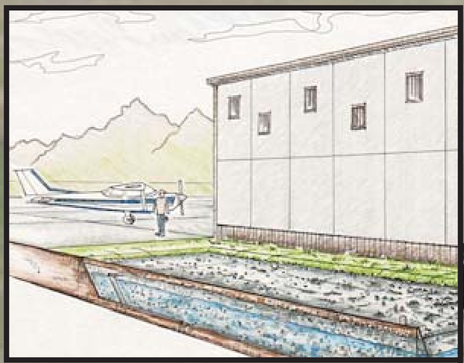
Washington State
Department of Transportation

Technical Manual

Aviation Stormwater Design Manual

Managing Wildlife Hazards Near Airports



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Note:

Some pages in this document have been intentionally skipped or blank pages inserted to ensure correct pagination and printing.

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Chapter 1. Introduction

1-1. Purpose of This Manual

The Aviation Stormwater Design Manual (ASDM) provides design guidance for best management practices (BMPs) for stormwater flow control and water quality treatment at or near airports (within the airport influence areas) that protect receiving waters and meet federal and state water quality standards in a safe manner. The ASDM is a joint effort by the Federal Aviation Administration (FAA), the Washington State Department of Transportation (WSDOT) Aviation Division and WSDOT Environmental Services.

The Washington State Department of Ecology (Ecology) has reviewed this manual to confirm that the modifications proposed to BMP design guidelines will not impact treatment or flow control mechanisms and are acceptable alternatives to guidelines presented in the Stormwater Management Manual for Western Washington (SMMWW) and the Stormwater Management Manual for Eastern Washington (SMMEW) (Ecology 2004, 2005). Section 1-3.4 provides information on other guidance manuals and documents that should be reviewed to determine applicable requirements. This manual does not provide guidance for determining when, or to what standard or threshold, treatment or flow control is required.

1-2. How to Use This Manual

- **Chapter 1** provides the regulatory background for stormwater management requirements in Washington State, emphasizing how they apply to airport operations.
- **Chapter 2** describes airport operations zones and how they affect stormwater management planning.
- **Chapter 3** discusses stormwater and wildlife planning, hazardous wildlife and provides recommendations for monitoring and designing based on airport-specific concerns. Chapter 3 also provides recommendations for adaptive management techniques that can be used with existing and new stormwater facilities.
- **Chapter 4** includes flow charts that provide guidance for selecting BMPs depending on pollutants of concern and site characteristics.
- **Chapter 5** provides guidance on hydrologic analysis for sizing of BMPs.
- **Chapter 6** provides design guidance for design of stormwater BMPs.

- **<u>Appendix A</u>** provides lists of vegetation recommended in airport settings, along with general guidelines for plant selection.
- **<u>Appendix B</u>** provides technical documentation for analyses that formed the basis for airport-specific design criteria for detention ponds (AR.09) and infiltration ponds (AR.04).

The three most common situations for use of this manual are described below. Please see the corresponding sections for additional information on how to perform each step.

A. Airports with new facility planned (runway, taxiway, etc.) or for other reasons, need new stormwater facilities		**See Section**
1	Determine applicable stormwater requirements	1-3.4
2	Identify other regulatory requirements	1-3.3
3	Map airport operational areas to determine potential sites for stormwater facilities, including maintenance access	2-1, 2-2.1, 2-2.2
4	Implement wildlife monitoring - consult with qualified airport wildlife biologist, if possible.	3-1.1
5	Based on monitoring, identify wildlife of concern and responsible attractants	3-1.2
6	Based on wildlife species, determine vegetative and structural considerations for BMPs	3-3.1, 3-3.2
7	Select BMPs for flow control	4-4
8	Select BMPs for runoff treatment	4-5

B. Airports with no new stormwater requirements but observed hazardous wildlife problems		**See Section**
1	Conduct a wildlife hazard assessment if any of the following apply: an air carrier aircraft experiences multiple wildlife strikes; an air carrier aircraft experiences substantial damage from a wildlife strike; an air carrier aircraft experiences an engine ingestion of wildlife near the airport; or wildlife are present in size, numbers, and locations such that there is a risk of wildlife strike (paraphrased from 14 CFR 139.337).	1-3.3
2	Implement wildlife monitoring - consult with qualified airport wildlife biologist, if possible.	3-1.1
3	Determine whether adaptive management techniques are needed for existing airport stormwater management facilities	3-4
4	Determine whether off-airport land is contributing to hazardous wildlife concerns	2-1.1, 2-2.4
5	If appropriate, coordinate with local jurisdictions regarding hazardous wildlife concerns	2-2.4
6	Identify any regulatory restrictions on adaptive design measures	1-3.3
7	Implement adaptive design measures	3-4

C. Airports with no new stormwater requirements and no hazardous wildlife issues		See Section
1	Implement wildlife monitoring	3-1.1
2	Make sure that planning documents reflect wildlife of concern and potential attractants (e.g. siting of proposed facilities)	3-2
3	Determine whether adaptive management techniques could benefit existing stormwater management facilities	3-4
4	Identify local jurisdictions and other land owners within Perimeter C, and identify which are most important in terms of hazardous wildlife concerns.	2-1.1, 2-2.4
5	Coordinate with local jurisdictions regarding hazardous wildlife concerns	2-2.4

1-3. Basis for Manual Development

1-3.1. Scope of Manual

This manual was developed to assist with the planning and design of stormwater management facilities on and around existing and new airports in the state of Washington, including those owned or operated by WSDOT. Airports are required to comply with federal, state, and local regulations to protect water resources by treating and controlling flow rates of stormwater runoff for new development and facility upgrades. However, airports are different from other industrial or commercial sites and must manage stormwater in a way that will not compromise aircraft safety. Many traditional stormwater BMPs, such as ponds, attract wildlife that may be hazardous to aircraft (Herrera 2007b). As a result, some traditional BMPs must be altered for use in the airport environment. This manual was developed to identify ways to treat and control stormwater without creating hazardous wildlife attractants. The manual focuses on technical issues related to stormwater management within the airport environment.

Wildlife attractants at airports are of concern because of the potential for collisions between wildlife and aircraft that threaten human safety. However, airports are not exempt from the Endangered Species Act (ESA), Bald and Golden Eagle Protection Act, or other federal, state, and local environmental regulations (see Section 1-3.3). Jurisdictional wetlands and other protected resources also may not be altered except as approved under applicable federal, state, and local regulations, even if they attract wildlife considered hazardous to aircraft. Active measures, such as sonic cannons, water sprays, dogs, and even laser beams have been used by airports to repel wildlife and will still need to be used in the future. However, airport managers also should design airports to avoid protected resources and/or ensure that the flight paths of birds that will be attracted to such protected resources will not pose an unacceptable risk of collisions. Chapter 3 provides general concepts for designing stormwater facilities to reduce the presence of hazardous wildlife.

In addition to posing a risk to wildlife and human life, wildlife-aircraft collisions cost the United States civil aviation industry at least $500 million in direct damage and associated costs and more than 500,000 hours of aircraft downtime per year (FAA 2005b). The majority of aircraft and wildlife collisions occur in the immediate airport environment (FAA 2005b). At airports in the state of Washington, there were 1,245 wildlife-aircraft collisions documented from January 1990 to April 2006 (FAA 2006a). Several studies have estimated that only 11 to 25 percent of all wildlife strikes are reported to the FAA (Linnel et al. 1999; Wright and Dolbeer 2005), so it is likely that many more strikes actually occurred.

The most common known bird species involved in aircraft collisions that were recorded in Washington were gulls, Canada geese, European starlings, killdeer, sparrows, barn swallows, ducks, and various raptors. Chapter 3 presents a summary of research on the factors that attract these birds to airports, which are primarily related to food and shelter. Stormwater facilities designed in accordance with traditional BMP design guidelines often provide food and shelter for wildlife, and thus increase the likelihood of a hazardous wildlife-aircraft collision.

It is important to note that the intent of this manual is not to deter all wildlife from airports. Many forms of wildlife exist on airports and sometimes pose little or no risk to aircraft. In this manual, the terms "hazardous wildlife" or "hazardous wildlife attractant" are used. These terms are intended to distinguish wildlife that could pose risks to aircraft and human life if they occur in unacceptable locations in the airport environment.

1-3.2. Airport Regulatory Issues

This manual is intended for all airports within the Washington Aviation System Plan (WSDOT 2001).

1-3.3. Overview of Federal and State Regulations Related to Stormwater Management at Airports

This manual is intended to complement and be used in conjunction with other Ecology-approved stormwater manuals. To determine when new impervious surfaces require water quality treatment, when flow control is required for receiving water protection, or the effluent discharge limits for pollutants, the permit documents described in this section and locally approved and equivalent manuals described in Section 1-3.4 should be consulted.

A number of operational and regulatory requirements create the framework for how airports in Washington State must manage stormwater on their property. This section describes the applicable state and federal requirements.

Federal Aviation Regulations

The FAA issues airport operating certificates for airports serving certain air carrier aircraft under Title 14, Code of Federal Regulations (CFR), Part 139. Section 139.337 stipulates that airports must conduct a wildlife hazard assessment if one of the following occurs at or near the airport:

an air carrier aircraft experiences multiple wildlife strikes; an air carrier aircraft experiences substantial damage from a wildlife strike; an air carrier aircraft experiences an engine ingestion of wildlife near the airport; or wildlife are present in size, numbers, and locations such that there is a risk of wildlife strike (paraphrased from 14 CFR 139.337).

In addition, all airports that have received Federal grant-in-assistance must comply with the standards outlined in FAA Circular Hazardous Wildlife Attractants on or near airports (AC 5200-33). The FAA recommends that all uncertified airports also adhere to these standards.

If a wildlife hazard management plan is deemed necessary based on the wildlife hazard assessment, it will become part of the Airport Certification Manual and, accordingly, federal law (for an explanation of the Airport Certification Manual, see the Glossary). The wildlife hazard management plan may contain provisions related to stormwater management and water quality, which should be reviewed for consistency with the provisions of this manual.

Clean Water Act, Section 404 Permits: Permit for Discharge of Dredge or Fill Material

While creating new constructed treatment wetlands is discouraged at airports, existing jurisdictional wetlands must be protected in accordance with Section 404 of the Clean Water Act.

Section 404 of the Clean Water Act prohibits the discharge of dredged and/or fill material into jurisdictional waters of the United States, including adjacent wetlands, without authorization from the U.S. Army Corps of Engineers (the Corps). The Corps evaluates the need to protect receiving waters from the effects of a proposed development, requires avoidance and minimization of proposed effects and requires mitigation to compensate for unavoidable effects. Section 404 of the Clean Water Act applies to airport management, especially because many airports are built in floodplains and flat areas near lakes, streams, and rivers.

Clean Water Act, Section 401 Permits

Applicants receiving a section 404 permit from the Corps, a Coast Guard permit, or a license from the Federal Energy Regulatory Commission (FERC), are required to obtain a section 401 water quality certification from the Ecology. Issuance of a certification means that Ecology anticipates that the applicant’s project, if constructed and operated according to conditions included with the certification, will comply with state water quality standards and other aquatic resource protection requirements under Ecology's authority. Conditions of the 401 Certification become conditions of the Federal permit or license.

Clean Water Act, Section 402: National Pollutant Discharge Elimination System Permit

In 1972, as part of the Clean Water Act, the U.S. Congress initiated the federal National Pollutant Discharge Elimination System (NPDES) program. To comply with the NPDES program, as amended in 1987, municipalities and many types of industrial sites are required to obtain a permit to discharge stormwater pollutants into navigable or regulated waters. The Clean Water Act also requires management of runoff from construction sites for water resource protection. Ecology is the agency that administers NPDES permits in the state of Washington on behalf of the U.S. Environmental Protection Agency (U.S. EPA).

Public-use airports in Washington are under multiple ownerships including facilities owned by WSDOT Aviation, a port district, private or a local entity such as a county, city, or tribe ownership. In the state of Washington, air transportation is considered an industrial activity (Standard Industrial Classification [SIC] 4500 series) requiring coverage under the Industrial Stormwater General Permit ISGP). As of October 6, 2006, 41 facilities in the state with this SIC code were covered under the permit. Other airports may have an individual (rather than general) NPDES stormwater permit, such as the Seattle-Tacoma International Airport, which is owned by the Port of Seattle. Some airport-related activities, such as aircraft maintenance or refueling activities, may be covered by a permit for an on-site waste treatment system. These permits typically specify effluent limitations for regulated pollutants that are created or used for that activity.

Endangered Species Act

The purpose of the Endangered Species Act (ESA) is to protect and promote recovery of imperiled species and the ecosystems upon which they depend. Three provisions of the Endangered Species Act may apply directly to stormwater management (Ecology 2005): Section 4(d) rules, Section 7 consultations and Section 10 habitat conservation plans. Brief descriptions of these provisions are provided in the SMMWW (Ecology 2005). These provisions ensure that conservation of endangered species is considered when proposing actions that may adversely affect these species. For example, several endangered fish species in the state of Washington may be adversely affected by stormwater pollutants. Because of their potential impact on endangered species development projects—including those at airports—are required to implement stormwater plans to minimize and mitigate these impacts.

For federally-funded projects that drain to receiving waters with ESA-listed species, there may be special water quality treatment and/or flow control requirements imposed through consultation with NOAA Fisheries. These requirements may exceed the level of treatment or flow control required based on the Ecology manuals, the HRM, and locally approved and equivalent manuals.

Bald and Golden Eagle Protection Act

The Bald and Golden Eagle Protection Act (16 United States Code [U.S.C.] 668-668c), enacted in 1940, prohibits the "take" of "any bald eagle ... [or any golden eagle], alive or dead, or any part, nest, or egg thereof." The act defines "take" as "pursue, shoot, shoot at, poison, wound, kill, capture, trap, collect, molest or disturb." With regard to the act, "disturb" means: "to agitate or bother a bald or golden eagle to a degree that causes, or is likely to cause, based on the best scientific information available, 1) injury to an eagle, 2) a decrease in its productivity, by substantially interfering with normal breeding, feeding, or sheltering behavior, or 3) nest abandonment, by substantially interfering with normal breeding, feeding, or sheltering behavior."

This definition also prohibits impacts that result from "human-induced alterations initiated around a previously used nest site during a time when eagles are not present, if, upon the eagle's return, such alterations agitate or bother an eagle to a degree that injures an eagle or substantially interferes with normal breeding, feeding, or sheltering habits and causes, or is likely to cause, a loss of productivity or nest abandonment" (USFWS 2007). To clarify activities that are prohibited or not prohibited under the act, the United States Fish and Wildlife Service (USFWS) released the National Bald Eagle Management Guidelines for landowners with the potential to encounter eagles while conducting activities on their property (USFWS 2007). Where bald or golden eagles use habitat at airports for breeding, feeding, or sheltering, these species must be protected in accordance with the Bald and Golden Eagle Protection Act. If bald eagles pose a threat to aircraft or human safety, a permit to disturb or trap and relocate bald eagles may be obtained from the USFWS (USFWS 2005).

Washington Growth Management Act

The Washington Growth Management Act (Revised Code of Washington, Chapter 36.70A [RCW 36.70A]), as well as Article 11 of the Washington State Constitution, require that local jurisdictions protect critical areas by adopting ordinances that classify, designate, and regulate land use. *Critical areas* are defined in this manual as wetlands, floodplains, aquifer recharge areas, geologically hazardous areas, and those areas necessary for fish and wildlife conservation. Critical areas are often found near airports and can, therefore, be affected by stormwater runoff from airports. Airport managers need to comply with the local jurisdictional requirements for protecting critical areas when managing stormwater at airports.

The Washington State Growth Management Act also contains provisions (RCW 36.70.547) whereby all general aviation airports operating for the benefit of the general public should discourage the siting of incompatible land uses adjacent to such airports through their comprehensive plan and development regulations.

Underground Injection Control Regulation

In accordance with Part C of the Federal Safe Drinking Water Act (SDWA), *Protection of Underground Sources of Drinking Water*, Washington State has an underground injection control (UIC) program which regulates discharges to UIC wells to protect groundwater quality. The UIC program is administered by Ecology under Chapter 173-218 Washington Administrative Code [173-218 WAC].

Infiltration facilities are the preferred BMPs for flow control and treatment, as noted in Chapter 4. Since infiltration facilities need to comply with UIC requirements, it is important that airport managers are aware of UIC provisions. The two major requirements of the UIC program are 1) register UIC wells with Ecology (unless wells are located on tribal land, in which case they must be registered with EPA); and 2) make sure that current and future underground sources of groundwater are not contaminated.

The following are not considered by Ecology to be UIC wells, so registration requirements and other restrictions do not apply (Ecology 2006):

- Buried pipe and/or tile networks that serve to collect water and discharge that water to a conveyance system or to surface water.
- Surface infiltration basins and flow dispersion stormwater infiltration facilities (AR.01, AR.02, AR.03.AR.04, AR.06).
- Infiltration trenches designed **without** perforated pipe or a similar mechanism (BMP AR.05).

UIC wells may not receive stormwater from the following types of areas (this is a partial list only; see 173-218-040(5)(b) WAC for additional prohibited UIC wells):

- Vehicle maintenance, repair and service.
- Commercial or fleet vehicle washing.
- Airport de-icing activities.
- Storage or handling of hazardous materials.
- Generation, storage, transfer, treatment or disposal of hazardous wastes.

More information can be found on Ecology's UIC program home page:
http://www.ecy.wa.gov/programs/wq/grndwtr/uic/index.html

Sole Source Aquifer

There are currently twelve sole source aquifers (SSAs) (U.S. EPA undated) in Washington state. If an existing or proposed federally-funded airport project has the potential to contaminate a SSA, that project would be subject to EPA review. In particular, stormwater management plan(s) would be reviewed in light of the following restrictions:

- Stormwater Treatment and Disposal Practices - All federally funded projects with the potential to contaminate a SSA that may generate, increase, collect, or dispose of storm or surface water runoff from impervious surfaces, must use BMPs to treat stormwater. Shallow injection wells, such as dry wells, french drains, sumps, and drainfields, must be avoided whenever possible.

- Shallow Injection Wells - In those cases where stormwater treatment and disposal systems must utilize a shallow injection well, the project proponent must notify and register the shallow injection well with Ecology's UIC Program and ensure that the shallow injection well(s) does not dispose any fluids that do not meet Washington's ground water quality standards (Chapter 173-200 WAC).

1-3.4. Relationship of this Manual to Other Stormwater Programs

This manual is a technical design guidance manual that is intended to supplement other stormwater programs, manuals and permits to address airport-related concerns. To determine whether stormwater quality treatment and/or flow control is required, consult other locally approved and equivalent manuals or permit documents.

Minimum Requirements/Core Elements

To comply with Ecology stormwater management requirements, project proponents must complete a set of documentation, analysis, design, planning, and maintenance activities related to stormwater management. These activities are referred to as *minimum requirements* in the SMMWW and *core elements* in the SMMEW.

Ten minimum requirements pertaining to stormwater management may apply to new and redevelopment projects in western Washington, including such projects at airports. See Volume I of the SMMWW for details. The 10 requirements are:

1. Preparation of stormwater site plans
2. Construction stormwater pollution prevention
3. Source control of pollution
4. Preservation of natural drainage systems and outfalls
5. Onsite stormwater management
6. Runoff treatment
7. Flow control
8. Wetlands protection
9. Basin/watershed planning
10. Operation and maintenance

Similarly, in eastern Washington, the project must comply with the following core elements:

1. Preparation of a Stormwater Site Plan
2. Construction Stormwater Pollution Prevention
3. Source Control of Pollution
4. Preservation of Natural Drainage Systems
5. Runoff Treatment
6. Flow Control
7. Operation and Maintenance

8. Local Requirements

Other Manuals and Permit Documents

To determine which of these minimum requirements apply, including requirements for water quality treatment and/or flow control, other locally approved and equivalent manuals or permit documents should be consulted. The following is a brief list of potentially applicable manuals and permit documents:

- **Highway Runoff Manual (HRM), Washington State Department of Transportation** (WSDOT 2008a)**:** The current version of this manual should be consulted for road projects adjacent to airports. The June 2008 version of the HRM was deemed equivalent to Ecology's Stormwater Manuals in November 2008 (Susewind 2008).
- **Ecology Stormwater Manuals (**Ecology 2004, 2005): Thresholds and requirements for water quality treatment and flow control can be found in the Ecology stormwater manuals for eastern Washington and western Washington (SMMWW or SMMEW), unless more stringent local guidelines apply.
- **Puget Sound Action Team (PSAT) Low Impact Development Technical Guidance Manual for Puget Sound (**PSAT 2005**)**: This manual does not provide information on thresholds and requirements for water quality treatment and flow control. However, some of the site planning and layout techniques described in Chapter 3 of the PSAT manual can effectively reduce impervious area, thereby reducing flow control and treatment requirements. The Puget Sound Partnership plans to update this manual as appropriate to reflect state-of-the-practice guidance for design of low impact developments and related stormwater facilities.
- **Locally Approved and Equivalent Manuals:** If an airport is located within a county or city with an Ecology-approved stormwater manual, the airport must comply with any applicable stormwater requirements in that locally approved and equivalent manual. These include manuals developed mainly by NPDES "Phase 1" communities in Washington as equivalent to the Ecology manuals. Examples are King County, Pierce County, and the city of Olympia.
- **FAA Wildlife Hazard Management Plan (FAA 2005b):** As described in Section 1-3.3, for airports where wildlife strikes have occurred or with a high risk of wildlife strikes, a wildlife hazard management plan may be part of the regulatory Airport Certification Manual. Stormwater management facilities must be designed in accordance with any applicable safety requirements documented in the wildlife hazard management plan.

- N**PDES Permits**, as described in Section 1-3.3, may include effluent discharge limits and other restrictions applicable to stormwater management. Some airports have individual NPDES permits or are subject to a local municipality's NPDES permit (if they discharge to a regulated small Municipal Separate Storm Sewer System [MS4]) that may impose requirements beyond those described in this manual. The more stringent flow control and water quality treatment requirements apply.
- **Basin Plan, Waste Load Allocation (WLA), or Water Cleanup Plan**: An adopted and implemented basin plan, a WLA required by Total Maximum Daily Load (TMDL) requirements established by Ecology, or a water cleanup plan may also govern runoff treatment requirements that are tailored to a specific basin. However, basin-specific requirements must be at least as rigorous as Ecology's basic treatment requirements (Ecology 2004, Ecology 2005).
- **ESA Recovery Plans**: Section 4(f) of the ESA requires that NMFS and USFWS develop and implement recovery plans for threatened and endangered species, unless such a plan would not promote conservation of the species. These plans incorporate management actions necessary to achieve recovery of the species, which could affect stormwater management requirements.

Chapter 2. Airport Operations and Stormwater

This chapter contains stormwater planning and design information specific to airports.

- **Section 2-1** describes airport operations zones and FAA restrictions within each zone, especially as they potentially affect stormwater management.
- **Section 2-2** describes general considerations and principles that should be evaluated when siting proposed stormwater facilities.

2-1. Airport Operation Zones and Restrictions

In the 150/5200-33 series of Advisory Circulars, the FAA (2004a) identified three airport operation zones, known as Perimeters A through C, relating to stormwater facilities and other potential hazardous wildlife attractants near air operations areas. For certificated airports, airport operators are *required to adhere to the intent of the guidelines in the FAA Advisory Circulars*. For surrounding municipalities and jurisdictions outside of the airport grounds that fall within Perimeters A through C, restrictions associated with each zone are considered *recommended guidelines*.

In addition, local, state, or federal agencies may have more stringent requirements for specific land uses. In those cases, those regulations must also be followed.

2-1.1. Description of Airport Operation Zones and Guidelines

Perimeter A applies to airports serving piston-powered aircraft. No hazardous wildlife attractants should be located within this perimeter, which is defined as 5,000 feet from the nearest Air Operations Areas (AOA). An AOA is defined as any area of an airport used or intended to be used for landing, takeoff, or surface maneuvering of aircraft. This includes such paved or unpaved areas that are used or intended to be used for the unobstructed movement of aircraft in addition to associated runways, taxiways, or aprons.

Perimeter B applies to airports serving turbine-powered aircraft. No hazardous wildlife attractants should be located within this perimeter, which is defined as 10,000 feet from the nearest AOA.

Perimeter C applies to all airports, regardless of the types of aircraft served. If possible, hazardous wildlife attractants that could cause wildlife movement into or across the approach or departure airspace should not be located within this perimeter, which is defined as 5 statute miles from the nearest AOA.

These perimeters are described in this section because, for certificated airports, airport operators are *required to adhere to the intent of the guidelines in Advisory Circulars*, and to alert airport operators to the fact that land uses outside of the airport could present aircraft hazards by attracting wildlife. In many cases, wildlife attractants within Perimeter C consist of existing natural features. Where possible, airport facility planning should take into consideration the existing natural features within Perimeter A (e.g., avoid locating critical AOA facilities within or between habitat features where birds are likely to fly).

Airport operators are strongly encouraged to engage a wildlife specialist on any significant proposed projects within Perimeters A, B or C early in the conceptual or preliminary design phase to ensure that hazardous wildlife considerations are incorporated at an early stage. Refer to Chapter 3 for more information on stormwater and wildlife planning considerations.

Restrictions on Off-Airport Land

If a local jurisdiction owns an airport and adjacent land within Perimeter C, the jurisdiction would be obligated to meet the Perimeter C restrictions for that adjacent land.

When land within Perimeter C is owned by other entities (who have no affiliation with the airport), airport operators should also work with and educate landowners within Perimeter C regarding stormwater management practices that will not present risks to aircraft. These landowners are not obligated to meet the FAA restrictions although their cooperation is encouraged.

The Perimeter A, B, and C restrictions also apply to off-airport land that is owned by certificated airports, which is common for industrial land in the vicinity of airports.

Regardless of ownership of the land adjacent to or in the vicinity of airports, airport managers should be aware of all proposed development within Perimeter C. Airport managers are encouraged to take a proactive approach with project proponents, make sure that they are aware of hazardous wildlife concerns, and encourage design measures that are compatible with the airport environment.

Airspace Restrictions

In addition to the Perimeter A, B, and C regulations/recommendations, the FAA Northwest Mountain Region, Part 77 regulations (airspace restrictions) usually apply. The Seattle Airport Districts Office (ADO) has recommended that a form 7460 be completed when detention ponds are proposed to be located within the set limits of airports if the ponds are not covered with netting, balls, or a floating cover to discourage wildlife use. The rationale is that attractants can result in potential airspace conflicts with wildlife. Design methods proposed in this manual will greatly reduce the attractiveness of stormwater detention facilities, reducing the area that must be covered with netting, balls, or floating covers.

The FAA also has formal operational zones with restrictions and requirements that *must* be followed. These operational zones are listed in Section 2-1.2.

The BMP descriptions and design guidelines in Chapter 6 refer to *airside* and *landside* locations at airports. For the purposes of this manual, these terms are defined as follows:

- **Airside** refers to all areas where aircraft are operated or serviced. These include the AOA, which is described above, as well as airport areas where maintenance, refueling, storage, and other support activities for aircraft are conducted.
- **Landside** refers to all other areas of the airport (e.g., parking areas, rental car lots, arrival and departure pickup/dropoff roadways, and terminals).

2-1.2. Stormwater Facility Restrictions

The FAA formally defines several operational areas with specific delineation criteria and requirements that must be considered when designing airport stormwater facilities. Dimensions of these areas vary depending on the specific airport environment. Delineation guidelines, while beyond the scope of this document, are found in the *Airport Design Advisory Circular 150/5300-13* (FAA 2006b).

The FAA defines the following areas of significance to designers of stormwater facilities. Each area is also illustrated in Figure 2-1:

- **Clearway (CWY):** A defined rectangular area beyond the end of a runway cleared or suitable for use in lieu of runway to satisfy takeoff distance requirements. This is the region of space above an inclined plane that leaves the ground at the end of the runway. FAA design standards state that the ground area underneath the clearway need not be suitable for stopping aircraft in the event of an aborted takeoff. Because of this standard, it is acceptable to place stormwater BMPs on the ground under the clearway as long as objects associated with the BMPs do not protrude through the clearway plane.
- **Object-Free Area (OFA):** An area on the ground centered on a runway, taxiway, or taxi lane centerline. It is provided to enhance the safety of aircraft operations by having the area free of aboveground objects protruding above the Runway Safety Area (RSA, defined below) edge elevation, except for objects that need to be located in the OFA for air navigation or aircraft ground maneuvering purposes. Per FAA design standards, restricted objects include but are not limited to the following: aboveground structures, navigational aids, people, equipment, vehicles, natural growth, terrain, parked aircraft, and agricultural operations. OFA design guidelines limit the types of stormwater BMPs that may be located within the OFA. Stormwater BMPs within the OFA must not include objects that protrude above the RSA edge elevation.

- **Runway Protection Zone (RPZ):** An area off the runway end that enhances the protection of people and property. According to the FAA Advisory Circular, Hazardous Wildlife Attractants On or Near Airports, stormwater facilities are permitted within the RPZ, provided they do not attract wildlife and are located outside of the runway OFA. They may not interfere with navigational aids (FAA 2006a).

- **Runway Safety Area (RSA):** A defined ground surface surrounding the runway prepared or suitable for reducing the risk of damage to aircraft in the event of an undershoot, overshoot, or excursion from the runway. FAA design standards require that the RSA be:

  - Cleared and graded and have no potentially hazardous ruts, humps, depressions, or other surface variations.

  - Drained by grading or storm sewers to prevent water accumulation.

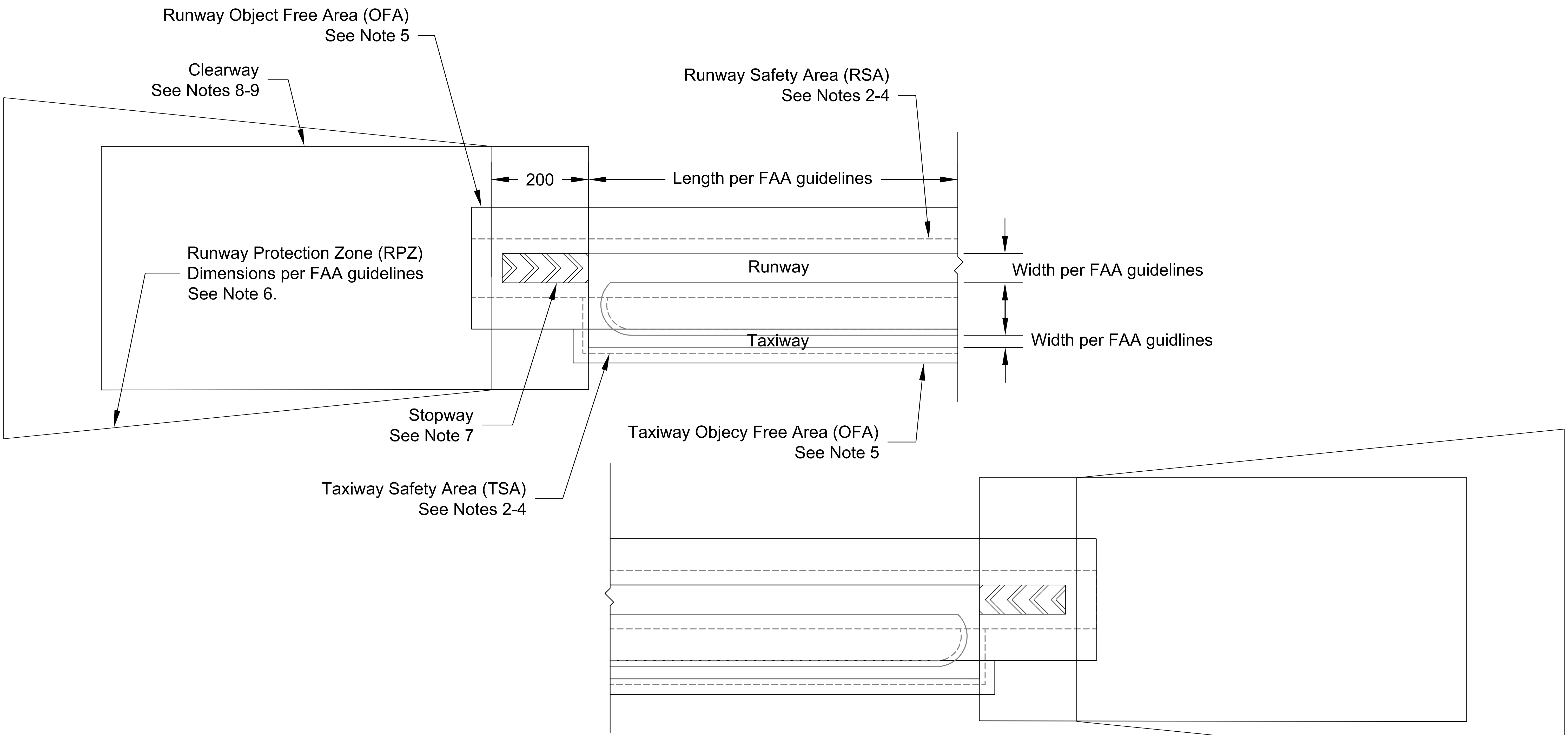
  - Capable, under dry conditions, of supporting snow removal equipment, aircraft rescue and firefighting equipment, and the occasional passage of aircraft without causing structural damage to the aircraft.

  - Free of objects, except for objects that need to be located in the RSA because of their function. Objects higher than 3 inches above grade should be constructed, to the extent practicable, on low-impact, resistant supports of the lowest practical height with the frangible (i.e., fragile or easily broken) point no higher than 3 inches above grade. Other objects, such as manhole covers, should be constructed at grade. In no case should their height exceed 3 inches above grade.

  These RSA design standards have direct implications for the design and location of stormwater facilities. In most cases, stormwater BMPs must be located outside of the RSA unless they are subsurface facilities and can be driven over without damage to vehicles, aircraft, or the stormwater system. Any manholes within the RSA must be constructed flush with existing grade. Unlike some airport design standards, RSA standards cannot be modified or waived.

  The FAA also recommends that the entire RSA be accessible to rescue and firefighting vehicles so that no part of the RSA is more than 330 feet from either an all-weather road or a paved operational surface. Components of the stormwater management system within the RSA should accommodate this.

- **Stopway (SWY):** A defined rectangular surface beyond the end of a runway prepared or suitable for use in lieu of the runway to support an aircraft without causing structural damage to the aircraft during an aborted



Notes

1. Dimensions from *Airport Design*, FAA Advisory Circular 150/5300-13.
2. No surface variations or water accumulation within RSA (AC 150/5300-13 CHG7/305).
3. Manhole covers shall be constructed at or near surface grade elevation (max. protrusion 3" above grade) within RSA.
4. All areas within RSA must be capable of supporting snow removal, aircraft, and emergency vehicles.
5. No objects non-essential for air navigation or aircraft ground maneuvering permitted in OFA.
6. Stormwater facilities are permitted within RPZ (outside of OFA). Facilities must not attract wildlife or interfere with navigational aids.
7. If a Stopway is provided, it must be able to support an airplane during an aborted takeoff without causing structural damage to the airplane.
8. The Clearway slopes upward (from end of Runway) at a maximum slope of 1.25%.
9. No object or terrain (except threshold lights) may protrude through the Clearway plane.

Airport Stormwater Design Manual Figure 2-1.
Stormwater Facility Restrictions wtihin Airport Operation Zones.

takeoff. If stormwater BMPs are located within the SWY, they need to be subsurface and capable of supporting aircraft in the case of an aborted takeoff.

- **Taxiway Safety Area (TSA):** A defined surface alongside the taxiway prepared or suitable for reducing the risk of damage to an aircraft unintentionally departing the taxiway. FAA design standards for TSAs are the same as those for RSAs and have direct implications for the design and location of stormwater facilities. In most cases, stormwater BMPs must be located outside of the TSA unless they are constructed subsurface and can be driven over without damage to vehicles, aircraft, or the stormwater system. Any manholes within the TSA must be constructed flush with the existing grade. Like the RSA standards, TSA standards cannot be modified or waived.

2-2. General Airport Stormwater Considerations

2-2.1. Safety and Emergency Access

Safety is of primary importance at airports and must be considered first while developing stormwater management facilities. In the event of a problematic landing, emergency vehicles and personnel may need to access certain parts of the airport. The location and configuration of stormwater facilities must not impede the operation of emergency vehicles.

2-2.2. Maintenance

Stormwater facilities must be maintained periodically to remove accumulated sediment deposits, trim vegetation, or clean filters and trash racks. Stormwater facilities that require routine maintenance should not be located in areas where the maintenance activities would hinder or disrupt airport operations. For example, a location within an OFA would not be suitable for a filtration system requiring frequent trips by personnel and equipment for maintenance during airport operational hours. Instead, stormwater could be piped to the filtration system outside the OFA.

2-2.3. Target Pollutants

The manuals and permit documents identified in Sections 1-3.3 and 1-3.4 of this manual should be consulted to determine levels of treatment and pollutants of concern.

2-2.4. Community Planning

If an airport is located within or adjacent to a community that may be installing stormwater management facilities, the airport operators may want to encourage nearby communities to use this manual for BMP design considerations and guidelines. At a minimum, airport operators should discourage the implementation of stormwater BMPs that are known wildlife attractants within the airport's operation zones. This is similar to coordination that airports already do with local jurisdictions to discourage the siting of landfills, food processors, certain agricultural operations, or other hazardous wildlife attractants in locations where they could potentially affect air operations. If communities are interested in providing wildlife habitat along with stormwater management, airport operators are encouraged to help neighboring communities identify high-value habitat areas for mitigation that will benefit wildlife without posing unacceptable risks to humans, wildlife, and aircraft.

Chapter 3. Stormwater and Wildlife Planning

Minimizing risks associated with wildlife-aircraft interactions should be of paramount concern during airport site planning, design, and operation. Even at sites where animals are not present under existing conditions, nearby or migratory wildlife could be attracted to a new facility that is inappropriately designed. Designing stormwater management facilities that are compatible with airports requires knowledgeable staff, flexibility, coordination, and long-term commitment.

3-1. Identifying and Monitoring Species of Concern

A critical step in selecting stormwater facilities for the airport environment is determining the wildlife species of concern that may be present in or attracted to new facilities. Although this section provides some general guidelines and considerations for identifying and deterring wildlife of concern, it does not replace the expertise of a qualified airport wildlife biologist. Biologists are aware of the inherent complexities associated with wildlife hazard identification in a diverse and seasonally variable environment and can conduct a wildlife hazard assessment, identifying species that may be attracted to stormwater facilities. However, in many cases, airport operators are aware of at least some of the wildlife species of concern at a given airport, and their input should be seriously considered. Data documenting distribution, migratory routes, or habits of potentially hazardous wildlife also should be consulted (see below for resources).

This section includes a brief description of the most typical hazardous wildlife species on and near airports. It is important to note that this section does not address all possible wildlife species that may present hazards in an airport environment. For this reason, the designer is encouraged to contract with a qualified airport wildlife biologist familiar with the area to conduct a hazardous wildlife assessment and identify the species of concern. For certificated airports, this biologist must meet the qualifications in FAA Advisory Circular 150/5200-36 (FAA 2006c). For additional information on wildlife species, the designer is referred to the following sources:

- National Wildlife Strike Database (FAA 2006a), which documents collisions between aircraft and wildlife throughout the United States.
- Regional biologists with WSDOT, WDFW, or the U.S. Fish and Wildlife Service.
- U.S. Department of Agriculture (USDA) Wildlife Services.
- The technical memorandum entitled *Stormwater Management Guidance Manual for Airports in the State of Washington: Potential Wildlife Attractant Hazards at Airport Stormwater Facilities* (Herrera 2007b), which provides detailed information on habitat quality factors that influence use of stormwater facilities by wildlife, as well as methods for limiting habitat quality within stormwater facilities.

- WDFW Heritage and Priority Habitats and Species databases: This geographic information system (GIS) database contains information on important fish and wildlife species that can help identify species within the airport environment that should be considered in land use decisions and activities. This database is updated as new information is submitted and is available to local jurisdictions at their request. This information can be requested at: www.wdfw.wa.gov/hab/release.
- Washington Nature Mapping Program: http://depts.washington.edu/natmap/maps/.

Virtually any animal species of reasonable size that is present in the airport environment may be considered hazardous if the potential exists for it to disrupt air operations. Of all wildlife species, deer pose the greatest risk to aviation safety. Most deer strikes result in damage and over half result in a negative effect on the flight (FAA 2008). However, deer are easily managed with the appropriate installation of a wildlife fence and man-made stormwater ponds are not considered a significant attractant to deer. Birds also present significant risk to aircraft because of their abundance, size, and ability to fly. Aerial collisions present great risk to human safety and equipment, and the number of occurrences of aerial collisions with birds are far more than collisions on the ground.

In general, if open water areas or wetlands exist near the airport, shorebirds, gulls, ducks, herons, and geese may be an issue. If raptors have been observed nearby, they should be considered during stormwater planning efforts and monitored on an ongoing basis. Mammals of potential concern in airport environments include deer, elk, and coyotes. If present near airport facilities, these species should be monitored and appropriate management strategies taken (e.g., a wildlife fence with a buried apron).

3-1.1. Wildlife Monitoring

Wildlife monitoring plans must be developed to assist with airport development planning and ensure the continued effectiveness of mitigation measures. These plans should be tailored to address concerns of individual airports. Wildlife hazard management plans prepared for several airports were reviewed as background information for the wildlife attractants technical memorandum entitled *Stormwater Management Guidance Manual for Airports in the State of Washington: Potential Wildlife Attractant Hazards at Airport Stormwater Facilities* (Herrera 2007b). Many of these management plans included monitoring and adaptive management. The following issues should be addressed in wildlife monitoring plans:

- **Conduct a wildlife evaluation**. Document the numbers observed at various times (seasonal or during the day), activities (nesting, feeding), and airport features or facilities that appear to attract the species. This section provides guidance to determine which species typically pose the greatest hazard potential at an individual airport. (Unfortunately, the only evidence highlighting the presence of some hazardous species may be feces found on paved surfaces or in short grass or tracks and may be difficult for the lay person to identify.)

- Identify the monitoring methods and develop a monitoring schedule.
- Document when any changes to reduce wildlife attractants have been made (e.g., maintenance of stormwater facilities, filling of ruts or depressions to avoid standing water, change in mowing or irrigation schedule).
- Develop a program and schedule for implementing wildlife controls based on the species of concern and the site-specific wildlife attractants. Track any changes in behavior or observed numbers of wildlife associated with each modification.
- Record all wildlife strikes and report them to the FAA. Follow FAA Form 5200-7 (Bird/Other Wildlife Strike Report) or report strikes online at the following website: http://wildlife.pr.erau.edu/strikeform/birdstrikeform.php.
- Document the stormwater BMP selection process, particularly how wildlife issues affected BMP site and selection. Provide site-specific operations and maintenance or monitoring recommendations, as appropriate.

3-1.2. Wildlife of Concern

Waterfowl

Waterfowl include ducks, geese, swans, and mergansers. In general, these species are migratory, although some populations remain in a given area year round. Most species are omnivorous, with diets consisting of aquatic and wetland vegetation (e.g., seeds, stems, leaves, rhizomes, and roots), agricultural vegetation, aquatic insects, fish, mollusks, and crustaceans. These species commonly are found where there is a combination of protection from predators, open water, wetland vegetation, and adjacent uplands for food, cover, and nesting.

The Canada goose is one of the most hazardous wildlife species to aircraft operations in North America and Washington State. Canada geese require upland and aquatic habitat. They graze on cultivated and wild terrestrial vegetation, including grasses and clover, and on aquatic plants (e.g., pondweed, bulrush, sedges, and cattails) (WDFW 2005). Canada geese tend to congregate on low vegetation adjacent to open water, which affords them an unobstructed sight line to scan for predators. When the open sight line is less than 30 feet, geese will generally move to a more suitable grazing area (WDFW 2005). This is the basis for the 30-foot width restriction for detention ponds and infiltration ponds presented in this manual (see Section 6-2.9, AR.09).

To reduce waterfowl attraction to stormwater facilities in airport settings, open standing water and wetland areas that provide food, cover, and nesting habitat should be minimized. Only those types of vegetation that generally are not favored by waterfowl for food or cover should be used in airport stormwater facilities. Appendix A presents lists of vegetation species recommended for use at airports. Stormwater detention times in ponds should be minimized.

Raptors

Raptors include hawks, falcons, owls, eagles, and vultures. Food preference and hunting approach vary among species, but primary food sources include small mammals, birds, amphibians, and fish. Unlike other raptors, turkey vultures (*Cathartes aura*) scavenge for all of their food rather than hunt. Vultures feed primarily on carrion, human garbage, and some agricultural crops.

Raptor species are protected under the Bald and Golden Eagle Protection Act (see Section 1-3.3) and the Migratory Bird Treaty Act. Because of the protected status of bald eagles, existing habitats that they use in and around airports may not be altered, except in accordance with the National Bald Eagle Management Guidelines (USFWS 2007). If other raptors are observed (perching, roosting, hunting, and/or nesting) near an airport facility, state wildlife officials should be contacted to determine appropriate management strategies.

Raptors, including vultures, represent a significant hazard to aircraft (Dolbeer et al. 2000). These birds may be attracted to airport environments if food sources, perching locations, and/or nesting opportunities are available. In particular, an abundance of small rodents in conjunction with short, manicured vegetation attracts birds of prey (Barras et al. 2000), as does an abundance of pigeons, starlings, or other avian prey species. To discourage birds of prey from frequenting stormwater facilities in airport settings, care should be taken to minimize factors that result in an abundance of prey species. Vultures are problematic primarily where airports are located near landfills or other areas in which they scavenge for food. Properly designed and maintained stormwater facilities do not incorporate features that would typically attract vultures.

Doves and Pigeons

Doves and feral pigeons are common hazard species at airports. Their natural habitat is rock cliffs, but several of these species (particularly the rock dove or common pigeon, and mourning dove) have adapted well to urban areas, taking advantage of human food sources and roosting on buildings and bridges. Their diet in natural environments consists primarily of seeds, fruits, and soft plant material. The rock dove is most likely to be of concern at airports. The band-tailed pigeon, a native pigeon to Washington, is not associated with cliffs and is not typically an issue for air traffic (McAllister 2008).

Pigeons and doves present significant hazards to aircraft in airport environments. Although the individual birds are not particularly large, they often form large flocks. To avoid attracting pigeons and doves, stormwater facilities should not include vegetation that produces seeds or berries favored by doves and pigeons. For example, seed mixes used to revegetate disturbed areas at airports should not include millet or other plants that produce large seeds (Castellano

1998). Stormwater facilities also should not include sand or small pebbles, which pigeons and doves ingest to aid in the breakdown and digestion of seeds.

Cranes

Sandhill cranes are listed as endangered in Washington State. They are opportunistic feeders that alter their diet based on seasonal food abundance and dietary requirements. Sandhill cranes feed on small rodents, fish, amphibians, insects, grains, berries, and plants. This species forages in fields and in shallow, standing water. Sandhill cranes nest on the ground near water in wetland/marsh vegetation.

Because this species is endangered, existing sandhill crane habitat in and around airports may not be altered. To avoid attracting cranes to stormwater facilities in airport settings, managers should avoid constructing shallow-water wetlands, ponds with long detention times, or other habitat that may attract or appear to attract common prey species.

Cranes are unlikely to be a significant species of concern at airports, except potentially during migration. Their only known nesting locations in Washington State are some remote marshes in Klickitat and Yakima counties (McCallister 2008).

Herons

Herons are large wading birds that frequent wetland habitat and feed on aquatic species such as fish, crayfish, and amphibians. Herons also feed on frogs, snakes, voles, and other small rodents in upland fields, provided there is water nearby. The grass and forb communities that attract voles and other small rodents tend to dominate airport environments, so eliminating these upland habitat areas is unlikely to be feasible. However, promoting good drainage adjacent to these upland areas to eliminate standing water may reduce the attraction of these areas to herons (McCallister 2008). To minimize the risk of stormwater facilities attracting herons, standing water and wetland habitats should be minimized.

Shorebirds

Shorebirds include gulls, terns, avocets, plovers, and sandpipers. These birds typically inhabit wetland and coastal environments. They are attracted to large, open areas, which dominate the airport environment. The majority of these species eat small invertebrates foraged from mud or exposed soil. Several shorebird species are listed as threatened, endangered, or as species of concern in Washington State. There are no state-mandated habitat restrictions associated with state-listed shorebirds, but local governments may have environmental ordinances addressing habitat protection (McCallister 2008). Existing habitats used by the snowy plover, the only federally listed shorebird in Washington State, may not be altered. However, it is unlikely to be found at airports.

Of the shorebirds, gulls typically pose the greatest threat to aircraft. Gulls are highly adaptable birds that hunt prey and scavenge for food. Gulls pose hazards to aircraft operation due to their size, abundance, tendency to flock, and use of coastal habitats close to airports (Dolbeer et al. 2000). They are also a serious aircraft hazard where airports are located near landfills or other major food sources, including large number of invertebrates (e.g., grasshoppers, or worms on runways following heavy rains). Therefore, stormwater BMPs that include deep organic soils attractive to earthworms may represent a risk where rainfall and gulls are common.

Crows/Ravens

Crows and ravens are omnivores that feed on insects, berries, fruits, bird eggs, carrion, small birds and mammals, and human refuse. They prefer habitat with trees or wooded areas and water nearby. Ravens and crows show a preference for carrion and are often observed feeding on roadkill. Stormwater facilities should minimize vegetative food sources favored by crows and ravens and avoid trees that may be utilized by the birds as roosting areas.

Other Small Birds

This group encompasses a large number of smaller bird species including blackbirds, starlings, sparrows, swallows, and other songbirds. Compared to other bird species, individuals of this group are less hazardous to aircraft because of their smaller size, although large flocks represent a cumulative hazard to aircraft. Preferred habitat and dietary habits vary by species. Specific habitat and food availability that could result in overabundance of potential problem species should be researched and addressed on a case-by-case basis. In general, stormwater facilities should not use vegetation that develops seeds that identified hazardous species prefer (e.g., sunflower, millet).

Deer

Deer represent a serious threat to aircraft when present near airport runways. White-tailed and mule/black-tailed deer are found in Washington and occupy a range of habitats across the state. Both species are browsers and consume the leaves, twigs, fruits, and berries of such plants as chokecherry, serviceberry, snowberry, and dogwood. Agricultural crops such as alfalfa also attract deer. Seasonally, mule deer may graze on other plant species.

Stormwater facilities should not include vegetation preferentially foraged by deer. In arid regions, where deer are present, access to standing water in stormwater facilities should be prevented. Normally, however, deer are easily managed with the appropriate installation of a wildlife fence and man-made stormwater ponds are not considered a significant attractant to deer.

Coyotes

Coyotes are a highly adaptable species that hunts and feeds on small animals such as rabbits, mice, grouse, and geese. They account for only a small fraction of wildlife strikes (FAA 2008), however, and stormwater facilities are unlikely to attract coyotes unless the facilities are already attracting other wildlife species that coyotes prey upon. Standing water should be minimized to decrease the chance of coyotes using facilities as a watering hole. As with deer, an appropriately designed wildlife fence including a buried apron (to avoid tunneling) is frequently used to deter coyotes from entering airports.

3-2. Site Planning and Layout Considerations

Avoiding conflicts between aircraft and wildlife should be a primary consideration during airport planning and design. A detailed discussion of how wildlife considerations should factor into all decisions related to airport siting, planning, upgrades, and operations is beyond the scope of this manual. However, some general considerations are provided in this section.

3-2.1. Existing Habitat

The location and type of existing wildlife habitat on and around airports must be considered when siting new stormwater BMPs since the wildlife species themselves may not always be readily apparent or placement of the new facility may increase wildlife conflicts.

As a rule, designers should identify existing rivers, streams, lakes, wetlands, forests, vegetated corridors, and other habitat in the vicinity of the airport, and determine the hazardous species attracted to that habitat (see Section 3-1). Be sure to include manmade habitats such as water treatment wetlands or ponds in this assessment. GIS can be a useful tool for this task. It is in the designer's best interest to employ the expertise of a qualified airport wildlife biologist familiar with the area to define existing habitats and the hazardous wildlife species that may be present.

Based on a thorough understanding of existing habitats and species of concern, the designer should attempt to determine likely migratory paths for birds and other wildlife of concern that may be present only during certain seasons. When siting new stormwater facilities, it is imperative that designers do not inadvertently create the potential for new migratory paths or local bird flyways that intersect with important airport functions such as taxiways, runways, or aircraft flight paths.

3-2.2. Low Impact Development

Low impact development is a term used to describe design practices that mimic natural hydrology and preserve vegetation to the extent possible. Airports should incorporate low impact development design features, such as reduced impervious surfaces and infiltration, where feasible. These practices can reduce the overall stormwater management requirements for the site. However, some low impact development features such as ecoroofs and bioretention facilities (rain gardens) pose risks of becoming hazardous wildlife attractants and are therefore discouraged at airports. You can find more information on low impact development design practices in the *Low Impact Development Technical Guidance Manual for Puget Sound* (PSAT 2005).

3-2.3. Urban Encroachment

Encroachment of incompatible land uses is a key issue for general aviation airports in the United States. To protect quality of life for humans and wildlife, communities and airports need a proactive approach that promotes airport land use compatibility. If necessary, designers of stormwater facilities at airports may have to look well beyond the physical boundaries of the airport property to anticipate potential land use conflicts associated with urban encroachment. Inadequate planning may result in a poor quality of life for adjacent neighborhoods and constrained operations for aviation facilities, and may limit future economic development (WSDOT 2007). In addition, encroachment may have negative effects on wildlife and wildlife habitat that unintentionally create airport safety issues. The following are examples of wildlife hazard issues that may be associated with urban encroachment on airports.

- As urban encroachment occurs near airports, available habitat is also diminished, concentrating wildlife nearer to the airport. For this reason, airport planners need to consider a wider geographic range than the immediate airport vicinity to account for potential future encroachment.
- Urban development encroaching on airports presents the potential for installation of traditional vegetated and/or open water stormwater BMPs outside of the airport property, but within flight paths, which may act as wildlife attractants.
- Development reduces the amount of favorable habitat available and concentrates wildlife in the remaining habitats, such as poorly designed and sited stormwater facilities.

3-3. General BMP Design Considerations

If not appropriately designed for airport settings, traditional stormwater facilities may provide wildlife habitat, attracting wildlife species that could present hazards to aircraft. The primary habitat features of traditional stormwater facilities are vegetative cover and access to water. A technical memorandum produced as a precursor to this manual provides detailed information on habitat quality factors that influence the use of stormwater facilities by wildlife, and methods for limiting habitat quality within stormwater facilities (Herrera 2007b). In all instances, identification of wildlife species of concern should precede design of stormwater facilities. Design guidelines for individual BMPs presented in Chapter 6 include recommendations for siting, design, and operations and maintenance considerations. This section provides a general overview of vegetative and structural methods to prevent or reduce wildlife attractants.

For longer term planning efforts, airport operators may want to initiate discussions with adjacent local governments regarding partnering on construction of a new regional facility that can serve airport and community needs and be designed and sited to minimize wildlife attractants in the airport environment. Any regional facilities must be designed and constructed in accordance with Ecology requirements; for example, flow control facilities must be operational prior to and have adequate capacity for new development; and if used for runoff treatment, conveyances used to transport the stormwater to the facility must not include waters of the state that have existing or attainable beneficial uses other than drainage (Ecology 2004).

3-3.1. Vegetation Considerations

In general, vegetation that provides food and/or cover for wildlife species identified as hazardous to aircraft should be avoided at airports. Vegetation with berries, nuts, desirable forage, attractive flowers, edible tubers or roots, or large, abundant or high-nutrient seeds is a potential wildlife attractant and should be avoided. In terms of shelter, the height and density of vegetation play a major role in whether or not it will attract wildlife species. In some instances, a plant species that may attract one wildlife species may actually deter another. The physical location of vegetation relative to other vegetated areas or water features must also be considered.

It is critical that planting design and plant species selection either deter or do not particularly attract potentially hazardous wildlife species at a given airport. Exactly which wildlife species constitute the greatest risk differs from airport to airport. Appendix A provides additional information on selection of plant species for installation at airports. Additional landscape design guidance is provided in the individual BMP design guidelines (Chapter 6). In general, guidelines for planting design and plant species selection within stormwater facilities include the following:

- Use low-diversity planting strategies less likely to attract potentially hazardous wildlife. Carefully select a limited number of plant species specifically adapted to facility conditions for use in planting plans.
- Provide planting design solutions using plants that are not particularly attractive to potentially hazardous wildlife. As noted above, avoid using plants with high-nutrient berries, nuts, desirable forage, attractive flowers, edible tubers or roots, or large, abundant, or high-nutrient seeds.
- Limit creation of planting conditions within BMPs that result in standing water or mud.
- Limit use of soil amendments in planting specifications that will result in installation of deep organic soils in BMP substrate. Deep organic soils may result in high invertebrate populations that can attract certain wildlife and their predators.
- Limit placement of trees in open areas that may function as roosting, perching, or predatory hunting habitat features.

- Where possible, the AOA should not be located between large, isolated trees (a preferred roosting/perching area) and a food/water source, or between multiple food/water sources, such as several wetlands.
- If open water is anticipated over extended periods within BMPs, provide dense shrub or groundcover vegetation that may deter potentially hazardous wildlife that prefer open water. Refer to Appendix A for species-specific guidance.
- After determining which species may provide the greatest hazard at a given airport, refer to Section 3-1 of this manual for additional species-specific guidance on avoiding creation of attractive stormwater BMPs.
- Select plants that at maturity grow well below the maximum height restrictions applicable to airport operation zones.

3-3.2. Structural Considerations

In general, structural features that provide shelter for wildlife species identified as hazardous to aircraft should be avoided at airports. Specific considerations include the following:

- Avoid constructing shallow-water wetlands or other habitat that may attract wading birds such as great blue herons or sandhill cranes, or that provide nesting habitat for waterfowl (e.g., islands, points).
- Properly maintain open-water stormwater facilities. See Section 6-3 of this manual for operations and maintenance requirements specific to airports.
- Minimize areas where standing water is present for extended durations (greater than 48 hours).
- Avoid amending existing soils with deep or high-nutrient organic soil amendments. If organic soils are present, implement structural measures to keep worms away from the runway (to avoid attracting species that eat worms, such as gulls). If chemical worm repellents are used, appropriate source control measures must be implemented to prevent chemicals from entering receiving waters. Use of chemicals for worm control applications must comply with the Washington Pesticide Control Act (15.58 RCW) and Washington State Department of Agriculture requirements for pesticide and fertilizer control.
- Configure stormwater facilities to reduce line of sight. This includes using steeper embankments, narrower/longer configurations, shrub vegetation, fences, or other installations that disrupt sight lines and reduce comfort and habitat suitability for hazardous wildlife (primarily waterfowl).

- Do not locate stormwater facilities in a way that encourages wildlife to migrate/travel from existing stormwater facilities or natural habitats on one side of the air operations area to new facilities located on the other side, causing the wildlife to cross the runway or paths of aircraft.

3-3.3. Adaptive Management at Airports

Despite the extensive planning that goes into vegetative and structural considerations to prevent attracting wildlife that are potentially hazardous to aircraft, the effectiveness of preventative measures may decrease, or a different species of hazardous wildlife may become more prevalent over time. It is critical to adopt a strategy allowing for adaptive management and retrofitting of stormwater facilities to properly deal with changing conditions. Important components of adaptive management include continued monitoring of wildlife use, effects of operations and maintenance activities, and retrofitting existing stormwater facilities that have open water which attracts hazardous wildlife.

3-4. Adaptive Stormwater Facility Design

The previous section includes general guidelines for designing BMPs at airports to reduce the creation of attractants for hazardous wildlife. This section focuses on specific design modifications depending on the species of concern that have been identified.

This information may also be useful for retrofit situations. At many airports, existing open water facilities do not meet the design guidelines for airport facilities presented in this manual. The techniques described in this section are mainly intended to lessen the wildlife attractiveness of existing stormwater facilities.

3-4.1. Customizing the Design of Stormwater BMPs for Specific Species of Concern

The BMP design guidelines in Chapter 6 were developed to minimize a stormwater facility's potential to attract hazardous wildlife. The features of the BMPs including slopes, shape/configuration, siting, and detention time were selected to reduce or eliminate many of the factors that a number of the most common hazardous wildlife species find attractive. In general, the BMP design guidelines strive to minimize the chances that habitat or food sources are created through contouring, selection of appropriate vegetation, and other appropriate techniques.

Because these BMP design guidelines are based on general wildlife attractants rather than specific features that may attract a certain hazardous species, the designer must take time to consider the results of hazardous wildlife assessments and research the specific habitat and food preferences of the most critical or high-risk hazardous species that are expected at a given airport when designing stormwater features on or near airports. Once the specific food and habitat requirements of a hazardous species are known and their behavior understood, the designer can more effectively select BMPs, site them properly, and tailor the design of BMPs to minimize attractiveness to hazardous species by selecting specific vegetation, configuration, or materials found unfavorable by that species.

For example, if deer are identified as a hazardous species, vegetation known to be favored by deer for browsing should be avoided, as should thickets providing daytime shelter. Care should be taken to avoid locating food sources across a runway from areas used by hazardous wildlife for shelter. Facilities should not routinely contain standing water, or they should have tall fences installed or otherwise be configured to make access more difficult for a drinking water source.

The designer is referred to Section 3-1 of this manual for additional information on hazardous wildlife and is encouraged to consult a qualified airport wildlife biologist to conduct a hazardous wildlife assessment, identify hazardous species, and explain the specific behavioral, food, and habitat requirements of the identified hazardous species.

3-4.2. Adaptive Management of Open Water Areas

Because of their innate adaptability, wildlife may modify their behavior in response to installation of new stormwater facilities in ways that were not anticipated during design, resulting in an aviation safety problem. As a result, airport managers and stormwater facility designers must also be adaptable to minimize threats associated with hazardous wildlife.

Open water stormwater features are the most likely types of BMPs to attract hazardous wildlife. These BMPs include detention ponds, combined wet/detention ponds, wet ponds, constructed wetlands, infiltration ponds, and wet biofiltration swales. Note that of the BMPs listed here, detention ponds and infiltration ponds that have been designed in accordance with the guidelines in Chapter 6 of this manual are the only facilities that are recommended for airport settings. However, some open water facilities may already exist on some airports. When present, these BMPs may contain open water for extended periods of time, which may promote the growth of aquatic vegetation. The open water and aquatic vegetation have the potential to create habitat and food for a number of wildlife species that present hazards to aircraft operation, including shorebirds and waterfowl (Herrera 2007b).

This section describes open water controls that may be implemented to minimize or eliminate the hazards of wildlife attraction caused by existing or new stormwater BMPs with open water features. These controls deter or exclude wildlife from stormwater BMPs by eliminating access, altering suitability, or otherwise reducing the attractiveness of the open water to wildlife. Such measures may be installed either in response to wildlife using an existing facility, or as a preemptive measure added to one of the BMP designs described in Chapter 6 to ensure that a new stormwater facility in a high risk area will not become attractive to wildlife. The three types of controls described include reduction in habitat suitability, open water covers, and access control:

- Habitat suitability reduction is generally preferable where feasible because it presents a long-term, relatively low-maintenance control.
- Where wildlife continues to be attracted to stormwater facilities despite habitat suitability reduction actions, open water covers (e.g., bird balls or floating covers) may be implemented.
- Open water access control methods (e.g., netting and/or overhead wires) are one of the most commonly used techniques to deter wildlife use. Their effectiveness may be enhanced when used with a synthetic side and bottom liner system to prevent vegetation growth (Osmek et al. 2005).

Habitat Suitability Reduction

Vegetation

Vegetation can be used to discourage wildlife from using temporary open water areas such as detention ponds and infiltration areas. Waterfowl are attracted to interspersion of open water and emergent vegetation. If this characteristic is replaced by densely planted scrub-shrub vegetation, waterfowl may be less likely to use it. A study conducted at the Snohomish County Airport (Paine Field) in Everett, Washington, demonstrated that a constructed mitigation wetland densely planted with scrub-shrub vegetation greatly reduced the percentage of waterfowl using the facility (Stevens et al. 2005). However, this study also found an increase in use of the wetland by red-winged blackbirds after the scrub-shrub vegetation was established. Establishing scrub-shrub vegetation may be an effective technique for discouraging hazardous wildlife from using wetlands and other open water facilities at airports, as waterfowl are usually more hazardous to aircraft than blackbirds. The use of scrub-shrub vegetation to reduce habitat suitability may be effective as long as the area's hydrology is fully understood. Long periods of flooding can lead to significant plant mortality and the creation of preferred wildlife habitat (Osmek et al. 2005). The construction of new mitigation or treatment wetlands should be avoided at airports, if possible.

Before using scrub-shrub vegetation as a wildlife deterrent in airport ponds, two primary design issues need to be considered: the depth of the standing water and the storage capacity of the pond. Tolerance to inundation varies among scrub-shrub vegetation species. Therefore, inundation depth, duration, and frequency must be considered when selecting species and communities. In addition, once the vegetation has been planted, it will take a while to become established enough to deter birds. Until the vegetation has become established, special care must be taken to avoid excessive ponding, including possible temporary inflow diversion. Without such care, the birds may be drawn to any accessible open water in the pond. Another issue to consider is that once the vegetation is established, the water storage capacity of the stormwater facility will be slightly diminished. The facility size may be increased by 10 percent to accommodate this decrease in capacity. The effects of the vegetation on pond access and maintenance must also be considered as part of the design. For instance, an access route for personnel and equipment may be needed through the vegetated area.

Typical design guidelines and considerations for scrub-shrub vegetation in stormwater ponds are listed below (Stevens et al. 2005):

- A wetland biologist shall be consulted to confirm that the site hydrology supports the proposed vegetation.
- Select plants recommended for airport settings (see Appendix A).
- Water depth shall not exceed 18 inches.
- Plants shall be placed 3 to 5 feet on center.
- Monitoring shall occur to ensure that plantings have resulted in the desired growth. Dead plants shall be replaced as necessary to ensure a complete canopy over the water.

Waterfowl Disruption Fences

Many waterfowl species do not like taking off or landing in narrow spaces, and they also do not like limited sight lines (Herrera 2007b). That is the basis behind a number of the stormwater facility design changes presented in Chapter 6 of this manual, such as the 30-foot maximum width for detention ponds. However, existing facilities may not meet these width limitations.

Managers at the Portland International Airport in Portland, Oregon, have successfully used silt fences to discourage geese from using mowed turf areas (Port of Portland 2006). Geese are unwilling to land and risk predation in a field where parallel rows of fence limit the sight lines. The rows of fencing may also disrupt a bird’s ability to take off and land in an area.

In-water earthen berms have been suggested for ponds to serve a similar disruptive function, but berms take up additional pond volume and may provide preferable peninsular habitat for some species. However, it may be possible to use a variation of the “waterfowl disruption fence” concept for stormwater facilities with standing water.

Suggested design guidelines and considerations for waterfowl disruption fences are listed below

- Fences should be designed to disrupt sight lines and restrict waterfowl from taking off and landing in short-term open water areas. Hence, the fences must be tall enough to disrupt use when the pond is at maximum capacity.
- Fences should not concentrate or disrupt the movement of stormwater within the pond. While silt fencing would block sight lines, it would likely interfere with water flow. Post and rail construction would allow easy movement of water, but may not disrupt sight lines enough.

- Fences should be placed to reduce the width of open water areas to less than 30 feet without compromising access to the pond for routine maintenance.
- The fences should be constructed of inert materials such as ultraviolet (UV)-resistant high-density polyethylene (HDPE) rather than galvanized metals, steel, or wood, which may leach metals into stormwater, rust, or rot, respectively.

At present, waterfowl disruption fences are a new and untested technology. Additional field testing and study would be beneficial before relying on these systems as the primary wildlife deterrent. One potential concern is that rigid fencing may provide roosting/perching spots for larger wading birds, such as herons.

Open Water Covers

Floating Covers

Floating covers may be adapted from their uses in the drinking water, waste water, and agricultural industries (GeoCHEM 2007; Layfield Group undated) to cover open water in stormwater facilities at airports. Most floating covers are proprietary and should be designed and installed with the assistance of the manufacturer and/or an engineer. Floating covers completely cover the surface of a pond, making the water invisible to birds from the air, and making it appear as a large, unvegetated, and unappealing area. Floating cover systems vary in complexity based on the size of the area to be covered. Floating covers may be one of the best ways to cover very large (multiple acre) areas effectively.

General design guidelines and considerations for floating cover systems are listed below.

- Floating cover facilities shall be positioned to minimize the effect of prevailing winds. Stabilizing floats may be required if repositioning is not an option.
- If used outside of controlled areas at airports, warning signs should be posted and access to covered ponds should be controlled for safety reasons.
- The BMP designers should work with the floating cover supplier to ensure that:
    - Lighter color fabrics are selected for use in hot climates or where exposure to sunlight is severe.
    - Designs consider the need for rainwater and snowmelt removal from the surface of the cover.

- ☐ Designs consider freezing. This is especially important in eastern Washington where water on the surface of the cover may freeze for extended periods of time.
- ☐ The ponds remain oxygenated. Covering ponds may decrease the amount of oxygen in the water, especially if there are high organic loads to the pond. The resulting anoxic conditions may release nutrients or dissolved metals from pond sediments, causing water quality problems.

- Debris and plant life may gather atop floating covers. A water source that may be used to clean the floating cover shall be available.
- Covers shall be removable to facilitate maintenance of the underlying stormwater BMP.
- Typical stormwater management facility features such as inlet and outlet structures shall be designed to minimize impact on the floating cover.

Floating Ball Covers

Floating ball cover systems are commonly referred to by their proprietary names – Bird Balls™ (Euromatic undated) or E-balls™. In general, the balls are approximately 4 inches in diameter, hollow, UV-stabilized, and made of HDPE. The balls float and cover the surface of an open water facility, making the water surface invisible to birds from the air and difficult or impossible to land on. The manufacturers claim several advantages, including that the balls rise and fall with changing water levels, they easily accommodate objects such as floating pump barges or aerators, they reduce sunlight penetration and algae formation, they are easy to install and relatively maintenance free, and they are unaffected by snow and rain accumulation. Balls commonly have an estimated design life of more than 10 years and have been used at the San Francisco International Airport (SFO) for over 15 years without the need for ball replacement.

Like other floating covers, ball covers require little maintenance and exclude wildlife by concealing the water surface. Floating ball covers are an excellent choice for areas such as ditches where some vegetation may already be present, but may not be appropriate for ponds where frequent maintenance will be required. The Port of Seattle has used vactor trucks to remove balls when maintenance is needed and has observed some ball damage during this removal process (Osmek et al. 2005). Typical design guidelines and considerations for floating ball covers are listed below.

- Outflow structures must be secured (welded wire/rebar) such that all openings are smaller than the diameter of any ball to prevent loss of the floating balls or clogging of the outlet.
- Density of coverage shall be 10 balls per square foot of full pool water surface area using 4-inch-diameter balls.

- Minimum ball weight shall be 40 grams.
- In environments where high winds are common (over 28 miles per hour [mph]), water-filled balls that weigh at least 240 grams each are recommended.

Birdballs at SeaTac Airport.

Open Water Access Control

If wildlife species are attracted to stormwater facilities, such as open water, due to inadequate facility design, a change in operations, or even an unexpected change in wildlife, some sort of barrier may be required. This may take the form of fencing, netting, wires, or pond lining. The type of barrier should be matched to the hazardous wildlife species.

Fencing

If deer, elk, coyote, or other nonflying animals are attracted to stormwater facilities, fencing may provide the simplest answer. Care must be taken to ensure that the fencing does not impede access for emergencies or maintenance. The fencing also must comply with height restrictions in airport operations zones. An FAA CertAlert 04-16 (FAA 2004b) contains some information on fencing requirements for deer.

Netting

Netting involves stretching and suspending a net over the entire surface of a pond or other open water BMP to prevent wildlife access to the water surface. Netting is a simple, readily available, and relatively inexpensive solution that may be acceptable for covering smaller areas of open water.

Netting can be effective in areas where time is needed to allow vegetation to grow in height and density to exclude hazardous wildlife from shallow, open water areas. In western Washington, when vegetation is allowed to permanently remain at a site, the netting frequently fails at the same time that dense vegetation, capable of excluding most hazardous wildlife use from the area, has formed (Osmek et al. 2005). Netting must be installed so the lowest point of the netting will remain above the highest expected water level for the pond.

When netting is used in conjunction with synthetic liners, the Port of Seattle has found bird netting to be cost effective considering total life cycle costs. Without liners, vegetative growth must be removed to avoid the need for frequent net replacement (Osmek et al. 2005).

Netting requires maintenance and needs to be securely fastened. If the netting is not attached properly, it can be damaged or even be blown off the pond during high winds. The Port of Seattle found that netting needs to be replaced at 7- to 10-year intervals when installed over lined ponds prohibiting vegetative growth. If netting is constructed correctly and installed at grade, wind has not been an issue for the Port of Seattle (Osmek et al. 2005).

Netting is susceptible to damage over time. Exposure to sunlight, snow, and extreme cold temperatures can break down the netting and create holes that provide birds with access to the water surface.

Design considerations for netting over open water are listed below.

- Netting material shall be UV-stabilized, knotted polyethylene net.
- Netting material shall be waterproof, flame-resistant, nonconductive, and stable in extreme cold temperatures. In eastern Washington, in areas of extreme low temperatures and subject to extensive periods of ice loading, extra reinforcement may be needed through use of additional or thicker cables (Thorsell 2008).
- Netting material shall have a minimum breaking strength of 52 pounds per strand, and an International Organization for Standardization (ISO) 1806 mesh burst strength of 48.54 pounds.
- Netting mesh size shall be approximately 2 inches. Smaller mesh can lead to increased weight due to ice and snow buildup and subsequent follow-up maintenance to retention the supporting wires and netting (Osmek et al. 2005).

- If netting is used in areas larger than 30 feet in dimension, it may require cabling or other additional means to keep tension and avoid excessive sag in the netting.

Overhead Wires

Overhead wire systems, consisting of monofilament, Kevlar lined, and stainless steel wire, can be a simple, durable, and relatively inexpensive alternative to netting for deterring birds from using open water areas. In general, a grid or system of parallel wires is strung above the water surface. Multiple levels of wires increase the effectiveness of bird wires as they become more difficult for flying birds to negotiate. To fully enclose a pond, fences or additional wires around the sides of the open water area may be required. Vegetated ponds remain attractive to wildlife, and birds will continue to attempt to access the pond beneath the wires.

These systems are more expensive to install over large areas but require minimal maintenance. As with netting, the wires cannot be easily seen from the air, so even though birds cannot use the pond, they may still be attracted to it from the air and come closer to investigate, thereby creating a hazard to airport operations. Like netting, wires offer some deterrence but are not as effective as completely covering the water surface.

Typical design guidelines and considerations for overhead wires are listed below.

- The wire systems should be installed close to the water surface at a height of approximately 1 to 1-1/2 feet above the maximum water level in the pond (Rural Development Service 2006).
- Wires shall be spaced at intervals of 25 feet or less, depending on the target bird species. A qualified airport wildlife biologist should be consulted to determine the appropriate grid size.
- Wire systems should be highly visible to birds flying overhead. One method for increasing visibility is to fasten brightly colored or reflective streamers to the wires.
- To minimize maintenance activities, wires should be strung as single strands, rather than a looped, continuous wire.
- In some cases, a 3-dimensional configuration of wires may be required to sufficiently defend the pond from use by wildlife.
- Ponds defended by overhead wires should be lined with a synthetic barrier to prevent vegetation from developing. Failure to line the pond will likely result in plant matter growing through the wires and destroying it.

Pond Liners

The effectiveness of netting and overhead wires may be enhanced by using pond liners to limit the growth of vegetation in the open water facility. The following are design considerations for pond liners:

- Ponds being defended by netting should be lined with a synthetic barrier to prevent vegetation from developing. Failure to do so will likely result in plant matter growing through the netting and destroying it. Port of Seattle staff has observed birds attempting to access ponds beneath the netting when liners were not used in conjunction with netting (Osmek et al. 2005).
- At a minimum, the sides of the pond should be lined to minimize vegetation growth that might harm the netting. Fully lined ponds are preferable.
- Pond liners are not maintenance-free. Exposure to sunlight may weaken synthetic materials. Organic material in the pond trapped beneath the liner will decompose and may cause bubbles in the liner. Any rips or tears in the liner will be quickly exploited by vegetation. Any sediment deposited in the pond will cover the liner, providing a substrate for plant growth.
- Liners are not appropriate for treatment ponds such as constructed wetlands that use vegetation as a treatment mechanism because they will interfere with the pond function.
- Rip-rap and concrete block systems are not considered appropriate liners. The gaps would accumulate sediment, so they would not inhibit vegetative growth. Cleaning sediment from these surfaces would be labor intensive, difficult, and expensive.

Chapter 4. Best Management Practice (BMP) Selection Process

This chapter provides guidance on selecting specific BMPs based on the target pollutant(s) (total suspended solids, dissolved metals, oil, and/or nutrients) or flow control method (infiltration, dispersion, or detention). As described in Section 1-3.4 of this manual, other guidance documents (HRM, SMMWW, SMMEW, or locally approved and equivalent manuals) should be consulted first to determine water quality treatment and flow control thresholds and requirements.

4-1. Flow Control Requirements

Based on a review of the applicable guidance documents, the project proponent will determine the following:

1. Is flow control required (based on thresholds and receiving water status)?
2. What level of flow control is required? For most projects in Washington, flow control facilities must be designed to match predeveloped peak flows and durations, from one-half of the 2-year to the 50-year design storm using the Western Washington Hydrologic Model (WWHM), MGSFlood, or another approved continuous hydrologic model, with predeveloped conditions modeled based on forested conditions. For eastern Washington, nonexempt projects are required to limit the peak rate of runoff to 50 percent of the predeveloped or existing 2-year peak flow, maintain the predeveloped or existing 25-year peak runoff rate, and demonstrate that the entire 2-year runoff volume from the proposed development condition shall be released at no more than 50 percent of the predeveloped or existing 2-year peak flow rate.

If flow control is required, the project proponent should consult Chapter 5 of this manual to determine whether the site is suitable for infiltration.

4-2. Treatment Targets

There are four runoff treatment targets:

- Total suspended solids removal (referred to by Ecology as basic treatment)
- Dissolved metals removal (referred to by Ecology as enhanced treatment)
- Oil control

- Phosphorus control (most nutrient-impaired water bodies in Washington are phosphorus limited).

4-3. Source Control BMPs

Source control BMPs are the preferred method of decreasing pollutant loads in stormwater. BMPs such as covering materials, providing secondary containment and good housekeeping measures such as regular sweeping that keep pollutants out of runoff are usually more effective and less expensive than treating runoff after the pollution has occurred.

Certain types of activities and facilities may also require pollutant source control BMPs. For detailed descriptions of the source control activities and associated BMPs, see Section 2.2 of Volume IV of the SMMWW (Ecology 2005) and Chapter 8 of the SMMEW (Ecology 2004). The project may have additional source control requirements as a result of area-specific pollution control plans (e.g., watershed or basin plans, water cleanup plans, groundwater management plans, or lake management plans), ordinances, and regulations.

4-4. Selection Process for Flow Control BMPs

This section provides guidance to the designer for selecting permanent BMPs for flow control for airport projects. Details for planning and design of each BMP are found in Chapter 6, with the BMPs presented in numerical order. (All BMPs contained in this manual contain the prefix “AR” for “Airport Runoff” to set them apart from similar BMPs in the SMMEW (Ecology 2004), SMMWW (Ecology 2005), or the HRM (WSDOT 2008a). The flow control BMP selection process described below applies if flow control applies to the project.

It is anticipated that the user of this manual will be directed here by requirements in the Ecology manuals or HRM (see Section 1-3.4). These thresholds include the amount of new or replaced impervious surface, landscaping, or other concerns. In addition, the use of the ASDM may be required as a condition of watershed plans or stormwater permits.

Once the designer has been directed to use this manual, they should complete a preliminary task, shown in Figure 4-1 (identification of wildlife of concern) using the methods described in Chapter 3. Different wildlife species may influence the choice of facilities, structural design of stormwater facilities, the vegetation mix used for the facilities, and/or operation and maintenance of the facilities. For example, Section 3-4 identifies some specific design modifications that should be implemented for BMPs depending on the species of concern, such as fencing around detention ponds if deer are of concern.

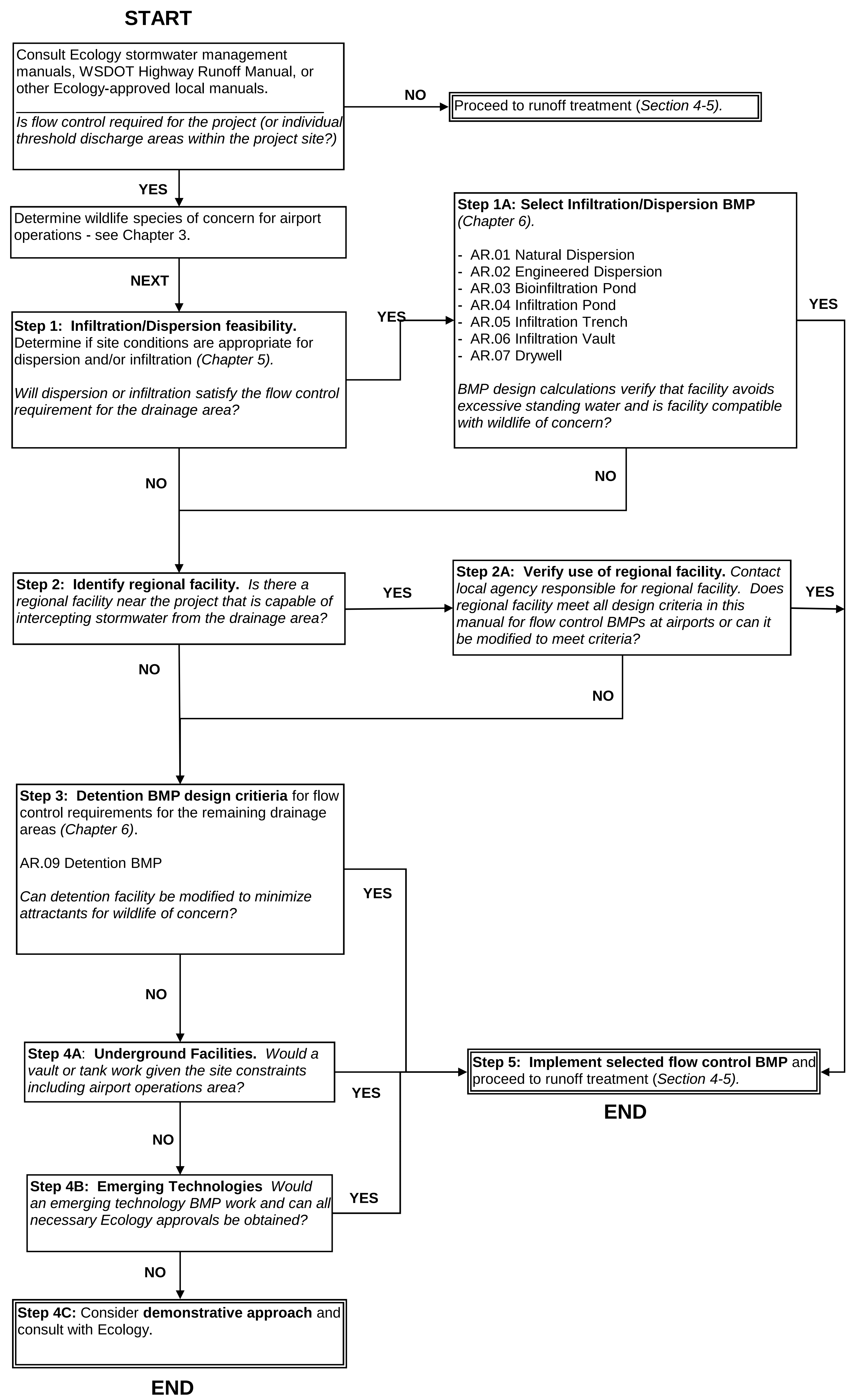


Figure 4-1. Airport Runoff Manual, Flow Control BMP Selection Process

4-4.1. Step 1: Determine if Site Conditions are Appropriate for Dispersion and/or Infiltration

As Figure 4-1 shows, dispersion or infiltration is the first choice to manage runoff from airport projects. Not only does dispersion/infiltration lessen downstream impacts on natural resources and infrastructure, but dispersion/infiltration facilities are less likely than open water facilities to attract wildlife that are potentially hazardous to aircraft (if the facilities are designed in accordance with the guidelines in Chapter 6 of this manual to ensure that they do not have standing water for extended periods of time). In addition, dispersion or infiltration will often have less infrastructure costs than a piped system.

The decision to be made in Step 1 is whether dispersion or infiltration will satisfy the flow control requirement for the project. If space for the facility is limited or other physical factors such as steep slopes or impermeable soils preclude the successful use of dispersion or infiltration, then continue to Step 2. Otherwise, proceed to Step 1A to determine which type of dispersion or infiltration BMP is most appropriate.

4-4.2. Step 1A: Select Infiltration/Dispersion BMP

Dispersion BMPs include AR.01 – Natural Dispersion and AR.02 – Engineered Dispersion. Either of these dispersion options can be used at airports, with natural dispersion typically preferred if site soil conditions, vegetation, and topography are appropriate and the vegetation does not unduly attract wildlife or present a hazard for aircraft.

The designer should consult the detailed design criteria for dispersion/infiltration facilities in Chapter 6 before making a final decision on the use of these facilities.

If dispersion is not possible because of land use, soils, or space limitations, infiltration BMPs may be applied instead. This manual contains five types of infiltration facilities:

- AR.03 – Bioinfiltration Pond (for use in eastern Washington only)
- AR.04 – Infiltration Pond
- AR.05 – Infiltration Trench
- AR.06 – Infiltration Vault
- AR.07 – Drywell.

Any of these facilities may be appropriate for use at airports, provided that they are designed in accordance with the design guidelines in Chapter 6 of this manual.

If a dispersion or infiltration BMP is identified as technically feasible and suitable for airports based on the design guidelines and restrictions in Chapter 6 of this manual, proceed to Step 5. If soils meet the site suitability criteria (SSC) for infiltration treatment in Chapter 5 (soil infiltration rate in SSC 4 and physical and chemical characteristics in SSC 6), dispersion and infiltration are assumed to provide adequate runoff treatment, and additional BMPs are not needed in most cases. If dispersion and infiltration are not suitable, the designer should go to Step 2 to evaluate the use of regional flow control facilities.

4-4.3. Step 2: Identify Regional Facility

In some locations, a regional facility may be near the airport that could be used for flow control. One of the key considerations is whether it is feasible to route flows from impervious airport surfaces to the regional facility. Possible regional facilities include those constructed for industrial or office parks adjacent to the airport and stormwater facilities constructed by an adjacent municipality.

If a potential regional facility is identified, proceed to Step 2A, otherwise go to Step 3.

4-4.4. Step 2A: Determine Feasibility of Regional Facility

Step 2A determines whether airport use of the regional facility is feasible or not. The regional facility should be examined in view of the design guidelines presented for the BMPs in Chapter 6 of this manual. For instance, the most common regional facilities are detention ponds. The design guidelines for detention ponds (BMP AR.09) in Chapter 6 should be consulted to assess suitability. In addition, many regional facilities do not have adequate capacity to effectively manage additional stormwater. A regional facility often does not have enough storage capacity available to accommodate flows from new or redeveloped areas of any substantial size and still meet applicable flow control standards. This is especially true for older facilities that were designed according to less stringent stormwater requirements.

Another concern is that the regional facility may be located near the airport and present a hazard to aircraft by attracting birds and other hazardous wildlife. Airport operators may not want to contribute to a facility that may already cause wildlife hazards, unless participation by the airport may present an opportunity to improve the facility by contributing to physical modifications, such as covering an otherwise exposed water surface (see Section 3-4).

If an appropriate regional facility is available or can be modified, then proceed to Step 5. If an appropriate regional facility is not available, continue to Step 3 to assess the use of detention facilities.

4-4.5. Step 3: Determine Feasibility of Detention Pond

Detention ponds (BMP AR.09) are the only type of surface detention BMP recommended for airports, because they are designed to drain completely between storms. The use of combined detention and treatment ponds (BMP CO.01 from the HRM or BMP T10.40 from the SMMWW) is not recommended for airside locations because they include a wet pool, which is a permanent pool of water intended for water quality treatment. Stormwater treatment wetlands (BMP T10.30 from the SMMWW) are also not recommended because they too have a permanent pool of water. They also have vegetation that may be attractive to hazardous wildlife.

Note: Detention pond design must address other issues, such as setback distance from an AOA and modifications to minimize attractants. In addition to the design modifications, the vegetation in or around the detention pond may need to be adjusted or additional controls, such as netting or fencing (see Section 3-4) may need to be used, depending on the hazardous wildlife that was identified in the preliminary step.

If a detention pond can be designed according to the detailed guidelines in Chapter 6, go to Step 5. If the detention pond is not feasible, go to Step 4A.

4-4.6. Step 4A: Determine Feasibility of Detention Vault or Tank

If none of the flow control BMPs introduced in the preceding steps is feasible, determine whether a detention vault (AR.10) or a detention tank (AR.11) will work.

If these BMPs are not feasible for the site or project, proceed to Step 4B.

4-4.7. Step 4B: Emerging Technologies

Emerging technologies are water quality treatment BMPs that have been evaluated by Ecology and 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 (basic, enhanced, etc.), 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 Ecology's website (Ecology 2008a).

At this time, no emerging technologies have been formally approved by Ecology for flow control, but preliminary data for some BMPs, such as the media filter drain or compost amended vegetated filter strip (CAVFS), both of which were originally developed by WSDOT for runoff treatment, show potential for decreasing flows as well. The use of these technologies requires pilot or conditional use approval from Ecology if proposed for flow control.

If no suitable emerging technology BMPs are identified, the user should proceed to Step 4C.

4-4.8. Step 4C: Consider Demonstrative Approach

If the project proponent believes that the project will comply with state and federal water quality protection laws without implementing completely the minimum requirements of the Ecology manuals (including flow control) or BMPs in this manual, the project proponent may work with Ecology to implement a monitoring program to demonstrate that proposed alternatives will be adequate. See Section 1.6.3 of Volume I of the SMMWW for more information on the “presumptive” versus the “demonstrative” approach.

4-4.9. Step 5: Implement Selected Flow Control BMPs

The final step is to implement whichever flow control BMPs are selected as most appropriate for the airport site. Detailed guidance on flow control BMP design is provided in Chapter 6.

If the selected BMP only addresses flow control, such as a detention pond or detention vault, then the user must also select an additional BMP to provide runoff treatment (Section 4-5). Other BMPs, such as dispersion or infiltration, are intended to both control flows and treat runoff, and their selection indicates that the user does not have to add separate treatment BMPs.

Note that several BMPs that were formerly considered to be "Category 1" BMPs by WSDOT (WSDOT 2006a) due to cost-effectiveness concerns are included in the Flow Control selection process. Some BMPs formerly referred to as "Category 2" BMPs (WSDOT 2006b) are now included as Emerging Technologies. These changes were intended to broaden the suite of potential BMPs for use near airports.

4-5. Selection Process for Runoff Treatment BMPs

Runoff treatment BMPs selected for airports must meet the applicable federal, state, and local water quality treatment standards without compromising aircraft safety. The runoff treatment BMP selection process in this manual differs from that in the HRM and Ecology manuals to reflect the unique safety concerns at airports. In addition to avoiding wildlife attractants, BMPs sited at airside locations must meet soil compaction and other structural design criteria to ensure that aircraft, emergency vehicles and snow removal equipment can be supported adjacent to airport operation areas. The safety concerns must be part of the selection process. Specifically, preferred treatment BMPs for airports include media filtration systems, vaults, and biofiltration facilities, many of which have been discouraged for WSDOT roadway projects because of cost or maintenance considerations. Some of these are known as Category 1 BMPs (WSDOT 2006a). At airports, however, these underground facilities are preferred over traditional wet pool facilities.

The selection process for runoff treatment is shown in Figure 4-2 and detailed below.

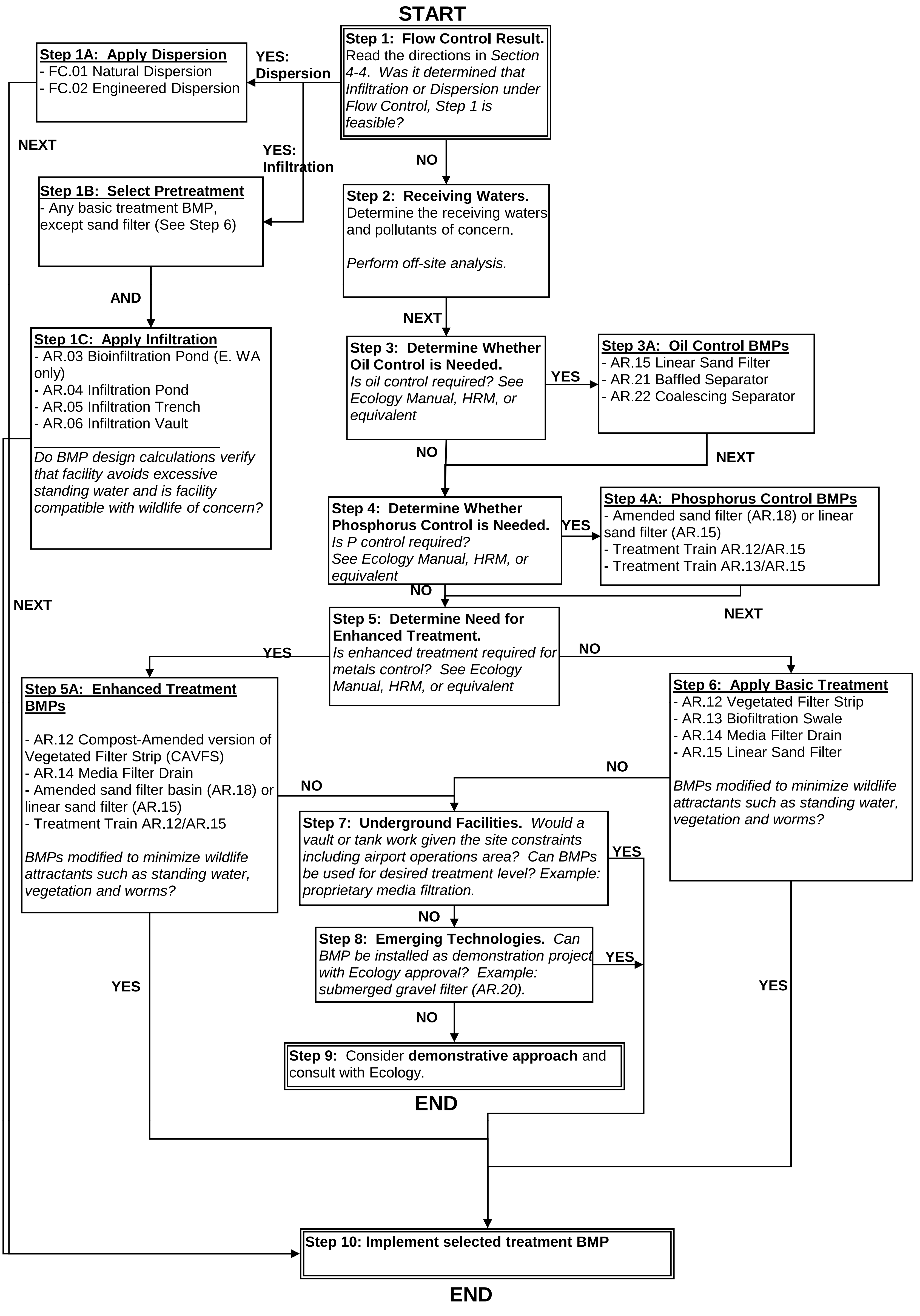


Figure 4-2. Airport Runoff Manual, Runoff Treatment BMP Selection Process

4-5.1. Step 1: Flow Control Result

If flow control is required and dispersion or infiltration BMPs are selected in Section 4-4.2, then proceed to Step 1A below for dispersion or Steps 1B and 1C for pretreatment and infiltration. Otherwise, go to Step 2. In some cases where flow control is not required, such as when discharging into an exempt water body, dispersion and infiltration should be examined for runoff treatment only.

4-5.2. Step 1A: Dispersion BMPs

If natural dispersion (AR.01) or engineered dispersion (AR.02) is selected as the flow control BMP, then it is also considered to meet runoff treatment criteria. Go to Step 10.

4-5.3. Step 1B: Select Pretreatment BMPs

Premature clogging of the filtration media or soils is the most common problem with infiltration facilities. If infiltration is chosen as the flow control BMP for the site, a pretreatment facility should also be selected. Pretreatment facilities include basic treatment BMPs (Step 6), such as a vegetated filter strip (BMP AR.12) or biofiltration swale (BMP AR.13). These BMPs should be used to remove the coarse particulates and debris in runoff that might clog the infiltration facility. Note that the linear sand filter (BMP AR.15), also a basic treatment BMP, is not recommended for pretreatment. As indicated in the individual BMP design guidelines in Chapter 6, the use of presettling basins is not recommended because of standing water concerns.

Note: Where applicable, the vegetation mix in the pretreatment BMP(s) should reflect the wildlife of concern for the airport (see Chapter 3 and Appendix A).

After selecting a pretreatment BMP, proceed to Step 1C.

4-5.4. Step 1C: Infiltration BMPs

Consult the hydrology section of this manual (Chapter 5) to determine whether site conditions are suitable for infiltration, if this was not already done as part of the flow control evaluation.

If infiltration can be used for runoff treatment at the site, proceed to Step 10.

4-5.5. Step 2: Receiving Waters

Different treatment requirements may apply depending on the water body that receives the runoff from the project site. The user should determine the receiving water and corresponding pollutants of concern based on Minimum Requirement 6 (Section 1-3.4 of this manual).

4-5.6. Step 3: Determine Whether Oil Control is Needed

For airports, refueling or maintenance activities are the primary sources of petroleum contamination in stormwater runoff; therefore, the user should proceed to Step 3A if either one of these activities occurs within the area served by the treatment BMP. If not, proceed to Step 4.

4-5.7. Step 3A: Oil Control BMPs

If oil control is required, select one of the following facilities specifically designed for oil removal:

- Linear sand filter (BMP AR.15)
- Baffle-type (API) oil/water separator (BMP AR.21)
- Coalescing plate separator (BMP AR.22).

These oil control devices do not work well with heavy sediment loads, so pretreatment should be included.

Catch basin inserts may be used on occasion to retrofit existing stormwater inlets, but special care must be taken to avoid clogging and slow drainage on runways and taxiways. In addition, frequent maintenance may preclude their use in heavily traveled areas of the airport.

More complex oil treatment facilities may be used in some airport applications, such as the industrial wastewater system (IWS) using dissolved air flocculation, but these are more expensive and more appropriate for indoor service facilities or if specifically required in a water quality permit. After selecting an oil control BMP, proceed to Step 4.

4-5.8. Step 4: Determine Whether Phosphorus Control is Needed

If the project is located in a designated area requiring phosphorus control as prescribed through an adopted basin plan or water cleanup plan/TMDL, then runoff treatment for phosphorus is required and the user is directed to Step 4A. If phosphorus control is not required, proceed to Step 5.

4-5.9. Step 4A: Phosphorus Control BMPs

If phosphorus control is required, the user must select one of the following methods for treatment:

- Media Filter Drain (BMP AR.14)
- Linear Sand Filter [with enhanced media] (BMP AR.15)
- Sand Filter Basin [with enhanced media] (BMP AR.16)
- Treatment Train Approach, using pretreatment (AR.12 or AR.13) with a linear sand filter (AR.15).

After selecting a phosphorus control BMP, proceed to Step 5.

4-5.10. Step 5: Determine Whether Enhanced Treatment is Needed

Enhanced treatment is required when elevated concentrations of metals in stormwater runoff are likely to result in adverse impacts on aquatic organisms. The user should first check with Minimum Requirement 6 in the applicable Ecology stormwater manual (eastern or western Washington) for a list of water bodies that require only basic treatment for stormwater runoff. If the receiving water for the airport is on this list, proceed to Step 6.

Section 2.1 of the SMMWW includes thresholds for determining whether enhanced treatment is required. There are no airport-specific water quality enhanced treatment requirements. However, monitoring at some larger airports, such as the Seattle-Tacoma International Airport (Sea-Tac), has shown high metal concentrations in some samples (RW Beck and Parametrix 2006). These include landside areas with high traffic volumes, such as parking garages, terminal areas, and airside locations, such as service and fueling areas or touchdown areas of the runways. Where feasible, the most effective control measure is removing or covering the source of metal, such as painting galvanized roofing or covering aircraft service areas. Basic treatment appears effective for treating most runoff from runways and taxiways. However, in some cases, such as landside parking lots, enhanced treatment is recommended to address potential toxicity issues associated with fish exposure to dissolved metals.

If enhanced methods are required for runoff treatment, the user should proceed to Step 5A. Otherwise proceed to Step 6 for selection of a basic treatment BMP.

4-5.11. Step 5A: Enhanced Treatment BMPs

The enhanced treatment BMPs are similar in configuration to basic treatment BMPs, but with amendments added to the filter media or soil to enhance the removal of dissolved metals. Some amendments may also help remove phosphorus.

After selecting an enhanced treatment BMP, proceed to Step 10. If an enhanced treatment BMP is required but a suitable BMP cannot be identified or sited as part of Step 5A, proceed to Step 7.

4-5.12. Step 6: Basic Treatment BMPs

Basic treatment BMPs are intended to provide general pollutant removal and do not have special media designed for extra treatment of specific pollutants, such as dissolved metals. Basic treatment BMPs that are suitable for airports include vegetated filter strips (BMP AR.12) and biofiltration swales (BMP AR.13). The wet pool BMPs listed in the HRM and in the Ecology manuals for basic treatment are not considered appropriate for airport settings because of the attraction of wildlife to a permanent pool of water.

After selecting a basic treatment BMP that meets the siting and other restrictions included in the design guidelines in Chapter 6, the user may proceed to Step 10. If a basic treatment BMP is required but a suitable method cannot be found or applied as part of Step 6, go to Step 7.

4-5.13. Step 7: Underground Facilities

If none of the runoff treatment BMPs introduced in the preceding steps is feasible, alternative measures must be investigated. If surface facilities will not work, underground facilities may be a possibility. An important advantage of underground facilities at airports is that they do not attract wildlife of concern. Combining media for filtration may enhance the pollution removal potential for these facilities.

However, underground facilities also have a number of limitations. Many are proprietary, and many have not received full approval from Ecology. Underground facilities should not be placed under the main runway because of maintenance concerns. Vaults and tanks for runoff treatment are not as desirable as surface facilities as they are generally less effective at pollutant removal because of space constraints. They also present maintenance difficulties and are usually more expensive than a surface facility, although space constraints may necessitate their use.

If underground facilities are not feasible or are cost prohibitive, an emerging technology, as described in Step 8, or the demonstrative approach, as described in Step 9, may be considered. Both of these options require approval from Ecology.

4-5.14. Step 8: Emerging Technologies

Emerging technologies are those BMPs showing promise for runoff treatment, but that have not yet received full approval from Ecology. In some cases they may be allowed only as a pretreatment facility or as part of a treatment train. A number of proprietary media filtration systems and a variety of vault-type BMPs fall into this category, as does the submerged gravel biofilter (AR.20). Ecology may allow these emerging technologies to be installed as a demonstration project, requiring additional review and/or monitoring.

If a suitable emerging technology BMP is identified and the necessary approvals are obtained, proceed to Step 10.

4-5.15. Step 9: Consider Demonstrative Approach

If the project proponent believes that the project will comply with state and federal water quality protection laws without implementing completely the minimum requirements of the Ecology manuals (including runoff treatment) or BMPs in this manual, the project proponent may work with Ecology to implement a monitoring program to demonstrate that the proposed alternatives will be adequate. See Section 1.6.3 of Volume I of the SMMWW for more information on the “presumptive” versus the “demonstrative” approach.

4-5.16. Step 10: Implement Selected Runoff Treatment BMPs

The final step in satisfying runoff treatment requirements is to implement whichever BMPs are selected as most appropriate for the airport site. Detailed guidance on runoff treatment BMP design is presented in Chapter 6. The BMP selected for runoff treatment should be combined with any additional BMPs selected for flow control if necessary.

Chapter 5. Hydrologic Considerations for Airports

This chapter presents an overview of some of the hydrologic considerations and methods of analysis applicable to design and selection of stormwater BMPs in airport settings in eastern and western Washington.

Designers may also want to consult the following references for additional information related to hydrologic design of stormwater BMPs:

- Continuous simulation hydrologic modeling using MGSFlood – see the HRM.
- Continuous simulation hydrologic modeling using WWHM (western Washington only) – see the SMMWW.
- Single-event models (the Natural Resources Conservation Service [NRCS] hydrograph and the Santa Barbara Urban Hydrograph [SBUH]) – see the HRM.
- Simplified Method for determining infiltration rates – see the SMMWW.
- Closed depression analysis – see the HRM.

Section 5-1 provides an overview of the differences in hydrologic analysis for airport projects from the analytical methods presented in the SMMWW, SMMEW, and HRM.

Section 5-2 summarizes methods of analysis, depending on the facility type (flow-based or volume-based) and location (eastern or western Washington; on- or off-line).

Section 5-3 provides guidance for design of infiltration facilities, including assessing site suitability criteria and determining the long-term infiltration rate.

Section 5-4 provides specific hydrologic design guidance for some of the BMPs included in Chapter 6.

5-1. Airport-specific Hydrologic Design Considerations

The methods of analysis presented in this chapter are similar to those in the HRM and Ecology manuals with the following exceptions:

- The minimum recommended infiltration rate is 1 inch per hour, rather than 0.5 inches per hour, for use of infiltration facilities for flow control.
- There must be 5 feet minimum distance from the bottom of the infiltration facilities to the groundwater elevation or bedrock. Reducing the distance

to 3 feet based on site-specific information as allowed in the HRM and SMMWW is not recommended at airports, providing extra certainty that surface ponding will not occur.

5-2. Methods of Analysis

Tables 5-1 and 5-2 summarize the hydrologic methods of analysis for sizing runoff treatment facilities in western and eastern Washington, respectively.

Table 5-1. Criteria for sizing runoff treatment facilities in western Washington.

Facility Type	Criteria	Model
Flow-based (except for biofiltration swales): upstream of flow control facility (on-line and off-line)	Size treatment facility so that 91 percent of the annual average runoff will receive treatment at or below the design-loading criteria, under postdeveloped conditions. If the flow rate is split upstream of the treatment facility, use the off-line flow rates.	Use an approved continuous simulation model using 15-minute time steps.
Flow-based (except for biofiltration swales): downstream of flow control facility	Size treatment facility using the full 2-year release rate from the detention facility, under postdeveloped conditions.	Use an approved continuous simulation model using 1-hour time steps.
Volume-based (on-line and off-line)	*Wet pool—Volume-based, infiltration, or filtration:* Size the facility to treat 91 percent of the estimated historic runoff file for the postdeveloped conditions. OR *Wet pool*: Size treatment facility using the runoff volume predicted for the 6-month, 24-hour design storm under the postdeveloped conditions. This design storm is approximately 72 percent of the 2-year, 24-hour design storm or 91st percentile, 24-hour runoff volume.	Use an approved continuous simulation model with 1-hour time steps OR Use a single event model (SBUH).
Biofiltration swales	Peak design flow rate estimated by SBUH for a 6-month, 24-hour storm with a Type 1A rainfall distribution. Swale must be designed with a 9-minute residence time under design flow rate.	Use an approved continuous simulation model with 15-minute time steps multiplied by correction factors from Figures 9.6a or 9.6b from Ecology (2005) (depending on whether facility is off-line or on-line) OR Use a single event model (SBUH).

SBUH – Santa Barbara Urban Hydrograph method, based on Natural Resources Conservation Service (NRCS) (formerly the Soil Conservation Service [SCS]) curve number equations.

Table 5-2. Criteria for sizing runoff treatment facilities in eastern Washington.

Facility Type	Criteria	Model
Volume-based	Size facility using the runoff volume predicted for the 6-month, 24-hour storm event under postdeveloped conditions.	Use a single event model (NRCS method or SBUH). Climatic Regions 1 through 4 use a Regional Storm (see Section 5-2.2). Use a Type 1A storm for Climatic Regions 2 and 3.
Flow-based: upstream of detention/retention facility	Size facility using the peak flow rate predicted for the 6-month, short duration storm under postdeveloped conditions.	Use a single event model (NRCS or SBUH). Short duration storm.
Flow-based: downstream of detention facility	Size facility using the full 2-year release rate from the detention facility, under postdeveloped conditions.	Use a single event model (NRCS or SBUH). Short duration storm. Climatic Regions 1 through 4 Regional Storm; OR use a Type 1A storm for Climatic Regions 2 and 3, whichever produces the greatest flow.

SBUH – Santa Barbara Urban Hydrograph method, based on Natural Resources Conservation Service (NRCS) (formerly SCS) curve number equations.

5-2.1. Western Washington

Runoff Treatment and Flow Control BMPs Other Than Wet Pool Treatment Facilities

For all flow control and runoff treatment BMPs in western Washington, Ecology requires that a calibrated continuous simulation hydrologic model based on the U.S. EPA's HSPF (Hydrologic Simulation Program-Fortran) program, or an approved equivalent model, be used to calculate runoff and determine the water quality design flow rates and volumes.

The Western Washington Hydrology Model (WWHM) is one approved model, which is available for download at Ecology's website (Ecology 2008b). WSDOT prefers that project proponents for WSDOT projects use MGSFlood or the public domain version of MGSFlood, known as the Western Washington Highways Hydrology Analysis Model (WHAM). WHAM is available for download at WSDOT's website (WSDOT 2008c).

Wet Pool Facilities

Two acceptable methods are available for designing wet pool treatment facilities: an approved continuous runoff model to estimate the 91st percentile, 24-hour runoff volume; or the Natural Resources Conservation Service (NRCS) curve number method to determine a water quality design storm volume. The water quality design storm volume is the amount of runoff predicted from the 6-month, 24-hour storm.

5-2.2. Eastern Washington

Runoff Treatment Facilities

Runoff treatment facilities may be analyzed using one of the following methods in eastern Washington:

- Single event hydrograph methods (NRCS hydrograph and Santa Barbara urban hydrograph [SBUH])
- NRCS curve number equations
- Level-pool routing
- Rational method.

Flow Control Facilities

Flow control facilities may be analyzed using one of the following methods in eastern Washington:

- Single event hydrograph methods (NRCS hydrograph and SBUH)
- Level-pool routing
- Continuous runoff model or other hydrograph modeling method, if available.

Eastern Washington Design Storm Events

When WSDOT analyzed rainfall patterns during storms in eastern Washington, it concluded that the NRCS Type II rainfall does not match the historical records. Two types of storms were found to be prominent on the east side of the state: short-duration thunder storms (later spring through early fall seasons) and long-duration winter storms (any time of year, but most common in the late fall through winter period and the late spring and early summer period).

The short-duration storm generates the greatest peak discharges and should be used to design flow-based BMPs. The long duration storm occurs over several days, generating the greatest volume, and should be used to design volume-based BMPs.

When using the long-duration storm, it should be noted that eastern Washington has been divided into the following four climatic regions:

1. East Slope Cascades
2. Central Basin
3. Okanogan, Spokane, Palouse
4. NE and Blue Mountains.

The long-duration storms in Regions 2 and 3 are similar to the NRCS Type 1A storm.

Designers in those regions can choose to use either the long-duration storm or the NRCS Type 1A storm. Eastern Washington design storm events are further discussed in Appendix 4C of the HRM.

5-3. Infiltration Design Guidance

An infiltration facility provides stormwater flow control by containing excess runoff in a storage facility, then percolating that runoff into the surrounding soil. Infiltration facilities can provide runoff treatment and flow control, but to do so requires certain soil characteristics. Section 5-3.1, *Site Suitability Criteria*, provides a detailed discussion of soil characteristics needed to determine which type of infiltration facility is most appropriate for the site.

Chapter 6 lists many types of infiltration BMPs. Some of these facilities include ponds, vaults, trenches, and drywells, along with partial infiltration facilities such as natural and engineered dispersion and compost-amended vegetated filter strips (CAVFS).

This section provides design criteria on the various ways to determine infiltration rates and facility size, dependent on the facility and whether infiltration occurs at the surface or below the surface (subsurface). The simplified approach for determining infiltration rates is not included in this manual. Refer to the HRM or SMMWW for the simplified approach.

Surface infiltration BMP designs and subsurface infiltration BMP designs follow different criteria. Infiltration ponds, infiltration vaults, infiltration trenches (designed to intercept sheet flow), dispersion, and CAVFS are considered surface infiltration BMPs and are based on infiltration rates. To compute these infiltration rates, determination of the soil's saturated hydraulic conductivity must be completed. Infiltration trenches designed as an end-of-pipe application (with underdrain pipe) and drywells are considered subsurface infiltration BMPs and regulated by the Underground Injection Control (UIC) Rule, which is intended to protect underground sources of drinking water. As a result, subsurface infiltration BMPs are known as underground injection facilities and designed dependent on the treatment capacity of the subsurface soil conditions.

The sections that follow provide detailed information on site suitability criteria, saturated hydraulic conductivity determination, determination of infiltration rates, and underground injection facilities.

If the infiltration facility is designed for flow control, the minimum long-term infiltration rate of the native underlying soils must be at least 1 inch per hour, calculated as described in Section 5-3.3 (rather than the HRM requirement of minimum 0.5 inches per hour). This revised guideline is based on the FAA recommendation 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). Based on hydrologic modeling of 50 years of historical rainfall data, it was estimated that infiltration ponds with a design infiltration rate of 0.5 inches per hour would have standing water for greater than 48 hours six times over the 50 years of the record analyzed. The same modeling approach showed that no instances of ponding for more than 48 hours would occur with a design infiltration rate of 1 inch per hour (see Appendix B for details of this ponding analysis).

5-3.1. Site Suitability Criteria (SSC)

This section specifies the site suitability criteria that must be considered for siting stormwater infiltration systems. When a site investigation reveals that any of the following nine applicable criteria cannot be met, appropriate mitigation measures must be implemented so that the infiltration facility will not pose a threat to safety, health, or the environment or an alternative flow control facility should be selected.

For infiltration treatment, site selection, and design decisions, a qualified engineer with geotechnical and hydrogeologic experience should prepare a geotechnical and hydrogeologic report. A comparable professional may also conduct the work if it is under the seal of a registered Professional Engineer (P.E.). The design engineer may use a team of certified or registered professionals in soil science, hydrogeology, geology, and other related fields.

To design infiltration facilities, the following SSC must be followed (if applicable), in addition to those described in the BMP guidelines (Chapter 6).

SSC 1 – Setback Requirements

Setback requirements for infiltration facilities are generally provided in local regulations, Uniform Building Code requirements, or other state regulations. The following setback criteria apply to infiltration facilities at airports, unless otherwise required by critical area ordinance or other jurisdictional authorities:

- Infiltration ponds and other infiltration facilities must be located outside of the RSA and TSA.
- Infiltration facilities should be located a minimum of 20 feet downslope and 100 feet upslope from building foundations, and 50 feet or more from the top of slopes steeper than 15 percent. The designer should request a geotechnical report for the project that would evaluate structural site stability impacts because of extended subgrade saturation and/or head loading of the permeable soil layer, including the potential impacts on downgradient properties (especially on hills with known side-hill seeps). The report should address the adequacy of the proposed BMP locations and recommend any adjustments to the setback distances provided above, either greater or smaller, based on the results of this evaluation.

- Infiltration facilities must be located far enough from runways, taxiways, and other airport facilities as well as 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 the receiving water and runways, taxiways, and other areas treated with deicing chemicals, if such chemicals in runoff are not treated with a designed system. Distances between 30 and 600 feet have been reported for effects related to deicers, depending on their type (NCHRP 2005).
- 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 the 1-, 5-, and 10-year time of travel zones must comply with health department requirements (Washington Wellhead Protection Program, Washington Administrative Code [WAC] 246-290-135).
- 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 vegetative buffer. This distance may be increased based on permit conditions required by the local jurisdiction.

SSC 2 – Groundwater Protection Areas

A site is not suitable if the infiltration facility will cause a violation of Ecology's groundwater quality standards (WAC 173-200) (see SSC 9 for verification testing guidance). Local jurisdictions should be consulted for applicable pollutant removal requirements upstream of the infiltration facility, and to determine whether the site is located in an aquifer protection area, a sole-source aquifer recharge area, or a wellhead protection zone.

SSC 3 – High Vehicle Traffic Areas

An infiltration BMP may be considered for runoff from areas of industrial activity and the high vehicle traffic areas described below. For such applications, sufficient pollutant removal (including oil removal) must be provided upstream of the infiltration facility to ensure that groundwater quality standards will not be violated and that the infiltration facility is not adversely affected.

High vehicle traffic areas include the following:

- Commercial or industrial sites subject to an expected average daily traffic count (ADT) ≥100 vehicles/1,000 ft^2 gross building area (trip generation)

- Road intersections with an ADT of ≥ 25,000 on the main roadway, or ≥15,000 on any intersecting roadway
- Loading and unloading areas at airport terminals
- Parking areas at airports
- Aircraft gates.

SSC 4 – Soil Infiltration Rate

For infiltration facilities used for water quality treatment purposes, the short-term soil infiltration rate should be 2.4 inches/hour or less to a depth of 2.5 times the maximum design pond water depth, or a minimum of 6 feet below the base of the infiltration facility. This infiltration rate is also typical for soil textures that possess sufficient physical and chemical properties for adequate treatment, particularly for soluble pollutant removal (see SSC 6). It is comparable to the textures represented by Hydrologic Groups B and C (see *hydrologic soil groups*, in the Glossary). Long-term infiltration rates up to 2.0 inches/hour can also be considered, if the infiltration receptor is not a sole-source aquifer and in the judgment of the site professional, if the treatment soil has characteristics comparable to those specified in SSC 6 to adequately control the target pollutants.

The long-term infiltration rate (calculated in accordance with the methods described in Sections 5-3.2 and 5-3.3 for western Washington; or Section 5-3.4 for eastern Washington) should also be used for maximum drawdown time and routing calculations.

Drawdown Time

If sizing an infiltration facility for treatment in western Washington, the designer should document that the 91st percentile, 24-hour runoff volume (indicated by WWHM or MGSFlood) can infiltrate through the infiltration BMP surface within 36 hours.

If designing an infiltration facility for flow control in eastern Washington, the designer should confirm that the runoff volume associated with the design storm (in accordance with Core Element #6 this would typically be the 25-year, 24-hour design storm unless a higher level of flow control is required by a local jurisdiction) will infiltrate within 48 hours. This can be determined through equation 5-1.

$$t_{dd} = V/(A_{mid} \cdot i) \tag{5-1}$$

where: t_{dd} = drawdown time (hours)
V = runoff volume associated with design storm (cubic feet)
A_{mid} = area of the midpoint of the storage volume of the infiltration facility (square feet)
i = infiltration rate (inches per hour)

WWHM and MGSFlood do not readily allow the designer to determine runoff volumes (except the water quality volume) or drawdown times. Based on an analysis of 50 years of historic data, Parametrix found that infiltration facilities sized to meet the Ecology duration standard with native underlying soils with an infiltration rate of at least 1.0 inch per hour had no occurrences of inundation for greater than 48 hours during the period of analysis (Parametrix 2007 [included in Appendix B]). Based on this analysis, it is assumed that infiltration facilities designed for flow control in western Washington in accordance with the recommendations of this chapter meet the drawdown time criteria.

This drawdown restriction is intended to meet the following objectives:

- Aerate vegetation and soil to keep the vegetation healthy
- Enhance the biodegradation of pollutants and organic matter in the soil
- Comply with the FAA recommendation 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).

SSC 5 – Depth to Bedrock, Water Table, or Impermeable Layer

The base of all infiltration basins or trench systems shall be ≥ 5 feet above the seasonal high-water table, bedrock (or hardpan), or other low permeability layer.

SSC 6 – Soil Physical and Chemical Suitability for Treatment

(Applies to infiltration facilities used as treatment facilities, not to facilities used only for flow control.)

The soil texture and design infiltration rates should be considered along with the physical and chemical characteristics specified below to determine if the soil is adequate for removing the target pollutants. The following soil properties must be carefully considered in making such a determination:

- Cation exchange capacity (CEC) of the treatment soil must be greater than or equal to 5 milliequivalents CEC/100 g dry soil (U.S. EPA Method 9081).
- Depth of soil used for infiltration treatment must be a minimum of 18 inches.
- Organic content of the treatment soil (ASTM D 2974): Organic matter can increase the sorptive capacity of the soil for some pollutants. The designer should evaluate whether the organic matter content is sufficient for control of the target pollutant(s).

- Waste fill materials should not be used as infiltration soil media nor should such media be placed over uncontrolled or nonengineered fill soils.
- Engineered soils may be used to meet the design criteria in this chapter and the performance goals in Chapters 3 and 4 of Volume V of the Ecology manuals. Field performance evaluation(s), using acceptable protocols, would be needed to determine feasibility and acceptability by the local jurisdiction.

SSC 7 – Seepage Analysis and Control

Determine whether there would be any adverse effects caused by seepage zones on nearby building foundations, basements, roads, parking lots, or sloping sites.

Infiltration of stormwater is not recommended on or upgradient of a contaminated site where infiltration of even clean water can cause contaminants to mobilize.

Sidewall seepage is not usually a concern if seepage occurs through the same stratum as the bottom of the facility. However, for engineered soils or soils with very low permeability, the potential to bypass the treatment soil through the sidewalls may be significant. In those cases, the sidewalls must be lined, either with an impervious liner or with at least 18 inches of treatment soil, to prevent seepage of untreated flows through the sidewalls.

SSC 8 – Cold Climate and Impact of Deicers

- For cold climate design criteria (snowmelt/ice impacts), refer to Caraco and Claytor (1997).
- The potential impact of deicers on potable water wells must be considered in the siting determination. Mitigation measures must be implemented if infiltration of deicers could cause a violation of groundwater quality standards.

SSC 9 – Verification Testing of the Completed Facility

Verification testing of the completed full-scale infiltration facility is recommended to confirm that the design infiltration parameters are adequate. The site analysis professional should determine the duration and frequency of the verification testing program, including the monitoring program for the potentially impacted groundwater. Groundwater monitoring wells may be used for this purpose. Long-term (more than 2 years) in-situ drawdown and confirmatory monitoring of the infiltration facility would be preferable.

5-3.2. Simplified Approach to Determining Infiltration Rates (Western Washington)

The Stormwater Management Manual for Western Washington (Ecology 2005) provides two alternatives for determining infiltration rates: the simplified approach and the detailed approach. The simplified approach and the associated three methods for determining long-term infiltration rates are described in Sections 3.3.4 and 3.3.6 of the Ecology manual, respectively.

5-3.3. Detailed Approach to Determining Infiltration Rates (Western Washington)

The detailed approach was obtained from Massmann (2003). Procedures for the detailed approach are as follows (see Figures 5-1 and 5-2 for a flowchart of this process):

1. Select a location:

   This will be based on the ability to convey flow to the location and the expected soil conditions. The minimum setback distances must also be met. (See Site Suitability Criteria, SSC 1.)

2. Estimate volume of stormwater, V_{design}:

   For eastern Washington, a single event hydrograph or value for the volume can be used, allowing a modeling approach such as StormShed to be conducted. For western Washington, a continuous hydrograph should generally be used, requiring a model such as WWHM or MGSFlood to perform the calculations.

3. Develop a trial infiltration facility geometry based on length, width, and depth:

   To accomplish this, either assume an infiltration rate based on previously available data, or use a default infiltration rate of 1.0 inches/hour. This trial geometry should be used to locate the facility, and for planning purposes in developing the geotechnical subsurface investigation plan.

4. Conduct a geotechnical investigation:

   A geotechnical investigation must be conducted to evaluate the site's suitability for infiltration; to establish the infiltration rate for design; and to evaluate slope stability, foundation capacity, and other geotechnical design information needed to design and assess constructability of the facility. Geotechnical investigation requirements are provided below.

   The depth, number of test holes or test pits, and sampling described below should be increased if a licensed engineer with geotechnical expertise (P.E.) or other licensed professional judges that conditions are highly variable and make it necessary to increase the depth or the number of explorations to accurately

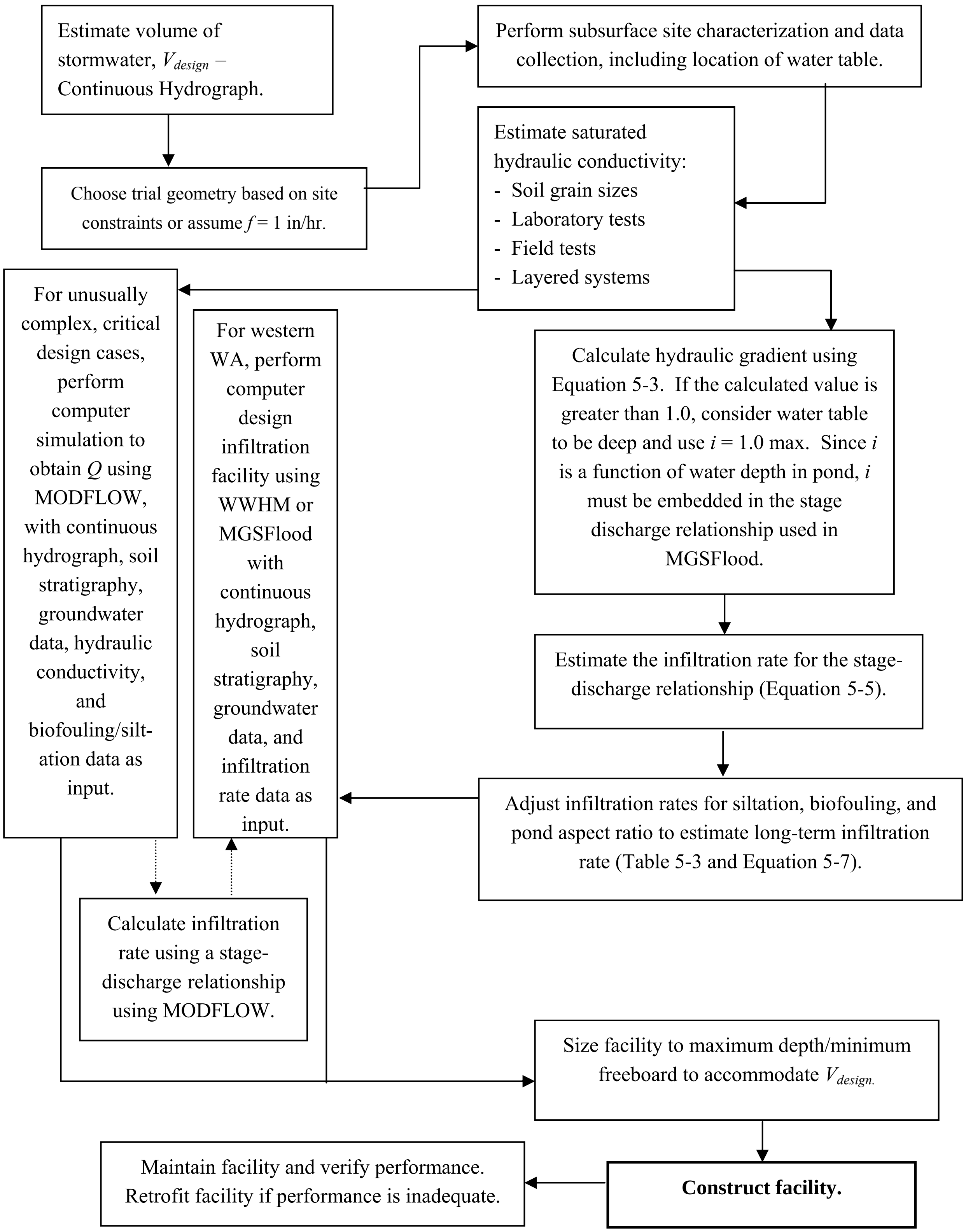


Figure 5-1. Engineering design steps for final design of infiltration facilities using the continuous hydrograph method (western Washington).

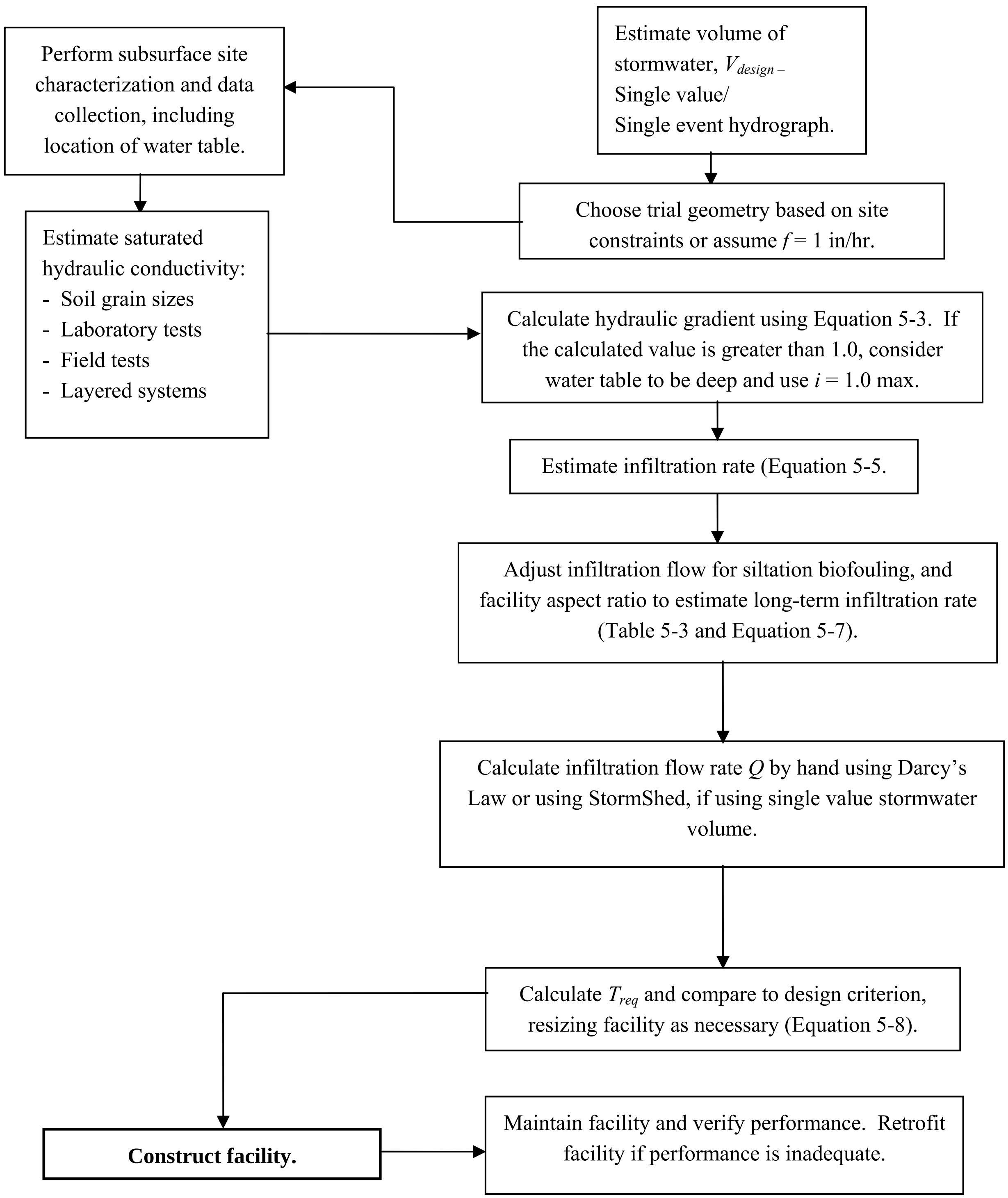


Figure 5-2. Engineering design steps for final design of infiltration facilities using the single hydrograph method (eastern Washington).

estimate the infiltration system's performance. The exploration program described below may be decreased if a licensed engineer with geotechnical expertise (P.E.) or other licensed professional judges that conditions are relatively uniform, or that design parameters are known to be conservative based on site-specific data or experience, and the borings/test pits omitted will not influence the design or successful operation of the facility.

- For infiltration basins (ponds), at least one test pit or test hole per 5,000 ft^2 of basin infiltrating bottom surface area.
- For infiltration trenches, at least one test pit or test hole per 100 feet of trench length.
- For drywells, samples should be collected from each layer beneath the facility to the depth of groundwater or to approximately 40 feet below the ground surface (approximately 30 feet below the base of the drywell). Subsurface explorations (test holes or test pits) to a depth below the base of the infiltration facility of at least 5 times the maximum design depth of water proposed for the infiltration facility, or at least 2 feet into the saturated zone.
- Continuous sampling to a depth below the base of the infiltration facility of 2.5 times the maximum design depth of water proposed for the infiltration facility, or at least 2 feet into the saturated zone, but not less than 6 feet. Samples obtained must be adequate for the purpose of soil gradation/classification testing.
- Groundwater monitoring wells installed to locate the groundwater table and establish its gradient, direction of flow, and seasonal variations, considering both confined and unconfined aquifers. (Monitoring through at least one wet season is required, unless site historical data regarding groundwater levels are available.) In general, a minimum of three wells per infiltration facility, or three hydraulically connected surface or groundwater features, are needed to determine the direction of flow and gradient. If gradient and flow direction are not required and there is low risk of downgradient impacts, one monitoring well is sufficient. Alternative means of establishing the groundwater levels may be considered. If the groundwater in the area is known to be greater than 50 feet below the proposed facility, detailed investigation of the groundwater regime is not necessary.
- Laboratory testing as necessary to establish the soil gradation characteristics, and other properties as necessary to complete the infiltration facility design. At a minimum, one grain-size analysis per soil stratum in each test hole must be conducted within 2.5 times the maximum design water depth, but not less than 6 feet. When assessing the hydraulic conductivity characteristics of the site, soil layers at greater depths must be

considered if the licensed professional conducting the investigation determines that deeper layers will influence the rate of infiltration for the facility, requiring soil gradation/classification testing for layers deeper than indicated above.

5. From the geotechnical investigation, determine the following, as applicable:

   - The stratification of the soil/rock below the infiltration facility, including the soil gradation (and plasticity, if any) characteristics of each stratum.
   - The depth to the groundwater table and to any bedrock/impermeable layers.
   - Seasonal variation of the groundwater table.
   - The existing groundwater flow direction and gradient.
   - The hydraulic conductivity or the infiltration rate for the soil/rock at the infiltration facility.
   - The porosity of the soil below the infiltration facility, but above the water table.
   - The lateral extent of the infiltration receptor.
   - The impact of the infiltration rate and volume on flow direction and water table at the project site, and the potential discharge point or area of the infiltrating water.
   - For other aspects of the design of infiltration facilities, see Chapter 6.

6. Determine the saturated hydraulic conductivity as follows:

   The geotechnical investigation will typically provide a computation of the saturated hydraulic conductivity (K_{sat}) for the area proposed for infiltration. In those cases where the K_{sat} is not provided, the designer can determine the K_{sat} value by referring to the detailed approach in this section or by the Guelph Permeameter described in the HRM (applicable to eastern Washington only).

   The K_{sat} derived using the detailed approach can then be used to design the following:

   - Infiltration pond (BMP AR.04)
   - Infiltration trench (BMP AR.05)
   - Infiltration vault (BMP AR.06)
   - Underlying soils of CAVFS (BMP AR.12)
   - Drywell (BMP AR.07)
   - Natural dispersion (BMP AR.01).

For each defined layer below the pond to a depth below the pond bottom of 2.5 times the maximum depth of water in the pond, but not less than 6 feet, estimate the saturated hydraulic conductivity in cm/second using the following relationship (see Massmann [2003], and Massmann et al. [2003]):

$$\log_{10}(K_{sat}) = -1.57 + 1.90 D_{10} + 0.015 D_{60} - 0.013 D_{90} - 2.08 f_{fines} \tag{5-1}$$

where: K_{sat} = the saturated hydraulic conductivity in cm/second
D_{10}, D_{60}, and D_{90} = grain sizes in mm for which 10%, 60%, and 90% of the sample is more fine
f_{fines} = the fraction of the soil (by weight) that passes the number-200 sieve

Use the following equation to convert K_{sat} from cm/second to ft/day:

K_{sat} (ft/day) = K_{sat} (cm/s) x 2,834.65

If the licensed professional conducting the investigation determines that deeper layers will influence the rate of infiltration for the facility, soil layers at greater depths must be considered when assessing the site's hydraulic conductivity characteristics. Massmann (2003) indicates that where the water table is deep, soil or rock strata up to 100 feet below an infiltration facility can influence the rate of infiltration. Note that only the layers near and above the water table or low permeability zone (e.g., a clay, dense glacial till, or rock layer) need to be considered, as the layers below the groundwater table or low permeability zone do not significantly influence the rate of infiltration. Also, note that this equation for estimating hydraulic conductivity assumes minimal compaction consistent with the use of tracked (i.e., low to moderate ground pressure) excavation equipment.

If the soil layer being characterized has been exposed to heavy compaction, or is overconsolidated because of its geologic history (e.g., overridden by continental glaciers), the hydraulic conductivity for the layer could be approximately an order of magnitude less than what would be estimated based on grain size characteristics alone (Pitt et al. 2003). In such cases, compaction effects must be taken into account when estimating hydraulic conductivity. For clean, uniformly graded sands and gravels, the reduction in K_{sat} because of compaction will be much less than an order of magnitude. For well-graded sands and gravels with moderate to high silt content, the reduction in K_{sat} will be close to an order of magnitude. For soils that contain clay, the reduction in K_{sat} could be greater than an order of magnitude.

- For critical designs, the in situ saturated conductivity of a specific layer can be obtained through field tests such as the packer permeability test (above or below the water table), the piezocone (below the water table), an air conductivity test (above the water table), or through the use of a pilot infiltration test (PIT), as described in Ecology's SMMWW. Note that these field tests generally provide a hydraulic conductivity combined with a hydraulic gradient (see Equation 5-4). In some of these tests, the hydraulic gradient may be close to 1.0; therefore, in effect, the magnitude of the test result is the same as the hydraulic conductivity. In other cases, the hydraulic gradient may be close to the gradient that is likely to occur in the full-scale infiltration facility. This issue will need to be evaluated on a case-by-case basis when interpreting the results of field tests. It is important to recognize that the gradient in the test may not be the same as the gradient likely to occur in the full-scale infiltration facility in the long-term (i.e., when groundwater mounding is fully developed).

- Once the saturated hydraulic conductivity for each layer has been identified, determine the effective average saturated hydraulic conductivity below the pond. Hydraulic conductivity estimates from different layers can be combined using the harmonic mean:

$$K_{equiv} = \frac{d}{\sum \frac{d_n}{K_{sat\_n}}} \qquad (5\text{-}2)$$

where: K_{equiv} = the average saturated hydraulic conductivity in ft/day
d = the total depth of the soil column in feet
d_n = the thickness of layer "*n*" in the soil column in feet
K_{sat_n} = the saturated hydraulic conductivity of layer "*n*" in the soil column in ft/day.

The depth of the soil column, *d*, typically would include all layers between the pond bottom and the water table. However, for sites with very deep water tables (>100 feet) where groundwater mounding to the base of the pond is not likely to occur, it is recommended that the total depth of the soil column in Equation 5-2 be limited to approximately 20 times the depth of the pond. This is to ensure that the most important and relevant layers are included in the hydraulic conductivity calculations. Deep layers that are not likely to affect the infiltration rate near the pond bottom should not be included in Equation 5-2. Equation 5-2 may over-estimate the effective hydraulic conductivity value at sites with low conductivity layers immediately beneath the infiltration pond. For sites where the lowest conductivity layer is within 5 feet of the base of the pond, it is suggested that this lowest hydraulic conductivity value be used as the equivalent hydraulic conductivity rather than the value from Equation 5-2. The harmonic mean given by Equation 5-2 is the appropriate effective hydraulic conductivity for flow that is perpendicular to stratigraphic layers, and will produce conservative results when flow has a significant horizontal component (such as could occur with groundwater mounding).

For the soils underlying a CAVFS, a correction factor should be applied to the saturated hydraulic conductivity to account for compaction in the embankment. A correction factor of 10 (1/10th of the estimated K_{sat} determined by Equation 4-12) should be used for "wellgraded sands and gravels with moderate-to-high silt content." For clean, uniformly graded sands and gravels, a correction factor of 5 should be used, and a correction factor of 15 should be applied to K_{sat} for soils that contain clay.

For drywells, once the saturated hydraulic conductivity for each layer has been identified, the designer must convert the saturated hydraulic conductivity to (ft/min) and then calculate the geometric mean of the multiple saturated hydraulic conductivity values. The HRM has additional guidance on determining the geometric mean of the saturated conductivity values.

7. For unusually complex, critical design cases, develop input data for a simulation model:

   Use MODFLOW, including trial geometry, continuous hydrograph data, soil stratigraphy, groundwater data, hydraulic conductivity data, and reduction in hydraulic conductivity due to siltation or biofouling on the surface of the facility. Use of this approach will generally be fairly rare. Otherwise, skip this step and develop the data needed to estimate the hydraulic gradient, as shown in the following steps.

8. Calculate the hydraulic gradient:

   The steady state hydraulic gradient is calculated as follows:

$$\text{gradient} = \text{i} \approx \frac{D_{wt} + D_{pond}}{138.62(K_{equiv}{}^{0.1})} CF_{size} \quad (5\text{-}3)$$

where: i = steady state hydraulic gradient
D_{wt} = the depth from the base of the infiltration facility to the water table in feet
K_{equiv} = the average saturated hydraulic conductivity in feet/day
D_{pond} = the depth of water in the facility in feet (see Massmann et al. 2003 for the development of this equation)
CF_{size} = the correction for pond size.

The correction factor was developed for ponds with bottom areas between 0.6 and 6 acres in size. For small ponds (ponds with area less than or equal to 2/3 acre), the correction factor is equal to 1.0. For large ponds (ponds with area greater than or equal to 6 acres), the correction factor is 0.2, as shown in Equation 5-4.

$$CF_{size} = 0.73(A_{pond})^{-0.76} \quad (5\text{-}4)$$

where: A_{pond} = the area of pond bottom in acres.

This equation generally will result in a calculated gradient of less than 1.0 for moderate to shallow groundwater depths (or to a low permeability layer) below the facility, and conservatively accounts for the development of a groundwater mound. A more detailed groundwater mounding analysis, using a program such as MODFLOW, will usually result in a gradient that is equal to or greater than the gradient calculated using Equation 5-3. If the calculated gradient is greater than 1.0, the water table is considered to be deep, and a maximum gradient of 1.0 must be used.

Typically, a depth to groundwater of 100 feet or more is required to obtain a gradient of 1.0 or more using Equation 5-3. Since the gradient is a function of depth of water in the facility, the gradient will vary as the pond fills during the season. Therefore, the gradient must be calculated as part of the stage-discharge calculation used in MGSFlood for the continuous hydrograph method. For designs using the single event hydrograph, it is sufficiently accurate to calculate the hydraulic gradient based on one-half of the maximum depth of water in the pond.

9. Calculate the infiltration rate using Darcy's Law as follows:

$$f = 0.5K_{equiv}\left(\frac{dh}{dz}\right) = 0.5K_{equiv}(i) \qquad (5\text{-}5)$$

where: f = the infiltration rate of water through a unit cross section of the infiltration facility (in/hr)

K_{equiv} = the average saturated hydraulic conductivity (ft/day)

dh/dz = the steady state hydraulic gradient

i = the steady state hydraulic gradient

0.5 = converts ft/day to in/hr.

10. Adjust the infiltration rate or infiltration stage-discharge relationship obtained in Steps 8 and 9:

This is done to account for reductions in the rate resulting from long-term siltation and biofouling, taking into consideration the degree of long-term maintenance and performance monitoring anticipated, the degree of influent control (e.g., presettling ponds, biofiltration swales), and the potential for siltation, litterfall, moss buildup, etc., based on the surrounding environment. It should be assumed that an average to high degree of maintenance will be performed on these facilities. A low degree of maintenance should be considered only when there is no other option (e.g., access problems). The infiltration rates estimated in Steps 8 and 9 are multiplied by the reduction factors summarized in Table 5-3.

Table 5-3. Infiltration rate reduction factors to account for biofouling and siltation effects for ponds.

Potential for Biofouling	Degree of Long-Term Maintenance/Performance Monitoring	Infiltration Rate Reduction Factor, $CF_{silt/bio}$
Low	Average to High	0.9
Low	Low	0.6
High	Average to High	0.5
High	Low	0.2

Based on Massmann (2003).

The values in this table assume that final excavation of the facility to the finished grade is deferred until all disturbed areas in the upgradient drainage area have been stabilized or protected (e.g., construction runoff is not allowed into the facility after final excavation of the facility).

An example of a situation with a high potential for biofouling would be a pond located in a shady area where moss and litterfall from adjacent vegetation can build up on the pond bottom and sides, the upgradient drainage area will remain in a disturbed condition over the long term, and no pretreatment (e.g., presettling ponds, biofiltration swales) is provided. A low degree of long-term maintenance includes, for example, situations where access to the facility for maintenance is very difficult or limited, or where there is minimal control of the party responsible for enforcing the required maintenance. A low degree of maintenance should be considered only when there is no other option.

Adjust this infiltration rate for the effect of pond aspect ratio by multiplying the infiltration rate determined in Step 9 (Equation 5-5) by the aspect ratio correction factor CF_{aspect} as shown in the following equation. In no case shall CF_{aspect} be greater than 1.4.

$$CF_{aspect} = 0.02A_r + 0.98 \qquad (5\text{-}6)$$

where: CF_{aspect} = the aspect ratio correction factor
A_r = the aspect ratio for the pond (length/width).

The final infiltration rate will therefore be as follows:

$$f = (0.5K_{equiv})(i)(CF_{aspect})(CF_{silt/bio}) \qquad (5\text{-}7)$$

The infiltration rates calculated based on Equations 5-5 and 5-6 are long-term design rates. No additional reduction factor or factor of safety is needed. If the design infiltration rate is less than 1 inch per hour, an infiltration facility may not be used for flow control.

11. Determine the infiltration flow rate Q:

    If the infiltration facility is located in eastern Washington, determine the infiltration flow rate Q using the Infiltration Calculation Spreadsheet in Ecology (2008c). If located in western Washington, determine the infiltration flow rate Q using MGSFlood.

12. Size the facility:

    Use one of the following two approaches to size the facility, depending on the type of hydrograph used:

    - If using a continuous hydrograph for design, size the facility to ensure that the desirable pond depth is 3 feet, with 1-foot-minimum required freeboard. The maximum allowable pond depth is 6 feet.
    - If using a single event/single hydrograph, calculate T_{req}, using StormShed to determine the time it takes the pond to empty, or from the value of Q determined from Step 11 and V_{design} from Step 2 as follows:

    $$T_{req} = \frac{V_{design}}{Q} \tag{5-8}$$

    where: T_{req} = the time required to infiltrate the design stormwater volume
    V_{design} = volume of stormwater in cubic feet
    Q = infiltration flow rate in cubic feet per second (cfs).

    This value of T_{req} must be less than or equal to the maximum allowed infiltration time specified in the Site Suitability Criteria.

13. Construct the facility:

    Maintain and monitor the facility for performance.

5-3.4. Design Infiltration Rate Determination (Eastern Washington)

Table 5-4 may be used for determining presumptive rates for surface treatment facilities based on the USDA soil classification or the Unified Soil Classification System. The infiltration rates in Table 5-4 provide conservative estimates based on homogenous soils. They do not consider the effects of site variability and long-term clogging in the infiltration facility.

For guidance on field tests to determine more accurate, site-specific infiltration rates, refer to Appendix 6B of the SMMEW.

Table 5-4. Presumptive infiltration rates based on USDA soil classification

USDA Soil Textural Classification	Short-term Infiltration Rate[a]	Correction Factor, CF	Estimated Long-term (Design) Infiltration Rate (inches/hour)
Clean sandy gravels and gravelly sands (i.e., 90% of the total soil sample is retained in the #10 sieve	20	2	10[b]
Sand	8	4	2[c]
Loamy Sand	2	4	0.5
Sandy Loam	1	4	0.25
Loam	0.5	4	0.13

[a] From WEF/ASCE 1998.
[b] Not suitable for infiltration treatment unless justified by geotechnical study and approved by permitting municipality.
[c] Refer to SSC-4 and SSC-6 for treatment acceptability criteria.

5-4. General BMP Design Guidelines

This section provides hydrologic design guidance for infiltration facilities (Section 5-4.1), compost amended vegetated filter strips (CAVFS) (Section 5-4.2), and volume-based runoff treatment (Section 5-4.3). The information contained in each of these sections is applicable to various BMPs. For example, the infiltration facility design guidance applies to infiltration ponds (BMP AR.04), infiltration trenches (BMP AR.05), infiltration vaults (BMP AR.06), and dry wells (BMP AR.07). Information on determining infiltration rates for soil amendment BMPs in Section 5-4.2 applies to natural and engineered dispersion (BMPs AR.01 and AR.02) as well as to CAVFS. This information is provided in Chapter 5 to minimize redundancy between individual BMP design guidelines (presented in Chapter 6).

5-4.1. Infiltration Facilities

This section covers hydrologic design guidelines and considerations for infiltration basins and trenches.

Design Criteria – Sizing Facilities (Western Washington)

The size of the infiltration facility can be determined by routing the influent runoff file generated by the continuous runoff model through the facility. To prevent the onset of anaerobic conditions, an infiltration facility designed for treatment purposes must be designed to drain the 91st percentile, 24-hour runoff volume within 48 hours (see the explanation under simplified or detailed design procedures). In general, an infiltration facility would have two discharge modes. The primary mode of discharge from an infiltration facility is infiltration into the ground. However, when the infiltration capacity of the facility is reached, additional runoff to the facility will cause the facility to overflow. Overflows from an infiltration facility must comply with the

Minimum Requirement 7 for flow control in Volume I of the Ecology manuals. Infiltration facilities used for runoff treatment must not overflow more than 9 percent of the influent runoff file, by volume.

To determine compliance with the flow control requirements, the WWHM, MGSFlood, or an appropriately calibrated continuous simulation model based on HSPF must be used. Refer to the SMMWW or HRM for more information on specific modeling procedures for infiltration facilities.

Additional Design Criteria

- Slope of the base of the infiltration facility should be <3 percent.
- A nonerodible outlet structure or spillway with a firmly established elevation must be constructed to discharge overflow. Ponding depth, drawdown time, and storage volume are calculated from that reference point.
- For infiltration treatment facilities, side-wall seepage is not a concern if seepage occurs through the same stratum as the bottom of the facility. However, for engineered soils or for soils with very low permeability, the potential to bypass the treatment soil through the sidewalls may be significant. In such cases, the sidewalls must be lined, either with an impervious liner or with at least 18 inches of treatment soil, to prevent seepage of untreated flows through the sidewalls.

Design Criteria – Sizing Facilities (Eastern Washington)

This section describes the iterative process for designing an infiltration facility in eastern Washington.

Step 1. Develop Trial Geometry

The designer should develop a preliminary geometry for the proposed facility. The design guidelines in Chapter 6 will include criteria for maximum and minimum depth for specific BMPs. Select facility dimensions that meet depth requirements and are reasonable in light of the total storm volume associated with the design storm. Often, site constraints will limit the surface are available for siting a facility.

Step 2. Develop Stage-Discharge Relationship for Facility

The stage-discharge relationship may be determined using Darcy's Law;

$$Q = fiA_s, \qquad (5\text{-}9)$$

where: Q = flow rate at which runoff is infiltrated (cfs)
f = infiltration rate of soil (in/hr). Note that the infiltration rate used in this equation should incorporate a safety factor of 2, such that f = *2 x design infiltration rate*
i = hydraulic gradient
A_s = surface area of the infiltration BMP (sf).

The hydraulic gradient, i, may be calculated as follows:

$$i = (h+L)/L; \qquad (5\text{-}10)$$

where: h = design depth of facility (feet)
L = distance from the bottom of the BMP to the water table, bedrock, impermeable layer, or soil layer of different infiltration rate (ft)

The stage-storage relationship may be calculated as follows:

$$S = A_s \times h \times \text{void ratio} \qquad (5\text{-}11)$$

where: A_s and h are as described above.

Step 3. Level Pool Routing

This section presents the methodology for routing a hydrograph through a stormwater facility using hydrograph analysis. Level pool routing is done the same way regardless of the method used to generate the hydrograph; therefore, this part of the analysis is not unique to the SBUH method. The level pool routing technique presented here is one of the simplest and most commonly used hydrograph routing methods.

This technique is based on the following continuity equation:

Inflow – Outflow = Change in Storage

$$((I1 + I2)/2) - ((O1 + O2)/2) = S2 - S1 \qquad (5\text{-}12)$$

where: $I1$, $I2$ = Inflow at time 1 and time 2
$O1$, $O2$ = Outflow at time 1 and time 2
$S1$, $S2$ = Storage at time 1 and time 2

The time interval for the routing analysis must be consistent with the time interval used in developing the inflow hydrograph. The time interval used for a 24-hour storm is 10 minutes.

The variables can be rearranged to obtain the following equation:

$$I1 + I2 + 2S1 - O1 = O2 + 2S2 \quad (5\text{-}13)$$

If the time interval is in minutes, the unit of storage (*S*) is now cubic feet per minute (cf/min), which can be converted to cfs by multiplying by 1 min/60 sec.

The terms on the left-hand side of the equation are known from the inflow hydrograph and from the storage and outflow values of the previous time step. The unknowns *O* and *S* can be solved interactively from the given stage-storage and stage-discharge curves. The best way to route a hydrograph through a stormwater facility is to use a computer program. Many hydrologic analysis software programs include features that simplify the hydrograph routing process.

Example

An infiltration trench is proposed to treat the 6-month, 24-hour design storm for a proposed development site. The following conditions apply:

- Design infiltration rate = 1.5 inches/hour for sandy loam soil (extends for at least 5 feet below land surface)
- Depth to water table estimated to be 75 feet
- Depth to impermeable soil layers 10 feet
- Trial geometry = 30 feet long x 3 feet wide x 2 feet deep
- Trench to be filled with rocks, such that void ratio = 0.4

Stage-Discharge

h (ft)	i (ft/ft)	Q (cfs)	S (cf)
0.0	1.0	5.6	0
0.5	1.05	5.9	18
1.0	1.1	6.2	36
1.5	1.15	6.5	54
2.0	1.2	6.8	72

ft = feet
cfs = cubic feet per second
cf = cubic feet

To confirm that the facility will drain within 24 hours, the designer would then need to conduct level pool routing.

Construction Criteria

- Initial basin excavation should be conducted to within 1 foot of the final elevation of the basin floor. Excavate infiltration trenches and basins to final grade only after all disturbed areas in the upgradient project drainage area have been permanently stabilized. The final phase of excavation should remove all accumulation of silt in the infiltration facility before putting it in service. After construction is completed, prevent sediment from entering the infiltration facility by first conveying the runoff water through an appropriate pretreatment system such as a presettling basin, wet pond, or sand filter.
- Infiltration facilities should generally not be used as temporary sediment traps during construction. If an infiltration facility 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 basin must be removed before putting it in service.
- For traffic control, relatively light-tracked equipment is recommended to avoid compaction of the basin floor. The use of draglines and trackhoes should be considered for constructing infiltration basins. The infiltration area should be flagged or marked to keep heavy equipment away.

Maintenance Criteria

Provision should be made for regular and perpetual maintenance of the infiltration basin/trench, including replacement and/or reconstruction of the soil or other filter media that are relied upon for treatment purposes. Maintenance should be conducted when water remains in the basin or trench for more than 24 hours after the end of a rainfall event, or when overflows occur more frequently than planned. For example, off-line infiltration facilities should not have any overflows. Infiltration facilities designed to completely infiltrate all flows to meet flow control standards should not overflow. An operation and maintenance plan, approved by the local jurisdiction, should ensure that the desired infiltration rate is maintained.

Adequate access for operation and maintenance must be included in the design of infiltration basins and trenches. Removal of accumulated debris/sediment in the basin/trench should be conducted every 6 months or as needed to prevent clogging, or when water remains in the pond for greater than 24 hours after the end of a rainfall event.

Verification of Performance

During the first 1 to 2 years of operation, verification testing (specified in SSC 9) is strongly recommended, along with a maintenance program that results in achieving expected performance levels. Operating and maintaining groundwater monitoring wells is also strongly encouraged.

5-4.2. Design of Compost-Amended Vegetated Filter Strips

This section provides guidance on the hydrologic analysis and soil specifications for compost amended vegetated filter strips (CAVFS).

Determining Infiltration Rates for Soil Amendment BMPs

It is necessary to establish the long-term infiltration rate of an amended soil when it is used as a BMP design component to achieve treatment or flow control requirements. The assumed design infiltration rate should be the lower of the estimated long-term rate of the engineered soil mix or the initial (short-term or measured) infiltration rate of the underlying soil profile. The underlying native soil can be tested using either the detailed approach in Section 5-3.3 or the simplified approach in the SMMWW (Ecology 2005).

The following guidance provides recommended test methods for engineered soil mixes when they are used as part of a stormwater management BMP application. Figure 5-3 illustrates the overall process.

Compost-Amended Engineered Soil Mix

Depending on the size of contributing area, use one of these two recommended test protocols:

Test 1

If the contributing area has less than 5,000 square feet of pollution-generating impervious surface, and less than 10,000 square feet of impervious surface, and less than ¾ acres of lawn and landscape:

- Use ASTM D 2434 Standard Test Method for Permeability of Granular Soils (Constant Head) with a compaction rate of 80 percent using ASTM D1557 Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort.
- Use 2 as the infiltration reduction factor.

Test 2

If the contributing area is equal to or exceeds any of the following limitations: 5,000 square feet of pollution-generating impervious surface, 10,000 square feet of impervious surface, or ¾ acres of lawn and landscape:

- Use ASTM D 2434 Standard Test Method for Permeability of Granular Soils (Constant Head) with a compaction rate of 80 percent using ASTM D 1557 Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort.
- Use 4 as the infiltration reduction factor.

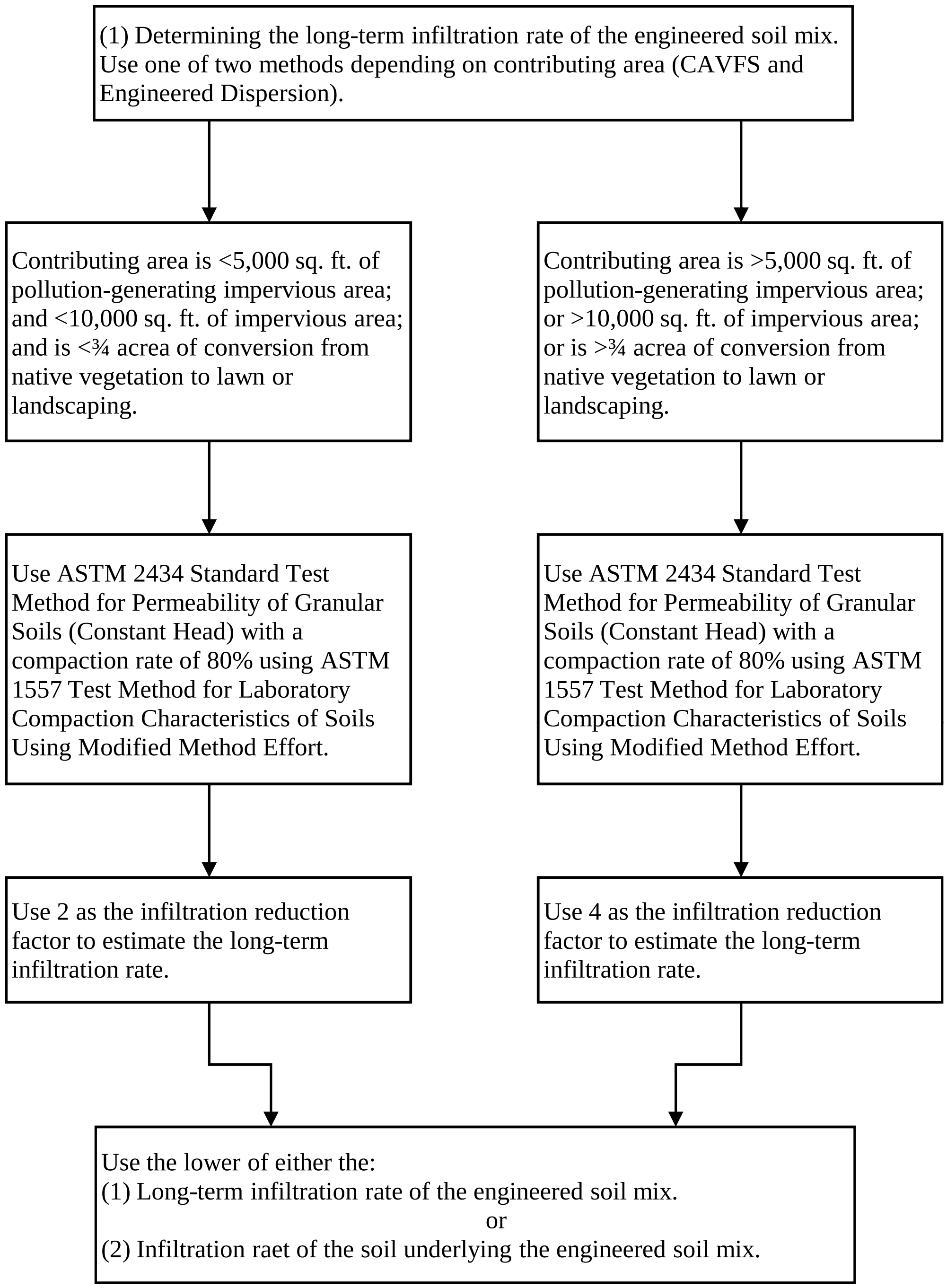


Figure 5-3. Determining the infiltration rate of soil amendments.

- Use the long-term infiltration rate of the engineered soil mix as the assumed infiltration rate of the overlying soil mix if it is higher than the underlying native soil. If the underlying native soil is lower than the engineered soil mix, use either the native soil infiltration rate or a varied infiltration rate that includes both the engineered soil mix infiltration rate and the native soil infiltration according to Step 6 of the detailed approach (Section 5-3.3).

Soil Specification

Proper soil specification, preparation, and installation are the most critical factors for CAVFS BMP performance. Soil specifications can vary according to the design objectives and the in situ soil. For additional information on soil specifications, see Section 5-4.3.2 in the HRM.

Design Procedure for Compost-Amended Vegetated Filter Strips (CAVFS) for Western Washington

This section provides hydrologic modeling guidance for CAVFS, when proposed for flow control in addition to water quality treatment.

CAVFS is most readily modeled in MGSFlood, which has a CAVFS link type (the assumptions and modeling procedures are described below).

The design for CAVFS is an iterative process in MGSFlood to adequately address the infiltrative capacity of both the compost amended layer and the underlying soils to achieve the 91 percent volume treatment criteria.

Flow through CAVFS is simulated using Darcy's Equation (as shown in Figure 5-4), where K_c is the saturated hydraulic conductivity. Note that the width dimension corresponds to the CAVFS width along the slope. Infiltration is accounted for using a constant infiltration rate into the underlying soils. During large storms, the voids in the CAVFS may become full (the CAVFS is saturated) in which case runoff is simulated as overflow down the surface of the CAVFS. The runoff volume filtered by the CAVFS, the volume infiltrated, and the volume flowing over the CAVFS surface are listed in the model output report.

Precipitation and evapotranspiration may (optionally) be applied to the CAVFS. If precipitation and evapotranspiration are applied in the CAVFS link, do not include the area of the CAVFS in the Subbasin Area input.

1. Follow Steps 1 through 11 in the Detailed Approach for Determining Infiltration Rates for the Underlying Soils of a CAVFS (see Section 5-3.3).
2. Follow Section 5-4.2 for CAVFS hydraulic conductivity.

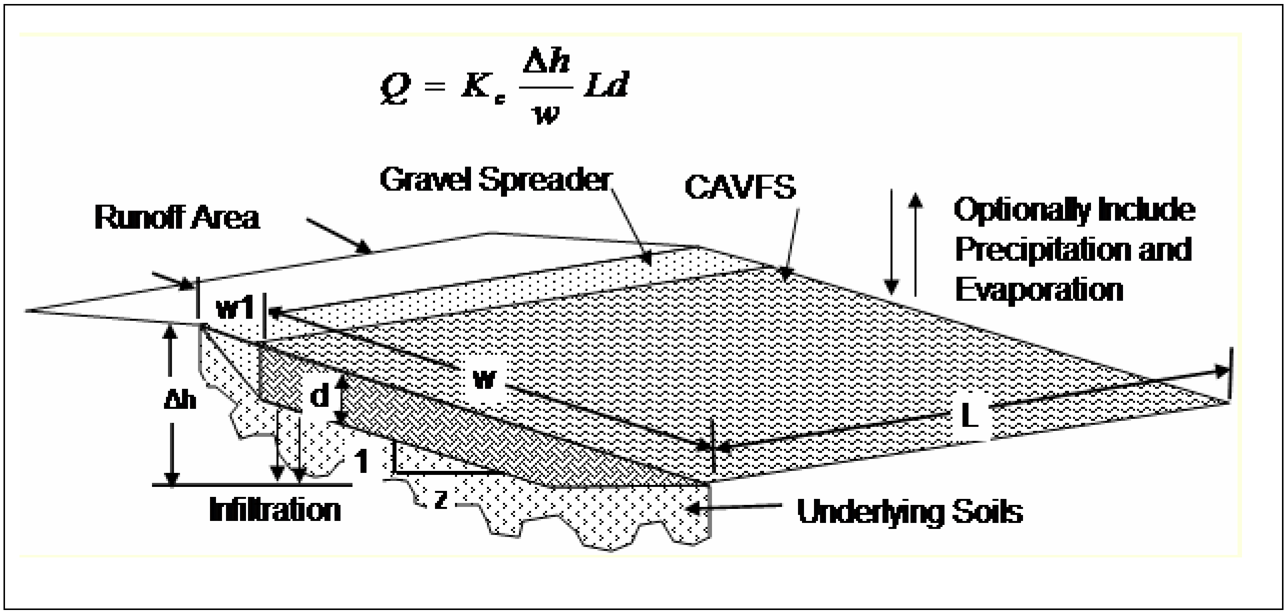


Figure 5-4. Flow-through CAVFS as simulated using Darcy's Equation.

Note: The methods described in Section 5-4.2 provide an infiltration rate. Assuming a hydraulic gradient of one, the infiltration rate is the same as the hydraulic conductivity.

3. Modeling steps for CAVFS.

Using MGSFlood, the dimensions of the CAVFS will be set as follows under the Network Tab:

- Select the Link type: CAVFS.
- ***CAVFS Depth d(ft):*** This is a constant depth of 1 foot for all CAVFS designs.
- ***CAVFS Porosity (% by Volume):*** The default value is 20 percent **but must be verified or reestablished by or a licensed geotechnical engineer for the particular site and particular installation.**
- ***CAVFS Hydraulic Conductivity (ft/day):*** The default value is 2 ft/day **and must be verified or reestablished by a licensed geotechnical engineer for the particular site and particular installation.**
- ***CAVFS Length (ft):*** The length parallel to the pavement.
- ***CAVFS Width (ft):*** The width perpendicular to the pavement. This is usually the parameter being solved for.
- ***Underlying Soil Infiltration Rate:*** Refer to Step 1.

- ***CAVFS Slope Z:*** The horizontal slope of the embankment—it cannot be steeper than 4:1.
- ***Gravel Spreader Width (ft):*** The width perpendicular to the pavement.
- ***Gravel Porosity (% by Volume):*** Typical value for gravel porosity is 30.
- ***Gravel Hydraulic Conductivity (ft/day):*** The default value is 4 ft/day **and must be verified or reestablished by a licensed geotechnical engineer for the particular site and particular installation.**

4. Determine that the volume of runoff infiltrated and filtered is 91 percent or greater than the total runoff volume.

MGSFlood will output Postdeveloped CAVFS Treatment Statistics in the MGSFlood Project Report file. The report file will give the percent treated for the structure defined in Step 3. The designer should verify that this number is equal to or greater than 91 percent.

5. Flow Control Compliance.

   After a successful runoff treatment design (Steps 1–4 above), the designer may be able to widen the CAVFS to try to meet the flow duration standard if flow control is required. Otherwise, a flow control structure should be linked downstream of the CAVFS to attenuate the resultant runoff and meet the flow duration standard. For an example problem, refer to Appendix 4A of the HRM.

5-4.3. Design Procedures for Volume-Based Runoff BMPs

For the purpose of designing runoff treatment BMPs based on volume (wet pool, vaults, tanks, and infiltration treatment facilities), in accordance with Minimum Requirement 6 (see Section 1-3.4), the following two methods can be used to derive the storage volume:

- **Wet Pool and Infiltration**: An approved continuous simulation hydrologic model based on the U.S. EPA's HSPF can be used (WWHM or MGSFlood, for example). The required storage volume is the 91st percentile, 24-hour runoff volume based on the long-term runoff record as predicted based on a 1-hour time step.
- **Wet Pool**: The SBUH method, which is based on NRCS curve number equations, can be used to determine the runoff treatment design storm runoff volume. This is the volume of runoff predicted from the 6-month, 24-hour recurrence interval storm. This design storm is approximated as 72 percent of the 2-year, 24-hour design storm. The size of the wet pool storage volume is the same whether located upstream or downstream of a flow control facility, or whether it is coupled with the flow control facility (e.g., a combination wet/detention facility).

If runoff from the new impervious surfaces and converted pervious surfaces is not separated from runoff from other surfaces on the project site, and/or is combined with run-on from areas outside the right-of-way, volume-based runoff treatment facilities must be sized based on runoff from the entire drainage area. This is because runoff treatment effectiveness can be greatly reduced if inflows to the facility are greater than the flows that the facility was designed to handle. A high-flow bypass (flow splitter) is used to route the incremental flow in excess of the treatment design runoff volume around the treatment facility. Facilities must infiltrate 91 percent of the total runoff volume from the infiltration basin within 36 hours. Under this premise, the storm/runoff ends 12 hours after the runoff period midpoint and combines with the 24-hour drain criteria. Therefore, the actual drawdown time is 36 hours.

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.

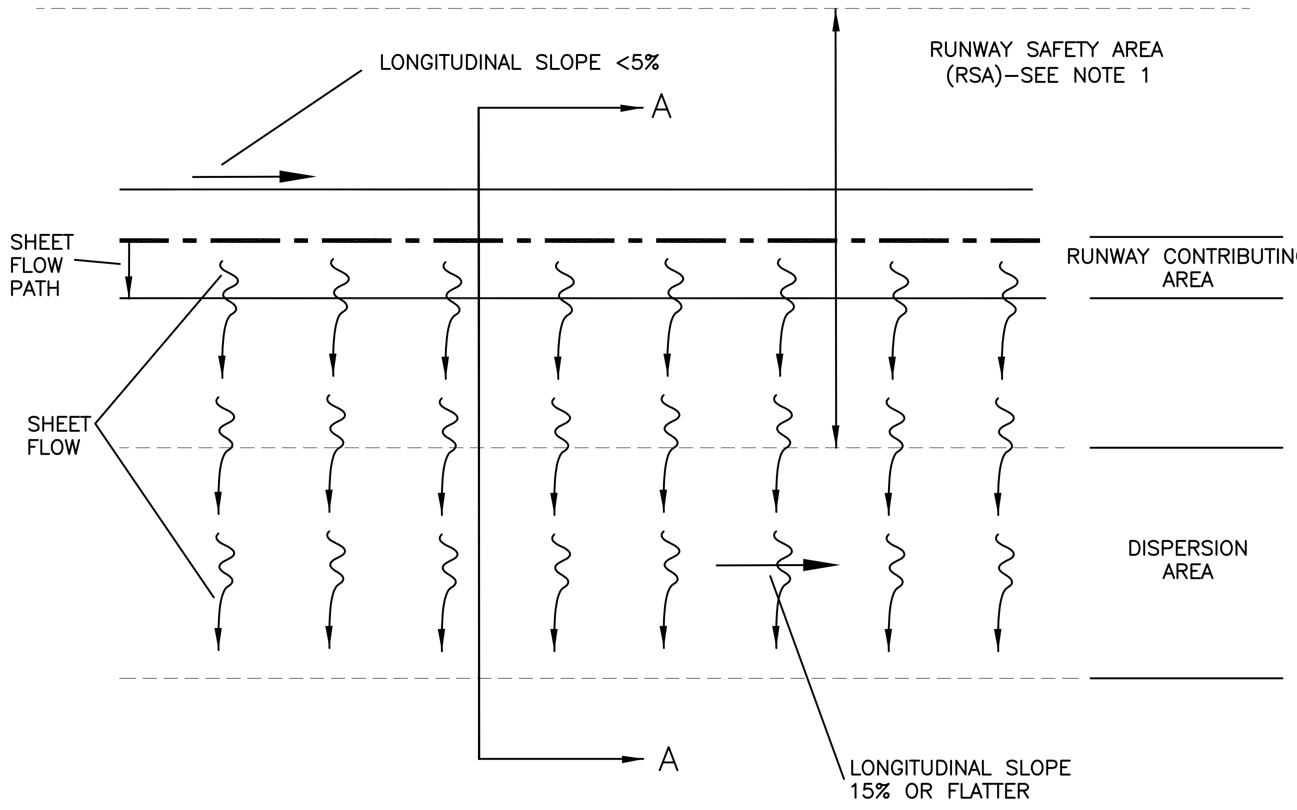
Sizing Criteria

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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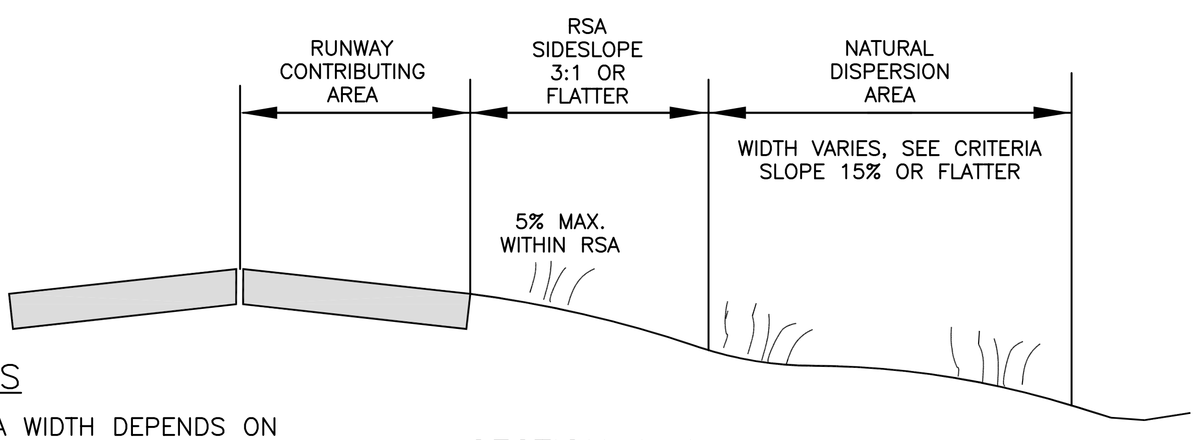

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NOTES

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

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

NATURAL DISPERSION

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.

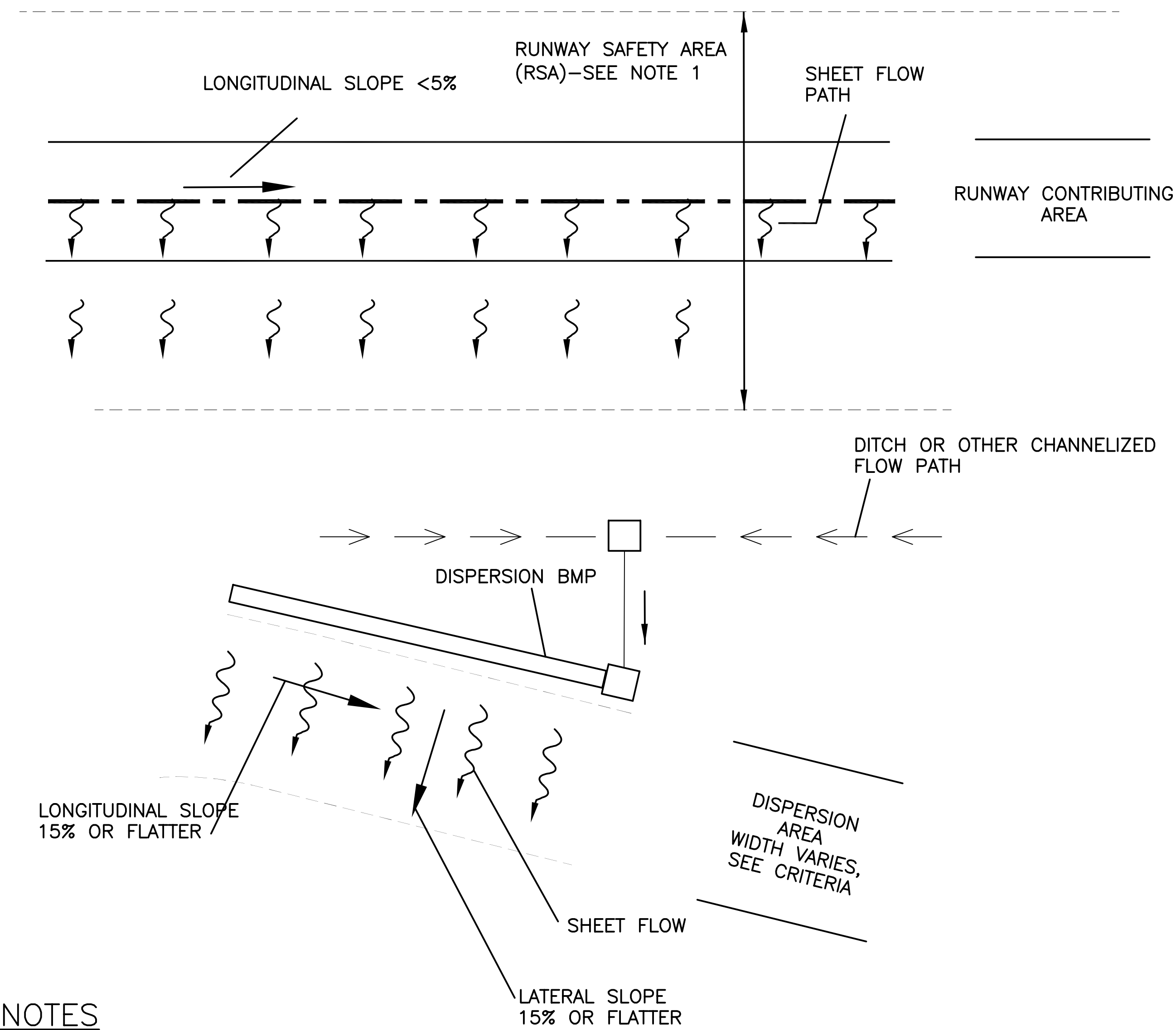
Sizing Criteria

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).

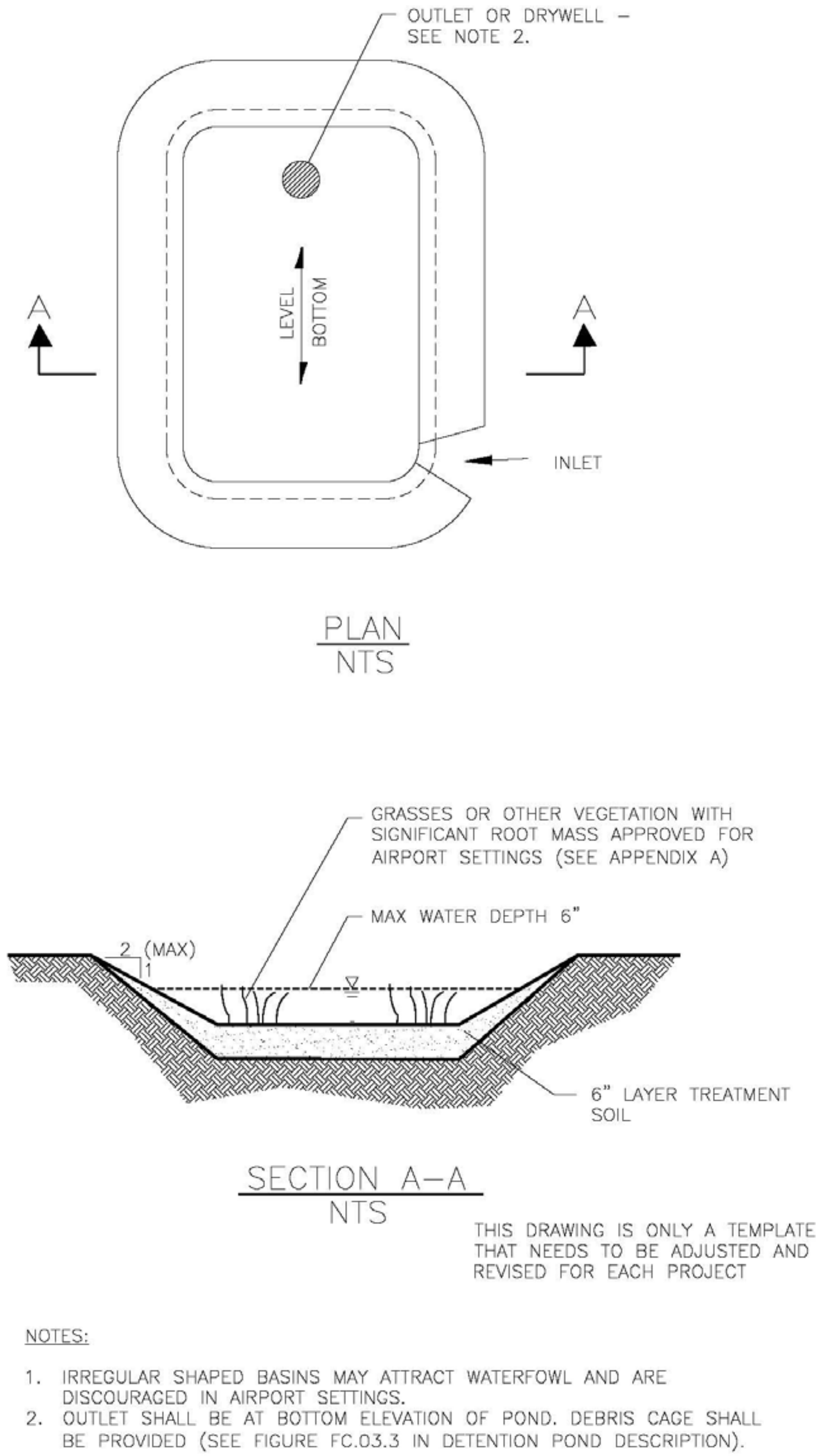


Figure AR.03.1. Bioinfiltration pond.

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

WSDOT. 2008d. Standard Specifications for Road, Bridge and Municipal Construction 2008. Publication M 41-10. Washington State Department of Transportation, Olympia, Washington.

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

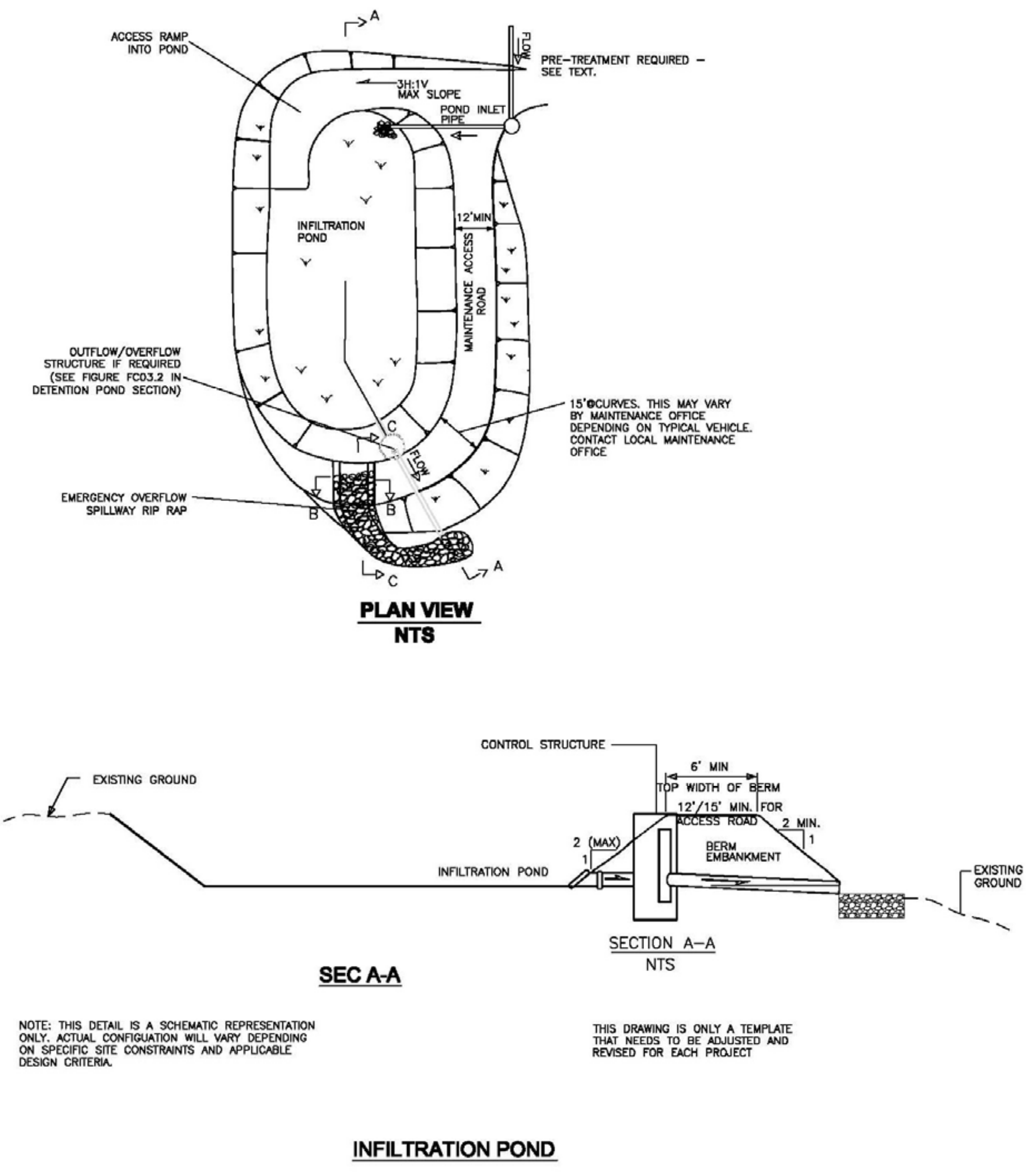


Figure AR.04.1. Infiltration pond.

- 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.

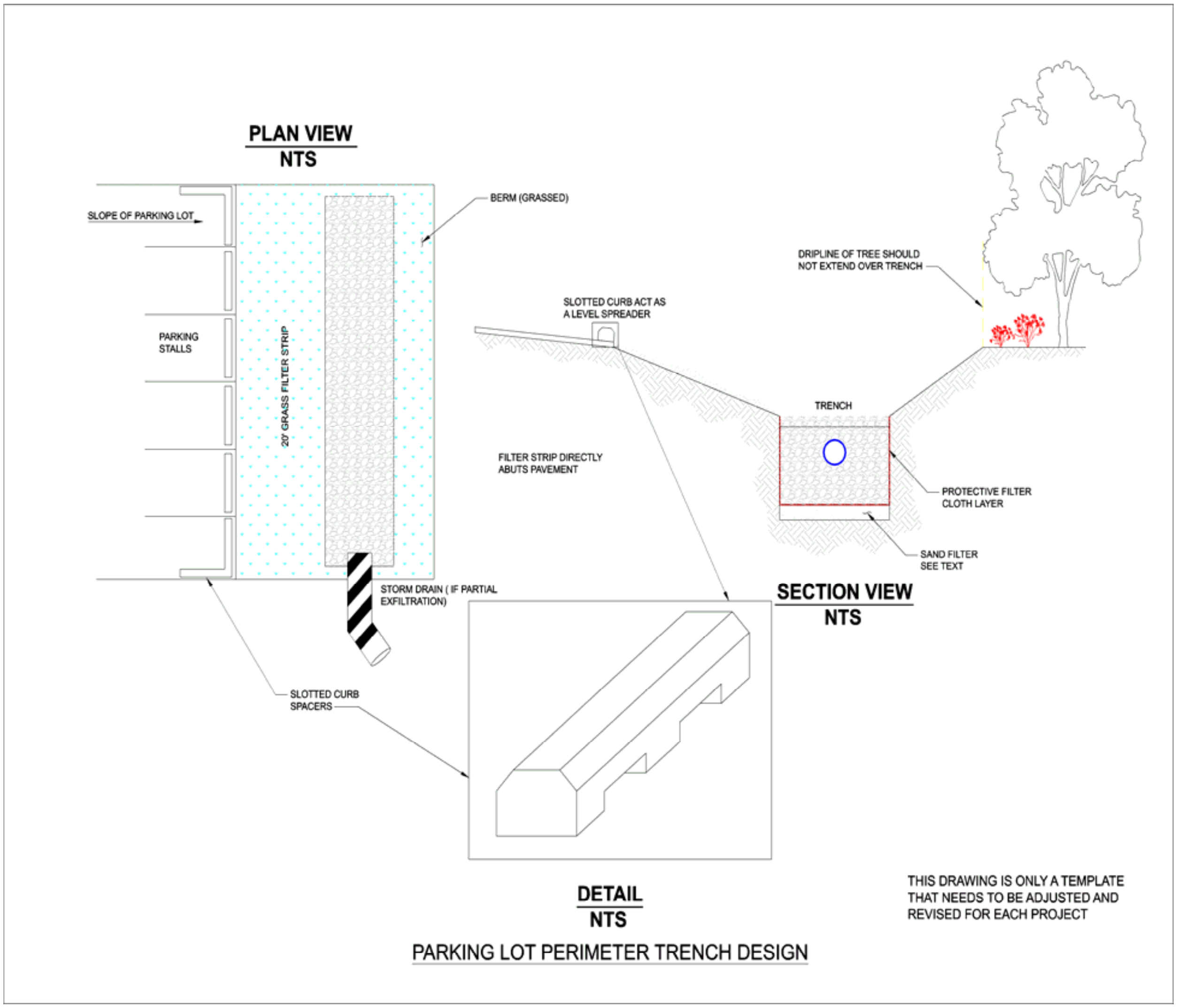
Introduction

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.

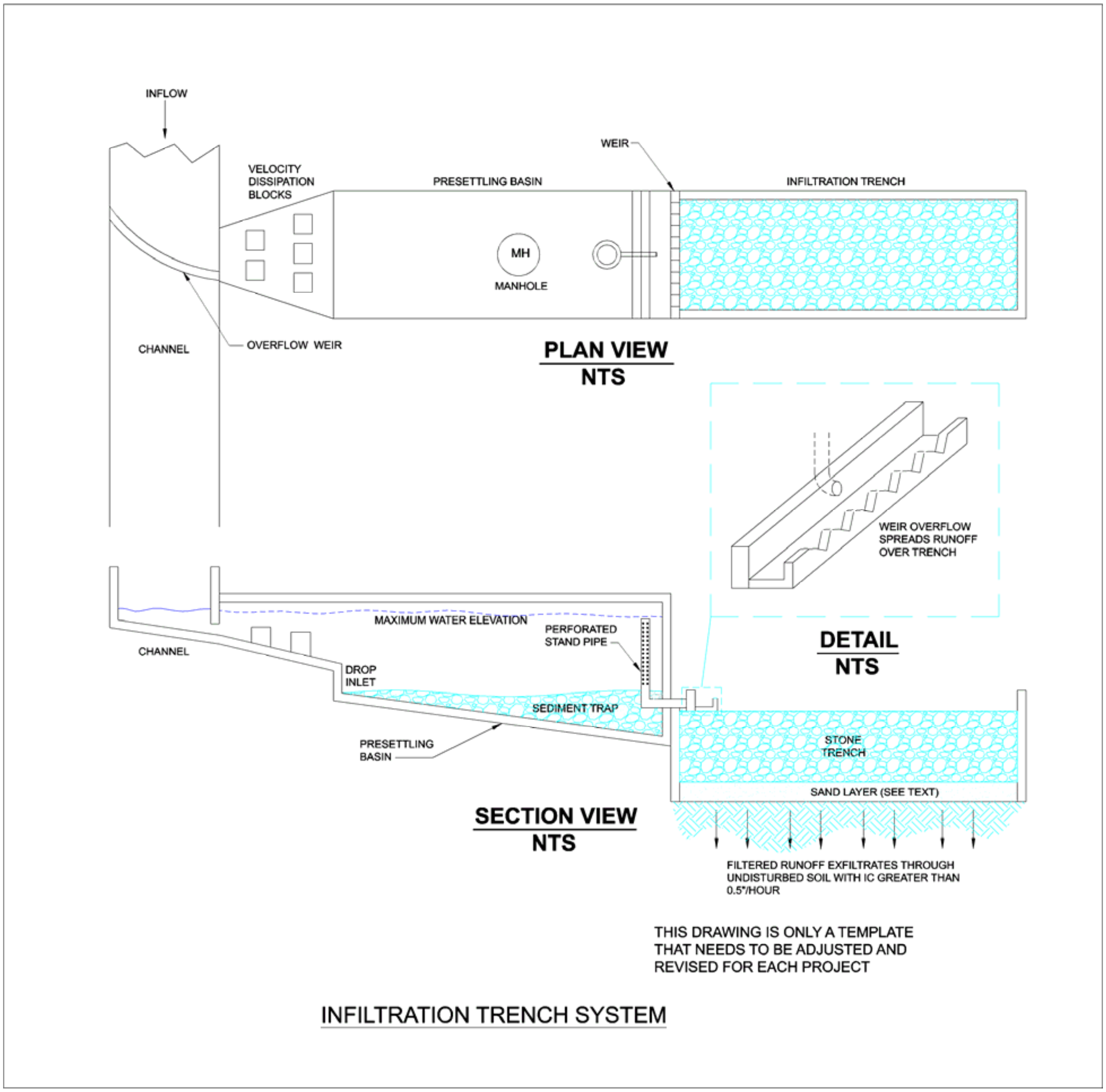
Applications and Limitations

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.



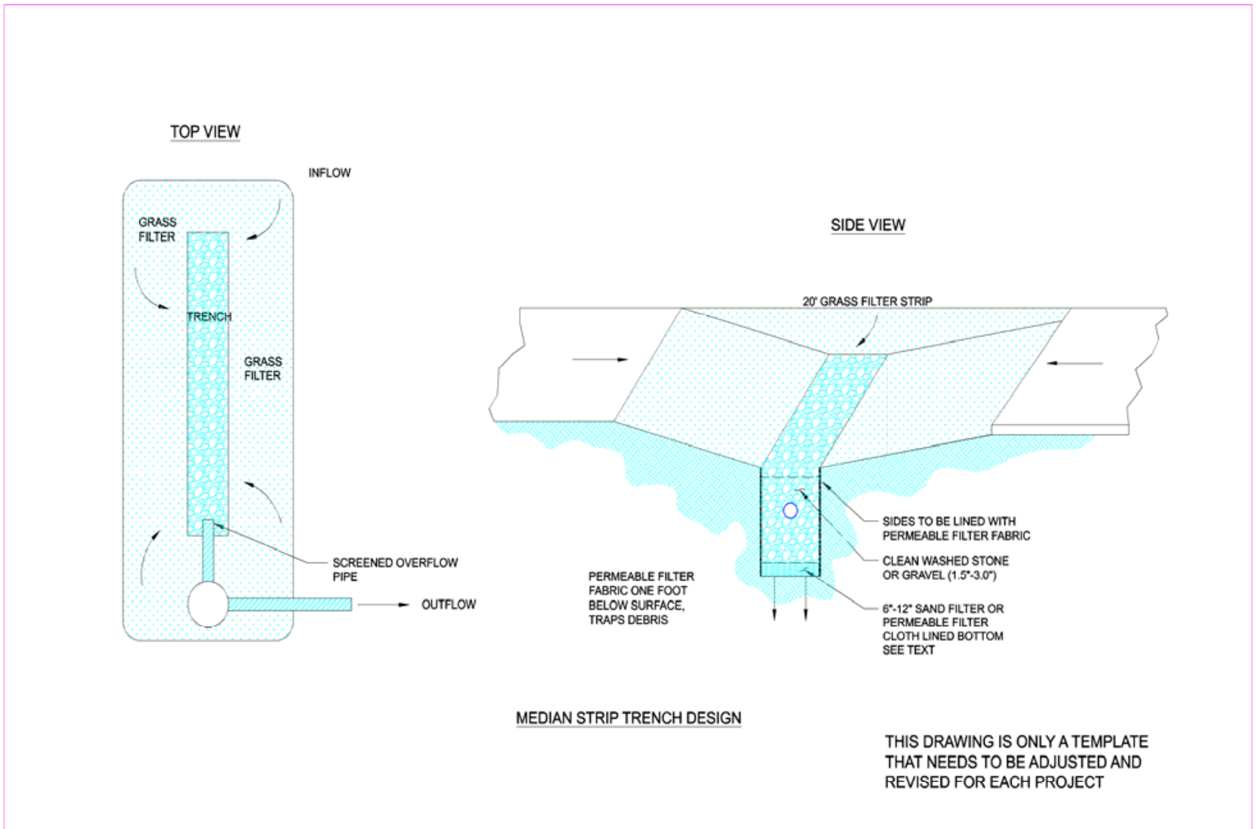
Source: Schueler.

Figure AR.05.1. Parking lot perimeter trench design.



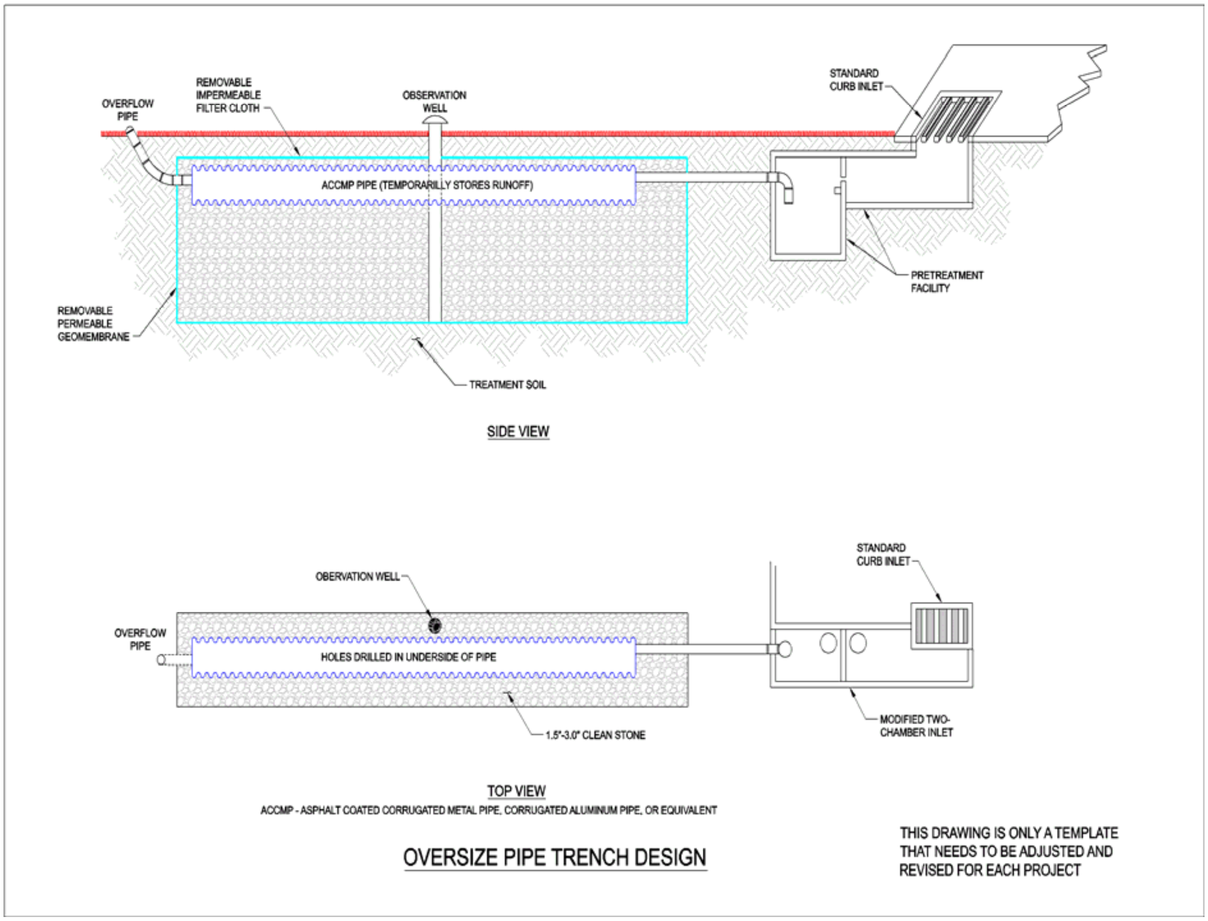
Source: Schueler.

Figure AR.05.2. Infiltration trench system.



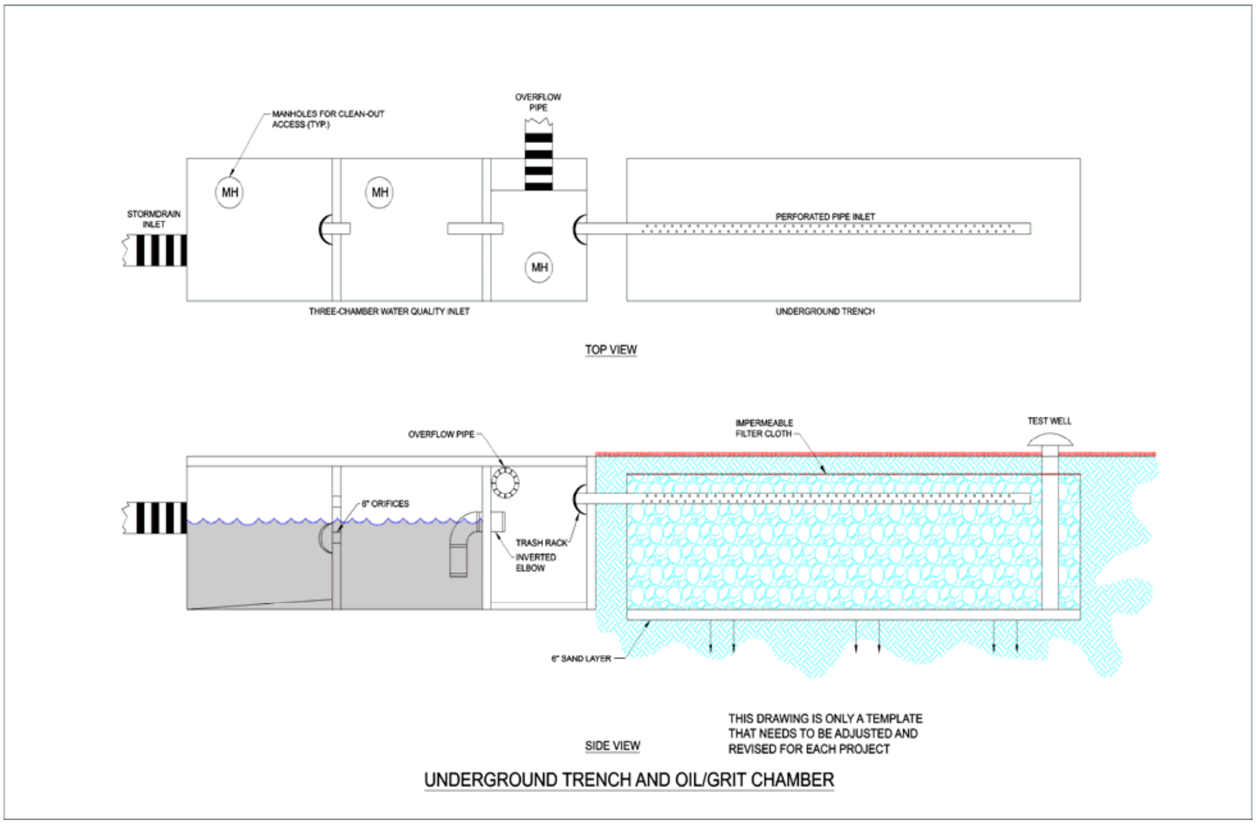
Source: Schueler.

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.

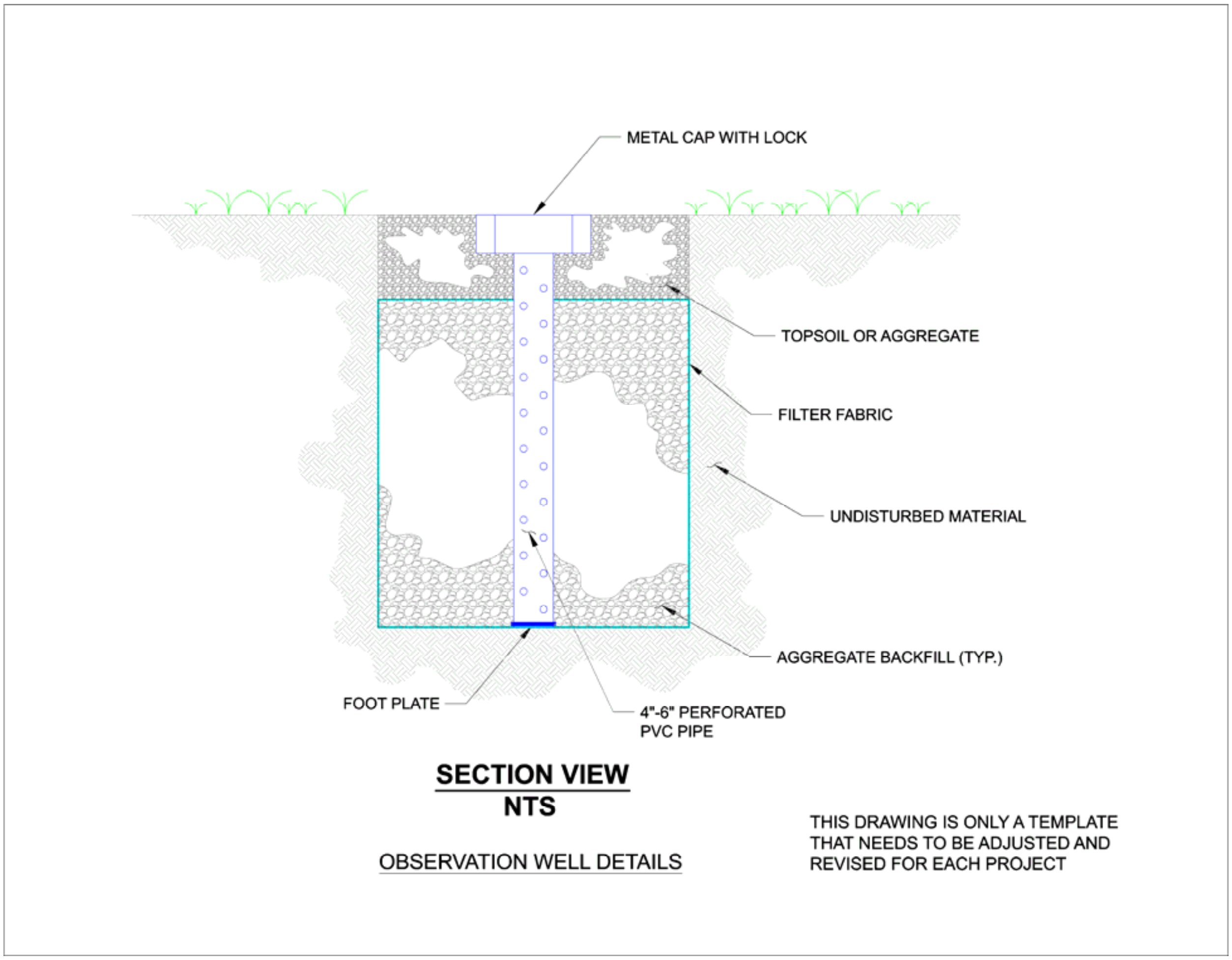
See the *References* section (at the end of this manual) for publications by the Federal Highway Administration (FHWA) (1995) for design guidance on geotextiles in drainage applications, and the National Cooperative Highway Research Program (NCHRP) (1994) for long-term performance data and background 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

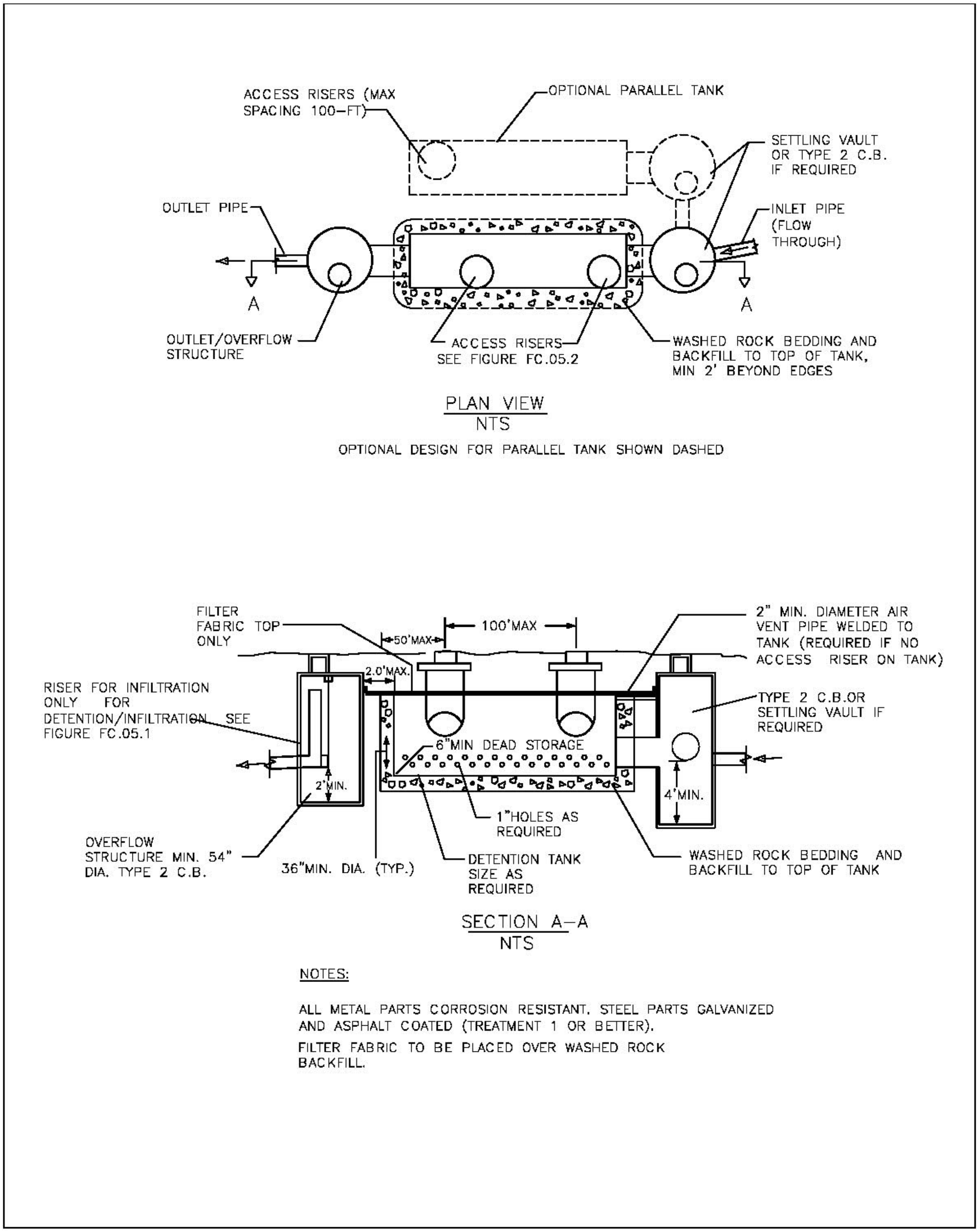


Figure AR.06.1. Infiltration vault constructed with corrugated pipe.

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 <u>Section 6-3</u> 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.

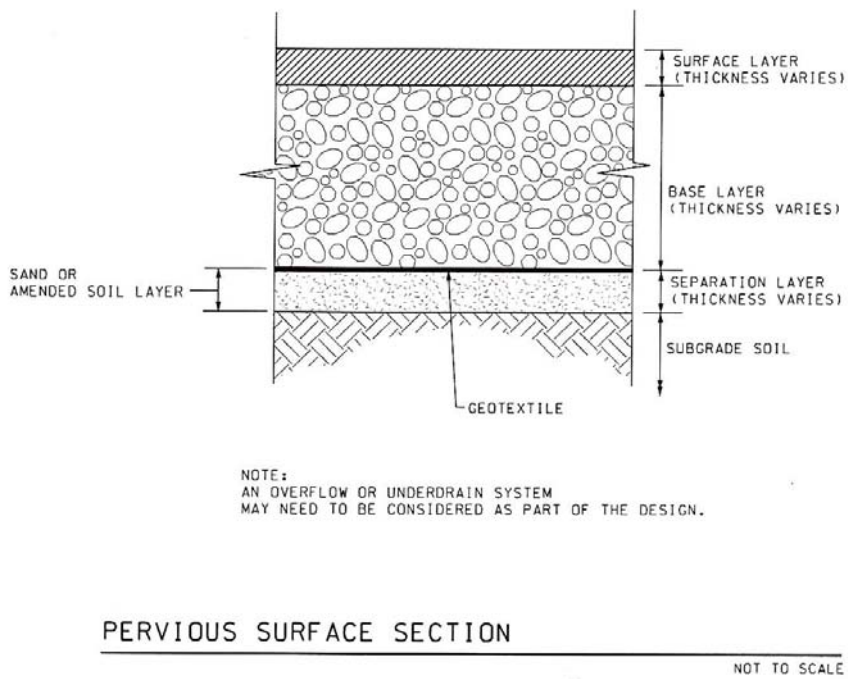


Figure AR.08.1. Permeable pavement surface detail.

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.

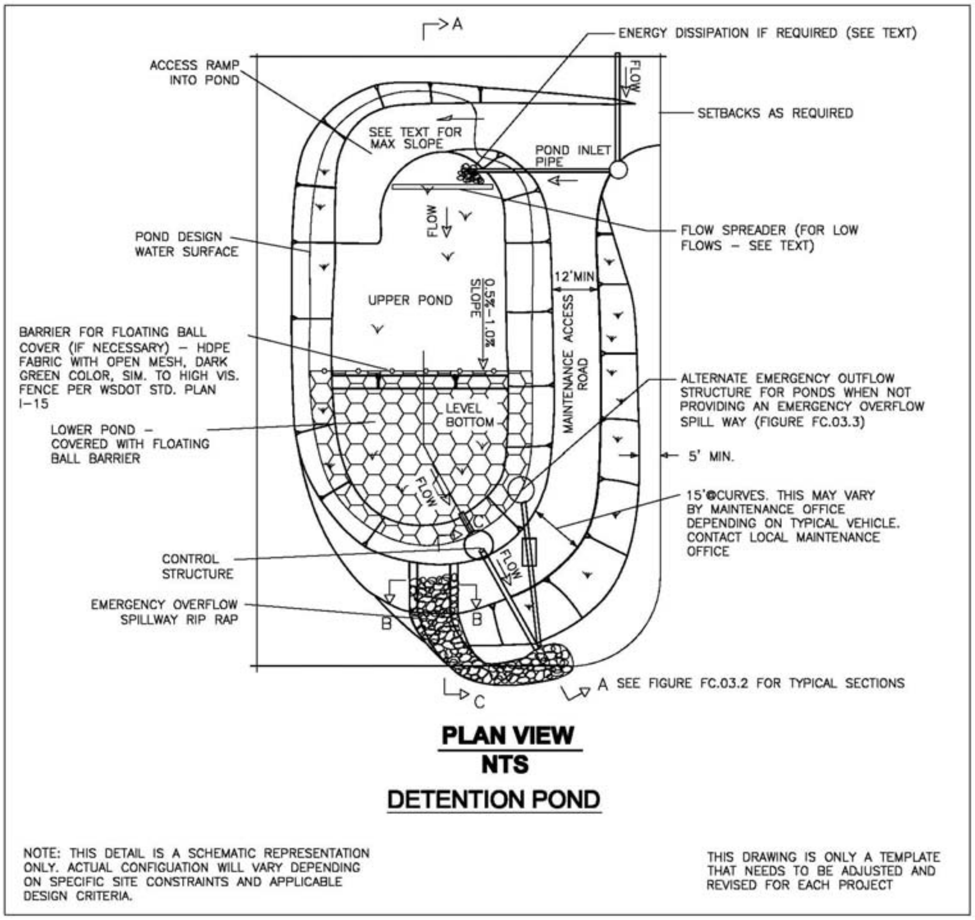


Figure AR.09.1. Detention pond.

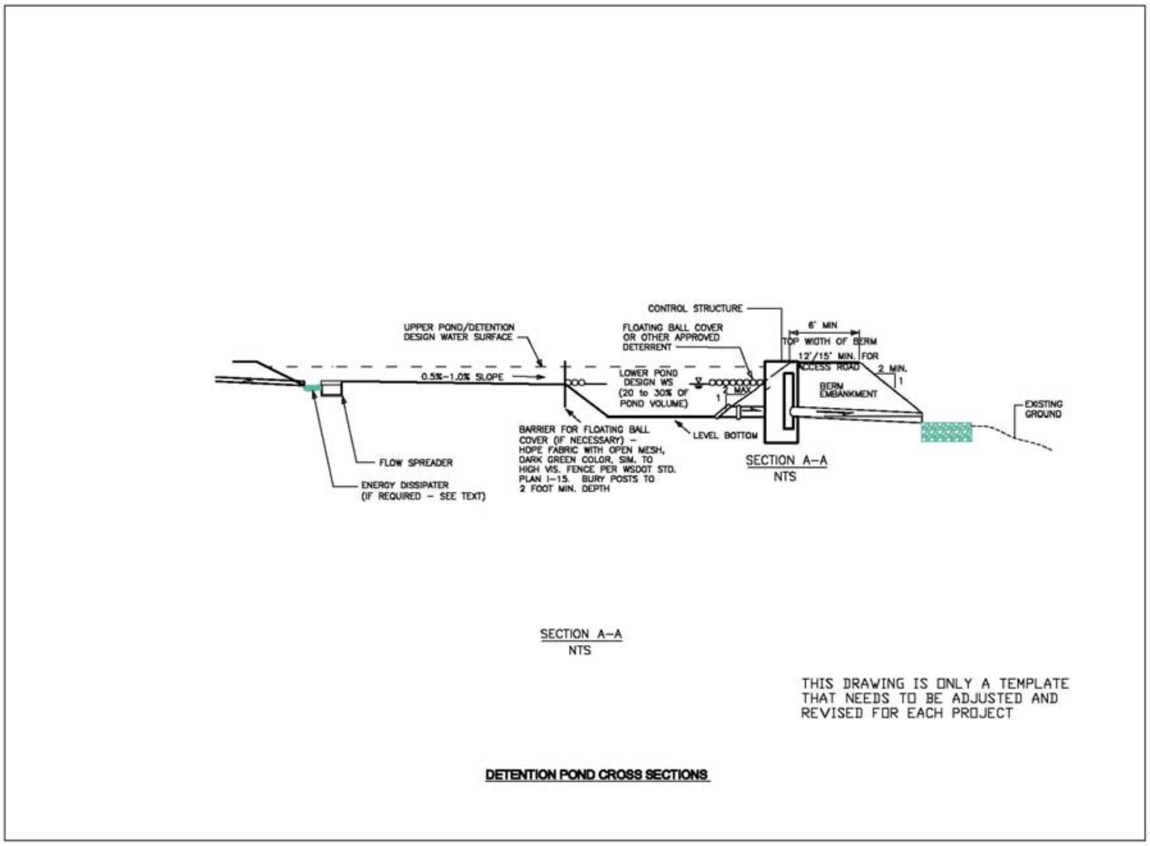


Figure AR.09.2. Detention pond: cross sections.

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).

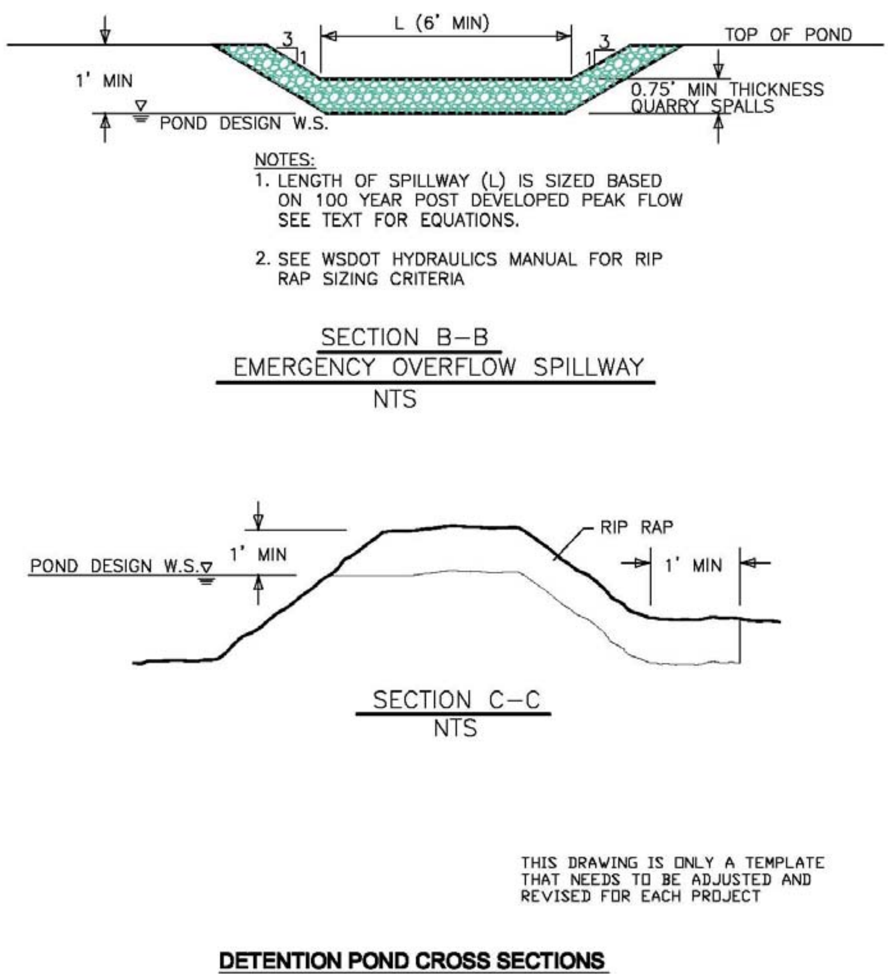


Figure AR.09.3. Overflow spillway cross section.

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):

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

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.

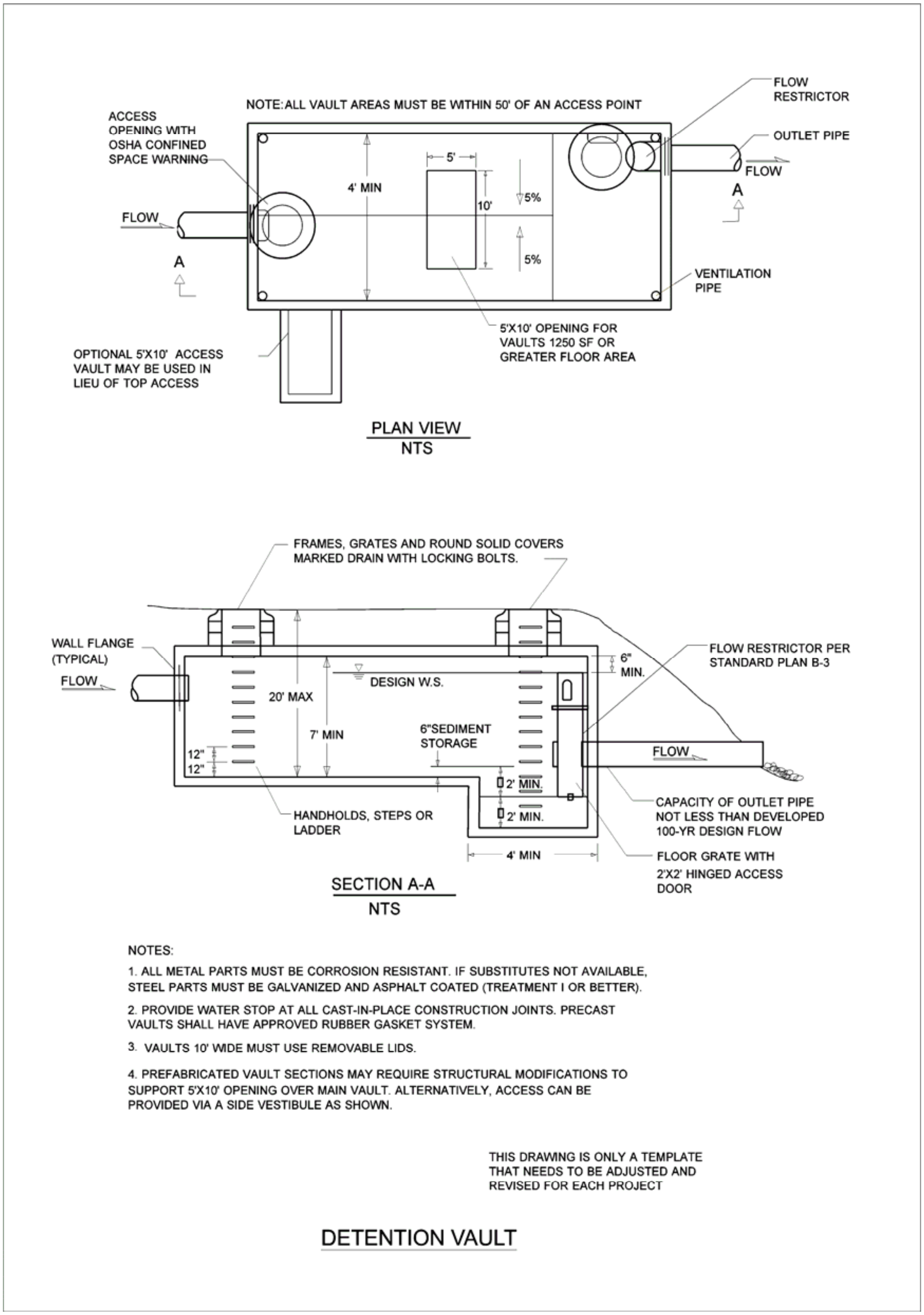


Figure AR.10.1. Detention vault.

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.

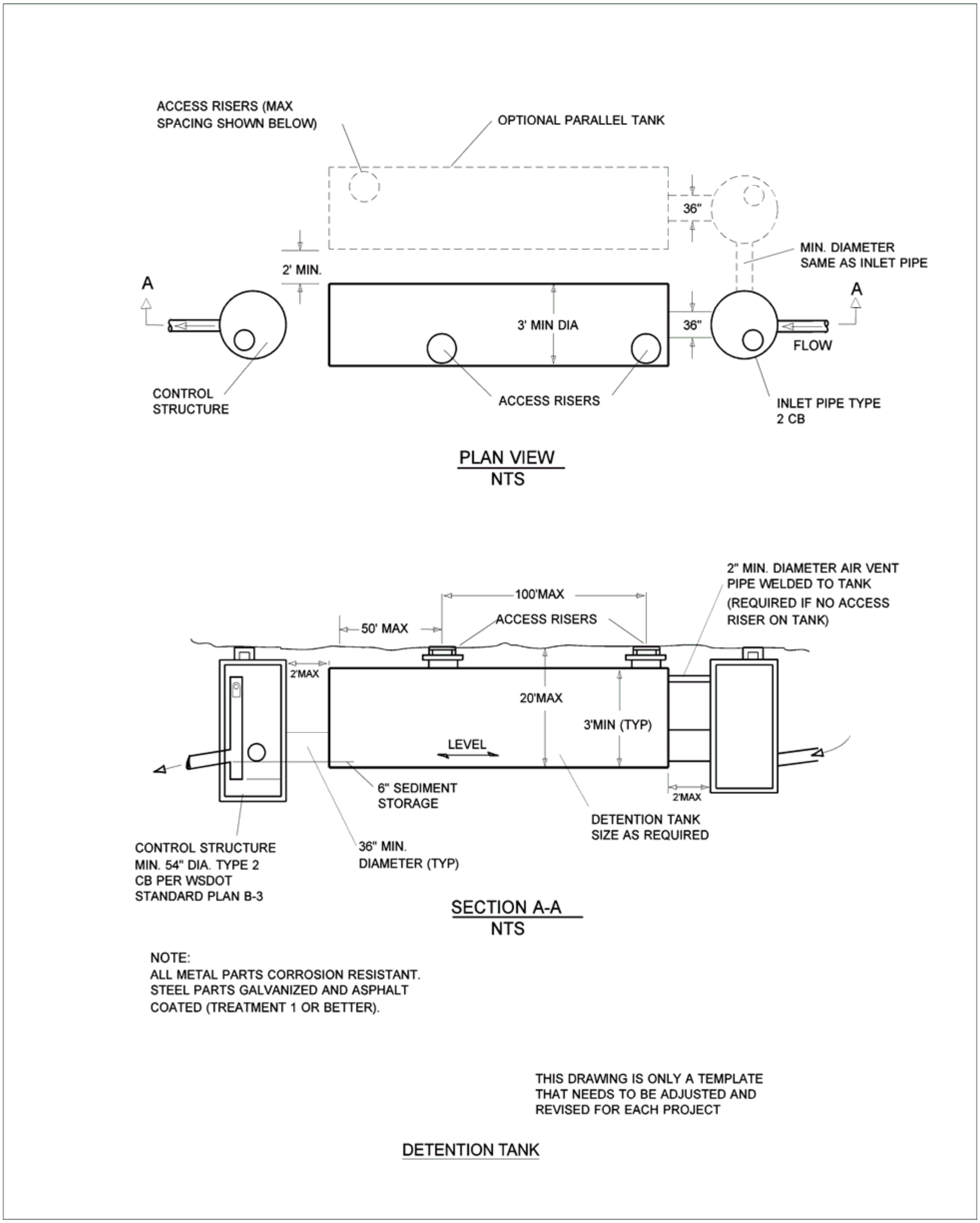


Figure AR.11.1. Detention tank.

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.

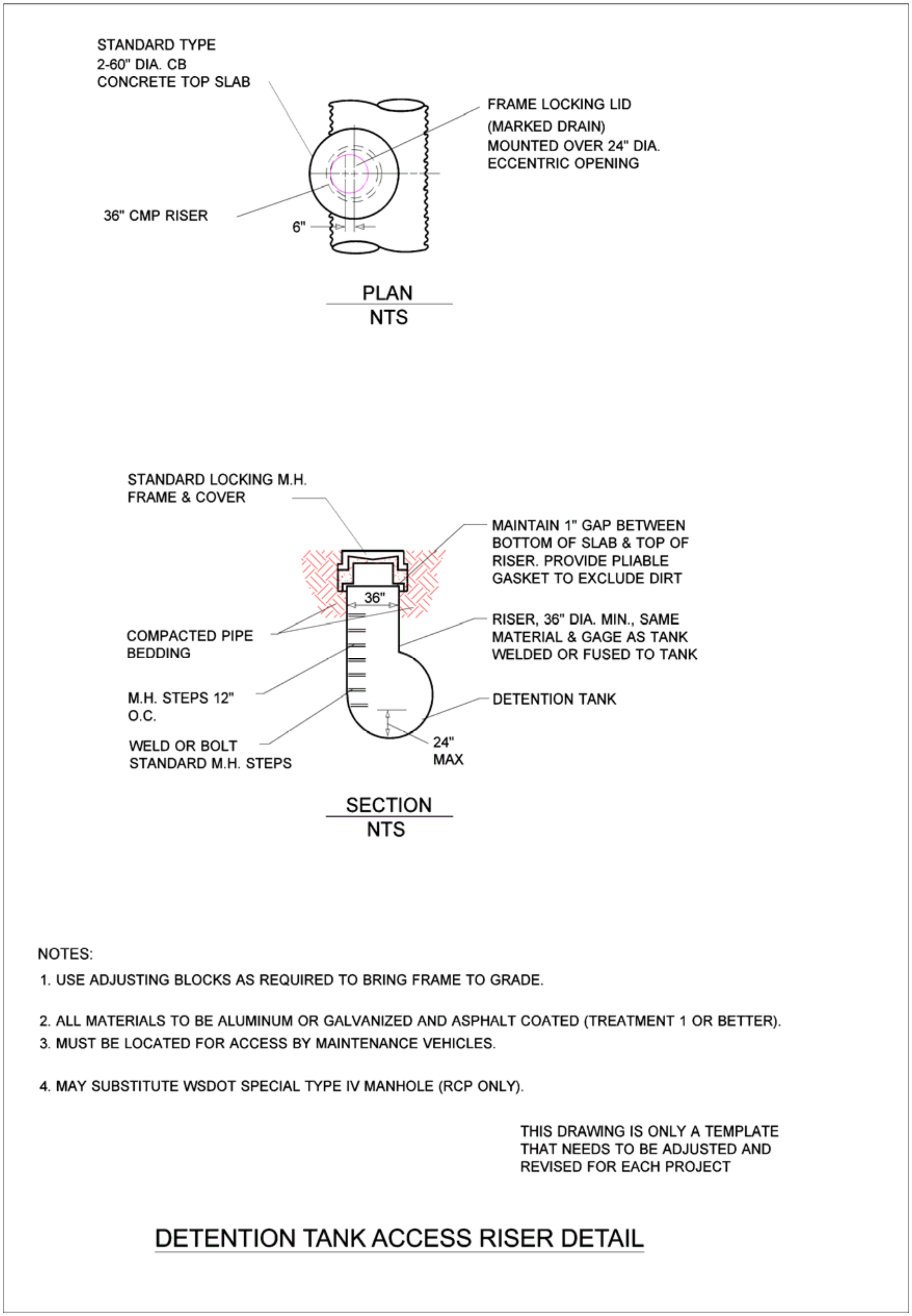


Figure AR.11.2. Detention tank access riser detail.

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	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

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

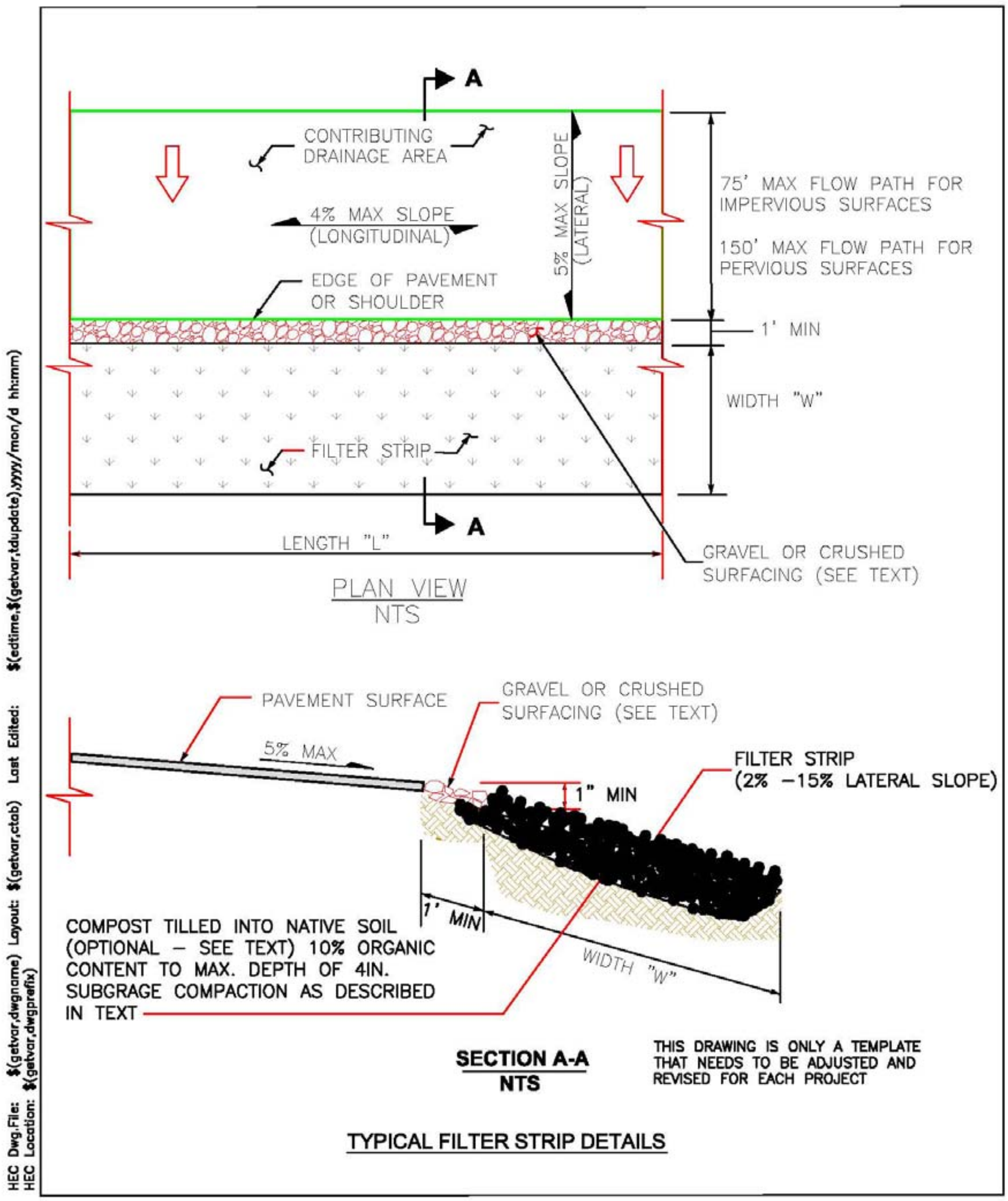


Figure AR.12.1. Typical vegetated filter strip.

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.

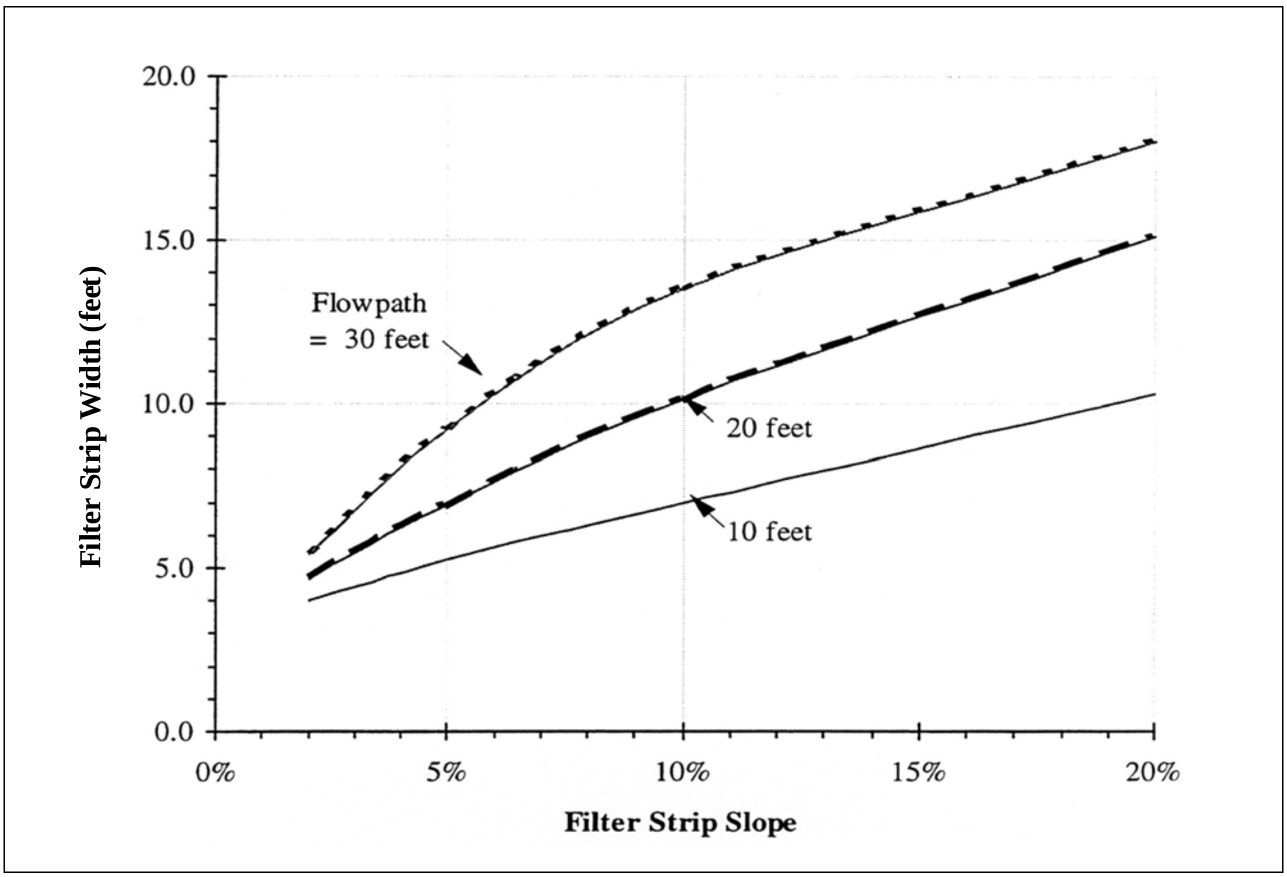


Figure AR.12.2. Narrow area vegetated filter strip design graph.

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	Object Free Area (OFA)	Maybe*
Western Washington	Yes	Runway Safety Area (RSA)	No
Landside Areas	Yes	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).

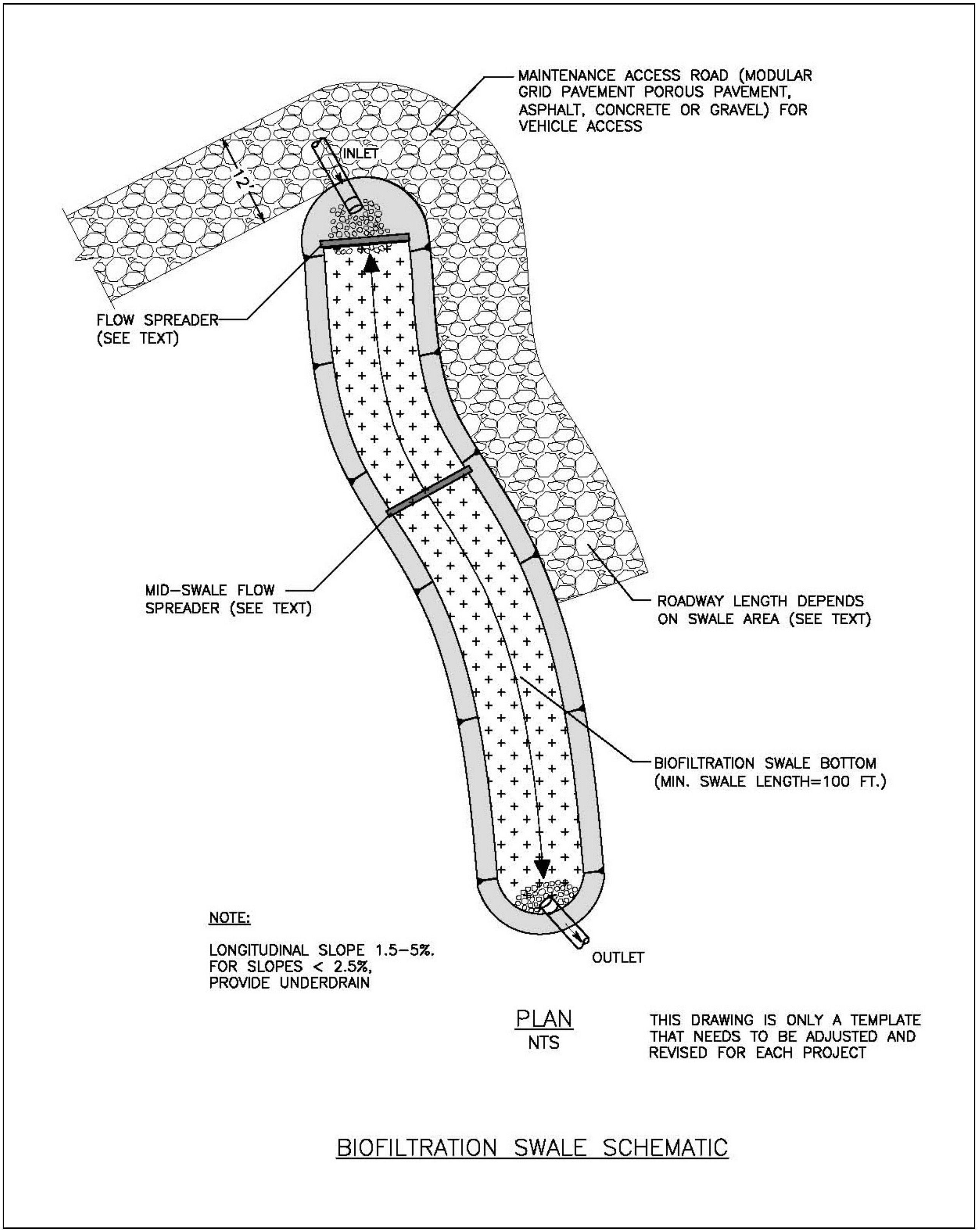


Figure AR.13.1. Biofiltration swale: plan view.

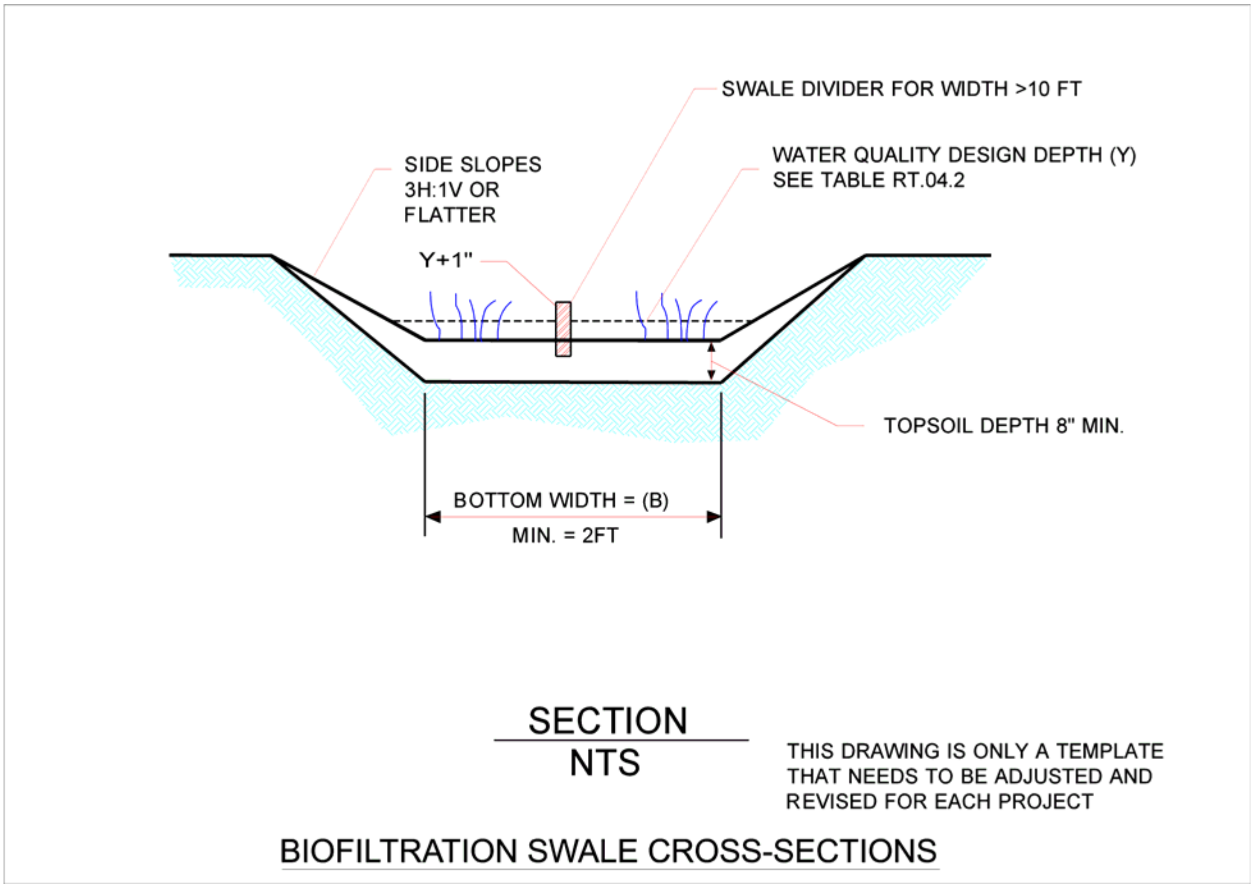


Figure AR.13.2. Biofiltration swale: cross section.

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.

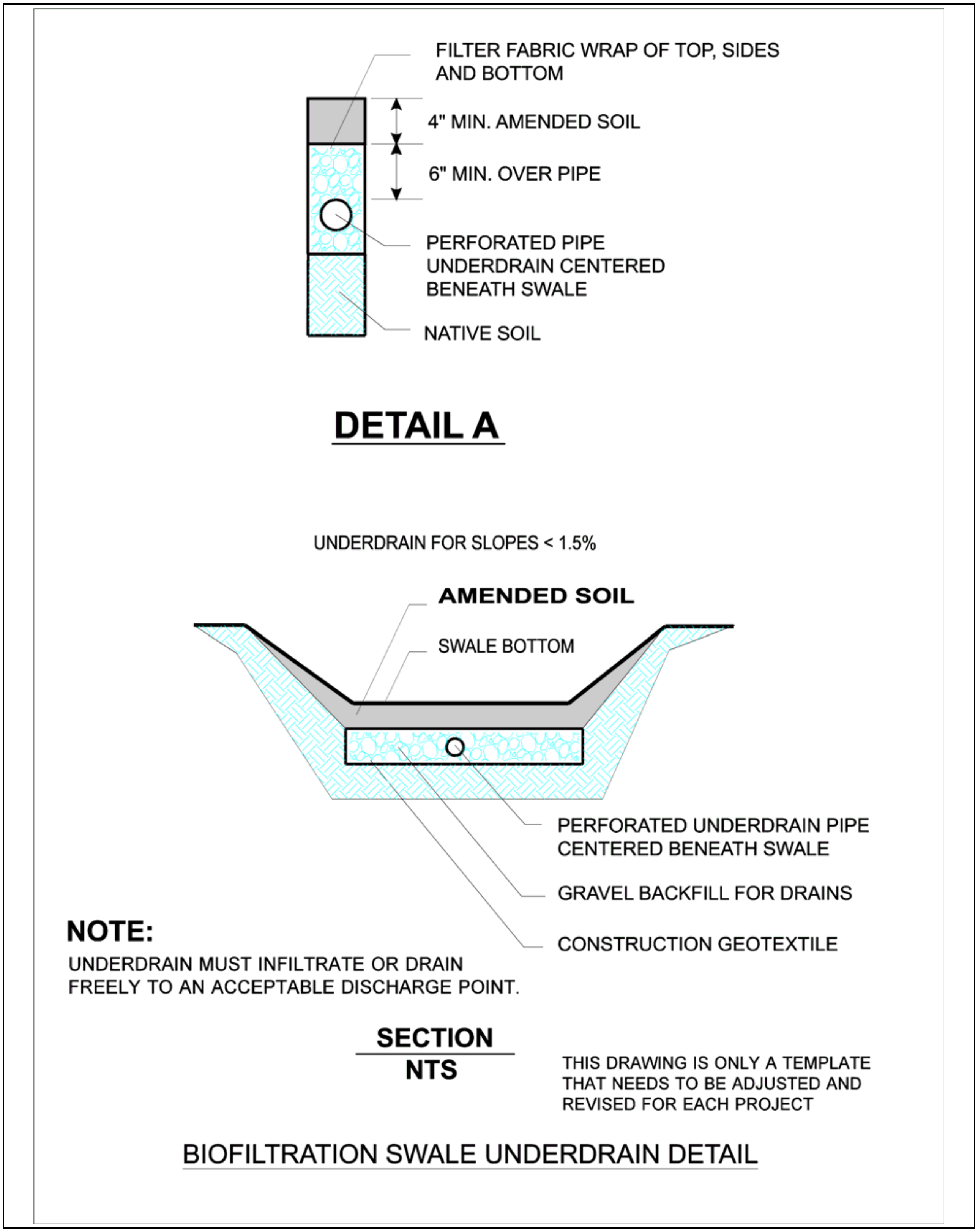


Figure AR.13.3. Biofiltration swale: underdrain detail.

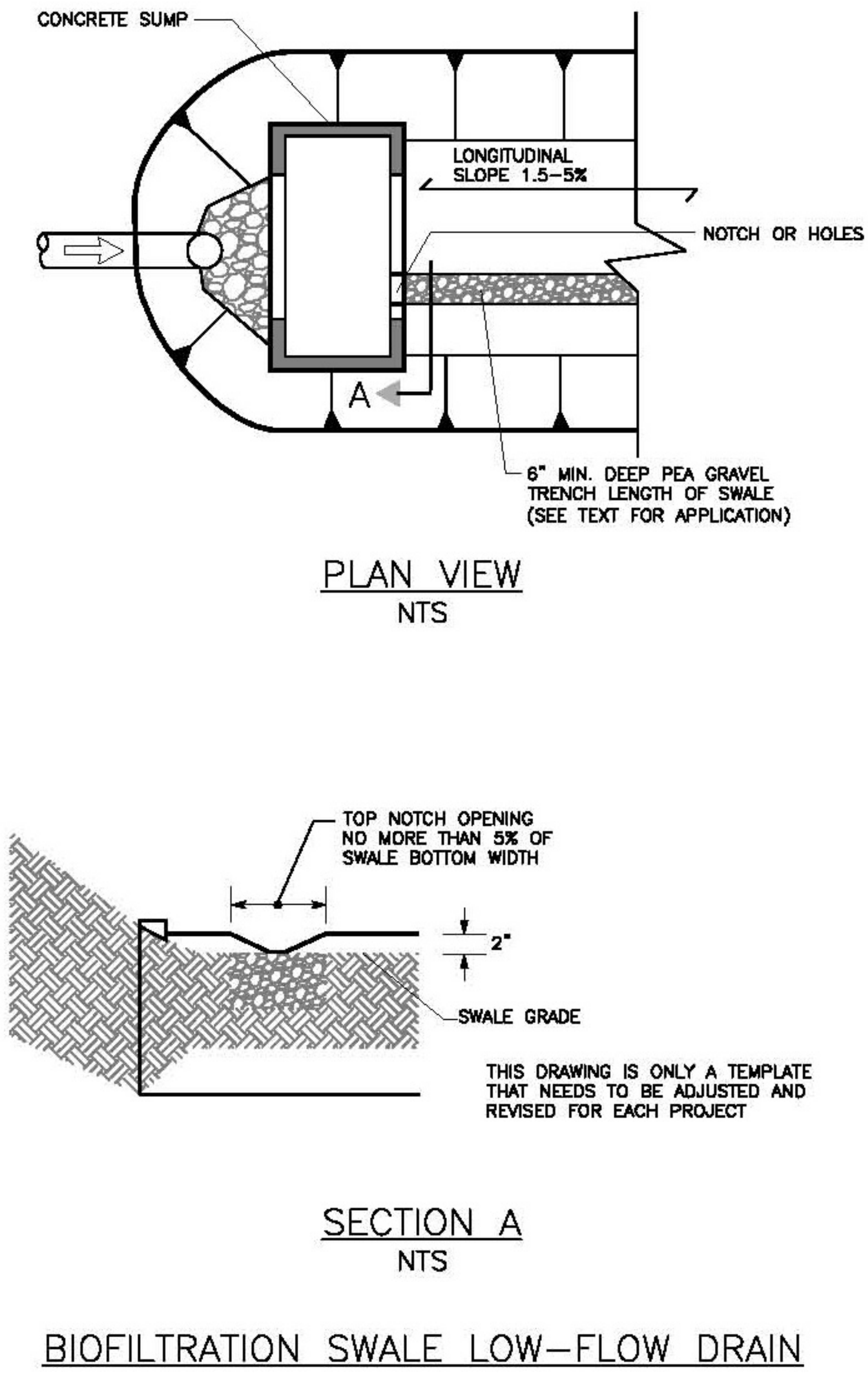


Figure AR.13.4. Biofiltration swale: low-flow drain detail.

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:

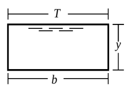
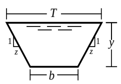
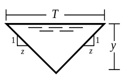
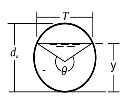
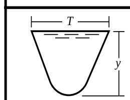
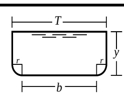
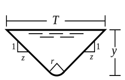
$$Q_{biofil} = \frac{1.49AR^{2/3}s^{1/2}}{n} \qquad \textbf{(AR.13-1)}$$

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 $AR^{0.67} = Q_{biofil}\, n / (1.49s^{0.5})$ 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	$2y\sqrt{1 + z^2}$	$\frac{zy}{2\sqrt{1 + z^2}}$	$2zy$	$\frac{1}{2}y$	$\frac{\sqrt{2}}{2}zy^{2.5}$
 Circle	$\frac{1}{8}(\theta - \sin\theta)d_o^2$	$\frac{1}{2}\theta d_o$	$\frac{1}{4}\left(1 - \frac{\sin\theta}{\theta}\right)d_o$	$(\sin(\frac{1}{2}\theta)d_o)$ *or* $2\sqrt{y(d_o - y)}$	$\frac{1}{8}\left(\frac{\theta - \sin\theta}{\sin\frac{1}{2}\theta}\right)d_o$	$\frac{\sqrt{2}}{32}\frac{(\theta - \sin\theta)^{1.5}}{(\sin\frac{1}{2}\theta)^{0.5}}d_o^{2.5}$
 Parabola	$\frac{2}{3}Ty$	$T + \frac{8y^2}{3T}$ *	$\frac{2T^2y}{3T^2 + 8y^2}$ *	$\frac{3A}{2y}$	$\frac{2}{3}y$	$\frac{2}{9}\sqrt{6}Ty^{1.5}$
 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 $P = (\frac{T}{2})\left[\sqrt{1 + x^2} + \frac{1}{x}\ln\left(x + \sqrt{1 + x^2}\right)\right]$

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.

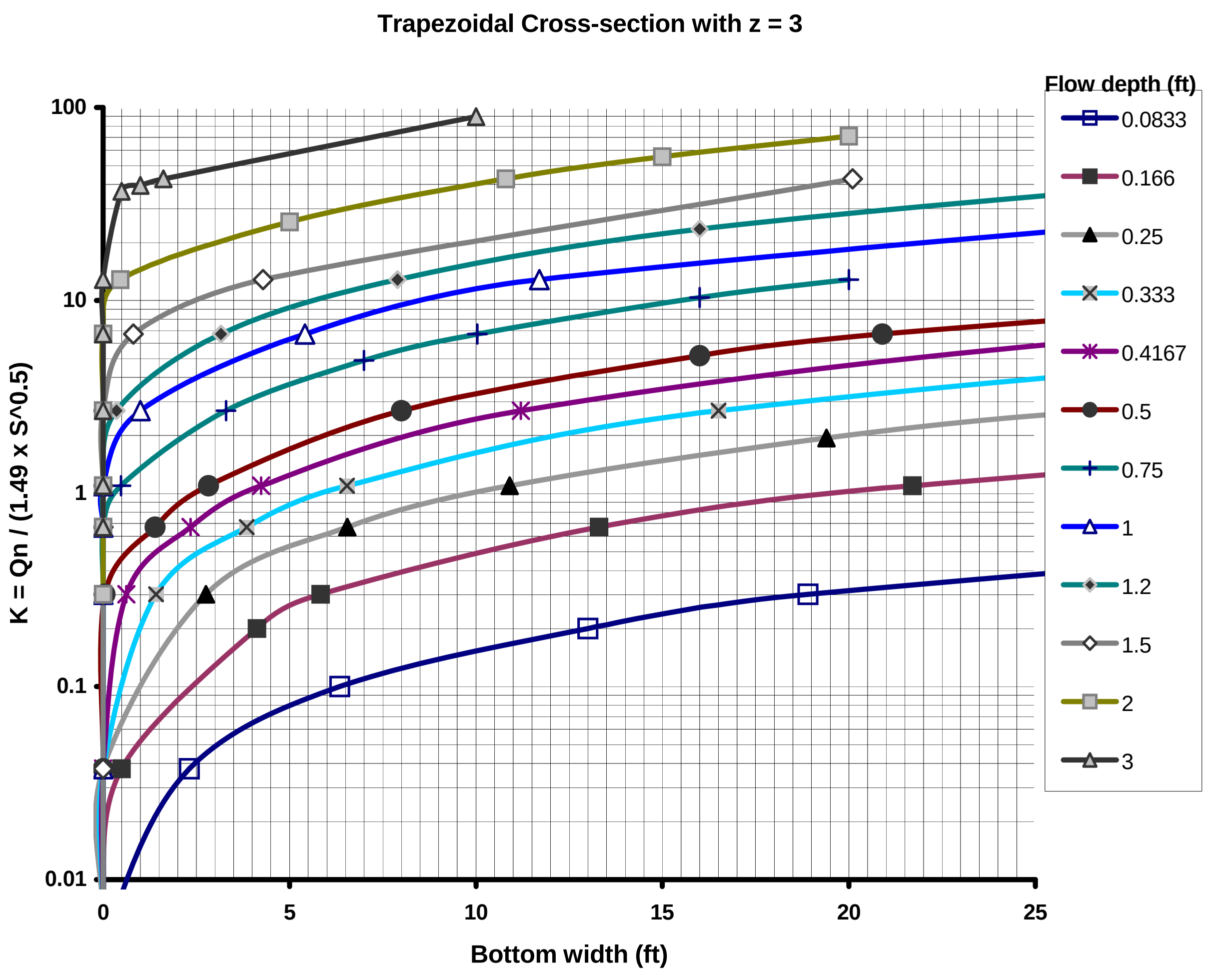


Figure AR.13.6. Open channel flow parameter, Qn/(1.49 $s^{0.5}$), versus bottom width (b) at different flow depths (z=3).

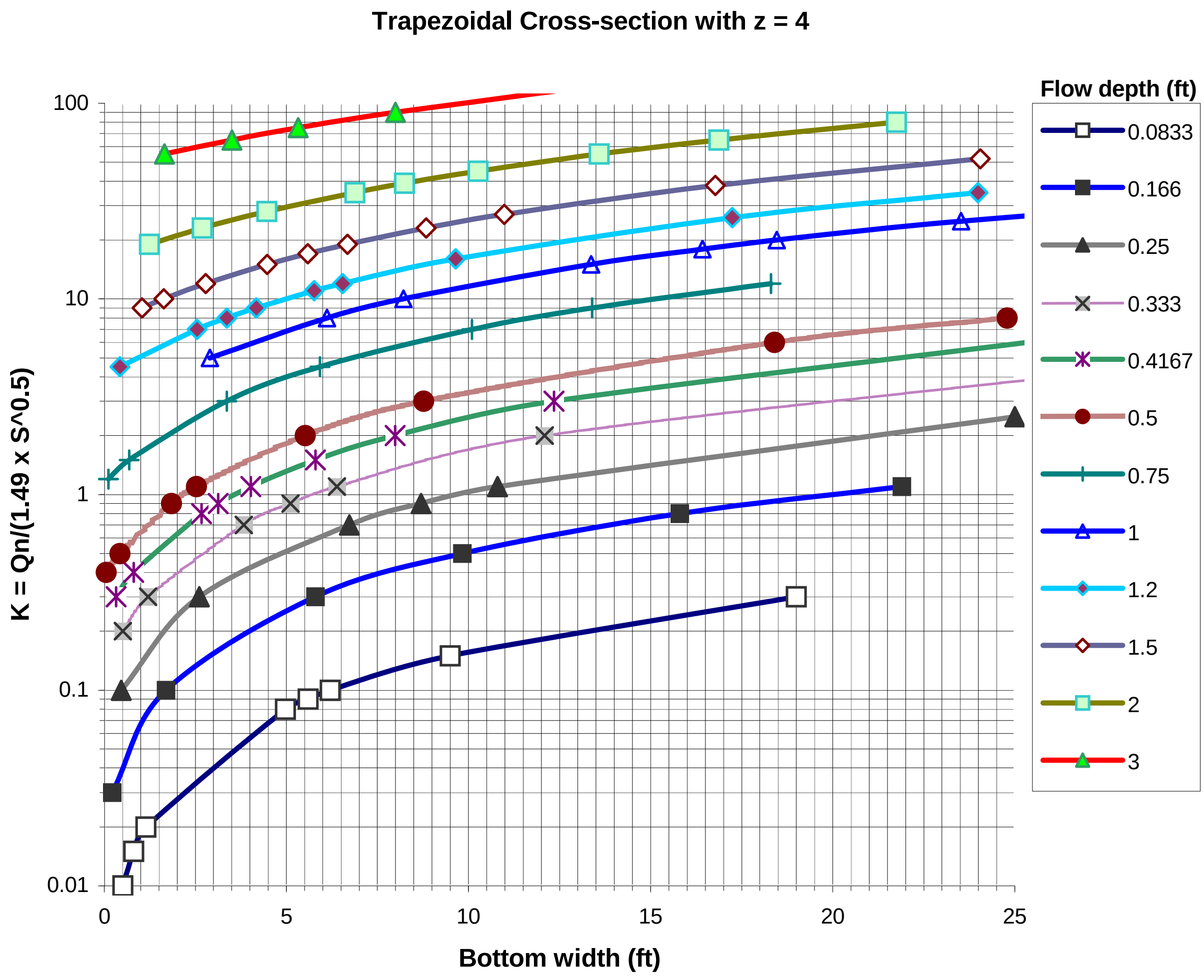


Figure AR.13.7. Open channel flow parameter, Qn/(1.49 $s^{0.5}$), versus bottom width (b) at different flow depths (z=4).

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.

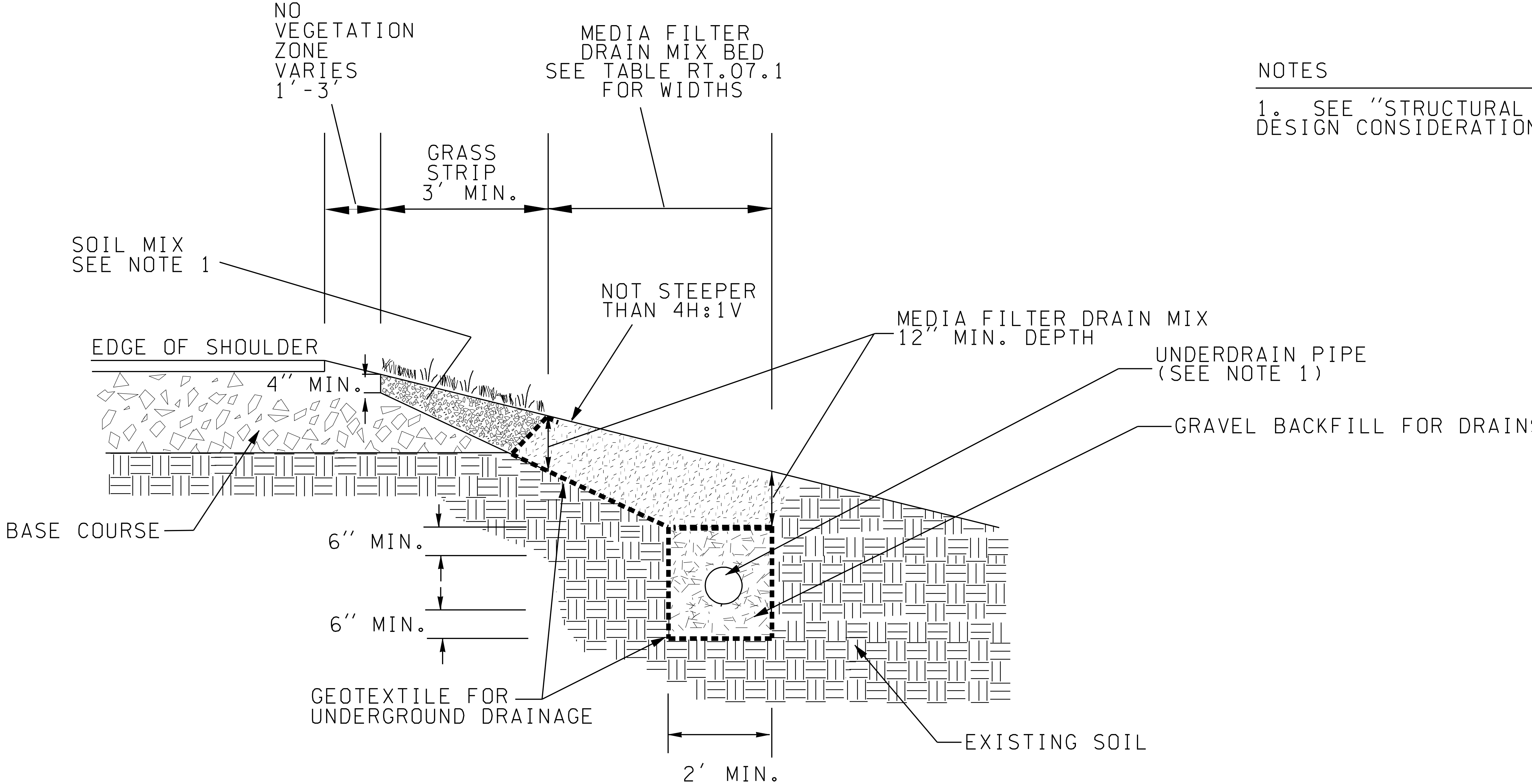
The underdrain trench is an option for hydraulic conveyance of treated stormwater to a desired location, such as a downstream flow control facility or stormwater outfall and should be evaluated for infiltration loss. The trench's perforated underdrain pipe is a protective measure to ensure free flow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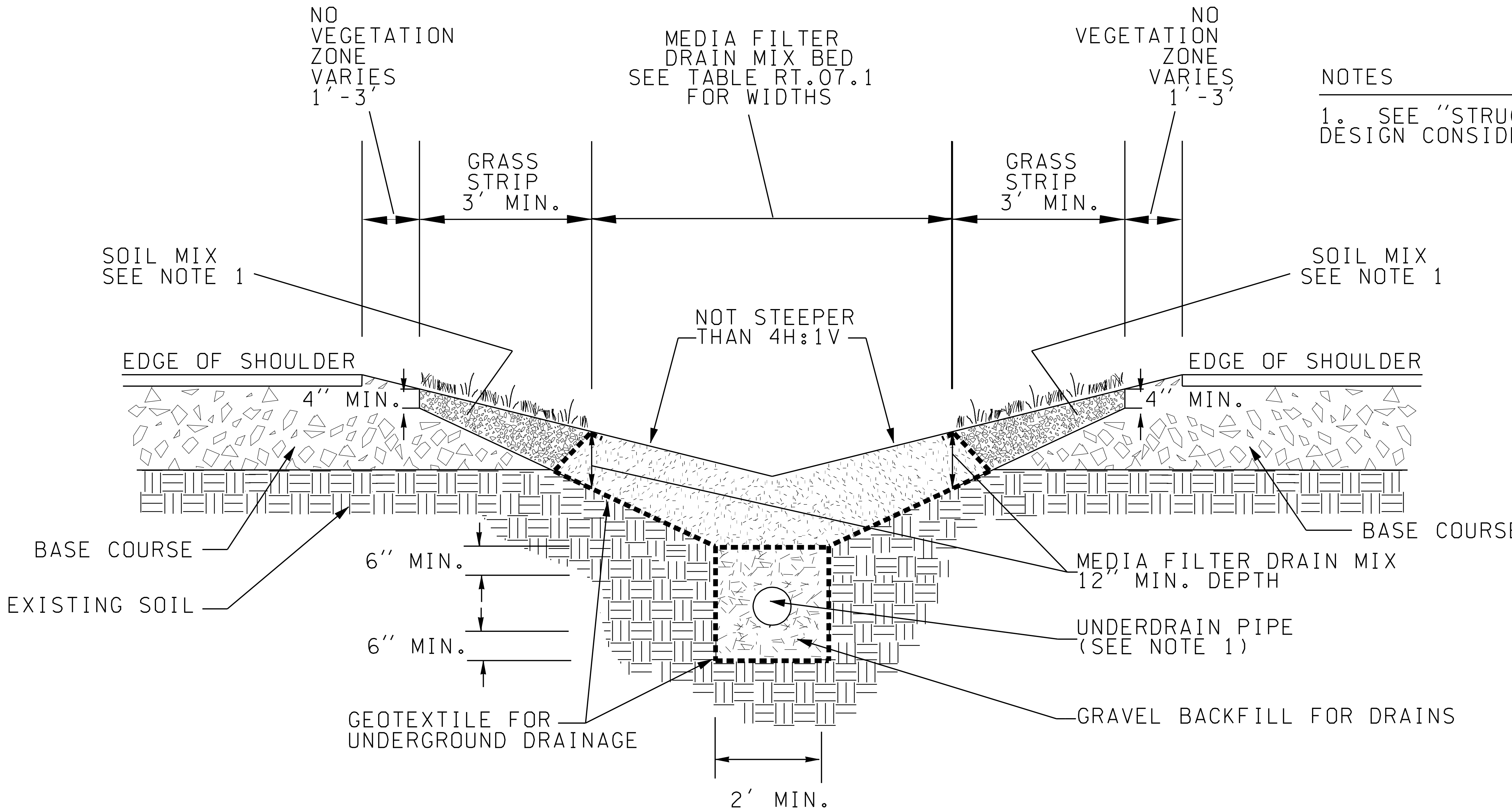
Washington State Department of Transportation

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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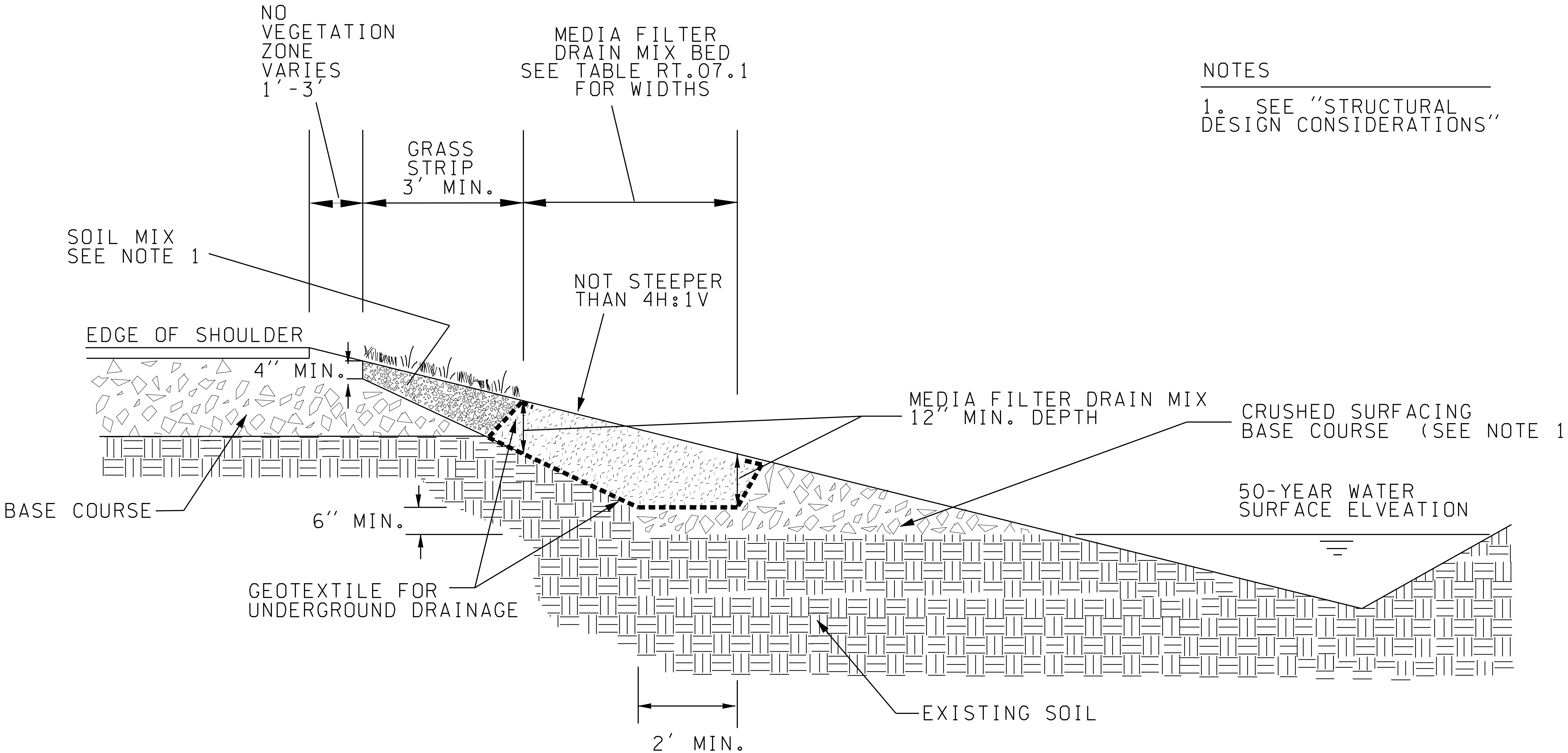
FIGURE 14.2
DUAL MEDIA FILTER DRAIN CROSS-SECTION

PLOT2

SHEET OF SHEETS



NOTES

1. SEE "STRUCTURAL DESIGN CONSIDERATIONS"

MEDIA FILTER DRAIN

SIDE SLOPE APPLICATION WITHOUT UNDERDRAIN

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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:

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

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 $CaSO_4{\bullet}2H_2O$ (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.

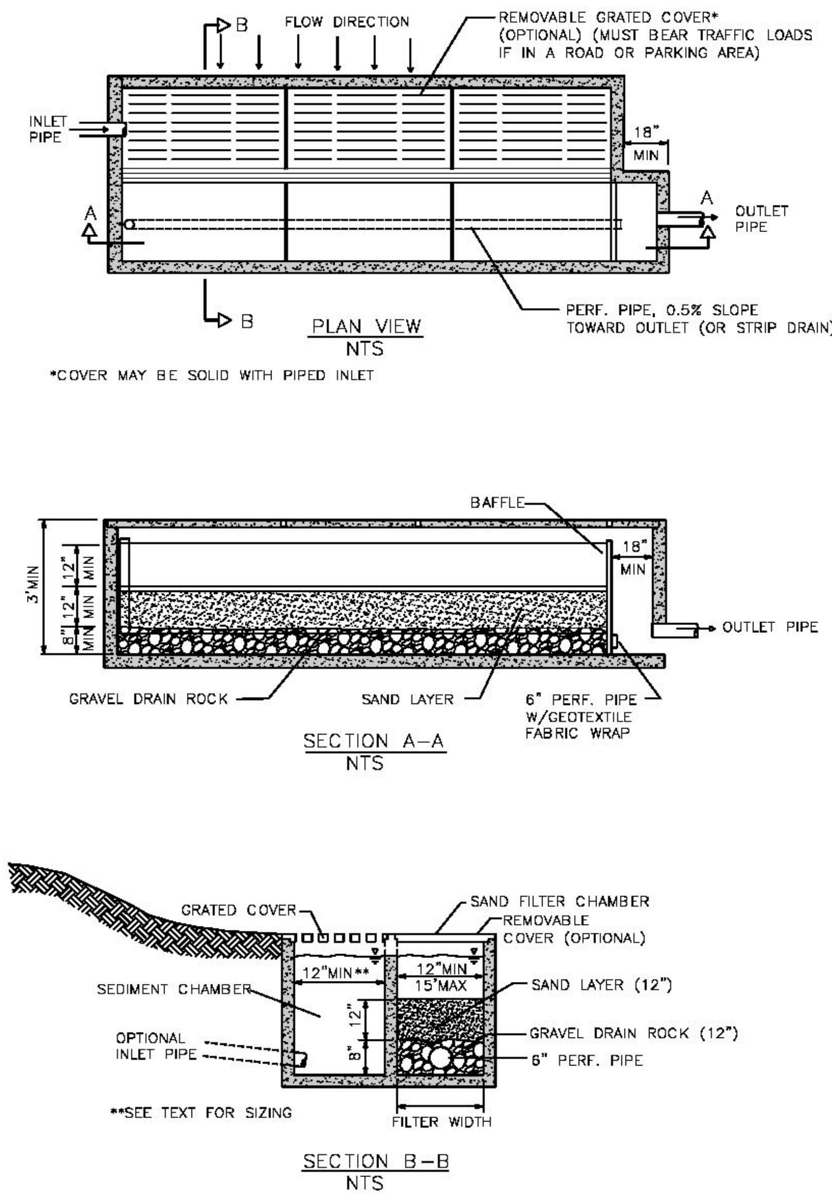

Figure AR.15.1. Linear sand filter with sediment chamber.

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.

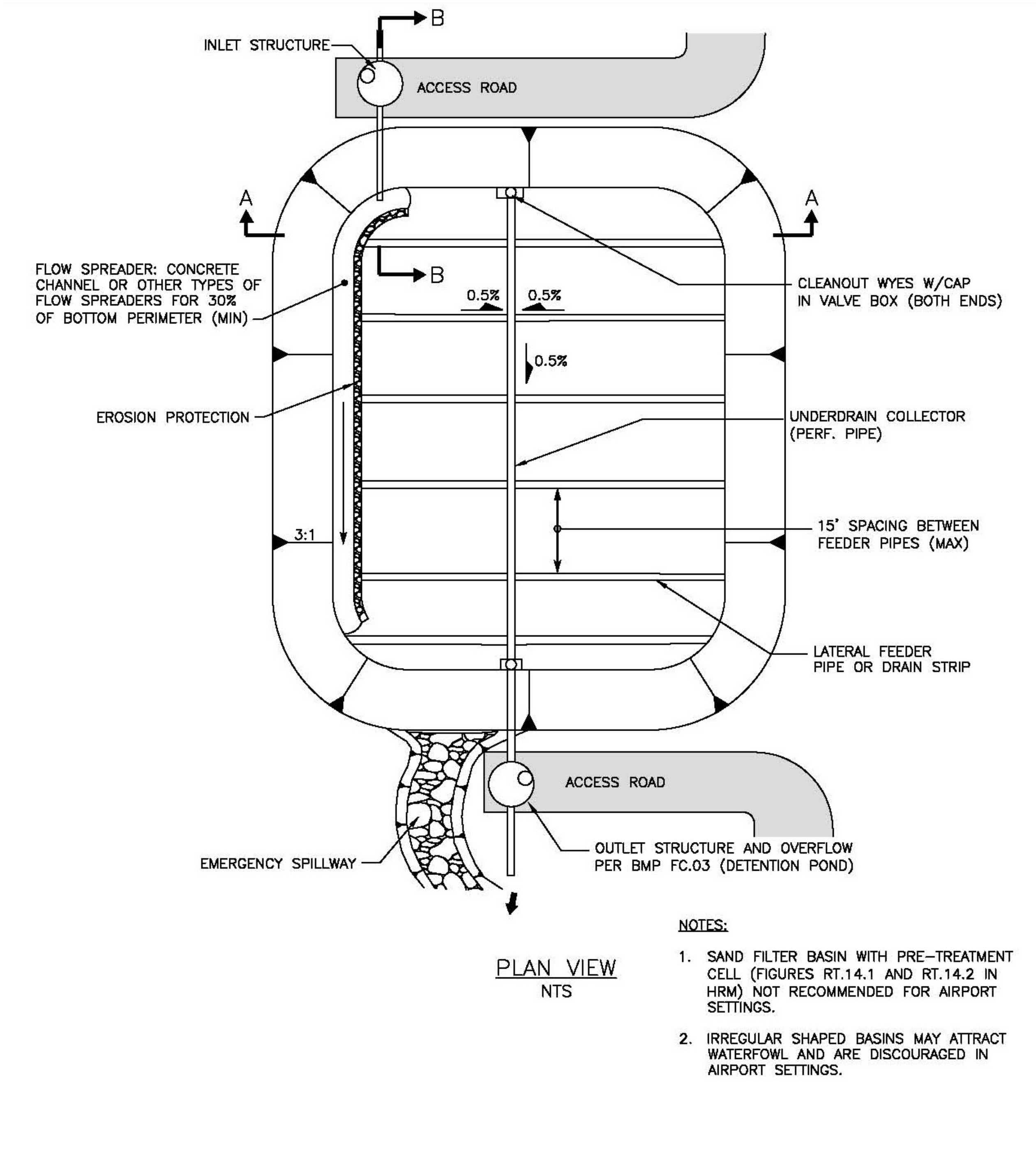

Figure AR.16.1. Sand filter basin with flow spreader.

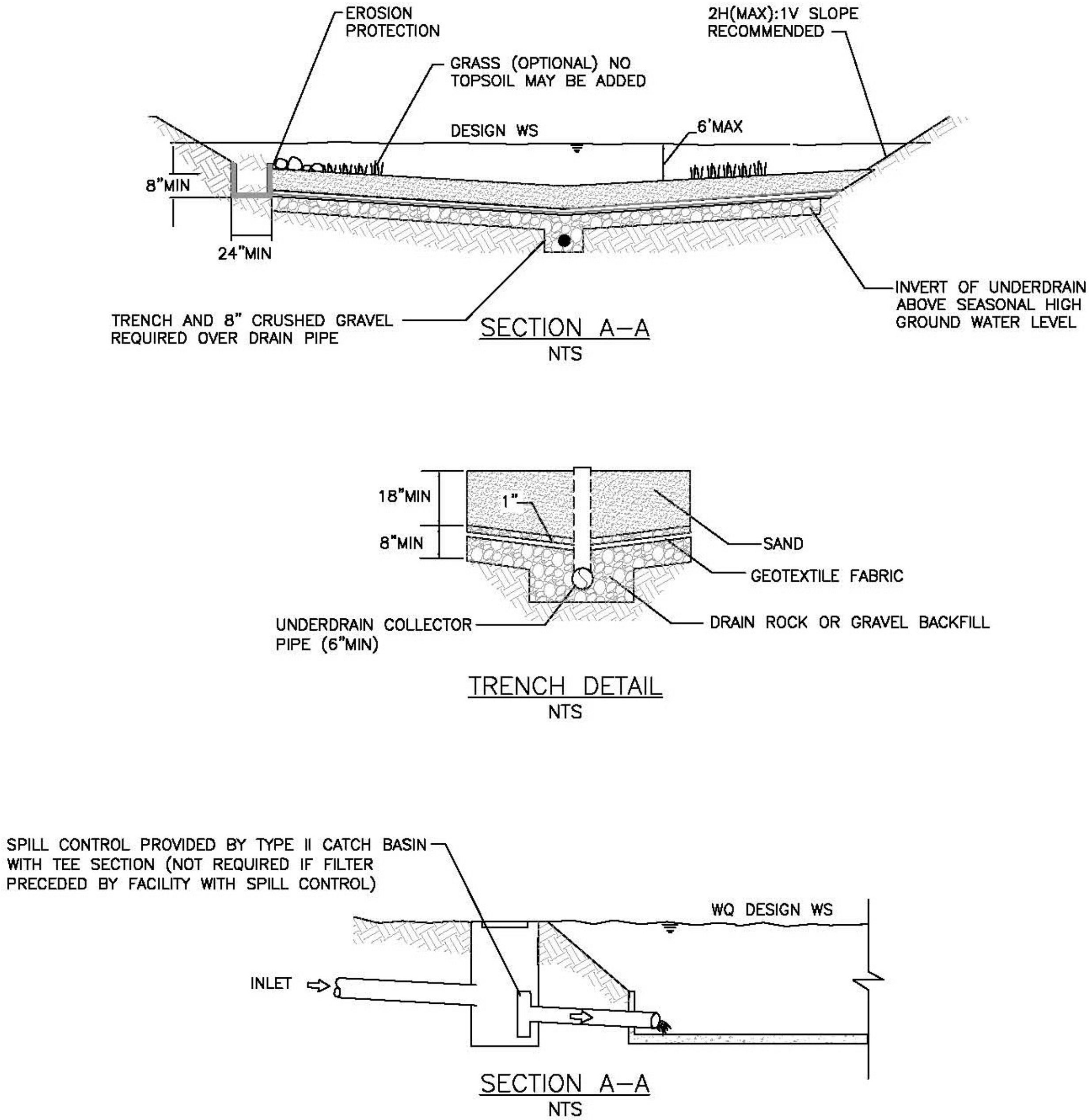

Figure AR.16.2. Sand filter basin with flow spreader: detail and cross sections.

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.

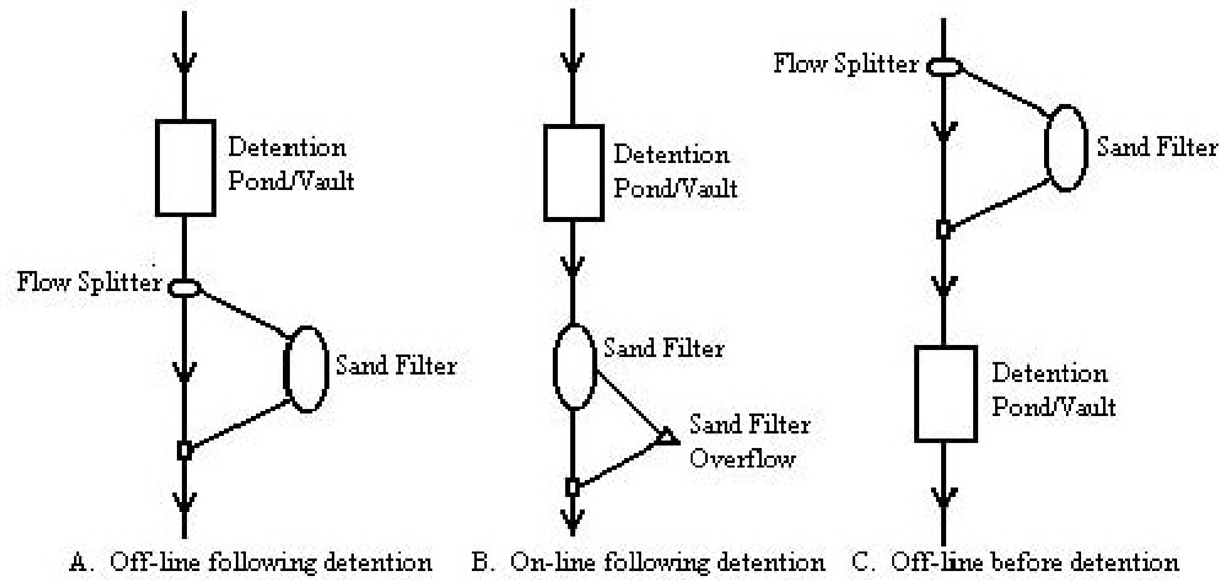

Figure AR.16.3. System layout options for sand filters with detention BMPs.

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.

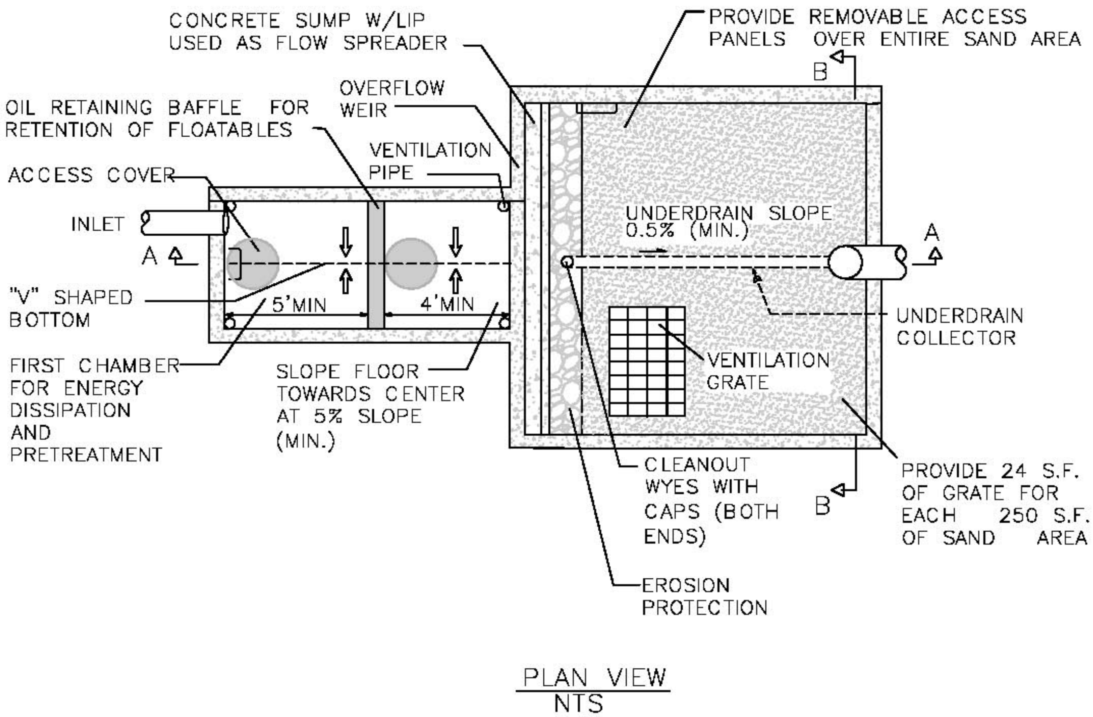

Figure AR.17.1. Sand filter vault.

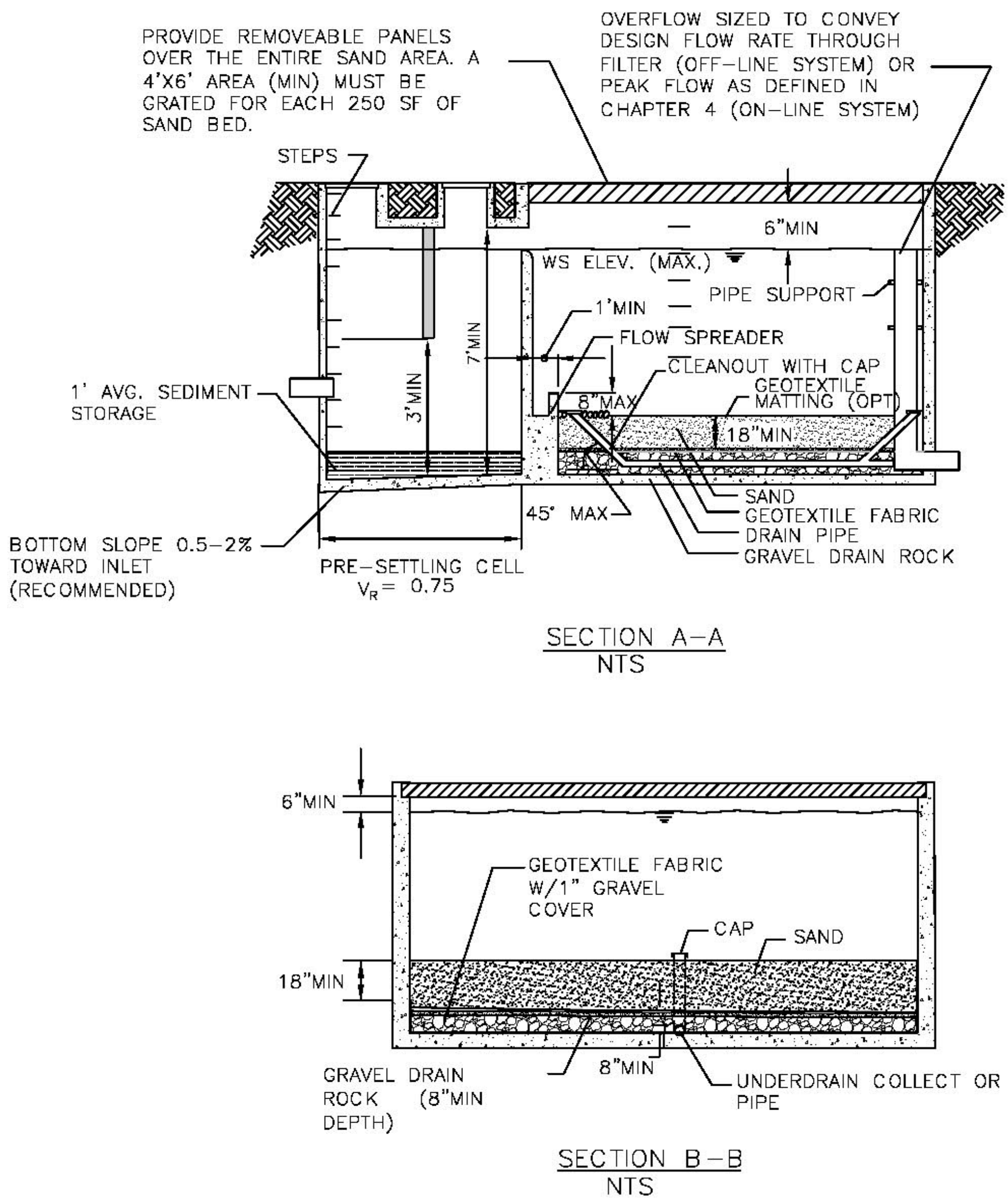

Figure AR.17.2. **Sand filter vault: Cross sections.**

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
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

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.

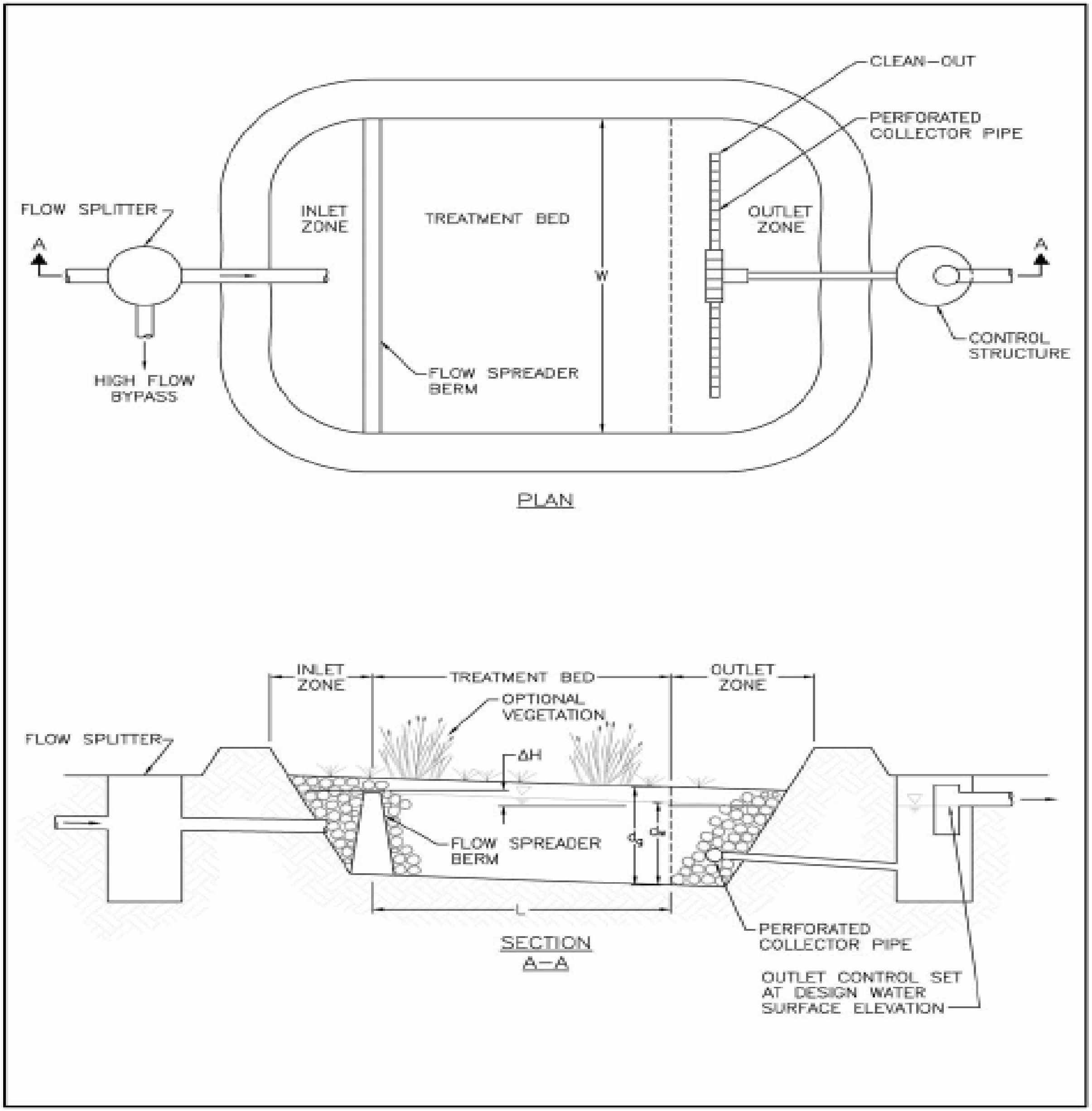

Figure AR.20.1. **Submerged gravel biofilter: plan and section.**

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.

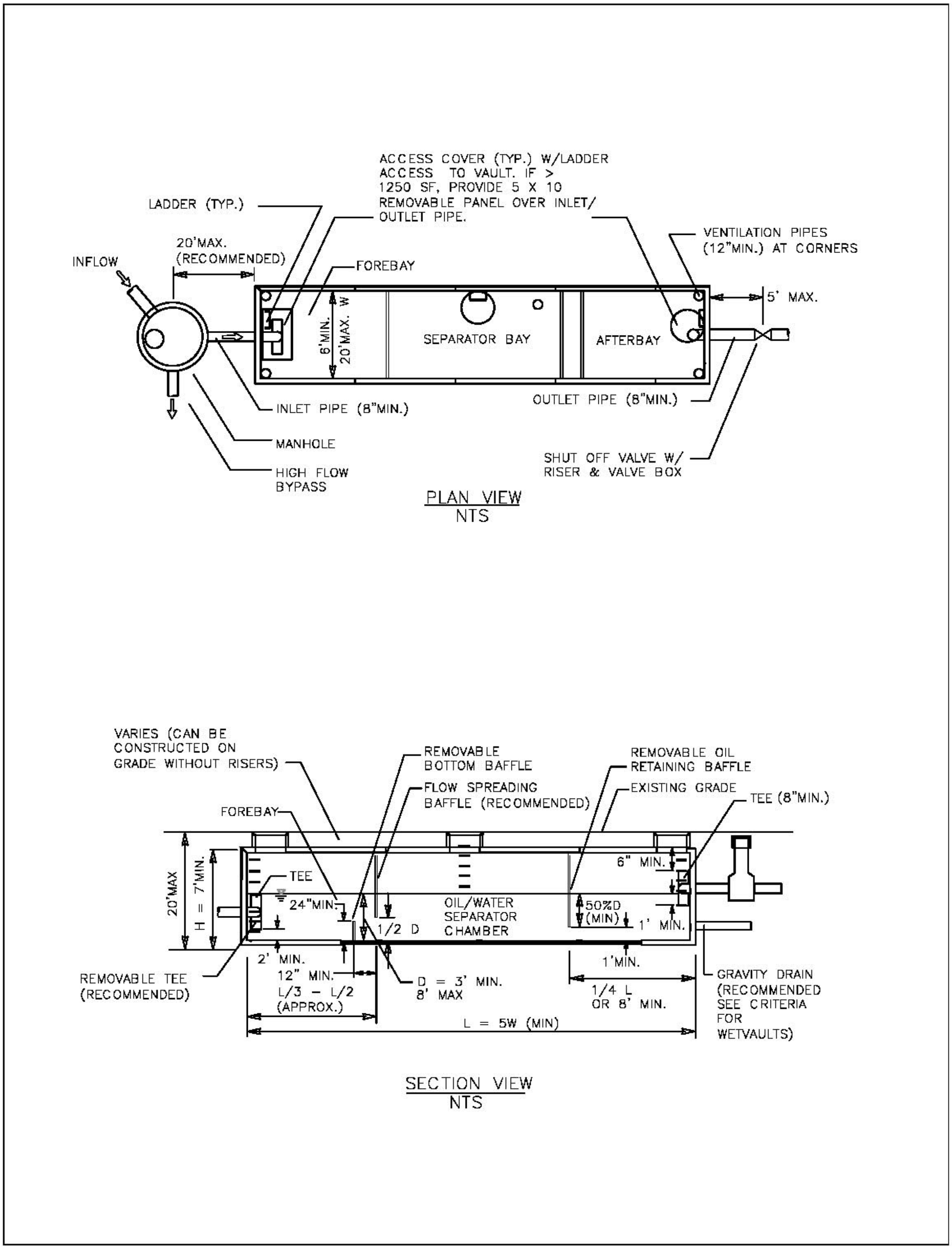

Figure AR.21.1. Baffle-type (API) oil/water separator.

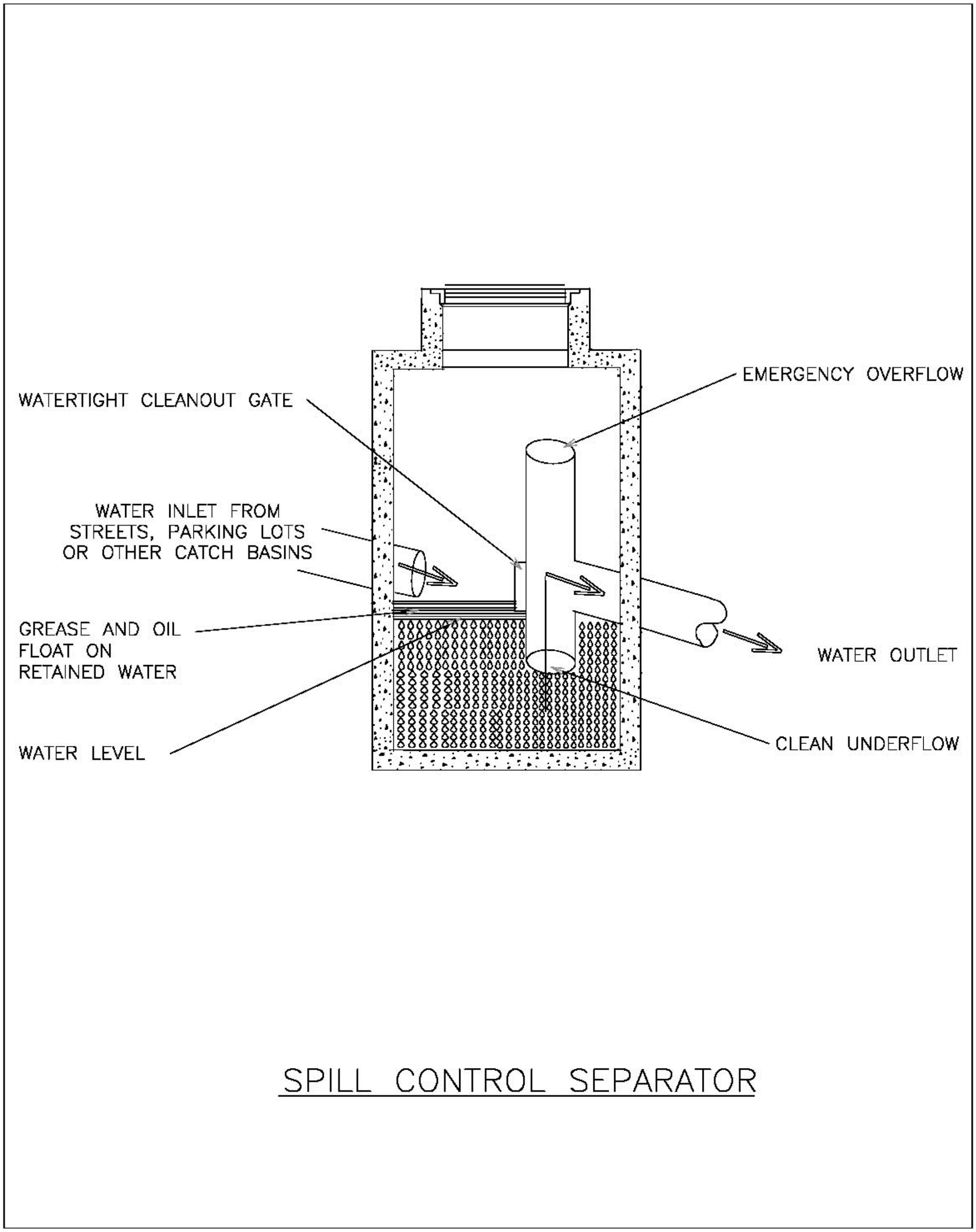

Figure AR.21.2. Spill control separator.

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):

$$V_h = Q/dw = Q/A_v \text{ (} V_h \text{ maximum at < 2.0 ft/min) (API 1990)}$$

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).

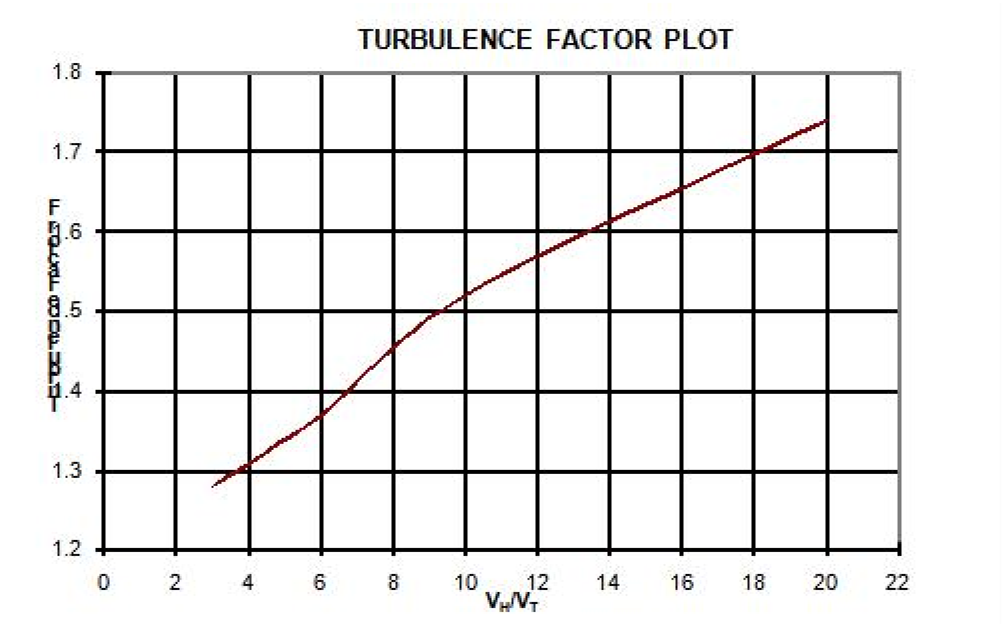

Figure AR.21.3. Turbulence factor plot.

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
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

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).

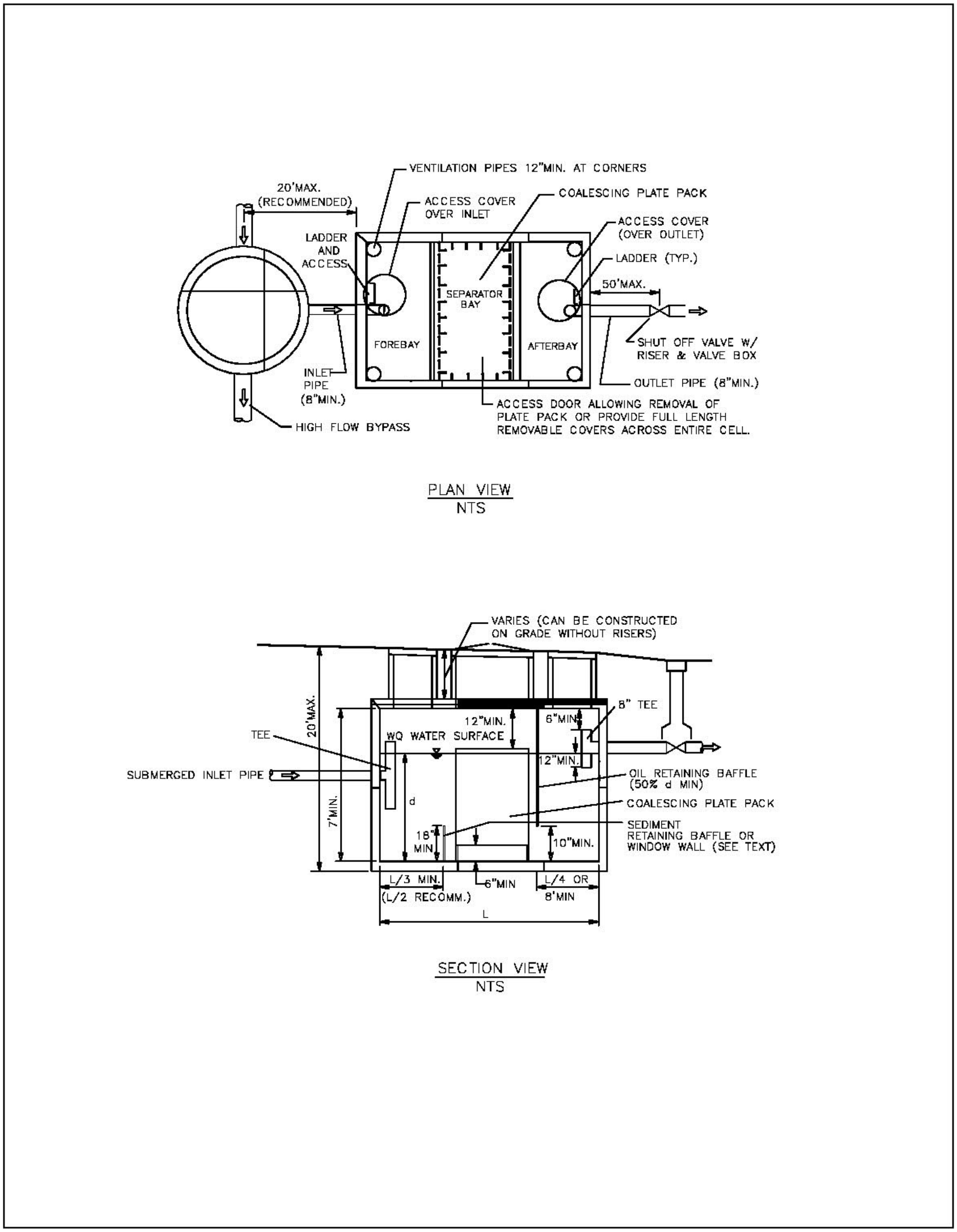

Figure AR.22.1. Coalescing plate separator.

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 = 1.931×10^{-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.

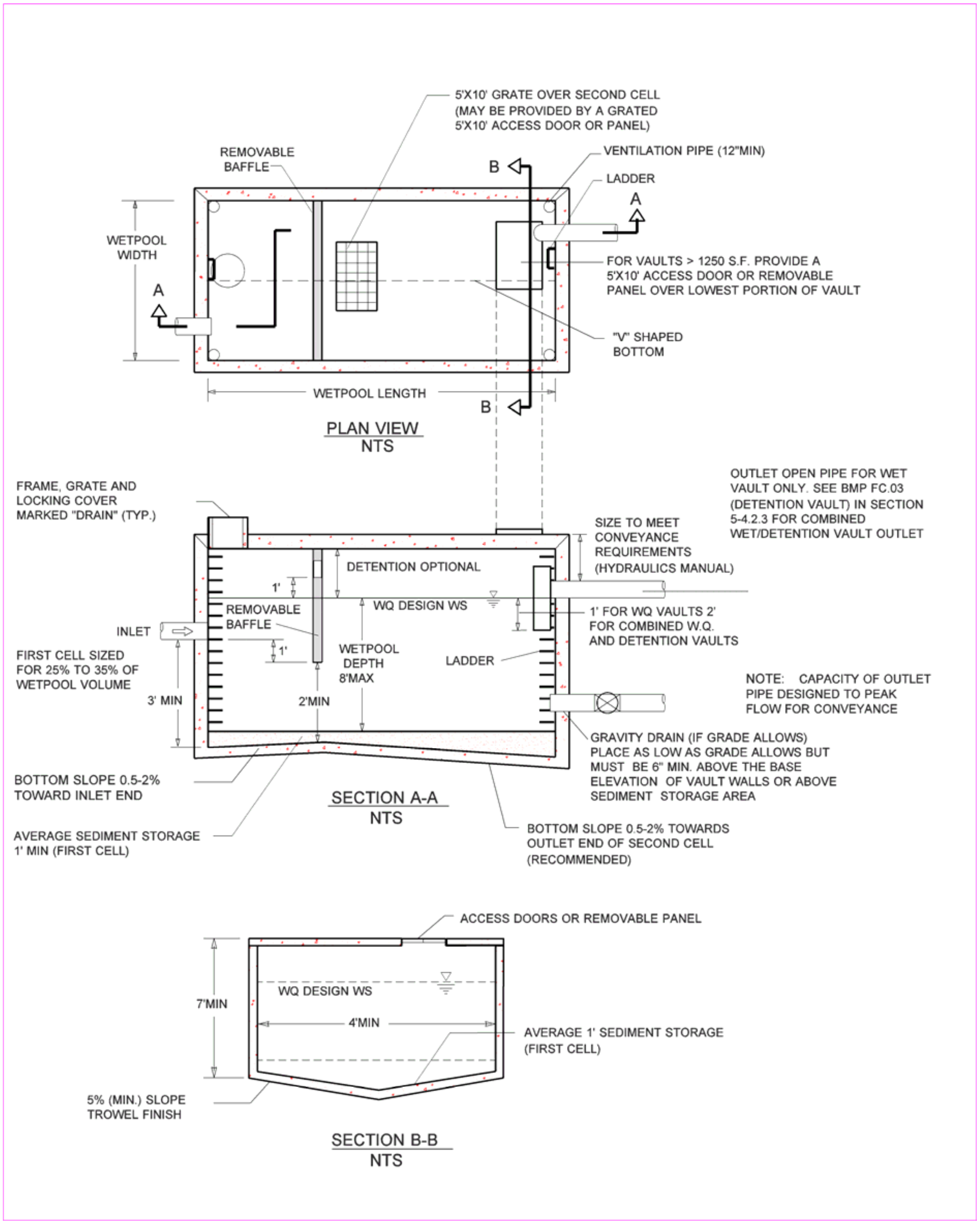

Figure AR.23.1. **Wet vault.**

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			Object Free Area (OFA)	
Western Washington			Runway Safety Area (RSA)	
Landside Areas			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.

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Glossary of Terms

Air Operations Areas (AOA). Any area of an airport used or intended to be used for landing, takeoff, or surface maneuvering of aircraft.

Airport Certification Manual (ACM). The ACM is a document that FAA requires airports to produce in accordance with requirements contained in Title 14, Code of Federal Regulations (CFR) Part 139, Certification of Airports. The ACM serves as the bridge between the requirements of Part 139 and their application to a particular airport, taking into account the airport's size, type/level of activity, and configuration. For additional information, please refer to FAA Advisory Circular (AC) 150/5210-22 (FAA 2004c).

Airport wildlife biologist. A qualified airport wildlife biologist is a wildlife biologist capable of conducting a hazardous wildlife assessment. For certificated airports, this biologist must meet the qualifications in FAA Advisory Circular 150/5200-36 (FAA 2006c).

Airports District Office (ADO). The Seattle ADO is responsible for Idaho, Oregon, and Washington and may be reached at:

U.S. Department of Transportation
Federal Aviation Administration
Northwest Mountain Region
Seattle Airports District Office
1601 Lind Avenue, S.W., Suite 250
Renton, WA 98057-3356
Voice: (425) 227-2650
Fax: (425) 227-1650

Airside. Any location where aircraft operations, fueling, maintenance, or support activities are conducted. The AOA is included in the airside area.

Basic water quality treatment (versus *enhanced water quality treatment*). The Washington State Department of Ecology's performance goal is to achieve 80 percent removal of total suspended solids for influent concentrations that are greater than 100 mg/l, but less than 200 mg/l. For influent concentrations greater than 200 mg/l, a higher treatment goal may be appropriate. For influent concentrations less than 100 mg/l, the facilities are intended to achieve an effluent goal of 20 mg/l total suspended solids.

Basin. The area of land drained by a river and its tributaries, which drains water, organic matter, dissolved nutrients, and sediments into a lake or stream (see *watershed*). Basins typically range in size from 1 to 50 square miles.

Basin plan. A plan that assesses, evaluates, and proposes solutions to existing and potential future impacts on the physical, chemical, and biological properties and beneficial uses of waters of the state within a drainage basin. A plan should include but not be limited to recommendations for the following elements:

- Stormwater requirements for new development and redevelopment
- Capital improvement projects
- Land use management through identification and protection of critical areas, comprehensive land use and transportation plans, zoning regulations, site development standards, and conservation areas
- Source control activities, including public education and involvement, and business programs
- Other targeted stormwater programs and activities, such as maintenance, inspections, and enforcement
- Monitoring
- An implementation schedule and funding strategy.

A basin plan that is adopted and implemented must have the following characteristics:

- Adoption by legislative or regulatory action of jurisdictions with responsibilities under the plan
- Recommended ordinances, regulations, programs, and procedures that are in effect or scheduled to go into effect
- An implementation schedule and funding strategy in progress.

Best management practices (BMPs). The structural devices, maintenance procedures, managerial practices, prohibitions of practices, and schedules of activities that are used singly or in combination to prevent or reduce the detrimental impacts of stormwater, such as pollution of water, degradation of channels, damage to structures, and flooding.

Biofiltration. The process of reducing pollutant concentrations in water by filtering the polluted water through biological materials, such as vegetation.

Bioinfiltration. The process of reducing pollutant concentrations in water by infiltrating the polluted water through grassy vegetation and soils into the ground.

Clearway (CWY). A defined rectangular area beyond the end of a runway cleared or suitable for use in lieu of runway to satisfy takeoff distance requirements. This is the region of space above an inclined plane that leaves the ground at the end of the runway.

Closed depression. A low-lying area that has either no surface water outlet or such a limited surface water outlet that during storm events, the area acts as a retention basin.

Compaction. The densification, settlement, or packing of soil in such a way that its permeability is reduced. Compaction effectively shifts the performance of a hydrologic group to a lower permeability hydrologic group. Compaction may also refer to the densification of a fill by mechanical means.

Converted pervious surface. Land cover changed from native vegetation to lawn, landscape, or pasture areas. (See also *pollution-generating impervious surface*.)

Critical areas. At a minimum, areas that include wetlands; areas with a critical recharging effect on aquifers used for potable water; fish and wildlife habitat conservation areas; frequently flooded areas; geologically hazardous areas, including unstable slopes; and associated areas and ecosystems.

Design flow rate. The maximum flow rate to which certain runoff treatment BMPs are designed for required pollutant removal. Biofiltration swales, vegetated filter strips, and oil/water separators are some of the runoff treatment BMPs that are sized based on a design flow rate.

Design storm. A rainfall event of specified size and return frequency (see Design storm frequency) that is used to calculate the runoff volume and peak discharge rate to a stormwater facility. A prescribed hyetograph and total precipitation amount (for a specific duration recurrence frequency) are used to estimate runoff for a hypothetical storm for the purposes of analyzing existing drainage, designing new drainage facilities, or assessing other impacts of a proposed project on the flow of surface water. (A hyetograph is a graph of percentages of total precipitation for a series of time steps representing the total time during which the precipitation occurs.)

Design storm frequency. The anticipated period in years that will elapse before a storm of a given intensity and/or total volume will recur, based on average probability of storms in the design region. For instance, a 10-year storm can be expected to occur on the average once every 10 years. Facilities designed to handle flows that occur under such storm conditions would be expected to be surcharged by any storms of greater amount or intensity.

Detention. The temporary storage of stormwater runoff in a stormwater facility, which is used to control the peak discharge rates and provide gravity settling of pollutants; the release of stormwater runoff from the site at a slower rate than it is collected by the stormwater facility system, with the difference held in temporary storage.

Dispersion. Release of surface water and stormwater runoff from a drainage facility system in such a way that the flow spreads over a wide area and is located so as not to allow flow to concentrate anywhere upstream of a drainage channel with erodible underlying granular soils.

Effective impervious surface. Replaced impervious surfaces minus those new and applicable replaced impervious surfaces that are noneffective impervious surfaces.

Energy dissipater. A means by which the total energy of flowing water is reduced, such as rock splash pads, drop manholes, concrete stilling basins or baffles, and check dams. In stormwater design, an energy dissipater is usually a mechanism that reduces velocity prior to or at discharge from an outfall to prevent erosion.

Enhanced runoff treatment, enhanced water quality treatment (versus *basic water quality treatment*). The use of runoff treatment BMPs designed to capture dissolved metals at a higher rate than basic treatment BMPs.

Erosion and sedimentation control (ESC). Any temporary or permanent measures taken to reduce erosion, trap sediment, and ensure that sediment-laden water does not leave the site.

Existing site conditions. The conditions (ground cover, slope, drainage patterns) of a site as they existed on the first day that the project entered the design phase.

Filter strip. A grassy area with gentle slopes that treats stormwater runoff from adjacent paved areas before it can concentrate into a discrete channel.

Flow control facility. A drainage facility (BMP) designed to mitigate the impacts of increased surface water and stormwater runoff flow rates generated by development. Flow control facilities are designed either to hold water for a considerable length of time and then release it by evaporation, plant transpiration, and/or infiltration into the ground, or to hold runoff for a short period of time, and then release it to the conveyance system at a controlled rate.

Hydrologic soil groups. A soil characteristic classification system defined by the U.S. Soil Conservation Service in which a soil may be categorized into one of four soil groups (A, B, C, or D) based on infiltration rate and other properties (based on *Water Quality Prevention, Identification, and Management of Diffuse Pollution* [Novotny and Olem 1994]):

- **Type A** – Low runoff potential. Soils with high infiltration rates, even when thoroughly wetted, and consisting chiefly of deep, well-drained to excessively drained sands or gravels. These soils have a high rate of water transmission.
- **Type B** – Moderately low runoff potential. Soils with moderate infiltration rates when thoroughly wetted, and consisting chiefly of moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.
- **Type C** – Moderately high runoff potential. Soils with slow infiltration rates when thoroughly wetted, and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine textures. These soils have a slow rate of water transmission.

- **Type D** – High runoff potential. Soils with very slow infiltration rates when thoroughly wetted, and consisting chiefly of clay soils with a high swelling potential; soils with a permanent high water table; soils with a hardpan, till, or clay layer at or near the surface; soils with a compacted subgrade at or near the surface; and shallow soils or nearly impervious material. These soils have a very slow rate of water transmission.

Impervious surface. A hard surface area that either prevents or retards the entry of water into the soil mantle as occurs under natural conditions (prior to development), and from which water runs off at an increased rate of flow or in increased volumes. Common impervious surfaces include but are not limited to rooftops, walkways, runways, taxiways, parking lots, storage areas, gravel roads, packed earthen materials, and other concrete, asphalt, or oiled surfaces. Open, uncovered retention/detention facilities are not considered impervious surfaces for the purpose of determining whether the thresholds for application of minimum requirements are exceeded. Open, uncovered retention/detention facilities are considered impervious surfaces for the purpose of runoff modeling.

Industrial activities. Material handling, transportation, or storage; manufacturing; maintenance; treatment; or disposal. Areas with industrial activities include plant yards; access roads and rail lines used by carriers of raw materials, manufactured products, waste material, or byproducts; material handling sites; refuse sites; sites used for the application or disposal of process waste waters; sites used for the storage and maintenance of material handling equipment; sites used for residual treatment, storage, or disposal; shipping and receiving areas; manufacturing buildings; storage areas for raw materials and intermediate and finished products; and areas where industrial activity has taken place in the past and significant materials remain and are exposed to stormwater.

Infiltration rate. The rate, usually expressed in inches per hour, at which water moves downward (percolates) through the soil profile. Short-term infiltration rates may be inferred from soil analysis or texture, or derived from field measurements. Long-term infiltration rates are affected by variability in soils and subsurface conditions at the site, the effectiveness of pretreatment or influent control, and the degree of long-term maintenance of the infiltration facility.

Jurisdictional wetland. A jurisdictional wetland as defined under Section 404 of the Clean Water Act, is a wetland that is connected to a Water of the United States (WOUS) using the U.S. Army Corps of Engineers (Corps) definition of WOUS. If an area meets the three standard wetland criteria (hydric soils, hydrology, and hydrophytic vegetation) and is connected to a WOUS, then it is considered a jurisdictional wetland and is regulated by the Corps. Because the connectedness of a wetland to a WOUS is not always easily defined, it is critical to get a jurisdictional determination, in writing, from the Corps, as early as possible in the project planning process.

Landside. Areas of the airport outside of the AOA (e.g., parking, rental car lots, and terminals).

Landslide hazard areas. Those areas subject to a severe risk of landslide.

Level spreader. A temporary erosion and sedimentation control device used to distribute stormwater runoff uniformly over the ground surface as sheet flow (i.e., not through channels) to enhance infiltration and prevent concentrated, erosive flows.

Low-impact development (LID). An evolving approach to land development and stormwater management that uses a site's natural features and specially designed BMPs to manage stormwater; it involves assessing and understanding the site, protecting native vegetation and soils, and minimizing and managing stormwater at the source. Low-impact development practices are appropriate for a variety of development types.

Low-permeability liner. A layer of compacted till or clay, or a geomembrane.

Manning's equation An equation used to predict the velocity of water flow in an open channel or pipeline:

$$V = (1.486(R^{2/3})(S^{1/2}))/n$$

where:

V = the mean velocity of flow in feet per second

R = the hydraulic radius in feet

S = the slope of the energy gradient or, for assumed uniform flow, the slope of the channel in feet per foot

n = Manning's roughness coefficient or retardance factor of the channel lining.

Media filter. A filter that includes material for removing pollutants (e.g., compost, gypsum, perlite, zeolite, or activated carbon).

Media filter drain. A stormwater treatment facility constructed in the pervious shoulder area of a roadway, consisting of a vegetation-covered french drain containing filter media. Also referred to as an ecology embankment.

Mitigation. Measures to reduce adverse impacts on the environment, in the following order of preference:

1. Avoid the impact altogether by not taking a certain action or part of an action.
2. Minimize the impact by limiting the degree or magnitude of the action and its implementation, by using appropriate technology, or by taking affirmative steps to avoid or reduce impacts.
3. Rectify the impact by repairing, rehabilitating, or restoring the affected environment.

4. Reduce or eliminate the impact over time by preservation and maintenance operations during the life of the action.
5. Compensate for the impact by replacing, enhancing, or providing substitute resources or environments.

Monitoring. The collection of data by various methods for the purposes of understanding natural systems and features, evaluating the impacts of development proposals on such systems, and assessing the performance of mitigation measures imposed as conditions of development.

National Pollutant Discharge Elimination System (NPDES). The part of the federal Clean Water Act that requires point source dischargers to obtain permits, called NPDES permits, which in Washington State are administered by the Department of Ecology.

Native growth protection easement (NGPE). An easement granted for the protection of native vegetation within a sensitive area or its associated buffer.

Native vegetation. Vegetation consisting of plant species other than noxious weeds that are indigenous to the region and that reasonably could be expected to occur naturally on the site.

New impervious surfaces. Those surfaces that expand paved areas, and those surfaces that are upgraded from gravel to bituminous surface treatment (BST), asphalt, or concrete pavement. For the purpose of conducting a flow control analysis, the representative predeveloped land cover directly below the new impervious surface shall be based on the predominant land cover adjacent to the existing paved areas.

Noneffective impervious surfaces. Those new, applicable replaced, or existing impervious surfaces that are being managed by dispersion areas meeting the dispersion BMP criteria in the HRM. The equivalent area concept generally applies to engineered dispersion areas and may apply to natural dispersion areas, as described in the following: The existing site currently collects runoff in a ditch or pipe and discharges it to a surface water. By changing this condition to a natural dispersion situation through sheet flow or channelized flow dispersion, a surface discharge is eliminated, resulting in a flow control improvement. Equivalent area trades for natural dispersion are allowed for this specific case.

Noneffective pollution-generating impervious surface (PGIS). Those new, applicable replaced, or existing PGIS surfaces that are being managed by dispersion areas meeting the dispersion BMP criteria in the HRM. The equivalent area concept generally applies to engineered dispersion areas and may apply to natural dispersion areas, as described in the following: The existing site currently collects runoff in a ditch or pipe and discharges to a surface water. By changing this condition to a natural dispersion situation through sheet flow or channelized flow dispersion, a surface discharge is eliminated, resulting in a flow control improvement. Equivalent area trades for natural dispersion are allowed for this specific case.

Nonroad-related project. A project involving structures, including rest areas, maintenance facilities, and ferry terminal buildings.

Object-Free Area (OFA). An area on the ground centered on a runway, taxiway, or taxi-lane centerline provided to enhance the safety of aircraft operations by having the area free of aboveground objects protruding above the Runway Safety Area (RSA, defined below) edge elevation, except for objects that need to be located in the OFA for air navigation or aircraft ground maneuvering purposes.

Off-line facilities. Runoff treatment facilities to which stormwater runoff is restricted to some maximum flow rate or volume by a flow-splitter.

Oil control. The treatment of stormwater runoff with BMPs to remove oil, grease, and total petroleum hydrocarbons (TPH).

Oil/water separator. A vault, usually underground, designed to provide a quiescent environment to separate oil from water.

On-line facilities. Runoff treatment facilities that receive all the stormwater runoff from a drainage area. Flows above the runoff treatment design flow rate or volume are passed through at a lower percentage removal efficiency.

Orifice. An opening with closed perimeter, usually sharp-edged, and of regular form in a plate, wall, or partition through which water may flow; generally used for the purpose of measurement or control of water.

Outfall. Any location where concentrated stormwater runoff leaves the right-of-way. Outfalls may discharge to surface waters or groundwater.

Outlet protection. A protective barrier of rock, erosion control blankets, vegetation, or sod constructed at a conveyance outlet.

Overflow. A pipeline or conduit device with an outlet pipe that provides for the discharge of portions of combined sewer flows into receiving waters or other points of disposal, after a regular device has allowed the portion of the flow that can be handled by interceptor sewer lines and pumping and treatment facilities to be carried by and to such water pollution control structures.

Peak discharge. The maximum instantaneous rate of flow during a storm, usually in reference to a specific design storm event.

Pollution-generating impervious surface (PGIS). An impervious surface that is considered a significant source of pollutants in stormwater runoff, including surfaces that receive direct rainfall (or run-on or blow-in of rainfall) and are subject to vehicular use; industrial activities; or storage of erodible or leachable materials, wastes, or chemicals. Erodible or leachable materials, wastes, or chemicals are substances that, when exposed to rainfall, measurably alter the physical or chemical characteristics of the rainfall runoff. Examples include erodible soils that are stockpiled, uncovered process wastes, manure, fertilizers, oily substances, ashes, kiln dust, and garbage container leakage. Metal roofs are also considered pollution-generating impervious surfaces unless they are coated with an inert, nonleachable material (e.g., baked-on enamel coating). A surface, whether paved or not, is considered subject to vehicular use if it is regularly used by motor vehicles. The following are considered regularly used surfaces: roads, unvegetated road shoulders, bicycle lanes within the travel lane of a roadway, driveways, parking lots, unfenced fire lanes, vehicular equipment storage yards, and airport runways. The following are not considered regularly used surfaces: paved bicycle pathways separated from roads for motor vehicles, fenced fire lanes, and infrequently used maintenance access roads.

Pollution-generating pervious surface (PGPS). Any pervious surface subject to the ongoing use of pesticides and fertilizers or loss of soil, such as lawns and landscaped areas.

Pretreatment. The removal of material such as solids, grit, grease, and scum from flows to improve treatability prior to biological or physical treatment processes; may include screening, grit removal, settling, oil/water separation, or application of a basic treatment BMP prior to infiltration.

Professional engineer (P.E.). A person registered with the state of Washington as a professional engineer.

Project limits. For road projects, the beginning project station to the end project station and from right-of-way line to right-of-way line. For nonroad projects, the legal boundaries of land parcels that are subject to project development (also called the project area perimeter).

Redevelopment. On a site that is already substantially developed (i.e., has 35 percent or more of existing impervious surface coverage), the creation or addition of impervious surfaces; the expansion of a building footprint or addition, or replacement of a structure; structural development including construction, installation, or expansion of a building or other structure; replacement of impervious surface that is not part of a routine maintenance activity; and land-disturbing activities.

Regional detention facility. A stormwater quantity control structure designed to correct surface water runoff problems within a drainage basin or subbasin, such as regional flooding or erosion problems; a detention facility sited to detain stormwater runoff from a number of new developments or areas within a catchment.

Release rate. The computed peak discharge rate in volume per unit time of surface and stormwater runoff from a site.

Replaced impervious surface. Those paved areas that are excavated to a depth at or below the top of the subgrade (pavement repair work excluded) and replaced in kind. The subgrade is taken to be the crushed surfacing directly below the pavement layer (ACP, PCCP, BST). If the removal and replacement of existing pavement do not go below the pavement layer, as with typical PCCP grinding, ACP planning, or "paver" projects, the new surfacing is not considered replaced impervious surface. For the purpose of conducting a flow control analysis, the representative predeveloped land cover directly below the replaced impervious surface shall be based on the predominant land cover adjacent to the existing paved area.

Riprap. A facing layer or protective mound of rocks placed to prevent erosion or sloughing of a structure or embankment due to flow of surface and stormwater runoff.

Riser. A vertical pipe extending from the bottom of a pond that is used to control the discharge rate from a stormwater facility for a specified design storm.

Road and parking lot-related projects. Pavement projects, including shoulders, curbs, and sidewalks.

Runoff. Rainwater or snowmelt that directly leaves an area as surface drainage.

Runoff treatment. Pollutant removal to a specified level via engineered or natural stormwater management systems.

Runoff treatment BMP. A BMP specifically designed for pollutant removal.

Runway Protection Zone (RPZ). An area off the runway end to enhance the protection of people and property on the ground.

Runway Safety Area (RSA). A defined surface surrounding the runway prepared or suitable for reducing the risk of damage to aircraft in the event of an undershoot, overshoot, or excursion from the runway.

Sand filter. A manmade depression or basin with a layer of sand that treats stormwater as it percolates through the sand and is discharged via a central collector pipe.

Saturated hydraulic conductivity. The rate of movement of water through a saturated porous medium.

Sensitive area. Any area designated by a federal, state, or local government as having unique or important environmental characteristics that may require additional protective measures (also see *critical areas*). These areas include but are not limited to:

- "Critical habitat" as defined in Section 3 of the federal Endangered Species Act of 1973.
- Designated "critical water resources" as defined in 33 CFR Part 330, Nationwide Permit Program.

- Water bodies designated as "impaired" under the provision of Section 303d of the federal Clean Water Act enacted by Public Law 92-500.
- Sole-source aquifers as defined under the federal Safe Drinking Water Act, Public Law 93-523.
- Wellhead protection zones as defined under WAC 246-290, Public Water Supplies.
- Areas identified in local critical area ordinances or in an approved basin plan.

Sheet flow. Runoff that flows over the ground surface as a thin, even layer, not concentrated in a channel.

Short-circuiting. The passage of runoff through a stormwater treatment facility in less than the design treatment time.

SIC code. Standard industrial classification code developed by the U.S. Department of Commerce to classify types of industry. Now often used by environmental agencies to assign regulatory requirements.

Silt fence. A temporary sediment barrier consisting of a geotextile fabric stretched across and attached to supporting posts, which are entrenched. Adding rigid wire fence backing can strengthen a silt fence.

Slope. Degree of deviation of a surface from the horizontal, measured as a numerical ratio, percent, or in degrees. Expressed as a ratio, the first number is the horizontal distance (run) and the second is the vertical distance (rise); e.g., 2H:1V. A 2H:1V slope is a 50 percent slope. Expressed in degrees, the slope is the angle from the horizontal plane, so that a 90° slope is vertical (maximum), and a 45° slope is 1H:1V (i.e., a 100 percent slope).

Soil amendments. Materials that improve soil fertility for establishing vegetation or permeability for infiltrating runoff.

Sole-source aquifer. An aquifer or aquifer system that supplies 50 percent or more of the drinking water for a given service area and for which there are no reasonably available alternative sources should the aquifer become contaminated, and the possibility of contamination exists. The U.S. Environmental Protection Agency designates sole-source aquifers, and Section 1424(e) of the Safe Drinking Water Act is the statutory authority for the Sole-Source Aquifer Protection Program.

Source control. A structure or operation intended to prevent pollutants from coming into contact with stormwater, either through physical separation of areas or through careful management of activities that are sources of pollutants.

- *Structural source control BMPs* are physical, structural, or mechanical devices or facilities intended to prevent pollutants from entering stormwater.
- *Operational BMPs* are nonstructural practices that prevent or reduce pollutants entering stormwater.

Spillway. A passage such as a paved apron or channel carrying surplus water over or around a dam or similar obstruction; an open or closed channel used to convey excess water from a reservoir. A spillway may contain gates, either manually or automatically controlled, to regulate the discharge of excess water.

Steep slope. A slope of 40 percent gradient or steeper with a vertical elevation change of at least 10 feet.

Stopway (SWY). A defined rectangular surface beyond the end of a runway prepared or suitable for use in lieu of runway to support an aircraft without causing structural damage to the aircraft during an aborted takeoff.

Swale. A natural depression or shallow drainage conveyance with relatively gentle side slopes, generally with flow depths less than 1 foot, used to temporarily store, route, or filter runoff.

Taxiway Safety Area (TSA). A defined surface alongside the taxiway prepared or suitable for reducing the risk of damage to an aircraft unintentionally departing the taxiway.

Threshold discharge area (TDA). An on-site area draining to a single natural discharge location or multiple natural discharge locations that combine within ¼ mile downstream (as determined by the shortest flow path).

Total Maximum Daily Load (TMDL) – water cleanup plan. A calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards, and an allocation of that amount to the pollutant's sources. A TMDL (also known as a water cleanup plan) is the sum of allowable loads of a single pollutant from all contributing point sources and nonpoint sources. The calculation must include a margin of safety to ensure that the water body can be used for the purposes the state has designated. The calculation must also account for seasonal variation in water quality. Water quality standards are set by states, territories, and tribes. They identify the uses for each water body: for example, drinking water supply, contact recreation (such as swimming), and aquatic support (such as fishing) and the scientific criteria to support each use. The federal Clean Water Act, Section 303, establishes the water quality standards and TMDL programs.

Touchdown. Section at the end of the runway where aircraft tires first meet the runway.

Trash rack. A structural device used to prevent debris from entering a spillway or other hydraulic structure.

Treatment train. A combination of two or more treatment facilities connected in series.

Underdrain. Plastic pipes with holes drilled through the top, installed on the bottom of an infiltration facility, that are used to collect and remove excess runoff.

Vegetated filter strip. A facility designed to provide runoff treatment of conventional pollutants (but not nutrients) through the process of biofiltration.

Wildlife hazard assessment. A wildlife hazard assessment, identified as an ecological study in FAA Title 14 Code of Federal Regulations, part 139.337(a), is conducted by a wildlife damage management biologist when any of the following events occurs on or near the airport:

- An air carrier aircraft experiences multiple wildlife strikes;
- An air carrier aircraft experiences substantial damage from striking wildlife;
- An air carrier aircraft experiences an engine ingestion of wildlife; or
- Wildlife of a size, or in numbers, capable of causing an event described in (1), (2), or (3) (above) is observed to have access to any airport flight pattern or aircraft movement area.

The assessment provides the scientific basis for the development, implementation, and refinement of a wildlife hazard management plan, if needed. Although parts of the wildlife hazard assessment may be incorporated directly in the wildlife hazard management plan, they are two separate documents.

Wildlife hazard management plan. Pending results and approval of a wildlife hazard assessment, an airport may be required to produce a wildlife hazard management plan. This is a document that addresses the specific issues/requirements prescribed in the FAA Title 14 Code of Federal Regulations, part 139.337. A summary of the requirements for a wildlife hazard management plan can be found at http://www.faa.gov/airports_airtraffic/airports/regional_guidance/central/airport_safety/part139/best_practice/wildlife/media/Summary_Wildlife_Management.pdf.

Water cleanup plan. See *total maximum daily load*.

Watershed. A geographic region within which water drains into a particular river, stream, or body of water. Watersheds can be as large as those identified and numbered by the state of Washington as water resource inventory areas (WRIAs), defined in WAC 173-500.

Appendix A – Vegetation Recommendations for Airport Settings

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Tables

Vegetation Recommendations for Airport Settings

A-1. Introduction

A-1.1. General Description

WSDOT has promoted the use of native plant species because of the effective treatment, lower irrigation and maintenance needs, and reduced requirements for pesticides and fertilizers (WSDOT 2003). Many of these plant species provide important food sources and habitat for native birds and other wildlife. ***These vegetation characteristics are not desirable in airport settings because of the potential hazards to aircraft posed by wildlife.*** This appendix provides guidance on vegetation selection in airport settings. It is intended for use as a starting point for the selection of appropriate vegetation in and around stormwater best management practices (BMPs) in conjunction with the BMP descriptions in Chapters 5 and 6 of the Aviation Stormwater Design Manual (ASDM).

Vegetation plays a crucial role in many water quality treatment facilities, enhancing physical and biological treatment processes such as filtration, sedimentation, adsorption, and uptake. The dense root zone of many plant species enhances filtration and straining of pollutants. In addition, landscaping can improve the aesthetics of treatment facilities and provide a public benefit.

Vegetation is important to wildlife because it provides both food and cover. Some waterfowl species eat the bulbs and roots of aquatic plants such as pondweed, cattails, and arrowhead. Many species of wildlife eat the fruit, nuts, and seeds produced by aquatic and riparian plants, whereas other wildlife feed on the leaves and/or stems of the plants. Herrera (2007) includes a table that shows the food types that attract birds to an area.

In addition to vegetative food sources, wildlife may be attracted to frogs, fish, or invertebrates that are often associated with stormwater facilities. For example, raptors feed on small rodents that hide in grassy vegetation. A less obvious problem reported by many airports is worms. Large numbers of worms may find their way onto paved areas after rainstorms, attracting birds, leading to potential collisions between the feeding bird and aircraft (Transport Canada 2004). Plants also provide cover for some wildlife species that serve as prey for other species. Many aquatic plants provide habitat for fish and invertebrates, which may also attract birds.

Plants can attract and provide hazardous wildlife with cover to shield them and protect their nests from predators. Plants can also shelter wildlife during periods of inclement weather. The appeal of vegetation to wildlife species depends both on the types of vegetation and the height of the plants.

A-1.2. Applications and Limitations

The focus of this appendix is vegetation for stormwater BMPs, in particular, information about vegetation that is suitable for flow control and runoff treatment facilities in the airport environment. This appendix presents lists of plant species, identifying certain species of plants as either "recommended" or "not recommended" for use at Washington airports.

The recommended plant list presents information on species that have been used in the airport and/or stormwater setting with documented satisfactory results. These species are often perennial, easy to establish, readily available, suitable for erosion control, require minimal maintenance, adapted to stormwater facility conditions, and do not possess notable morphological characteristics that are clearly attractive to wildlife. Plants may be less attractive to wildlife if they have low forage value; produce few, low-nutritional value seeds; have low-nutrition roots or tubers; are low growing if groundcover; or produce minimized flowering parts with limited value to pollinators.

Those plant species identified as not recommended have been documented as inappropriate for use in an airport environment because they contain morphological characteristics that are considered wildlife attractants, or they possess behavioral characteristics that are considered overly aggressive or invasive. While they may be available in your area, use of these plants is discouraged since they may present wildlife-aircraft hazard risks or require significant additional maintenance.

In general, native plants possess many of the characteristics desired for vegetation stormwater BMPs. Many are perennial, low maintenance, have deep roots that stabilize soils, and are adapted to fluctuating water conditions. However, they may also possess morphological characteristics attractive to wildlife, making them unsuitable for use near airports. Conversely, many nonnative or ornamental plants do not possess functional characteristics necessary for planting in stormwater facilities. However, some of the nonnatives that do exhibit these characteristics also possess aesthetic traits suitable for use in high-visibility areas that require stormwater facilities. In generating the recommended plant lists, native and nonnative plants have been provided with a balance of characteristics that minimize risks and maintenance liability.

This appendix is not a comprehensive resource on vegetation suitable for use in the airport stormwater treatment environment. There may be plant species that are not included in the recommended plant lists that are, in fact, appropriate for use in the airport stormwater environment. Similarly, site-specific conditions may render recommended plants unsuitable for use in certain airport environments. To ensure final selection of the plants that are most appropriate for your site, designers are encouraged to contact an agency landscape architect, consulting landscape architect, or other regional vegetation expert to determine the site-specific needs with regard to plant selection, installation, and establishment of vegetation associated with stormwater BMPs. Regionally oriented plant guides can provide additional guidance (e.g., Brenzel 2001, Pojar and MacKinnon 1994) but are no substitute for informed local knowledge and experience.

When selecting plants for use in stormwater treatment facilities, determining the overall diversity of selected plantings is an important consideration. For example, increased plant species diversity within an applied seed mix can improve the likelihood of meeting plant establishment objectives, since this increased diversity will result in a greater likelihood that one or more of the selected species is well adapted to the fluctuating and often unpredictable hydrologic conditions typically encountered within stormwater treatment facilities. However, increasing vegetative diversity can contribute to the diversity of habitats and therefore greater potential for a facility to attract wildlife. To limit the potential for a stormwater facility to attract wildlife, plant diversity should be limited to the greatest degree possible while still achieving high plant establishment rates. This can be achieved by thorough site assessment that accurately characterizes site conditions, plant selection that matches these conditions to specific plant capabilities, and site construction and maintenance care that maximize the success of plant establishment.

A-2. Recommended Plants for Airports Stormwater BMPs.

Tables A-1 and A-2 identify plants that are recommended for use in or around stormwater facilities at airports west and east of the Cascades, respectively. The common name, scientific name, plant structural type, maximum height and spread, and moisture requirements are summarized. The recommended species list for west of the Cascades (western Washington) is based primarily on information originally prepared for Sea-Tac International Airport (Port of Seattle 2007). The recommended species list for east of the Cascades (eastern Washington) is based on approved highway planting lists from WSDOT Eastern Region (WSDOT undated a,b,c,d,e) and Spokane County Public Works (Spokane County 1998).

A-2.1. Plant Moisture Requirements

Selecting vegetation appropriate for the expected moisture conditions is critical if the vegetation is expected to survive and provide benefits to a stormwater BMP. Because moisture regimes commonly vary within a given BMP, it is important that the designer be aware of the expected conditions and be prepared to select a variety of plants that will achieve stormwater treatment goals. For example, the upper slopes of a biofiltration swale will be much drier than the lower slopes and the swale bottom. An appropriate planting design will consider this and specify appropriate plants for each moisture zone. To aid the designer, the plant list tables include information on typical moisture requirements for the listed plants. Specific moisture requirements or zones include dry, moist, wet, saturated, and submerged. Many plant species are able to adapt across a range of moisture regimes. This has been noted wherever possible by including hyphenated categories such as dry–moist, which indicates that a given plant is comfortable in conditions ranging from dry to moist.

- **Dry:** A dry moisture regime is one in which soils are moist only during seasons of high precipitation (in general, winter and early spring). The rest of the year, the soils are very dry except for short periods of moisture provided by rare summer rains. Vegetation adapted to these conditions has a flush of growth in the spring, followed by a period of dormancy or semidormancy. Grasses tend to have rapid growth followed by seed production, after which their foliage dries out and appears to be dead. Deep-rooted trees and shrubs also have a spring flush of growth but are able to remain green throughout the summer by tapping deep soil moisture. Plants suitable for a dry moisture regime are appropriate for revegetating upland areas adjacent to stormwater facilities and many stormwater facilities in arid regions of the state east of the Cascades. These plants are also appropriate for the side slopes of infiltration ponds and detention ponds above the design water surface elevation. Grasses in this category would be suitable for vegetated filter strips (AR.12) or media filter drains (AR.14).

- **Moist:** A moist moisture regime has a consistent source of moisture available for plant growth throughout the growing season. Both shallow and deep-rooted plants are able to survive and actively grow even through periods of little or no precipitation. The soil surface is generally dry, with moisture evident 2 to 4 inches below the surface. Plants in the moist moisture zone category are appropriate for the bottom of continuous inflow biofiltration swales (AR.13) west of the Cascades. These plants are also suitable for the lower cell of detention ponds (AR.09) and infiltration ponds (AR.04) below the design water surface elevation.

- **Wet:** A wet moisture regime is constantly wet without a period of surface drying. It does, however, have aerobic soil conditions for at least part of the year. Plants in the wet moisture zone category are suitable for periodically inundated areas of constructed stormwater treatment wetlands or wet ponds. Note that newly constructed wetlands or wet ponds are not recommended for airports, but airports may have existing facilities with permanent wet pools.

- **Saturated:** A saturated moisture regime is one in which soils are at or exceeding their saturation point. A small pit excavated in the soil will fill with water. The surface is constantly wet but without permanent standing water that exceeds 1 inch in depth. Soils are generally anaerobic.

- **Submerged:** A submerged moisture regime has standing water the entire year. Plants in the submerged moisture zone category are suitable for permanent pool areas of constructed wetlands or wet ponds. Note that newly constructed wetlands or wet ponds are not recommended for airports, but airports may have existing facilities with permanent wet pools. Many aquatic plant species are also attractive to waterfowl as a food source.

- **Moist–wet:** Plants that can handle a range of conditions from wet to moist are appropriate for moist–wet regimes. Plants suitable for moist–

wet conditions are recommended for flow-through facilities with appropriate hydrologic conditions, such as the biofiltration swale below the design water surface (AR.13).

- **Moist–dry:** Plants that can handle seasonal conditions of moist soils yet survive a dry period are suitable for the moist–dry regimes. Plants suitable for moist-dry conditions are recommended for infiltration facilities, such as the bioinfiltration pond (AR.03) or infiltration pond (AR.04). These plants are also appropriate for the side slopes of biofiltration swales (AR.13) and the upper cell of detention ponds (AR.09) below the design water surface elevation. These plants may also be used in "live storage" areas of constructed wetlands or wet ponds subject to periodic inundation. Note that newly constructed wetlands or wet ponds are not recommended for airports, but airports may have existing facilities with permanent wet pools.
- **Moist–saturated:** Many wetland plants are able to handle a range of moisture, from moist to wet and saturated. Most of the plants that survive this range have physiological mechanisms to obtain oxygen during mid- to long-term anaerobic conditions.
- **Wet–saturated:** Plants in the wet–saturated moisture zone category are suitable for permanent pools of water in constructed stormwater treatment wetlands (HRM, RT.13) or wet ponds (HRM, RT.12). Note that new constructed wetlands or wet ponds are not recommended for airports, but airports may have existing facilities with permanent wet pools.

Tables A-1 and A-2 list the recommended plant species for use in or around airport stormwater facilities. The recommended plant lists are intended to serve only as a starting point for selection of plant species.

It is important to note that there are pronounced and extreme variations in climate, hydrology, and soil types east of the Cascades despite generally dry conditions. For this reason, it is critical that the designer consult with experienced vegetation specialists in eastern Washington including WSDOT staff, regional landscape architects, or the Roadside and Site Development Unit within the WSDOT headquarters Design Office with any questions related to vegetation, planting times, and methods, as well as for assistance in selecting the appropriate vegetation for stormwater BMPs.

A-3. Plants Not Recommended for Use on Airports

Table A-3 lists the plant species that are NOT appropriate for use in or around airport stormwater facilities. These plants are either known wildlife attractants, or have other characteristics undesirable in the airport environment. In general, plants with fruits, shoots, roots, seeds, tubers, roots, or other vegetative features that could provide wildlife forage or habitat should be avoided.

Table A-1. Recommended plants for airports west of the Cascades.

Native?	Genus	Species var.	Common Name	Plant Category and Type	Moisture Regime	Height (ft)	Spread (ft)	Notes
N	*Alisma*	*plantago-aquatica*	Water Plantain	Groundcover	Wet-Saturated	2.5-4	N/A	Wetland associate
	Alopecurus	*geniculatus*	Water Foxtail	Groundcover	Moist-Wet	1	1.5	Wetland associate
N	*Aster*	*subspicatus*	Douglas' Aster	Groundcover	Moist-Dry	0.6-2.5	N/A	
N	*Bromus*	*sitchensis*	Alaska Brome	Groundcover	Moist-Dry	1.5-6	N/A	
N	*Bromus*	*vulgaris*	Columbia Brome Grass	Groundcover	Moist-Dry	1.5-6	N/A	
N	*Carex*	*densa*	Dense Sedge	Groundcover	Moist	1–2	N/A	
N	*Carex*	*hendersonii*	Henderson Sedge	Groundcover	Moist	1–2	N/A	
N	*Carex*	*vesicaria*	Inflated Sedge	Groundcover	Moist	1–2	N/A	
N	*Carex*	*aperta*	Columbia Sedge	Groundcover	Moist-Wet	1–2	N/A	Wetland associate
N	*Carex*	*deweyana*	Dewey Sedge	Groundcover	Moist-Wet	0.7-4	N/A	Wetland associate
N	*Deschampsia*	*caespitosa*	Tufted Hairgrass	Groundcover	Moist-Dry	1–2	2	
N	*Eleocharis*	*acicularis*	Needle Spike-Rush	Groundcover	Moist	1–2	N/A	
N	*Eleocharis*	*ovata*	Ovate Spike Rush	Groundcover	Wet-Saturated	0.2-1.6	N/A	Wetland associate
N	*Eleocharis*	*palustris*	Creeping Spike Rush	Groundcover	Wet-Saturated	0.3-3.3	N/A	Wetland associate
	Epimedium x	*rubrum*	Bishop's Hat	Groundcover	Dry	2	1	
	Heuchera	*sanguinea*	Coral Bells	Groundcover	Dry	2	2	
N	*Iris*	*tenax*	Oregon Iris	Groundcover	Moist-Dry	1.3	N/A	
N	*Juncus*	*effusus*	Common/Soft Rush	Groundcover	Moist-Wet	2.5	2.5	Wetland associate
N	*Juncus*	*ensifolius*	Dagger-leaf Rush	Groundcover	Moist-Wet	0.5-2	N/A	Wetland associate
N	*Juncus*	*oxymeris*	Pointed Rush	Groundcover	Moist-Wet	1-2.5	N/A	Wetland associate
N	*Juncus*	*patens*	Grooved Rush; Spreading Rush	Groundcover	Moist-Wet	2	2	Wetland associate
N	*Juncus*	*tenuis*	Slender Rush	Groundcover	Moist-Saturated	0.5-2.3	N/A	Wetland associate
	Lavandula	*angustifolia*	Jean Davis; English Lavender	Groundcover	Dry	5	3	
N	*Lupinus*	*micranthus/polycarpus*	Small Flowered Lupine	Groundcover	Moist-Dry	0.3-1.5	N/A	
N	*Lupinus*	*polyphyllus*	Large-leaved Lupine	Groundcover	Moist-Wet	1.5-4	1-2.5	Wetland associate

Table A-1 (continued). Recommended plants for airports west of the Cascades.

Native?	Genus	Species var.	Common Name	Plant Category and Type	Moisture Regime	Height (ft)	Spread (ft)	Notes
	Ophiopogon	*planiscapus*	Nigrescens; Black Mondo Grass	Groundcover	Moist	1	1	Evergreen
N	*Scirpus*	*americanus*	Three-square or American Bulrush	Groundcover	Wet-Saturated	0.5-3.3	N/A	Wetland associate
N	*Scirpus*	*microcarpus*	Small-fruited Bulrush	Groundcover	Wet-Saturated	5	N/A	Wetland associate
N	*Scirpus*	*acutus*	Hardstem Bulrush	Groundcover	Wet-Saturated	3–9	N/A	Wetland associate
N	*Sisyrinchium*	*idahoense*	Blue-eyed Grass	Groundcover	Moist	0.5-2	0.5-2	
	Abeilia	*grandiflora*	Edward Goucher Abelia	Shrub	Dry	5	5	Evergreen
N	*Athyrium*	*felix-femina*	Lady Fern	Shrub	Moist	4	2–3	
	Ceanothus	*prostratus*	Mahala Mat	Shrub	Dry	<1	N/A	
N	*Ceanothus*	*sanguineus*	Redstem Ceanothus	Shrub	Moist-Dry	3–10	N/A	
	Cistusx purpureus		Orchid Rock Rose; Purple Rock Rose	Shrub	Dry	10	6	
	Cistus	*corbariensis (hybridus)*	White Rock Rose	Shrub	Dry	5	5	Evergreen
	Erica	*carnea*	Pink Heather; Springwood Pink	Shrub	Moist	1	3	Low shrub
	Escallonia	*langleyensis*	Apple Blossom Escallonia	Shrub	Dry	5	6	Evergreen
	Euonymus	*alatus compactus*	Winged Euonymus; Dwarf Burning Bush	Shrub	Dry	10	8	Deciduous
	Euonymus	*fortunei coloratus*	Wintercreeper Euonymus	Shrub	Dry	2	3	Evergreen
	Hydrangea	*quercifolia*	Oakleaf Hydrangea	Shrub	Dry	10	8	Deciduous
	Leucothoe	*axillaris*	Coast Leucothoe	Shrub	Moist	4	6	Evergreen
	Osmanthus	*delavayi*	Delavay Osmanthus	Shrub	Dry	10	10	
	Osmanthus	*heterophyllus (Variegatus)*	Variegated Holly Leaf Osmanthus	Shrub	Dry	10	8	Evergreen
	Pachysandra	*terminalis*	Japanese Spurge	Shrub	Dry	2	3	Evergreen
N	*Philadelphus*	*lewisii*	Mock Orange	Shrub	Dry	20	8	Deciduous
	Phyllodoce	spp.	Mountain Heath	Shrub	Moist	1	N/A	Low shrub
N	*Physocarpus*	*capitatus*	Pacific Ninebark	Shrub	Moist-Wet	8	8	
N	*Polystichum*	*munitum*	Western Sword Fern	Shrub	Dry	5	3	
N	*Rosa*	*gymnocarpa*	Baldhip Rose	Shrub	Moist	5	N/A	
N	*Rosa*	*nutkana*	Nootka Rose	Shrub	Moist	6	4	

Table A-1 (continued). Recommended plants for airports west of the Cascades.

Native?	Genus	Species var.	Common Name	Plant Category and Type	Moisture Regime	Height (ft)	Spread (ft)	Notes
N	*Rosa*	*piscocarpa*	Wild Clustered Rose	Shrub	Moist	10	N/A	
N	*Salix*	*lucida* (or *S. lasiandra*)	Pacific Willow	Shrub	Moist-Wet	40	N/A	Arboreal Shrub
N	*Salix*	*sessilifolia*	Soft leafed Willow	Shrub	Moist-Wet	40	N/A	Arboreal Shrub
N	*Salix*	*fluviatalis*	Columbia Willow	Shrub	Moist-Saturated	N/A	N/A	
N	*Salix*	*hookeriana*	Hookers Willow	Shrub	Moist-Saturated	20	N/A	
N	*Salix*	*scouleriana*	Scouler’s Willow	Shrub	Moist	6–40	N/A	
N	*Salix*	*sitchensis*	Sitka Willow	Shrub	Moist-Saturated	3–25	N/A	
N	*Spiraea*	*betulifolia*	Shiny-leaf Spiraea	Shrub	Moist-Dry	2	N/A	
N	*Spiraea*	*douglasii*	Douglas Spirea	Shrub	Moist	3–6	3–6	
N	*Alnus*	*rubra*	Red Alder	Tree	Moist-Wet	45-50	20-30	Deciduous
N	*Arbutus*	*menziesii*	Madrone	Tree	Dry	20-100	N/A	Evergreen
	Betula	*jacquemontii*	Jacquemontii Birch	Tree	Moist	40+	N/A	Deciduous
N	*Betula*	*occidentalis*	Water Birch	Tree	Moist-Wet	40+	N/A	Deciduous
N	*Castanopsis*	*chrysopylla*	Chinquapin	Tree	Dry	25-45	20-25	Evergreen
	Ceanothus	*thyrisiflorus*	Victoria Ceanothus	Tree	Dry	9	12	Evergreen
	Cupressocyparis	*leylandii*	Leyland Cypress	Tree	Dry	40+	25	Evergreen
N	*Fraxinus*	*latifolia*	Oregon Ash	Tree	Moist-Wet	40-80	30-50	Deciduous
N	*Pinus*	var. *contorta*	Shore Pine	Tree	Dry	40+	N/A	Evergreen
N	*Pinus*	*monticola*	Western White Pine	Tree	Moist-Dry	60	20	Evergreen
	Thuja	*Occidentalis ‘Emerald’*	Emerald Green Aborvitae	Tree	Moist	20	4	Evergreen
	Thuja	*Occidentalis ‘Little Gem’*	Little Gem; Dwarf Aborvitae	Tree	Moist	5	3	Evergreen
N	*Tsuga*	*heterophylla*	Western Hemlock	Tree	Moist	70-130	20-30	Evergreen

Sources: Port of Seattle (2007) and City of Portland (2004).

Table A-2. Recommended plants for airports east of the Cascades.

Native?	Genus	Species var.	Common Name	Plant Category and Type	Moisture Regime	Height (ft)	Spread (ft)	Notes
	Achillea	*millefolium*	Common Yarrow	Groundcover	Dry	0.5-3	N/A	
N	*Balsamorhiza*	*sagittata*	Arrowleaf Balsamroot	Groundcover	Dry	N/A	N/A	
N	*Bromus*	*marginatus*	Mountain Brome	Groundcover	Dry-Moist	1.5-5	N/A	Grass
N	*Distichlis*	*Stricta/ spicata*	Inland Saltgrass	Groundcover	Wet-Saturated	0.5	N/A	
N	*Koeleria*	*cristata*	Prairie Junegrass	Groundcover	Dry	N/A	N/A	Grass
N	*Lupinus*	*sericeus*	Silky Lupine	Groundcover	Dry	1.5-2	1	
N	*Poa*	*sandbergii*	Sandberg Bluegrass	Groundcover	Moist-Wet	0.75	N/A	Grass
N	*Pseudoroegneria*	*spicata*	Bluebunch Wheatgrass	Groundcover	Dry	N/A	N/A	Grass
	Artemisia	*tridentata*	Big Sagebrush	Shrub	Dry	2–6	N/A	
N	*Ericameria Teretifolia*	*nauseosus*	Rubber Rabbitbrush	Shrub	Dry	6	3	
	Ericameria Nauseosa	*vicidiflorus*	Green Rabbitbrush	Shrub	Dry	3	4	
N	*Physocarpus*	*malvaceus*	Mallow Ninebark	Shrub	Moist	5	N/A	
N	*Purshia*	*tridentata*	Antelope Bitterbrush	Shrub	Dry	N/A	N/A	
N	*Salix*	*exigua*	Coyote Willow/ Narrowleaf Willow	Shrub	Moist-Saturated	20	N/A	
N	*Spiraea*	*douglasii*	Spirea	Shrub	Moist	6	N/A	Deciduous
N	*Betula*	*occidentalis*	Water Birch	Tree	Moist-Wet	40+	N/A	

Table A-3. Plant species identified as inappropriate for use in airport settings.

Native?	Genus	Species var.	Common Name
N	*Agropyron*	*smithii*	Western Wheatgrass
N	*Amelanchier*	*alnifolia*	Serviceberry
	Berberis	*thunbergii*	Atropurpurea Nana; Crimson Pygmy Barberry
	Betula	*pendula*	Weeping Birch
	Chamaecyparis	*lawsoniana*	Lawson Cypress
	Clematis	*ligusticfolia*	White Clematis
N	*Cornus*	*sericea (stolonifera)*	Redosier Dogwood
	Cornus	*alba elegantissima*	Elegantissima; Varigated Tatarian Dogwood
N	*Corylus*	*cornuta*	Hazel
	Cotoneaster	*adpressa praecox*	Early Cotoneaster
	Cotoneaster	*lucida*	Hedge Cotoneaster
	Cotoneaster	*horizontalis*	Rockspray Cotoneaster
	Eleagnus	*angustifolia*	Russian Olive
	Fagus	*grandifolia*	American Beech
	Fagus	*sylvatica*	Purple Beech
	Festuca	*ovina duriuscula*	Hard Fescue
	Festuca	*ovina L.*	Covar/Sheep Fescue
N	*Gaultheria*	*shallon*	Salal
	Hamamelis	*virginiana*	Witchhazel
	Hedera	*Helix*	English Ivy, Hahn's Ivy, Hahnii
N	*Holodiscus*	*discolor*	Oceanspray
	Lolium	*perenne L.*	Elka Perrenial Rye
N	*Mahonia*	*aquifolium*	Oregon Grape
N	*Mahonia*	*nervosa*	Longleaf Mahonia
N	*Mahonia*	*repens*	Creeping Mahonia
N	*Malus*	*ioensis*	Betchel Crabapple
	Oemleria	*cerasiformis*	Indian Plum
N	*Oplopanax*	*horridus*	Devil's Club
N	*Parthenocissus*	*quinquefolia*	Virginia Creeper
	Parthenocissus	*tricuspidata*	Vietchi Boston Ivy
	Poa	*compressa*	Reubens Canadian Bluegrass
	Populus	*nigra*	Theves Popular or Thevestina
N	*Populus*	*tremuloides*	Quaking Aspen
N	*Prunus*	*emarginata*	Bitter Cherry
	Prunus	*cerasifera*	Pissard Plum
	Prunus	*maackii*	Amur Choke Cherry
	Prunus	*padus commutata*	May Day Tree
	Prunus	*subhirtella*	Autumn Flowering Higan Cherry
	Prunus	*tomentosa*	Western Sand Cherry

Table A-3 (continued). Plant species identified as inappropriate for use in airport settings.

Native?	Genus	Species var.	Common Name
	Prunus	*triloba*	Flowering Almond
N	*Prunus*	*virginiana*	Shubert Choke Cherry
N	*Rhamnus*	*purshiana*	Cascara
	Rhododendron	Spp.	Rhodendron
	Rhus	*typhina*	Staghorn Sumac
N	*Ribes*	*aureum*	Golden Currant
N	*Ribes*	*cereum*	Wax Currant
	Ribes	*alpinum*	Alpine Currant
	Rosa	*foetida*	Austrian Brier Rose
	Rosa	*nitida*	Shining Rose
	Rosa	*rubrifolia*	Redleaf Rose
	Rosa	*spinosissima*	Burnett Rose
	Rubus	*calycinoides*	Blackberry
N	*Sambucus*	*ceruleum*	Blue Elderberry
N	*Symphoricarpos*	*albus*	Snowberry
N	*Vaccinium*	*ovatum*	Evergreen Huckleberry
	Viburnum	*plicatum tomentosum*	Marie's Double File viburnum
	Viburnum	*carlesii*	Korean spice Viburnum
	Viburnum	*lantana*	Wayfaring Tree
	Viburnum	*opulus*	European Highbush Cranberry

Sources: Port of Seattle (2007), Transport Canada (2004), Morin and Salisbury (2007), WSDOT (Undated ae), and Spokane County (1998).

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Appendix B – Detention and Infiltration Pond Design Analyses–Technical Documentation (Parametrix Technical Memorandum)

Parametrix
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M E M O R A N D U M

Date: **July 18, 2007 – Revised July 31, 2007**

To: **Mark Ewbank; Herrera**
Dave Felstul; Herrera

From: **Jenna Friebel**

Subject: **Detention and Infiltration Pond Design Analyses Technical Documentation**

cc: **Tom Atkins; Parametrix**
Paul Fendt; Parametrix
Joan Lee; Parametrix

Project Number: **558-2535-005 AZ.AZ4**

Project Name: **Airport Runoff Manual**

OVERVIEW

Many of the traditional methods for managing stormwater identified in the Washington State Department of Ecology (Ecology) 2005 Stormwater Management Manual for Western Washington (Ecology Manual), such as open ponds, attract wildlife that can pose a hazard for aircraft (Washington State Department of Transportation [WSDOT] Aviation 2006). However, airports in Washington are still required to manage stormwater runoff for new development and facility upgrades. This Technical Memorandum provides documentation on how the Western Washington Hydrology Model (WWHM) and the Ecology Manual were used to evaluate traditional detention and infiltration pond designs and develop recommendations for modifications to these designs resulting in the facilities being less of a wildlife attractant and more appropriate for use at airports.

DESIGN GUIDANCE

A number of operational and regulatory requirements determine how airports in the State of Washington must manage stormwater on their property. Ecology is the lead agency responsible for stormwater regulations in the state and has developed two stormwater management manuals (one for eastern Washington and one for western Washington), which include standards and criteria related to controlling the quality and quantity of stormwater runoff (Ecology 2004, 2005).

In addition, the Federal Aviation Administration (FAA) has developed the following recommendations for mitigation techniques to reduce wildlife hazards associated with existing stormwater facilities (FAA 2004). These mitigation techniques include the following:

- Modify stormwater detention ponds to allow a maximum 48-hour detention (ponding) period for the design storm.
- Use steep-sided, narrow, linear-shaped detention basins.

- Increase the depth of the facility and make it more linear to achieve capacity without increasing surface area.
- Use a two-chambered design if necessary, and design the pond with at least a ½ to 1 percent gradient from the upper to lower pond, making sure that the outlet/control structure is at the absolute lowest point.

To meet the mitigation techniques, the required modifications to the traditional methods for managing stormwater generally fell into two categories:

- Category 1 Modifications: Modifications in the first category are intended to minimize the duration and frequency of inundation of water to less than 48 hours. Hydrologic modeling was used to generate recommendations for modifications to detention and infiltration best management practices (BMPs) to help achieve this goal. The methods used for the hydrologic modeling and the associated results are documented in the following sections.

- Category 2 Modifications: The second category includes simple modifications to the physical geometry of the BMP to make it less likely to attract wildlife. These modifications did not require hydrologic or hydraulic analysis and are the same for both detention and infiltration BMPs. These modifications are included in the proposed BMP fact sheets and are not discussed further in this Technical Memorandum.

DETENTION POND HYDROLOGIC ANALYSIS

As discussed in the previous section, traditional detention ponds are considered a wildlife attractant. For verification, a hydrologic analysis was performed for a traditional detention pond (Step 1). Once it was verified that a traditional pond design is a wildlife attractant, a more detailed analysis was performed to modify the pond geometry to reduce the attractant potential (Step 2).

Step 1: Hydrologic Model to Evaluate Traditional Detention Pond Design

The WWHM and Ecology Manual (Ecology 2005) were used to design a traditional detention pond (Table 1; Attachment 1).

Table 1. Land Use for Traditional Pond Design

	Land Use (Acres on Till Soils)					
	Pre-Development			**Post-Development**		
	Forest	**Landscape**	**Impervious**	**Forest**	**Landscape**	**Impervious**
Pond 1	5.0	0.0	0.0	0.0	2.0	3.0

Once the pond was sized, the hourly volume information in the WWHM output files for the entire data set (50 years) was exported to excel. The duration of time in consecutive hours, that the pond had a volume greater than zero was calculated for each year. Based on output from WWHM, it was determined that Pond 1 had a volume of water greater than 0.0 for an average of 80 consecutive days per year (Attachment 1). It was assumed that the analysis performed on Pond 1 is representative of detention ponds designed for a variety of land-use conditions in western Washington. Therefore, it was assumed that all detention ponds sized to meet Ecology requirements would exceed the 48-hour maximum inundation criteria and would be considered a wildlife attractant.

Based on these results, Parametrix recommended that the traditional detention pond design be modified for use in the vicinity of an airport to reduce the risk of attracting hazardous wildlife.

Step 2: Recommended Detention Pond Modifications

The recommended detention pond modifications include designing the pond with two cells instead of the traditional one cell. The first cell (adjacent to the discharge structure) would be inundated frequently and for more than 48 hours; the second cell would be inundated less frequently and for less than 48 hours. Therefore, only the first cell would require additional wildlife deterrent such as wire grid or bird balls. This design approach minimizes installation and maintenance costs and still meets Ecology's stormwater management requirements and FAA's wildlife deterrent goals.

In order to recommend a size for the first cell of the pond, a return frequency analysis using WWHM was performed on the pond volume for four different land use scenarios (Table 2).

Table 2. Land Use for the Return Frequency Analysis

	Land Use (Acres on Till Soils)						
	Pre-Development			Post-Development			
	Forest	Landscape	Impervious	Forest	Landscape	Pasture	Impervious
Pond 1	5	0	0	0	2	0	3
Pond 2	4	0	0	0	3	0	1
Pond 3	10	0	0	0	2	2	6
Pond 4	40	10	0	5	15	0	30

The average daily pond volume was selected for this analysis because it is more representative of project goals, which are to reduce the area ponded for more than 48-hours and to minimize the area that required additional wildlife deterrent BMPs. The average daily pond volume for each year of record was calculated for each pond. This value was then ranked, the return frequency was determined using Weibull's equations, and the values were plotted (Figures 1 through 4) (Linsley et al. 1982).

Although the ponds represent a wide range of land uses, the results for each pond were consistent. Based on this analysis, the large, less frequent storm events accounted for most of the pond volume. Storms with a frequency of less than 5 years only accounted for between 13 and 21 percent of the total pond volume and storms with a 10-year return frequency accounted for between 16 and 29 percent of the total pond volume (see Figures 1 through 4). Therefore, it was recommended that the first cell of the pond be designed to have a volume that is 20 to 30 percent of the total pond volume[1]. To optimize this recommendation and calculate the actual time the second cell is inundated additional modeling would be required.

INFILTRATION POND ANALYSIS

As discussed in the previous section, traditional infiltration ponds may also be considered a wildlife attractant. To evaluate this, a hydrologic analysis was performed for a traditional infiltration pond using a variety of infiltration rates to determine if the pond meets the 48-hour drawdown time requirement. The Pond 1 land use (see Table 2) was used to size the infiltration facility. As shown in Table 3, the period of inundation varies depending on the infiltration rate selected.

[1] The Ecology Manual (or equivalent) should be used to determine the total pond volume and allowable discharge rates.

Table 3. Infiltration Pond Analysis Results

Results	Infiltration = 1.0 in/hr[a]	Infiltration = 0.5 in/hr[a]
Average days per year inundated	8.6	18.7
Maximum days per year inundated	13	26.8
Maximum consecutive hours of inundation	39	77
Number of years with greater than 48-hours inundation	0	6

[a] Safety factor of 4 applied per Section 3.3.6 Vol. 3 Ecology 2005

As shown in Table 3, the infiltration pond designed with an infiltration rate of 0.5 inch per hour results in a pond that exceeds the 48-hour maximum ponding period six times during the 50-year record time, and therefore would be considered a wildlife attractant. Based on these results, Parametrix recommends that airport infiltration ponds only be permitted at locations where the native underlying soils have an infiltration rate greater than 1.0 inch per hour[2].

[2] Infiltration rates should be determined using the guidance in the Ecology (or equivalent) Manual.

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FIGURES

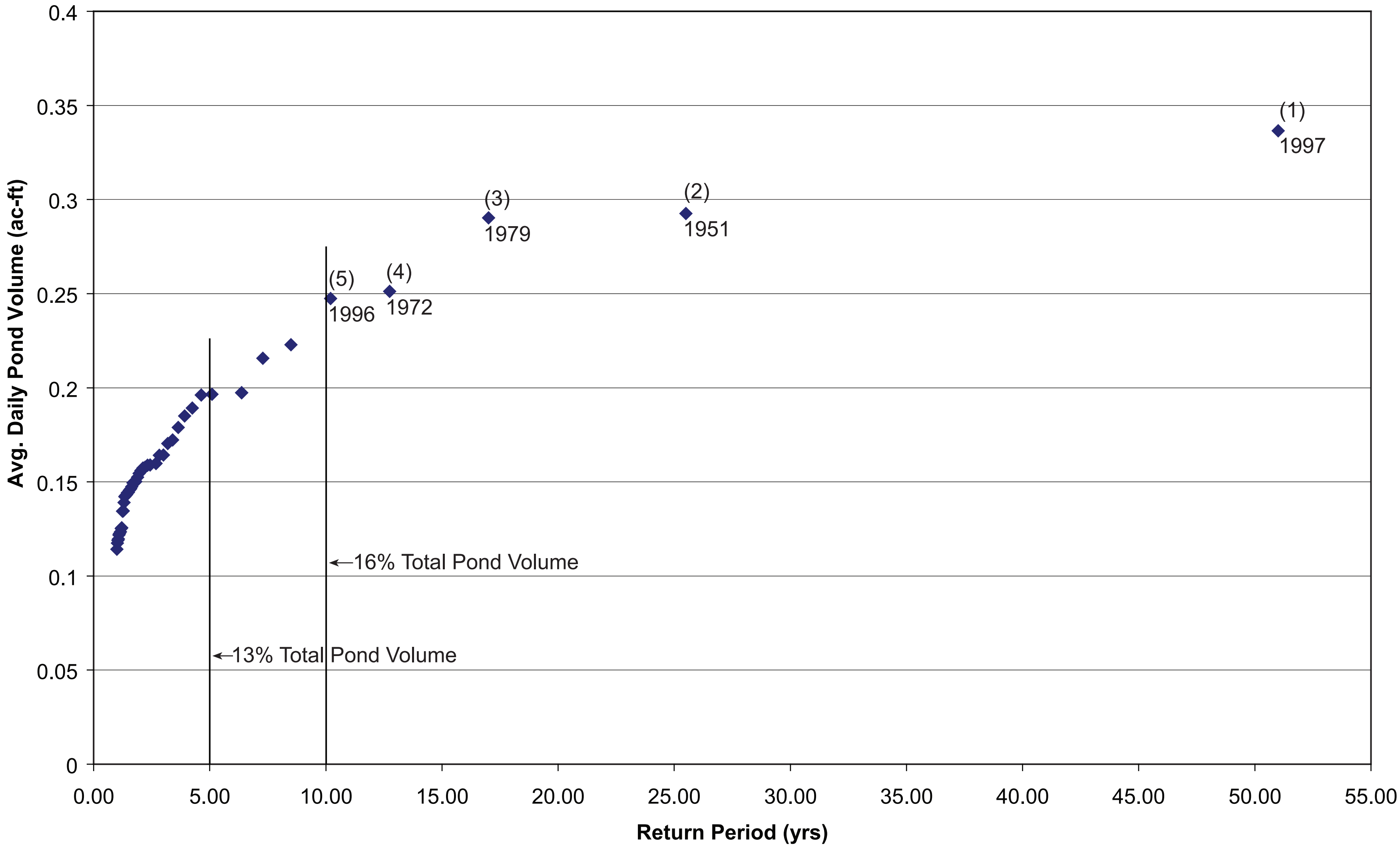
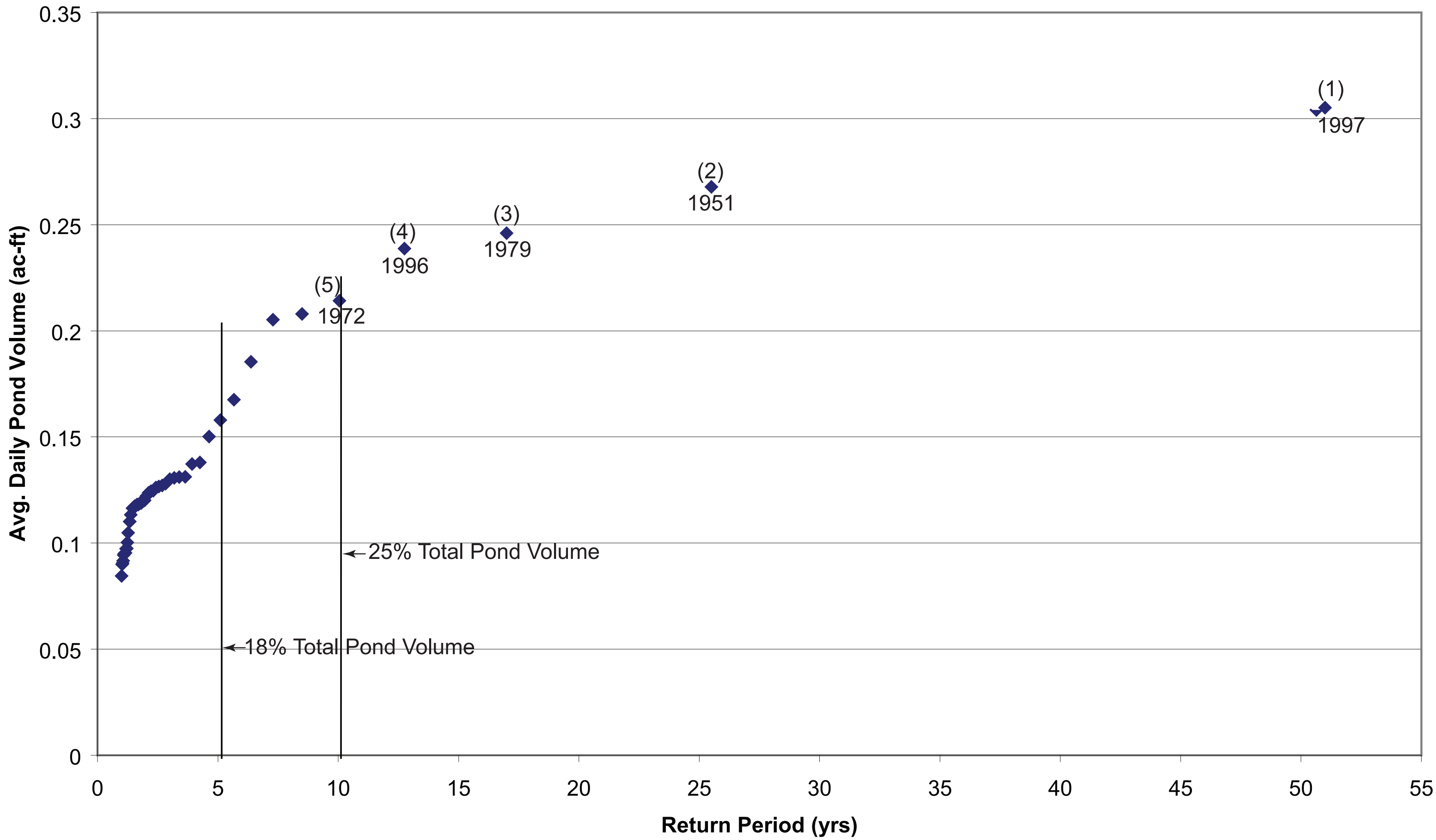


Figure 1
ARM Detention Pond 1
Return Frequency Analysis



Parametrix 558-2535-005/AZ/AZ) 7/07 (B)

Figure 2
ARM Detention Pond 2
Return Frequency Analysis

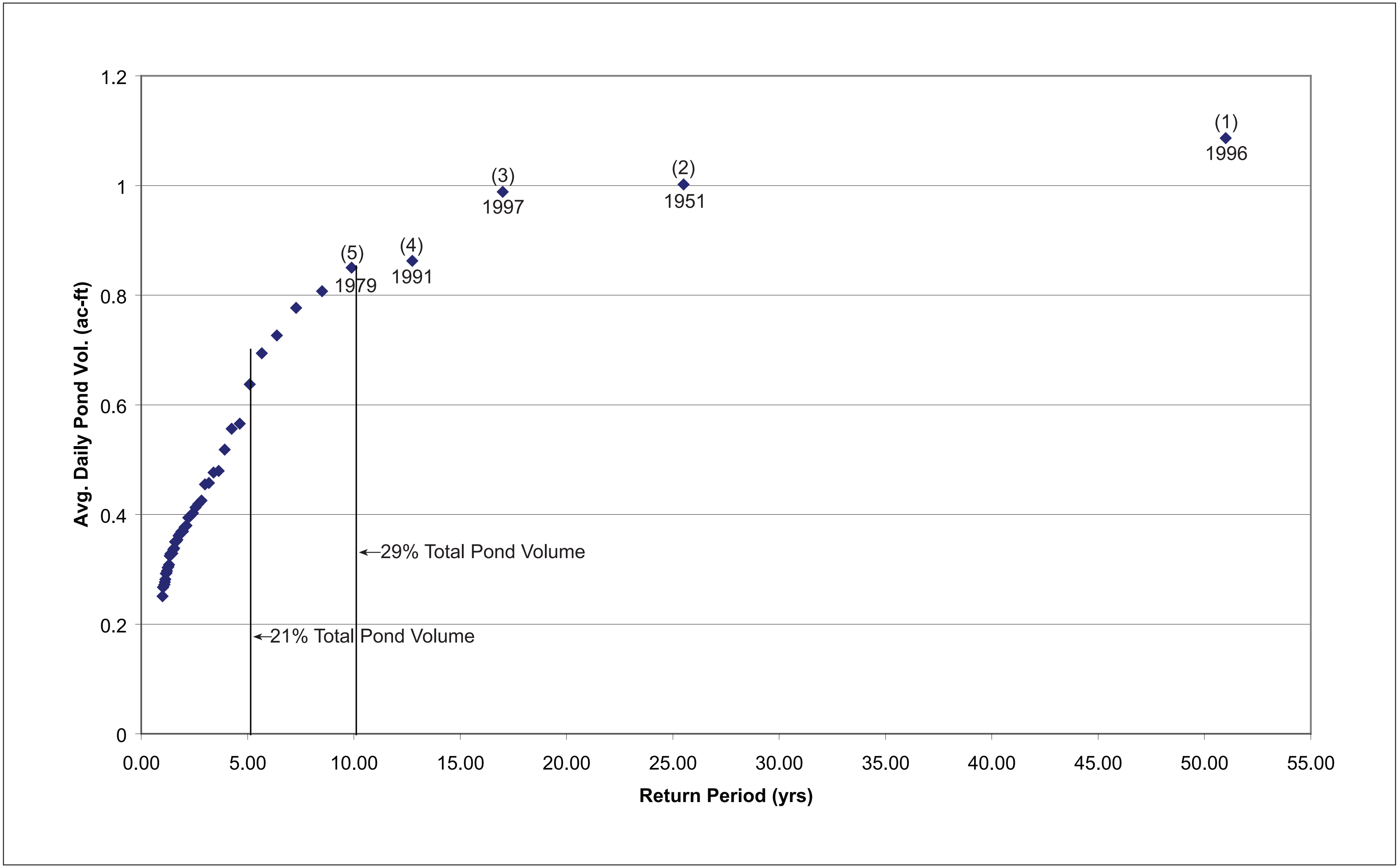


Figure 3
ARM Detention Pond 3
Return Frequency Analysis

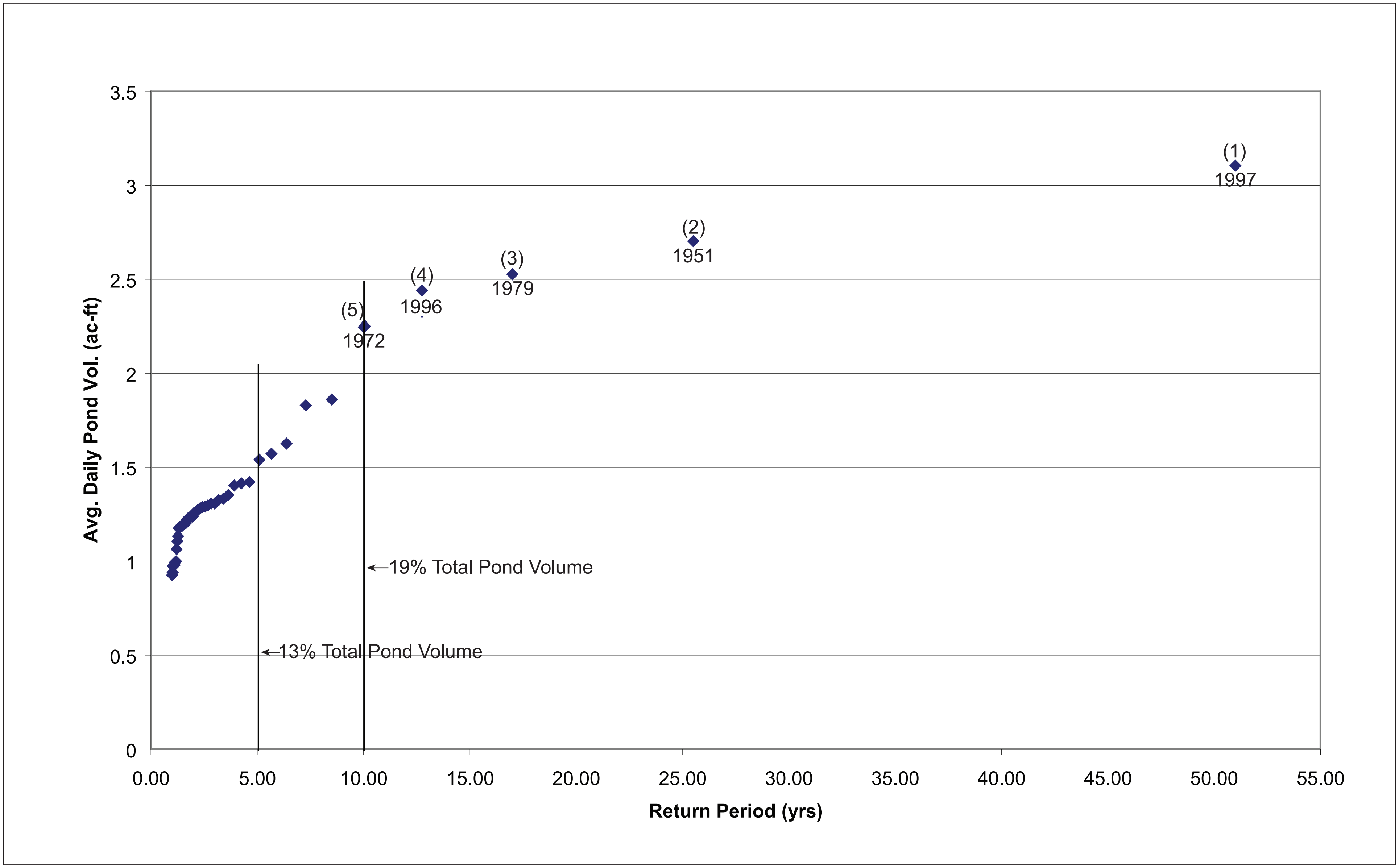


Figure 4
ARM Detention Pond 4
Return Frequency Analysis

ATTACHMENTS

POND TRIAL #1

ARMDET1.prj Detention Pond Design WWHM
Land Use predev = 5ac forest till
Land Use dev = 3ac Imp; 2ac landscape till
Infiltration rate = 0.0
L:W = 3:1; 160.8ft x 53.6ft x 6ft + 1 ft freeboard
ss=2:1

Total Pond Volume @ Riser =	1.57	ac-ft
Avg. Daily Pond Vol. Max	0.33	ac-ft
% of pnd volume	21%	

	Return Frequncy Volume		
	5-yr	**10-yr**	**max**
Avg. Daily Pond Volume (ac-ft)	0.20	0.25	0.34
% of Total Pond Volume	13%	16%	21%

POND TRIAL #2

ARMDET2.prj Detention Pond Design - WWHM
Land Use predev = 4ac forest till
Land Use dev = 1ac Imp; 3ac landscape till
Infiltration rate = 0.0
L:W = 3:1; 113.4 ft x 37.8 ft x 6 ft + 1 ft freeboard
ss=2:1

Total Pond Volume @ Riser =	0.87	ac-ft
Avg. Daily Pond Vol. Max	0.31	ac-ft
% of pnd volume	36%	

	Return Frequncy Volume		
	5-yr	**10-yr**	**max**
Pond Volume (ac-ft)	0.16	0.21	0.31
% of Total Pond Volume	18%	25%	35%

POND TRIAL #3

ARMDET3.prj Detention Pond Design - WWHM
Land Use predev = 10ac forest till
Land Use dev = 6ac Imp; 2ac landscape till; 2ac pasture till
Infiltration rate = 0.0
L:W = 3:1; 230.5 ft x 76.9 ft x 6 ft + 1 ft freeboard
ss=2:1

Total Pond Volume @ Riser =	2.98	ac-ft
Avg. Daily Pond Vol. Max	1.09	ac-ft
% of pnd volume	37%	

	Return Frequncy Volume		
	5-yr	**10-yr**	**max**
Pond Volume (ac-ft)	0.64	0.85	1.09
% of Total Pond Volume	21%	29%	37%

POND TRIAL #4

ARMDET4.prj Detention Pond Design - WWHM
Land Use predev = 40ac forest till; 10ac till grass
Land Use dev = 30ac Imp; 15ac grass till; 5ac forest
Infiltration rate = 0.0
L:W = 3:1; 485.7 ft x 161.9 ft x 6 ft + 1 ft freeboard
ss=2:1

Total Pond Volume @ Riser =	11.93	ac-ft
Avg. Daily Pond Vol. Max	3.10	ac-ft
% of pnd volume	26%	

	Return Frequncy Volume		
	5-yr	**10-yr**	**max**
Pond Volume (ac-ft)	1.54	2.24	3.10
% of Total Pond Volume	13%	19%	26%

	WESTERN	WASHINGTON	HYDROLOGY	MODEL	V2	
	PROJECT	REPORT				

Project	Name:	ARMDET1		
Site	Address:			
City	:			
Report	Date	:		1/24/2007
Gage	:	Seatac		
Data	Start	:		1948
Data	End	:		1998
Precip	Scale:		1.17	

PREDEVELC	LAND	USE			
Basin	:	Basin		1	
Flows	To	:	Point	of	Compliance
GroundWater	No				
Land	Use	Acres			
TILL	FOREST:		5		

DEVELOPED	LAND	USE			
Basin	:	Basin		1	
Flows	To	:	Pond		1
GroundWater	No				
Land	Use	Acres			
TILL	GRASS:		2		
IMPERVIOUS	3				

RCHRES	(POND)	INFORMATION					
Pond	Name:	Pond		1			
Pond	Type:	Trapezoidal	Pond				
Pond	Flows	to	:	Point	of	Compliance	
Pond	Rain	/	Evap	is	not	activated.	
Dimensions							
Depth:	7ft.						
Bottom	Length:	160.81ft.					
Bottom	Width	:	53.64ft.				
Side	slope	1:00		2	To	1	

Side	slope		2:00	2	To	1	
Side	slope		3:00	2	To	1	
Side	slope		4:00	2	To	1	
Volume	at	Riser	Head:		1.569	acre-ft.	
Discharge	Structure						
Riser	Height:		6 ft.				
Riser	Diameter:		18 in.				
NotchType	:	Rectangular					
Notch	Width	:		0.034 ft.			
Notch	Height:		2.338 ft.				
Orifice	1	Diameter:		1.307 in.		Elevati	0 ft.

Pond Stage(ft)	Hydraulic Area(acr)	Table Volume(acr-ft)	Dschrg(cfs)	Infilt(cfs)
0.00	0.20	0.00	0.00	0
0.08	0.20	0.02	0.01	0
0.16	0.20	0.03	0.02	0
0.23	0.20	0.05	0.02	0
0.31	0.20	0.06	0.03	0
0.39	0.21	0.08	0.03	0
0.47	0.21	0.10	0.03	0
0.54	0.21	0.11	0.03	0
0.62	0.21	0.13	0.04	0
0.70	0.21	0.14	0.04	0
0.78	0.21	0.16	0.04	0
0.86	0.22	0.18	0.04	0
0.93	0.22	0.19	0.04	0
1.01	0.22	0.21	0.05	0
1.09	0.22	0.23	0.05	0
1.17	0.22	0.25	0.05	0
1.24	0.22	0.26	0.05	0
1.32	0.23	0.28	0.05	0
1.40	0.23	0.297	0.05	0
1.48	0.23	0.315	0.06	0
1.56	0.23	0.33	0.06	0
1.63	0.23	0.35	0.06	0
1.71	0.23	0.37	0.06	0
1.79	0.23	0.39	0.06	0
1.87	0.24	0.41	0.06	0
1.94	0.24	0.42	0.06	0
2.02	0.24	0.44	0.06	0
2.10	0.24	0.46	0.07	0
2.18	0.24	0.48	0.07	0
2.26	0.24	0.50	0.07	0
2.33	0.25	0.52	0.07	0
2.41	0.25	0.54	0.07	0
2.49	0.25	0.56	0.07	0
2.57	0.25	0.58	0.07	0
2.64	0.25	0.60	0.07	0
2.72	0.25	0.61	0.07	0
2.80	0.26	0.63	0.075	0
2.88	0.26	0.65	0.076	0

2.96	0.26	0.67	0.077	0	
3.03	0.26	0.70	0.078	0	
3.11	0.26	0.72	0.079	0	
3.19	0.27	0.74	0.080	0	
3.27	0.27	0.76	0.081	0	
3.34	0.27	0.78	0.082	0	
3.42	0.27	0.80	0.083	0	
3.50	**0.27**	**0.82**	**0.084**	**0**	50% of Predev Q2yr
3.58	0.27	0.84	0.09	0	
3.66	0.28	0.86	0.09	0	
3.73	0.28	0.88	0.09	0	
3.81	0.28	0.90	0.09	0	
3.89	0.28	0.93	0.10	0	
3.97	0.28	0.95	0.11	0	
4.04	0.28	0.97	0.12	0	
4.12	0.29	0.99	0.12	0	
4.20	0.29	1.01	0.13	0	
4.28	0.29	1.04	0.14	0	
4.36	0.29	1.06	0.15	0	
4.43	0.29	1.08	0.16	0	
4.51	**0.29**	**1.11**	**0.17**	**0**	Predev Q2yr
4.59	0.30	1.13	0.18	0	
4.67	0.30	1.15	0.19	0	
4.74	0.30	1.17	0.20	0	
4.82	0.30	1.20	0.21	0	
4.90	0.30	1.22	0.23	0	
4.98	0.31	1.25	0.24	0	
5.06	0.31	1.27	0.25	0	
5.13	0.31	1.29	0.27	0	
5.21	0.31	1.32	0.28	0	
5.29	0.31	1.34	0.29	0	
5.37	0.31	1.37	0.31	0	
5.44	**0.32**	**1.39**	**0.32**	**0**	Predev Q10yr
5.52	0.32	1.41	0.34	0	
5.60	0.32	1.44	0.35	0	
5.68	0.32	1.46	0.37	0	
5.76	0.32	1.49	0.38	0	
5.83	0.33	1.51	0.40	0	
5.91	0.33	1.54	0.42	0	
5.99	0.33	1.57	0.43	0	
6.07	0.33	1.59	0.69	0	
6.14	0.33	1.62	1.24	0	
6.22	0.34	1.64	1.97	0	
6.30	0.34	1.67	2.84	0	
6.38	0.34	1.70	3.83	0	
6.46	0.34	1.72	4.93	0	
6.53	0.34	1.75	6.13	0	
6.61	0.34	1.78	7.42	0	
6.69	0.35	1.80	8.80	0	
6.77	0.35	1.83	10.25	0	
6.84	0.35	1.86	11.78	0	
6.92	0.35	1.88	13.38	0	

7.00	0.35	1.91	15.05	0

ANALYSIS RESULTS

Flow Return	Frequency Period	Return Flow(cfs)	Predeveloped	
2	year	0.17		0.0859835
5	year	0.27		
10	year	0.33		
25	year	0.42		
50	year	0.48		
100	year	0.54		

Flow Return	Frequency Period	Return Flow(cfs)	Developed Mitigated
2	year	0.08	
5	year	0.10	
10	year	0.12	
25	year	0.14	
50	year	0.16	
100	year	0.17	

Yearly Peaks for

Year	Predeveloped	Developed
1949	0.20	0.07
1950	0.42	0.08
1951	0.40	0.16
1952	0.13	0.06
1953	0.11	0.08
1954	0.15	0.07
1955	0.25	0.07
1956	0.23	0.11
1957	0.20	0.07
1958	0.18	0.08
1959	0.15	0.07
1960	0.29	0.12
1961	0.15	0.08
1962	0.10	0.06
1963	0.14	0.08
1964	0.15	0.08
1965	0.13	0.09
1966	0.13	0.08
1967	0.26	0.08
1968	0.15	0.07
1969	0.16	0.07
1970	0.14	0.08
1971	0.14	0.08
1972	0.33	0.13

1973	0.14	0.09
1974	0.15	0.08
1975	0.26	0.07
1976	0.15	0.07
1977	0.03	0.06
1978	0.14	0.08
1979	0.08	0.06
1980	0.22	0.15
1981	0.12	0.08
1982	0.30	0.09
1983	0.19	0.08
1984	0.12	0.06
1985	0.07	0.06
1986	0.32	0.08
1987	0.29	0.10
1988	0.12	0.07
1989	0.07	0.06
1990	0.46	0.11
1991	0.38	0.11
1992	0.14	0.08
1993	0.15	0.06
1994	0.05	0.06
1995	0.20	0.08
1996	0.38	0.14
1997	0.36	0.19
1998	0.10	0.06

Ranked Yearly Peaks for Predevelope and Developed-Mitigated

Rank	Predeveloped	Developed
1	0.4244	0.1564
2	0.3978	0.1496
3	0.3807	0.1373
4	0.3778	0.1313
5	0.362	0.115
6	0.3298	0.1134
7	0.3176	0.1092
8	0.2956	0.1055
9	0.2942	0.1005
10	0.293	0.0931
11	0.2597	0.0927
12	0.2548	0.0877
13	0.2479	0.0837
14	0.2258	0.0836
15	0.2164	0.0819
16	0.1977	0.0814
17	0.1957	0.0812
18	0.1953	0.0809
19	0.1916	0.0803
20	0.1806	0.0803
21	0.159	0.0798
22	0.1543	0.0786

23	0.1538	0.0774
24	0.1503	0.0772
25	0.1502	0.0766
26	0.1492	0.0761
27	0.147	0.0756
28	0.1467	0.0755
29	0.1464	0.0748
30	0.1421	0.0736
31	0.141	0.0734
32	0.1408	0.073
33	0.1389	0.0729
34	0.1388	0.072
35	0.1385	0.0697
36	0.133	0.0688
37	0.1288	0.0684
38	0.1262	0.0683
39	0.1242	0.068
40	0.1226	0.0639
41	0.116	0.0634
42	0.1078	0.0632
43	0.0956	0.062
44	0.0949	0.0616
45	0.0781	0.0614
46	0.069	0.0611
47	0.0682	0.0597
48	0.0481	0.0566
49	0.0328	0.0548

1/2 2-year to the 50-year

Flow(CFS)	Predev	Final	Percentage	Pass/Fail
0.086	4286	3855	89	Pass
0.09	3859	2793	72	Pass
0.0939	3501	2459	70	Pass
0.0979	3186	2169	68	Pass
0.1019	2928	1978	67	Pass
0.1058	2679	1799	67	Pass
0.1098	2426	1651	68	Pass
0.1138	2217	1517	68	Pass
0.1177	2045	1395	68	Pass
0.1217	1897	1293	68	Pass
0.1257	1732	1209	69	Pass
0.1297	1581	1142	72	Pass
0.1336	1457	1065	73	Pass
0.1376	1355	994	73	Pass
0.1416	1247	933	74	Pass
0.1455	1156	873	75	Pass
0.1495	1071	823	76	Pass
0.1535	1005	771	76	Pass
0.1574	931	723	77	Pass
0.1614	868	683	78	Pass

0.1654	813	650	79	Pass
0.1694	758	611	80	Pass
0.1733	708	572	80	Pass
0.1773	665	529	79	Pass
0.1813	623	498	79	Pass
0.1852	583	472	80	Pass
0.1892	554	437	78	Pass
0.1932	511	409	80	Pass
0.1971	473	397	83	Pass
0.2011	439	373	84	Pass
0.2051	408	352	86	Pass
0.2091	386	339	87	Pass
0.213	368	323	87	Pass
0.217	349	314	89	Pass
0.221	330	304	92	Pass
0.2249	309	293	94	Pass
0.2289	283	278	98	Pass
0.2329	264	270	102	Pass
0.2368	252	254	100	Pass
0.2408	235	238	101	Pass
0.2448	224	224	100	Pass
0.2488	211	213	100	Pass
0.2527	202	195	96	Pass
0.2567	192	176	91	Pass
0.2607	183	162	88	Pass
0.2646	174	150	86	Pass
0.2686	167	134	80	Pass
0.2726	160	124	77	Pass
0.2765	151	113	74	Pass
0.2805	138	103	74	Pass
0.2845	129	93	72	Pass
0.2885	119	81	68	Pass
0.2924	112	76	67	Pass
0.2964	99	68	68	Pass
0.3004	92	66	71	Pass
0.3043	82	60	73	Pass
0.3083	76	57	75	Pass
0.3123	67	52	77	Pass
0.3162	64	45	70	Pass
0.3202	56	42	75	Pass
0.3242	54	34	62	Pass
0.3282	49	32	65	Pass
0.3321	41	30	73	Pass
0.3361	37	29	78	Pass
0.3401	33	26	78	Pass
0.344	31	24	77	Pass
0.348	27	23	85	Pass
0.352	26	23	88	Pass
0.3559	24	20	83	Pass
0.3599	21	17	80	Pass
0.3639	19	15	78	Pass
0.3679	19	11	57	Pass

0.3718	18	10	55	Pass
0.3758	14	8	57	Pass
0.3798	10	8	80	Pass
0.3837	8	6	75	Pass
0.3877	8	4	50	Pass
0.3917	6	3	50	Pass
0.3956	6	2	33	Pass
0.3996	5	0	0	Pass
0.4036	5	0	0	Pass
0.4076	5	0	0	Pass
0.4115	5	0	0	Pass
0.4155	5	0	0	Pass
0.4195	4	0	0	Pass
0.4234	4	0	0	Pass
0.4274	3	0	0	Pass
0.4314	3	0	0	Pass
0.4353	2	0	0	Pass
0.4393	2	0	0	Pass
0.4433	2	0	0	Pass
0.4473	2	0	0	Pass
0.4512	2	0	0	Pass
0.4552	1	0	0	Pass
0.4592	0	0	0	Pass
0.4631	0	0	0	Pass
0.4671	0	0	0	Pass
0.4711	0	0	0	Pass
0.475	0	0	0	Pass
0.479	0	0	0	Pass

WESTERN WASHINGTON HYDROLOGY MODEL V2
PROJECT REPORT

Project Name: ARMDET2
Site Address:
City :
Report Date : 1/24/2007
Gage : Seatac
Data Start : 1948
Data End : 1998
Precip Scale: 1.17

PREDEVELOPED LAND USE

Basin : Basin 1
Flows To : Point of Compliance
GroundWater: No

Land Use	Acres
TILL FOREST:	4

DEVELOPED LAND USE
Basin : Basin 1
Flows To : Pond 1
GroundWater: No

Land Use	Acres
TILL GRASS:	3
IMPERVIOUS:	1

RCHRES (POND) INFORMATION
Pond Name: Pond 1
Pond Type: Trapezoidal Pond
Pond Flows to : Point of Compliance
Pond Rain / Evap is not activated.
Dimensions
Depth: 7ft.
Bottom Length: 113.36ft.
Bottom Width : 37.8ft.
Side slope 1: 2 To 1

Side slope 2: 2 To 1
Side slope 3: 2 To 1
Side slope 4: 2 To 1
Volume at Riser Head: 0.867 acre-ft.
Discharge Structure
Riser Height: 6 ft.
Riser Diameter: 18 in.
NotchType : Rectangular
Notch Width : 0.012 ft.
Notch Height: 2.301 ft.
Orifice 1 Diameter: 1.166 in. Elevation: 0 ft.

Pond Hydraulic Table

Stage(ft)	Area(acr)	Volume(acr-ft)	Dschrg(cfs)	Infilt(cfs)
0.00	0.10	0.00	0.00	0.00
0.08	0.10	0.01	0.01	0.00
0.16	0.10	0.02	0.01	0.00
0.23	0.10	0.02	0.02	0.00
0.31	0.10	0.03	0.02	0.00
0.39	0.10	0.04	0.02	0.00
0.47	0.11	0.05	0.02	0.00
0.54	0.11	0.06	0.03	0.00
0.62	0.11	0.06	0.03	0.00
0.70	0.11	0.07	0.03	0.00
0.78	0.11	0.08	0.03	0.00
0.86	0.11	0.09	0.03	0.00
0.93	0.11	0.10	0.03	0.00
1.01	0.11	0.11	0.04	0.00
1.09	0.11	0.12	0.04	0.00
1.17	0.12	0.12	0.04	0.00
1.24	0.12	0.13	0.04	0.00
1.32	0.12	0.14	0.04	0.00
1.40	0.12	0.15	0.04	0.00
1.48	0.12	0.16	0.04	0.00
1.56	0.12	0.17	0.05	0.00
1.63	0.12	0.18	0.05	0.00
1.71	0.12	0.19	0.05	0.00
1.79	0.12	0.20	0.05	0.00
1.87	0.13	0.21	0.05	0.00
1.94	0.13	0.22	0.05	0.00
2.02	0.13	0.23	0.05	0.00
2.10	0.13	0.24	0.05	0.00
2.18	0.13	0.25	0.05	0.00
2.26	0.13	0.26	0.05	0.00
2.33	0.13	0.27	0.06	0.00
2.41	0.13	0.28	0.06	0.00
2.49	0.14	0.29	0.06	0.00
2.57	0.14	0.30	0.06	0.00
2.64	0.14	0.31	0.06	0.00
2.72	0.14	0.32	0.06	0.00
2.80	0.14	0.33	0.06	0.00
2.88	0.14	0.34	0.06	0.00

2.96	0.14	0.36	0.06	0.00	
3.03	0.14	0.37	0.06	0.00	
3.11	0.15	0.38	0.06	0.00	
3.19	0.15	0.39	0.06	0.00	
3.27	0.15	0.40	0.065	0.00	
3.34	0.15	0.41	0.065	0.00	
3.42	0.15	0.42	0.066	0.00	
3.50	0.15	0.44	0.067	0.00	
3.58	0.15	0.45	0.068	0.00	
3.66	0.15	0.46	0.068	0.00	
3.73	0.16	0.47	0.069	0.00	
3.81	**0.16**	**0.48**	**0.071**	**0.00**	**50% 2-year Predev Q2**
3.89	0.16	0.50	0.074	0.00	
3.97	0.16	0.51	0.08	0.00	
4.04	0.16	0.52	0.08	0.00	
4.12	0.16	0.53	0.08	0.00	
4.20	0.16	0.55	0.09	0.00	
4.28	0.16	0.56	0.09	0.00	
4.36	0.17	0.57	0.09	0.00	
4.43	0.17	0.58	0.10	0.00	
4.51	0.17	0.60	0.10	0.00	
4.59	0.17	0.61	0.10	0.00	
4.67	0.17	0.62	0.11	0.00	
4.74	0.17	0.64	0.11	0.00	
4.82	0.17	0.65	0.12	0.00	
4.90	0.18	0.66	0.12	0.00	
4.98	0.18	0.68	0.13	0.00	
5.06	0.18	0.69	0.13	0.00	
5.13	0.18	0.70	0.136	0.00	
5.21	**0.18**	**0.72**	**0.141**	**0.00**	**2-yr Predev Q**
5.29	0.18	0.73	0.15	0.00	
5.37	0.18	0.75	0.15	0.00	
5.44	0.19	0.76	0.16	0.00	
5.52	0.19	0.78	0.16	0.00	
5.60	0.19	0.79	0.17	0.00	
5.68	0.19	0.81	0.17	0.00	
5.76	0.19	0.82	0.18	0.00	
5.83	0.19	0.83	0.19	0.00	
5.91	0.19	0.85	0.19	0.00	
5.99	0.20	0.86	0.20	0.00	
6.07	0.20	0.88	0.45	0.00	
6.14	0.20	0.90	1.00	0.00	
6.22	0.20	0.91	1.73	0.00	
6.30	0.20	0.93	2.60	0.00	
6.38	0.20	0.94	3.59	0.00	
6.46	0.20	0.96	4.69	0.00	
6.53	0.21	0.97	5.89	0.00	
6.61	0.21	0.99	7.18	0.00	
6.69	0.21	1.01	8.56	0.00	
6.77	0.21	1.02	10.01	0.00	
6.84	0.21	1.04	11.54	0.00	
6.92	0.21	1.05	13.14	0.00	

7.00	0.21	1.07	14.81	0.00

ANALYSIS RESULTS

Flow Frequency Return Periods for Predeveloped

Return Period	Flow(cfs)	
2	year	0.14
5	year	0.22
10	year	0.27
25	year	0.33
50	year	0.38
100	year	0.43

Flow Frequency Return Periods for Developed Mitigated

Return Period	Flow(cfs)	
2	year	0.06
5	year	0.08
10	year	0.10
25	year	0.12
50	year	0.14
100	year	0.16

Yearly Peaks for Predeveloped and Developed-Mitigated

Year	Predeveloped	Developed
1949	0.16	0.05
1950	0.34	0.07
1951	0.32	0.14
1952	0.11	0.05
1953	0.09	0.06
1954	0.12	0.06
1955	0.20	0.06
1956	0.18	0.08
1957	0.16	0.06
1958	0.15	0.06
1959	0.12	0.05
1960	0.23	0.11
1961	0.12	0.07
1962	0.08	0.05
1963	0.11	0.06
1964	0.12	0.06
1965	0.10	0.07
1966	0.10	0.06
1967	0.21	0.06
1968	0.12	0.06
1969	0.13	0.06
1970	0.11	0.06
1971	0.11	0.06
1972	0.26	0.11
1973	0.11	0.07
1974	0.12	0.06
1975	0.20	0.06

1976	0.12	0.06
1977	0.03	0.04
1978	0.11	0.06
1979	0.06	0.04
1980	0.17	0.13
1981	0.10	0.06
1982	0.24	0.08
1983	0.15	0.06
1984	0.10	0.05
1985	0.06	0.05
1986	0.25	0.07
1987	0.24	0.09
1988	0.09	0.05
1989	0.06	0.05
1990	0.37	0.10
1991	0.30	0.09
1992	0.11	0.07
1993	0.12	0.05
1994	0.04	0.04
1995	0.16	0.07
1996	0.31	0.13
1997	0.29	0.16
1998	0.08	0.05

Ranked Yearly Peaks for Predeveloped and Developed-Mitigated

Rank	Predeveloped	Developed
1	0.34	0.14
2	0.32	0.13
3	0.30	0.13
4	0.30	0.11
5	0.29	0.11
6	0.26	0.10
7	0.25	0.09
8	0.24	0.09
9	0.24	0.08
10	0.23	0.08
11	0.21	0.07
12	0.20	0.07
13	0.20	0.07
14	0.18	0.07
15	0.17	0.07
16	0.16	0.07
17	0.16	0.07
18	0.16	0.06
19	0.15	0.06
20	0.14	0.06
21	0.13	0.06
22	0.12	0.06
23	0.12	0.06
24	0.12	0.06
25	0.12	0.06

26	0.12	0.06
27	0.12	0.06
28	0.12	0.06
29	0.12	0.06
30	0.11	0.06
31	0.11	0.06
32	0.11	0.06
33	0.11	0.06
34	0.11	0.06
35	0.11	0.06
36	0.11	0.06
37	0.10	0.05
38	0.10	0.05
39	0.10	0.05
40	0.10	0.05
41	0.09	0.05
42	0.09	0.05
43	0.08	0.05
44	0.08	0.05
45	0.06	0.05
46	0.06	0.05
47	0.05	0.04
48	0.04	0.04
49	0.03	0.04

1/2 2 year to 50 year

Flow(CFS)	Predev	Final	Percentage	Pass/Fail
0.0688	4286	4093	95.0	Pass
0.0720	3883	3331	85.0	Pass
0.0751	3432	2760	80.0	Pass
0.0783	3155	2430	77.0	Pass
0.0815	2911	2131	73.0	Pass
0.0847	2679	1861	69.0	Pass
0.0878	2441	1681	68.0	Pass
0.0910	2182	1451	66.0	Pass
0.0942	2025	1319	65.0	Pass
0.0974	1885	1213	64.0	Pass
0.1005	1732	1116	64.0	Pass
0.1037	1590	1039	65.0	Pass
0.1069	1473	956	64.0	Pass
0.1101	1335	853	63.0	Pass
0.1133	1237	781	63.0	Pass
0.1164	1156	740	64.0	Pass
0.1196	1075	705	65.0	Pass
0.1228	1010	659	65.0	Pass
0.1260	946	620	65.0	Pass
0.1291	864	565	65.0	Pass
0.1323	813	524	64.0	Pass
0.1355	760	468	61.0	Pass
0.1387	717	438	61.0	Pass
0.1418	668	409	61.0	Pass

0.1450	622	359	57.0	Pass
0.1482	583	344	59.0	Pass
0.1514	556	325	58.0	Pass
0.1545	517	311	60.0	Pass
0.1577	480	292	60.0	Pass
0.1609	447	276	61.0	Pass
0.1641	408	250	61.0	Pass
0.1672	389	228	58.0	Pass
0.1704	372	201	54.0	Pass
0.1736	348	176	50.0	Pass
0.1768	330	151	45.0	Pass
0.1799	310	131	42.0	Pass
0.1831	278	115	41.0	Pass
0.1863	263	101	38.0	Pass
0.1895	251	87	34.0	Pass
0.1927	235	67	28.0	Pass
0.1958	224	49	21.0	Pass
0.1990	209	31	14.0	Pass
0.2022	201	29	14.0	Pass
0.2054	192	28	14.0	Pass
0.2085	183	27	14.0	Pass
0.2117	175	25	14.0	Pass
0.2149	169	24	14.0	Pass
0.2181	159	21	13.0	Pass
0.2212	149	21	14.0	Pass
0.2244	138	21	15.0	Pass
0.2276	129	20	15.0	Pass
0.2308	120	19	15.0	Pass
0.2339	113	19	16.0	Pass
0.2371	98	19	19.0	Pass
0.2403	92	18	19.0	Pass
0.2435	82	17	20.0	Pass
0.2466	76	17	22.0	Pass
0.2498	68	16	23.0	Pass
0.2530	66	15	22.0	Pass
0.2562	56	14	25.0	Pass
0.2593	54	12	22.0	Pass
0.2625	49	11	22.0	Pass
0.2657	41	11	26.0	Pass
0.2689	39	11	28.0	Pass
0.2721	33	10	30.0	Pass
0.2752	31	10	32.0	Pass
0.2784	29	10	34.0	Pass
0.2816	26	9	34.0	Pass
0.2848	24	9	37.0	Pass
0.2879	21	9	42.0	Pass
0.2911	19	7	36.0	Pass
0.2943	19	7	36.0	Pass
0.2975	17	6	35.0	Pass
0.3006	14	6	42.0	Pass
0.3038	10	6	60.0	Pass
0.3070	8	6	75.0	Pass

0.3102	8	5	62.0	Pass
0.3133	6	5	83.0	Pass
0.3165	6	5	83.0	Pass
0.3197	5	5	100.0	Pass
0.3229	5	5	100.0	Pass
0.3260	5	5	100.0	Pass
0.3292	5	4	80.0	Pass
0.3324	5	4	80.0	Pass
0.3356	4	4	100.0	Pass
0.3387	4	4	100.0	Pass
0.3419	3	3	100.0	Pass
0.3451	3	2	66.0	Pass
0.3483	2	2	100.0	Pass
0.3515	2	2	100.0	Pass
0.3546	2	2	100.0	Pass
0.3578	2	2	100.0	Pass
0.3610	2	2	100.0	Pass
0.3642	1	0	.0	Pass
0.3673	0	0	.0	Pass
0.3705	0	0	.0	Pass
0.3737	0	0	.0	Pass
0.3769	0	0	.0	Pass
0.3800	0	0	.0	Pass
0.3832	0	0	.0	Pass

WESTERN WASHINGTON HYDROLOGY MODEL V2
PROJECT REPORT

Project Name: ARMDET3
Site Address:
City :
Report Date : 1/24/2007
Gage : Seatac
Data Start : 1948
Data End : 1998
Precip Scale: 1.17

PREDEVELOPED LAND USE

Basin : Basin 1
Flows To : Point of Compliance
GroundWater: No

Land Use	Acres
TILL FOREST:	10

DEVELOPED LAND USE
Basin : Basin 1
Flows To : Pond 1
GroundWater: No

Land Use	Acres
TILL PASTURE:	2
TILL GRASS:	2
IMPERVIOUS:	6

RCHRES (POND) INFORMATION
Pond Name: Pond 1
Pond Type: Trapezoidal Pond
Pond Flows to : Point of Compliance
Pond Rain / Evap is not activated.
Dimensions
Depth: 7ft.
Bottom Length: 230.55ft.
Bottom Width : 76.85ft.

Side slope 1: 2 To 1
Side slope 2: 2 To 1
Side slope 3: 2 To 1
Side slope 4: 2 To 1
Volume at Riser Head: 2.975 acre-ft.
Discharge Structure
Riser Height: 6 ft.
Riser Diameter: 18 in.
NotchType : Rectangular
Notch Width : 0.035 ft.
Notch Height: 2.498 ft.
Orifice 1 Diameter: 1.87 in. Elevation: 0 ft.

Pond Hydraulic Table

Stage(ft)	Area(acr)	Volume(acr-ft)	Dschrg(cfs)	Infilt(cfs)
0.0	0.41	0.00	0.00	0.00
0.1	0.41	0.03	0.03	0.00
0.2	0.41	0.06	0.04	0.00
0.2	0.41	0.10	0.04	0.00
0.3	0.42	0.13	0.05	0.00
0.4	0.42	0.16	0.06	0.00
0.5	0.42	0.19	0.06	0.00
0.5	0.42	0.23	0.07	0.00
0.6	0.42	0.26	0.07	0.00
0.7	0.43	0.29	0.08	0.00
0.8	0.43	0.33	0.08	0.00
0.9	0.43	0.36	0.09	0.00
0.9	0.43	0.39	0.09	0.00
1.0	0.44	0.43	0.09	0.00
1.1	0.44	0.46	0.10	0.00
1.2	0.44	0.49	0.10	0.00
1.2	0.44	0.53	0.10	0.00
1.3	0.45	0.56	0.11	0.00
1.4	0.45	0.60	0.11	0.00
1.5	0.45	0.63	0.11	0.00
1.6	0.45	0.67	0.12	0.00
1.6	0.45	0.70	0.12	0.00
1.7	0.46	0.74	0.12	0.00
1.8	0.46	0.77	0.12	0.00
1.9	0.46	0.81	0.13	0.00
1.9	0.46	0.85	0.13	0.00
2.0	0.47	0.88	0.13	0.00
2.1	0.47	0.92	0.13	0.00
2.2	0.47	0.95	0.14	0.00
2.3	0.47	0.99	0.14	0.00
2.3	0.48	1.03	0.14	0.00
2.4	0.48	1.06	0.14	0.00
2.5	0.48	1.10	0.15	0.00
2.6	0.48	1.14	0.15	0.00
2.6	0.48	1.18	0.15	0.00
2.7	0.49	1.21	0.15	0.00
2.8	0.49	1.25	0.15	0.00

2.9	0.49	1.29	0.16	0.00	
3.0	0.49	1.33	0.16	0.00	
3.0	0.50	1.37	0.16	0.00	
3.1	0.50	1.41	0.16	0.00	
3.2	0.50	1.45	0.16	0.00	
3.3	0.50	1.48	0.166	0.00	
3.3	0.51	1.52	0.168	0.00	
3.4	**0.51**	**1.56**	**0.170**	**0.00**	**50% 2-yr Predev Q**
3.5	0.51	1.60	0.172	0.00	
3.6	0.51	1.64	0.18	0.00	
3.7	0.52	1.68	0.18	0.00	
3.7	0.52	1.72	0.19	0.00	
3.8	0.52	1.76	0.20	0.00	
3.9	0.52	1.80	0.21	0.00	
4.0	0.52	1.84	0.22	0.00	
4.0	0.53	1.88	0.23	0.00	
4.1	0.53	1.93	0.24	0.00	
4.2	0.53	1.97	0.25	0.00	
4.3	0.53	2.01	0.26	0.00	
4.4	0.54	2.05	0.27	0.00	
4.4	0.54	2.09	0.28	0.00	
4.5	0.54	2.13	0.29	0.00	
4.6	0.54	2.18	0.30	0.00	
4.7	0.55	2.22	0.32	0.00	
4.7	0.55	2.26	0.33	0.00	
4.8	**0.55**	**2.30**	**0.34**	**0.00**	**2-yr Predev Q**
4.9	0.55	2.35	0.36	0.00	
5.0	0.56	2.39	0.37	0.00	
5.1	0.56	2.43	0.39	0.00	
5.1	0.56	2.48	0.40	0.00	
5.2	0.56	2.52	0.42	0.00	
5.3	0.57	2.56	0.43	0.00	
5.4	0.57	2.61	0.45	0.00	
5.4	0.57	2.65	0.47	0.00	
5.5	0.57	2.70	0.48	0.00	
5.6	0.58	2.74	0.50	0.00	
5.7	0.58	2.79	0.52	0.00	
5.8	0.58	2.83	0.54	0.00	
5.8	0.58	2.88	0.55	0.00	
5.9	0.59	2.92	0.57	0.00	
6.0	**0.59**	**2.97**	**0.59**	**0.00**	**10-yr Predev Q**
6.1	0.59	3.01	0.85	0.00	
6.1	0.59	3.06	1.40	0.00	
6.2	0.60	3.11	2.13	0.00	
6.3	0.60	3.15	3.00	0.00	
6.4	0.60	3.20	3.99	0.00	
6.5	0.60	3.25	5.09	0.00	
6.5	0.61	3.29	6.29	0.00	
6.6	0.61	3.34	7.58	0.00	
6.7	0.61	3.39	8.96	0.00	
6.8	0.62	3.44	10.41	0.00	
6.8	0.62	3.48	11.94	0.00	

6.9	0.62	3.53	13.55	0.00
7.0	0.62	3.58	15.22	0.00

ANALYSIS RESULTS

Flow Frequency Return Periods for Predeveloped

Return Period		Flow(cfs)
2	year	0.34
5	year	0.54
10	year	0.67
25	year	0.84
50	year	0.96
100	year	1.08

Flow Frequency Return Periods for Developed Mitigated

Return Period		Flow(cfs)
2	year	0.16
5	year	0.21
10	year	0.25
25	year	0.30
50	year	0.34
100	year	0.38

Yearly Peaks for Predeveloped and Developed-Mitigated

Year	Predeveloped	Developed
1949	0.40	0.14
1950	0.85	0.16
1951	0.80	0.34
1952	0.27	0.12
1953	0.22	0.16
1954	0.30	0.15
1955	0.50	0.14
1956	0.45	0.21
1957	0.39	0.15
1958	0.36	0.16
1959	0.29	0.14
1960	0.59	0.24
1961	0.29	0.17
1962	0.19	0.12
1963	0.28	0.15
1964	0.30	0.16
1965	0.26	0.18
1966	0.25	0.15
1967	0.52	0.16
1968	0.31	0.15
1969	0.32	0.15
1970	0.28	0.16
1971	0.28	0.15

1972	0.66	0.29
1973	0.28	0.19
1974	0.30	0.15
1975	0.51	0.14
1976	0.31	0.15
1977	0.07	0.12
1978	0.28	0.16
1979	0.16	0.11
1980	0.43	0.32
1981	0.25	0.15
1982	0.59	0.19
1983	0.38	0.15
1984	0.25	0.12
1985	0.14	0.13
1986	0.64	0.16
1987	0.59	0.21
1988	0.23	0.13
1989	0.14	0.12
1990	0.92	0.25
1991	0.76	0.22
1992	0.28	0.16
1993	0.29	0.12
1994	0.10	0.11
1995	0.39	0.17
1996	0.76	0.31
1997	0.72	0.41
1998	0.19	0.13

Ranked Yearly Peaks for Predeveloped and Developed-Mitigated

Rank	Predeveloped	Developed
1	0.8488	0.3433
2	0.7955	0.3218
3	0.7614	0.3052
4	0.7556	0.2862
5	0.7240	0.2454
6	0.6595	0.2431
7	0.6352	0.2237
8	0.5912	0.2128
9	0.5885	0.2070
10	0.5859	0.1870
11	0.5195	0.1854
12	0.5096	0.1775
13	0.4959	0.1678
14	0.4516	0.1670
15	0.4327	0.1636
16	0.3953	0.1635
17	0.3914	0.1628
18	0.3907	0.1619
19	0.3831	0.1614
20	0.3612	0.1607
21	0.3180	0.1569

22	0.3086	0.1568
23	0.3076	0.1563
24	0.3006	0.1544
25	0.3004	0.1535
26	0.2984	0.1535
27	0.2941	0.1517
28	0.2934	0.1514
29	0.2927	0.1484
30	0.2842	0.1475
31	0.2820	0.1471
32	0.2816	0.1471
33	0.2779	0.1470
34	0.2777	0.1455
35	0.2771	0.1418
36	0.2660	0.1372
37	0.2577	0.1371
38	0.2524	0.1366
39	0.2484	0.1330
40	0.2452	0.1255
41	0.2321	0.1248
42	0.2157	0.1244
43	0.1913	0.1242
44	0.1899	0.1233
45	0.1561	0.1225
46	0.1380	0.1210
47	0.1365	0.1203
48	0.0961	0.1134
49	0.0656	0.1094

1/2 2 year to 50 year

Flow(CFS)	Predev	Final	Percentage	Pass/Fail
0.1720	4231	3839	90.0	Pass
0.1799	3812	3000	78.0	Pass
0.1878	3457	2563	74.0	Pass
0.1958	3155	2228	70.0	Pass
0.2037	2899	1969	67.0	Pass
0.2117	2641	1760	66.0	Pass
0.2196	2396	1570	65.0	Pass
0.2275	2194	1433	65.0	Pass
0.2355	2025	1314	64.0	Pass
0.2434	1876	1202	64.0	Pass
0.2514	1714	1095	63.0	Pass
0.2593	1565	1000	63.0	Pass
0.2672	1440	917	63.0	Pass
0.2752	1335	839	62.0	Pass
0.2831	1229	772	62.0	Pass
0.2911	1144	718	62.0	Pass
0.2990	1065	650	61.0	Pass
0.3069	1005	613	60.0	Pass
0.3149	931	579	62.0	Pass
0.3228	868	548	63.0	Pass

0.3308	813	520	63.0	Pass
0.3387	758	491	64.0	Pass
0.3466	708	464	65.0	Pass
0.3546	665	439	66.0	Pass
0.3625	623	418	67.0	Pass
0.3705	583	386	66.0	Pass
0.3784	554	356	64.0	Pass
0.3863	511	333	65.0	Pass
0.3943	473	312	65.0	Pass
0.4022	439	287	65.0	Pass
0.4102	408	266	65.0	Pass
0.4181	386	247	63.0	Pass
0.4260	368	231	62.0	Pass
0.4340	346	209	60.0	Pass
0.4419	329	195	59.0	Pass
0.4499	307	177	57.0	Pass
0.4578	280	159	56.0	Pass
0.4657	263	146	55.0	Pass
0.4737	251	132	52.0	Pass
0.4816	234	113	48.0	Pass
0.4896	223	96	43.0	Pass
0.4975	209	81	38.0	Pass
0.5054	201	72	35.0	Pass
0.5134	190	59	31.0	Pass
0.5213	182	51	28.0	Pass
0.5293	173	45	26.0	Pass
0.5372	166	36	21.0	Pass
0.5451	159	30	18.0	Pass
0.5531	145	24	16.0	Pass
0.5610	138	22	15.0	Pass
0.5690	129	18	13.0	Pass
0.5769	119	15	12.0	Pass
0.5848	112	12	10.0	Pass
0.5928	99	10	10.0	Pass
0.6007	92	9	9.0	Pass
0.6087	82	9	10.0	Pass
0.6166	76	9	11.0	Pass
0.6245	67	9	13.0	Pass
0.6325	64	8	12.0	Pass
0.6404	56	7	12.0	Pass
0.6484	54	7	12.0	Pass
0.6563	49	7	14.0	Pass
0.6642	41	7	17.0	Pass
0.6722	37	7	18.0	Pass
0.6801	33	7	21.0	Pass
0.6881	31	6	19.0	Pass
0.6960	27	6	22.0	Pass
0.7039	26	6	23.0	Pass
0.7119	23	6	26.0	Pass
0.7198	21	5	23.0	Pass
0.7278	19	5	26.0	Pass
0.7357	19	3	15.0	Pass

0.7436	17	3	17.0	Pass
0.7516	14	3	21.0	Pass
0.7595	10	3	30.0	Pass
0.7675	8	3	37.0	Pass
0.7754	8	3	37.0	Pass
0.7833	6	3	50.0	Pass
0.7913	6	3	50.0	Pass
0.7992	5	3	60.0	Pass
0.8072	5	2	40.0	Pass
0.8151	5	2	40.0	Pass
0.8230	5	2	40.0	Pass
0.8310	5	2	40.0	Pass
0.8389	4	2	50.0	Pass
0.8469	4	1	25.0	Pass
0.8548	3	0	.0	Pass
0.8627	3	0	.0	Pass
0.8707	2	0	.0	Pass
0.8786	2	0	.0	Pass
0.8866	2	0	.0	Pass
0.8945	2	0	.0	Pass
0.9024	2	0	.0	Pass
0.9104	1	0	.0	Pass
0.9183	0	0	.0	Pass
0.9263	0	0	.0	Pass
0.9342	0	0	.0	Pass
0.9421	0	0	.0	Pass
0.9501	0	0	.0	Pass
0.9580	0	0	.0	Pass

WESTERN WASHINGTON HYDROLOGY MODEL V2
PROJECT REPORT

Project Name: armdet4
Site Address:
City :
Report Date : 1/30/2007
Gage : Seatac
Data Start : 1948
Data End : 1998
Precip Scale: 1.00

PREDEVELOPED LAND USE

Basin : Basin 1
Flows To : Point of Compliance
GroundWater: No

Land Use	Acres
TILL FOREST:	40
TILL GRASS:	10

DEVELOPED LAND USE
Basin : Basin 1
Flows To : DET4
GroundWater: No

Land Use	Acres
TILL FOREST:	5
TILL GRASS:	15
IMPERVIOUS:	30

RCHRES (POND) INFORMATION
Pond Name: DET4
Pond Type: Trapezoidal Pond
Pond Flows to : Point of Compliance
Pond Rain / Evap is not activated.
Dimensions
Depth: 7ft.
Bottom Length: 485.68ft.

Bottom Width : 161.92ft.
Side slope 1: 2 To 1
Side slope 2: 2 To 1
Side slope 3: 2 To 1
Side slope 4: 2 To 1
Volume at Riser Head: 11.929 acre-ft.
Discharge Structure
Riser Height: 6 ft.
Riser Diameter: 18 in.
NotchType : Rectangular
Notch Width : 0.226 ft.
Notch Height: 2.462 ft.
Orifice 1 Diameter: 3.824 in. Elevation: 0 ft.

Pond Hydraulic Table

Stage(ft)	Area(acr)	Volume(acr-ft)	Dschrg(cfs)	Infilt(cfs)
0.000	1.805	0.000	0.000	0.000
0.078	1.810	0.141	0.107	0.000
0.156	1.815	0.282	0.151	0.000
0.233	1.819	0.423	0.186	0.000
0.311	1.824	0.565	0.214	0.000
0.389	1.829	0.707	0.240	0.000
0.467	1.833	0.849	0.262	0.000
0.544	1.838	0.992	0.283	0.000
0.622	1.843	1.135	0.303	0.000
0.700	1.847	1.278	0.321	0.000
0.778	1.852	1.422	0.339	0.000
0.856	1.857	1.566	0.355	0.000
0.933	1.861	1.711	0.371	0.000
1.011	1.866	1.856	0.386	0.000
1.089	1.871	2.001	0.401	0.000
1.167	1.875	2.147	0.415	0.000
1.244	1.880	2.293	0.428	0.000
1.322	1.885	2.439	0.442	0.000
1.400	1.889	2.586	0.454	0.000
1.478	1.894	2.733	0.467	0.000
1.556	1.899	2.881	0.479	0.000
1.633	1.903	3.029	0.491	0.000
1.711	1.908	3.177	0.502	0.000
1.789	1.913	3.325	0.514	0.000
1.867	1.918	3.474	0.525	0.000
1.944	1.922	3.624	0.536	0.000
2.022	1.927	3.773	0.546	0.000
2.100	1.932	3.924	0.557	0.000
2.178	1.937	4.074	0.567	0.000
2.256	1.941	4.225	0.577	0.000
2.333	1.946	4.376	0.587	0.000
2.411	1.951	4.527	0.596	0.000
2.489	1.956	4.679	0.606	0.000
2.567	1.960	4.832	0.615	0.000
2.644	1.965	4.984	0.625	0.000
2.722	1.970	5.137	0.634	0.000

2.800	1.975	5.291	0.643	0.000
2.878	1.980	5.445	0.652	0.000
2.956	1.984	5.599	0.660	0.000
3.033	1.989	5.753	0.669	0.000
3.111	1.994	5.908	0.677	0.000
3.189	1.999	6.063	0.686	0.000
3.267	2.004	6.219	0.694	0.000
3.344	2.008	6.375	0.702	0.000
3.422	2.013	6.531	0.710	0.000
3.500	2.018	6.688	0.719	0.000
3.578	2.023	6.845	0.732	0.000
3.656	2.028	7.003	0.764	0.000
3.733	2.032	7.161	0.804	0.000
3.811	2.037	7.319	0.851	0.000
3.889	2.042	7.478	0.903	0.000
3.967	2.047	7.637	0.958	0.000
4.044	2.052	7.796	1.016	0.000
4.122	2.057	7.956	1.077	0.000
4.200	2.062	8.116	1.139	0.000
4.278	2.066	8.277	1.203	0.000
4.356	2.071	8.438	1.267	0.000
4.433	2.076	8.599	1.332	0.000
4.511	2.081	8.760	1.398	0.000
4.589	2.086	8.923	1.472	0.000
4.667	2.091	9.085	1.552	0.000
4.744	2.096	9.248	1.635	0.000
4.822	2.101	9.411	1.720	0.000
4.900	2.106	9.575	1.808	0.000
4.978	2.110	9.739	1.898	0.000
5.056	2.115	9.903	1.990	0.000
5.133	2.120	10.07	2.084	0.000
5.211	2.125	10.23	2.181	0.000
5.289	2.130	10.40	2.279	0.000
5.367	2.135	10.56	2.380	0.000
5.444	2.140	10.73	2.483	0.000
5.522	2.145	10.90	2.587	0.000
5.600	2.150	11.06	2.693	0.000
5.678	2.155	11.23	2.802	0.000
5.756	2.160	11.40	2.912	0.000
5.833	2.165	11.57	3.023	0.000
5.911	2.170	11.74	3.137	0.000
5.989	2.175	11.90	3.252	0.000
6.067	2.180	12.07	3.526	0.000
6.144	2.185	12.24	4.082	0.000
6.222	2.190	12.41	4.817	0.000
6.300	2.195	12.58	5.693	0.000
6.378	2.200	12.76	6.690	0.000
6.456	2.205	12.93	7.796	0.000
6.533	2.210	13.10	9.000	0.000
6.611	2.215	13.27	10.29	0.000
6.689	2.220	13.44	11.67	0.000
6.767	2.225	13.62	13.13	0.000

6.844	2.230	13.79	14.67	0.000
6.922	2.235	13.96	16.28	0.000
7.000	2.240	14.14	17.95	0.000

ANALYSIS RESULTS

Flow Frequency Return Periods for Predeveloped

Return Period	Flow(cfs)
2 year	1.445288
5 year	2.324012
10 year	2.931093
25 year	3.709506
50 year	4.291359
100 year	4.871527

Flow Frequency Return Periods for Developed Mitigated

Return Period	Flow(cfs)
2 year	0.650784
5 year	0.855746
10 year	1.008362
25 year	1.221237
50 year	1.394998
100 year	1.582343

Yearly Peaks for Predeveloped and Developed-Mitigated

Year	Predeveloped	Developed
1949	1.763	0.562
1950	4.139	0.673
1951	3.342	1.453
1952	1.154	0.507
1953	0.868	0.648
1954	1.215	0.601
1955	2.083	0.577
1956	2.023	0.877
1957	1.708	0.592
1958	1.468	0.639
1959	1.212	0.563
1960	2.341	0.965
1961	1.219	0.681
1962	0.747	0.493
1963	1.139	0.629
1964	1.296	0.664
1965	0.987	0.712
1966	1.116	0.609
1967	2.354	0.665
1968	1.334	0.602
1969	1.334	0.604
1970	1.178	0.644

1971	1.125	0.618
1972	2.911	1.199
1973	1.148	0.733
1974	1.272	0.632
1975	2.287	0.560
1976	1.326	0.602
1977	0.277	0.489
1978	1.153	0.659
1979	0.614	0.459
1980	1.725	1.323
1981	1.084	0.619
1982	2.514	0.722
1983	1.612	0.627
1984	1.116	0.500
1985	0.550	0.512
1986	2.700	0.670
1987	2.446	0.827
1988	0.907	0.546
1989	0.533	0.508
1990	4.169	0.971
1991	3.504	0.896
1992	1.214	0.667
1993	1.192	0.499
1994	0.345	0.441
1995	1.637	0.691
1996	3.333	1.268
1997	2.946	1.767
1998	0.703	0.513

Ranked Yearly Peaks for Predeveloped and Developed-Mitigated

Rank	Predeveloped	Developed
1	4.1395	1.4527
2	3.5043	1.3234
3	3.3425	1.2678
4	3.3335	1.1987
5	2.9461	0.9713
6	2.9106	0.9651
7	2.6998	0.8956
8	2.5139	0.8768
9	2.4456	0.8271
10	2.3543	0.7333
11	2.3414	0.7222
12	2.2866	0.7118
13	2.0828	0.6914
14	2.0231	0.6811
15	1.7632	0.6735
16	1.7250	0.6695
17	1.7082	0.6669
18	1.6370	0.6648
19	1.6117	0.6641
20	1.4681	0.6586

21	1.3344	0.6477
22	1.3341	0.6444
23	1.3263	0.6394
24	1.2965	0.6320
25	1.2722	0.6287
26	1.2191	0.6273
27	1.2147	0.6188
28	1.2141	0.6179
29	1.2118	0.6094
30	1.1923	0.6041
31	1.1784	0.6025
32	1.1540	0.6024
33	1.1535	0.6013
34	1.1475	0.5919
35	1.1388	0.5772
36	1.1249	0.5627
37	1.1158	0.5616
38	1.1157	0.5595
39	1.0842	0.5458
40	0.9874	0.5125
41	0.9066	0.5117
42	0.8679	0.5079
43	0.7470	0.5074
44	0.7034	0.5002
45	0.6144	0.4988
46	0.5496	0.4929
47	0.5334	0.4885
48	0.3451	0.4594
49	0.2774	0.4408

1/2 2 year to 50 year

Flow(CFS)	Predev	Final	Percentage	Pass/Fail
0.7226	3659	3265	89.0	Pass
0.7587	3312	2632	79.0	Pass
0.7947	3005	2273	75.0	Pass
0.8308	2741	1999	72.0	Pass
0.8668	2477	1795	72.0	Pass
0.9029	2238	1625	72.0	Pass
0.9389	2051	1481	72.0	Pass
0.9750	1888	1354	71.0	Pass
1.0110	1738	1235	71.0	Pass
1.0471	1577	1145	72.0	Pass
1.0831	1453	1070	73.0	Pass
1.1192	1328	992	74.0	Pass
1.1552	1220	921	75.0	Pass
1.1913	1128	843	74.0	Pass
1.2273	1041	779	74.0	Pass
1.2634	969	738	76.0	Pass
1.2994	896	705	78.0	Pass
1.3355	838	667	79.0	Pass
1.3715	787	624	79.0	Pass

1.4075	728	588	80.0	Pass
1.4436	670	553	82.0	Pass
1.4796	627	513	81.0	Pass
1.5157	590	473	80.0	Pass
1.5517	553	445	80.0	Pass
1.5878	511	419	81.0	Pass
1.6238	473	399	84.0	Pass
1.6599	441	380	86.0	Pass
1.6959	410	353	86.0	Pass
1.7320	378	333	88.0	Pass
1.7680	348	319	91.0	Pass
1.8041	326	307	94.0	Pass
1.8401	304	295	97.0	Pass
1.8762	279	287	102.0	Pass
1.9122	263	272	103.0	Pass
1.9483	247	260	105.0	Pass
1.9843	231	250	108.0	Pass
2.0204	220	236	107.0	Pass
2.0564	206	223	108.0	Pass
2.0925	191	197	103.0	Pass
2.1285	183	179	97.0	Pass
2.1645	172	167	97.0	Pass
2.2006	165	152	92.0	Pass
2.2366	158	138	87.0	Pass
2.2727	148	125	84.0	Pass
2.3087	139	113	81.0	Pass
2.3448	128	98	76.0	Pass
2.3808	118	90	76.0	Pass
2.4169	104	83	79.0	Pass
2.4529	97	81	83.0	Pass
2.4890	86	72	83.0	Pass
2.5250	75	67	89.0	Pass
2.5611	68	60	88.0	Pass
2.5971	65	52	80.0	Pass
2.6332	60	50	83.0	Pass
2.6692	53	40	75.0	Pass
2.7053	48	37	77.0	Pass
2.7413	43	33	76.0	Pass
2.7774	37	32	86.0	Pass
2.8134	34	30	88.0	Pass
2.8495	31	28	90.0	Pass
2.8855	30	26	86.0	Pass
2.9215	26	22	84.0	Pass
2.9576	23	20	86.0	Pass
2.9936	22	16	72.0	Pass
3.0297	21	15	71.0	Pass
3.0657	20	13	65.0	Pass
3.1018	18	13	72.0	Pass
3.1378	16	11	68.0	Pass
3.1739	15	9	60.0	Pass
3.2099	12	8	66.0	Pass
3.2460	9	8	88.0	Pass

3.2820	9	7	77.0	Pass
3.3181	8	6	75.0	Pass
3.3541	6	5	83.0	Pass
3.3902	6	5	83.0	Pass
3.4262	6	2	33.0	Pass
3.4623	6	2	33.0	Pass
3.4983	6	2	33.0	Pass
3.5344	5	2	40.0	Pass
3.5704	5	2	40.0	Pass
3.6065	5	2	40.0	Pass
3.6425	5	1	20.0	Pass
3.6785	5	0	.0	Pass
3.7146	5	0	.0	Pass
3.7506	5	0	.0	Pass
3.7867	5	0	.0	Pass
3.8227	5	0	.0	Pass
3.8588	5	0	.0	Pass
3.8948	5	0	.0	Pass
3.9309	5	0	.0	Pass
3.9669	4	0	.0	Pass
4.0030	4	0	.0	Pass
4.0390	3	0	.0	Pass
4.0751	2	0	.0	Pass
4.1111	2	0	.0	Pass
4.1472	1	0	.0	Pass
4.1832	0	0	.0	Pass
4.2193	0	0	.0	Pass
4.2553	0	0	.0	Pass
4.2914	0	0	.0	Pass

Detention Pond Design - WWHM
Land Use predev = 5ac forest till
Land Use dev = 3ac Imp; 2ac landscape till
Infiltration rate = 0.0

Year	Hours Inundated	Days Inundated	Consecutive Hours Inundated	Consecutive Days Inundated
1948	4,446	185.3	1480	61.7
1949	5,902	245.9	3577	149.0
1950	5,405	225.2	3138	130.8
1951	5,390	224.6	1288	53.7
1952	5,186	216.1	2073	86.4
1953	6,371	265.5	2403	100.1
1954	6,277	261.5	2439	101.6
1955	5,878	244.9	2439	101.6
1956	6,071	253.0	1136	47.3
1957	5,671	236.3	1413	58.9
1958	6,671	278.0	3291	137.1
1959	6,126	255.3	1303	54.3
1960	5,998	249.9	1695	70.6
1961	5,856	244.0	948	39.5
1962	5,856	244.0	1261	52.5
1963	7,027	292.8	3058	127.4
1964	5,622	234.3	1349	56.2
1965	6,335	264.0	2341	97.5
1966	5,739	239.1	2748	114.5
1967	6,948	289.5	1279	53.3
1968	6,123	255.1	1889	78.7
1969	5,924	246.8	766	31.9
1970	6,714	279.8	2348	97.8
1971	6,943	289.3	4077	169.9
1972	5,504	229.3	1833	76.4
1973	6,316	263.2	2316	96.5
1974	5,996	249.8	2169	90.4
1975	6,602	275.1	3001	125.0
1976	5,385	224.4	631	26.3
1977	6,989	291.2	2121	88.4
1978	5,484	228.5	798	33.3
1979	6,450	268.8	1092	45.5
1980	6,728	280.3	1763	73.5
1981	5,981	249.2	1420	59.2
1982	7,169	298.7	1128	47.0
1983	6,119	255.0	1632	68.0
1984	5,848	243.7	1802	75.1
1985	5,932	247.2	1136	47.3
1986	5,463	227.6	1372	57.2
1987	5,857	244.0	793	33.0
1988	5,802	241.8	2412	100.5
1989	6,353	264.7	1514	63.1
1990	6,270	261.3	2234	93.1
1991	5,718	238.3	2029	84.5
1992	5,858	244.1	1498	62.4

Detention Pond Design - WWHM
Land Use predev = 5ac forest till
Land Use dev = 3ac Imp; 2ac landscape till
Infiltration rate = 0.0

Year	Hours Inundated	Days Inundated	Consecutive Hours Inundated	Consecutive Days Inundated
1993	5,584	232.7	1074	44.8
1994	6,155	256.5	2193	91.4
1995	6,450	268.8	1918	79.9
1996	7,232	301.3	5312	221.3
1997	5,370	223.8	1264	52.7
AVG		**252.6**		**80.2**

POND TRIAL #1
Infiltration Pond Design - WWHM
Land Use predev = 5ac forest till
Land Use dev = 3ac Imp; 2ac landscape till
Infiltration rate = 1.0 in/hr w/ 4 SF
L:W = 4:1
ss=3:1

Year	Hours Inundated	Days Inundated	Consecutive Hours Inundated
1948	150	6.3	
1949	295	12.3	7
1950	288	12.0	12
1951	144	6.0	7
1952	211	8.8	12
1953	253	10.5	14
1954	170	7.1	15
1955	295	12.3	18
1956	194	8.1	13
1957	172	7.2	13
1958	265	11.0	13
1959	214	8.9	33
1960	269	11.2	16
1961	122	5.1	7
1962	195	8.1	15
1963	255	10.6	14
1964	212	8.8	22
1965	188	7.8	11
1966	222	9.3	14
1967	282	11.8	17
1968	231	9.6	15
1969	195	8.1	14
1970	231	9.6	14
1971	281	11.7	23
1972	153	6.4	17
1973	263	11.0	11
1974	196	8.2	20
1975	240	10.0	21
1976	88	3.7	8
1977	182	7.6	13
1978	123	5.1	11
1979	212	8.8	21
1980	175	7.3	9
1981	201	8.4	17
1982	225	9.4	25
1983	192	8.0	12
1984	149	6.2	14
1985	162	6.8	20
1986	202	8.4	29
1987	157	6.5	14
1988	149	6.2	6
1989	211	8.8	17
1990	250	10.4	39
1991	163	6.8	14
1992	158	6.6	20
1993	94	3.9	6
1994	215	9.0	16
1995	311	13.0	21
1996	305	12.7	30
1997	172	7.2	11
Average	**206**	**8.6**	**15.9**
Maximum	**311**	**13.0**	**39**
Minimum	**88**	**3.7**	**6**
Number of years with > 48 hrs			**0**

POND TRIAL #2
Infiltration Pond Design - WWHM
Land Use predev = 5ac forest till
Land Use dev = 3ac Imp; 2ac landscape till
Infiltration rate = 0.5 in/hr w/ 4 SF
L:W = 4:1
ss=3:1

Year	Hours Inundated	Days Inundated	Consecutive Hours Inundated
1948	357	14.9	18
1949	595	24.8	31
1950	568	23.7	72
1951	346	14.4	19
1952	438	18.3	22
1953	536	22.3	43
1954	377	15.7	32
1955	642	26.8	25
1956	423	17.6	23
1957	402	16.8	23
1958	583	24.3	27
1959	484	20.2	48
1960	560	23.3	33
1961	309	12.9	22
1962	440	18.3	41
1963	542	22.6	28
1964	442	18.4	23
1965	438	18.3	22
1966	485	20.2	37
1967	547	22.8	36
1968	523	21.8	24
1969	374	15.6	31
1970	521	21.7	52
1971	631	26.3	60
1972	336	14.0	20
1973	580	24.2	18
1974	426	17.8	25
1975	512	21.3	29
1976	210	8.8	23
1977	423	17.6	22
1978	238	9.9	21
1979	465	19.4	43
1980	425	17.7	18
1981	492	20.5	40
1982	517	21.5	31
1983	417	17.4	23
1984	316	13.2	29
1985	371	15.5	35
1986	415	17.3	45
1987	327	13.6	28
1988	402	16.8	19
1989	407	17.0	36
1990	534	22.3	54
1991	360	15.0	19
1992	362	15.1	28
1993	225	9.4	12
1994	455	19.0	33
1995	622	25.9	60
1996	574	23.9	77
1997	419	17.5	25
Average	**448**	**18.7**	**32.1**
Maximum	**642**	**26.8**	**77**
Minimum	**210**	**8.8**	**12**
Number of years with > 48 hrs			**6**

Washington State
Department of Transportation

Aviation Stormwater Design Manual

Comment Form

Your comments are important, as they will help in future revision of the manual. Please take a few moments to share your thoughts and ideas.

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Questions? Contact: John Shambaugh, Senior Planner, WSDOT Aviation
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Fax: 360-651-6319

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