalculate the depth using Manning's Equation, and return to P-5.

P-7 Select a location where a biofiltration swale with the calculated width and a length of 200 feet will fit. If a length of 200 feet is not possible, the width of the biofiltration swale must be increased so that the area of the biofiltration swale is the same as if a 200-foot length had been used.

P-8 Select a vegetation cover suitable for the site. Consult Table AR.13.2 or the local NRCS office or the County Extension Service for guidance. Vegetation also must have characteristics particularly attractive to hazardous wildlife. See a list of recommended aps in Appendix A.

P-9 Using Manning's Equation, find the depth of flow (typically n=0.04 during Q_{biofil}). The depth of the channel shall be 1 foot deeper than the depth of flow. Check to determine that shear stresses do not cause erosion; the velocity needs to stay below 2 ft/sec.

Design Steps (D)

D-1 Though the actual dimensions for a specific site may vary, the swale should generally have a length of 200 feet. The maximum bottom width is typically 10 feet. The depth of flow shall not exceed 4 inches during the design storm. The flow velocity shall not exceed 1 ft/sec.

D-2 The channel slope shall be at least 1.5 percent and no greater than 5 percent.

D-3 The swale can be sized as a treatment facility for Q_{biofil}.

D-4 The ideal cross section of the swale is a trapezoid. The side slopes shall be no steeper than 3H:1V.

D-5 Roadside ditches are good potential biofiltration sites and shall be utilized for this purpose whenever possible.

D-6 If flow is to be introduced through curb cuts, place pavement slightly above the biofiltration swale elevation. Curb cuts shall be at least 12 inches wide to prevent clogging.

D-7 Biofiltration swales must be vegetated in order to provide adequate treatment of runoff.

D-8 It is important to maximize water contact with vegetation and the soil surface. For general purposes, select fine, close-growing grasses (or other vegetation) that can withstand prolonged periods of wetting, as well as prolonged dry periods (to minimize the need for irrigation). See Appendix A for a list of representative plant species recommended for use in airport settings.

D-9 Biofiltration swales shall generally not receive construction-stage runoff. If they do, presettling facilities shall be provided. (See Volume II of the SMMWW for construction BMPs) Biofiltration swales that have received construction-stage runoff shall be evaluated for the need to remove sediments and restore vegetation following construction. The maintenance of presettling basins or sumps is critical to their effectiveness as pretreatment devices.

D-10 If possible, divert runoff (other than minor runoff associated with necessary irrigation) during the period of vegetation establishment. Where runoff diversion is not possible, protect graded and seeded areas with suitable erosion control measures.

Site Design Elements

- Install level spreaders at the head of the biofiltration swale in swales 6 feet or greater in bottom width. Include sediment cleanouts at the head of the swale as needed (see the HRM for level spreader options). Swales with a bottom width in excess of 6 feet or greater shall have a level spreader for every 50 feet of swale length.
- Use energy dissipaters for swales on longitudinal slopes exceeding 2.5 percent.
- Specify that topsoil extends to at least an 8-inch depth (unless an underdrain system is needed—see Table AR.13.1).
- To improve infiltration on longitudinal slopes less than 2.5 percent, ensure that the swale bed material contains a sand percentage greater than 70 percent (i.e., greater than 70 percent by weight retained on the No. 40 sieve) before organic amendments are added. The maximum organic content allowed is 20 percent (FAA AC 150/5370.10B).
- Gravel Underdrain – Within the underdrain a perforated pipe shall be installed in Group C and D soils for drainage during wet periods. In most Group A and B soils, an underdrain is not necessary because most water will percolate into subsoils from the underdrain. The underdrain shall be a minimum of 2 feet wide. The underdrain pipe shall be a 6-inch-diameter PVC perforated pipe with the holes situated 30 to 45 degrees from vertical for every 2 feet of underdrain width as per the standard listed in Section 9-05.2(6) (Underdrain Pipe) of the WSDOT *Standard Specifications*. The gravel backfill for the underdrains shall conform to Section 9-03.12(4) (Gravel Backfill) of the WSDOT *Standard Specifications*.

- Low Flow Drains – If a swale will receive base flows, then a low-flow drain is required. *Low-flow drains* are narrow surface drains filled with pea gravel that run lengthwise through the swale to bleed off base flows; they should not be confused with underdrains. Biofiltration swales shall not be used where base flows exceed 0.01 cfs per acre of tributary drainage area. If a low-flow drain is used, it shall extend the entire length of the swale. The drain shall be a minimum of 6 inches deep, and its width shall be no greater than 5 percent of the calculated swale bottom width; the width of the drain shall be in addition to the required bottom width per the calculation procedures presented above. If an anchored plate or concrete sump is used for flow spreading at the swale inlet, the plate or sump wall shall have a v-notch (maximum top width = 5 percent of swale width) or holes to allow preferential exit of low flows into the drain. If there is no plate or sump at the swale inlet, the low-flow drain consists of the pea gravel surface drain. See Figure AR.13.4 for low-flow drain specifications and details. To ensure that the low flow drain does not become plugged, compaction of the pea gravel shall be avoided during construction. The vegetation selected for swales with low-flow drains shall have root systems that encourage infiltration, while providing adequate treatment. Refer to Appendix A for information on appropriate vegetation. Swales in Group C and D soils which receive base flows may require both an underdrain and a low flow drain – the underdrain trench would extend to the swale bottom. To avoid short-circuiting water quality treatment, the low flow drain should be offset from the underdrain pipe where swales contain both a low flow drain and underdrain.
- If groundwater contamination is a concern, seal the bed or underdrain area with either a treatment liner or an impermeable liner that is appropriate for site conditions (see the HRM for additional information on these liner types).

Landscaping (Planting Considerations)

Appendix A contains lists of plants recommended as generally suitable for revegetation and landscaping in airport settings. Guidance for planting methods is also provided below. For plant species lists and planting methods specific to local site conditions, consult a qualified landscape architect, biologist, and/or other specialist.

- Plants must be selected that encourage filtering and settling of suspended solids and that are not attractive to hazardous wildlife. Select fine, turf-forming grasses where moisture is appropriate for growth. For plants appropriate for use in the different moisture zones of a biofiltration swale (e.g. below the design water surface, side slopes, or the bottom of a continuous inflow Biofiltration swale) refer to Appendix A.

- If sod will be used, use only sod with grass species that exhibit characteristics as described. For examples of vegetation that are suitable, see Appendix A. Selection of plant species and condition will depend on stormwater facility design objectives, site-specific environmental variables, site specific wildlife concerns, local availability of nursery stock, and budget. A high diversity of plant species is not desirable on or in the vicinity of airfields.
- If possible, perform seeding of the BMP during the seeding windows specified in the WSDOT Standard Specifications section 8-01.3(2)F, Dates for Application of Final Seed, Fertilizer, and Mulch. To the greatest extent possible, seeding should be conducted at a time when hazardous wildlife are not as prevalent and/or are less likely to be attracted to seed. Perform planting of the BMP during the planting windows specified in the WSDOT Standard Specifications section 8-03.3(8) Planting. Supplemental irrigation may be required depending on seeding and planting times.
- Stabilize soil areas upslope of the biofiltration swale to prevent erosion and excessive sediment deposition.
- Apply seed via hydroseeder or broadcaster, using methods that limit the attractiveness of the seeded area to hazardous wildlife. Seeding should be coordinated with a qualified airport wildlife biologist to make sure seeds or young plant shoots are not available when hazardous migratory wildlife are expected.
- Biofiltration swales shall be planted with grass that can withstand relatively high velocity flows as well as wet and dry periods.

Construction Criteria

- Avoid over-compaction during construction. Over-compaction may result in localized ponding of runoff.
- Grade biofiltration swales to attain uniform longitudinal and lateral slopes.
- Do not put the biofiltration swale into operation until areas of exposed soil in the contributing drainage catchment have been sufficiently stabilized and vegetation established.
- Keep effective erosion and sediment control measures in place until the swale vegetation is established.

6-2.14. AR.14 – Media Filter Drain (previously referred to as the Ecology Embankment)

Media filter drain along SR 167 in King County.

Eastern Washington	Yes
Western Washington	Yes
Landside Areas	Yes

Object Free Area (OFA)	Yes
Runway Safety Area (RSA)	No
Taxiway Safety Area (TSA)	No
Clearway (CWY)	Yes*

* Contact FAA Seattle ADO for approval.

Introduction

General Description

The media filter drain (MFD), previously referred to as the ecology embankment, is a linear flow-through stormwater runoff treatment device that can be sited adjacent to roadside embankments (conventional design) and medians (dual media filter drain), borrow ditches, or other linear depressions. Cut-slope applications may also be considered. The media filter drain can be used where available right-of-way is limited, sheet flow is feasible, lateral gradients are generally less than 25 percent (4H:1V), and longitudinal gradients are less than 5 percent. The media filter drain has a general use level designation (GULD) from the Department of Ecology for basic, phosphorus, and enhanced treatment. More information on the use level designation may be found at the following website: http://www.ecy.wa.gov/Programs/wq/stormwater/newtech/technologies.html.

Monitoring of media filter drains has shown excellent pollutant removal, including dissolved metals, as well as reduction in flows (Herrera 2006).

Media filter drains have four basic components: a gravel no-vegetation zone, a grass strip, the MFD mix bed, and a conveyance system for flows leaving the MFD mix. This conveyance system usually consists of a gravel-filled underdrain trench or a layer of crushed surfacing base course (CSBC). This layer of CSBC must be porous enough to allow treated flows to freely drain away from the MFD mix. A gravel-filled underdrain trench is a common option in areas with drainage problems.

For typical media filter drain configurations, see Figures AR.14.1, AR.14.2, and AR.14.3.

Functional Description

The media filter drain removes suspended solids, phosphorus, and metals from stormwater runoff through physical straining, ion exchange, carbonate precipitation, and biofiltration.

Stormwater runoff is conveyed to the media filter drain via sheet flow over a vegetation-free gravel zone to ensure sheet dispersion, and to provide some pollutant trapping. Next, a grass strip, which may be amended with compost, is incorporated into the top of the fill slope to provide pretreatment, further enhancing filtration and extending the life of the system. The runoff is then filtered through a bed of porous, alkalinity-generating granular medium—the MFD mix. The MFD mix is a fill material composed of crushed rock (sized by screening), dolomite, gypsum, and perlite. The dolomite and gypsum additives serve to buffer acidic pH conditions and exchange light metals for heavy metals. Perlite is incorporated to improve moisture retention, which is critical for the formation of biomass epilithic biofilm to assist in the removal of solids, metals, and nutrients. Treated water drains from the MFD mix bed into the conveyance system below the MFD mix. Geotextile lines the underside of the media filter drain mix bed and the conveyance system.

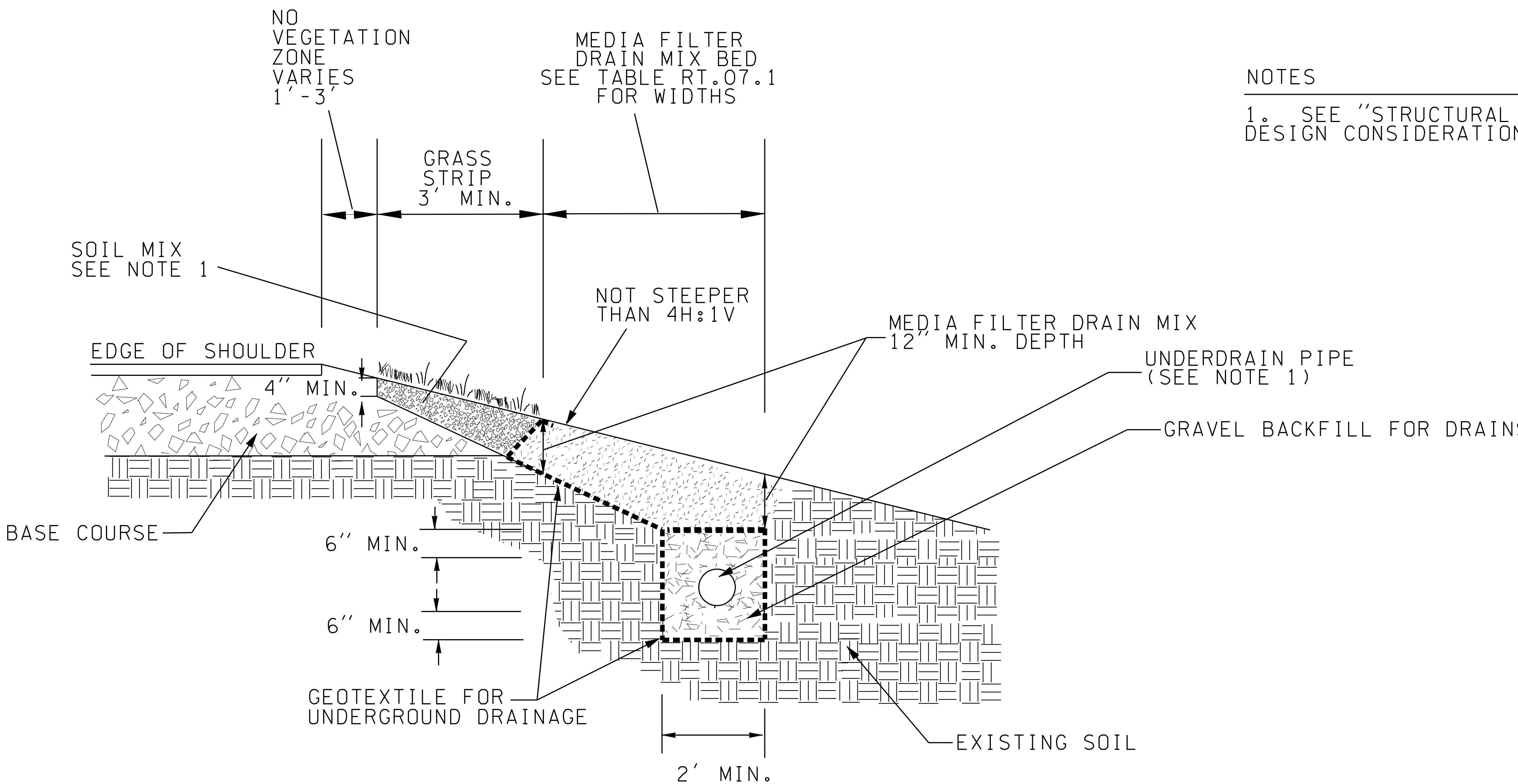
The underdrain trench is an option for hydraulic conveyance of treated stormwater to a desired location, such as a downstream flow control facility or stormwater outfall and should be evaluated for infiltration loss. The trench's perforated underdrain pipe is a protective measure to ensure free flow through the MFD mix.

It may be possible to omit the underdrain pipe if it can be demonstrated that the pipe is not necessary to maintain free flow through the media filter drain mix and underdrain trench.

It is critical to note that water should sheet flow across the media filter drain. Channelized flows or ditch flows running down the middle of the dual media filter drain (continuous offsite inflow) should be minimized.

NOTES

1. SEE "STRUCTURAL DESIGN CONSIDERATIONS"



MEDIA FILTER DRAIN

SIDE SLOPE APPLICATION WITH UNDERDRAIN

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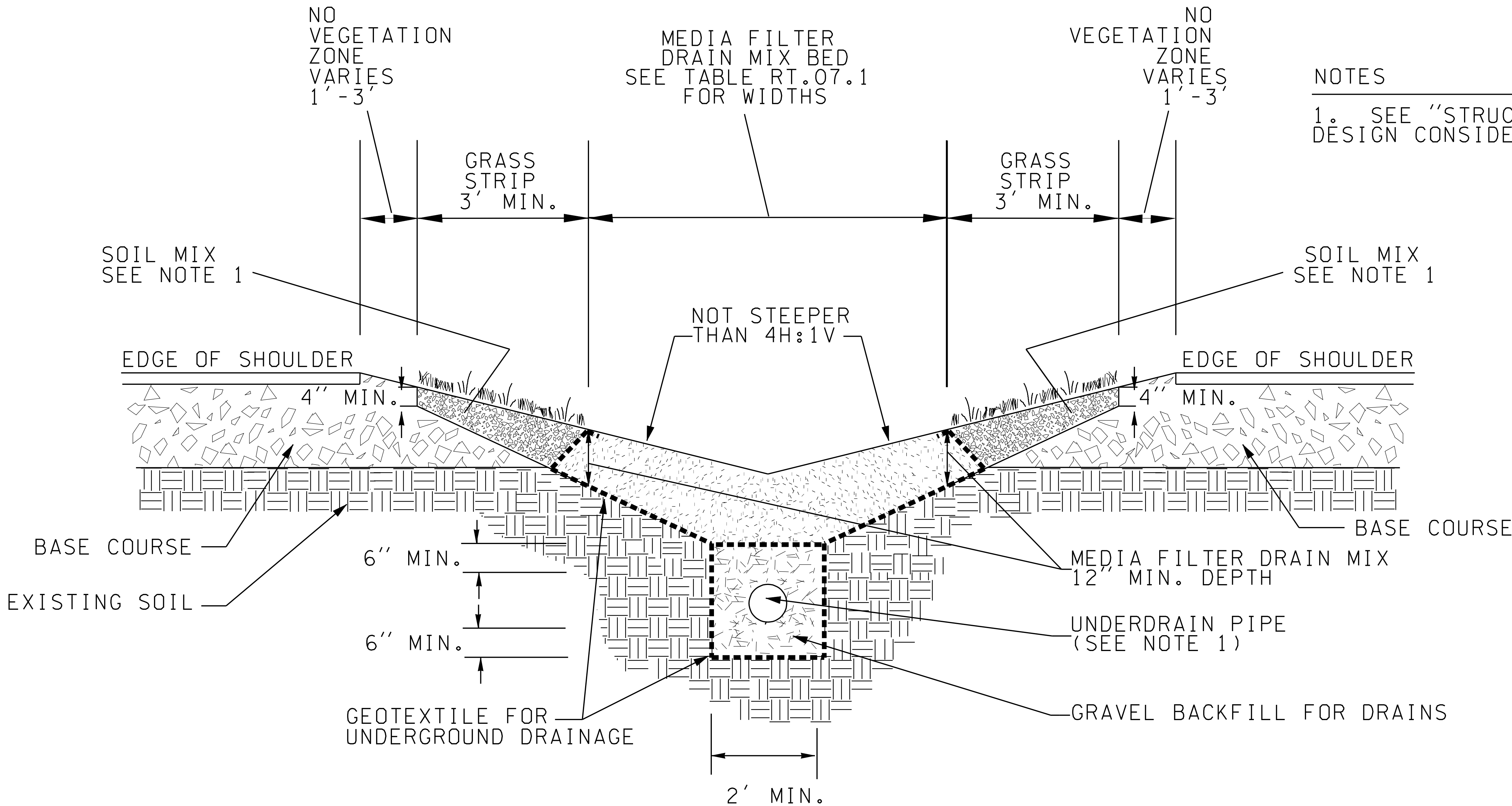
Washington State Department of Transportation

FIGURE 14.1
MEDIA FILTER DRAIN
CROSS-SECTION

PLOT3

SHEET OF SHEETS



NOTES

1. SEE "STRUCTURAL DESIGN CONSIDERATIONS"

DUAL MEDIA FILTER DRAIN

MEDIAN APPLICATION WITH UNDERDRAIN

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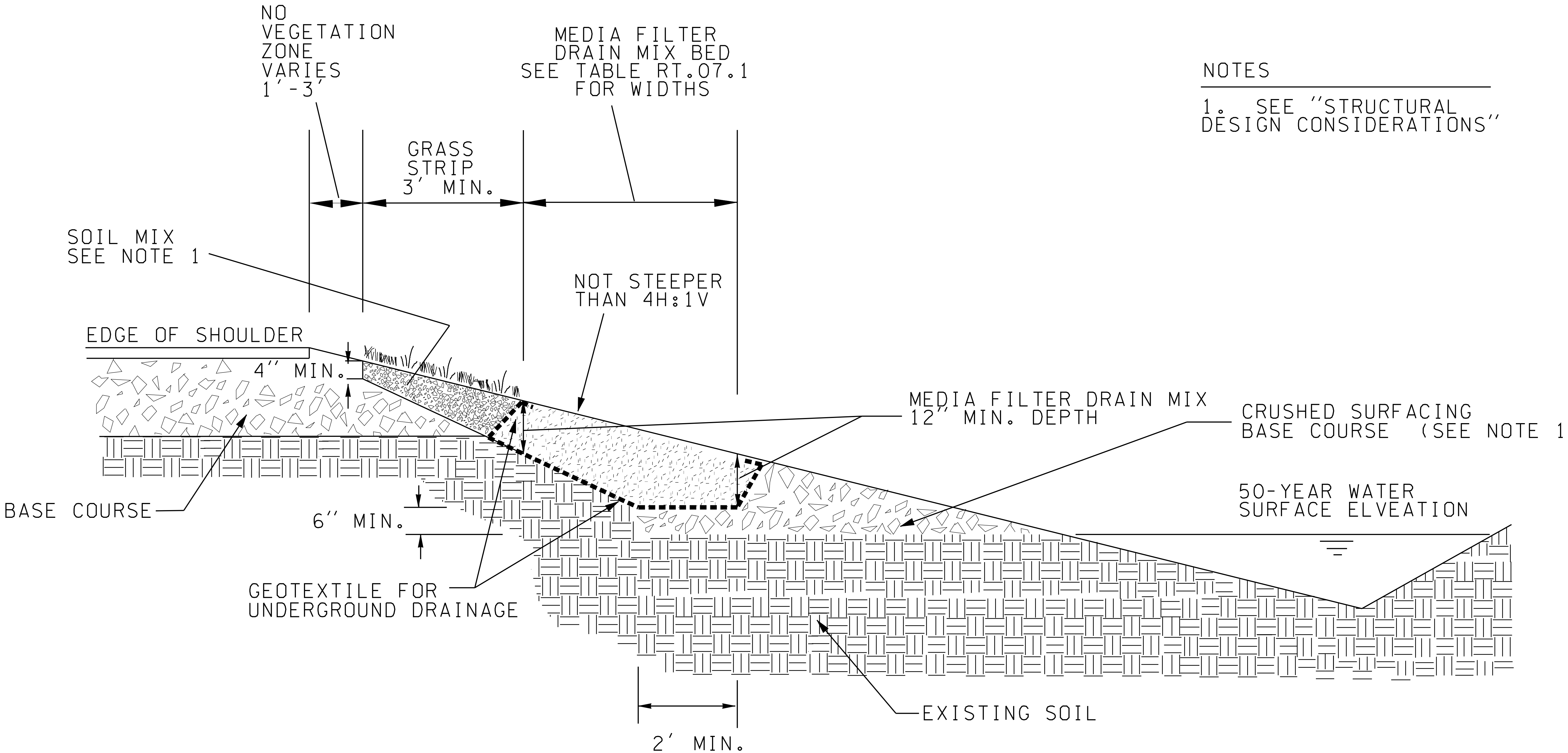
Washington State Department of Transportation

FIGURE 14.2
DUAL MEDIA FILTER DRAIN CROSS-SECTION

PLOT2
SHEET OF SHEETS



NOTES

1. SEE "STRUCTURAL DESIGN CONSIDERATIONS"

MEDIA FILTER DRAIN

SIDE SLOPE APPLICATION WITHOUT UNDERDRAIN

NTS

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FIGURE 14.3
MEDIA FILTER DRAIN
WITHOUT
UNDERDRAIN TRENCH

PLOT1

SHEET OF SHEETS

Applications and Limitations

The following are recommended design modifications from the HRM to make media filter drains suitable for airport applications. Additional information on the specific modifications and the reason for the modified design are summarized in this chapter:

- Underdrain pipe is required in sites subject to ponding that may attract hazardous wildlife. Details are found under Structural Design Considerations.

In many roadway situations, conventional runoff treatment is not feasible due to right-of-way constraints (adjacent wetlands, geotechnical considerations, etc.). The media filter drain and the dual media filter drain are effective runoff treatment options that can be sited in most right-of-way confined situations, as well as many space-limited airport situations. In addition, a media filter drain or a dual media filter drain is an attractive alternative to the capital-intensive expenditures for underground wet vaults. Parking areas, runway touchdown areas, and other locations that may have higher dissolved metals concentration in runoff (R.W. Beck and Parametrix 2006) are potential applications for media filter drains based on their effectiveness with dissolved metals removal.

However, adequate structural support must be provided to meet FAA regulations. The 12-inch MFD mix that overlays the gravel backfill cannot, by itself, meet FAA compaction requirements for these airside locations while providing adequate treatment. Media filter drains are **not suitable** for locations within the RSA, TSA, CWY, or SWY at airports unless reinforced. They may easier to use on perimeter roads or other landside locations, where areas adjacent to roadways are too narrow for other treatment BMP options.

Applications

Media Filter Drains

The media filter drain can achieve basic, phosphorus, and enhanced water quality treatment. Since maintaining sheet flow across the media filter drain is required for its proper function, the ideal locations for media filter drains are roadside embankments or other long, linear grades with lateral slopes less than 4H:1V, and longitudinal slopes no steeper than 5 percent. As slopes approach 3H:1V, without design modifications, sloughing may become a problem due to friction limitations between the separation geotextile and underlying soils. The longest flow path from the contributing area delivering sheet flow to the media filter drain should not exceed 75 feet for impervious surfaces and 150 feet for pervious surfaces.

Dual Media Filter Drains

The dual media filter drain is fundamentally the same as the side-slope version. It differs in siting and is more constrained with regard to drainage options. Prime locations for dual media filter drains in an airport setting are medians, roadside drainage or borrow ditches, or other linear depressions. It is especially critical for water to sheet flow across the dual media filter drain.

Media filter drains shall not be used where continuous off-site inflow may result in channelized flows or ditch flows running down the middle of the dual media filter drain.

Limitations

Media Filter Drains

- Steep slopes – Avoid construction on longitudinal slopes steeper than 5 percent. Avoid construction on 3H:1V lateral slopes, and preferably use flatter than 4H:1V slopes. In areas where lateral slopes exceed 4H:1V, it may be possible to construct terraces to create 4H:1V slopes, or to otherwise stabilize up to 3H:1V slopes. (For details, see *Geometry, Components* and *Sizing Criteria, Cross Section* in the Structural Design Considerations section below).
- Wetlands – Do not construct in wetlands and wetland buffers. In many cases, a media filter drain (due to its small lateral footprint) can fit within the fill slopes adjacent to a wetland buffer. In those situations where the fill prism is located adjacent to wetlands, an interception trench/underdrain will need to be incorporated as a design element in the media filter drain.
- Shallow groundwater – Mean high water table levels in the project area need to be determined to ensure that the MFD mix bed and the underdrain will not become saturated by shallow groundwater. There must be at least one foot of depth between the seasonal high groundwater table and the bottom of the facility.
- Unstable slopes – In areas where slope stability may be problematic, consult a geotechnical engineer.

Dual Media Filter Drains

In addition to the limitations on the media filter drain (above):

- Dual media filter drains shall not be constructed in areas of seasonal groundwater inundation. There must be at least 1 foot vertical separation between the bottom of the embankment facility and the seasonal high groundwater level. Otherwise, the hydraulic and runoff treatment performance of the dual media filter drain may be compromised due to backwater effects and lack of sufficient hydraulic gradient, and ponding water could result in a hazardous wildlife attractant. Additionally, insufficient separation from high groundwater could result in untreated water reaching the underlying groundwater.

Design Flow Elements

Flows to Be Treated

The basic design concept behind the media filter drain and dual media filter drain is to fully filter all runoff through the MFD mix. Therefore, the infiltration capacity of the MFD mix and of the drainage below the MFD mix bed needs to match or exceed the hydraulic loading rate. See Chapter 5 of this manual for hydraulic analysis requirements.

Structural Design Considerations

Geometry

Components

No-Vegetation Zone

The no-vegetation zone (i.e., vegetation-free zone) is a shallow gravel trench located directly adjacent to the impervious surface to be treated. The no-vegetation zone is a crucial element in a properly functioning media filter drain or other BMPs that use sheet flow to convey runoff from the impervious surface to the BMP. The no-vegetation zone functions as: a level spreader to promote sheet flow, a deposition area for coarse sediments, and an infiltration area to reduce runoff volumes. The no-vegetation zone should be between 1 foot and 3 feet wide. Depth will be a function of how the adjacent paved section is built from subgrade to finish grade; the resultant cross section will typically be triangular to trapezoidal.

Grass Strip

The width of the vegetated filter strip is dependent on the availability of space within the sloped area where the media filter drain is to be constructed. The baseline design criterion for the grass strip within the media filter drain is a 3-foot-minimum-width, but wider grass strips are recommended if the additional space is available. The designer may consider adding aggregate to the soil mix to minimize rutting problems from errant vehicles. The soil mix should ensure grass growth for the design life of the media filter drain.

Media Filter Drain Mix Bed

The MFD mix is a mixture of crushed rock (screened to 3/8" to #10 sieve), dolomite, gypsum, and perlite. The crushed rock provides the support matrix of the medium; the dolomite and gypsum add alkalinity and ion exchange capacity to promote the precipitation and exchange of heavy metals; and the perlite improves moisture retention to promote the formation of biomass within the MFD mix. The combination of physical filtering, precipitation, ion exchange, and biofiltration enhances the water treatment capacity of the mix. The MFD mix has an estimated initial filtration rate of 50 inches per hour and a long-term filtration rate of 28 inches per hour, which accounts for siltation. With an additional safety factor, the rate used to size the length of the media filter drain should be 14 inches per hour.

Structural Reinforcement

The MFD mix does not meet FAA requirements for structural support in RSA, TSA, CWY, and SWY. On a case-by-case basis, reinforcement through the use of a plastic matrix or other suitable soil reinforcement technique may be used to meet FAA requirements. The proposed structural reinforcement in these restricted areas must be approved by a geotechnical engineer prior to construction.

Conveyance System Below Media Filter Drain Mix

The gravel underdrain trench provides hydraulic conveyance when treated runoff needs to be conveyed to a desired location, such as a downstream flow control facility or stormwater outfall.

In Group C and D soils, an underdrain pipe would help to ensure free flow of the treated runoff through the media filter drain mix bed. In some Group A and B soils, an underdrain pipe may be unnecessary if most water percolates into subsoil from the underdrain trench. The need for underdrain pipe should be evaluated in all cases. The underdrain trench should be a minimum of 2 feet wide for either the conventional or dual media filter drain. The gravel underdrain trench may be eliminated if there is evidence to support that flows can be conveyed laterally to an adjacent ditch or onto a fill slope that is properly vegetated to protect against erosion. The media filter drain mix should be kept free, draining up to the 50-year storm event water surface elevation represented in the downstream ditch.

Sizing Criteria

Width

The width of the media filter drain mix-bed is determined by the amount of contributing pavement routed to the embankment. The surface area of the MFD mix bed needs to be sufficiently large to fully infiltrate the runoff treatment design flow rate using the long-term filtration rate of the MFD mix. For design purposes, a 50 percent safety factor is incorporated into the long-term MFD mix filtration rate to accommodate variations in slope, resulting in a design filtration rate of 14 inches per hour. The MFD mix bed should have a bottom width of at least 2 feet in contact with the conveyance system below the media filter drain mix.

Length

In general, the length of a media filter drain or dual media filter drain is the same as that of the contributing pavement. Any length is acceptable as long as the surface area of the MFD mix bed is sufficient to fully infiltrate the runoff treatment design flow rate.

Cross Section

In profile, the surface of the media filter drain should preferably have a lateral slope less than 4H:1V (<25 percent). On steeper terrain, it may be possible to construct terraces to create a 4H:1V slope, or other engineering may be employed if approved by Ecology, to ensure slope stability up to 3H:1V. If sloughing is a concern on steeper slopes, consideration should be given to incorporating permeable soil reinforcements, such as geotextiles, open-graded/permeable pavements, or commercially available ring and grid reinforcement structures, as top layer components to the MFD mix bed. Consultation with a geotechnical engineer is required.

Inflow

Runoff is always conveyed to a media filter drain using sheet flow from the pavement area. The longitudinal pavement slope contributing flow to a media filter drain should be less than 5 percent. Although there is no lateral pavement slope restriction for flows going to a media filter drain, the designer should ensure that flows remain as sheet flow.

MFD Mix Bed Sizing Procedure

The MFD mix should be a minimum of 12 inches deep, including the section on top of the underdrain trench.

For runoff treatment, sizing the MFD mix bed is based on the requirement that the runoff treatment flow rate from the pavement area $Q_{Pavement}$ cannot exceed the long-term infiltration capacity of the media filter drain, $Q_{Infiltration}$:

$$Q_{Pavement} \leq Q_{Infiltration}$$

For western Washington, $Q_{Pavement}$ is the flow rate at or below which 91 percent of the runoff volume will be treated, based on a 15-minute time step (see Chapter 5 this manual), and can be determined using the water quality data feature in MGSFlood or the water quality analysis feature in WWHM. For eastern Washington, $Q_{Pavement}$ is the peak flow rate predicted for the 6-month, short duration storm under post-developed conditions.

The long-term infiltration capacity of the media filter drain is based on the following equation:

$$\frac{LTIR_{EM} * L_{EE} * W_{EE}}{C * SF} = Q_{Infiltration}$$

where: $LTIR_{EM}$ = Long-term infiltration rate of the MFD mix (use 14 inches per hour for design) (in/hr)
L_{EE} = Length of media filter drain (parallel to contributing pavement) (ft)
W_{EE} = Width of the MFD mix bed (ft)
C = Conversion factor of 43,200 ((in/hr)/(ft/sec))
SF = Safety Factor (equal to 1.0, unless unusually heavy sediment loading is expected)

Assuming that the length of the media filter drain is the same as the length of the contributing pavement, solve for the width of the media filter drain:

$$W_{EE} \geq \frac{Q_{Pavement} * C * SF}{LTIR_{EM} * L_{EE}} \qquad \textbf{(AR.14-1)}$$

Project applications of this design procedure have shown that, in almost every case, the calculated width of the media filter drain does not exceed 1.0 foot. Therefore, Table AR.14.1 was developed to simplify the design steps and should be used to establish an appropriate width.

Table AR.14.1. Design widths for media filter drains.

Pavement Width that Contributes Runoff to the Media Filter Drain	Minimum Media Filter Drain Width*
≤ 20 feet	2 feet
≥ 20 and ≤ 35 feet	3 feet
> 35 feet	4 feet

Width does not include the required 1–3 foot gravel vegetation-free zone or the 3-foot filter strip width. (See Figure AR.14.1.)

Materials

Gravel Backfill for Drains, Underdrain Pipe, and Construction Geotextile for Underground Drainage

These materials should be used in accordance with the WSDOT Standard Specifications.

MFD Mix

The MFD mix used in the construction of media filter drains consists of the amendments listed in Table AR.14.2. Mixing and transportation must be done in a manner that ensures the materials are thoroughly mixed prior to pouring into the ground, and that separation does not occur during transportation or pouring.

Crushed Surfacing Base Course (CSBC)

If the design is configured to allow the media filter drain to drain laterally into a ditch, the crushed surfacing base course below the media filter drain should conform to Section 9-03.9(3) of the WSDOT *Standard Specifications*. The designer should consult with a professional to ensure that the CSBC will not impede the flow of water out of the media filter drain mix. If needed, a different gradation may be specified to ensure the free flow of water out of the media filter drain mix.

Table AR.14.2. MFD mix.

Amendment	Quantity
Mineral aggregate Crushed screenings 3/8-inch to #10 sieve Crushed screenings shall be manufactured from ledge rock, talus, or gravel, in accordance with Section 3-01 of the *Standard Specifications for Road, Bridge, and Municipal Construction* (WSDOT 2008d), which meets the following test requirements: Los Angeles Wear, 500 Revolutions 35% max. Degradation Factor 30 min. Crushed screenings shall conform to the following requirements for grading and quality: Sieve Size Percent Passing (by weight) 1/2" square 100 3/8" square 90-100 U.S. No. 4 30-56 U.S. No. 10 0-10 U.S. No. 200 0-1.5 % fracture, by weight, min. 75 Static stripping test Pass The fracture requirement shall be at least one fractured face and will apply to material retained on the U.S. No. 10 if that sieve retains more than 5% of the total sample. The finished product shall be clean, uniform in quality, and free from wood, bark, roots, and other deleterious materials. Crushed screenings shall be substantially free from adherent coatings. The presence of a thin, firmly adhering film of weathered rock shall not be considered as coating unless it exists on more than 50% of the surface area of any size between successive laboratory sieves.	3 cubic yards
Perlite • Horticultural grade, free of any toxic materials • Size gradation: at least 70% retained by US Sieve No. 18 and no more than 10% smaller than that which passes through US Sieve No. 30	1 cubic yard per 3 cubic yards of mineral aggregate
Dolomite: $CaMg(CO_3)_2$ (calcium magnesium carbonate) • Horticultural grade, free of any toxic materials • Size gradation: that which passes through US Sieve No. 8 and is retained by US Sieve No. 16.	10 pounds per cubic yard of perlite
Gypsum:Non-calcined, agricultural gypsum $CaSO_4 \cdot 2H_2O$ (hydrated calcium sulfate) • Horticultural grade, free of any toxic materials • Size gradation: that which passes through US Sieve No. 8 and is retained by US Sieve No. 16.	1.5 pounds per cubic yard of perlite

Site Design Elements

Landscaping (Planting Considerations)

Landscaping is the same as for biofiltration swales (see BMP AR.13) unless otherwise specified in the special provisions for the project's construction documents. Plants selected must be suitable for airport settings (Appendix A).

Operations and Maintenance

Maintenance will consist of routine embankment management. While herbicides will not be applied directly over the media filter drain, it may be necessary to periodically control noxious weeds with herbicides in areas around the media filter drain. The use of pesticides is prohibited if the media filter drain is in a critical aquifer recharge area for drinking water supplies. Areas of the media filter drain that show signs of physical damage shall be replaced by airport maintenance staff.

Signing

Nonreflective guideposts will delineate the media filter drain, if approved by airport managers. This practice allows maintenance personnel to identify where the system is installed and to make appropriate repairs should damage occur to the system. If the media filter drain is in a critical aquifer recharge area for drinking water supplies, signage prohibiting the use of pesticides must be provided.

6-2.15. AR.15 – Linear Sand Filter

Eastern Washington	Yes
Western Washington	Yes
Landside Areas	Yes

Object Free Area (OFA)	Maybe*
Runway Safety Area (RSA)	No
Taxiway Safety Area (TSA)	No
Clearway (CWY)	Yes

* Contact FAA Seattle ADO for approval.

Introduction

General Description

Linear sand filters are long, shallow, rectangular vaults (see Figure AR.15.1) housing the same type and depth of sand media specified in BMP AR.16, Sand Filter Basin. They typically consist of two cells or chambers, one for settling the coarse sediment in the runoff entering the filter facility and the other for housing the sand filter media. Stormwater flows from the settling cell into the sand filter cell via a weir section that also functions as a flow spreader to distribute the flow over the sand. The outlet consists of an underdrain pipe system that connects to the storm drain system.

Applications and Limitations

Linear sand filters can be designed in two sizes: basic and large. Basic linear sand filters can be used to meet oil control and basic runoff treatment requirements or as part of a two-facility treatment train for phosphorus or enhanced treatment. Large linear sand filters are used to meet the enhanced treatment objectives.

Linear sand filters are designed to treat runoff from high-use sites for removal of TSS and oil and grease. They are best suited for treating runoff from small drainage areas (less than 5 acres), particularly long, narrow spaces such as the perimeter of a paved surface. The goal is to keep linear sand filters fairly shallow and narrow. A linear sand filter can be located along the perimeter of a paved impervious surface and can be installed upstream or downstream of a vegetated filter strip. If used for oil control, the filter should be located upstream from the main runoff treatment facility.

Presettling/Pretreatment

A sediment chamber is included in linear sand filter design. If the sand filter is preceded by another runoff treatment facility and the flow enters the sand filter as sheet flow, the requirement for the sediment cell may be waived.

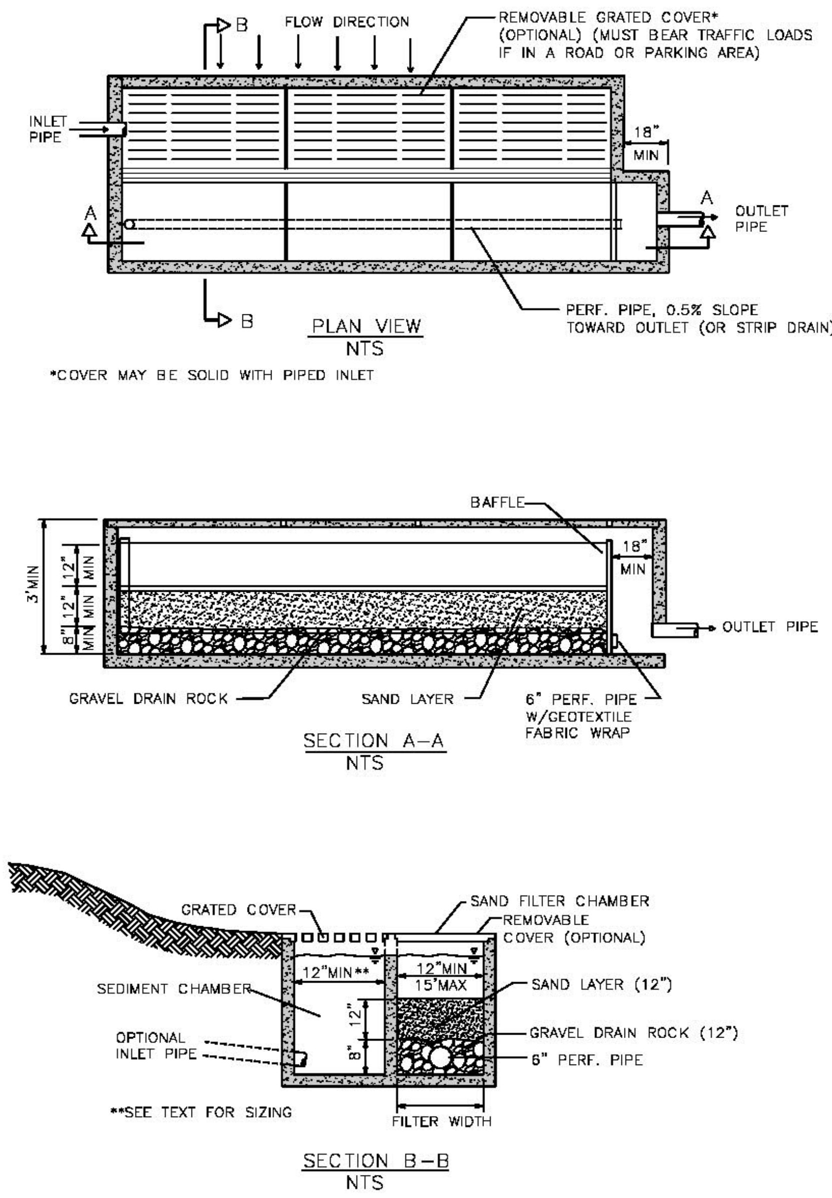

Figure AR.15.1. Linear sand filter with sediment chamber.

Design Flow Elements

Flows to Be Treated

Linear sand filters are designed to capture and treat the runoff treatment design storm volume when the simple sizing method described below (for eastern Washington) is used. When the continuous runoff model sizing method (for western Washington, also described below) is used, sand filters are designed to capture and treat 91 percent of the total runoff volume and bypass or overflow 9 percent of the total runoff volume.

Flow Spreaders

The weir section dividing the presettling and sand filter cells functions as a flow spreader.

Emergency Overflow Spillway

A linear sand filter must have a surface overflow spillway, a piped overflow, or other emergency overflow route for safely controlling the overflow.

Structural Design Considerations

Geometry

Calculate sand filter area using one of the methods described in BMP AR.16. The width of the sand cell must be 1 foot minimum—up to 15 feet maximum. The sand filter bed must be a minimum of 12 inches deep and have an 8-inch layer of drain rock with perforated drainpipe beneath the sand layer.

Set sedimentation cell width as follows:

Sand filter width (w), inches	12-24	24-48	48-72	72+
Sedimentation cell width, inches	12	18	24	w/3

Stormwater may enter the sedimentation cell as sheet flow or via a piped inlet. The two cells should be separated by a divider wall that is level and extends a minimum of 12 inches above the sand bed.

The drainpipe must be a minimum 6-inch diameter, wrapped in geotextile fabric, and sloped a minimum of 0.5 percent.

If separated from traffic areas, a linear sand filter may be covered or open. If covered, the cover must be removable for the entire length of the filter. Covers must be grated if flow to the filter is from sheet flow. Covered linear sand filters must be vented as described for sand filter vaults (see BMP AR.17).

Materials

Linear sand filters must conform to the materials and structural suitability criteria specified for detention vaults (see BMP AR.10).

Specifications for sand media and drain rock are the same as those for sand filter basins (see BMP AR.16).

Site Design Elements

Setback Requirements

Linear sand filters must be a minimum of 5 feet from any property line or vegetative buffer. This distance may need to be increased based on the permit requirements of the local jurisdiction.

Linear sand filters must be 100 feet from any septic tank or drain field, except wet vaults, which must be a minimum of 20 feet.

The designer should obtain a geotechnical report for the project that evaluates any potential structural site instability due to extended subgrade saturation or head loading of the permeable layer, including the potential impacts to downgradient properties (especially on hills with known side-hill seeps). The report should address the adequacy of the proposed linear sand filter locations and recommend the necessary setbacks from any steep slopes and building foundations.

Maintenance Access Roads (Access Requirements)

Maintenance access provisions are the same as those required for detention vaults (see BMP AR.10), except that if the linear sand filter is covered, the cover must be removable for the entire length of the filter.

6-2.16. AR.16 – Sand Filter Basin

Eastern Washington	Yes
Western Washington	Yes
Landside Areas	Yes

Object Free Area (OFA)	Maybe*
Runway Safety Area (RSA)	No
Taxiway Safety Area (TSA)	No
Clearway (CWY)	Yes

* Contact FAA Seattle ADO for approval.

Introduction

General Description

Sand filter basins operate much like runoff treatment infiltration ponds (see Figures AR.16.1 and AR.16.2). However, instead of infiltrating the stormwater runoff into native soils, stormwater filters through a constructed sand bed with an underdrain system. Runoff enters the sand filter bed area and spreads over the surface of the filter. As flows increase, water ponds to a greater depth above the filter bed until it can percolate through the sand. Common configurations for this BMP are open basins with side slopes similar to stormwater ponds and open basins with structural walls or stabilized side slopes. The treatment pathway is vertical (downward through the sand) rather than horizontal as it is in biofiltration swales and filter strips. Water that percolates through the sand is collected in an underdrain system consisting of drain rock and perforated pipes, which directs the treated runoff to the downstream drainage system.

A sand filter removes pollutants by filtration. As stormwater passes through the sand, pollutants are trapped in the small spaces between sand grains or adhere to the sand surface. Over time, soil bacteria will also grow in the sand bed, and some biological treatment may occur.

Based upon experience in King County, Washington, and Austin, Texas, basic sand filters should be capable of achieving the following average pollutant-removal goals:

- 80 percent TSS removal at influent event mean concentrations (EMCs) of 30 to 300 milligrams per liter (mg/L) (King County 1998; Chang 2000)
- Oil and grease removal to below 10 mg/L daily average and 15 mg/L at any time, with no ongoing or recurring visible sheen in the discharge.

Although the SMMWW allows the use of large sand filters for treatment of phosphorus and dissolved metals, Ecology is now emphasizing the use of amended sand filters for this purpose (O’Brien 2007).

The sand filter basin has a high construction cost and high maintenance frequency (and associated costs). It should be considered only when it can be assured that regular maintenance will not interfere with airport operations.

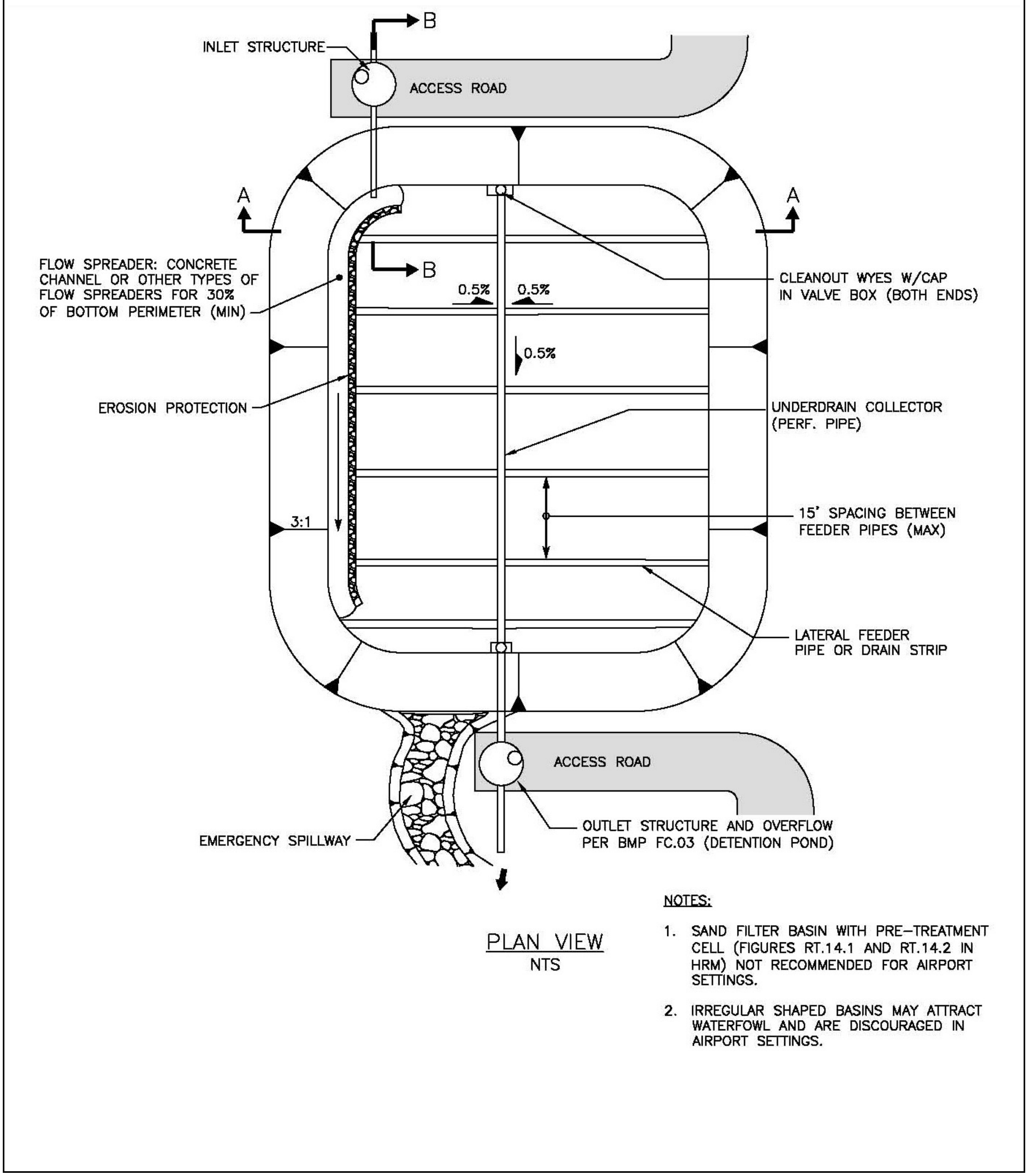

Figure AR.16.1. Sand filter basin with flow spreader.

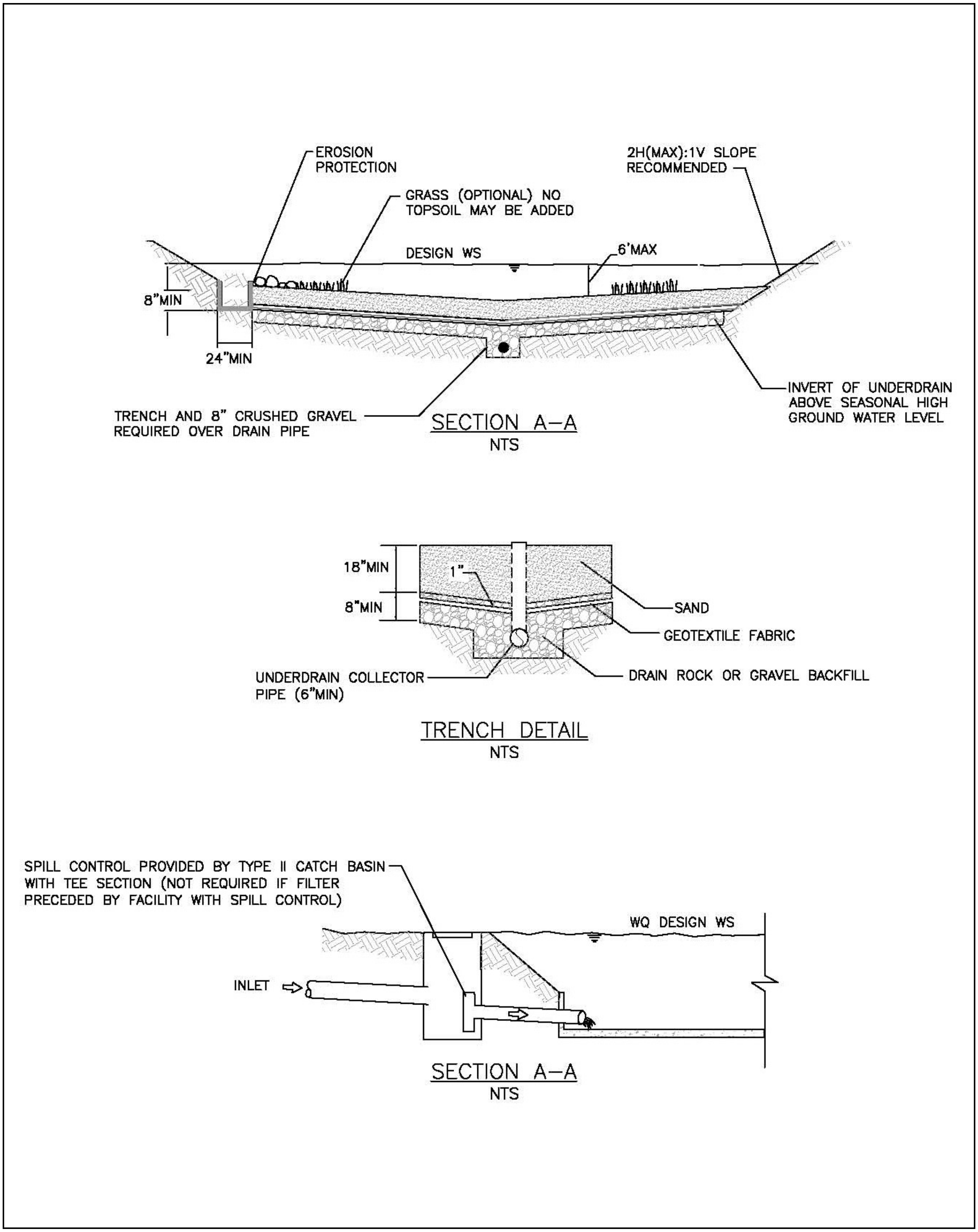

Figure AR.16.2. Sand filter basin with flow spreader: detail and cross sections.

Linear sand filters (BMP AR.15) and sand filter vaults (BMP AR.17) may also be used in airports.

Applications and Limitations

If sand filter basins are to be constructed in the airport environment, wildlife deterrence must be a top priority. In order for these facilities to provide effective water quality treatment, regular maintenance is critical, so maintenance access and features that will not conflict with airport operations must be considered in the initial design. Likewise, for use in airport applications, several design modifications must be included relative to the sand filter basin design presented in the HRM, SMMWW, and SMMEW. These modifications are listed below:

- Steeper side slopes
- Vegetation restrictions
- Irregularly shaped sand filter basins discouraged.

Additional information on the specific modifications and the reason for the modified design are summarized in this section.

Basic sand filters can be used to meet basic runoff treatment objectives, and amended sand filters can be used to treat stormwater for additional removal of phosphorus or dissolved metals. Sand filters can also be used as part of a two-facility treatment train with basic runoff treatment facilities such as biofiltration swales (BMP AR.13), wet vaults (BMP AR.23), and combined wet/detention vaults (BMP AR.24) to treat stormwater for removal of phosphorus or dissolved metals. See BMP AR.25 for more information on treatment trains.

Sand filters can be used where site topography and drainage provide adequate hydraulic head to operate the filter. An elevation difference of at least 4 feet between the inlet to the sand filter basin and the outlet of the filter bed underdrain system is usually needed.

Sand filters can be located off-line before or after detention facilities. On-line sand filters should be located only downstream of a detention facility.

Sand filters are designed to prevent water from backing up into the sand layer from underneath, and thus the underdrain system must drain freely. A sand filter is more difficult to install in areas with high water tables where groundwater could potentially flood the underdrain system. In addition to the wildlife attractant presented by standing water, water standing in the underdrain system also keeps the sand saturated. Under these conditions, oxygen can be depleted, releasing pollutants such as metals and phosphorus that are more mobile under anoxic conditions. Due to the risk to aircraft and the potential for inadequate water quality treatment, sand filter basins shall not be used in airport settings with high water tables (i.e., less than 2 feet between the seasonal high groundwater level and the bottom of the sand filter).

An underground filter (see BMP AR.15, Linear Sand Filter, or BMP AR.17, Sand Filter Vault) should be considered in areas subject to freezing.

Because the surface of the sand filter clogs with sediment and other debris, this BMP shall not be used in areas where heavy sediment loads are expected. A sand filter shall not be used during construction to control sediments unless the sand bed is replaced periodically during construction and after the site is stabilized.

Although the sand filter basin BMP may have fairly good applications in urbanized settings where space is limited, its initial high construction cost and high maintenance frequency (and associated costs) must be considered when deciding whether it is a practical treatment choice for a particular site. It should be considered only when it can be assured that regular maintenance will not interfere with airport operations.

Presettling and/or Pretreatment

Pretreatment is required to reduce velocities to the sand filter and to remove debris, floatables, large particulate matter, and oils.

Pretreatment can be accomplished by one of the following:

- Biofiltration swale (BMP AR.13)
- Filter strip (BMP AR.12)
- **Proprietary Presettling Devices**. These devices are designed to remove debris, sediment, and large oil droplets. They are considered "emerging technologies" by Ecology. Emerging technologies that have been evaluated by Ecology have one of three designations; general use level designation (GULD), conditional use level designation (CUD), or pilot level designation (PLD). Technologies with a GULD may be used without additional approval for the designated treatment category (pretreatment in this case), while Ecology approval would be required for technologies that are designated as PLD or CUD. Additional information on proprietary presettling devices may be found at the following Washington State Department of Ecology website: <http://www.ecy.wa.gov/programs/wq/stormwater/newtech/vortex_enhanced_sedimentation.html>.

Design Flow Elements

Flows to Be Treated

Sand filters are designed to capture and treat the runoff treatment design storm volume when the simple sizing method described below (for eastern Washington) is used. When the continuous runoff model sizing method (for western Washington, also described below) is used, sand filters are designed to capture and treat 91 percent of the total runoff volume and bypass or overflow 9 percent of the total runoff volume.

Overflow or Bypass

Sand filter facilities must include an overflow structure. The overflow elevation should coincide with the maximum design hydraulic head above the sand bed. For overflow structure design guidance, see the HRM.

Location of Sand Filter with Respect to Detention Facilities and Conveyance Systems

The size of the sand filter varies depending on whether it is upstream or downstream of the on-site detention facility. Additionally, the location of the sand filter with respect to the on-site drainage conveyance system dictates the need (or lack thereof) for a flow splitter. Figure AR.16.3 shows various configurations for sand filters in relation to detention facilities and conveyance systems that are referred to throughout this section.

Flow Splitters

An off-line sand filter must be designed to filter all of the water it receives. Therefore, a continuous runoff model that simulates direction of all flows at or below a design flow rate to the filter must be used to determine an acceptable combination of filter size and minimum storage reservoir above the filter. The system needs to ensure complete filtration of all runoff directed to the filter. (See the HRM for flow splitter design guidance.)

Flow Spreaders

Flow spreading structures (e.g., flow spreaders, weirs, or multiple orifice openings) shall be designed to minimize turbulence and to spread the flow uniformly across the surface of the sand filter (see Figures AR.16.1 and AR.16.2). Stone riprap or other energy-dissipation devices shall be installed to prevent erosion of the sand medium and to promote uniform flow (see the HRM).

Emergency Overflow Spillway

As illustrated in Figure AR.16.3, sand filters designed as on-line facilities shall include an emergency overflow spillway. For design guidance, see BMP AR.09.

Drawdown Time

A drawdown time of 1 day (24 hours) is used from the completion of inflow into the sand filter facility to the completion of outflow from the sand filter underdrain of that same storm event.

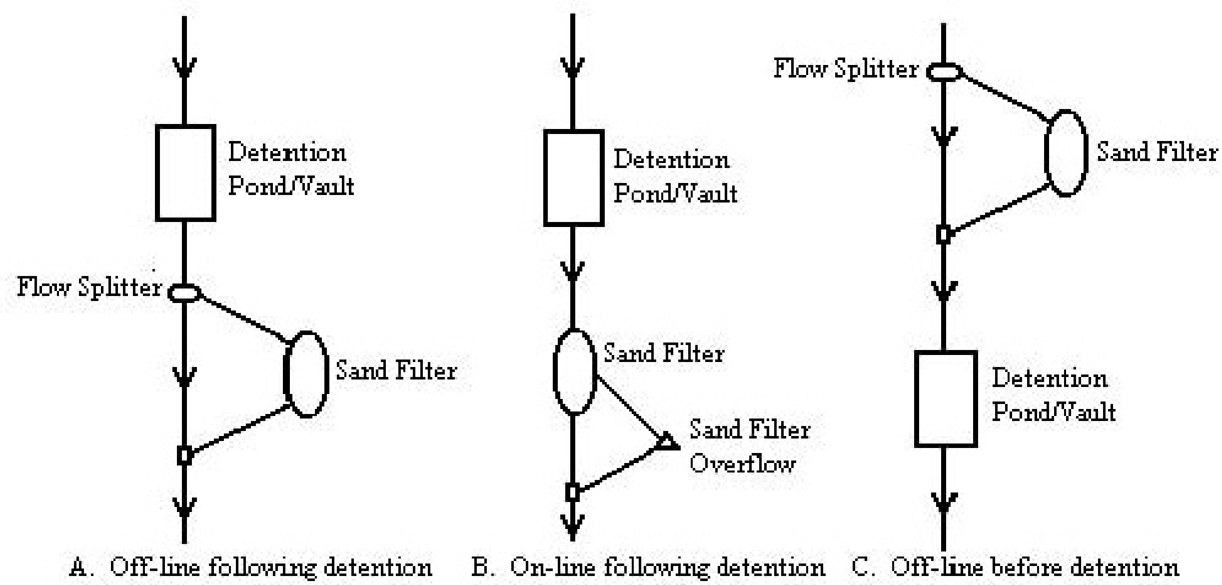

Figure AR.16.3. System layout options for sand filters with detention BMPs.

Structural Design Considerations

A sand filter is designed with two parts: a temporary storage reservoir to store runoff, and a sand filter bed through which the stored runoff percolates. Usually the storage reservoir is placed directly above the filter, i.e., the base of the reservoir is the top of the sand bed. For this case, the storage volume determines the hydraulic head over the filter surface. Greater hydraulic head increases the rate of flow through the sand.

Geometry

Two methods are given here to size sand filters: a simple sizing method (for eastern Washington) and a continuous runoff model sizing method (for western Washington). The simple sizing method uses standard values to define filter hydraulic characteristics for determining the sand surface area. This method is useful for planning purposes, for a first approximation to begin iterations in the detailed method, or when use of the continuous runoff model is not desired, required, or available.

The continuous runoff model sizing method uses a continuous simulation computer model to determine sand filter area and pond size based on specific site conditions. Use of the continuous runoff model design method often results in filter sizes that are smaller than those derived by the simple method, especially if the facility is downstream of a detention pond.

For either method, the following design criteria apply:

- Sand filter bed depth: 1.5 to 2.5 feet
- Maximum ponding (storage reservoir) depth: 1.0 to 6.0 feet
- Percentage of sand filter perimeter with flow spreader: 30 percent minimum (if the length-to-width ratio of the filter is 2:1 or greater, then a flow spreader must be located on the longer side).

Simple Sizing Method (for Eastern Washington)

This method applies to the off-line placement of a sand filter upstream or downstream of detention facilities. A conservative design approach is described below using a routing adjustment factor. If this approach is used, computations of flow routing through the filter do not need to be performed. An alternative simple approach for off-line placement downstream of detention facilities is to route the full 2-year release peak flow rate from the detention facility (sized to match the predeveloped peak flow rates) to a sand filter with sufficient surface area and reservoir storage volume to effectively filter the peak flow rate.

For sizing a sand filter, apply a routing adjustment factor of 0.7 to the runoff volume associated with a 6-month, 24-hour storm event to compensate for routing through the sand bed at the maximum ponding depth. Design a flow splitter to route the runoff treatment design flow rate to the sand filter.

Example Calculation

Design Specifications

The sizing of the sand filter is based on routing the design runoff volume through the sand filter and using Darcy's law to account for variations in flow percolation through the sand bed caused by the hydraulic head variations in the water ponded above the sand bed during and following a storm. Darcy's law is represented by the following equation:

$$Q_{sf} = KiA_{sf} = FA_{sf}$$

where: $i = (h+L)/L$

Therefore, $A_{sf} = Q_{sf}/Ki$

Also, $Q_{sf} = A_tQ_dR/t$

Substituting for Q_{sf}, $A_{sf} = A_tQ_dR/Kit$

Or, $A_{sf} = A_tQ_dR/\{K(h+L)/L\}t$

Or, $A_{sf} = A_tQ_dR/Ft$

where: Q_{sf} = flow rate (ft^3/day) at which runoff is filtered by the sand filter bed

A_{sf} = sand filter surface area (ft^2)

Q_d = design storm runoff depth (ft) for the 6-month, 24-hour storm. Use the NRCS curve number equations in Chapter 4 of the HRM to estimate Q_d.

R = routing adjustment factor. Use R = 0.7 (R = 1.0 for large sand filter).

A_t = tributary drainage area (ft^2)

K = hydraulic conductivity of the sand bed (ft/day). Use 2 feet per day for filters with pretreatment.

i = hydraulic gradient of the pond above the filter (h+L)/L (ft/ft)

F = filtration rate (ft/day) (F = Ki)

d = maximum depth of water over sand filter surface (ft)

h = average depth of water over sand filter surface (ft) (h = d/2)

t = recommended maximum drawdown time (days). In general, 1 day (24 hours) is used from the completion of inflow into the sand filter facility (assume the presettling basin in front of the sand filter is full of water) of a discrete storm event to the completion of outflow from the sand filter underdrain of that same storm event.

L = sand bed depth (ft). Generally use 1.5 feet.

Given conditions:

- Sedimentation basin is fully ponded and no ponded water is above the sand filter
- A_t = 10 acres
- Q_d = 0.922 inches (0.0768 feet) for SeaTac rainfall
- Curve number = 96.2 for 85 percent impervious and 15 percent till grass tributary surfaces
- R = 0.7
- Maximum drawdown time through sand filter = 24 hours
- Maximum pond depth above sand filter = either 3 feet or 6 feet (two examples are calculated below)
- h = 1.5 feet or 3 feet
- Design hydraulic conductivity of basic sand filter, K = 2.0 feet/day (1 inch/hour).

Using design equation:

$$A_{sf} = A_t Q_d RL/Kt(h+L)$$

At pond depth of 6 feet:

$$A_{sf} = (10)43{,}560(0.0768)(0.7)(1.5)/(2)(1)(4.5) = 3{,}911 \text{ square feet}$$

Therefore, A_{sf} for the basic sand filter becomes:

3,911 square feet at pond depth of 6 feet
5,867 square feet at pond depth of 3 feet.

Continuous Runoff Model Sizing Method (for Western Washington)

This method uses a long-term history of rainfall or runoff to size the stormwater facility. The rainfall history (preferably in 15-minute or hourly increments) is entered into a continuous runoff model. The model then calculates inflow to the facility, the volume required to treat the inflow, and the discharge rate. In western Washington, the facility size is intended to capture and treat 91 percent of the annual runoff volume.

Off-line: An off-line basic sand filter located upstream of detention facilities should have an upstream flow splitter that is designed to bypass the incremental portion of flows above the runoff treatment design flow rate. The long-term runoff time series used as input to the sand filter should be modified to use all flows up to the runoff treatment design flow rate and to disregard all flows above that rate. The design overflow volume for off-line sand filters is zero because all flows routed to the filter are at or below the runoff treatment design flow. Therefore, the goal is to size the storage reservoir so that its capacity is not exceeded. (Note: An emergency overflow should nonetheless be included in the design.)

If a modeling routine is not available to modify a runoff time series as described above, then the storage reservoir for the off-line facility can be sized as if in an on-line mode. All of the post-development runoff time series is routed to the storage reservoir, which is then sized to allow overflow of 9 percent of the total runoff volume of the time series. In actual practice, an off-line flow splitter does not route all of the postdevelopment time series to the storage reservoir, and so the reservoir should not overflow if operating within design criteria. This design approach should result in slightly oversizing the storage reservoir.

Downstream of detention facilities, the flow splitter should be designed to bypass the incremental portion of flows above the flow rate that corresponds with treating 91 percent of the runoff volume of the long-term time series. Because flow rates are reduced by the detention facility, this flow rate is lower than the runoff treatment design flow rate for facilities located upstream of detention facilities. Accordingly, the design flow rate should be adjusted to use the flow rate corresponding to treating 91 percent of the runoff volume from the postdetention runoff time series.

On-line: Sand filters that are on-line (i.e., all flows enter the storage reservoir) should be located only downstream of detention facilities to prevent exposure of the sand filter surface to high flow rates that could cause loss of media and resuspension of previously removed pollutants. The storage pond above the sand bed should be sized to restrict the total amount of overflow from the reservoir to 9 percent of the total runoff volume of the long-term time series.

Underdrains

Acceptable types of underdrains include (1) a central collector pipe with lateral feeder pipes, (2) a geotextile drain strip in an 8-inch gravel backfill or drain rock bed, and (3) longitudinal pipes in an 8-inch gravel backfill or drain rock bed with a collector pipe at the outlet end. The following are design criteria for the underdrain piping:

- Where placed upstream of detention facilities, underdrain piping should be sized to convey double the 2-year return frequency flow calculated by a continuous simulation model (the doubling factor is a conversion from the 1-hour time step to a 15-minute time step—omit this factor if a 15-minute time step is used for the design). Downstream of detention, the underdrain piping should be sized for the 2-year return frequency flow calculated by a continuous simulation model.
- Internal diameters of underdrain pipes should be a minimum of 6 inches, with perforations of ½-inch holes spaced 6 inches apart longitudinally (maximum). Rows of perforations should be 120º radially apart (with holes oriented downward). The maximum perpendicular distance between two feeder pipes must be 15 feet. All piping is to be Schedule 40 PVC or

greater wall thickness. Drain piping can be installed in both basin and trench configurations.

- The main collector underdrain pipe should be laid on a slope of at least 0.5 percent minimum, allowing a flow velocity of approximately 2.5 feet per second (fps). Maximum velocities are dependent on downstream characteristics, but should generally be less than 15 fps.
- A geotextile fabric for underground drainage (see Section 9-33 of the WSDOT Standard Specifications) must be used between the sand layer and drain rock and placed so that 1 inch of drain rock is above the fabric. Drain rock should be washed free of clay and organic material.

An inlet shutoff or bypass valve is recommended to facilitate maintenance of the sand filter. Cleanout wyes with caps or junction boxes must be provided at both ends of the collector pipes. Cleanouts must extend to the surface of the filter. A valve box must provide access to the cleanouts. Access for cleaning all underdrain piping is needed, which may consist of installing cleanout ports that tee into the underdrain system and surface above the top of the sand bed.

Materials

The filter medium must consist of a sand meeting the size gradation (by weight) given in Table AR.16.1. This gradation is equivalent to fine aggregate Class 1 for Portland Cement Concrete, as referenced in Section 9-03.1(2)B of the Standard Specifications, which can also be used in a sand filter application.

Table AR.16.1. Sand medium specification.

U.S. Sieve Number	Percent Passing
4	95-100
8	70-100
16	40-90
30	25-75
50	2-25
100	<4
200	<2

Berms, Baffles, and Slopes

Side slopes for earthen/grass embankments should not exceed 3H:1V to facilitate mowing.

Liners

- Low-permeability liners may be installed below the sand bed and underdrain system to provide retention of soluble pollutants such as metals and toxic organics and where the underflow could cause problems with nearby structures (see the HRM). Low-permeability liners may be made of clay, concrete, or geomembrane materials. Geotextile fabric liners shall meet underground drainage geotextile specifications listed in Section 9-33 of the WSDOT Standard Specifications, unless the basin has been excavated to bedrock.

- If a low-permeability liner is not provided, then an analysis should be made of the possible adverse effects of seepage zones on groundwater and on nearby building foundations, basements, roads, runway operations facilities, parking lots, and sloping sites. Sand filters should be located at least 20 feet downslope and 100 feet upslope from building foundations. Sand filters without low-permeability liners should not be built on fill sites.

Site Design Elements

Setback Requirements

Setback requirements for sand filter basins are the same as those for detention ponds (see BMP AR.09).

Landscaping (Planting Considerations)

Landscape uses may be somewhat constrained because the vegetation capable of surviving in sand is limited. Grass has been grown successfully on top of several sand filters in western Washington where the grass seed was tailored for growth in sand with highly variable degrees of saturation. Trees and shrubs that generate a large leaf fall should be avoided in the immediate vicinity of the filter because leaves and other debris can clog the surface of the filter.

Should planting within sand filters be desired, general guidelines is provided below. Appendix A contains lists of plants recommended as generally suitable for revegetation and landscaping in airport settings. Guidance for planting methods is also provided below. For plant species lists and planting methods specific to local site conditions, consult a qualified landscape architect, biologist, and/or other specialist.

- Plants must be selected that encourage filtering and settling of suspended solids and that are not attractive to wildlife potentially hazardous to aircraft. Select fine, turf-forming grasses where moisture is appropriate for growth.
- If possible, perform seeding of the BMP during the seeding windows specified in the WSDOT Standard Specifications section 8-01.3(2)F, Dates for Application of Final Seed, Fertilizer, and Mulch. To the greatest extent possible, seeding should be conducted at a time when hazardous wildlife are not as prevalent and/or are less likely to be attracted to seed.

Perform planting of the BMP during the planting windows specified in the WSDOT Standard Specifications section 8-03.3(8) Planting. Supplemental irrigation may be required depending on seeding and planting times.

- Stabilize soil areas upslope of the BMP to prevent erosion and excessive sediment deposition.
- Apply seed using methods and timing that limits the attractiveness of the seeded area to hazardous wildlife. Seeding should be coordinated with a qualified airport wildlife biologist to make sure seeds or young plant shoots are not available when hazardous migratory wildlife are expected.
- Plant BMPs with species that can withstand periodic saturation as well as extended dry periods.

Maintenance Access Roads (Access Requirements)

An access ramp, or equivalent access, is necessary for maintenance purposes at the inlet and the outlet of an aboveground sand filter. The ramp slope must not exceed 15 percent.

6-2.17. AR.17 – Sand Filter Vault

Eastern Washington	Yes
Western Washington	Yes
Landside Areas	Yes

Object Free Area (OFA)	Yes*
Runway Safety Area (RSA)	No
Taxiway Safety Area (TSA)	No
Clearway (CWY)	Yes*

* Contact FAA Seattle ADO for approval.

Introduction

General Description

Sand filter vaults are similar to sand filter basins, except that the sand layer and underdrains are installed below grade in a vault (see Figures AR.17.1 and AR.17.2). Like an aboveground sand filter, a sand filter vault can be sized as either a basic or a large facility to meet different runoff treatment objectives. The basic sand filter vault is designed to meet a performance goal of 80 percent total suspended solids (TSS) removal for the runoff treatment design flow. In addition, the large sand filter vault is expected to meet a performance goal of 50 percent total phosphorus removal.

Applications and Limitations

Basic sand filter vaults can be used to meet basic runoff treatment objectives, and large sand filter vaults can be used to treat stormwater for additional removal of phosphorus or dissolved metals. Basic sand filter vaults can also be used as part of a two-facility treatment train to treat stormwater for removal of phosphorus or dissolved metals.

A sand filter vault can be used on sites where space limitations preclude the installation of aboveground facilities. In highly urbanized areas, particularly on redevelopment and infill projects, a vault is a viable alternative to other treatment technologies that require more area to construct.

Like aboveground sand filter basins (see BMP AR.16), sand filter vaults are not suitable for areas with high water tables where infiltration of groundwater into the vault and underdrain system interferes with the hydraulic operation of the filter. Soil conditions in the vicinity of the vault installation should be evaluated to identify special design or construction requirements for the vault.

It is desirable to have an elevation difference of 4 feet between the inlet and outlet of the filter for efficient operation. Therefore, site topography and drainage system hydraulics must be evaluated to determine whether use of an underground filter is feasible.

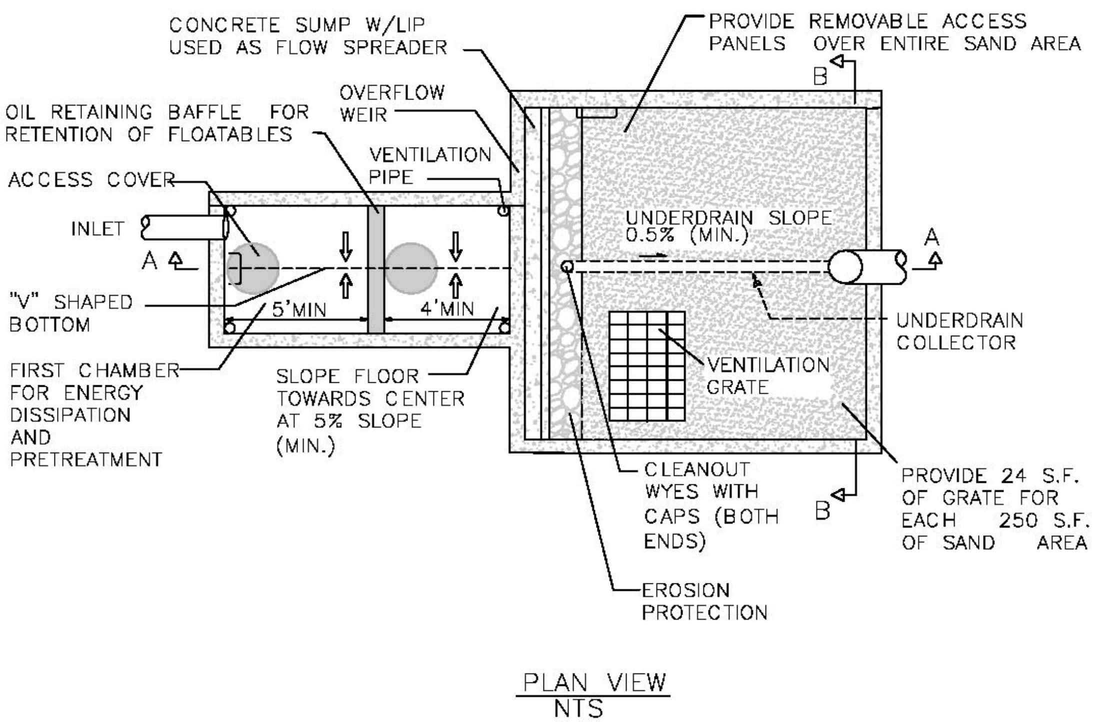

Figure AR.17.1.   Sand filter vault.

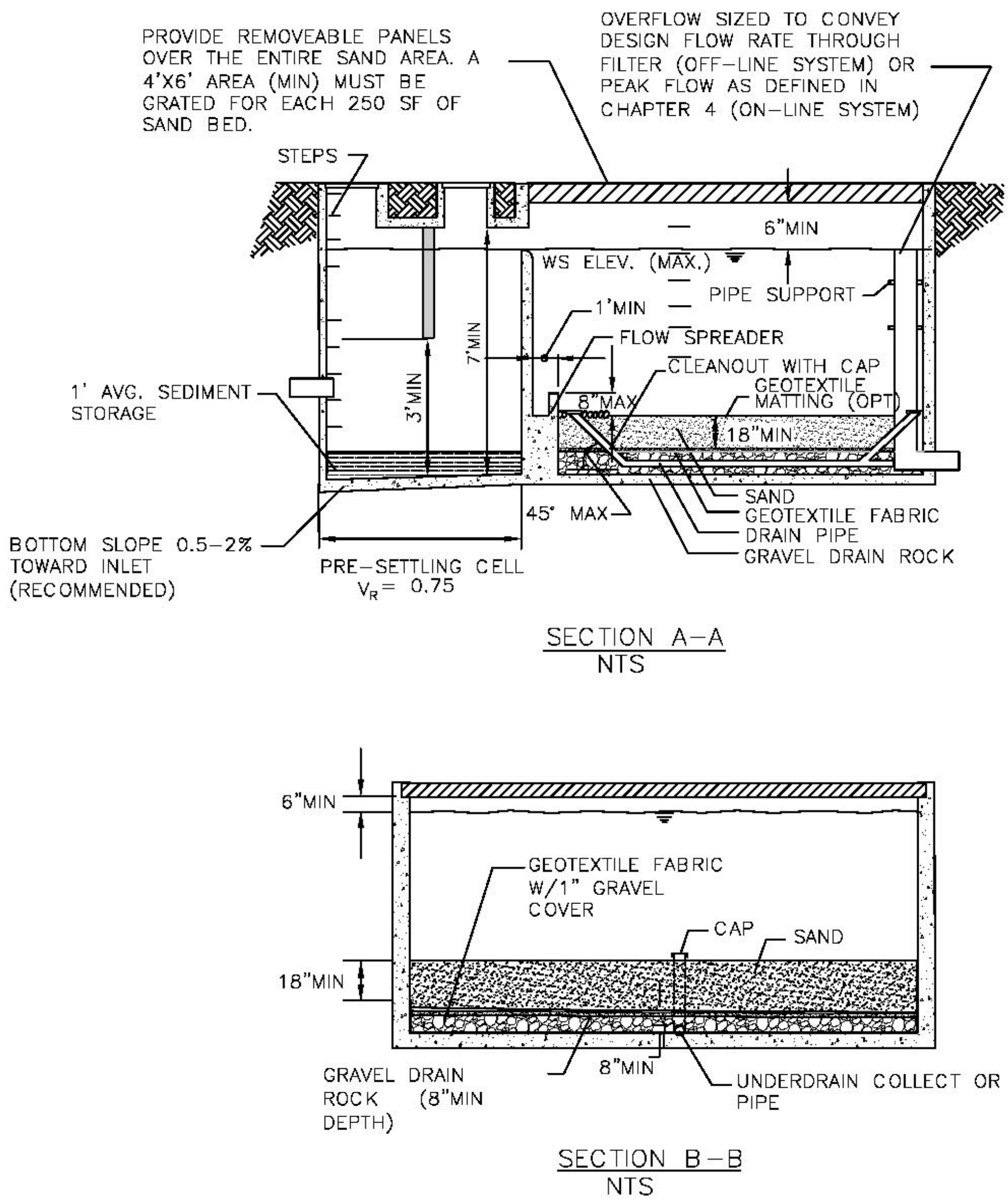

Figure AR.17.2. Sand filter vault: Cross sections.

Because the surface of a sand filter bed is prone to clogging from sediment and other debris, this BMP should not be used in areas where heavy sediment loads are expected.

Sand filter vaults should be located off-line before or after detention facilities. However, if necessary, vaults may be located on-line for small drainages or a detention facility. Overflow or bypass structures must be carefully designed to handle the larger storms.

Although this BMP may have fairly good applications in urban settings where space is limited, its initial high construction cost and high maintenance frequency (and associated costs) make it an undesirable choice of treatment. It should be considered only when no other options are feasible.

Presettling and/or Pretreatment

Pretreatment is necessary to reduce flow velocities entering the sand filter and to remove debris, floatables, large particulate matter, and oils. A pretreatment cell is included as a part of sand filter vault design.

Design Flow Elements

Flows to Be Treated

The flows to be treated by sand filter vaults are the same as those for sand filter basins (see BMP AR.16).

Overflow or Bypass

Sand filters designed as on-line facilities must include an overflow structure for flows greater than the design flow (see Figure AR.17.2).

Flow Splitters

In an off-line system, a diversion structure should be installed to divert the design flow rate into the sediment chamber and to bypass higher flows. (See the HRM for flow bypass design guidelines.)

Flow Spreaders

A flow spreader must be installed at the inlet to the filter bed to evenly distribute incoming runoff across the filter and prevent erosion of the filter surface.

The flow spreader must be positioned so that the top of the spreader is no more than 8 inches above the top of the sand bed and at least 2 inches higher than the top of the inlet pipe if a pipe and manifold distribution system is used. (See the HRM for flow spreader design options.) For vaults with presettling cells, a concrete sump-type flow spreader must be built into or affixed to the divider wall. The sump must be a minimum of 1 foot wide and extend the width of the sand filter. The downstream lip of the sump must be no more than 8 inches above the top of the sand bed (see Figure AR.17.2).

Flows may enter the sand bed by spilling over the top of the wall into a flow spreader pad. Alternatively, a pipe and manifold system may be designed to deliver water through the wall to the flow spreader. If an inlet pipe and manifold system are used, the minimum pipe size should be 8 inches. Multiple inlets are recommended to minimize turbulence and reduce local flow velocities.

Note: Water in the first or presettling cell is dead storage. Any pipe and manifold system design must retain the required dead storage volume in the first cell, minimize turbulence, and be readily maintainable.

Erosion protection must be provided along the first foot of the sand bed width adjacent to the spreader. Geotextile fabric secured on the surface of the sand bed, or an equivalent method, may be used.

Structural Design Considerations

Geometry

The sand filter area is calculated using one of the methods described in BMP AR.16.

The bottom of the presettling cell may be longitudinally level or inclined toward the inlet. To facilitate sediment removal, the bottom must also slope from each side toward the center at a minimum of 5 percent, forming a broad V. Note that more than one V may be used to minimize cell depth.

Exception: The bottom of the presettling cell may be flat rather than V-shaped if removable panels are installed over the entire presettling cell.

An average 1 foot of sediment storage must be provided in the presettling cell.

To prevent anoxic conditions, a minimum of 24 square feet of ventilation grate should be provided for each 250 square feet of sand bed surface area. For sufficient distribution of airflow across the sand bed, grates may be located in one area if the sand filter is small, but placement at each end is preferred. Small grates may also be dispersed over the entire sand bed area.

Intent: Grates are important to allow air exchange above the sand. Poor air exchange hastens anoxic conditions, which may result in release of pollutants such as phosphorus and metals and may cause objectionable odors.

Materials

Sand filter vaults must conform to the materials and structural suitability criteria specified for detention vaults (see BMP AR.10).

Vaults must have removable panels over the entire area of the sand filter bed. The panels must be at grade, have stainless steel lifting eyes, and weigh no more than 5 tons per panel. If located within the roadway, the panels must meet H-20 wheel loading requirements.

The filter bed should consist of a top layer of sand, an underlying layer of sand encased in geotextile fabric, and an underdrain system at the bottom. The geotextile fabric protects the intermediate layer from clogging so that periodic filter reconditioning can focus on the top layer of the bed. The specifications for each of these layers are the same as those for sand filter basins (see BMP AR.16).

A geotextile fabric may be installed over the entire sand bed to trap trash and litter. It must be flexible, highly permeable, a three-dimensional matrix, and adequately secured.

Berms, Baffles, and Slopes

If an oil-retaining baffle is used for control of floatables in the presettling cell, it must:

- Extend from 1 foot above to 1 foot below the runoff treatment design water surface (minimum requirements).
- Be spaced a minimum of 5 feet horizontally from the inlet.
- Provide for passage of flows in the event of plugging.

Site Design Elements

Setback Requirements

Setback requirements for sand filter vaults are the same as those for detention vaults (see BMP AR.10).

Maintenance Access Roads (Access Requirements)

Maintenance access requirements for sand filter vaults are the same as those for detention vaults (see BMP AR.10), except for the following modifications:

- Provide maintenance vehicle access to enable removal of all panels atop the sand filter bed and presettling cell, if applicable
- Provide an access opening and ladder on both sides of the oil-retaining baffle into the presettling cell

Install an inlet shutoff/bypass valve for maintenance.

6-2.18. AR.18 – Amended Sand Filters

Eastern Washington	Yes	Object Free Area (OFA)	Yes*
Western Washington	Yes	Runway Safety Area (RSA)	No
Landside Areas	Yes	Taxiway Safety Area (TSA)	No
		Clearway (CWY)	Yes*

* Contact FAA Seattle ADO for approval.

Introduction

An amended sand filter for enhanced (metals) treatment is included in the SMMWW and SMMEW as an emerging technology. Depending on the media selected, an amended sand filter may also be designed to target phosphorus removal. This section provides design guidance for amended sand filters that target phosphorus and/or dissolved metals. The filter media amendments discussed in this section differ depending on the target pollutant. Note that the filter media discussed is experimental and has not met the testing protocols of the technology assessment protocol Ecology (TAPE) program. It is the responsibility of the project owner or designer to select an appropriate media and complete the Ecology approval process as discussed under *Applications and Limitations*.

General Description

An amended sand filter is a sand filter basin (AR.16), linear sand filter (AR.15), or sand filter vault (AR.17) that is constructed with an amended sand medium designed to target the pollutant of concern (metals or phosphorus).

Applications and Limitations

Amended sand filters have not received approval for general use by Ecology. There is limited data available on the performance of filtration media amendments. Implementation of amended sand filters for phosphorus or enhanced treatment will be subject to Ecology's evaluation process (see Chapter 12 of the SMMWW and Section 5.12 of the SMMEW) before the actual project application can be permitted to meet applicable Minimum Requirements. This BMP may be considered for use on a “pilot” scale if Ecology accepts the design proposal.

The design guidelines in this section have been modified from the WSDOT guidelines (WSDOT 2006b) to reflect special considerations needed for airport settings.

Design Flow Elements

Flows to be treated, overflow/bypass, location and other design criteria related to design flow elements are identical to those for AR.16, Sand Filter Basin, in the preceding section.

Structural Design Considerations

Materials

Amended sand filters should follow the design criteria of BMP AR.16, Sand Filter Basin (see Table AR.16.1 in the preceding section), with the filter medium amended to target the specific pollutant of concern. This section summarizes recent research on the performance of various media:

Steel Wool

The City of Bellevue conducted a study of a sand filter that was amended with processed steel fiber (95 percent sand and 5 percent processed steel fiber by volume), and crushed calcitic limestone (90 percent sand and 10 percent crushed calcitic limestone by volume) (Varner 1999) to target total phosphorus and dissolved zinc. While initial performance was good, the City later found that the processed steel fiber formed a cemented layer of ferric oxide, greatly reducing the infiltration in the sand filter. More recent laboratory research by Erickson et al. (2007) found good removal of phosphorous using steel wool. Steel fibers were added below the sand and above filter fabric to reduce the risk of steel fibers migrating and forming a cemented layer as was observed in the Bellevue facility. Due to the serious concerns that continue with the Bellevue facility, steel fiber will not be accepted as a sand amendment medium.

Enhanced (Metals) Treatment – Coarse Compost and Granular Calcitic Limestone Amendment

Note that this is considered an experimental media mix by Ecology. Any project proposing to use this mix would need to go through Ecology's evaluation process. The enhanced media consists of several layers:

- The top 12 inches contain sand (per Table AR.16.1 from the preceding section) (80 percent to 95 percent by volume) and coarse compost (5 percent to 20 percent by volume). The compost is added to support herbaceous vegetation (as noted below). The top of the filter should be seeded with herbaceous vegetation recommended for airport settings (see Appendix A) to maintain bed permeability, shade the bed surface, and limit the extent of invasive vegetation establishment.
- Granular calcitic limestone may be added at a rate of 3 to 15 pounds per cubic yard of the sand/compost mix. The calcitic limestone raises the pH, enhancing the pollutant removal effectiveness of the sand exchange media.
- Sand per the specifications listed in Table AR.16.1 from the preceding section for the next 6 to 12 inches or a 70:30 mix of sand exchange media, by volume (70 percent sand, per the specifications in Table AR.16.1: 30 percent zeolite or other exchange media, by volume). Experimental exchange media may consist of zeolite or activated soybean hulls. Zeolite is a naturally occurring mineral which has been found to remove metals

and ammonia (Minton 2005). Activated soybean hulls are a form of granular activated carbon, which is used to remove organic pollutants, metals, and petroleum hydrocarbons.

Phosphorus Treatment

- Sand (per the specification in Table AR.16.1 from the previous section) (80 percent to 95 percent by volume), coarse compost (5 percent to 20 percent by volume) for the top 12 inches of the sand filter bed.
- Sand per the specification in Table AR.16.1 from the preceding section for the next 6 to 12 inches or a 70:30 mix of iron oxide coated sand (IOCS) or manganese coated "greensand", by volume. These media have been used extensively in wastewater treatment processes to remove phosphorus.
- Top of filter seeded with herbaceous vegetation recommended for airport settings (see Appendix A) to maintain bed permeability, shade the bed surface, and limit the extent of invasive vegetation establishment.

6-2.19. AR.19 – Media Filters

Underground media filter (Stormfilter) at SeaTac.

Eastern Washington	Yes
Western Washington	Yes
Landside Areas	Yes

Object Free Area (OFA)	Yes*
Runway Safety Area (RSA)	No
Taxiway Safety Area (TSA)	No
Clearway (CWY)	Yes*

* Contact FAA Seattle ADO for approval.

Introduction

General Description

The Washington State Department of Ecology (Ecology) is responsible for reviewing and approving proprietary stormwater BMPs for runoff treatment, flow control, and pretreatment uses. The designer needs to review and understand the specific applications and limitations of the specific canister filter type BMP before specifying it for a project. A detailed list of canister filter BMPs can be found at:
🖰 www.ecy.wa.gov/programs/wq/stormwater/newtech/media_filtration.html.

The designer should also note whether or not the BMP is approved for general use. Examples of general use media filter type BMPs include CONTECH'S Stormfilter™ (using zeolite-perlite-granulated carbon media) for basic runoff treatment and CONTECH's CDS Media Filtration System using perlite media for basic runoff treatment.

6-2.20. AR.20 – Submerged Gravel Biofilter

Eastern Washington	Yes
Western Washington	Yes
Landside Areas	Yes

Object Free Area (OFA)	No
Runway Safety Area (RSA)	No
Taxiway Safety Area (TSA)	No
Clearway (CWY)	No

Introduction

The submerged gravel biofilter BMP is not approved by Ecology for runoff treatment, and is therefore regarded as an emerging technology. Variations of the submerged gravel filter have been used to treat wastewater for years and are now being used to treat runoff in airports (U.S. EPA 2000b). These airports include Edmonton in Alberta, Canada; Heathrow in London; and Wilmington in Ohio (Higgins 2007). The pollutant removal mechanism, a biofilm on gravel substrate, shows promise for removal of several types of pollutants, including metals. The available media surface area is much larger than a treatment wetland promising higher reaction rates. Finally, since the facility is underground it should not attract hazardous wildlife and can operate better in cold weather than many surface facilities.

General Description

Submerged gravel biofilters (Figure AR.20.1) are gravel or crushed rock-filled depressions in the ground through which runoff is conveyed at a low velocity. The water flowing through the filter is subsurface, thereby limiting its attractiveness to hazardous wildlife. The primary pollutant removal mechanisms associated with this technology are settling and physical straining within the media void spaces, and biological uptake by bacteria films that form on the gravel surface. Submerged gravel biofilters have the potential to substantially reduce metals concentrations (including copper and zinc) through removal of particulates and sulfide reduction. These facilities can be designed to support wetland vegetation, but research has shown that the soil and roots associated with wetland vegetation decrease the hydraulic conductivity of the media, thereby limiting the overall treatment capacity of the system (U.S. EPA 2000a). In addition, vegetation would increase the attraction to hazardous wildlife. Therefore, wetland vegetation is not generally recommended for these facilities.

Submerged gravel biofilters are considered to be an emerging technology that would require Ecology approval.

Applications and Limitations

Submerged gravel biofilters have been used primarily in wastewater treatment applications with wetland vegetation. Some applications for stormwater have been constructed (Higgins and Maclean 2002) for airport runoff treatment. Because submerged gravel biofilters are considered an experimental BMP, any proposed use of this technology will require prior approval. For instructions on seeking approval for using this BMP, refer to the SMMWW. The design guidelines provided here represent a starting point from which regionally appropriate parameters can be developed.

The submerged gravel biofilter, like other media filtration devices is limited by the effective flow rate through the media. Submerged gravel biofilters are usually limited to less than 60,000 gallons per day. As a result, the large facility size that would be required to treat runoff from larger drainage basins makes this technology impractical for treating areas larger than a few acres.

Design Flow Elements

Flows to Be Treated

Submerged gravel biofilters are flow-through systems designed to treat the runoff treatment discharge rate (Q_{WQ}, using the flow-based sizing criteria) described under Minimum Requirement 6 in Section 1-3.4. Hydrologic methods are presented in Chapter 5.

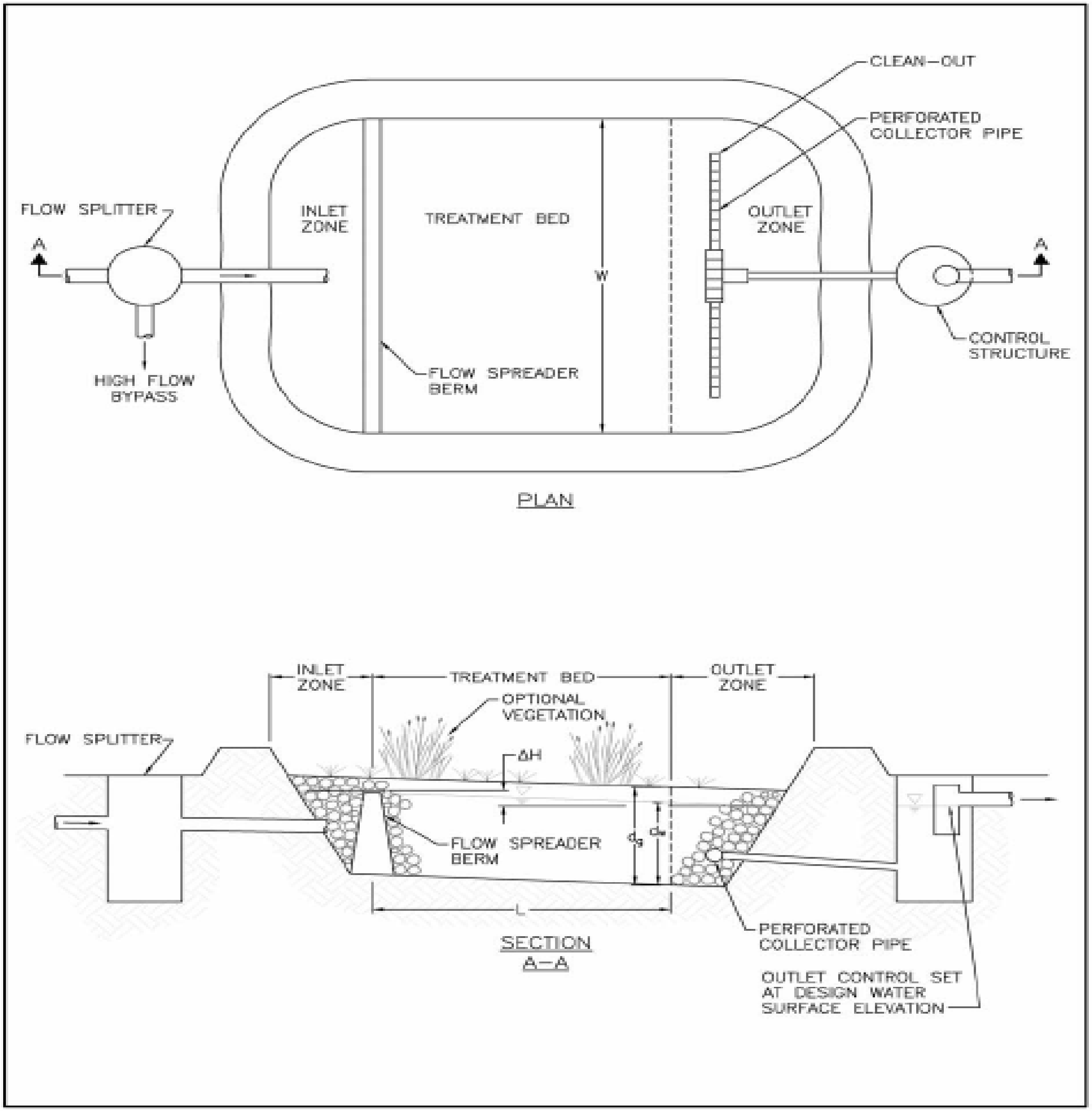

Figure AR.20.1. **Submerged gravel biofilter: plan and section.**

Bypass

Submerged gravel biofilters shall be designed as off-line systems. Flow greater than the design discharge shall be routed around the facility using a flow splitter. Flow splitter options are described in the HRM.

Structural Design Considerations

General Design Criteria and Sizing

The submerged gravel biofilter is composed of three zones: 1) Inlet Zone; 2) Treatment Bed; and 3) Outlet Zone (see Figure AR.20.1). If earthen grassed berms are used for facility walls, sideslopes should not exceed 3H:1V to facilitate mowing.

Design criteria for each zone of the facility are described below.

Design Criteria – Inlet and Outlet Zones

Inlet and outlet zones are composed of coarse gravel. These zones are 6 feet long and have a width equal to that of the treatment bed (see below). At the downstream end of the inlet zone is an inlet flow spreader. The outlet zone includes a perforated outlet collector pipe at the base of the gravel bed. The flow spreader and outlet collector are discussed in a separate section below.

Design Criteria – Treatment Bed

1. Pretreatment is required to prevent rapid clogging of the gravel media. Pretreatment may be accomplished by use of a biofiltration swale (BMP AR.13), vegetated filter strip (BMP AR.12), or proprietary presettling devices. Alternatively, a presettling cell may be used in landside locations only, if adaptive management of open stormwater areas, as described in Chapter 3, are incorporated.

2. Use of wetland vegetation for treatment is not recommended. This is because vegetation requires soil in the gravel bed, which will dramatically decrease the hydraulic conductivity of the gravel filter media. Research suggests that treatment occurs due to a biofilm that forms on the surface of the gravel, and vegetation does not appreciably improve pollutant removal performance. If vegetation is desired in a submerged gravel biofilter, see the Landscape Considerations section below for modified design criteria.

3. Medium to coarse gravel (1 to 1-1/2 inch effective size) shall be used as treatment media.

4. The gravel bed depth (d_g as shown in Figure AR.20.1) shall be between 2 and 6 feet. It is recommended that 4 feet be used as an initial value that can be revised as needed during facility design. Bed depths shall not be greater than ¼ of the bed length to promote plug flow through the length of the biofilter.

5. Design water depth (d_w as shown in Figure AR.20.1) of 90 percent of the gravel bed depth (0.9 d_g) is recommended to prevent surface exposure of water during storm events.

6. A design hydraulic conductivity (k) of 0.038 feet per second shall be used for medium to coarse gravel. This is a conservative, long-term "dirty" hydraulic conductivity that is based on a short-term ("clean") hydraulic conductivity of 0.380 feet per second with a reduction factor of 90 percent to account for clogging. Other media sizes can be used if the appropriate parameters are determined (see the *Materials* section below).

7. Bed width (W) shall not exceed 100 feet. It is recommended that 50 feet be used as a starting value in the design steps below. This can be revised as needed during project design. Facility width also may be constrained by available area. If the design requires a width greater than 100 feet, multiple beds must be constructed to function in parallel.

8. Gravel bed porosity (n) shall be 0.42.

9. Submerged gravel biofilters shall be designed with a hydraulic retention time (θ_h) of 18 hours.

10. Total bed length should be less than 10 times the bed width, but greater than 0.5 times the bed width.

11. Total bed elevation drop across the treatment bed (ΔH) will be determined by the estimated slope of the water surface during design flow. This elevation drop shall not exceed ¼ of the design water depth (d_w) to avoid dewatering of a substantial portion of the treatment bed between runoff events.

Treatment Bed Sizing Procedure

The step-by-step procedure described below is an iterative process that may require revision of input parameters to result in a reasonable facility design.

Step 1 Select initial design gravel bed depth (d_g [ft]), water depth (d_w [ft]), hydraulic conductivity (k [ft/s]), and bed width (W [ft]) based on Criteria 4 through 7 above.

Step 2 Using the predetermined design water quality flow rate (Q_{WQ}), calculate the hydraulic loading rate (q [ft/s]):

$$q = \frac{Q_{WQ}}{W \times d_w}$$

Step 3 Calculate bed slope (S_B [ft/ft]) using Darcy's Law:

$$S_B = \frac{q}{k}$$

Step 4 Calculate the required treatment bed length (L [ft]) based on the design hydraulic retention time (θ_h [hrs]) and porosity (n; see Criteria 8 and 9 above):

$$L = \frac{q \times \theta_h \times 3{,}600}{n}$$

Check the calculated treatment bed length against site constraints and ensure that it is a reasonable value (i.e., the calculated length should be less than 10 times the width and greater than 0.5 times the width). If the resulting length does not fit the site or is unreasonable, return to Step 1 and revise the initial input variables. If the calculated length is unreasonably low, decrease the depth and/or width input values. If the calculated length does not fit the site or is unreasonably high, increase the depth and/or width values.

Step 5 Calculate the bed elevation drop (ΔH [ft]):

$$\Delta H = S_B \times L$$

Check the calculated bed elevation drop against Criterion 11 above. If the calculated bed elevation drop exceeds the criterion, the facility dimensions can be revised by returning to Step 1 and increasing the depth and/or width values. Alternately, the facility can be designed as multiple beds in series, each meeting the bed elevation drop criterion.

Example Calculation

This example calculation assumes a design discharge (Q_{WQ}) of 0.1 cubic feet per second.

Step 1 Select input parameters.

Design gravel depth (d_g) = 4.0 feet,

Design water depth (d_w) = 0.9 x 4.0 = 3.6 feet,

Hydraulic conductivity (k) = 0.038 feet per second,

Bed width (W) = 50 feet.

Step 2 Hydraulic loading rate (q [ft/s]) =

$$q = \frac{0.1}{50 \times 3.6} = 0.000556$$

Step 3 Bed Slope (S_B) =

$$S_B = \frac{0.000556}{0.038} = 0.0146$$

Step 4 Bed length (L [ft]) based on the design hydraulic retention time (θ_h) and porosity (n) of 0.42 =

$$L = \frac{0.000556 \times 18 \times 3{,}600}{0.42} = 85.7$$

Length is reasonable, continue to Step 5.

Step 5 Bed elevation drop (ΔH [ft]) =

$$\Delta H = 0.0146 \times 85.7 = 1.25$$

Bed elevation drop exceeds Criterion 11 (¼ of the design water depth [1/4 x 3.6 feet = 0.9 feet]). Return to Step 1 and increase the width (W) to 75 feet. Resulting length (L) is 57.1 feet. Resulting bed elevation drop (ΔH) is 0.56 feet, which meets Criterion 11.

Inlet Flow Spreader

Inflow must enter the submerged gravel bed evenly along the bed width and from the surface. To provide these conditions, an inlet zone (6 feet in length) of coarse material (coarser than the treatment bed media) shall be provided prior to the treatment bed. A berm with level crest above the design water surface elevation should be used as a flow spreader. Alternately, a masonry block wall with level crest can be used.

Outlet Collector and Control Structure

Treated effluent is to be collected at the base of the gravel bed system through a perforated pipe that extends along the entire width of the facility (see Figure AR.20.1). This pipe will convey collected flow into a manhole/catch basin structure with an adjustable weir that will control the design water surface elevation in the treatment bed. The perforated collector pipe should be of equal diameter to the downstream conveyance pipe.

Cleanouts must be provided at both ends of the collector pipe for maintenance. Access for cleaning all collector piping is needed, which may consist of installing cleanout ports that tee into the collector system and surface above the top of the gravel bed.

Materials

Medium to coarse gravel (1 to 1-1/2 inch effective size) is recommended for the treatment media. Alternate sized material is permitted as long as the appropriate design parameters are modified in the sizing steps outlined previously. The grain size distribution selected will determine the hydraulic characteristics, and therefore the geometry of the facility. Table AR.20-1 provides estimated values of porosity and hydraulic conductivity for various media sizes.

Table AR.20-1. Typical media characteristics for submerged gravel biofilters.

Media Type	Effective Size (mm)	Porosity (*n*, percent)	Short-Term "Clean" Hydraulic Conductivity (*k*, ft/s)	Long-Term "Dirty" Hydraulic Conductivity (*k*, ft/s)
Coarse Sand [a]	2	32	0.038	NA
Gravelly Sand [a]	8	35	0.190	NA
Fine Gravel [a]	16	38	0.285	NA
Medium Gravel [a]	32	40	0.380	NA
Coarse Rock [a]	128	45	3.797	NA
Gravel [b]	5 – 10	NA	1.291	0.034 – 0.456
Creek Rock [b]	17	NA	3.797	1.671
Pea Gravel [b]	6	NA	0.797	0.342
Coarse Gravel [b]	30 – 40	NA	NA	0.038
Fine Gravel [b]	5 – 14	NA	NA	0.456
Pea Gravel [b]	5	NA	0.235	0.023
Rock [b]	19	NA	4.557	0.114

[a] U.S. EPA (1993).
[b] U.S. EPA (2000).
NA = data not available.

Berms, Baffles, and Slopes

Side slopes for earthen/grass embankments shall not exceed 3H:1V to facilitate mowing.

Liners

If soil permeability allows sufficient water retention, lining is not necessary. In infiltrative soils, the base of the submerged gravel biofilter must be lined. Two types of liner are acceptable: low-permeability liners and treatment liners.

Site Design Elements

Setback Requirements

Setback requirements for submerged gravel biofilters are the same as those for detention ponds (see BMP AR.09).

Landscaping (Planting Considerations)

Vegetation is not recommended for submerged gravel biofilters, but can be established on the berms surrounding the facility. General guidance on vegetation can be found in Appendix A.

Maintenance Access Roads (Access Requirements)

An access road, or equivalent access, is necessary for maintenance purposes at the inlet and the outlet of a submerged gravel biofilter.

- Cleanout wyes with caps or junction boxes must be provided at both ends of the collector pipes. Cleanouts must extend to the surface of the filter. A valve box must be provided for access to the cleanouts. A bypass or shutoff valve shall be provided at the biofilter inflow location to enable the biofilter to be taken off-line for maintenance purposes.

6-2.21. AR.21 – Baffle-Type (API) Oil/Water Separator

Eastern Washington	Yes
Western Washington	Yes
Landside Areas	Yes

Object Free Area (OFA)	Yes*
Runway Safety Area (RSA)	No
Taxiway Safety Area (TSA)	No
Clearway (CWY)	Yes*

* Contact FAA Seattle ADO for approval.

Introduction

General Description

Baffle-type (API) oil/water separators are multicelled vaults separated by baffles extending down from the top of the vault (see Figure AR.21.1). The baffles impede oil flow out of the vault by inducing oil to float to the water surface in the baffled compartments. Additional baffles are also commonly installed at the bottom of the vault to trap solids and sludge that accumulate over time. A spill control separator (see Figure AR.21.2) is a simple catch basin with a tee inlet for temporarily trapping small volumes of oil. The spill control separator included below is for comparison only and is not intended to be used for treatment purposes. In many situations, simple floating skimmers or more sophisticated mechanical skimmers are installed to remove the oil once it has separated from the water.

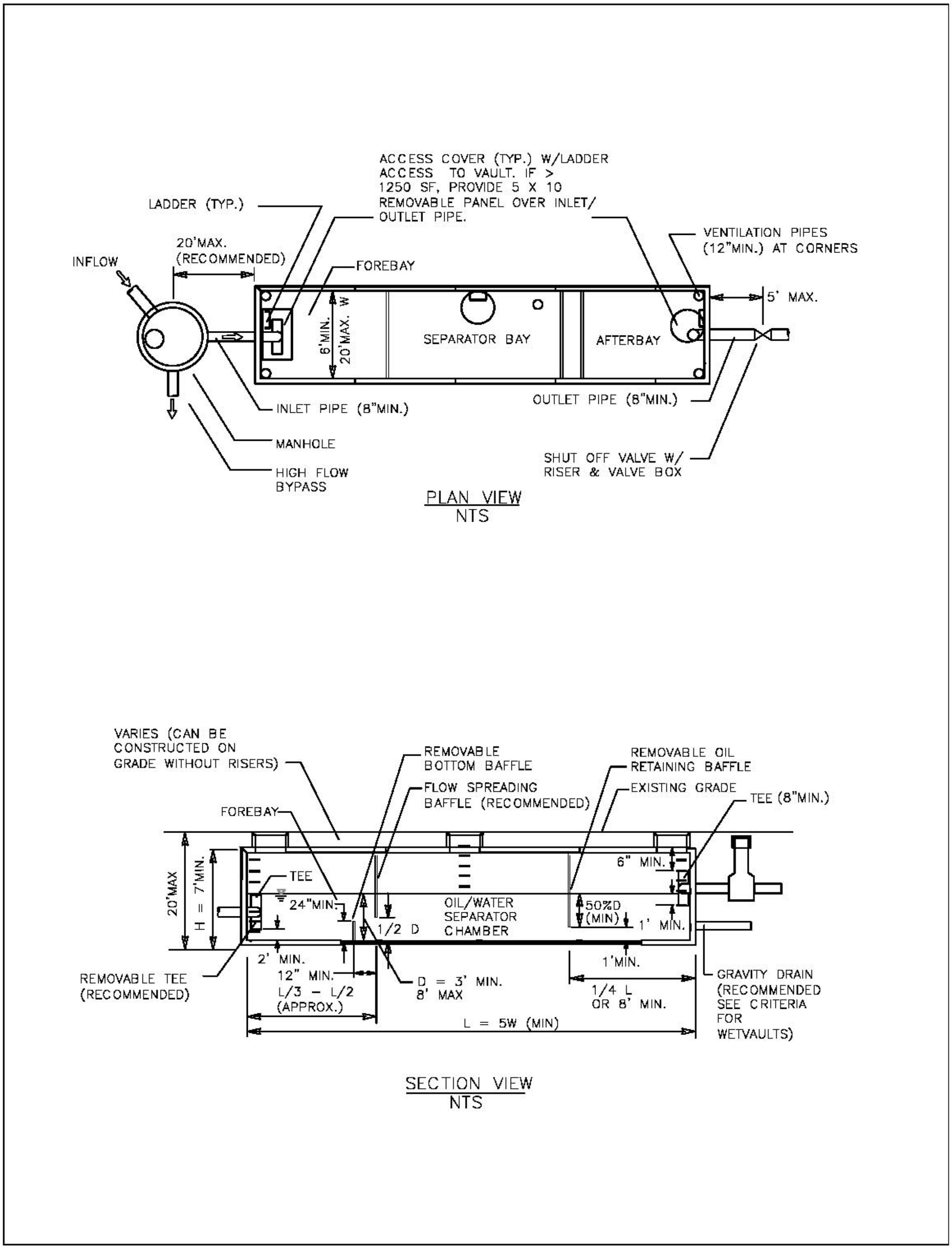

Figure AR.21.1. Baffle-type (API) oil/water separator.

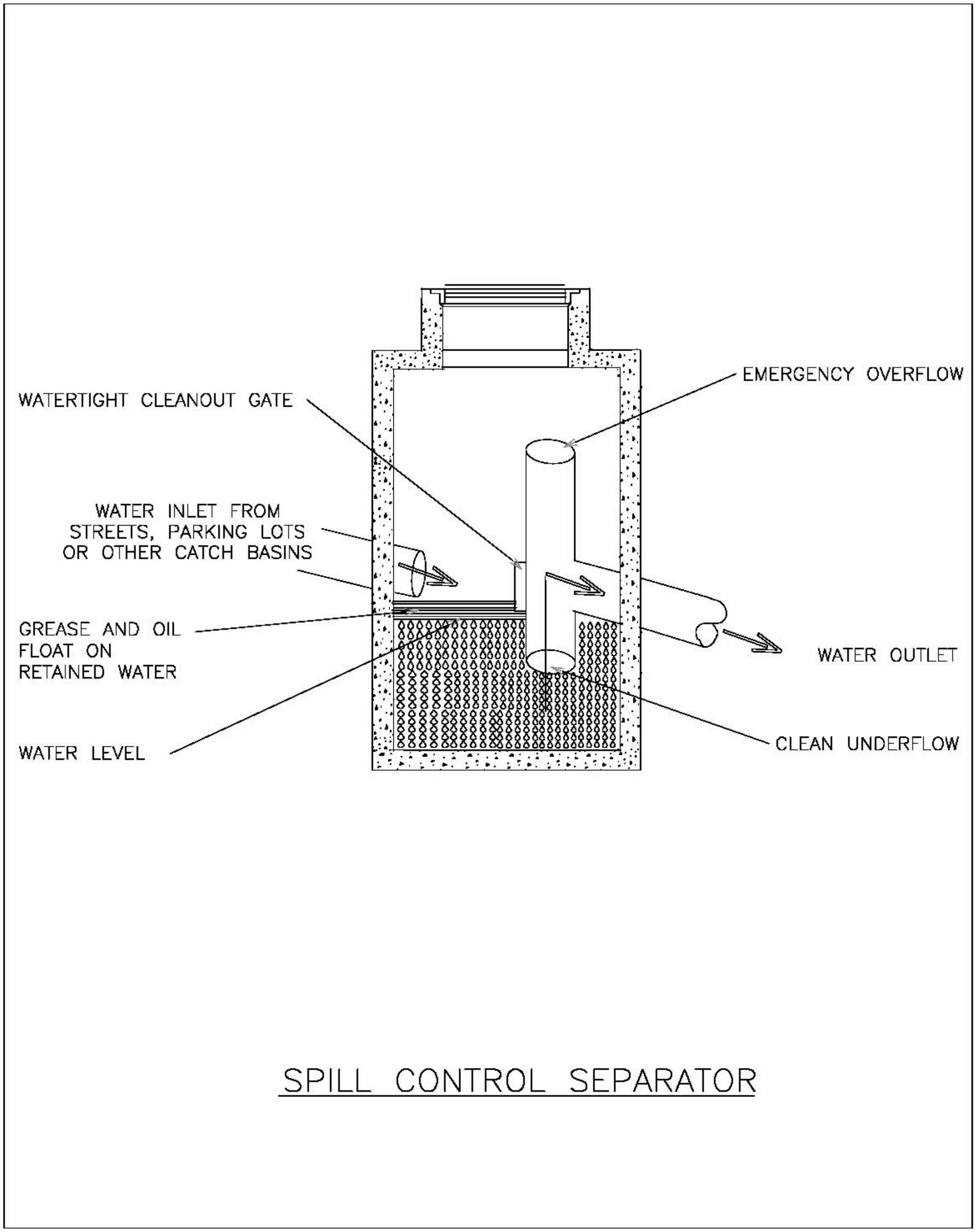

Figure AR.21.2. Spill control separator.

Oil/water separators are meant to treat stormwater runoff from areas with intensive land use, such as high-use sites, and from facilities that produce relatively high concentrations of oil and grease. Although baffle-type separators historically have been used to remove larger oil droplets (150 microns or larger), they can also be sized to remove smaller oil droplets. Baffle-type separators can be used to meet a performance goal of 10 to 15 milligrams per liter oil concentration by designing the unit to remove oil droplets 60 microns and larger.

Applications and Limitations

Baffle-type oil/water separators can be used to meet oil control requirements. Separators should be used where free oil is expected to be present at treatable high concentrations and sediment will not overwhelm the separator. For low concentrations of oil, other treatment methods (such as sand filters or emerging technologies) may be more applicable.

For inflows from small drainage areas (such as fueling stations and maintenance shops), a coalescing plate separator (see BMP AR.22) is typically considered due to space limitations. However, if the plates are likely to become plugged, then a new design basis for the baffle-type separator may be considered on an experimental basis. (See the *Structural Design Considerations* below.)

Oil/water separators are designed to remove free oil and are not generally effective in separating oil that has become either chemically or mechanically emulsified and dissolved in water. Therefore, it is desirable that separators be installed upstream of drainage facilities and conveyance structures that introduce flow turbulence and consequently promote emulsification. Emulsification of oil can also result wherever surfactants or detergents are used to wash vehicles and in parking/maintenance areas that drain to the separator. Detergents should not be used to clean vehicles or in parking/maintenance areas unless the wash water is collected and disposed of properly (usually to the sanitary sewer).

Without intense maintenance, oil/water separators may not be sufficiently effective in removing oil and total petroleum hydrocarbons (TPH) down to desired levels. Excluding runoff from unpaved areas helps to minimize the amount of sediment entering the vault, reducing the need for maintenance. A unit that fails and ceases to function can release previously trapped oil to the downstream receiving water, both from the oily sediments and the entrainment of surface oils.

In moderately pervious soils where seasonal groundwater may induce flotation, buoyancy of the separator vault structure must be balanced by ballasting or other methods, as appropriate.

Wet vaults may also be modified to function as baffle-type oil/water separators (see design criteria for wet vaults, BMP AR.23). Construction of oil/water separators should follow and conform to the manufacturer's recommended construction procedures and installation instructions as well as the WSDOT *Standard Specifications*. After the oil/water separator is installed, it must be thoroughly cleaned and flushed before it begins operating.

Presettling/Pretreatment

Pretreatment should be considered if the level of total suspended solids (TSS) in the inlet flow would impair the long-term efficiency of the separator.

Design Flow Elements

Flows to Be Treated

Oil/water separators must be designed to treat 2.15 times the runoff treatment design flow rate (see Section 1-3.4, Minimum Requirement 5). Hydrologic methods are presented in Sections 5-1 and 5-2 in this manual.

Flow Splitters

Oil/water separators must be installed off-line from the primary drainage system. All flows greater than 2.15 times the runoff treatment design flow must bypass the separator. For flow splitter design guidelines, see the HRM.

Structural Design Considerations

Details for a typical baffle-type oil/water separator are shown in Figure AR.21.1. Other designs and configurations of separator units and vaults are allowed, including aboveground units. However, they must produce equivalent treatment results and treat equivalent flows as conventional units.

Geometry

Baffle separators are divided into three compartments: a forebay, a separator bay, and an afterbay. The forebay is primarily to trap and collect sediments, encourage plug flow, and reduce turbulence. The separator bay traps and holds oil as it rises from the water column, and it serves as a secondary sediment collection area. The afterbay, a relatively oil-free cell before the outlet, provides a secondary oil separation area and holds oil entrained by high flows.

Forebay/Afterbay

To collect floatables and settleable solids, the surface area of the forebay must be at least 20 square feet per 10,000 square feet of area draining to the separator. The length of the forebay should be one-third to one-half the length of the entire separator. Roughing screens for the forebay or upstream of the separator may be needed to remove debris. Screen openings should be about ¾ inch.

The inlet must be submerged. A tee section may be used to submerge the incoming flow; it must be at least 2 feet from the bottom of the tank and extend above the runoff treatment design water surface. The intent of the submerged inlet is to dissipate the energy of the incoming flow. The minimum 2-foot distance from the bottom is to minimize resuspension of settled sediments. Extending the tee to the surface allows air to escape the flow, thus reducing turbulence. Alternative inlet designs that accomplish these objectives are acceptable.

The vault outlet pipe must be sized to pass the design flow before overflow. The vault outlet pipe must be backsloped or have a tee extending 1 foot above and below the runoff treatment design water surface to provide for secondary trapping of oils and floatables in the vault. Note: The invert of the outlet pipe sets the runoff treatment design water surface elevation.

Separator vaults must have a shutoff mechanism on the outlet pipe to prevent oil discharges during maintenance and to serve as an emergency shutoff in case of a spill. A valve box and riser must also be provided according to the design criteria for wet ponds (see BMP RT.12 in the HRM).

Separator vaults must be watertight. Where pipes enter and leave a vault below the runoff treatment design water surface, they must be sealed using a nonporous, nonshrinking grout.

Absorbents and/or skimmers should be used in the afterbay as needed.

Separator Bay

The geometry criteria for small drainages is based on horizontal velocity (V_h), oil rise rate (V_t), residence time, width, depth, and length considerations. A correction factor based on American Petroleum Institute (API) turbulence criteria is applied to increase the length.

Ecology is modifying the API criteria for treating stormwater runoff from small drainage areas (such as fueling stations and commercial parking lots) by using the design V_h for the design V_h/V_t ratio rather than the API minimum of $V_h/V_t = 15$. The API criteria appear to be applicable for sites with more than 2 acres of impervious drainage area. Performance verification of this design basis must be obtained during at least one wet season.

The following is the sizing procedure using modified API criteria:

Determine the oil rise rate, V_t (cm/sec), using Stokes' law (WPCF 1985), empirical determination, or 0.033 ft/min for 60-micron oil droplets. The application of Stokes' law to site-based oil droplet sizes and densities, or empirical rise rate determinations, recognizes the need to consider actual site conditions. In those cases, the design basis would not be the 60-micron droplet size and the 0.033 ft/min rise rate.

Stokes' law equation for rise rate, V_t:

$$V_t = [(g)(\sigma_w - \sigma_o)(d^2)] / [(18\mu_w)]$$

where: V_t = rise rate of the oil droplet (cm/s or ft/sec)
g = gravitational constant = 981 cm/sec²
d = diameter of the oil droplet (cm) = 60 microns (0.006 cm)

σ_w = density of water at 32°F = 0.999 gm/cc

σ_o = density of petroleum oil at 32°F. Select a conservatively high oil density. For example, if both diesel oil at σ_o = 0.85 gm/cc and motor oil at σ_o = 0.90 gm/cc might be present, use σ_o = 0.90 gm/cc.

μ_w = absolute viscosity of the water = 0.017921 poise (gm/cm-sec or lbm/ft-s) (API 1990)

Use the following separator dimension criteria:

- Separator water depth (d): ≥3≤8 feet (to minimize turbulence) (API 1990; Corps 1994)
- Separator width (w): 6 to 20 feet (WEF & ASCE 1998; King County 1998)
- Depth-to-width ratio (d/w): 0.3 to 0.5 (API 1990)
- Minimum length-to-width ratio of separator vaults: 5

For stormwater inflow from drainages less than 2 acres:

1. Determine V_t and select depth and width of the separator section based on the above criteria.
2. Calculate the minimum residence time (t_m) of flow through the separator at depth d:

$$t_m = d/V_t$$

3. Calculate the horizontal velocity of the bulk fluid, V_h; vertical cross-sectional area, A_v; and actual design V_h/V_t (API 1990; Corps 1994):

V_h = Q/dw = Q/A_v (V_h maximum at < 2.0 ft/min) (API 1990)

where: Q = 2.15 x the runoff treatment design flow rate (ft^3/min) at minimum residence time, t_m

At V_h/V_t determine F, turbulence factor (see Figure AR.21.3). API F factors range from 1.28 to 1.74 (API 1990).

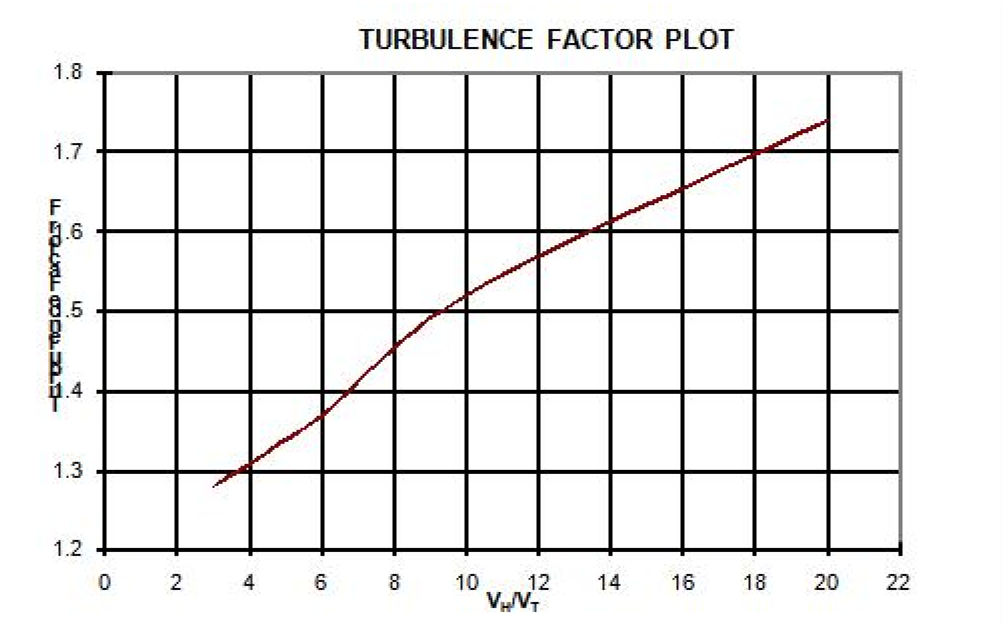

Figure AR.21.3. Turbulence factor plot.

4. Calculate the minimum length of the separator section, l(s), using:

l(s) = FQtm/wd = F(Vh/Vt)d

L = l(f) + l(s) +l(a)

L = l(t)/3 + l(s) + l(t)/4

where: L = total length of 3 bays (ft)
l(f) = length of forebay (ft)
l(a) = length of afterbay (ft)

5. Calculate V = l(s)wd = FQt_m, and A_h = l(s)w

V = minimum hydraulic design volume (ft^3)
A_h = minimum horizontal area of the separator (ft^2)

For stormwater inflow from drainages greater than 2 acres:

1. Use $V_h = 15\ V_t$ and $d = (Q/2V_h)^{1/2}$ (with d/w = 0.5) and repeat calculation steps 3 through 5.

Materials

- Vault material and structural specifications are the same as those for BMP AR.10, Detention Vault.

- All metal parts must be corrosion-resistant. Avoid the use of zinc and galvanized materials—because of their aquatic toxicity potential—when substitutes are available. Painting metal parts for corrosion resistance is not allowed because paint does not provide long-term protection.
- Vault baffles must be made of concrete, stainless steel, fiberglass-reinforced plastic, or other acceptable material, and must be securely fastened to the vault.
- Gate valves, if used, must be designed for seating and unseating heads appropriate for the design conditions.

Berms, Baffles, and Slopes

- A removable flow-spreading baffle, extending downward from the water surface to no more than one-half the vault depth, is recommended to spread flows (see Figure AR.21.1).
- A removable bottom baffle (sediment-retaining baffle) must be provided with a minimum height of 24 inches (see Figure AR.21.1), located at least 1 foot from the oil-retaining baffle. A window wall baffle may be used, but the area of the window opening must be at least three times greater than the area of the inflow pipe.
- A removable oil-retaining baffle must be provided and located approximately ¼ L from the outlet wall or a minimum of 8 feet, whichever is greater (the 8-foot minimum is for maintenance purposes). The oil-retaining baffle must extend downward from the water surface to a depth of at least 50 percent of the design water depth, but no closer than 1 foot above the vault bottom (see Figure AR.21.1). Various configurations are possible, but the baffle must be designed to minimize turbulence and entrainment of sediment.
- Baffles may be fixed rather than removable if additional entry ports and ladders are provided to make both sides of the baffle accessible for maintenance.

Site Design Elements

Setback Requirements

Setback requirements for baffle-type oil/water separators are the same as those for detention vaults (see BMP AR.10).

Maintenance Access Roads (Access Requirements)

Access requirements for baffle-type oil/water separators are the same as those for detention vaults (see BMP AR.10), except for the following modifications:

- Access to each compartment is required. If the length or width of any compartment exceeds 50 feet, an additional access point for each 50 feet is required.
- Access points for the forebay and afterbay must be positioned partially over the inlet or outlet tee to allow visual inspection as well as physical access to the bottom of the vault.

Operation and Maintenance

Oil/water separators must be cleaned regularly (see BMP Maintenance Standards for further details) to keep accumulated oil from escaping during storm events.

6-2.22. AR.22 – Coalescing Plate Separator

Eastern Washington	Yes		Object Free Area (OFA)	Yes*
Western Washington	Yes		Runway Safety Area (RSA)	No
Landside Areas	Yes		Taxiway Safety Area (TSA)	No
			Clearway (CWY)	Yes*

* Contact FAA Seattle ADO for approval.

Introduction

General Description

Coalescing plate oil/water separators typically are manufactured units consisting of a baffled vault containing several inclined corrugated plates stacked and bundled together (see Figure AR.22.1). The plates are equally spaced (typical plate spacing ranges from ¼ to 1 inch) and are made of a variety of materials, the most common being fiberglass and polypropylene. Efficient separation results because the plates reduce the vertical distance oil droplets must rise in order to separate from the stormwater. Once they reach a plate, oil droplets form a film on the plate surface. The film builds up over time until it becomes thick enough to migrate upward under the influence of gravity along the inclined plate. When the film reaches the edge of the plate, oil is released as large droplets, which rise rapidly to the surface where the oil accumulates until it is removed during maintenance activities. Because the plate pack significantly increases treatment effectiveness, coalescing plate separators can achieve a specified treatment level with a smaller vault size than that required for a simple baffle-type oil/water separator. A spill control separator (see Figure AR.21.2) is a simple catch basin with a tee inlet for temporarily trapping small volumes of oil. The spill control separator is included here for comparison only and is not intended to be used for treatment purposes.

Applications and Limitations

Coalescing plate oil/water separators can be used to meet oil control requirements. Separators should be used where free oil is expected to be present at treatable high concentrations and sediment will not overwhelm the separator. Coalescing plate separators can be used to meet a performance goal of 10 to 15 milligrams per liter oil concentration by designing the unit to remove oil droplets 60 microns and larger. For low concentrations of oil, other treatment methods (such as sand filters or emerging technologies) may be more applicable.

For inflows from small drainage areas (such as fueling stations and maintenance shops), a coalescing plate separator is typically considered due to space limitations. However, if the plates are likely to become plugged, then a new design basis for the baffle-type (API) separator may be considered on an experimental basis (see BMP AR.21).

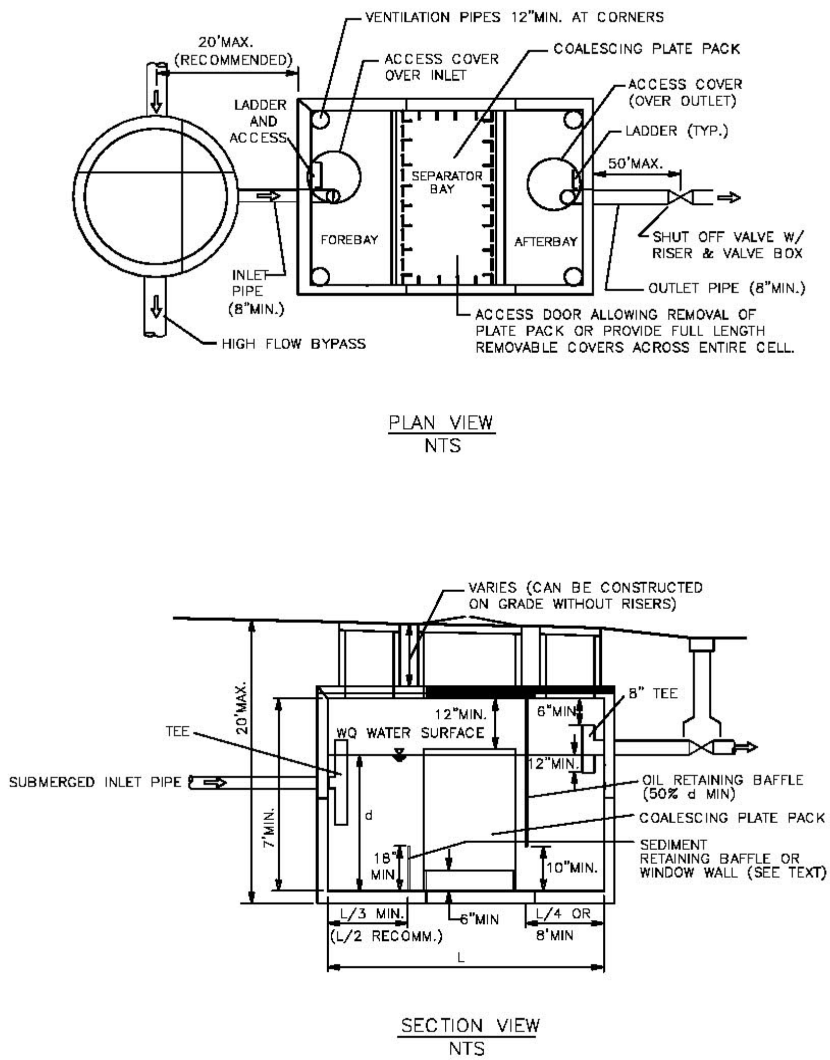

Figure AR.22.1. Coalescing plate separator.

Oil/water separators are designed to remove free oil and are not generally effective in separating oil that has become either chemically or mechanically emulsified and dissolved in water. Therefore, it is desirable that separators be installed upstream of drainage facilities and conveyance structures that introduce flow turbulence and consequently promote emulsification. Emulsification of oil can also result wherever surfactants or detergents are used to wash vehicles and in parking/maintenance areas that drain to the separator. Detergents should not be used to clean vehicles or in parking/maintenance areas unless the wash water is collected and disposed of properly (usually to the sanitary sewer).

Without intense maintenance, oil/water separators may not be sufficiently effective in removing oil and total petroleum hydrocarbons (TPH) down to desired levels. Excluding runoff from unpaved areas helps to minimize the amount of sediment entering the vault, reducing the need for maintenance. A unit that fails and ceases to function can release previously trapped oil to the downstream receiving water, both from the oily sediments and the entrainment of surface oils.

In moderately pervious soils where seasonal groundwater may induce flotation, buoyancy of the vault structure must be balanced by ballasting or other methods, as appropriate.

Wet vaults may also be modified to function as coalescing plate oil/water separators. (See the design criteria for wet vaults, BMP AR.23.)

Construction of coalescing plate separators should follow and conform to the manufacturer's recommended construction procedures and installation instructions as well as the WSDOT *Standard Specifications*. Particular care must be taken when inserting coalescing plate packs in the vault so as not to damage or deform the plates. After the separator is installed, it must be thoroughly cleaned and flushed before it begins operating.

Presettling/Pretreatment

Pretreatment should be considered if the level of total suspended solids (TSS) in the inlet flow would cause the coalescing plates to clog or otherwise impair the long-term efficiency of the separator.

Design Flow Elements

Flows to Be Treated

Coalescing plate separators must be designed to treat 2.15 times the runoff treatment design flow (see Section 1-3.4, Minimum Requirement 5). Hydrologic methods are presented in Sections 5-1 and 5-2 in this manual.

Flow Splitters

Coalescing plate separators must be installed off-line from the primary drainage system. All flows greater than 2.15 times the runoff treatment design flow must bypass the separator. For flow splitter design guidelines, see the HRM.

Structural Design Considerations

Details for a typical coalescing plate oil/water separator are shown in Figure AR.22.1. Other designs and configurations of separator units and vaults are allowed, including aboveground units. However, they must produce equivalent treatment results, and treat equivalent flows as conventional units.

Geometry

Coalescing plate separators are divided by baffles or berms into three compartments: a forebay, a separator bay that houses the plate packs, and an afterbay. The forebay controls turbulence and traps and collects debris. The separator bay captures and holds oil. The afterbay provides a relatively oil-free exit cell before the outlet.

Forebay/Afterbay

The length of the forebay must be a minimum of one-third the length of the vault (1/3 *L*), but 1/2 *L* is recommended. In addition, it is recommended that the surface area of the forebay be at least 20 square feet per 10,000 square feet of tributary impervious area draining to the separator. In lieu of an attached forebay, a separate grit chamber, sized to be at least 20 square feet per 10,000 square feet of tributary impervious area, may precede the oil/water separator.

The inlet must be submerged. A tee section may be used to submerge the incoming flow, but it must be at least 2 feet from the bottom of the tank and extend above the runoff treatment design water surface. The intent of the submerged inlet is to dissipate the energy of the incoming flow. The minimum 2-foot distance from the bottom is to minimize resuspension of settled sediments. Extending the tee to the surface allows air to escape the flow, thus reducing turbulence. Alternative inlet designs that accomplish these objectives are acceptable.

The vault outlet pipe must be sized to pass the design flow before overflow. The vault outlet pipe must be backsloped or have a tee extending 1 foot above and below the runoff treatment design water surface to provide for secondary trapping of oils and floatables in the vault. Note that the invert of the outlet pipe sets the runoff treatment design water surface elevation.

Separator vaults must have a shutoff mechanism on the outlet pipe to prevent oil discharges during maintenance and to serve as an emergency shutoff in case of a spill. A valve box and riser must also be provided according to the design criteria for wet ponds (see BMP RT.12 in the HRM).

Separator vaults must be watertight. Where pipes enter and leave a vault below the runoff treatment design water surface, they must be sealed using a nonporous, nonshrinking grout.

Absorbents and/or skimmers should be used in the afterbay, as needed.

Separator Bay

Calculate the projected (horizontal) surface area of plates needed using the following equation:

$$A_p = Q/V_t = [Q] / [(0.00386) * ((\sigma_w - \sigma_o) / (\mu_w))]$$

$$A_p = A_a(\text{cosine } b)$$

where: Q = 2.15 x the runoff treatment design flow rate (ft^3/min)
- V_t = rise rate of 0.033 ft/min, or empirical determination, or Stokes' law-based
- A_p = projected surface area of the plate (ft^2); 0.00386 is unit conversion constant
- σ_w = density of water at 32º F = 62.4 lb/ft^3
- σ_o = density of petroleum oil at 32º F = 51.2 lb/ft^3
- A_a = actual plate area (ft^2) (one side only)
- b = angle of the plates with the horizontal (deg) (usually varies from 45º to 60º)
- μ_w = absolute viscosity of water at 32º F = 1.931 x 10^{-5} cfs

- Space plates a minimum of ¾ inch apart (perpendicular distance between plates) (WEF & ASCE 1998; Corps 1994; USAF 1991; Jaisinghani et al. 1979).
- Select a plate angle between 45º to 60º from the horizontal.
- Locate plate pack at least 6 inches from the bottom of the separator to provide for sediment storage.
- Add 12 inches minimum headspace from the top of the plate pack and the bottom of the vault cover.
- Design inlet flow distribution and baffles in the separator bay to minimize turbulence, flow short-circuiting, and channeling of the inflow, especially through and around the plate packs of the separator. The Reynolds number (a dimensionless parameter used to determine laminar to turbulent flow in pipes) through the separator bay should be <500 (laminar flow).
- Design plates for ease of removal and cleaning with high-pressure rinse or equivalent.

Materials

- For vault material and structural specifications, see BMP AR.10.

- All metal parts must be corrosion-resistant. Avoid use of zinc and galvanized materials—because of their aquatic toxicity potential—when substitutes are available. Painting metal parts for corrosion resistance is not allowed because paint does not provide long-term protection.
- Vault baffles must be made of concrete, stainless steel, fiberglass-reinforced plastic, or other acceptable material and must be securely fastened to the vault.
- Gate valves, if used, must be designed for seating and unseating heads appropriate for the design conditions.
- Plate packs must be made of fiberglass, stainless steel, or polypropylene.
- It is recommended that the entire space between the sides of the plate pack and the vault wall be filled with a solid but lightweight removable material, such as a plastic or polyethylene foam, to prevent the flow from short-circuiting around the sides of the plate pack. Rubber flaps are not effective for this purpose.

Berms, Baffles, and Slopes

- A bottom sediment-retaining baffle must be provided upstream of the plate pack. The minimum height of the sludge-retaining baffle must be 18 inches. Window walls may be used, but the window opening must be a minimum of three times greater than the area of the inflow pipe.
- An oil-retaining baffle must be provided. The baffle must be at least 8 feet from the outlet wall for maintenance purposes. For large units, a baffle position of 1/4 L from the outlet wall is recommended. The oil-retaining baffle must extend from the water surface to a depth of at least 50 percent of the design water depth. Various configurations are possible, but the baffle must be designed to minimize turbulence/entrainment of sediment.

Site Design Elements

Setback Requirements

Setback requirements for coalescing plate oil/water separators are the same as those for detention vaults (see BMP AR.10).

Maintenance Access Roads (Access Requirements)

Access requirements for coalescing plate oil/water separators are the same as those for detention vaults (see BMP AR.10), except for the following modifications:

- Access to each compartment is required. If the length or width of any compartment exceeds 50 feet, an additional access point for each 50 feet is required.
- Access points for the forebay and afterbay must be positioned partially over the inlet or outlet tee to allow visual inspection as well as physical access to the bottom of the vault.
- Access to the compartment containing the plate pack must be via a removable panel that can be opened wide enough to remove the entire coalescing plate pack from the cell for cleaning or replacement. Doors or panels must have stainless steel lifting eyes, and panels must weigh no more than 5 tons per panel.
- A parking area or access pad (25- by 15-foot minimum) must be provided near the coalescing plate oil/water separator structure to allow the plate pack to be removed from the vault by a truck-mounted crane or backhoe and to allow accumulated solids and oils to be extracted from the vault using a Vactor truck.

Operation and Maintenance

Oil/water separators must be cleaned regularly (see BMP Maintenance Standards below for further details) to keep accumulated oil from escaping during storm events.

6-2.23. AR.23 – Wet Vault

Eastern Washington	Yes
Western Washington	Yes
Landside Areas	Yes

Object Free Area (OFA)	No
Runway Safety Area (RSA)	No
Taxiway Safety Area (TSA)	No
Clearway (CWY)	No

Introduction

General Description

Wet vaults are underground structures similar in appearance to detention vaults (see BMP AR.10), except wet vaults have permanent pools of water in the bottom that dissipate flow energy and improve the settling of particulate pollutants (see Figure AR.23.1). Being underground, wet vaults lack the biological pollutant-removal mechanisms, such as soil microbial activity and algae uptake, present in surface wet ponds (see BMP RT.12 in the HRM).

Applications and Limitations

Wet vaults may be used for roadway projects if space limitations preclude the use of other treatment BMPs. However, they are most practical in relatively small catchments (less than 10 acres of impervious surface) with high land values because vaults are relatively expensive. Combined wet/detention vaults (see BMP AR.24) are typically considered in like situations.

A wet vault is believed to be ineffective in removing dissolved pollutants such as soluble phosphorus or metals such as copper. Declining oxygen levels are also a concern, especially in warm summer months, because of limited contact with air and wind. However, the extent to which this potential problem occurs has not been documented.

Belowground structures like wet vaults are relatively difficult and expensive to maintain. The need for maintenance is not often recognized and maintenance is often neglected.

Design Flow Elements

Flows to Be Treated

Wet vaults are designed to treat the runoff treatment volume described in Section 1-3.4 under Minimum Requirement 6. Large wet ponds are designed to treat a volume 1.5 times greater than the runoff treatment volume. Hydrologic methods are presented in Sections 5-1 and 5-2 of this manual.

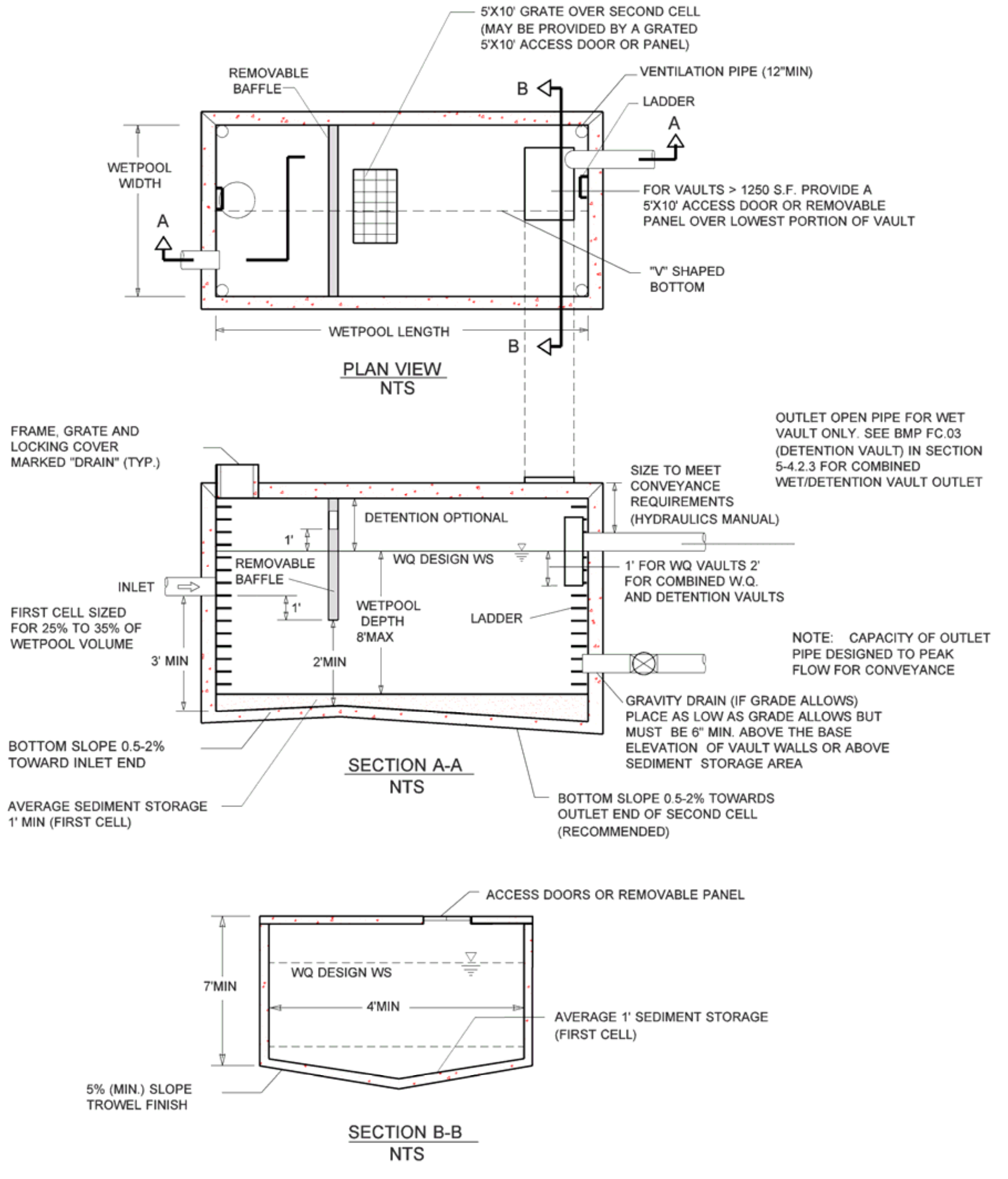

Figure AR.23.1. Wet vault.

Outlet Control Structure

The outlet pipe must be backsloped or have a tee section; the lower arm should extend 1 foot below the runoff treatment design water surface to trap oils and floatables in the vault.

Overflow or Bypass

The capacity of the outlet pipe and available head above the outlet pipe must be designed to pass the 100-year peak design flow for developed site conditions without exceeding the head space within the vault. (See Chapter 5 of this manual for hydrologic methods.) The available headspace above the outlet pipe must be a minimum of 6 inches. Provisions should be made to maintain the passage of flows should the outlet plug.

Structural Design Considerations

Geometry

Sizing Procedure

Wet vault sizing procedures are as follows:

Design Steps (D)

D-1 Identify the required wet vault volume (Vol_{wq}). For options to determine this volume using continuous runoff models, see Chapter 5. For large wet ponds, the wet pool volume is 1.5 times the water quality volume.

D-2 Estimate wet pool dimensions satisfying the following design criterion:

$$Vol_{wq} = [h_1(A_{t1} + A_{b1}) / 2] + [h_2(A_{t2} + A_{b2}) / 2] + \ldots\ldots + [h_n(A_{tn} + A_{bn}) / 2]$$

where: A_{tn} = top area of wet vault surface in cell n (ft^2)
A_{bn} = bottom area of wet vault surface in cell n (ft^2)
h_n = depth of wet vault in cell n (above top of sediment storage) (ft)

D-3 Design pond outlet pipe and determine primary overflow water surface.

- The sediment storage depth in the first cell must average 1 foot. Because of the V-shaped bottom, the depth of sediment storage needed above the bottom of the side wall is roughly proportional to vault width according to the following schedule:

Vault Width (feet)	Sediment Depth (inches from bottom of the side wall)
15	10
20	9
40	6
60	4

- The second cell must be a minimum of 3 feet deep because planting cannot be used to prevent resuspension of sediment in shallow water as it can in open ponds.
- A flow length-to-width ratio greater than 3:1 is desirable.
- The inlet to the wet vault must be submerged, with the inlet pipe invert a minimum of 3 feet from the vault bottom (not including sediment storage). The top of the inlet pipe should be submerged at least 1 foot, if possible.
- The number of inlets to the wet vault should be limited, and the flow path length should be maximized from inlet to outlet (for example, locate the inlet and outlet in opposing corners of the vault).
- A gravity drain for maintenance must be provided if grade allows.
- The gravity drain should be as low as the site situation allows; however, the invert must be no lower than the average sediment storage depth. At a minimum, the invert must be 6 inches above the base elevation of the vault sidewalls.
- The drain must be 8 inches (minimum) in diameter and controlled by a valve. Use of a shear gate is allowed only at the inlet end of a pipe located within an approved structure.
- Operational access to the valve must be provided at the finished ground surface. The valve location must be accessible and well marked, with at least 1 foot of paving placed radially around the box. The valve must also be protected from damage and unauthorized operation.
- If not located in the vault, a valve box without an access manhole is allowed to a maximum depth of 5 feet. If the valve box is more than 5 feet deep, an access manhole is required.

Materials

Wet vaults must conform to the materials and structural stability criteria specified for detention vaults (see BMP AR.10).

Wet vaults may be constructed using alternative materials, such as arch culvert sections or large corrugated metal pipe, provided the top area at the runoff treatment design water surface is, at a minimum, equal to that of a vault with vertical walls designed with an average depth of 6 feet. If alternative materials are used to construct a wet vault, all seams and gaps must be sealed so that water does not leak out of the wet pool.

Where pipes enter and leave the vault below the runoff treatment design water surface, they must be sealed using a nonporous, nonshrinking grout.

Berms, Baffles, and Slopes

If a removable baffle is used to separate the two wet vault cells, the following criteria apply:

- The baffle must extend from a minimum of 1 foot above the runoff treatment design surface to a minimum of 1 foot below the invert elevation of the inlet pipe.
- The lowest point of the baffle must be a minimum of 2 feet (and greater if feasible) from the bottom of the vault.

If the vault storage volume is less than 2,000 cubic feet (inside dimensions), or if the length-to-width ratio of the vault pool is 5:1 or greater, the baffle wall may be omitted and the vault may be one-celled.

The two cells of a wet vault should not be divided into additional subcells by internal walls. If internal structural support is needed, post-and-pier construction (rather than walls) is preferred to support the vault lid. Any walls used within cells must be positioned to lengthen, rather than divide, the flow path.

The bottom of the first cell must be sloped toward the inlet. Slope should be between 0.5 percent (minimum) and 2 percent (maximum). The second cell may be level (longitudinally), sloped toward the outlet, with a high point between the first and second cells.

The vault bottom must slope laterally a minimum of 5 percent from each side toward the center, forming a broad V to facilitate sediment removal. (Note that more than one V may be used to minimize vault depth.)

Exception: The vault bottom may be flat if removable panels are provided over the entire vault. Removable panels must be at grade, have stainless steel lifting eyes, and weigh no more than five tons per panel.

The highest point of the vault bottom must be at least 6 inches below the outlet elevation to provide for sediment storage over the entire bottom.

Site Design Elements

Setback Requirements

The following setback criteria apply to wet vaults:

- Wet vaults must be a minimum of 5 feet from any property line or vegetative buffer. This distance may need to be increased based on the permit requirements of the local jurisdiction.
- Wet vaults must be a minimum of 20 feet from any septic tank or drain field.
- A geotechnical report should be prepared for the project that evaluates any potential structural site instability due to extended subgrade saturation or head loading of the permeable layer, including the potential impacts to downgradient properties, especially on hills with known side-hill seeps. The report should address the adequacy of the proposed wet vault location and recommend the necessary setbacks from any steep slopes and building foundations.

General Maintenance Requirements

General maintenance criteria for wet vaults are the same as those for detention vaults (see BMP AR.10), except for the following:

- A minimum of 50 square feet of grate must be provided over the second cell. If the surface area of the second cell is greater than 1,250 square feet, 4 percent (minimum) of the top must be grated. This requirement may be met by one grate or by many smaller grates distributed over the second cell area. Note: A grated access door can be used to meet this requirement.

Lockable grates instead of solid manhole covers are recommended to increase air contact with the wet pool. Note: Underground vaults with stagnant water make prime habitat for mosquito larvae. Grated covers allow easy access by adult mosquitoes. From a vector control aspect, solid covers are preferred. Wet vaults designed as oil/water separators could potentially trap enough oil to create lethal conditions for mosquito larvae.

6-2.24. AR.24 – Combined Wet/Detention Vault

Eastern Washington	Yes
Western Washington	Yes
Landside Areas	Yes

Object Free Area (OFA)	No
Runway Safety Area (RSA)	No
Taxiway Safety Area (TSA)	No
Clearway (CWY)	No

Introduction

General Description

Combined wet/detention vaults have the appearance of detention vaults (see BMP AR.10), but contain a permanent pool of water in the bottom for runoff treatment. The following design procedures, requirements, and recommendations cover differences in the design of the stand-alone wet vault (see BMP AR.23) combined with detention storage.

Applications and Limitations

Combined wet/detention vaults are very efficient for sites where space limitations preclude the use of surface runoff treatment and flow control facilities. The runoff treatment facility may often be placed beneath the detention facility without increasing the facility surface area.

The basis for pollutant removal in a combined wet/detention vault is the same as that for the stand-alone wet vault (see BMP AR.23). However, in the combined facility, the detention function creates fluctuating water levels and added turbulence. For simplicity, the positive effect of the extra live storage volume and the negative effect of increased turbulence are assumed to balance, and are thus ignored, when sizing the wet pool volume.

Design Flow Elements

Flows to Be Treated

Flows to be treated by a combined wet/detention vault are the same as those for wet vaults (see BMP AR.23) and detention vaults (see BMP AR.10).

Overflow or Bypass

Overflow must be provided as described in BMP AR.10, Detention Vault.

Outlet Control Structure

Outlet control structures must be designed as specified in BMP AR.09.

Structural Design Considerations

Geometry

The methods of analysis for combined wet/detention vaults are identical to those outlined for wet vaults (see BMP AR.23) and for detention facilities. The wet vault volume for a combined facility must be equal to or greater than the total volume of runoff from the 6-month, 24-hour storm event. The procedure specified in BMP AR.10, Detention Vault, is used to size the detention portion of the vault.

The design criteria for detention vaults (see BMP AR.10) and wet vaults (see BMP AR.23) must both be met, except for the following modifications or clarifications:

- The minimum sediment storage depth in the first cell must average 1 foot. The 6 inches of sediment storage required for detention vaults do not need to be added to this, but 6 inches of sediment storage must be added to the second cell to comply with detention vault sediment storage requirements.
- The oil-retaining baffle must extend a minimum of 2 feet below the runoff treatment design surface.

Intent: The greater depth of the baffle in relation to the runoff treatment design water surface compensates for the greater water level fluctuations in the combined wet/detention vault. The greater depth is deemed prudent to better ensure that separated oils remain within the vault, even during storm events.

Materials

Combined wet/detention vaults must conform to the materials and structural stability criteria specified for detention vaults (see BMP AR.10).

Where pipes enter and leave the vault below the runoff treatment design water surface, they must be sealed using a nonporous, nonshrinking grout.

Galvanized materials should be avoided whenever possible because they can leach zinc into the environment.

Berms, Baffles, and Slopes

Criteria for vault baffles are the same as those for wet vaults (see BMP AR.23).

Groundwater Issues

Live storage requirements are the same as for detention ponds (see BMP AR.09). This does not apply to the wet vault dead storage component.

Site Design Elements

Setback Requirements

Setback requirements are the same as those for wet vaults (see BMP AR.23).

Right of Way

Right of way requirements for wet/detention vaults are the same as those for detention vaults (see BMP AR.10).

General Maintenance Requirements

- General maintenance criteria are the same as those for wet vaults (see BMP AR.23).

6-2.25. AR.25 – Treatment Train Approach

Eastern Washington	
Western Washington	
Landside Areas	

Object Free Area (OFA)	
Runway Safety Area (RSA)	
Taxiway Safety Area (TSA)	
Clearway (CWY)	

The treatment train approach involves implementing combinations of basic treatment BMPs to meet enhanced or phosphorus treatment goals where individual BMPs that could meet the treatment goals are inappropriate or infeasible.

Because of the unique considerations at airports, where excluding hazardous wildlife for aircraft safety concerns must be a top priority, there may be limited options for phosphorus treatment or enhanced treatment. The most cost-effective option for phosphorous control in non-airport settings is likely to be a large wet pond, so long as there is adequate land available. However, a large wet pond is not recommended at airports, due to the potential for attracting hazardous wildlife. Similarly, constructed wetlands, compost amended vegetated filter strips (CAVFS [BMP AR.12 in this manual]), and media filter drains (BMP AR.14 in this manual) are options for enhanced treatment in the HRM and/or SMMWW. While CAVFS and media filter drains are permitted in landside areas at airports, their application is limited in the RSA, TSA, or other airside areas (see Chapter 2 for a description of landside and airside areas). If enhanced treatment is required in airport operations areas, the treatment train approach may be the only option available for enhanced or phosphorus treatment.

Tables AR.25.1 and AR.25.2 list recommended treatment train combinations for phosphorus removal and enhanced treatment, respectively, in airport settings.

Table AR.25.1 Treatment train combinations for phosphorus removal.

First Basic Runoff Treatment Facility	Second Runoff Treatment Facility
AR.13 Biofiltration Swale	AR.16, AR.17 Sand Filter Basin or Vault (basic)
AR.13 Biofiltration Swale	AR.15 Linear Sand Filter (basic) with no presettling cell needed
AR.12 Vegetated Filter Strip	AR.15 Linear Sand Filter (basic) with no presettling cell needed
AR.23 Wet Vault (basic)	AR.16, AR.17 Sand Filter Basin or Vault (basic)
AR.24 Combined Wet/Detention Vault (basic)	AR.16, AR.17 Sand Filter Basin or Vault (basic)

Table AR.25.2 Treatment train combinations for dissolved metals removal (enhanced treatment).

First Basic Runoff Treatment Facility	Second Runoff Treatment Facility
AR.13 Biofiltration Swale	AR.16, AR.17 Sand Filter Basin or Vault, or AR.19 Media Filter
AR.13 Biofiltration Swale	AR.15 Linear Sand Filter (basic) with no presettling cell needed
AR.12 Vegetated Filter Strip	AR.15 Linear Sand Filter (basic) with no presettling cell needed
AR.23 Wet Vault (basic)	AR.16, AR.17 Sand Filter Basin or Vault, or AR.19 Media Filter
AR.24 Combined Wet/Detention Vault (basic)	AR.16, AR.17 Sand Filter Basin or Vault, or AR.19 M
AR.16, AR.17 Sand Filter Basin or Vault (basic) with a presettling cell if the filter is not preceded by a detention facility	AR.19 Media Filter

Additional details on two treatment trains which are acceptable in airside operations areas are provided later in this document. These specific treatment trains have been described in detail because they are identified as phosphorus and enhanced treatment options in the Runoff Treatment BMP selection process (Figure 4-2).

- Vegetated filter strip (AR.12) / Linear sand filter (AR.15)
- Biofiltration swale (AR.13) / Linear sand filter (AR.15).

Vegetated Filter Strip (AR.12) / Linear Sand Filter (AR.15)

Eastern Washington	Yes
Western Washington	Yes
Landside Areas	Yes
Airside Areas	Yes

Object Free Area (OFA)	Yes
Runway Safety Area (RSA)	Yes
Taxiway Safety Area (TSA)	Yes
Clearway (CWY)	No

Introduction

General Description

The vegetated filter strip/linear sand filter treatment train is appropriate for either phosphorus or enhanced treatment.

The linear sand filter must be located so that maintenance associated with the facility does not interfere with airport operations. If located within the RSA, TSA, Object Free Area, or Clearway, the sand filter vault must be able to structurally support emergency vehicles, snow removal equipment, and aircraft loads and the vault cover must be no more than 3 inches above adjacent grade.

Biofiltration Swale (AR.13) / Linear Sand Filter (AR.15)

Eastern Washington	Yes
Western Washington	Yes
Landside Areas	Yes
Airside Areas	No

Object Free Area (OFA)	No
Runway Safety Area (RSA)	No
Taxiway Safety Area (TSA)	No
Clearway (CWY)	No

Introduction

General Description

The biofiltration swale/linear sand filter treatment train is appropriate for either phosphorus or enhanced treatment.

The linear sand filter must be located so that maintenance associated with the facility does not interfere with airport operations. If located within the RSA, TSA, Object Free Area, or Clearway, the sand filter vault must be able to structurally support emergency vehicles, snow removal equipment, and aircraft loads and the vault cover must be no more than 3 inches above adjacent grade.

6-3. Operations and Maintenance

Operations and maintenance must be a top priority throughout the BMP selection and design process at airports. Effective maintenance at appropriate intervals is essential to ensure that the primary stormwater management mechanisms continue to operate, and facilities do not clog or otherwise become impaired. In airport settings in particular, proper operations and maintenance is necessary to ensure that there are no extended periods of ponded water in open stormwater facilities.

Maintenance standards for typical BMPs are summarized by BMP in Tables 6-1 through 6-10, with similar BMPs grouped together as appropriate.

Table 6-1. Maintenance standards for BMPs AR.01 (Natural Dispersion), AR.02 (Engineered Dispersion), and AR.12 (Vegetated Filter Strip).

Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Recommended Maintenance to Correct Problem
General	Sediment accumulation on dispersion area	Sediment depth exceeds 2 inches.	Remove sediment deposits while minimizing compaction of soils in dispersion area; re-level so slope is even and flows pass evenly over/through dispersion area. Handwork is recommended rather than use of heavy machinery.
	Vegetation	Vegetation is sparse or dying; significant areas are without ground cover.	Control nuisance vegetation. Add vegetation, preferably native ground cover, bushes, and trees (where consistent with safety standards) to bare areas or areas where the initial plantings have died.
		Grass becomes excessively tall (greater than 10 inches); nuisance weeds and other vegetation start to take over.	Mow grass and control nuisance vegetation so that flow is not impeded. Grass should be mowed to a height between 3 and 4 inches.
	Trash and debris	Trash and debris have accumulated on the dispersion area.	Remove trash and debris from filter. Handwork is recommended rather than use of heavy machinery.
	Erosion/scouring	Eroded or scoured areas due to flow channelization or high flows are observed.	For ruts or bare areas less than 12 inches wide, repair the damaged area by filling with crushed gravel/compost mix (see Section 5-4.2 for the compost specifications). The grass will creep in over the rock mix in time. If bare areas are large (generally greater than 12 inches wide), the dispersion area should be reseeded. For smaller bare areas, overseed when bare spots are evident. Look for opportunities to locate flow spreaders, such as dispersion trenches and rock pads.
	Flow spreader	Flow spreader is uneven or clogged so that flows are not uniformly distributed over entire filter width.	Level the spreader and clean so that flows are spread evenly over entire filter width.

Table 6-2. Maintenance standards for Infiltration BMPs: AR.03 (Bioinfiltration Pond); AR.04 (Infiltration Pond); AR.05 (Infiltration Trench); AR.09 (Detention Pond); AR.06 (Infiltration Vault); AR.07 (Dry Well).

Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Results Expected When Maintenance is Performed
General	Trash and debris	Accumulations exceed 1 cubic feet per 1,000 square feet (this is about equal to the amount of trash needed to fill one standard-size garbage can). In general, there should be no visual evidence of dumping. If less than threshold, all trash and debris will be removed as part of the next scheduled maintenance.	Trash and debris are cleared from site.
	Poisonous vegetation and noxious weeds	Poisonous or nuisance vegetation may constitute a hazard to maintenance personnel or the public. Noxious weeds as defined by state or local regulations are evident. (Apply requirements of adopted integrated pest management [IPM] policies for the use of herbicides).	No danger is posed by poisonous vegetation where maintenance personnel or the public might normally be. (Coordinate with local health department.) Complete eradication of noxious weeds may not be possible. Compliance with state or local eradication policies is required.
	Contaminants and pollution	Oil, gasoline, contaminants, or other pollutants are evident. (Coordinate removal/cleanup with local water quality response agency.)	No contaminants or pollutants are present.
	Rodent holes	For facilities acting as a dam or berm: rodent holes are evident or there is evidence of water piping through dam or berm via rodent holes.	Rodents are destroyed and dam or berm repaired. (Coordinate with local health department; coordinate with Ecology Dam Safety Office if pond exceeds 10 acre-feet.)
	Beaver dams	Dam results in change or function of the facility.	Facility is returned to design function. (Coordinate trapping of beavers and removal of dams with appropriate permitting agencies.)
	Insects	Insects such as wasps and hornets interfere with maintenance activities.	Insects are destroyed or removed from site. Apply insecticides in compliance with adopted IPM policies.
	Tree growth and hazard trees	Tree growth does not allow maintenance access or interferes with maintenance activity (i.e., slope mowing, silt removal, vactoring, or equipment movements). If trees are not interfering with access or maintenance, do not remove. Dead, diseased, or dying trees are observed. (Use a certified arborist to determine health of tree or removal requirements.)	Trees do not hinder maintenance activities. Harvested trees should be recycled into mulch or other beneficial uses (e.g., alders for firewood). Remove hazard trees.
	Water level	First cell is empty, does not hold water.	Line the first cell to maintain at least 4 feet of water. Although the second cell may drain, the first cell must remain full to control turbulence of the incoming flow and reduce sediment resuspension.
	Inlet/outlet pipe	Inlet/outlet pipe is clogged with sediment or debris material.	The inlet and outlet piping are not clogged or blocked.

Table 6-2 (continued). Maintenance standards for Infiltration BMPs: AR.03 (Bioinfiltration Pond); AR.04 (Infiltration Pond); AR.05 (Infiltration Trench); AR.09 (Detention Pond); AR.06 (Infiltration Vault); AR.07 (Dry Well).

Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Results Expected When Maintenance is Performed
General (continued)	Sediment depth in first cell	Sediment depth exceeds 6 inches.	Sediment is removed from pond bottom.
	Oil sheen on water	Oil sheen is prevalent and visible.	Oil is removed from water using oil-absorbent pads or Vactor truck. Source of oil is located and corrected. If chronic low levels of oil persist, plant wetland species such as *Juncus effusus* (soft rush), which can uptake small concentrations of oil.
	Erosion	Pond side slopes or bottom show evidence of erosion or scouring in excess of 6 inches and the potential for continued erosion is evident.	Slopes are stabilized using proper erosion control measures and repair methods.
	Settlement of pond dike/berm	Any part of the pond dike/berm has settled 4 inches or lower than the design elevation, or the inspector determines dike/berm is unsound.	Dike/berm is repaired to specifications.
	Internal berm	Berm dividing cells are not level.	Berm surface is leveled so that water flows evenly over entire length of berm.
	Overflow/ spillway	Rock is missing and soil exposed at top of spillway or outside slope.	Rocks are replaced to specifications.
Side slopes of pond	Erosion	Eroded damage is over 2 inches deep and cause of damage is still present or there is potential for continued erosion. Erosion is observed on a compacted berm embankment.	Slopes are stabilized using appropriate erosion control measures; e.g., rock reinforcement, planting of grass, compaction. If erosion is occurring on compacted berms, a licensed civil engineer should be consulted to resolve source of erosion.
Storage area	Sediment	Accumulated sediment exceeds 10% of the designed pond depth, unless otherwise specified, or affects inletting or outletting condition of the facility.	Sediment is cleaned out to designed pond shape and depth; pond is reseeded if necessary to control erosion.
		Water ponds in infiltration pond after rainfall ceases and appropriate time has been allowed for infiltration. (A percolation test pit or test of facility indicates facility is working at only 90% of its designed capabilities. If 2 inches or more sediment is present, remove sediment).	Sediment is removed or facility is cleaned so that infiltration system works according to design.
		Sediment accumulation is such that that it permits undesireable numbers, height, or species of plant growth.	Undesireable plants and sediment are removed.
	Liner (if applicable)	Liner is visible and has more than three 1/4-inch holes in it.	Liner is repaired or replaced. Liner is fully covered.
	Vegetation	Grass becomes excessively tall (greater than 10 inches); nuisance weeds and other vegetation start to take over.	Mow vegetation or remove nuisance vegetation so that flow is not impeded. Grass should be mowed to a height of 3 to 4 inches. Remove grass clippings.

Table 6-2 (continued). Maintenance standards for Infiltration BMPs: AR.03 (Bioinfiltration Pond); AR.04 (Infiltration Pond); AR.05 (Infiltration Trench); AR.09 (Detention Pond); AR.06 (Infiltration Vault); AR.07 (Dry Well).

Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Results Expected When Maintenance is Performed
Rock filters	Sediment and debris	By visual inspection, little or no water flows through filter during heavy rainstorms.	Gravel in rock filter is replaced.
Pond berms (dikes)	Settlements	Any part of berm has settled 4 inches lower than the design elevation. If settlement is apparent, measure berm to determine amount of settlement. Settling can be an indication of more severe problems with the berm or outlet works. A licensed civil engineer should be consulted to determine the source of the settlement.	Dike is built back to the design elevation.
	Piping	Water flow is discernible through pond berm. Ongoing erosion is observed, with potential for erosion to continue. (Recommend a geotechnical engineer be called in to inspect and evaluate condition and recommend repair of condition.)	Piping is eliminated. Erosion potential is resolved.
Emergency overflow/ spillway and berms over 4 feet high	Tree growth	Tree growth on emergency spillways reduces spillway conveyance capacity and may cause erosion elsewhere on the pond perimeter due to uncontrolled overtopping. Tree growth on berms over 4 feet high may lead to piping through the berm, which could lead to failure of the berm and related erosion or flood damage.	Trees should be removed. If root system is small (base less than 4 inches), the root system may be left in place; otherwise, the roots should be removed and the berm restored. A licensed civil engineer should be consulted for proper berm/spillway restoration.
	Piping	Water flow is discernible through pond berm. Ongoing erosion is observed, with potential for erosion to continue. (Recommend a geotechnical engineer be called in to inspect and evaluate condition and recommend repair of condition.)	Piping is eliminated. Erosion potential is resolved.
Emergency overflow/ spillway	Spillway lining insufficient	Only one layer of rock exists above native soil in area 5 square feet or larger, or native soil is exposed at the top of outflow path of spillway. (Riprap on inside slopes need not be replaced.)	Rocks and pad depth are restored to design standards.
Presettling ponds and vaults	Facility or sump filled with sediment or debris	Sediment/debris exceeds 6 inches or designed sediment trap depth.	Sediment is removed.

Table 6-3. Maintenance standards for BMP AR.08 (Permeable Pavement).

Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Recommended Maintenance to Correct Problem
General	Sediment accumulation	Collection of sediment is too coarse to pass through pavement.	Remove sediment deposits with high-pressure vacuum sweeper.
	Accumulation of leaves, needles, and other foliage	Accumulation on top of pavement is observed.	Remove with a leaf blower or high-pressure vacuum sweeper.
	Trash and debris	Trash and debris have accumulated on the pavement.	Remove by hand or with a high-pressure vacuum sweeper.
	Oil accumulation	Oil collection is observed on top of pavement.	Immediately remove with a vacuum and follow up by a pressure wash or other appropriate rinse procedure.
Visual facility identification	Not aware of permeable pavement location	Facility markers are missing or not readable.	Replace facility identification where needed.
Annual minimum maintenance			Remove potential void-clogging debris with a biannual or annual high-pressure vacuum sweeping.

Table 6-4. Maintenance standards for closed detention and wet vault system BMPs: AR.10 (Detention Vault), AR.11 (Detention Tank), AR.23 (Wet Vault), and AR.24 (Combined Wet Vault/Detention Vault).

Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Results Expected When Maintenance is Performed
Storage area	Plugged air vents	One-half of the cross section of a vent is blocked at any point or the vent is damaged.	Vents are open and functioning.
	Debris and sediment	Accumulated sediment depth exceeds 10% of the diameter of the storage area for ½ length of storage vault, or any point depth exceeds 15% of diameter. (Example: 72-inch storage tank requires cleaning when sediment reaches depth of 7 inches for more than ½ length of tank.)	All sediment and debris are removed from storage area.
	Joints between tank/pipe section	Openings or voids allow material to be transported into facility. (Will require engineering analysis to determine structural stability.)	All joints between tank/pipe sections are sealed.
	Tank/pipe bent out of shape	Any part of tank/pipe is bent out of shape more than 10% of its design shape. (Review required by engineer to determine structural stability.)	Tank/pipe is repaired or replaced to design specifications.
	Vault structure: includes cracks in walls or bottom, damage to frame or top slab	Cracks are wider than ½ inch and there is evidence of soil particles entering the structure through the cracks, or maintenance/inspection personnel determine that the vault is not structurally sound.	Vault is replaced or repaired to design specifications and is structurally sound.
		Cracks are wider than ½ inch at the joint of any inlet/outlet pipe, or there is evidence of soil particles entering the vault through the walls.	No cracks are more than 1/4 inch wide at the joint of the inlet/outlet pipe.
Manhole	Cover not in place	Cover is missing or only partially in place. Any open manhole requires maintenance.	Manhole is closed.
	Locking mechanism not working	Mechanism cannot be opened by one maintenance person with proper tools. Bolts into frame have less than ½ inch of thread (may not apply to self-locking lids).	Mechanism opens with proper tools.
	Cover difficult to remove	One maintenance person cannot remove lid after applying normal lifting pressure. *Intent: To prevent cover from sealing off access to maintenance*.	Cover can be removed and reinstalled by one maintenance person.
	Ladder unsafe	Ladder is unsafe due to missing rungs, misalignment, not securely attached to structure wall, rust, or cracks.	Ladder meets design standards. Allows maintenance person safe access.

Table 6-5. Maintenance standards for BMP AR.13 (Biofiltration Swale).

Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Recommended Maintenance to Correct Problem
General	Sediment accumulation on grass	Sediment depth exceeds 2 inches.	Remove sediment deposits on grass treatment area of the swale. When finished, swale should be level from side to side and drain freely toward outlet. There should be no areas of standing water once inflow has ceased.
	Standing water	Water stands in the swale between storms and does not drain freely.	Any of the following may apply: remove sediment or trash blockages; improve grade from head to foot of swale; remove clogged check dams; add underdrains; or convert to a wet biofiltration swale.
	Flow spreader	Flow spreader is uneven or clogged so that flows are not uniformly distributed through entire swale width.	Level the spreader and clean so that flows are spread evenly over entire swale width.
	Constant baseflow	Small quantities of water continually flow through the swale, even when it has been dry for weeks, and an eroded, muddy channel has formed in the swale bottom.	Add a low-flow pea gravel drain the length of the swale, or bypass the baseflow around the swale.
	Poor vegetation coverage	Grass is sparse or bare, or eroded patches occur in more than 10% of the swale bottom.	Determine why grass growth is poor and correct that condition. Replant with plugs of grass from the upper slope: plant in the swale bottom at 8-inch intervals; or reseed into loosened, fertile soil.
	Vegetation	Grass becomes excessively tall (greater than 10 inches); nuisance weeds and other vegetation start to take over.	Mow vegetation or remove nuisance vegetation so that flow is not impeded. Grass should be mowed to a height of 3 to 4 inches. Remove grass clippings. Mowing is not required for wet biofiltration swales. However, fall harvesting of very dense vegetation after plant die-back is recommended.
	Excessive shading	Grass growth is poor because sunlight does not reach swale.	If possible, trim back overhanging limbs and remove brushy vegetation on adjacent slopes.
	Inlet/outlet	Inlet/outlet areas are clogged with sediment and/or debris.	Remove material so there is no clogging or blockage in the inlet and outlet area.
	Trash and debris	Trash and debris have accumulated in the swale.	Remove trash and debris from bioswale.
	Erosion/scouring	Swale bottom has eroded or scoured due to flow channelization or high flows.	For ruts or bare areas less than 12 inches wide, repair the damaged area by filling with crushed gravel. If bare areas are large (generally greater than 12 inches wide), the swale should be regraded and reseeded. For smaller bare areas, overseed when bare spots are evident, or take plugs of grass from the upper slope and plant in the swale bottom at 8-inch intervals.

Table 6-6. Maintenance standards for BMP AR.14 (Media Filter Drain).

Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Recommended Maintenance to Correct Problem
General	Sediment accumulation on grass filter strip	Sediment depth exceeds 2 inches or creates uneven grading that interferes with sheet flow.	Remove sediment deposits on grass treatment area of the embankment. When finished, embankment should be level from side to side and drain freely toward the toe of the embankment slope. There should be no areas of standing water once inflow has ceased.
	No-vegetation zone/flow spreader	Flow spreader is uneven or clogged so that flows are not uniformly distributed over entire embankment width.	Level the spreader and clean so that flows are spread evenly over entire embankment width.
	Poor vegetation coverage	Grass is sparse or bare, or eroded patches are observed in more than 10% of the vegetated filter strip surface area.	Consult with roadside vegetation specialists to determine why grass growth is poor and correct the offending condition. Replant with plugs of grass from the upper slope or reseed into loosened, fertile soil or compost.
	Vegetation	Grass becomes excessively tall (greater than 10 inches); nuisance weeds and other vegetation start to take over.	Mow vegetation or remove nuisance vegetation so that flow is not impeded. Grass should be mowed to a height of 3 to 4 inches. Remove grass clippings.
	MFD mix replacement	Water is seen on the surface of the MFD mix from storms that are less than a 6-month, 24-hour precipitation event. Maintenance also needed on a 10-year cycle and during a preservation project.	Excavate and replace all of the MFD mix contained within the media filter drain.
	Excessive shading	Grass growth is poor because sunlight does not reach embankment.	If possible, trim back overhanging limbs and remove brushy vegetation on adjacent slopes.
	Trash and debris	Trash and debris have accumulated on embankment.	Remove trash and debris from embankment.

Table 6-7. Maintenance standards for above-ground sand filter BMPs: AR.15 (Linear Sand Filter) and AR.16 (Sand Filter Basin).

Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Recommended Maintenance to Correct Problem
General	Sediment Accumulation on top layer	Sediment depth exceeds ½-inch.	No sediment deposit on grass layer of sand filter that would impede permeability of the filter section.
	Trash and Debris Accumulations	Trash and debris accumulated on sand filter bed.	Trash and debris removed from sand filter bed.
	Sediment/Debris in Clean-Outs	When the clean-outs become full or partially plugged with sediment and/or debris.	Sediment removed from clean-outs.
	Sand Filter Media	Drawdown of water through the sand filter media takes longer than 24-hours, and/or flow through the overflow pipes occurs frequently.	Top several inches of sand are scrapes. May require replacement of entire sand filter depth depending on extent of plugging (a sieve analysis is helpful to determine if the lower sand has too high a proportion of fine material).
	Prolonged Flows	Sand is saturated for prolonged periods of time (several weeks) and does not dry out between storms due to continuous base flow or prolonged flows from detention facilities.	Low, continuous flows are limited to a small portion of the facility by using a low wooden divider or slightly depressed sand surface.
	Short Circuiting	When flows become concentrated over one section of the sand filter rather than dispersed.	Flow and percolation of water through sand filter is uniform and dispersed across the entire filter area.
	Erosion Damage to Slopes	Erosion over 2-inches deep where cause of damage is prevalent or potential for continued erosion is evident.	Slopes stabilized using proper erosion control measures.
	Rock Pad Missing or Out of Place	Soil beneath the rock is visible.	Rock pad replaces or rebuilt to design specifications.
	Flow Spreader	Flow spreader uneven or clogged so that flows are not uniformly distributed across sand filter.	Spreader leveled and cleaned so that flows are spread evenly over sand filter.
	Damaged Pipes	Any part of the piping that is crushed or deformed more than 20% or any other failure to the piping.	Pipe repaired or replaced.

Table 6-8. Maintenance standards for below-ground sand filter BMP: AR 17 (Sand Filter Vault).

Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Recommended Maintenance to Correct Problem
General	Sediment Accumulation on Sand Media Section	Sediment depth exceeds ½-inch.	No sediment deposits on sand filter that would impede permeability of the filter section.
	Sediment Accumulation in Pre-Settling Portion of Vault	Sediment accumulation in vault bottom exceeds the depth of the sediment zone plus 6-inches.	No sediment deposits in first chamber of vault.
	Trash/Debris Accumulation	Trash and debris accumulated in vault, or pipe inlet/outlet, floatables and non-floatables	Trash and debris removed from vault and inlet/outlet piping.
	Sediment in Drain Pipes/Cleanouts	When drain pipes, cleanouts become full with sediment and/or debris.	Sediment and debris removed.
	Short Circuiting	When seepage/flow occurs along the vault walls and corners. Sand eroding near inflow area.	Sand filter media section re-laid and compacted along perimeter of vault to form a semi-seal. Erosion protection added to dissipate force of incoming flow and curtail erosion.
	Damaged Pipes	Inlet or outlet piping damaged or broken and in need of repair.	Pipe repaired to proper working specifications or replaced.
	Ventilation	Ventilation area blocked or plugged.	Blocking material removed or cleared from ventilation area. A specified % of the vault surface area must provide ventilation to the vault interior (see design specifications).
	Vault Structure Damaged; Includes Cracks in Walls, Bottom, Damage to Frame and/or Top Slab	Cracks wider than ½-inch or evidence of soil particles entering the structure through the cracks, or maintenance/inspection personnel determine that the vault is not structurally sound.	Vault replaces or repairs made so that vault meets design specifications and is structurally sound.
		Cracks wider than ½-inch at the joint of any inlet/outlet pipe or evidence of soil particles entering through the cracks.	Vault repaired so that no cracks exist wider than ¼-inch at the joint of the inlet/outlet pipe.
	Baffles/Internal Walls	Baffles or walls corroding, cracking, warping and/or showing signs of failure as determined by maintenance/inspection person.	Baffles repaired or replaces to specifications.
	Access Ladder Damaged	Ladder is corroded or deteriorated, not functioning properly, not securely attached to structure wall, missing rungs, cracks, and misaligned.	Ladder replaced or repaired to specifications, and is safe to use as determined by inspection personnel.

Table 6-9. Maintenance standards for BMP AR.21 (API Oil/Water Separator).

Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Recommended Maintenance to Correct Problem
General	Monitoring	Inspection of discharge water for obvious signs of poor water quality.	Effluent discharge from vault should be clear without thick visible sheen.
	Sediment Accumulation	Sediment depth in bottom of vault exceeds 6-inches in depth.	No sediment deposits in vault bottom that would impede flow through the vault and reduce separation efficiency.
	Trash and Debris Accumulation	Trash and debris accumulation in vault, or pipe inlet/outlet, floatables and non-floatables.	Trash and debris removed from vault, and inlet/outlet piping.
	Oil Accumulation	Oil accumulations that exceed 1-inch at the surface of the water.	Extract oil from vault by vactoring. Disposal in accordance with state and local regulations.
	Damaged Pipes.	Inlet or outlet piping damaged or broken and in need of repair.	Pipe repaired or replaced.
	Access Cover Damaged/Not Working	Cover cannot be opened, corrosion/deformation of cover.	Cover replaced or repairs made so that vault meets design specifications and is structurally sound.
	Structure Damage to Frame and/or Top Slab	Top slab has holes larger than 2 square inches or cracks wider than 1/4 inch.	Top slab is free of holes and cracks.
		Frame not sitting flush on top slab, i.e., separation of more than ¾ inch of the frame from the top slab. Frame not securely attached.	Frame is sitting flush on the riser rings or top slab and firmly attached.
	Fractures or Cracks in Walls/Bottom	Maintenance person judges that structure is unsound.	Basin replaced or repaired to design standards.
		Grout fillet has separated or cracked wider than ½ inch and longer than 1 foot at the joint of and inlet/outlet pipe or any evidence of soil particles entering through cracks.	Pipe is regrouted and secure at basin wall.
	Baffles	Baffles corroding, cracking, warping and/or showing signs of failure as determined by maintenance/inspection person.	Baffles repaired or replaced to specifications.
	Access Ladder Damaged	Ladder is corroded or deteriorated, not functioning properly, not securely attached to structure wall, missing rungs, cracks, and misaligned.	Ladder replaced or repaired and meets specifications, and is safe to use as determined by inspection personnel.

Table 6-10.Maintenance standards for BMP AR.22 (Coalescing Plate Separator).

Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Recommended Maintenance to Correct Problem
General	Monitoring	Inspection of discharge water for obvious signs of poor water quality.	Effluent discharge from vault should be clear without thick visible sheen.
	Sediment Accumulation	Sediment depth in bottom of vault exceeds 6-inches in depth and/or visible signs of sediment plates.	No sediment deposits in vault bottom and plate media, which would impede flow through the vault and reduce separation efficiency.
	Trash and Debris Accumulation	Trash and debris accumulation in vault, or pipe inlet/outlet, floatables and non-floatables.	Trash and debris removed from vault, and inlet/outlet piping.
	Oil Accumulation	Oil accumulations that exceed 1-inch at the water surface.	Oil is extracted from vault using vactoring methods. Coalescing plates are cleaned by thoroughly rinsing and flushing. Should be no visible oil depth on water.
	Damaged Coalescing Plates	Plate media broken, deformed, cracked and/or showing signs of failure.	A portion of the media pack of the entire plate is replaced, depending on severity of failure.
	Damaged Pipes.	Inlet or outlet piping damaged or broken and in need of repair.	Pipe repaired or replaced.
	Access Cover Damaged/Not Working	Cover cannot be opened, corrosion/deformation of cover.	Cover replaced or repairs made so that vault meets design specifications and is structurally sound.
	Vault Structure Damage – Includes Cracks in Walls, Bottom, Damage to Frame and/or Top Slab	Cracks wider than ½-inch or evidence of soil particles entering the structure through the cracks, or maintenance/inspection personnel determine that the vault is not structurally sound.	Vault replaced or repairs made so that vault meets design specifications and is structurally sound.
		Cracks wider than ½-inch at the joint of any inlet/outlet pipe or evidence of solid particles entering through the cracks.	Vault repaired so that no cracks exist wider than 1/4–inch at the joint of the inlet/outlet pipe.
	Baffles	Baffles corroding, cracking, warping and/or showing signs of failure as determined by maintenance/inspection person.	Baffles repaired or replaced to specifications.
	Access Ladder Damaged	Ladder is corroded or deteriorated, not functioning properly, not securely attached to structure wall, missing rungs, cracks, and misaligned.	Ladder replaced or repaired and meets specifications, and is safe to use as determined by inspection personnel.