ADOT POST-CONSTRUCTION BEST MANAGEMENT PRACTICES MANUAL

For Highway Design and Construction

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Arizona Department of Transportation

Intermodal Transportation Division

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Disclaimer

This manual is intended to serve as a general guidance to assist roadway designers in understanding when and where post-construction BMPs can be implemented. The manual is most applicable/ useful during the planning and preliminary design (30%) phase of roadway projects and, as such, the following limitations should be considered:

- The manual is intended to guide the user through important decision-making steps, not to serve as a “cookbook” for post-construction BMP selection and implementation. Moreover, the manual is not necessarily inclusive of all potential project conditions or scenarios. The actual selection, design and implementation of BMPs must be done on a project-specific basis.
- The design standards, schematics and materials specifications for the BMPs presented in this manual are subject to change. Water quality/treatment BMPs, in particular, are a rapidly evolving category of stormwater post-construction BMPs that should be periodically checked for updated changes or trends in design methods or specifications.
- Any references to proprietary products, vendors, companies or agencies in this manual are intended as examples, reference or guidance and are not endorsed or promoted by ADOT or its authors.

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1.0 - Introduction

In a transportation setting, post-construction best management practices (BMPs) are necessary to reduce peak runoff flows and manage discharge volumes. With the regulatory adoption of stormwater discharge control programs in the early 1990's, post-construction BMPs are now also important to help prevent and/or mitigate potentially harmful effects of highway pollutants in stormwater runoff (FHWA, 2000). This manual serves to guide the roadway designer, both internal and external to the Arizona Department of Transportation (ADOT), in the selection and design of structural post-construction BMPs.

1.1 Purpose of Manual

Over the years, numerous structural BMPs have been developed and used by ADOT for permanent (post-construction) stormwater pollutant and erosion control. This manual formalizes and compiles the post-construction BMPs that ADOT presently implements along with the design of additional BMPs to allow ADOT to comply with regulatory requirements and related permits. Specifically, this manual is intended to achieve the following goals:

- Allow ADOT to meet the goals submitted to the Arizona Department of Environmental Quality (ADEQ) as part of the Statewide Stormwater Management Plan (SSWMP) and comply with their Statewide Individual Permit (ADEQ, 2008) (discussed in further detail in **Section 1.2**).
- Provide the roadway designer with a background for the motivations and needs for post-construction BMPs (see **Section 1.3** for more details).
- Discuss the project planning and design factors that should be considered in the proper selection of post-construction BMPs (see **Section 2.0**). Note that selecting the most appropriate BMPs for a specific roadway is a critical step for effective, long-term stormwater pollutant and erosion control. The discussion of the design factors that should be considered (**Section 2.2**) focuses on the Water Quality/Treatment category of BMPs, as these are BMPs that ADOT has not focused on as much in the past.

- Guide the roadway designer in the proper design of post-construction BMPs (see Section 3.0). Proper BMP design includes understanding the objectives, appropriate applications, and limitations of a particular BMP. It also requires the roadway designer to consider maintenance and inspection needs which, in the long-term, may prove to be costlier than the original design and construction.

1.2 Water Quality Regulations and Permits

ADOT has developed a SSWMP that describes ADOT's program to reduce the discharge of pollutants associated with the stormwater drainage and conveyance systems that serve ADOT's highways and transportation-related properties, facilities, and activities. The plan identifies how ADOT complies with the provisions of the Arizona Pollutant Discharge Elimination System (AZPDES) stormwater program. In addition to managing runoff/drainage flows and volumes off its roadway systems, ADOT must now also consider the quality and erosive potential of its drainage discharges and the impact of these to receiving lands and/or water bodies. Refer to the ADOT SSWMP for additional regulatory background and more details regarding ADOT's permits and statutory responsibility for carrying out its stormwater management program.

In addition to the SSWMP, ADOT also developed various stormwater-related manuals to provide guidance to assist staff consultants regarding regulations and proper best management practices. ADOT also developed a set of specifications specific to stormwater management and erosion control as part of the agency's overall framework for the stormwater management program. This Post-Construction Best Management Practices (BMP) Manual is the latest in ADOT's manual development as part of the stormwater management program.

The SSWMP and related manuals are the basis for overall compliance with the ADOT Statewide Stormwater Discharge Permit (ADEQ, 2008) issued by ADEQ in August 2008 (effective September 2008). This individual permit regulates ADOT with respect to its Municipal Separate Storm Sewer System (MS4s), as well as its construction and industrial activities. Based on the 2008 ADOT Statewide Stormwater Discharge Permit, ADOT is required to update the SSWMP and other related manuals and documents for compliance with the permit.

1.2.1 Municipal Separate Storm Sewer System (MS4) Activities

ADOT is considered and regulated as a Large MS4 (as defined by the US Census Bureau). A MS4 is defined as a conveyance or system of conveyances owned by a state, city, town, or other public body, that is designed or used for collecting or conveying stormwater, and is not a combined sewer or a publicly-owned treatment works [40 CFR 122.26(b)(8)]. Thus, ADOT's roadways and highways are considered MS4s and regulated under a permit-based program. ADOT's 2008 Statewide Stormwater Discharge Permit includes both the Phase I MS4 and the Phase II MS4 permit requirements.

1.2.2 Industrial Activities

ADOT's industrial activities for which stormwater discharges are regulated include ADOT-owned or –operated material sources, the Grand Canyon National Park Airport, the ADOT print shop, and the Traffic Operations' sign factory. Specific requirements for management (use of appropriate BMPs), monitoring, and reporting associated with ADOT's regulated industrial activities are included in ADOT's 2008 Statewide Stormwater Discharge Permit.

1.2.3 Construction Activities

The majority of stormwater pollution control activities conducted by ADOT are related to roadway/highway construction and maintenance activities. This manual focuses on the post-construction (or permanent) BMPs to be used in new construction and re-construction (widening) of existing ADOT roadways and highways. This manual, along with the ADOT Erosion and Pollution Control Manual, ADOT's Stormwater Monitoriring Guidance Manual for Construction Activities, the Standard Specifications for Road and Bridge Construction, the Stored Specifications, and Project Special Provisions that are incorporated into highway construction contracts, represent ADOT's complete collection of guidance and process-defining material in relation to stormwater pollution prevention technology and requirements by ADOT for construction activities.

1.3 Principles and Practices

Roadway development can impact stormwater runoff and the quality of the downstream receiving waterbody in several ways. Newly constructed or modified slopes are highly susceptible to erosion, drainage patterns are altered, drainage crossings become concentrated and modified, and the roadway surface increases the impermeable surface area. While roadside development (i.e. seeding and/or establishment of vegetation) reduces the potential for erosion, it may also lead to new pollution sources, such as excessive nutrient constituents, pesticides, and herbicides.

Of course, new roadways and roadway expansions also increase traffic volumes, leading to increased loadings of sediment, oils and greases, and heavy metals, among other pollutants. Pollutant loading from traffic is dependent on many variables, including Average Daily Traffic (ADT)[1], traffic speed[2], and vehicle characteristics[3]. It is important to be able to anticipate the relative loading and types of stormwater pollutants in the proper selection of post-construction BMP(s), as discussed in further detail in **Section 2.2.1**.

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[1] Studies have shown some correlations between increased ADT and pollutant concentrations in stormwater runoff, particularly on interstates, which typically have the largest ADT.

[2] Idling or slow moving traffic may have more time to deposit stormwater pollutants to the roadway surface, such as leaking petroleum products and other vehicle fluids. Also, frequent braking on highways increases the loading of metals and other particulates due to increased brake and tire wear.

[3] Poorly maintained vehicles are more likely to leak and deposit oils, fluids, and other potential pollutants than well maintained vehicles.

ADOT's permit requires that post-construction controls be installed for all newly developed or redeveloped roadways that discharge stormwater runoff to impaired or unique waters. ADOT must also evaluate the need for post-construction BMPs within MS4 compliance areas and install where appropriate.

1.3.1 Non-Structural Practices

Impacts from traffic loading can be minimized through various non-structural practices. Routine road sweeping and pavement maintenance have been shown to substantially reduce the concentration of suspended sediment and heavy metals in stormwater runoff. Public education and volunteer clean-up programs can reduce pollutants, by curtailing traffic litter and debris along the ADOT highway system. While post-construction non-structural practices, such as those mentioned above, are highly effective (and required) to reduce stormwater pollution, they are outside of the scope of this manual, which is focused on post-construction ***structural*** BMPs.

1.3.2 Erosion Control

Soil erosion is critical to control, as it is a major source of surface water pollution in the United States, particularly in Arizona. Sediment loading to surface waterbodies can impair aquatic life by filling spawning gravels voids in streams and lakes and reducing beneficial habitat structure in stream channels (EPA, 2005). Suspended sediment also increases turbidity, which has several repercussions: it impairs the ability of fish and other aquatic life to search for food, interferes with the gill functions of fish, absorbs heat from incoming sunlight, raises the water temperature, and blocks out light needed by aquatic organisms to perform critical nutrient-cycling processes. Suspended sediment can also carry nutrients, pesticides, and other bound pollutants through water systems, and eventually impact aquatic organisms. Erosion also displaces valuable nutrients and organic matter in the topsoil needed to sustain vegetation.

The objective of erosion control is to reduce excessive losses of topsoil through stormwater runoff. While simple in concept, erosion control requires the designer to consider many site-specific conditions (discussed in further detail in **Section 2.2**). Erosion control BMPs typically are installed in the form of pervious and impervious groundcover. Roadside landscaping features (trees, shrubs and plants) can also provide erosion control. Refer to the Landscape Design Guidelines for Urban Highways (ADOT, 1988). The roadway designer should keep in mind that erosion control is the first, and often most effective, step in preventing the release and suspension of pollutants, particularly sediment, into stormwater runoff.

1.3.3 Conveyance

Roadway designers have long understood the importance of effectively removing water from the roadway or other critical areas of the infrastructure (i.e. steep roadway shoulders or banks). Based on a hydrologic review of the contributing drainage area(s), conveyance structures can be sized and designed to accommodate stormwater runoff during a design storm event. In arid climates such as Arizona, conveyance systems can also be used to "harvest" stormwater for later beneficial uses, such as roadside landscape irrigation. In addition to managing stormwater ***quantity***, conveyance can also serve to protect and/or improve stormwater ***quality***, as described in the following examples:

- Conveyance BMPs can be used to separate ADOT runoff from non-ADOT sources, which is to ADOT's benefit. Refer to **Section 2.2.1** for more discussion of this issue.

- Pervious conveyance channels can remove or retard suspended pollutants through infiltration along the channel bottom and side slopes, filtration through the channel lining (vegetated or rock), and sedimentation along the channel reach before the point of discharge.

Conveyance structures inherently concentrate runoff, resulting in increased velocity and shear stress at the soil-water interface, leaving the channel bottom and side slopes susceptible to erosion and scour. Proper design and consideration of lining, alignment, and curvature of the channel will reduce the potential for erosion. Channel inlets and outlets are particularly susceptible to erosion because they are often transitions from one flow regime to another. Transitions could include changing: from an impermeable surface to a permeable surface, from concentrated flow to sheet flow, or from an engineered channel profile to a natural stream profile. Outlet protection can come in the form of an impervious surface, protecting the underlying erodible soil and/or as energy dissipation devices. Angular rock or baffle structures dissipate the velocity (and therefore erosive energy) of concentrated flows by creating turbulent eddies in the flow path.

1.3.4 Treatment

Until recent years, proper erosion control and conveyance BMPs were typically sufficient for stormwater quality management. However, per the requirements of the 2008 ADOT Statewide Stormwater Individual Permit, ADOT is also focusing on the treatment (pollutant displacement/removal) of stormwater before discharging to and/or beyond the storm drain. Treatment BMPs[4] can operate by means of sedimentation/flotation, infiltration, filtration, and/or biological processes (Minton, 2005), as described below:

<u>Sedimentation/flotation</u> – A process by which gravity and buoyancy simultaneously remove sediment and attached pollutants, floatables, and dispersed petroleum products. Particles with a density greater than water settle to the bottom while constituents lighter than water (i.e. oils and floatable debris) float to the top.

<u>Infiltration</u> – Underlying soils serve as the treatment mechanism by filtering and adsorbing pollutants through the unsaturated soil matrix[5]. Infiltration provides other benefits, such as groundwater recharge and stormwater **quantity** management. Infiltration is the most common treatment mechanism along ADOT roadways.

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[4] Treatment/Water Quality BMPs may consist of a combination of multiple treatment processes.

[5] Note that infiltration ceases after the soil matrix becomes saturated, at which point stormwater would pond or runoff at the soil surface.

Filtration – A unit treatment process which can consist of inert or sorptive media filtration. Inert media removes suspended solids and attached pollutants by means of physical interception as the water passes through the filter matrix. Sorptive media also removes suspended solids, but is intended to remove dissolved constituents by means of chemical attachment to media. Filtration BMPs can be custom designed and constructed or they can be purchased and installed as a pre-manufactured device.

Biological – Refers to a broad group of processes in which living organisms remove pollutants or transform them to inert constituents. Plants and trees that take up dissolved nutrients through the root system. Grasses or turf can filter suspended sediments and absorb dissolved nutrients. Microorganisms (bacteria and fungi) can use, consume, and/or degrade organic pollutants, forming inert compounds such as carbon dioxide. Biological degradation is dependant on a number of factors, including the presence of aerobic conditions, sufficient dissolved organic carbon, and the pH of the soil and stormwater.

1.4 Compilation of ADOT Recommended Post-Construction BMPs

Over the years, numerous post-construction BMPs have been developed for stormwater pollutant and erosion control. In order to identify the post-construction BMPs best suited for ADOT's needs, BMPs were selected through the use of the following methods:

- *Review of BMPs currently used* – After reviewing current practices, institutional ADOT knowledge, past erosion control field studies, and published drainage design guidance (ADOT, 2005), a list of existing post-construction BMPs was compiled and formalized. In many cases, ADOT also implements post-construction BMPs by retaining or modifying temporary BMPs.

- *Process of elimination* – For some post-construction BMPs, particularly Water Quality/ Treatment BMPs, a "common sense" approach was used to eliminate BMP technologies that were deemed inappropriate for ADOT's needs. Examples of these "common sense" reasons to automatically not consider certain BMPs include:

    - Excessively high construction and/or operation and maintenance costs;
    - Not appropriate in any climatic zone of Arizona; and
    - Experimental or currently lacking well-documented data on the operation and maintenance costs.

    Table A-5 in **Appendix A** shows the rationale behind why some BMPs were recommended and others were eliminated from consideration.

A list of ADOT recommended post-construction BMPs was compiled (see **Section 2.1**) to serve as a "tool box" of options for effectively controlling stormwater pollutants and erosion for the life of a roadway. The tool box is dynamic and should be updated as new methods and technologies are developed and as ADOT deems necessary.

1.5 References and Resources

Arizona Department of Environmental Quality (ADEQ), Arizona Department of Transportation Statewide Permit for Discharges to Waters of the United States under the Arizona Pollutant Discharge Elimination System Program, August 2008.

Arizona Department of Environmental Quality (ADEQ) – Arizona Department of Transportation Consent Order 2004

Arizona Department of Transportation (ADOT), *Erosion and Pollution Control Manual: for Highway Design and Construction, January 25, 2005*

Arizona Department of Transportation (ADOT), *Statewide Storm Water Management Plan,* February 2005 (3rd revision)

Arizona Department of Transportation (ADOT), Landscape Design Guidelines for Urban Highways, May 1988.

Environmental Protection Agency (EPA), *National Management Measures to Control Nonpoint Source Pollution from Urban Areas,* November 2005, www.epa.gov/owow/nps/urbanmm

Federal Highway Administration (FHWA), Storm Water Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring, FHWA A-EP-00-002, 2000, U.S. Department of Transportation, Federal Highway Administration, Washington, DC, Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring, http://www.fhwa.dot.gov/environment/ultraurb/index.htm

Minton, G., *Stormwater Treatment: Biological, Chemical and Engineering Principles*, 2005

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2.0 - Project Planning and Design Guide

The key to effective, long-term stormwater pollution and erosion control is selecting and applying the most appropriate BMP to the particular situation. Roadways navigate a wide range of conditions that affect the functionality and effectiveness of post-construction BMPs. As a result, a wide variety of conditions and requirements must be considered with respect to stormwater pollution and erosion control. The improper selection of post-construction BMPs can result in costly and burdensome long-term maintenance obligations, ineffective erosion and stormwater pollutant source controls, and insufficient treatment methods. This chapter describes how to properly plan for and select post-construction BMPs on ADOT roadway projects.

2.1 ADOT Recommended Post-Construction BMPs

For purposes of this manual, post-construction BMPs in ADOT's systems can be categorized as:

1. ***Off-road, Overland Flow Erosion Control*** – Minimizing the release and suspension of pollutants, particularly erosion of roadway shoulders by drainage. Erosion control BMPs typically are installed in the form of pervious cover (vegetation, decomposed granite, etc.), impervious cover (shotcrete, concrete, etc.) or velocity/energy dissipation devices.

2. ***Roadway Drainage Conveyance*** – Effectively and safely removing water from the roadway or other critical areas of the infrastructure (i.e. steep roadway shoulders or banks). Conveyance BMPs operate as either open (spillway, channel, etc.) or closed (culvert, conduit pipe, etc.) systems.

3. ***Water Quality and Treatment*** – Water quality and treatment BMPs focus on the treatment (pollutant displacement/removal) of stormwater before discharging to and/or beyond the storm drain. Treatment BMPs operate by means of sedimentation, infiltration, filtration, and biological degradation.

The following is a list of ADOT recommended post-construction BMPs that the roadway designer should consider[1]. Note that the colors used in the table are consistent with the colors used in a BMP selection flowchart to be presented in **Section 3.0**.

Table 2.1 – ADOT Recommended List of Post-Construction BMPs

Off-road, Overland Flow Erosion Control
▪ Decomposed Granite Cover ▪ Erosion Control Blankets ▪ Impervious Cover ▪ Retaining Wall ▪ Riprap ▪ Seed Mix ▪ Slope Modification and New Slope Construction ▪ Wire-tied Rock
Roadway Drainage Conveyance
▪ Bridge Drainage Systems ▪ Catch Basins and Downdrain Conduits ▪ Culverts ▪ Impervious Channel Lining ▪ Inlet Protection ▪ Outlet Protection ▪ Pervious Channel Lining ▪ Rainwater Harvesting ▪ Spillways
Water Quality and Treatment
▪ ADOT Approved Vendor Treatment Devices ▪ Bioretention ▪ Filtration Structures ▪ Infiltration Basin ▪ Infiltration Trench ▪ Retention and Detention Basins (pond-in-place practices) ▪ Vegetated Filter Strips

[1] This list was developed from a review of current ADOT practices and research of additional BMPs (particularly water quality and treatment) that other Department of Transportations (DOTs) have implemented. As BMP technology is continually evolving and developing, this list is dynamic and open to revision. Moreover, ADOT will always be able to propose new or variations of proposed BMPs, provided that the technology meets ADOT criteria and the site-specific and sensitive area conditions, climate zone restrictions, and management considerations are successfully addressed (Section 2.0).

2.2 General Post-Construction BMP Restrictions and Considerations

When determining the most appropriate set of BMPs to select and implement at a site, the designer needs to consider site-specific conditions, sensitive area considerations, climatic zone restrictions, management criteria and unique agreements. These are discussed in more detail in **Sections 2.2.1** through **2.2.5**. BMP specific data related to these restrictions and considerations are included in **Tables A-1** through **A-4** (**Appendix A**). These tables focus on Treatment/Water Quality BMPs more than the other categories of BMPs because they are newest to ADOT. However, note that many of the considerations and restrictions discussed also apply to Erosion Control and Drainage Conveyance BMPs.

2.2.1 Site-Specific Conditions

A thorough assessment of the site-specific conditions will help identify those BMPs most suitable for the location. Not all BMPs will fit site-specific conditions. For example, a BMP may require excessive maintenance or fail altogether after a short period of time if it is not suited to site-specific conditions.

Site Area – The drainage area must be estimated in order to determine and/or design appropriate BMP storage and/or treatment volumes. For example, infiltration trenches typically are designed for much smaller drainage areas (2-4 acres) than infiltration basins (up to 20 acres), even though the intent is the same.

In urban settings and/or where space is limited, it may be necessary to install BMPs off-line and/or retrofit post-construction BMPs into existing structures within a MS4. To accommodate such conditions, BMPs must either be compact, broken up into smaller structures, or able to be installed off-line from the collection point. *Detention basins*, for example, can either be split up into multiple, smaller “pocket basins” to accommodate the necessary volume of runoff or can be installed off-line. In contrast, in more open, rural areas, a single BMP with a larger footprint may be more cost effective yet still meet the level of treatment required. In addition, with the exception of stack interchanges, roadway footprints are predominately linear, and therefore BMPs that can accommodate linear footprints are considered advantageous for roadway transportation systems, where maintenance may dictate the basins needed dimensions. *Vegetated Filter Strips*, for example, can run along segments of roadway that parallel a sensitive waterbody.

Soils – The applicability and predicted functionality of several BMPs is dependent on surface and subsurface geology. Subsurface soils and geology need to be properly characterized at least four (4) feet below the ground surface for infiltration practices (NJDA, et. al., 2000). Surface soil chemistry must also be considered. Soils with high organic content, for example, may have high absorptive capacity for highway pollutants such as petroleum hydrocarbon compounds. Each Treatment/Water Quality BMP is either dependent or independent of the soil factors. ADOT Office of Environmental Services advises against the use of drywells, if and whenever possible.

Hydraulic Head – Most structural treatment BMPs operate under gravity flow conditions. The minimum hydraulic head must be considered in the selection of a Treatment/Water Quality BMP. Hydraulic head may refer to the depth of water, such as for storage and infiltration devices; or the total drop in water level for flow-through designs, such as for swales.

Slopes – The upstream slope, as well as the slope within a site is critical in evaluating the applicability of a BMP. The slopes will determine the susceptibility of a site to surface erosion and the need to implement post-construction controls to prevent elevated sediment loading. Steep slopes represent higher erosive potential when compared to mild or flat terrain. Steep slopes can also cause breakthrough or short-circuiting of treatment BMPs if there are not sufficient velocity dissipation controls.

Fracturing Geology – Certain subsurface geologic features found in various parts of Arizona, such as sinkholes, fissures, and subsidence, can form crevices and enlarged joints in the soil. Such voids in the soil can significantly impair the filtering capacity of vadose zone soil before recharged stormwater reaches groundwater.

Depth to Groundwater – The depth to groundwater must be determined when selecting the appropriate BMP. The recharging of stormwater through infiltration practices may exacerbate contamination plumes that exist in a shallow aquifer below the area of infiltration. Moreover, a shallow depth to groundwater alone can substantially reduce the percolation rate of stormwater runoff from infiltration practices.

Figure 2.1 - Site Specific Conditions.
The roadway designer should consider a wide variety of site-specific conditions that can impact BMP selections and integration into a project.

Anticipated Pollutant Loading – Predicting the anticipated pollutant type and concentration is important in selecting the appropriate BMP. Water quality requirements may also restrict the use of certain BMPs. Runoff from high density highways most likely contain elevated concentrations of total suspended and dissolved solids, petroleum hydrocarbon compounds, and metals, as well as miscellaneous litter and debris, compared to smaller, less frequently used roadways. Urbanized areas also pose a higher risk of non-stormwater discharges in roadway drainage systems.

Safety – ADOT's primary focus on roadway design is ensuring public traffic safety. Post-construction BMPs are an integral component of the final roadway design and, as such, must not pose safety hazards to oncoming roadway traffic. In addition, the post-construction BMPs can not compromise the function of safety roadway infrastructure (i.e. medians, guard rails and cables). Non-traffic related safety issues from post-construction BMPs must also be considered, for example, retention basins maintain a pool of water which can pose safety hazards to nearby children and attract mosquitoes and vector-borne diseases.

Non-ADOT Runoff – ADOT roadways and drainage areas are routinely surrounded by non-ADOT drainage areas. During the design of conveyance channels, the mixing of non-ADOT and ADOT runoff should be avoided whenever possible. When runoff from all or a portion of the upstream or adjacent non-ADOT drainage area commingles with runoff from the ADOT roadway drainage area, the runoff may potentially carry pollutants from both ADOT and non-ADOT sources. In general, commingled flows are undesirable from ADOT's standpoint since treatment BMPs must accommodate an additional pollutant load from non-ADOT sources and larger runoff volumes. When it is not practicable for external runoff to be diverted around or under an ADOT roadway (i.e. preventing it from commingling with ADOT runoff), or allowed under an encroachment permit, the treatment BMP(s) need to be designed and sized to accommodate the additional potential pollutant loading. Non-ADOT runoff should be addressed on a case-by-case basis. Refer to "Draft Water Quality Protection Issues and Recommendations for Discharges from External Entities into ADOT's Storm Water Conveyance System" (ADOT, 2006) for further guidance.

Highway Design Standards – ADOT is responsible for the design, construction, maintenance and operation of Arizona's State Highway System[2]. The highway nomenclature is based on past federal historical funding, a national numbering system in accordance to the American Association of State Highway and Transportation Officials (AASHTO) and a state numbering system. Highway roadway design standards for construction and operation are based on applicable ADOT Roadway Design Manual and AASHTO design standards and guidelines. Design is based on factors such as type or level of access control, design speed, existing and projected design-year traffic volumes, topography and urban or rural design, and other environmental considerations and requirements. Design requirements can vary from one roadway to another based not on nomenclature, but by consideration of design factors. The post-construction stormwater treatment BMP design requirements, in addition to the above factors, may also be affected by the design of the roadway components such as pavement thickness and design, barriers, bridge and overpass design, etc.

2.2.2 Environmental Stewardship Considerations

ADOT transportation projects spread across an extensive network of roadways that traverse a wide range of land uses. The following items are specific to the Arizona roadways and must be taken into consideration when determining the appropriate BMP for the site.

Urban Areas – Typically urban areas have a higher percentage of impervious drainage areas, less available space for storage and infiltration practices, higher pollutant loading from increased traffic density, and a higher probability of illicit discharges. Public perception and safety concern are additional considerations in the BMP selection process within urban areas. Such concerns may include safety hazards, aesthetics, standing water, vectors, algae, and other environmental and wildlife nuisances.

[2] The nomenclature for highway system operated is designated as Interstate Highways (i.e. I-10), U.S. Highways (US 60), and State Highways or State Routes (SR 85).

Jurisdictional Setbacks and Requirements – In both urban and rural settings, there can be several setback and zoning requirements for structural BMP installations. Setback distance requirements may be in place for jurisdictional wetlands, forest conservation areas, roadways, utilities, structures, septic drain fields, and water wells. One or more of these setback requirements may exclude a potential structural BMP from consideration or require it to be installed offline at a different location.

Streambank Erosion – Special attention must be given to BMPs for projects that release stormwater directly to waters of the U.S. Note that waters of the U.S. include intermittent streams and wetlands in addition to obvious surface waterbodies. Velocity dissipation BMPs may be required in conjuction with treatment BMPs to prevent streambank erosion.

Protected Waterbodies – The selection of the appropriate BMP (or set of BMPs) becomes even more critical when the location is in close proximity to waterbodies that are classified as impaired, unique, (outstanding Arizona water) or not attaining waterbodies. In these cases, site specific designs are particularly important.

Wildlife Habitats – Waterways designated as critical habitat areas for endangered animals may require extra levels of protection by BMPs (Clar et al., 2003). For example, cold water species protection may rule out BMPs that are placed without any canopy or shade (i.e. temperature pollution), unless the BMP can be designed offline with significant shading over open pool areas. Vegetative practices may provide a substantial habitat for sensitive wildlife.

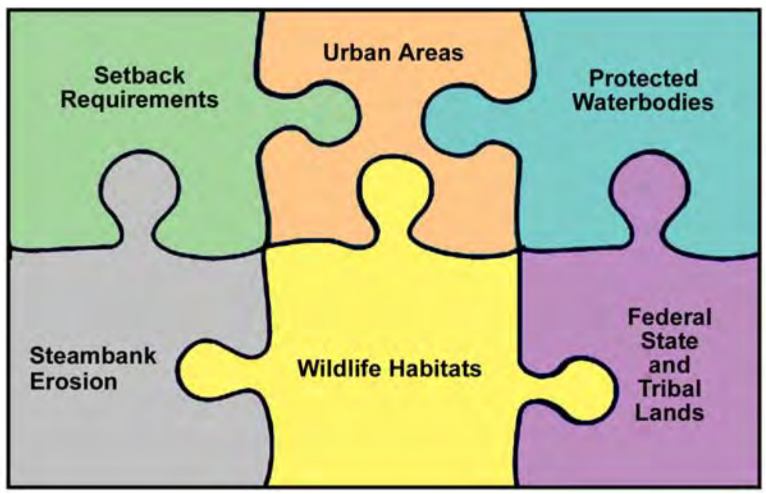

Figure 2.2 – Environmental Stewardship Considerations. These can refer to several different practices and/or considerations and often involves integrating multiple factors together.

Federal, State, and Tribal Lands – ADOT operates under various Intergovernmental Agreements (IGAs) with entities such as the Flood Control District of Maricopa County and local municipal governments. ADOT and other state/federal agencies also have memoranda of understanding (MOUs) for lands under federal agency jurisdictions, such as the US Forest Service (USFS) and the Arizona Bureau of Land Management (BLM). These IGAs and MOUs stipulate procedures for ADOT to follow when constructing or maintaining roadways on lands under the jurisdiction of a federal entity and, subsequently, may influence or dictate the selection and implementation of post-construction BMPs. For more details on the BLM-USFS MOU, refer to **Section 2.2.5**. Finally, ADOT must also consult with Indian tribes and take special consideration when selecting and implementing post-construction BMPs on Indian Lands.

2.2.3 Climatic Zone Restrictions

In addition to the various sensitive areas listed above, ADOT roadways span a wide range of climatic zones throughout Arizona.

Annual Precipitation –The annual precipitation is not uniform throughout Arizona. The local annual precipitation may dictate the type of erosion control measures, storage capacity and conveyance needed.[3] The annual and seasonal precipitation considerations may also include peak flow reduction requirements.

Peak Flow Reduction – Post-construction BMPs must be able to effectively contain and/or divert water during peak flows. Precipitation volume and intensity for a given area must be evaluated in order to determine appropriate storage volume capacities. Additionally, the need for stabilized conveyance and/or interception systems and energy dissipation must be evaluated.

Temperature Extremes – Temperature extremes and associated conditions can significantly impact the performance and applicability of certain BMPs. Frozen soil can significantly reduce the efficiency of infiltration practices. Vegetative BMPs must be tolerant to various conditions: below freezing temperatures and de-icing salts in cold environments, and drought in hot and dry environments. Moreover, treatment BMPs must handle a higher pollutant loading during winter months; studies have shown that snow mounded along highways can accumulate pollutants and lead to elevated pollutant concentrations in snow melt runoff (EPA, 2005).

2.2.4 Management Considerations

After an appropriate set of BMPs has been established taking into consideration the specific site conditions, the costs and level of effort associated with installing and maintaining the post-construction BMP and the anticipated life span of the BMP must be evaluated prior to the final selection. In the event that two or more BMPs are all equally appropriate to implement based on the criteria from all of the above stages, the factors below can be used to determine more specific conditions or situations for when one BMP should be selected over another.

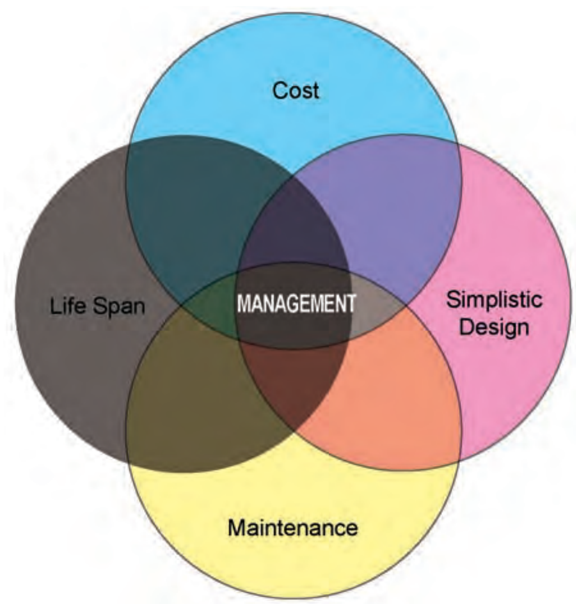

Figure 2.3 – Management Considerations. These refer to the consideration, integration and fulfillment of BMP cost, life span, simplistic design and maintenance requirements.

[3] This does not mean that protecting and managing stormwater quality is less important or necessary in areas with less precipitation. Arid areas in Arizona have extended antecedent (dry) periods allowing for the buildup of pollutants on the roadway surface (Minton, 2005). Furthermore, when they do occur, the storm intensity is often higher in arid areas, requiring effective erosion and pollution controls.

Costs – The costs of implementing a post-construction BMP should be considered from the standpoint of planning, design, construction, and maintenance. The level of effort (and associated costs) including expertise, engineering design, and extent of labor required to plan and install a post-construction BMP can vary greatly, ranging from the relative low cost of vegetating a channel to the design and construction of a large scale retention pond. In some cases, the upfront capital costs of a post-construction BMP may be negligible compared to the long term, ongoing costs for maintenance and repair. The costs for appropriate safety controls also must be considered.

Simplistic Designs – Due to the large linear extent of the ADOT system compared to conventional MS4s and industrial facilities, post-construction structural BMPs should be simplistic in design and require minimal maintenance effort and costs; while still meeting the intended water quality objectives (erosion control, conveyance, velocity dissipation, or treatment). In comparison, localized industrial facilities, for example, can implement more specialized BMP technologies such as vortex separators, multi-chambered treatment trains (MCTTs), and chemical flocculation/treatment. These advanced BMPs may effectively dissipate energy or have high pollutant removal efficiencies, but they also require frequent inspections and close oversight, which is more difficult to implement in a transportation system extending throughout the state of Arizona. An infiltration basin is an example of a more simplistic design that can still achieve high pollutant removal simply by infiltrating the runoff to the subsurface.

Maintenance – The performance and estimated life span (discussed below) depend on whether the BMP has been diligently inspected and maintained. Maintenance activities vary in scope from one BMP to another, involving regular inspections, media and sediment removal, vegetation replacement, and mowing. Post-construction BMPs must also be routinely maintained to ensure traffic safety.

Life Span – Even with diligent maintenance, post-construction BMPs eventually need to be replaced. In the final selection of BMPs to implement at a site, consider that BMP life spans can range from 5 years for infiltration practices to 50+ years in retention pond systems. During and after the life of a post-construction BMP, the effectiveness of the BMP must be evaluated to decide whether a similar BMP should be reconstructed.

Winter Storm Management – For ADOT, stormwater management also entails keeping highways safe and operational during winter months in regions where snow and ice can accumulate (ADOT 2008). ADOT uses a variety of winter storm management techniques, including the application of anti-acing/de-icing chemicals and abrasives. These chemicals and abrasives, which have accumulated and concentrated over the course of the winter season, become released in the melting snow/ice runoff. The roadway designer should consider the potential impacts from such winter storm management techniques and ensure that the Treatment/Water Quality post-construction BMPs can address these impacts.

2.2.5 External Entity Agreements and MOUs

All ADOT transportation projects must adhere to the restrictions and guidelines of the BLM-USFS MOU, which was developed to provide guidance for the design, construction and maintenance of ADOT projects on lands managed by BLM and the USFS. This MOU describes accepted procedures, as well as the needs and concerns of each agency in an effort to minimize conflict and facilitate the creation of safe, environmentally sound and aesthetically pleasing highway corridors. Components of the BLM-USFS MOU that can impact the design and implementation of post-construction BMPs include:

Roadside Vegetation – Use seed with native species according to project ecology or bio-zone. Avoid species that are attractive to large browsing animals, use tall trees to allow animals to pass overhead, and use dense vegetation to serve as "fences" to roadway traffic. Cut and/or mow vegetation within the right-of-way to reduce forage for large mammals. The MOU outlines revegetation and seeding requirements, such as compost, fertilizers and soil amendments, seed mixes, seed application rates and techniques, mulches, tackifier, and mobilization requirements. Other landscape restoration practices addressed in the MOU that should be considered during the roadway design phase include: native plant salvage, container-grown stock, live cuttings and pole plantings, addressing noxious and invasive vegetation.

Earthwork – Fill-slopes should be flattened, whenever possible, using waste materials from cut-slopes. Roadway designers should generally not steepen cut-slopes in order to reduce waste material. Decide between steeper slope (difficult to revegetate) and flatter slopes (increased disturbance area). Use proper slope ratios, ripping, mini-benches, track walking, slope mitigation practices (rounding, laying back, through cuts, crown ditches, rock outcroppings) for soil cuts.

Retaining Walls – Roadway designers should consider various retaining wall alternatives, such as Mechanically Stabilized Earth (MSE), crib metal bin, gabion, modular block system, soil nail, reinforced concrete, and masonry faced walls.

Bridges – Roadway designers must address abutment/stormwater runoff interface with permanent erosion control measures. Refer to the ADOT Bridge Design Guidelines and ADOT Bridge Hydraulics Guidelines for more information (see References at the end of this Section).

Sensitive Waterbodies – Protection of riparian areas is of critical importance. BLM and USFS will consider additional easement for crown ditch alignment, reducing cut slope ratios to reduce erosion, promote revegetation and access for future maintenance to drainage structures. Consider bank protection (riprap, gabions, rail bank, revetment systems, concrete, shotcrete, soil cement, and sheet piling. Evaluate drainage structures (ditches/dikes, overside drains, and culvert/channel inlets and outlets) that will protect riparian areas. Roadway designers must sufficiently complete the project ADOT Drainage Report.

Other Design Considerations – The BLM-USFS MOU requires that post-construction BMPs accomplish the following:

- Minimize impermeable surfaces;
- Preserve existing vegetation and re-establish vegetation to disturbed soils;
- Mitigate increased runoff flows;

- Include concentrated flow structures; and
- Include measures to protect disturbed slopes

2.3 Selecting Post-Construction BMPs for a Specific Project

The various considerations and restrictions described above can be compiled and effectively addressed through the use of a methodical decision process. A decision flowchart (see **Appendix A-1**) has been developed to assist in selecting appropriate post-construction BMPs. The flow chart generally captures and maps out several design steps and considerations that ADOT roadway designers should follow in order to properly select post-construction BMPs. Note that the roadway designer may need to deviate to some extent from the flowchart due to project specific conditions and requirements. The flowchart is organized into the following sections:

2.3.1 Applicability Analysis (Section I)

Before starting the process, the roadway designer should first assess whether post-construction BMPs are applicable to the project of interest. In cases such as roadway safety/emergency projects or maintenance projects, selecting and implementing temporary erosion and pollutant BMPs is a higher priority than selecting and implementing post-construction BMPs. In some cases, temporary controls can be modified to be permanent at any time during the project. If it is determined that post-construction BMPs are necessary, the remaining design and decision data must be obtained, as illustrated in the figure below.

2.3.2 Off-road, Overland Flow Erosion Control (Section II)

Once it is determined that the roadway project requires post-construction BMPs and the necessary background information has been gathered, the roadway designer can select erosion control post-construction BMPs. The flowchart will assist in the evaluation of the preferred design slopes along the roadway and match the correct soil stabilization BMP with the different slopes within the project.

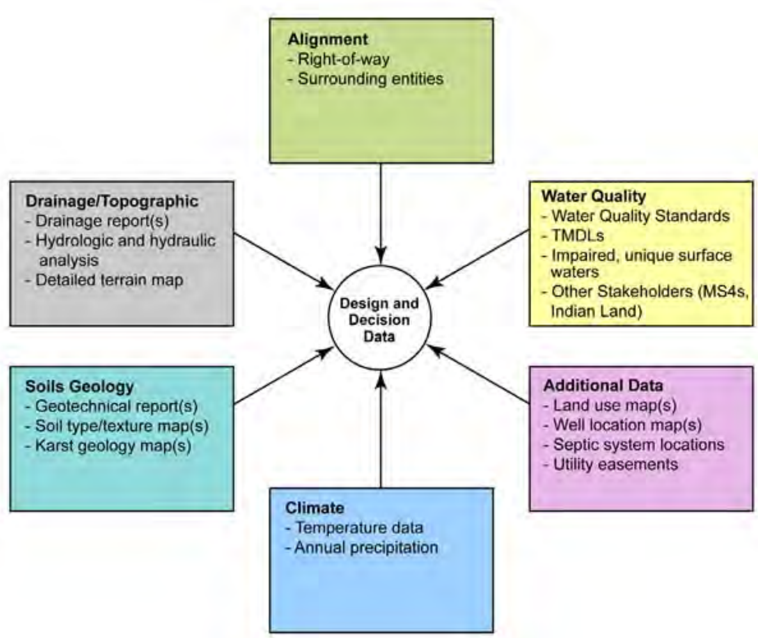

Figure 2.4 - Design and Decision Data.
There are a number of design and decision data that must be developed, researched, and/or compiled prior to proceeding further in the decision flow chart. The types of data listed in the figure are representative of transportation projects.

Note that retaining walls are used in areas requiring slope stability for erodible slopes ranging from vertical to the lowest allowable angle of repose as well as stakeholder requirements, nearby Superfund sites, and other purposes. Slope modification (flattening or benching) should be incorporated into slope designs whenever feasible. Steep erodible slopes (between 2:1 and lowest allowable angle of repose) should be stabilized with seed mix and/or soil cover BMPs (riprap, erosion control blankets, and/or rock mulch) if the steep slope is allowed to have some infiltration. Otherwise, an impervious cover should be applied. Each time an erosion control BMP is identified/selected, the roadway designer is directed to Water Quality and Treatment (Section IV) of the flow chart to determine if a treatment BMP is important to include with the erosion control BMP.

2.3.3 Roadway Drainage Conveyance (Section III)

Once the off-road and overland flow erosion control BMPs have been identified, the post-construction BMPs can be selected. The selected BMPs will effectively and safely drain water from the roadway or other critical areas of the infrastructure (i.e. steep roadway shoulders or banks) as well as meet the other considerations. The hydrologic analysis and the delineation of the draining areas needs to be completed prior to attempting Section III. Section III addresses the need for culverts or culvert extensions within the right-of-way, the need to collect and convey runoff away from the roadway, and the use of non-roadway areas to convey drainage (channels, ditches, medians, etc.). It also evaluates the need for outlet protection, bridge drainage, and water harvesting practices within the roadway project. As in the previous section, each time a conveyance BMP is identified and selected, the roadway designer is directed to Section IV to determine if a treatment BMP is important to include with the conveyance BMP.

Many ADOT roadway projects contain channels paralleling the roadway to collect, intercept, and convey concentrated drainage flows across portions of the roadway. Conveyance channels, themselves, can effectively remove suspended and dissolved stormwater pollutants. Highly permeable soil can infiltrate a significant fraction of the flow before it reaches the end of the channel. Pervious channel lining can reduce total runoff volume (influent to effluent). Vegetation in a channel bed limits the re-suspension of sediment particles, filters larger suspended particles, and adsorbs dissolved organics and nutrients in the runoff. In cases where the velocity of the conveyed flow exceeds approximately six feet per second, impervious channel lining is more appropriate to avoid channel erosion. An evaluation of the post-construction BMPs for concentrated and peak flow must also be completed.

2.3.4 Water Quality and Treatment (Section IV)

The intent of Section IV is to select appropriate post-construction BMPs that treat stormwater prior to discharge to a receiving water body and integrate them into the project. As mentioned earlier, each time a source control BMP is selected in Sections II and III, the roadway designer is directed to Section IV (in its entirety) to determine if a treatment BMP is appropriate to incorporate with the erosion control or conveyance BMP.

The first aspect to consider is whether there are sheetflow discharges to regulated MS4s, sensitive waterbodies, or other stakeholders that require water quality and/or treatment BMPs. The decision must balance a combination of physical constraints (hydraulic head, flow rates, and footprint) and political requirements (MS4s, sensitive water bodies, or other stakeholders).

Vegetated Filter Strips – Sheet flow is most effectively treated by Vegetative Filter Strips (VFSs). A VFS is a long, relatively narrow area of undisturbed or planted vegetation used to retard or collect sediment. VFSs remove pollutants from sheet flow runoff by means of filtration, adsorption, and biodegradation. They also minimize streambank erosion. It is important to consider the limitations of VFSs (and the need for additional structural BMPs). VFSs are most appropriate in non-arid climates where vegetation can be sustained without irrigation. In most cases, however, VFSs are installed adjacent or in close proximity to a surface waterbody, so water to sustain the vegetation is usually available. Additionally, VFSs are also effective in disconnecting impervious areas. VFSs should generally be restricted to drainage areas less than 5 acres and offer minimal treatment for dissolved constituents. VFSs often are well-suited to compliment other treatment (pond-in-place, filtration, and infiltration) practices.

Once the sheetflow discharges within the project have been addressed, point discharges to regulated MS4s, sensitive water bodies, or other stakeholders that require water quality and/or treatment BMPs are evaluated.

Infiltration Practices – If the project site is within ¼ mile of a sensitive waterbody, a VFS alone may not sufficiently remove the target pollutants before the runoff enters the waterbody. In this case, the runoff should be concentrated to a single point. Infiltration is often the initial practice considered for treating runoff collected at a single point. Infiltration is achieved either through a trench or a basin structure. Infiltration basins collect and infiltrate stormwater to the subsurface, and require highly permeable soils for effective recharge. An infiltration trench has a footprint similar to that of a channel parallel to the roadway, but has no outlet. Infiltration trenches work in the same principle as an infiltration basin. In theory, infiltrating water achieves close to 100% treatment through a combination of sedimentation and filtration mechanisms. Infiltration practices also minimize stream bank erosion. However, there are a number of physical constraints that may inhibit or prohibit infiltration, such as the presence of karst geology, contaminated groundwater, or shallow groundwater (less than 5 feet) in the drainage area.

When infiltration is not feasible or allowed, and a VFS is either not feasible or does not provide sufficient pollutant removal, a filtration or storage practice should be considered.

Pond-in-place Practices – If the contributing drainage area upstream from the discharge point is greater than approximately 5 acres, a pond-in-place practice is recommended to effectively treat the larger runoff volume. Pond-in-place practices remove pollutants through sedimentation of particulate pollutants. Pond-in-place practices are advantageous when a project is adjacent or near a surface water body since they can effectively minimize stream bank erosion. In arid environments, a conventional detention basin is generally the most appropriate pond-in-place practice. Impounded runoff often evaporates and infiltrates, leaving the suspended particles behind. If ice formation is common in the area, dry extended detention should be used. For non-arid climates, retention basins are practicable. Retention basins retain water above a permanent pool of water. Having a semi-permanent to permanent pool of water allows retention basins to remove dissolved pollutants through enhanced biodegradation. In general, retention basins should not be designed to store water for more than 36 hours to minimize vectors, algae, and other environmental and wildlife nuisances, as well as avoid potential safety hazards to nearby children.

Filtration Practices – Literature generally recommends that if the contributing drainage area upstream from the discharge point is less than approximately 5 acres, the choice of treatment BMPs just before discharge should be filtration, if the other practices (discussed above) are not an option or sufficient. Filtration practices have high removal efficiencies for suspended particles. They remove large particles through a straining mechanism near the top of the filter whereas the granular material within the depth of the filter removes smaller particles through interception. Filters are particularly useful in high density urban settings with impervious drainage areas. Filtration can be accomplished at grade (surface sand filters) or below grade (underground filters). Design factors such as capital and maintenance costs, available footprint, and aesthetics should be evaluated to determine whether surface or underground filters are more appropriate. In most cases, a sand media is sufficient for filtering suspended solids. However, if petroleum hydrocarbons are of particular concern (i.e. urban settings), organic filter media is recommended to effectively adsorb hydrocarbons.

Bridge Drainage Systems – Runoff from bridges can be treated on the bridge, at a single point off of the bridge, or a combination of both. Treatment on the bridge is generally done at the drain or outlet from the edge of the bridge deck (also called scuppers), generally at multiple points on the bridge structure. This can be achieved by installing pre-manufactured drop inlet filters and absorbents. Runoff can also be concentrated to a single point before discharging to a receiving waterbody below. Refer to the discussion above for treatment options for concentrated flows. Moreover, some DOTs choose to collect and pond runoff from a bridge prior to discharge as a spill control contingency in the event that petroleum or a hazardous material is spilled on or nearby the bridge. An isolation/diversion structure can be used to separate first flush runoff, as discussed above. Finally, if a bridge is not crossing a sensitive waterbody, treatment may be achieved by installing vegetated filter strips along the bank of the waterbody.

Additional considerations and restrictions may require another form of treatment BMPs. Consult with published literature on the most appropriate BMP for the site and discuss the decision with ADOT. ADOT may have additional recommendations based on the local conditions.

Manufactured Treatment Devices – Stormwater treatment technologies are rapidly developing and evolving as more focus is placed on stormwater quality. Treatment devices should be used when there is insufficient footprint for simpler practices (i.e. ultra-urban locations) or a higher level of treatment/water quality is necessary. The roadway designer should ensure that the manufactured treatment system meets ADOT's material specifications and that the device is installed and used as specified by the manufacturer. The designer should also keep in mind that manufactured devices require more frequent maintenance and monitoring.

2.3.5 Flow Chart Footnotes

Additional details and design restrictions are presented in footnotes which can be found on pages 8 through 10 of the flowchart.

2.4 References and Resources

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3.0 - Post-Construction Best Management Practices

This section is intended as a technical guidance for the design of post-construction BMPs. Each BMP sheet (**Sections 3.2, 3.3** and **3.4**) contains an overview of key BMP design attributes and discussion on the appropriate applications, limitations and specific design factors that should be considered. Each BMP sheet also highlights material specifications, design standards and maintenance and inspection requirements. When applicable, design schematics are also included.

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3.1 Design Attributes

3.1.1 Design, Construction and Maintenance Costs

The costs of implementing a post-construction BMP should be considered from the standpoint of planning, design, construction, and maintenance. The level of effort (and associated costs) including expertise, engineering design, and extent of labor required to plan and install a post-construction BMP can vary greatly, ranging from the relative low cost of applying decomposed granite cover to the design and construction of a large scale bioretention system. In some cases, the upfront capital costs of a post-construction BMP may be negligible compared to the long term, ongoing costs for maintenance and repair. The costs for appropriate safety controls also must be considered. Refer to **Table B.6 (Appendix B)** for unit construction and maintenance costs for each BMP.

3.1.2 Target Pollutants

New roadways and roadway expansions also increase traffic volumes, leading to increased loadings of sediment, oils and greases, and heavy metals, among other pollutants (Table 3.1).

3.1.3 BMP Substitution and Combinations

Every project site has a unique set of conditions (physical, political and/or economic) that may necessitate the designer to substitute an alternative BMP, without compromising water quality or erosion control. For example, decomposed granite cover may be substituted for seed mix, where appropriate and approved. In most cases, multiple post-construction BMPs must be combined to achieve the project goals and needs. One of the most important examples of this is incorporating pretreatment (decomposed granite cover or vegetated filter strips) with water quality/treatment BMPs. Combining BMPs together enhances both the effectiveness and lifespan of the BMPs.

Low Impact Development (LID) is a proven strategy for controlling stormwater at its source, rather than managing stormwater off site though a conveyance system, in order to restore a site's natural, pre-developed capacity to handle stormwater. As an alternative to traditional stormwater conveyance systems, LID techniques include constructed green spaces, native landscaping, and a variety of innovative bioretention and infiltration techiques to capture and manage stormwater on-site. LID reduces peak runoff by promoting infiltration, evaporation, and rainwater harvesting. The result is development that more closely maintains pre-development hydrology. Furthermore, LID has been shown to be cost effective, and in some cases, cheaper than using traditional stormwater management techniques. After considering design factors, roadway designers should incorporate LID techniques and BMPs whenever possible, such as:

- Infiltration practices
- Pervious cover and channel lining
- Bioretention, and
- Rainwater harvesting

Table 3.1 - Target Pollutants

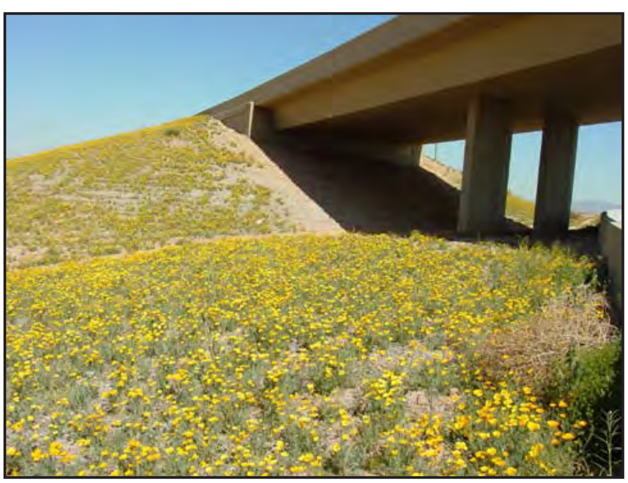
Water Quality Indicators
▪ Color ▪ Hardness ▪ pH ▪ Specific Conductance ▪ Water temperature
Dissolved or Suspended Sediment
▪ Total Dissolved Solids (TDS) ▪ Total Suspended Solids (TSS) ▪ Turbidity
Biological Constituents
▪ Biological Oxygen Demand (BOD) ▪ Chemical Oxygen Demand (COD) ▪ Fecal Coliform ▪ Total Coliform
Nutrients and Pesticides
▪ Ammonia ▪ Calcium ▪ Chloride ▪ DDE ▪ Nitrate (NO3 as N) ▪ Nitrite (NO2 as N) ▪ Nitrogen ▪ Sodium ▪ Total Kjeldahl Nitrogen (TKN) ▪ Total Phosphorus and Ortho-Phosphate
Heavy Metals
▪ Cadmium ▪ Chromium ▪ Copper ▪ Iron ▪ Lead ▪ Manganese ▪ Nickel ▪ Zinc
Organics
▪ Cyanide (CN) ▪ Dissolved Organic Compounds (DOCs) ▪ Particulate and dissolved Polyaromatic Hydrocarbons (PAHs) ▪ Surfactants (detergents) ▪ Total Organic Carbon (TOC) ▪ Total Petroleum Hydrocarbons (TPH), Oil and Grease ▪ Total Phenols

3.2 Off-Road, Overland Flow Erosion Control

Minimizing the release and suspension of pollutants, particularly erosion of roadway shoulders by drainage is the first line of defense against stormwater pollution, particularly suspended sediment particles. Off-road, overland erosion control BMPs typically are installed in the form of pervious cover (vegetation, decomposed granite, etc.), impervious cover (shotcrete, concrete, etc.) or velocity/energy dissipation devices. Roadway landscaping (i.e. trees, shrubs, and groundcover) provides additional erosion control and sediment stabilization benefits. Regardless of its form, the application of the proper erosion control BMP depends on various site-specific conditions including:

- Slope and slope length;
- Soil classification and texture;
- Anticipated volume of runoff;
- Distance to unique, impaired or not attaining waterbodies;
- Location (urban vs. rural); and
- Maintenance requirements; among others.

Erosion cover BMPs are often the most cost-efficient BMPs in terms of upfront capital/construction costs and long-term maintenance and inspection costs.



Decomposed Granite Cover

DEFINITION

Granite rock, ranging from ¼" to 2" nominal diameter, used for drains, erosion control, and a temporary driving surface. Rock mulch (3" minus) can also be used for small pipe inlets/outlets, headwalls/wingwalls, and rock check dams.

OVERVIEW

GENERAL INFORMATION
Key design factors: ▪ Decomposed granite should be clean and meet project gradation requirements.
Maintenance needs: ▪ Removal of weeds, floatable debris, and trash. ▪ Replace decomposed granite in washed out areas.
Most effective when used with: ▪ Slope modification (slopes should be as flat as possible).
Alternative BMPs to consider: ▪ Vegetated filter strips ▪ Seed mix

RATINGS	H	M	L
Associated Costs			
Design			X
Construction			X
Maintenance			X
BMP Objective			
Erosion control		X	
Drainage conveyance			X
Water Quality/Treatment			X
DOT Target Pollutants Removal			
Dissolved or suspended sediment			X
Biological constituents			X
Nutrients and pesticides			X
Heavy metals			X
Organics			X

PHOTOGRAPHS

PURPOSE

Decomposed granite cover provides erosion control in non-roadway areas for flat to moderate erodible slopes (2:1 slopes and less) within urban areas. In addition to erosion control, decomposed granite cover can act as a pretreatment mechanism for various treatment and water quality BMPs (infiltration and filtration structures). Rock mulch can also be used around small pipe inlets/outlets, headwalls/wingwalls, and rock check dams.

APPROPRIATE APPLICATIONS

Decomposed granite cover can be applied in the following areas:

- Moderate, erodible slopes (between 2:1 and 4:1) if the project is within urban areas.
- Flat, erodible slopes (less than 4:1) if the project is within an urban area, and the area is a median, flat area, or otherwise visual area that does not drain towards the roadway. Refer to the Seed Mix BMP for non-visual areas.
- Rock mulch can be applied to small areas around pipe inlets/outlets, headwalls/wingwalls, and rock check dams.

LIMITATIONS

Decomposed granite cover is ***NOT*** appropriate in the following conditions:

- Roadways outside of urban limits. Refer to the Seed Mix BMP for erosion control in such areas.
- Areas that require a vegetated filter strip for water quality/treatment purposes. Refer to the Vegetated Filter Strip BMP for more details.

DESIGN CONSIDERATIONS

Consider the following decomposed granite cover design factors:

<u>Local government code</u> Refer to local municipal code or other stakeholder requirements for appearance and placement of the decomposed granite.

MATERIAL SPECIFICATIONS

Decomposed granite cover shall consist of stone, gravel or other approved inert material of similar characteristics, and shall be clean and free from vegetable matter and other deleterious substances. Refer to Table 303-1 of the ADOT Standard Specifications for Road and Bridge Construction for the proper decomposed granite gradation.

DESIGN STANDARDS

Refer to Section 803-3.02 of the ADOT Standard Specifications for Road and Bridge Construction for design and construction standards of decomposed granite cover. Section 803.3.03 has design and construction standards for rock mulch.

Apply aggregate base material at a depth of at least 2 inches or as directed by the roadway designer. Unless otherwise required by traffic safety standards/regulations, granite erosion control shall be applied without eliminating the dense existing perennial vegetation. Refer to Item 3030110 - Aggregate Base at Median Cable Barrier Alignment for more details of applying granite erosion control along median cable barriers.

MAINTENANCE AND INSPECTION REQUIREMENTS

Refer to Activity 341 – Granite Erosion Control in the ADOT Maintenance and Facilities Best Management Practices Manual for information on inspecting and repairing damage to granite erosion control.

SCHEMATICS

Not applicable.

REFERENCES AND RESOURCES

Arizona Department of Transportation (ADOT), *Standard Specifications for Road and Bridge Construction*, 2008.

Arizona Department of Transportation (ADOT), *Maintenance and Facilities Best Management Practices Manual*, 2006

Erosion Control Blanket

DEFINITION

A protective blanket or soil stabilization mat installed to reduce soil erosion by wind or water. Erosion control blankets usually consist of photodegradable mesh filled with straw, excelsior, coconut fiber, wood fiber, or jute.

OVERVIEW

GENERAL INFORMATION
Key design factors: ▪ Application of erosion control blanket (slope or channel). ▪ Site preparation.
Maintenance needs: ▪ Re-anchor loosened matting and replace lost matting and staples as required. ▪ Repair slope or channel damage before re-installing matting if washout or breakage occurs.
Most effective when used with: ▪ Seed Mix
Alternative BMPs to consider: ▪ Seed Mix ▪ Decomposed Granite Cover

RATINGS	H	M	L
Associated Costs			
Design			X
Construction		X	
Maintenance			X
BMP Objective			
Erosion control	X		
Drainage conveyance			X
Water Quality/Treatment			X
DOT Target Pollutants Removal			
Dissolved or suspended sediment			N/A
Biological constituents			N/A
Nutrients and pesticides			N/A
Heavy metals			N/A
Organics			N/A

PHOTOGRAPHS

PURPOSE

Erosion control blankets reduce rainfall impact, reduce the erosion effects of concentrated flows, protect exposed soil from wind and rain, and hold moisture near the soil surface. Erosion control blankets also provide a microclimate to promote seedling establishment.

APPROPRIATE APPLICATIONS

Erosion control blankets are used on steep slopes, slopes with highly erosive soils, slopes adjacent to bodies of water, concentrated flow areas (channel lining), and in areas inaccessible to hydraulic mulch application equipment or where plant establishment is likely to be slow. Additional information on channel lining can be found in Chapters 6 and 7 of the ADOT Highway Drainage Design Manual.

LIMITATIONS

Erosion control blankets are ***NOT*** appropriate in the following conditions:

- Excessively rocky sites or rough slopes;
- Areas where erosion control blankets are costly and may trap wildlife.

DESIGN CONSIDERATIONS

<u>Application of erosion control blanket</u> –The planned use of erosion control blankets (channel, slope, etc.) will determine the type of blanket needed. Other factors that may influence the type of erosion control blanket used include cost, flow velocity and runoff, ease of installation, vegetation enhancement, longevity, and maintenance needs.

<u>Site preparation</u> – Upon completion of grading and shaping an area; all rocks, clods, vegetation, and other obstructions should be removed so the blanket will have direct contact with the soil. If the area is to be seeded, prepare soil as directed in the project’s specification before applying the blanket.

<u>Seeding</u> – Seed should be applied to the disturbed area before installation of the blanket to ensure revegetation. Seed application is often specified for turf reinforcement mats. Refer to Section 805 of the ADOT Standard Specifications for Road and Bridge Construction for ADOT approved or preferred seed mix specifications and seed application procedures.

<u>Installation</u> – Erosion control blankets should be installed based on the application (slope or channel) and as specified by the manufacturer. Additional information and general guidelines for anchoring and installation of erosion control blanket can be found Section 5.1.8 of the ADOT Erosion and Pollution Control Manual.

Soil filling – Soil filling should be placed per the manufacturer's recommendations. Shovels, rakes, or brooms should be used for fine grading and touch up. The soil filling should be smooth, just exposing the top netting of the blanket. Prevent traffic and heavy equipment from driving over blankets, especially if the soil is loose or wet.

Maintenance – Damaged or loosened blankets should be re-anchored or replaced as required. Slope or channel damage should be repaired before re-installing blanket if washout or breakage occurs.

MATERIAL SPECIFICATIONS

Refer to Section 5.1.8 of the ADOT Erosion and Pollution Control Manual for erosion control blanket material specifications.

DESIGN STANDARDS

Refer to Section 5.1.8 of the ADOT Erosion and Pollution Control Manual for design standards.

MAINTENANCE AND INSPECTION REQUIREMENTS

Inspections – Follow the inspection procedures described in the ADOT Erosion and Pollution Control Manual.

Maintenance – Follow the maintenance procedures described in the ADOT Erosion and Pollution Control Manual. Additionally, prior to mowing an area that was treated with an erosion control blanket, the area should be checked for any plastic cover that has yet to degrade and has detached from the surface. Loose plastic can entangle and damage mowing equipment. Loose plastic should be carefully pulled from the surface and discarded prior to mowing.

SCHEMATICS

Refer to the schematics in Section 5.1.8 of the ADOT Erosion and Pollution Control Manual for Highway Design and Construction.

REFERENCES AND RESOURCES

Arizona Department of Transportation (ADOT), *Standard Specifications for Road and Bridge Construction*, 2008.

Arizona Department of Transportation (ADOT), *Erosion and Pollution Control Manual for Highway Design and Construction*, 2005.

Arizona Department of Transportation (ADOT), *Highway Drainage Design Manual (draft),* 2006.

Impervious Cover

DEFINITION

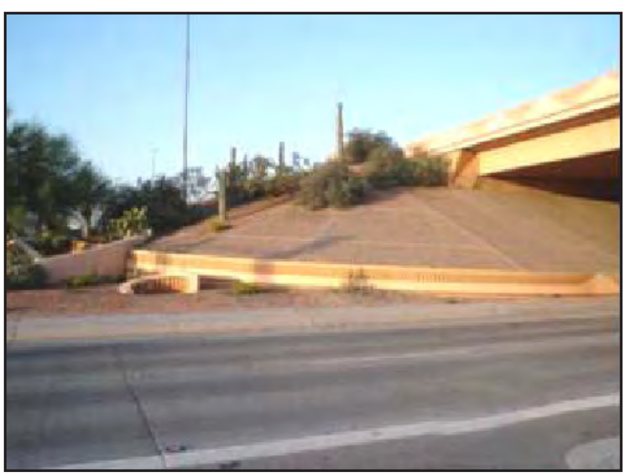
Artificial surfacing of a soil surface to resist erosion or scour. Impervious cover can consist of soil cement (a dry mix of sand, cement and admixtures, compacted to the required density); shotcrete (mortar or concrete applied, pneumatically, through a hose); grouted **Riprap** (rock voids filled with concrete grout); concrete slope pavement (cast-in-place or pre-cast and place concrete monolithic armor) and grouted fabric slope pavement (sand-cement mortar, injected between two layers of double-woven fabric).

OVERVIEW

GENERAL INFORMATION
Key design factors: ▪ Impervious cover material strength and durability.
Maintenance needs: ▪ Replacement of deteriorated sections of the impervious cover.
Most effective when used with: ▪ Slope modification
Alternative BMPs to consider: ▪ Pervious cover ▪ Wire-tied rock

RATINGS	H	M	L
Associated Costs			
Design			X
Construction	X		
Maintenance			X
BMP Objective			
Erosion control	X		
Drainage conveyance			X
Water Quality/Treatment			X
DOT Target Pollutants Removal			
Dissolved or suspended sediment			X
Biological constituents			X
Nutrients and pesticides			X
Heavy metals			X
Organics			X

PHOTOGRAPHS



PURPOSE

Impervious cover provides erosion control on steep slopes and embankments.

APPROPRIATE APPLICATIONS

Impervious cover is most applicable along steep erodible slopes (2:1 or greater) that can not be made pervious.

- Embankments and abutments along roadways, bridges, overpasses, and underpasses are typically made impervious to maintain structural integrity.
- Impervious surfaces can prevent runoff from infiltrating and affecting underlying contaminated groundwater or collapsible soils.

LIMITATIONS

Impervious cover should ***NOT*** be selected if infiltration along the slope is feasible. Allowing runoff to infiltrate decreases the runoff flow and/or volume that must be managed downstream.

DESIGN CONSIDERATIONS

Consider the following impervious cover design factors:

- Engineering cost evaluations should be conducted to determine the appropriate impervious cover for a particular application to meet the required design life.

MATERIAL SPECIFICATIONS

Soil cement – Typically specified by the Project Special Provisions. Special Provisions may refer to local agency specifications, such as Maricopa Association of Governments Standard Specifications Section 312 for soil cement base and Section 705 for portland cement treated base.

Shotcrete – Refer to Section 912 of the ADOT Standard Specifications for Road and Bridge Construction for shotcrete material specifications.

Grouted riprap – Grouted riprap should conform to Section 913-2 of the ADOT Standard Specifications for Road and Bridge Construction for bank protection. Riprap should also conform to Gradations A or B, as defined by Section 810 of the ADOT Standard Specifications for Road and Bridge Construction.

Concrete slope pavement – Typically specified by the Project Special Provisions.

Grouted fabric slope pavement – Typically specified by the Project Special Provisions.

DESIGN STANDARDS

Soil cement – Refer to Section 11.7.3 of the ADOT Highway Drainage Design Manual for soil cement design standards.

Shotcrete – Refer to Section 912 of the ADOT Standard Specifications for Road and Bridge Construction for shotcrete design standards.

Grouted riprap – Refer to Section 11.7.4 of the ADOT Highway Drainage Design Manual for grouted riprap design standards.

Concrete slope pavement – Refer to Section 11.7.5 of the ADOT Highway Drainage Design Manual for concrete slope pavement design standards.

Grouted fabric slope paving – Refer to Section 11.7.6 of the ADOT Highway Drainage Design Manual for grouted fabric slope paving design standards.

MAINTENANCE AND INSPECTION REQUIREMENTS

Inspections – Look for deterioration of the impervious cover that may expose significant areas of the covered slope to stormwater runoff and erosion.

Maintenance – Impervious cover may need to be repaired or replaced in sections over time. Severe deterioration may require the cover to be replaced all together.

SCHEMATICS

Not applicable.

REFERENCES AND RESOURCES

Arizona Department of Transportation (ADOT), *Standard Specifications for Road and Bridge Construction*, 2008.

Arizona Department of Transportation (ADOT), *Highway Drainage Design Manual (draft)*, 2006.

Maricopa Association of Governments (MAG) Standard Specifications, Section 312 and Section 705.

Retaining Walls

DEFINITION

Walls designed and constructed to hold back soil or rock below and around a building, structure, or a general area. Retaining walls provide stability, support and erosion control for soil slopes ranging from vertical to the angle of repose (or lower).

OVERVIEW

GENERAL INFORMATION
Key design factors: ▪ Soil type and stability. ▪ Proper surface and subsurface drainage. ▪ Wall height and height of retained soil. ▪ Retaining walls can be an expensive option.
Maintenance needs: ▪ Periodic inspection of weep holes.
Most effective when used with: ▪ Drainage channels above and below the retaining wall.
Alternative BMPs to consider: ▪ Slope Modification and New Slope Construction

RATINGS	H	M	L
Associated Costs			
Design	X		
Construction		X	
Maintenance			X
BMP Objective			
Erosion control	X		
Drainage conveyance			X
Water Quality/Treatment			X
DOT Target Pollutants Removal			
Dissolved or suspended sediment			X
Biological constituents			X
Nutrients and pesticides			X
Heavy metals			X
Organics			X

PHOTOGRAPHS

PURPOSE

Retaining walls are structures built to resist lateral pressure and prevent the advance of a mass of earth away from a slope. In addition to maintaining slope stability, retaining walls are also used to satisfy stakeholder requirements and to hydraulically separate off-site contaminated subsurface drainage.

APPROPRIATE APPLICATIONS

Retaining walls are appropriate for soil slopes ranging from vertical to the natural angle of repose, but are often also used at flatter slopes to meet other project needs/requirements.

LIMITATIONS

There are no limitations for retaining walls from an erosion and sediment control perspective. Retaining wall construction should be limited to soils that will provide for less than one (1) inch of settlement. For further geotechnical engineering limitations refer to the ADOT Standard Retaining Wall Specifications.

DESIGN CONSIDERATIONS

Consider the following retaining wall design factors for sediment and erosion control:

<u>Drainage channels</u> – Drainage flows that occur above the retaining wall should be diverted around the retaining wall whenever possible.

<u>Slope modification</u> – Retaining walls may not be necessary for slopes that can be flattened sufficiently below the angle of repose. Refer to the **Slope Modification and New Slope Modification** BMP for more information. Alternatively, a retaining wall can be broken up into smaller walls if the slope is terraced.

MATERIAL SPECIFICATIONS

Refer to Sections 203, 601, 610, and 914 of the ADOT Standard Specifications for Road and Bridge Construction for retaining wall material specifications.

DESIGN STANDARDS

Refer to the ADOT Highway Division Structures Sections Standard Drawings for retaining wall design guidelines and standards. For non-standard designs, the AASHTO Standard Specifications for Highway Bridges may also be followed.

MAINTENANCE AND INSPECTION REQUIREMENTS

Inspections – Perform inspections regularly to verify the structural integrity of the retaining wall. Inspections should focus on the presence of cracking, vertical displacement, and settlement greater than 1". Inspections should be conducted following each storm event to ensure that all weep holes are free of blockage and functioning properly.

Maintenance – Engineering measures should be taken to repair/address any structural deficiency like cracking or vertical displacement that may be identified during inspection.

SCHEMATICS

Refer to ADOT Standard Specification Drawings B-18.10 through B-18.50.

REFERENCES AND RESOURCES

Arizona Department of Transportation (ADOT), *Standard Specifications for Road and Bridge Construction,* 2008.

Arizona Department of Transportation (ADOT), *Highway Division Structures Section Standard Drawings*, 1992.

Arizona Association of State Highway and Transportation Officials (AASHTO) *Standard Specifications for Highway Bridges,* 2002.

Riprap

DEFINITION

Riprap is a controlled placement of erosion-resistant ground cover of large, loose, angular stone with a geotextile or granular underlining.

OVERVIEW

GENERAL INFORMATION
Key design factors: ▪ Intended purpose (streambank, slopes, inlet/outlet protection etc.). ▪ Riprap installation procedures.
Maintenance needs: ▪ Periodic inspections of riprap. ▪ Replacement or repositioning of riprap.
Most effective when used with: ▪ Proper conveyance structure design (culverts, spillways, etc.).
Alternative BMPs to consider: ▪ Wire-tied Rock ▪ Decomposed Granite Cover (Rock mulch)

RATINGS	H	M	L
Associated Costs			
Design			X
Construction			X
Maintenance			X
BMP Objective			
Erosion control	X		
Drainage conveyance			X
Water Quality/Treatment			X
DOT Target Pollutants Removal			
Dissolved or suspended sediment			N/A
Biological constituents			N/A
Nutrients and pesticides			N/A
Heavy metals			N/A
Organics			N/A

PHOTOGRAPHS

PURPOSE

Riprap reduces flow velocity, erosion, and sediment movement in areas where vegetative or geotextile measures are not adequate or appropriate.

APPROPRIATE APPLICATIONS

Riprap can be used to protect and stabilize culvert inlets and outlets, stream banks, drainage channels, slopes and other areas subject to erosion. Additional information about riprap use can be found in the **Inlet Protection**, **Impervious Channel Lining**, and **Outlet Protection** BMP sheets.

LIMITATIONS

Riprap transitions reduce erosion only when they have been sized and built properly. Undersized riprap channels will have the potential to scour with high velocity flows while oversized riprap channels will have the potential for undercutting and erosion of the supporting soils. Scour may also occur for improperly designed or installed geotextiles.

DESIGN CONSIDERATIONS

Consider the following riprap design factors:

<u>Application of riprap</u> – Riprap should be used when other methods of protection or stabilization are not appropriate. The planned application of riprap (streambank stabilization, outlet protection, slope protection, etc.) will determine the type and gradation (size class) of riprap needed. Machined riprap (placed by mechanical means and then compacted) is most often used because of its uniformity, flexibility in various applications, and ability to be compacted without manual sorting.

<u>Quality of riprap</u> – Riprap should generally consist of quarried or crushed shot rock that is angular and clean. Riprap should not contain sand, dust, organic material, cracks, or impurities. Riprap is usually solid limestone or river rock, which is generally resistant to erosion and corrosion (due to stream chemistry).

<u>General subgrade preparation</u> – The area should be cleared of trees, vegetation, and unsuitable soils, and then graded. The subgrade should be prepared to the specified depth necessary for installation of riprap and compacted to prevent slumping or undercutting. Geotextile and/or a granular filter should be installed to maintain separation of rock material from the underlying soil.

<u>Installation of riprap</u> – Quarried or crushed riprap is generally dumped and placed by the use of appropriate equipment. Placement should avoid segregating material by minimizing drop heights and by dumping material in large quantities. Riprap is then graded and compacted (using hand or mechanical tamping) to produce a surface uniform in appearance. Place riprap carefully to avoid puncturing or displacing geotextile fabric.

Construction sequencing – After the riprap area is constructed, install temporary controls upstream of the area until the project has been stabilized to prevent excessive, pre-mature sediment loading into the riprap area.

Pretreatment – In areas where dense vegetation can be maintained, vegetated filter strips should be installed upstream of the riprap area for pretreatment measure.

MATERIAL SPECIFICATIONS

Riprap should conform to Gradations A or B, as defined by Section 810 of the ADOT Standard Specifications for Road and Bridge Construction.

DESIGN STANDARDS

Refer to Section 5.2.2 of the ADOT Erosion and Pollution Control Manual for design standards at cut to fill slope transitions.

MAINTENANCE AND INSPECTION REQUIREMENTS

Refer to Section 5.2.2 of the ADOT Erosion and Pollution Control Manual for inspection and maintenance requirements at cut to fill slope transitions.

SCHEMATICS

Refer to schematics in Sections 5.2.2, 5.2.3 and 5.2.4 of the ADOT Erosion and Pollution Control Manual for Highway Design and Construction.

REFERENCES AND RESOURCES

Arizona Department of Transportation (ADOT), *Standard Specifications for Road and Bridge Construction*, 2008.

Arizona Department of Transportation (ADOT), *Erosion and Pollution Control Manual for Highway Design and Construction*, 2005.

Tennessee Department of Environment and Conservation (TDEC), *Erosion and Sediment Control Handbook*, 2002.

Seed Mix

DEFINITION

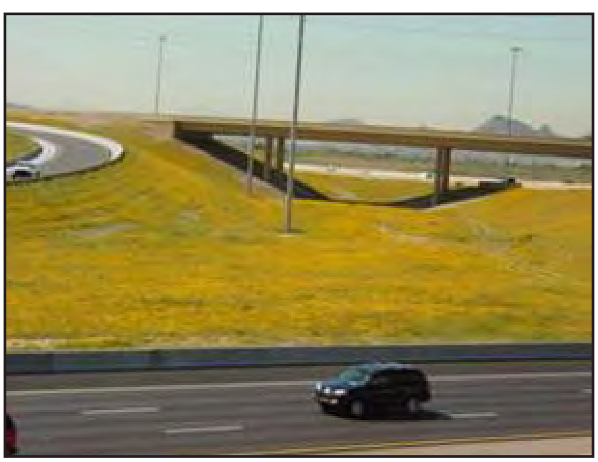
The application of native vegetation seed to a previously disturbed soil surface. Seed can be mixed with fiber, fertilizers, mulch, or stabilizing emulsions to enhance the seed germination.

OVERVIEW

GENERAL INFORMATION
Key design factors: ▪ Selection of correct seeding mixture. ▪ Proper seedbed preparation.
Maintenance needs: ▪ Periodic inspections of seeded areas. ▪ Re-seeding areas where vegetation does not establish.
Most effective when used with: ▪ Slope Modificaiton and New Slope Construction
Alternative BMPs to consider: ▪ Decomposed Granite Cover (urban areas) ▪ Erosion Control Blankets ▪ Vegetative Filter Strips

RATINGS	H	M	L
Associated Costs			
Design			X
Construction		X	
Maintenance			X
BMP Objective			
Erosion control		X	
Drainage conveyance			X
Water Quality/Treatment			X
DOT Target Pollutants Removal			
Dissolved or suspended sediment			N/A
Biological constituents			N/A
Nutrients and pesticides			N/A
Heavy metals			N/A
Organics			N/A

PHOTOGRAPHS



PURPOSE

Seed mix is applied to a disturbed area in order to establish permanent vegetation. Vegetation protects the soil surface from erosion, maintains sheet flow, promotes infiltration of runoff into the soil, and reduces stormwater runoff velocity.

APPROPRIATE APPLICATIONS

Seeding is appropriate for permanent vegetation and stabilization of disturbed soils. It also can be used as a temporary erosion control practice (refer to Section 5.1.5 of the ADOT Erosion and Pollution Control Manual for more details).

LIMITATIONS

Seeding is ***NOT*** appropriate in the following conditions:

- Steep slopes where seeds can not be effectively protected from erosion or established;
- Most conveyance channels and other areas with concentrated water flow; and,
- Excessively dry or cold climatic zones.

DESIGN CONSIDERATIONS

Consider the following seed mix design factors:

<u>Seed mix selection</u> – Seed mix should be selected on factors such as site, soil conditions, time of year, method of planting, and planned use of the seeded area. Annual companion crops (temporary) may be used in conjunction with permanent seed mixtures if the perennial species are not planted at their optimum planting period. Care should be taken when selecting an annual companion crop to ensure that it is not an aggressive species capable of overwhelming the permanent species.

<u>Grading and shaping</u> – Grade and shape areas to be seeded to allow safe and efficient operation of equipment used for seedbed preparation, seed and fertilizer application, mulching, and maintenance of the vegetation. Grading and shaping may not be required where hydraulic seeding and fertilizing equipment is to be used.

<u>Seedbed preparation</u> – In an area to be permanently stabilized, topsoil should be applied anywhere the disturbance results in subsoil being the final grade. The seedbed should be tilled prior to application of fertilizer, seed mix, and mulch. On slopes too steep for the safe operation of tillage equipment, the soil surface may be pitted or trenched across the slope with appropriate hand tools to provide consecutive seedbeds in which seed may lodge and germinate. Seedbed preparation may not be required where hydraulic seeding equipment is to be utilized.

Roadway shoulders – Native seed can also be established within milled asphalt concrete shoulder (which does not contain growth inhibitors). Establishing native vegetation on milled asphalt concrete shoulder reduces erosion, prevents the establishment of invasive and noxious weeds, defines the shoulder edge, and enhances the roadside aesthetics.

Seeding – Seeding may be accomplished by the following methods:

- Hydraulic seeding – Mix the seed, fertilizer, and wood cellulose or wood fiber mulch with water and apply in a slurry uniformly over the disturbed area. This method is commonly used on steep slopes and in areas where erosion control blankets will be applied.
- Conventional seeding – Seed should be applied to a freshly prepared seedbed. Seed and fertilizer may be applied with a cultipacker seeder, drill, rotary seeder, other mechanical seeder, or a hand seeder to distribute the seed uniformly over the disturbed area. Following seed application, the soil should be raked lightly to incorporate the seed within the surface of the soil.
- No-till seeding – No-till seeding may be applicable when annual cover crops have matured and the stand is sparse enough to allow adequate growth of the permanent (perennial) species. Seed should be uniformly distributed throughout the existing stand of vegetation.

Mulch application – Mulch assists in erosion control, moisture retention, and preventing unwanted transportation of seed, therefore increasing germination of the seed. If hydraulic seeding equipment is used, wood cellulose or wood pulp mulch should be incorporated with the seed mixture. Dry straw may be applied to areas that have been hydraulically seeded, conventionally seeded, or no-till seeded. Mulch should be applied to areas following seeding and should achieve 75% soil cover. Straw mulch should be anchored immediately following application by one of the following methods: emulsified asphalt, synthetic tackifiers or binders, pressed into the soil with a crimper or disk harrow, or other applicable method.

Irrigation – Irrigation may be used in areas where there is not sufficient rainfall to germinate the seed. Irrigation should be applied at a rate that will not cause runoff.

Invasive plant species – Invasive and noxious plant species can over-run native flora in the area. Invasive species are also often more flammable (i.e. Buffelgrass, *Pennisetum ciliare*) and require the use of herbicides, both of which can lead to pollutant loading in stormwater runoff. The designer should confirm that invasive species are not included in the seed mix being applied.

MATERIAL SPECIFICATIONS

Refer to Section 805-3.01 of the ADOT Standard Specifications for Road and Bridge Construction for ADOT approved or preferred seed mix specifications.

DESIGN STANDARDS

Refer to Section 805 of the ADOT Standard Specifications for Road and Bridge Construction for seed application procedures.

MAINTENANCE AND INSPECTION REQUIREMENTS

Inspections – Follow the inspection procedures described in Section 5.1.5 of the ADOT Erosion and Pollution Control Manual.

Maintenance – Follow the maintenance procedures described in Section 5.1.5 of the ADOT Erosion and Pollution Control Manual. Invasive plant species may need to be removed periodically.

SCHEMATICS

Not applicable.

REFERENCES AND RESOURCES

Arizona Department of Transportation (ADOT), *Standard Specifications for Road and Bridge Construction*, 2008.

Arizona Department of Transportation (ADOT), *Erosion and Pollution Control Manual for Highway Design and Construction*, 2005.

Tennessee Department of Environment and Conservation (TDEC), *Erosion and Sediment Control Handbook*, 2002.

Slope Modification and New Slope Construction

DEFINITION

Slope modification practices may include minibenches, furrows, terraces, serrations, stair-steps, or track-marks on the face of the slope. Existing and new slopes should also be flattened to the lowest extent possible, whenever feasible, to reduce erosive runoff velocities and increase infiltration time.

OVERVIEW

GENERAL INFORMATION
Key design factors: ▪ Proper slope construction sequencing (top down). ▪ Horizontal slope roughening techniques follow the original slope contours.
Maintenance needs: ▪ Periodic inspections of slope stability.
Most effective when used with: ▪ Riprap ▪ Wire-tied Rock
Alternative BMPs to consider: ▪ Retaining walls (i.e. if slope can not be flattened).

RATINGS	H	M	L
Associated Costs			
Design		X	
Construction		X	
Maintenance			X
BMP Objective			
Erosion control	X		
Drainage conveyance			X
Water Quality/Treatment			X
DOT Target Pollutants Removal			
Dissolved or suspended sediment			N/A
Biological constituents			N/A
Nutrients and pesticides			N/A
Heavy metals			N/A
Organics			N/A

PHOTOGRAPHS

PURPOSE

Slope modifications enhance water infiltration and increase the effectiveness of permanent soil stabilization practices by decreasing runoff velocities.

APPROPRIATE APPLICATIONS

Slope modification techniques are appropriate for most existing slopes or new slopes being formed during a roadway construction project. It is particularly appropriate in the following scenarios:

- Long (> 25 feet) and steep (< 2:1) slopes, particularly cut slopes in rural settings;
- Soils prone to erosion; and
- Prior to application of permanent seeding.

LIMITATIONS

Slope modification techniques are ***NOT*** appropriate for rock slopes.

DESIGN CONSIDERATIONS

Slope contours - Minibenches, terraces, furrows and other horizontal roughening techniques should always follow the elevation contour.

Construction sequencing – Minibenching and slope roughening shall be constructed as the slope is cut from the top of a cut slope to the bottom.

MATERIAL SPECIFICATIONS

Not applicable.

DESIGN STANDARDS

Slope modifications should comply, as applicable, with Section 802 of the ADOT Standard Specifications for Road and Bridge Construction.

MAINTENANCE AND INSPECTION REQUIREMENTS

Inspections – Follow the inspection scheduled required by the Construction General Permit Part IV.H. Where the horizontal roughening falls away from the contour, additional BMPs including **Seed Mix, Erosion Control Blanket, Retention Walls**, and other may be required to protect the slope.

SCHEMATICS

Refer to ADOT C-Standards 02.10 to 02.30 and Detail E7 (Minibenching) of Section 5.1.3 of the ADOT Erosion and Pollution Control Manual for Highway Design and Construction.

REFERENCES AND RESOURCES

Arizona Department of Transportation (ADOT), Standard Specifications for Road and Bridge Construction, 2008.

Arizona Department of Transportation (ADOT), *Erosion and Pollution Control Manual for Highway Design and Construction*, 2005.

Arizona Department of Transportation (ADOT), *Construction Standard Drawing C-02.10 to 02.30,* 2004.

Wire-tied Rock

DEFINITION

Wire-tied rock consists of a wire mesh structure filled with rock and can be constructed in the form of **Wire-tied Rock** mattresses or gabions. In wire-tied rock mattress designs, the individual wire mesh units are laid end-to-end and side-to-side to form a mattress layer along the channel bed or side slope. Generally, the depth is much smaller than the width or length. Gabions, in contrast, are typically rectangular or trapezoidal in shape. The depths are approximately the same as the widths and are stacked vertically.

OVERVIEW

GENERAL INFORMATION
Key design factors: ▪ Bank/foundation preparation and grading. ▪ Mattress/block unit size and configuration. ▪ Basket fabrication.
Maintenance needs: ▪ Are greatly reduced from standard riprap, but should still be inspected regularly.
Most effective when used with: ▪ Slope Modification and New Slope Construction.
Alternative BMPs to consider: ▪ Riprap ▪ Impervious cover

RATINGS	H	M	L
Associated Costs			
Design			X
Construction		X	
Maintenance			X
BMP Objective			
Erosion control	X		
Drainage conveyance			X
Water Quality/Treatment			X
DOT Target Pollutants Removal			
Dissolved or suspended sediment			N/A
Biological constituents			N/A
Nutrients and pesticides			N/A
Heavy metals			N/A
Organics			N/A

PHOTOGRAPHS

PURPOSE
Wire-tied rock structures provide stream bank stability and erosion control.

APPROPRIATE APPLICATIONS
Wire-tied rock mattresses are used to form a continuous revetment surface on flat slopes (less than 4:1) or as aprons. Wire-tied mattresses can also be used within steep cut-to-fill transitions.

Stacked block gabion revetments are typically used instead of rock mattresses when the slope to be protected is greater than 3:1 or for flow training. Gabions are also useful as retaining structures when the space for bank grading is limited. Gabions can be placed at the toe of embankment slopes to support other upper bank revetments and prevent undermining.

LIMITATIONS
Wire-tied rock mattresses and gabions are ***NOT*** appropriate on unstable soils where a firm foundation can not be established.

DESIGN CONSIDERATIONS
Consider the following wire-tied rock design factors:

Bank and Foundation Preparation – Channel banks should be graded to a uniform slope.

Mattress or Gabion Block Compartmentalization – Individual mattress or gabion block units should be a size that is easy to handle and position on site. Constructing the mattress or gabion structure as interlocking units or compartments improves the structural integrity; if one section of the mattress or gabion fails, the rest of the structure can remain in place.

Mattress or Gabion Block Unit Sizes – The thickness of a wire-tied rock mattress is a function of the erodibility of the bank soil, the maximum channel velocity and the side slope. Refer to Section 11.7.2.1 of the ADOT Highway Drainage Design Manual for more details. Refer to Table 11-6 of the ADOT Highway Drainage Design Manual for common commercial sizes for stacked gabions.

Edge Treatment – The edges of wire-tied rock structures should be designed to prevent undermining at the flank or toe of the structures. Refer to Sections 11.7.2.1 and 11.7.2.2 of the ADOT Highway Drainage Design Manual for edge treatment methods of mattresses and gabions, respectively.

Geotextile fabric – A layer of geotextile fabric should be used along the bottom of the wire-tied rock structure to help avoid the washout of fines from the structure during a storm event.

Fabrication – If the materials are available on-site, wire-tied rock is best constructed at the project site to avoid damaging the basket structures during delivery.

MATERIAL SPECIFICATIONS

Refer to Section 913 of the ADOT Standard Specifications for Road and Bridge Construction and Section 11.7.2 of the ADOT Highway Drainage Design Manual for materials specifications to construct wire-tied rock.

The rock gradation used in mattresses and gabions must be such that larger stones do not protrude outside the mattress and the wire mesh retains smaller stones.

DESIGN STANDARDS

Follow the design guidelines described in Section 11.7.2 of the ADOT Highway Drainage Design Manual for wire-tied rock designs.

MAINTENANCE AND INSPECTION REQUIREMENTS

Wire-tied rock applications typically require very little maintenance. Inspect regularly for settlement, scour, wire mesh damage or corrosion. Periodically check installation for excessive growth of bushes, trees, weeds and other vegetation. Remove vegetation as needed to maintain flow capacity of channels and to prevent damage to wire-tied rock. Many applications (particularly those near flowing water) will eventually lead to wire mesh corrosion and failure.

SCHEMATICS

Refer to schematics of wire-tied rock in Section 11.7.2 of the ADOT Highway Drainage Design Manual.

REFERENCES AND RESOURCES

Arizona Department of Transportation (ADOT), *Standard Specifications for Road and Bridge Construction*, 2008.

Arizona Department of Transportation (ADOT), *Highway Drainage Design Manual (draft),* 2006.

3.3 Roadway Drainage Conveyance

Roadway Drainage Conveyance BMPs are designed to effectively and safely remove water from the roadway or other critical areas of the infrastructure (i.e. steep roadway shoulders or banks). These BMPs operate as either open (spillway, channel, etc.) or closed (culvert, conduit pipe, etc.) systems. In addition to controlling water movement, drainage conveyance BMPs also provide stormwater reuse (Rainwater Harvesting) and energy dissipation (Inlet and Outlet Protection). Some of the key selection factors of a Drainage Conveyance BMP include:

- Distance from unique waters, MS4s, or other stakeholder boundaries;
- Closed (conduit) or open (spillway) systems;
- Peak runoff volume; and
- Pervious vs. impervious conveyance systems.

Bridge Drainage Systems

DEFINITION

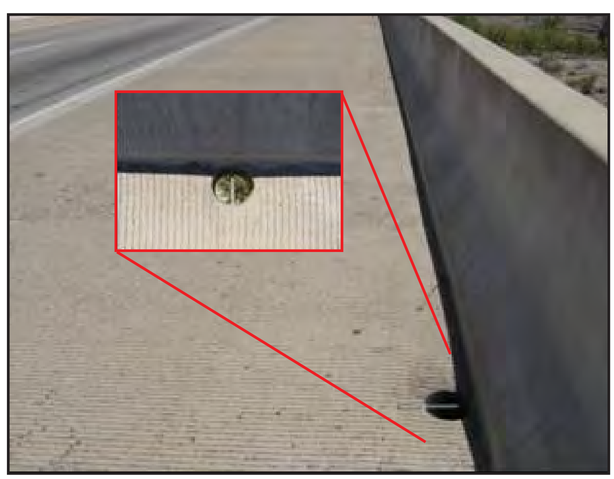
Bridge drainage systems refer to infrastructure that conveys runoff from the bridge deck. This may include channeling water through gutters to either end of the bridge for short bridge spans or immediately off of the deck through scuppers or closed conduit systems. Bridge drainage systems may need to be designed and constructed in combination with Treatment and Water Quality BMPs.

OVERVIEW

GENERAL INFORMATION
Key design factors: ▪ Design bridge girders to allow for drainage structures. ▪ Type of crossing will influence type of drainage system to be used.
Maintenance needs: ▪ Periodic inspections of the drainage system. ▪ Removal of floatable debris and trash.
Most effective when used with: ▪ Catch Basins and Downdrain Conduits ▪ Inlet Protection and Outlet Protection ▪ Water Quality and Treatment BMPs
Alternative BMPs to consider: ▪ N/A

RATINGS	H	M	L
Associated Costs			
Design		X	
Construction		X	
Maintenance			X
BMP Objective			
Erosion control			X
Drainage conveyance	X		
Water Quality/Treatment			X
DOT Target Pollutants Removal			
Dissolved or suspended sediment			N/A
Biological constituents			N/A
Nutrients and pesticides			N/A
Heavy metals			N/A
Organics			N/A

PHOTOGRAPHS



PURPOSE

A bridge drainage system is designed to effectively remove stormwater from the bridge deck in order to reduce potential ponding and hazards for drivers. Drainage systems are also designed to direct water away from critical structures beneath bridges (i.e. bridge piers, erodible embankments or cross traffic).

APPROPRIATE APPLICATIONS

Bridge deck drainage systems have various basic designs; traditional curb and gutter, corner drain inlets to downdrain conduit systems, or continuous drainage through perforated metal decks or scuppers. Drainage systems should also be included at the upstream approaches of the bridge to minimize additional stormwater runoff onto the bridge deck.

LIMITATIONS

Complex drainage systems are more susceptible to blockage by floatable debris; therefore, simplistic alternatives should be used wherever possible.

DESIGN CONSIDERATIONS

Consider the following bridge drainage system design factors:

<u>Footprint/geometry</u> – The type and size of the bridge drainage system is dependent on the span of the bridge. Downdrain systems are typically not practical for bridges more than 350 feet long if they have full width shoulders, adequate cross slopes, and catchbasins (or other drainage infrastructure) at the bridge approaches. In these cases, a curb and gutter drainage system may be sufficient.

<u>Drainage system safety and stability</u> – Drainage should not be directed to pervious embankments (bridge approach) or pier foundations where the bridge structural integrity would be compromised. Scuppers shall not discharge to traffic areas (vehicular, railroad, or pedestrian) that pass below the bridge. Because most bridge drainage systems have limited capacity, additional water from the approach roadways should not be imposed on the bridge drainage system.

<u>Downdrain conduit design</u> – All drain inlets should have properly sized and aligned grates for traffic protection and debris collection. All piping should be weather resistant (refer to Materials Specifications) and allow for cleanout/maintenance. Avoid long, horizontal runs of conduits.

<u>Local government code</u> – Refer to local municipal code for any additional bridge drainage design requirements.

<u>Construction sequencing</u> – After the drainage system is constructed, install temporary controls around the inlets until the project has been established to prevent sediment loading into the drainage system.

MATERIAL SPECIFICATIONS

Refer to the following sections of the ADOT Standard Specifications for Road and Bridge Construction:

- Section 503 – Concrete Catch Basins
- Section 506 – Underdrains
- Section 507 – Edge Drains
- Section 908 – Concrete Curbs, Gutters, Sidewalks and Driveways
- Section 913 – Bank Protection
- Section 917 – Embankment Spillways, Embankment Down-Drains, Inlets and Outlets

DESIGN STANDARDS

A. Refer to the following ADOT design guidance resources, standards, and specifications for bridge deck drainage design guidance (see References):

- Highway Drainage Design Manual, Section 10
- Standard Specifications for Road and Bridge Construction, Section 600
- Bridge Design Guidelines
- Bridge Hydraulics Guidelines

B. Catch basins should be installed at the upgrade end of the bridge approach to collect curb and gutter drainage. Inlets should be designed to intercept 100 percent of the approach flow using the return period selected for the roadway system.

MAINTENANCE AND INSPECTION REQUIREMENTS

<u>Inspections</u> – Perform inspections regularly to confirm the bridge is draining properly after a storm. Static water could be indicative of an ineffective, blocked drainage system.

<u>Trash and sediment removal</u> – Trash and other miscellaneous debris should be regularly removed from the bridge and drainage system.

SCHEMATICS

Refer to ADOT C-Standards C-5.10 and 5.12 for curb and gutter standard drawings.

REFERENCES AND RESOURCES

Arizona Department of Transportation (ADOT), *Standard Specifications for Road and Bridge Construction, 2008.*

Arizona Department of Transportation (ADOT), *Construction Standard Drawings C-5.10 and C-5.12*

Arizona Department of Transportation (ADOT), *Highway Drainage Design Manual (draft)*, *Section 10*, 2006.

Arizona Department of Transportation (ADOT), Bridge Design Guidelines
www.azdot.gov/Highways/bridge/Guidelines/DesignGuidelines/index.asp

Arizona Department of Transportation (ADOT), Bridge Hydraulics Guidelines
www.azdot.gov/Highways/bridge/Guidelines/HydraulicGuidelines/index.asp

New Jersey Department of Transportation (NJDOT), Design Manual for Bridges and Structures, Section 22; Deck Drainage, 2002.

Catch Basins and Downdrain Conduits

DEFINITION

Catch basins and downdrain conduits refer to a system of inlets and drains designed to convey surface runoff to a stabilized discharge point.

OVERVIEW

GENERAL INFORMATION
Key design factors: ▪ Downdrain conduits must be sized for the correct design storm. ▪ Inlet and outlet protection are necessary to prevent undercutting of the downdrain conduit.
Maintenance needs: ▪ Periodic inspections of catch basins and conduits. ▪ Removal of floatable debris and trash.
Most effective when used with: ▪ Inlet Protection ▪ Outlet Protection
Alternative BMPs to consider: ▪ Spillways

RATINGS	H	M	L
Associated Costs			
Design		X	
Construction		X	
Maintenance			X
BMP Objective			
Erosion control			X
Drainage conveyance	X		
Water Quality/Treatment			X
DOT Target Pollutants Removal			
Dissolved or suspended sediment			N/A
Biological constituents			N/A
Nutrients and pesticides			N/A
Heavy metals			N/A
Organics			N/A

PHOTOGRAPHS

PURPOSE

Catch Basins and Downdrain Conduits are effective in transporting stormwater runoff away from a roadway to an outfall through a piping system.

APPROPRIATE APPLICATIONS

Downdrain conduits are appropriate in areas where there is a discharge (not sheetflow) within 1/4 mile of regulated MS4s, sensitive water bodies, or other stakeholder boundaries. Bridge drainage systems can be connected to downdrain conduits.

LIMITATIONS

Downdrain conduits are ***NOT*** appropriate in locations with a short elevation differential. In these cases, consider implementing the **Spillways** BMP.

If not properly maintained, downdrain conduits will prematurely clog and will result in costly maintenance. Pretreatment (**Vegetated Filter Strips, Decomposed Granite Cover**, or other erosion control practices) can help to reduce influent sediment.

DESIGN CONSIDERATIONS

Consider the following downdrain conduit design factors:

Footprint/geometry – The total downdrain conduit conveyance volume must include the runoff from the design storm.

Local government code – Refer to local municipal code for any requirements.

Excavation practices – During construction, the excavated material may be used elsewhere on the project. During excavation properly bench or support the sides of the trench in order to prevent slope failure.

Inlet and outlet protection – Downdrain conduits must have proper inlet and outlet erosion protection in order to prevent water from undercutting the supporting structure (roadway bed, bridge supports, or overpass). Refer to **Inlet Protection** and **Outlet Protection** BMPs.

Construction sequencing – After the downdrain conduit is constructed, install temporary erosion controls around the inlet until the project has been established to prevent sediment loading into the downdrain conduit.

MATERIAL SPECIFICATIONS

Refer to Division V and Section 917 of the ADOT Standard Specifications for Road and Bridge Construction for downdrain conduit construction material specifications.

DESIGN STANDARDS

Refer to Chapter 13 of the ADOT Highway Drainage Design Manual for downdrain conduit design guidance.

MAINTENANCE AND INSPECTION REQUIREMENTS

Inspections – Perform inspections regularly to confirm the downdrain conduit is draining properly after a storm. Static water along the roadway is indicative of an ineffective or clogged downdrain.

Trash and sediment removal - Trash and other miscellaneous debris should be regularly removed from in and around the downdrain conduit.

SCHEMATICS

Refer to ADOT C-Standards C-15.10 to 92 for catch basin standard drawings and details and C-04.20, 04.40 and 04.50 for downdrain standard drawings and details.

REFERENCES AND RESOURCES

Arizona Department of Transportation (ADOT), *Standard Specifications for Road and Bridge Construction*, 2008.

Arizona Department of Transportation (ADOT), *Construction Standard Drawings C-15.10 to 92, C-04.20, 04.40 and 04.50*

Arizona Department of Transportation (ADOT), *Highway Drainage Design Manual (draft),* 2006.

Culverts

DEFINITION

A closed conduit or underpass, other than a bridge, that allows water to drain from and pass under a roadway. Culverts must be designed with proper inlet/outlet protection and headwalls.

OVERVIEW

GENERAL INFORMATION
Key design factors: ▪ Shape of culvert will depend of the vertical clearance available and the flow conveyance required. ▪ Material of culvert will depend on the roadway designation.
Maintenance needs: ▪ Periodic inspections of the culvert. ▪ Removal of floatable debris and trash.
Most effective when used with: ▪ Pretreatment (i.e. Vegetated Filter Strips or Decomposed Granite Cover). ▪ Inlet Protection ▪ Outlet Protection
Alternative BMPs to consider: ▪ Bridge Drainage Systems.

RATINGS	H	M	L
Associated Costs			
Design		X	
Construction		X	
Maintenance			X
BMP Objective			
Erosion control			X
Drainage conveyance	X		
Water Quality/Treatment			X
DOT Target Pollutants Removal			
Dissolved or suspended sediment			N/A
Biological constituents			N/A
Nutrients and pesticides			N/A
Heavy metals			N/A
Organics			N/A

PHOTOGRAPHS

PURPOSE

The primary function of a culvert is to convey stormwater and/or flow in natural streams and washes across a roadway and prevent ponding and overtopping of drainage across the roadway.

APPROPRIATE APPLICATIONS

Culverts are appropriate in areas where a significant amount of water must be conveyed from one side of a roadway to another. Culverts are usually placed in natural depressions, along a channel centerline, or beneath driveway connectors.

LIMITATIONS

Culverts are ***NOT*** appropriate in areas where they will limit the flow cross section and potentially cause flood waters to back up behind the culvert. If full flow within a stream cannot be properly conveyed below the roadway, a small bridge should be substituted for the culvert.

DESIGN CONSIDERATIONS

Consider the following culvert design factors:

Soil characteristics – The soil must have proper strength to support the culvert and have a low permeability in order to minimize seepage and prevent undercutting and possible failure. Do not locate the culvert above collapsible soils.

Footprint/geometry – The total conveyance volume must include the runoff from the design storm without overtopping or causing significant backwater flooding.

Local government code – Refer to local municipal code for any local requirements, such as sizing or material specifications.

Excavation practices – Prior to excavation and installation of a culvert in a stream, the flow must be diverted around the excavated area at a sufficient distance to allow for proper construction but limited so as not to needlessly disturb additional soils and vegetation. During construction, the excavated material may be used elsewhere on the project.

Culvert safety and stability – Culverts must be properly bedded on a graded slope and backfilled with compacted soils to ensure stability.

Construction sequencing – After the culvert is constructed, install temporary controls around the culvert entrance (but not within the active channel) until the project has been established to prevent premature sediment loading into the culvert.

Pretreatment - In areas where dense vegetation can be maintained, vegetated filter strips should be installed upstream of the culvert entrance as a pretreatment measure. Otherwise, decomposed granite or rock mulch should be used between the contributing roadway drainage area and the culvert.

MATERIAL SPECIFICATIONS

Refer to Section 501 of the ADOT Standard Specifications for Road and Bridge Construction for culvert construction material specifications.

DESIGN STANDARDS

Design the culvert and inlet/outlet protection per the design criteria in Chapter 8 of the ADOT Hydraulics Manual. Construction standards for culverts are included in Section 501 of the ADOT Standard Specifications for Road and Bridge Construction.

MAINTENANCE AND INSPECTION REQUIREMENTS

Inspections – Perform inspections regularly to confirm the culvert is draining properly after a significant storm event. Static water after a storm could be indicative of an ineffective, clogged culvert.

Trash and sediment removal - Trash and other miscellaneous debris should be regularly removed from the culvert.

Nuisance Control – Inspect for standing water at the end of each storm event. No additional nuisance control is necessary if the culvert is functioning properly.

SCHEMATICS

Refer to ADOT Bridge Standard Drawings (B-Standards) and Construction Standard Drawings C-13.10 to 13.59.

REFERENCES AND RESOURCES

Arizona Department of Transportation (ADOT), *Standard Specifications for Road and Bridge Construction*, 2008.

Arizona Department of Transportation (ADOT), *Highway Drainage Design Manual (draft)*, 2006.

Arizona Department of Transportation (ADOT) *Bridge Standard Drawings (B-Standards)*

Arizona Department of Transportation (ADOT) *Construction Standard Drawings C-13.10 to 13.59*

Impervious Channel Lining

DEFINITION

An impervious channel lining is a rigid facing for a drainage swale, ditch, or channel that is typically constructed out of concrete or grouted riprap for minimal infiltration and erosion.

OVERVIEW

GENERAL INFORMATION
Key design factors: ▪ Design impervious channel to prevent erosion in critical areas. ▪ Underlying soil conditions.
Maintenance needs: ▪ Periodic inspections of the channel. ▪ Removal of debris and trash.
Most effective when used with: ▪ Pretreatment (i.e. Vegetated Filter Strips or Decomposed Granite Cover). ▪ Inlet Protection ▪ Outlet Protection
Alternative BMPs to consider: ▪ Catch Basins and Downdrain Conduits ▪ Pervious Channel Lining.

RATINGS	H	M	L
Associated Costs			
Design		X	
Construction	X		
Maintenance			X
BMP Objective			
Erosion control		X	
Drainage conveyance	X		
Water Quality/Treatment			X
DOT Target Pollutants Removal			
Dissolved or suspended sediment			N/A
Biological constituents			N/A
Nutrients and pesticides			N/A
Heavy metals			N/A
Organics			N/A

PHOTOGRAPHS

PURPOSE

Impervious channel lining is utilized where infiltration of stormwater runoff must be minimized or to reduce the impacts of concentrated flows with erosive velocities.

APPROPRIATE APPLICATIONS

Impervious channel linings can also be applied where a consistent flow path is required, such as cut/fill slope transitions. Other applications include BMP outlet structures, low flow channel lining, and steep slope protection.

LIMITATIONS

Impervious channel lining is ***NOT*** appropriate in the following conditions:

- In perennial streams where interaction of channel base flow with groundwater is required to maintain the aquatic integrity of the stream.
- If not properly designed, constructed, and maintained, an impervious channel lining is susceptible to structural failure and aesthetic deterioration due to flow undercutting and differential settling.

In cases where impervious channel linings are not appropriate, consider the **Catch Basins and Downdrain Conduits** or **Pervious Channel Lining** BMPs.

DESIGN CONSIDERATIONS

Consider the following impervious channel lining design factors:

Soil characteristics – Ensure proper compaction is obtainable to support the channel lining. Do not locate the channel above collapsible soils.

Footprint/geometry – The channel must be designed per Section 7.6.3 of the ADOT Highway Drainage Design Manual.

Local government code – Refer to local municipal code for any local requirements, such as the accepted riprap gradation and riprap layer thickness if using a grouted riprap lining.

Excavation practices – During construction, the excavated material may be used elsewhere on the project.

Channel safety and stability – Channel lining should be located at or below the level of the adjacent grassed areas to ensure thorough drainage of these areas in order to prevent undermining by runoff flow and differential settling.

Construction sequencing – After the lining is constructed, install temporary erosion controls upstream of the channel until the project has been established to prevent sediment loading into the channel.

Pretreatment - In areas where dense vegetation can be maintained, **Vegetated Filter Strips** should be installed along the sides of the channel lining for pretreatment. Otherwise, **Decomposed Granite Cover** should be used between the contributing roadway drainage area and the basin.

MATERIAL SPECIFICATIONS

Soils – Meet the project specific soil compaction requirements for soils underlying the channel.

Riprap – Gradation and sizing must be appropriate for the intended application.

Grout – Composition must be satisfactory for permanently stabilizing the channel.

DESIGN STANDARDS

A. Design the channel geometry per the design criteria in Section 7.6.3 of the ADOT Highway Drainage Design Manual.

B. The design should include calculation of peak flows and velocities for the channel and erosion control measures where erodible velocities occur.

C. If feasible, include vehicle access to the channel for maintenance.

D. Vegetate along the sides of the channel in accordance with Section 805 of the ADOT Standard Specifications for Road and Bridge Construction.

MAINTENANCE AND INSPECTION REQUIREMENTS

Inspections – Perform inspections regularly to confirm the channel is draining properly after a storm. Static water could be indicative of channel settling or sediment accumulation.

Trash and sediment removal – Trash, sediment, and other miscellaneous debris should be regularly removed from the channel.

Nuisance Control – Inspect the channel for standing water following each storm event. No additional nuisance control is necessary if the channel drains properly.

SCHEMATICS

Refer to ADOT Construction Standard Drawing C-03.10.

REFERENCES AND RESOURCES

Arizona Department of Transportation (ADOT), *Standard Specifications for Road and Bridge Construction, 2008.*

Arizona Department of Transportation (ADOT), *Highway Drainage Design Manual (draft)*, 2006.

Arizona Department of Transportation (ADOT), *Erosion and Pollution Control Manual for Highway Design and Construction,* 2005.

Arizona Department of Transportation (ADOT), *Construction Standard Drawing C-03.10,* 2004.

California Department of Transportation (Caltrans), *Storm Water Quality Handbooks: Project Planning and Design Guide,* April 2003.

Massachusetts Department of Environmental Protection, *Stormwater Management Volume 2: Stormwater Technical Handbook, Chapter 3: Structural Best Management Practices*, March 1997.

Minnesota Pollution Control Agency (MPCA), *Protecting Water Quality in Urban Areas, Chapter 4: BMPs for Stormwater Systems*, 2000.

Inlet Protection

DEFINITION

Inlet protection consists of a rock mulch or riprap surface surrounding a storm drain inlet, culvert, spillway, channel, or other BMP structure. It can also refer to slots or screens to prevent floatable debris from entering a culvert or a storm drain system.

OVERVIEW

GENERAL INFORMATION
Key design factors: ▪ Type and geometry of inlet structure. ▪ Velocity and volume of flow at the structure inlet.
Maintenance needs: ▪ Periodic inspections of the inlet. ▪ Removal of floatable debris and trash.
Most effective when used with: ▪ Pretreatment (i.e. Vegetated Filter Strips or Decomposed Granite Cover).
Alternative BMPs to consider: ▪ Wire-tied Rock

RATINGS	H	M	L
Associated Costs			
Design			X
Construction			X
Maintenance			X
BMP Objective			
Erosion control			X
Drainage conveyance			X
Water Quality/Treatment			X
DOT Target Pollutants Removal			
Dissolved or suspended sediment		X	
Biological constituents			X
Nutrients and pesticides			X
Heavy metals			X
Organics			X

PHOTOGRAPHS

PURPOSE

Inlet protection serves as a final protection measure to filter sediment from entering the storm drain. Inlet protection reduces erosion along the soil interface at the entrance to the drainage structure and reduces entrance velocities (energy dissipation) before entering the storm drain system.

APPROPRIATE APPLICATIONS

Inlet protection is appropriate in the following conditions:

- Around any storm drain or structure inlet
- Where stormwater velocities and energies at the inlet to a concentrated flow conveyance has the potential to erode the soil around the inlet structure.

LIMITATIONS

Inlet protection should be installed in a manner that will prevent soil, rock, debris or other material from washing into the drainage structure to prevent clogging or causing a reduction in flow area.

In areas susceptible to high flows, frequent maintenance may be required if there is settling of the material and ponding or undercutting occurs.

DESIGN CONSIDERATIONS

The most commonly used device for inlet protection is a riprap apron, which can be grouted or loose. Grouted **Riprap** or **Wire-tied Rock** can withstand higher flow velocities than loose riprap. However, grouting or using wire-ties is more labor intensive and induces higher construction costs. Also, freeze/thaw cycles may break up the grout over time. Loose riprap is substantially less expensive in materials and labor than grouted or wire-tied riprap. However, loose riprap can be dislodged during high flow events and, subsequently, may require more maintenance than grouted or wire-tied riprap. Regardless of whether the rock is loose or grouted, the rock must be sized properly to be effective.

MATERIAL SPECIFICATIONS

Refer to Section 810 of the ADOT Standard Specifications for Road and Bridge Construction for material specifications of inlet protection.

DESIGN STANDARDS

A. Determine the anticipated flow volumes and velocities at the inlet of the conduit or channel to determine the size of rock to utilize.

B. The use of a geotextile is recommended as a separator between the graded rock and the soil base.

C. Where dense vegetation can be maintained, vegetate around the inlet protection.

MAINTENANCE AND INSPECTION REQUIREMENTS

Refer to the ADOT Erosion and Pollution Control Manual (Sections 5.2.3) for inspection and maintenance requirements of erosion protection at structures.

SCHEMATICS

Refer to ADOT Construction Standard Drawings C-13.60 and 13.65 for slotted drain details.

REFERENCES AND RESOURCES

Arizona Department of Transportation (ADOT), *Standard Specifications for Road and Bridge Construction*, 2008.

Arizona Department of Transportation (ADOT), *Construction Standard Drawings C-13.60 and 13.65.*

Arizona Department of Transportation (ADOT), *Highway Drainage Design Manual (draft),* 2006.

Outlet Protection

DEFINITION

Outlet protection consists of loose or grouted riprap placed at the outlet of culverts, conduits, spillways, or channels to reduce erosion along the soil interface and at the toe of concrete or metal structures.

OVERVIEW

GENERAL INFORMATION
Key design factors: ▪ Type and geometry of outlet structure. ▪ Velocity of discharge flow.
Maintenance needs: ▪ Periodic inspections of the outlet. ▪ Removal of floatable debris and accumulated sediment.
Most effective when used with: ▪ Inlet Protection
Alternative BMPs to consider: ▪ Wire-tied Rock

RATINGS	H	M	L
Associated Costs			
Design			X
Construction		X	
Maintenance			X
BMP Objective			
Erosion control		X	
Drainage conveyance			X
Water Quality/Treatment			X
DOT Target Pollutants Removal			
Dissolved or suspended sediment			N/A
Biological constituents			N/A
Nutrients and pesticides			N/A
Heavy metals			N/A
Organics			N/A

PHOTOGRAPHS

PURPOSE

The outlets of conduits and lined channels are susceptible to erosion. Outlet protection prevents scour and erosion at the outlet of concentrated flow conveyance structures by dissipating the energy and velocity of the discharge.

APPROPRIATE APPLICATIONS

Outlet protection is appropriate in the following conditions:

- Where discharge velocities and energies at the outlets of the concentrated flow conveyance have the potential to erode the downstream channel.
- At points where **Impervious Channels** or closed conduits discharge to pervious surfaces (other channels, streambeds, or other BMPs).

LIMITATIONS

Outlet protection should only be extended far enough downstream to prevent scour and erosion to ensure that impacts to vegetation and aquatic life are minimized.

DESIGN CONSIDERATIONS

The most commonly used device for outlet protection is a **Riprap** apron which can be grouted or loose. Grouted riprap (see also **Wire-Tied Rock**) can withstand higher flow velocities than loose riprap. However, grouting or using wire-ties is more labor intensive and induces higher construction costs. Also, freeze/thaw cycles may break up the grout over time. Loose riprap is substantially less expensive in materials and labor than grouted or wire-tied riprap. However, loose riprap can be dislodged during high flow events and, subsequently, may require more maintenance than grouted or wire-tied riprap. Regardless of whether the rock is loose or grouted, the rock must be sized properly to be effective.

MATERIAL SPECIFICATIONS

Refer to Section 810 of the ADOT Standard Specifications for Road and Bridge Construction for material specifications of outlet protection. Durable, angular rock is most effective to dissipate energy.

DESIGN STANDARDS

A. Determine the anticipated flow volumes and velocities at the outlet of the conduit or channel to determine the size of rock to utilize.

B. For low velocities (generally less than 10 ft/sec), the most commonly used outlet protection is a riprap apron. Regardless of whether the rock is loose or grouted, the rock must be sized properly to be effective. The area, depth, and size of riprap are based on the culvert or channel dimensions and hydraulic flow calculations. Refer to the Chapter 9 of the ADOT Highway Drainage Design Manual for design specifications.

C. For higher velocities, consider one of the following types of energy dissipaters (the corresponding sections of the ADOT Highway Drainage Design Manual are included for more detailed design guidance):

- Weir block basin – Section 9.6
- Impact basin – Section 9.7
- St. Anthony Falls (SAF) stilling basin – Section 9.8
- Straight drop stilling basin – Section 9.9

MAINTENANCE AND INSPECTION REQUIREMENTS

Refer to the ADOT Erosion and Pollution Control Manual (Sections 5.2.3 and 5.2.4) for inspection and maintenance requirements of outlet protection.

SCHEMATICS

Refer to schematics of velocity dissipation in Chapter 9 of the ADOT Highway Drainage Design Manual and ADOT Construction Standards Drawings C-13.75, 13.76 and 13.80 of storm drain outlets.

REFERENCES AND RESOURCES

Arizona Department of Transportation (ADOT), *Standard Specifications for Road and Bridge Construction*, 2008.

Arizona Department of Transportation (ADOT), *Construction Standard Drawings C-13.75, 13.76 and 13.80*

Arizona Department of Transportation (ADOT), *Highway Drainage Design Manual (draft),* 2006.

Pervious Channel Lining

DEFINITION

A pervious channel lining is typically a vegetated or rock-lined (non-grouted) swale, ditch, or channel that allows some infiltration in addition to providing a means for conveyance.

OVERVIEW

GENERAL INFORMATION
Key design factors: ▪ Minimal slope to allow for increased infiltration. ▪ If vegetated, the vegetation must remain viable during dry periods of the year.
Maintenance needs: ▪ Repair areas of erosion and revegetate as needed. ▪ Remove sediment buildup.
Most effective when used with: ▪ Pretreatment such as Vegetated Filter Strips. ▪ Outlet Protection
Alternative BMPs to consider: ▪ Infiltration Trench

RATINGS	H	M	L
Associated Costs			
Design			X
Construction			X
Maintenance			X
BMP Objective			
Erosion control		X	
Drainage conveyance		X	
Water Quality/Treatment			X
DOT Target Pollutants Removal			
Dissolved or suspended sediment			N/A
Biological constituents			N/A
Nutrients and pesticides			N/A
Heavy metals			N/A
Organics			N/A

PHOTOGRAPHS

PURPOSE

The primary function of a pervious channel lining is to provide stability and protection to the channel so that accumulated surface runoff can be conveyed safely to an acceptable outlet point. A secondary function is to provide pollutant/sediment removal and limited infiltration.

APPROPRIATE APPLICATIONS

Pervious channel linings are appropriate in areas where there is a discharge (not sheetflow) within 1/4 mile of regulated MS4s, sensitive water bodies, or other stakeholder boundaries ***and*** the existing soils have an infiltration rate greater than 0.5 inches per hour. Refer below for additional design considerations.

LIMITATIONS

Pervious channel linings are ***NOT*** appropriate in the following conditions:

- Along slopes greater than 4%;
- For drainage areas (contributing or effective) that are larger than 5 acres;
- In areas of shallow groundwater (less than 4 feet below the bottom of the channel) to allow proper draining; and
- If not properly maintained, channels will prematurely clog and will result in costly maintenance. Pretreatment (**Vegetated Filter Strips, Decomposed Granite Cover**, or other erosion control practices) can help to reduce influent sediment.

In the cases where pervious channel lining is not appropriate, consider implementing the **Impervious Channel Lining** BMP.

DESIGN CONSIDERATIONS

Consider the following pervious channel lining design factors:

<u>Soil characteristics</u> – Do not locate the channel above collapsible soils. All other soil types are suitable. The designer should verify that the soil can sustain permanent vegetation if a vegetative lining is desired.

<u>Footprint/geometry</u> – The channel must be designed per Section 7.6.3 of the ADOT Highway Drainage Design Manual.

<u>Local government code</u> – Refer to local municipal code for any local holding and infiltration requirements.

<u>Excavation practices</u> – During construction, the excavated material may be used elsewhere on

the project. When possible, scarify the sides and bottom of the trench to correct for any smearing of the interface. Avoid compaction of the soils below the channel whenever possible.

Channel safety and stability – Channel lining should be located at or below the level of the adjacent areas to ensure thorough drainage of these areas in order to prevent undermining by runoff flow.

Construction sequencing – After the channel is constructed, install temporary controls around the channel perimeter until the project has been established to prevent sediment loading into the channel.

Pretreatment – In areas where dense vegetation can be maintained, vegetated filter strips can be installed along the length of the channel for pretreatment measure. Otherwise, decomposed granite should be used between the contributing roadway drainage area and the channel.

MATERIAL SPECIFICATIONS

Soils – If infiltration is desired, the soils should have a minimum infiltration rate of 0.5 inches per hour.

Grasses – The vegetation in the channel shall be composed entirely of grasses that can withstand relatively high velocity and periods of drought.

DESIGN STANDARDS

A. Design the channel geometry per the design criteria in Section 7.6.3 of the ADOT Highway Drainage Design Manual.

B. The design should include calculation of peak flows and velocities for the channel and erosion control measures where erodible velocities occur.

C. If feasible, include vehicle access to the channel for maintenance.

D. Vegetate along the sides of the channel, if necessary, per Section 7.6.3 of the ADOT Highway Drainage Design Manual.

MAINTENANCE AND INSPECTION REQUIREMENTS

Inspections – Perform inspections regularly to confirm the channel is draining properly after a storm. Static water could indicate that a portion of the channel has settled and needs to be returned to the original engineered grade.

Trash and sediment removal – Trash and other miscellaneous debris should be regularly removed from the channel.

Nuisance Control – Inspect the channel for standing water following each storm event. No additional nuisance control is necessary if the channel drains properly.

SCHEMATICS

Refer to ADOT Construction Standard Drawing C-03.10.

REFERENCES AND RESOURCES

Arizona Department of Transportation (ADOT), *Standard Specifications for Road and Bridge Construction*, 2008.

Arizona Department of Transportation (ADOT), *Construction Standard Drawing C-03.10,* 2004.

Arizona Department of Transportation (ADOT), *Highway Drainage Design Manual (draft),* 2006.

California Department of Transportation (Caltrans), *Storm Water Quality Handbooks: Project Planning and Design Guide*, April 2003.

Minnesota Pollution Control Agency (MPCA), *Protecting Water Quality in Urban Areas, Chapter 4: BMPs for Stormwater Systems*, 2008.

Rainwater Harvesting

DEFINITION

Rainwater harvesting is the practice of collecting and storing rainwater for use in irrigation or any approved application where surface or groundwater resources would traditionally be consumed. Rainwater harvesting also acts as a retention/detention practice from a stormwater management perspective.

OVERVIEW

GENERAL INFORMATION
Key design factors: ▪ Collection infrastructure (tanks, conduits, basins, etc.). ▪ Pumping and irrigation mechanisms.
Maintenance needs: ▪ Ensure the storage system is free from debris and the irrigation system is operating.
Most effective when used with: ▪ Any other post construction BMPs that require vegetation or could sustain vegetation/landscaping
Alternative BMPs to consider: ▪ Infiltration practices

RATINGS	H	M	L
Associated Costs			
Design		X	
Construction		X	
Maintenance		X	
BMP Objective			
Erosion control			X
Drainage conveyance		X	
Water Quality/Treatment			X
DOT Target Pollutants Removal			
Dissolved or suspended sediment			N/A
Biological constituents			N/A
Nutrients and pesticides			N/A
Heavy metals			N/A
Organics			N/A

PHOTOGRAPHS

PURPOSE

Rainwater harvesting provides an alternate source of water to irrigate roadside landscaping and reduces the runoff volume by diverting it to a storage system.

APPROPRIATE APPLICATIONS

Rainwater harvesting is appropriate in areas with well-graded, impermeable surfaces. It is used in conjunction with other BMPs to reduce erosion and the overall pollutant load in the runoff, and independently to irrigate the landscape without relying on the municipal water supply.

LIMITATIONS

Rainwater harvesting systems are subject to the following limiting conditions:

- Storage tanks may need to be periodically pumped to remove sediment and other pollutants that have settled and accumulated at the bottom of the tank.
- Supplemental irrigation may be necessary if rainfall is exceptionally sparse or the landscaped vegetation requires more water than can be supplied by rainwater harvesting alone.

DESIGN CONSIDERATIONS

Although rainwater harvesting systems come in a variety of designs, they all must contain three main components: (1) a collection of the water supply (rainfall) to a storage system, (2) a demand for the collected water (vegetated landscaping), and (3) a delivery system to convey water from storage to the demand (irrigation). Storage tanks are optional and recommended if a dependable source of water is desired.

Delivery system – The stormwater can be diverted to the storage basin via canopy, subsurface, or rock channel delivery systems. For the purposes of highway BMPs subsurface systems are likely to be the most practical and common.

Footprint/geometry – Rainwater harvesting infrastructure (storage tanks and conduits) can often be installed in the sub-surface, below roadside landscaping.

Construction sequencing – Rainwater harvesting systems are most cost-effective when included in the initial design and grading of the undeveloped site; however they can be installed at any point during or after the construction period.

Drainage area – The size of the drainage area dictates the maximum volume of water that will be collected and the required size of the storage tank.

Appropriate vegetation – Equally important to designing a system that collects and provides rainwater for irrigation is selecting the appropriate vegetation. High water use plants will require supplemental irrigation beyond what a well-designed rainwater harvesting system is capable of providing. Refer to the Arizona Department of Water Resources (ADWR) list of drought tolerant/low water use plants (website included in the References section).

MATERIAL SPECIFICATIONS

Storage tanks, if below ground, can be constructed of concrete, polyethylene, or fiberglass. Concrete tanks are suitable for supporting loads, such as driveways or structures. Polyethylene and fiberglass are lighter-weight and the manufacturer should be contacted before in-ground placement is attempted.

All components of manufactured rainwater harvesting systems must conform to ADOT standards and specifications. All manufactured designs should be reviewed internally.

DESIGN STANDARDS

A. Review the drainage area and landscaping.

B. If using, size the storage tank based on the drainage area and the estimated rainfall.

C. Determine the natural slope of the site. Design the catchment system to follow the existing contours of the land, and place the storage area in the lowest part of the site.

D. Drainage areas with slopes of approximately 2% are recommended for paved surfaces. If compacted soil is used as the drainage area, the potential for erosion should be identified and appropriate site controls should be implemented.

E. When siting the storage tank, the weight of the water to be stored must be considered; underground tanks should not be sited in unstable soils where significant settling can occur.

MAINTENANCE AND INSPECTION REQUIREMENTS

Inspections - The system should be inspected after each rain event to ensure it is operating correctly. Inspect the system for signs of erosion and/or sediment accumulation.

Maintenance - Keep debris and sediment out of the drainage area and channels.

Nuisance Control – Stagnant water has the potential to attract mosquitoes. Ensure that mesh pipe covers are installed and in place to prevent adult mosquitoes from entering and breeding in the storage tank.

SCHEMATICS

Rainwater harvesting infrastructure can be integrated into the following Post-Construction BMP designs:

- Infiltration Trench
- Infiltration Basin

- Retention and Detention Basin
- Bioretention
- Filtration Structures
- Vegetated Filter Strips

Refer to the notes included in the schematics for each of the above BMPs for details on how rainwater harvesting can be incorporated into the designs.

REFERENCES AND RESOURCES

Arizona Department of Water Resources (ADWR) drought tolerant/low water use plant list: http://www.azwater.gov/dwr/Conservation/landscapePros/default.html#Plants

Gould, John and Erik Nissen-Petersen. *Rainwater Catchment Systems for Domestic Supply.* Intermediate Technology Publications, London: 1999.

Mittal, P.K.; Pathak, Namrata; Vasudevan, Padma. *Health Implications of Widespread Use of Domestic Rainwater Harvesting: Mosquito Control.* Indian Institute of Technology, New Dehli: 2001.

Rainwater Harvesting: Complete Rainwater Solutions. "Types of water storage vessels." Accessed April 6, 2007. http://www.rainharvesting.com.au

Rainwater Recovery Inc. "Smart Solutions for Water Management." Accessed April 6, 2007. http://www.rainwaterrecovery.com

Waterfall, Patricia H. *Harvesting Rainwater for Landscape Use*. Second Edition. University of Arizona, Tucson: 2004.

Spillways

DEFINITION

Spillways drain roadway surface runoff through an open channel down an embankment or side slope. Spillways must be designed with proper riprap inlet/outlet protection and headwalls.

OVERVIEW

GENERAL INFORMATION
Key design factors: ▪ The spillway must provide positive roadway drainage. ▪ Inlet and outlet protection is necessary to prevent undercutting of the spillway.
Maintenance needs: ▪ Periodic inspections of the spillway. ▪ Removal of floatable debris and trash.
Most effective when used with: ▪ Outlet Protection
Alternative BMPs to consider: ▪ Catch Basin and Downdrain Conduits

RATINGS	H	M	L
Associated Costs			
Design		X	
Construction		X	
Maintenance			X
BMP Objective			
Erosion control			X
Drainage conveyance	X		
Water Quality/Treatment			X
DOT Target Pollutants Removal			
Dissolved or suspended sediment			N/A
Biological constituents			N/A
Nutrients and pesticides			N/A
Heavy metals			N/A
Organics			N/A

PHOTOGRAPHS

PURPOSE

The purpose of a spillway is to provide a well defined, erosion resistant drainage way for stormwater to drain off the roadway and into a downstream conveyance, receiving waterbody, storm drain system, or other BMP.

APPROPRIATE APPLICATIONS

Spillways are typically appropriate in the following conditions:

- Short elevation differentials;
- Non-urban areas.

LIMITATIONS

Spillways are ***NOT*** appropriate in the following conditions:

- Locations where there is a large elevation differential, or
- Nearly vertical slopes.

In the cases where spillways are not appropriate, consider the **Catch Basins and Downdrain Conduits** BMP in order to remove water from the roadway.

DESIGN CONSIDERATIONS

Consider the following spillway design factors:

<u>Soil characteristics</u> – Refer to geotechnical data to ensure that the soil strength is sufficient to support the spillway. Do not locate the spillway above collapsible soils.

<u>Footprint/geometry</u> – The spillway conveyance volume must accommodate the design storm.

<u>Local government code</u> – Refer to local municipal code for any requirements.

<u>Excavation practices</u> – During construction, the excavated material may be used elsewhere on the project. During excavation, properly bench or support the sides of the spillway in order to prevent slope failure.

<u>Spillway safety and stability</u> – Spillways must have proper inlet and outlet erosion protection in order to prevent water from undercutting the structure and causing possible differential settlement and structural failure of the spillway.

<u>Construction sequencing</u> – After the spillway is constructed, install temporary erosion controls around the inlet until the project has been established to prevent sediment loading into the receiving waterbody.

<u>Pretreatment</u> - In areas where dense vegetation can be maintained, **Vegetated Filter Strips** should be installed above the inlet of the spillway for pretreatment. Otherwise, **Decomposed Granite Cover** should be used between the contributing roadway drainage area and the spillway.

MATERIAL SPECIFICATIONS

Refer to Section 917 of the ADOT Standard Specifications for Road and Bridge Construction for spillway construction material specifications.

DESIGN STANDARDS

Refer to Section 917 of the ADOT Standard Specifications for Road and Bridge Construction for spillway design standards.

MAINTENANCE AND INSPECTION REQUIREMENTS

Inspections – Perform inspections regularly to confirm the spillway is draining after each storm.

Trash and sediment removal – Trash, accumulated sediment, and other miscellaneous debris should be removed from the spillway immediately following a significant storm event.

Nuisance Control – Inspect for standing water at the toe of the spillway following each storm event. No additional nuisance control is necessary if the spillway drains properly.

SCHEMATICS

Refer to ADOT Construction Standard Drawing C-04.10 and 04.30 and the schematic in Section 5.2.3 of the ADOT Erosion and Pollution Control Manual for Highway Design and Construction.

REFERENCES AND RESOURCES

Arizona Department of Transportation (ADOT), *Standard Specifications for Road and Bridge Construction*, 2008.

Arizona Department of Transportation (ADOT), *Highway Drainage Design Manual (draft)*, 2006.

Arizona Department of Transportation (ADOT), *Erosion and Pollution Control Manual for Highway Design and Construction,* 2005.

Arizona Department of Transportation (ADOT), *Construction Standard Drawing C-04.10 and 04.30.*

3.4 Water Quality and Treatment

ADOT roadways can be the source of pollutants that accumulate during dry periods and are carried by stormwater from rainfall. Pollutants may originate from vehicular use including: tires, brake wear, engine fluids, as well as from non-vehicular sources such as litter and discarded trash. Those sources may also combine with dust and other accumulated materials from on site and remote sources, all becoming potential contributors. The first flush, defined as the runoff from the initial half inch of rain, typically results in the most polluted stormwater discharge from a rainfall event. Appropriate first flush containment should take into consideration the nature and sources of pollution in relation to the drainage facilities, pollutant mobility, and pollutant supply. Generally ADOT roadways and right-of-way corridors already contain and manage first flush volumes. The Water Quality/Treatment BMPs that are presented and described in this section are common stormwater drainage management systems addressing first flush requirements on ADOT roadway systems. These BMPs focus on the displacement or removal of pollutants from stormwater before discharging to and/or beyond the storm drain. They operate by means of sedimentation, infiltration, filtration, and biological degradation. The selection of the proper Water Quality/Treatment BMP depends on a number of factors including, but not limited to:

- Soil permeability;
- Proximity to unique waterbodies, MS4s, or other stakeholder boundaries;
- Sheetflow vs. Concentrated flow; and
- Maintenance requirements.

Water Quality/Treatment BMPs are most effectively used in conjunction with Erosion Control and Drainage Conveyance BMPs.

Manufactured Treatment Devices

DEFINITION

Manufactured water quality treatment devices include hydrodynamic (flow through) and filtration structures. Hydrodynamic structures rely on settling or separation of pollutants from stormwater runoff. These structures encourage sedimentation of particulate materials with sorbed oil and the separation of free oil, grease, and debris. Manufactured treatment devices commonly contain screens to retain larger or floating debris. Filtration devices such as catch basin inserts are also considered.

OVERVIEW

GENERAL INFORMATION
Key design factors: ▪ Contributing drainage area. ▪ Identify target pollutants to remove. ▪ Footprint required for treatment device.
Maintenance needs: ▪ Periodic inspections per the manufacturer's recommendation. ▪ Removal of floatable debris and trash.
Most effective when used with: ▪ Pretreatment (i.e. Vegetated Filter Strips or Decomposed Granite Cover).
Alternative BMPs to consider: ▪ Retention/detention basins (pond-in-place). ▪ Infiltration Basin or Infiltration Trench.

RATINGS*	H	M	L
Associated Costs			
Design	X		
Construction	X		
Maintenance	X		
BMP Objective			
Erosion control			X
Drainage conveyance			X
Water Quality/Treatment	X		
DOT Target Pollutants Removal			
Dissolved or suspended sediment	X		
Biological constituents	X		
Nutrients and pesticides	X		
Heavy metals	X		
Organics	X		

*Note: Ratings are general and highly dependent on the type of device and individual manufacturer specifications.

PHOTOGRAPHS

Photographs of manufactured treatment devices have not been included to avoid promotion of certain vendors and exclusion of others.

PURPOSE

Manufactured treatment devices are specifically designed and sized by various industry manufacturers to intercept stormwater runoff and prevent downstream pollutant loading.

APPROPRIATE APPLICATIONS

Manufactured systems are typically appropriate where space is limited or additional treatment is necessary. They can be also be retrofitted within existing development or redevelopment. Applications can range from catch basin inserts to oil/grit separators. Additional design considerations are described below. Manufactured treatment devices can be used online or offline to achieve storage volumes capable of containing the runoff from the design storm corresponding to ADOT's local drainage design requirements.

LIMITATIONS

Manufactured treatment devices are limited to the manufacturer's recommendation for appropriate applications. These devices are ***NOT*** appropriate in the following conditions:

- Rural locations where routine maintenance will be inconvenient or difficult;
- Locations where maintenance access will be limited or restricted.

DESIGN CONSIDERATIONS

Consider the following design factors:

Manufactured treatment devices must be installed and used in accordance with the manufacturer's specifications. Manufactured systems are usually designed for a specific flow rate or volume. Therefore, adequate overflow or bypass capacity must be designed into the drainage system to prevent downstream impacts.

<u>Footprint/geometry</u> – Manufactured treatment devices come in various shapes and sizes. The specific application and location will determine the type and size of unit used. Consideration of maintenance access is important and can often determine the type of device used.

<u>Local government code</u> – Refer to local municipal code for any local requirements, such as manhole placement and spacing for access to devices. Also, verify any applicable setback requirements from utilities, easements, and other properties.

<u>Construction sequencing</u> – After the system is constructed, install temporary controls around the perimeter until the project has been established to prevent excessive, premature sediment loading into the device.

<u>Pretreatment</u> – In areas where dense vegetation can be maintained, **Vegetated Filter Strips**

should be installed around the perimeter of the device for pretreatment. Otherwise, **Decomposed Granite Cover** should be used between the contributing roadway drainage area and the device.

MATERIAL SPECIFICATIONS

Material specifications will be dependent on the type of manufactured treatment device considered and specific project requirements.

DESIGN STANDARDS

Manufactured treatment devices must conform to all ADOT standards and specifications. All manufactured designs should be reviewed to ensure that the proposed system is appropriate for the project needs.

MAINTENANCE AND INSPECTION REQUIREMENTS

Inspections – All manufactured devices require regular inspection and maintenance to maximize their effectiveness. The specific maintenance requirements and schedule should be provided by the manufacturer. Maintenance frequency may vary from after any major storm to monthly. Lack of maintenance is widely acknowledged to be the most prevalent cause of failure.

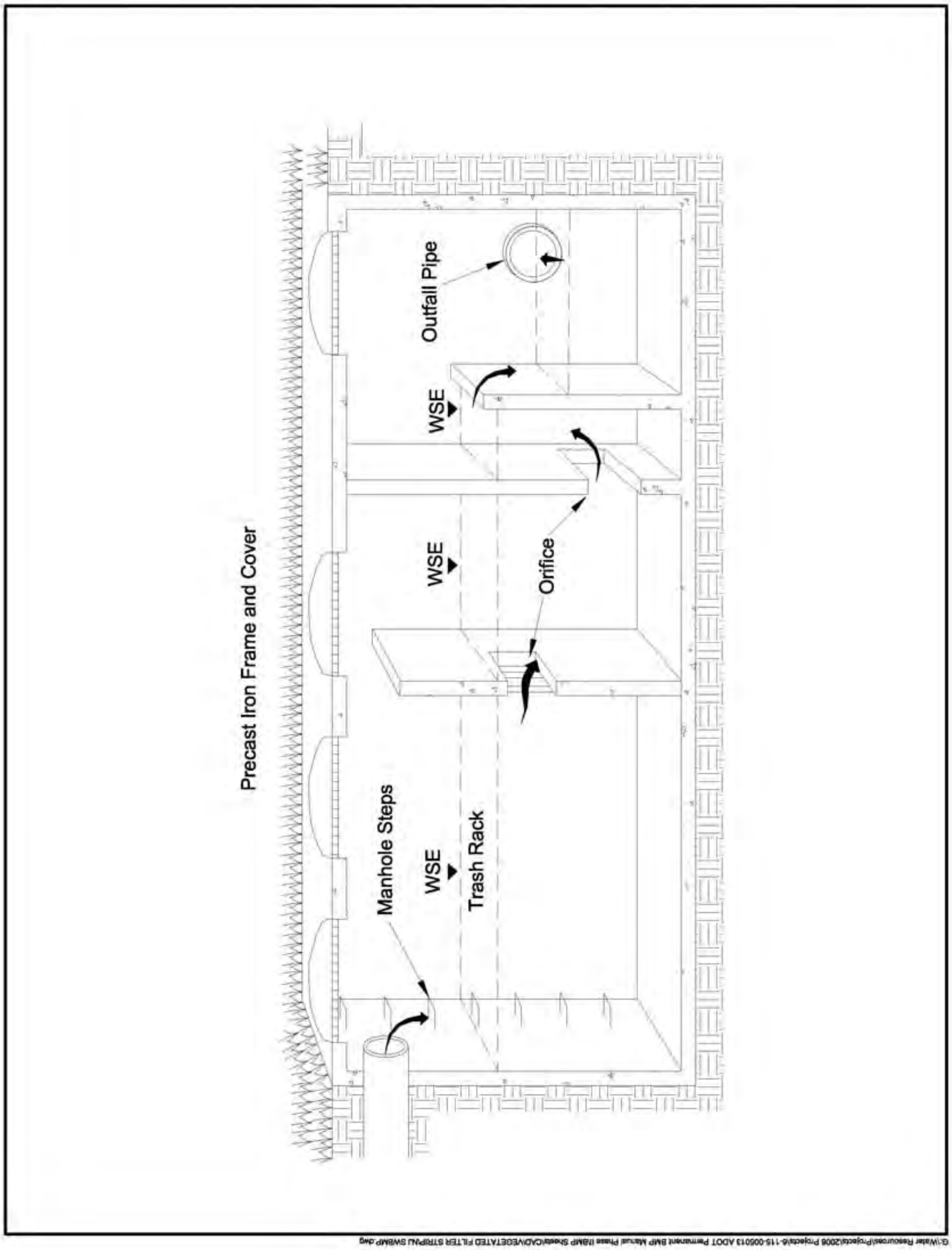
Sediment and Debris Removal – Sediment and other debris collected in manufactured systems may or may not be able to be disposed of as general municipal wastes. Proper disposal methods should be confirmed prior to performing cleanouts.

Nuisance Control – Inspect areas with installed devices for standing water following each storm event and remove any stored water.

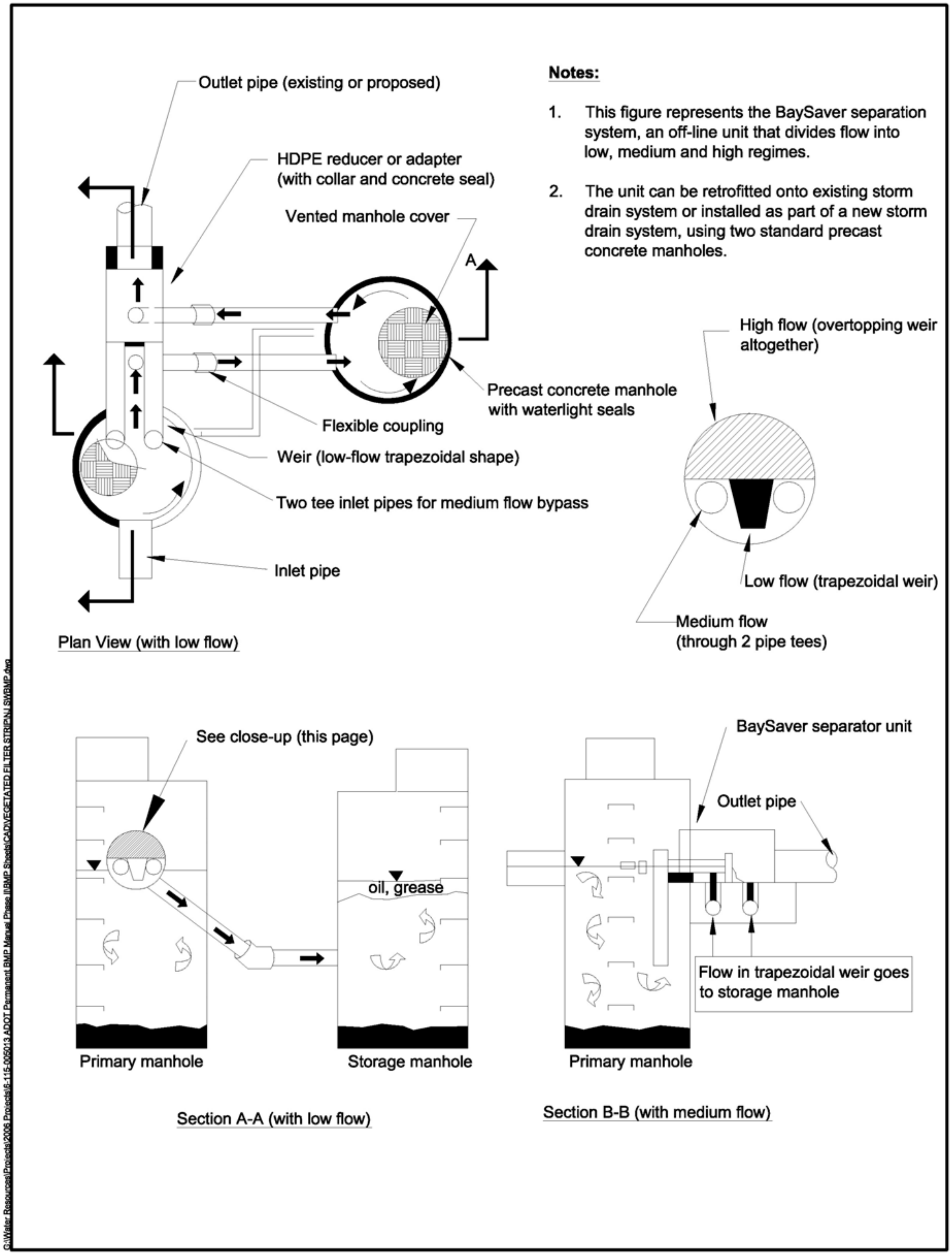
SCHEMATICS

Note: ADOT does not exclusively recommend the use of any manufacturer's product. The following schematics are provided for illustrative purposes only.

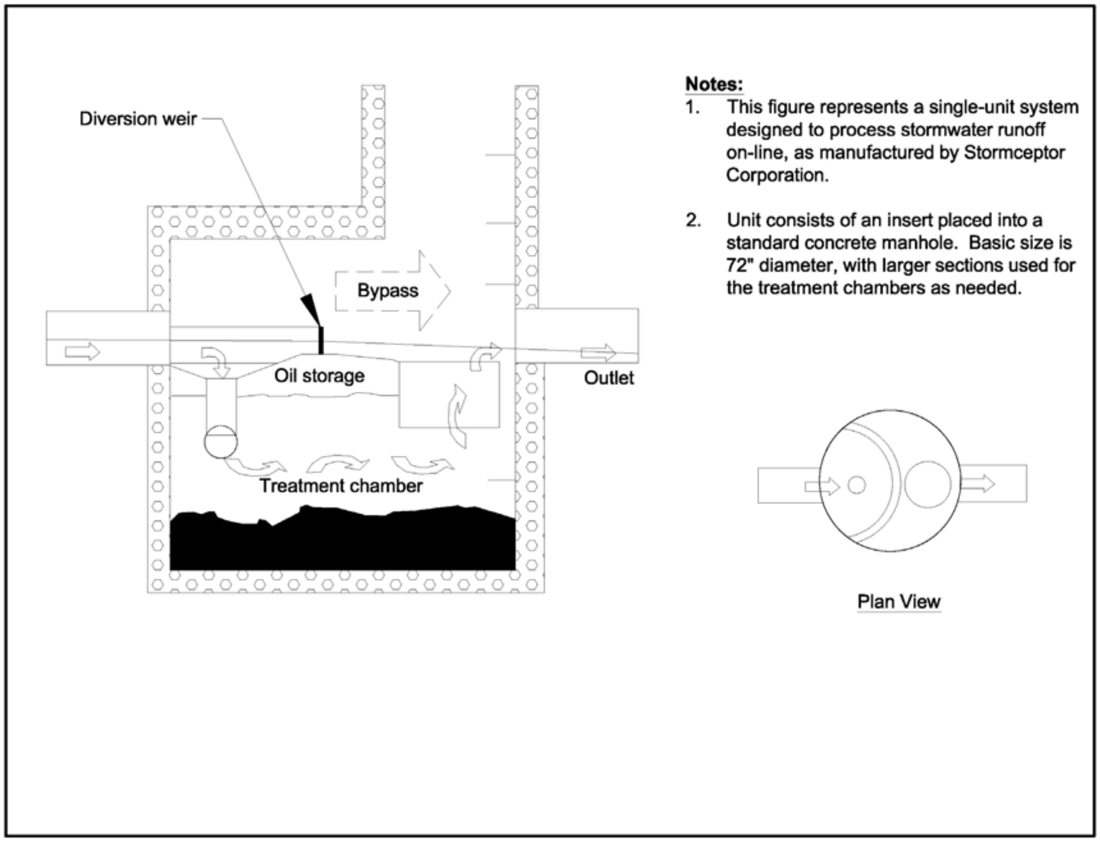
Schematic of an Example Gravity (Oil-Grit) Separator



Schematic of a Hydrodynamic Device

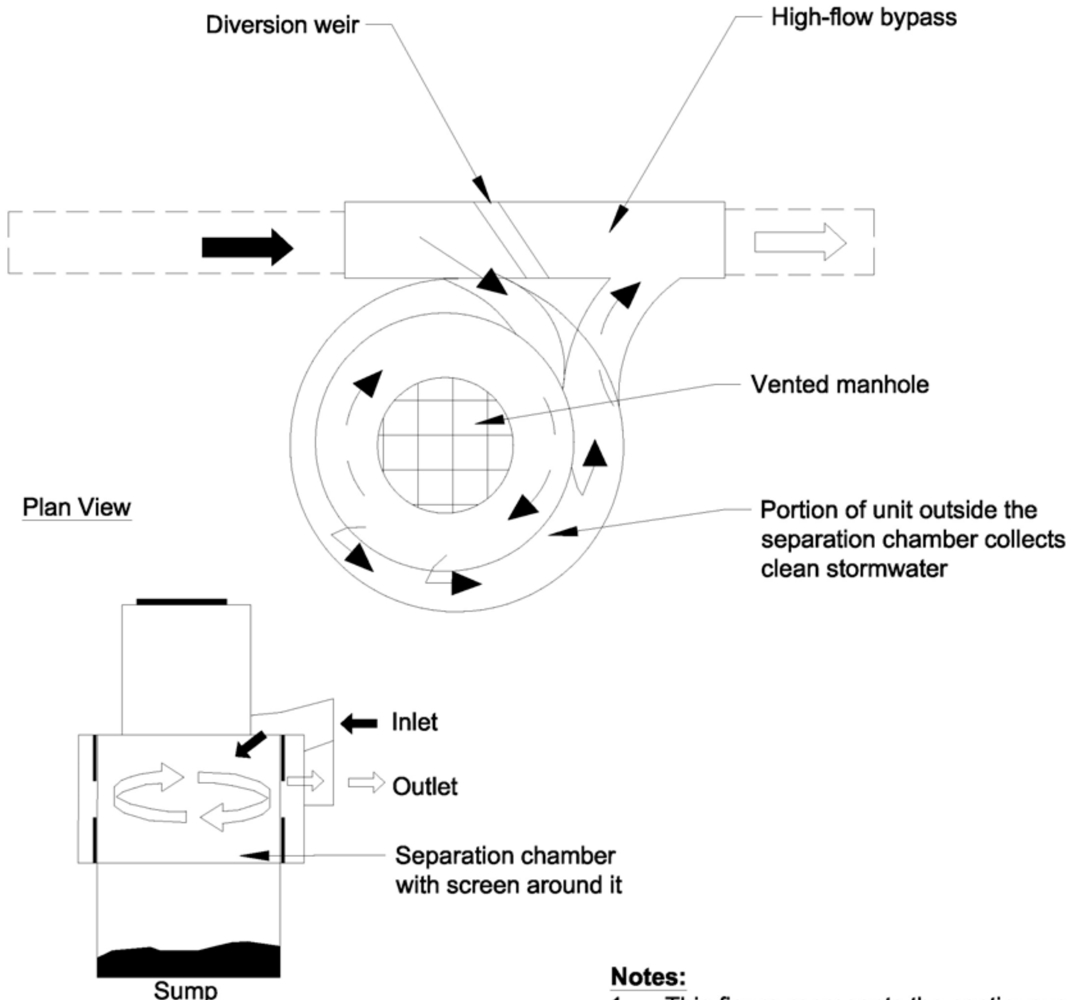


Schematic of an Oil-Water Separator with Bypass



Refer to ADOT C-Standards C-15.10 to 92 for catch basin standard drawings and details and C-18.10 for manhole standard drawings.

Schematic of a Continuous Deflector Vendor Device



Notes:

1. This figure represents the continuous deflection stormwater treatment as manufactured by CDS Technologies. Unites can also be retrofitted onto existing storm drains.

2. Units are manufactured from either fiberglass or precast concrete.

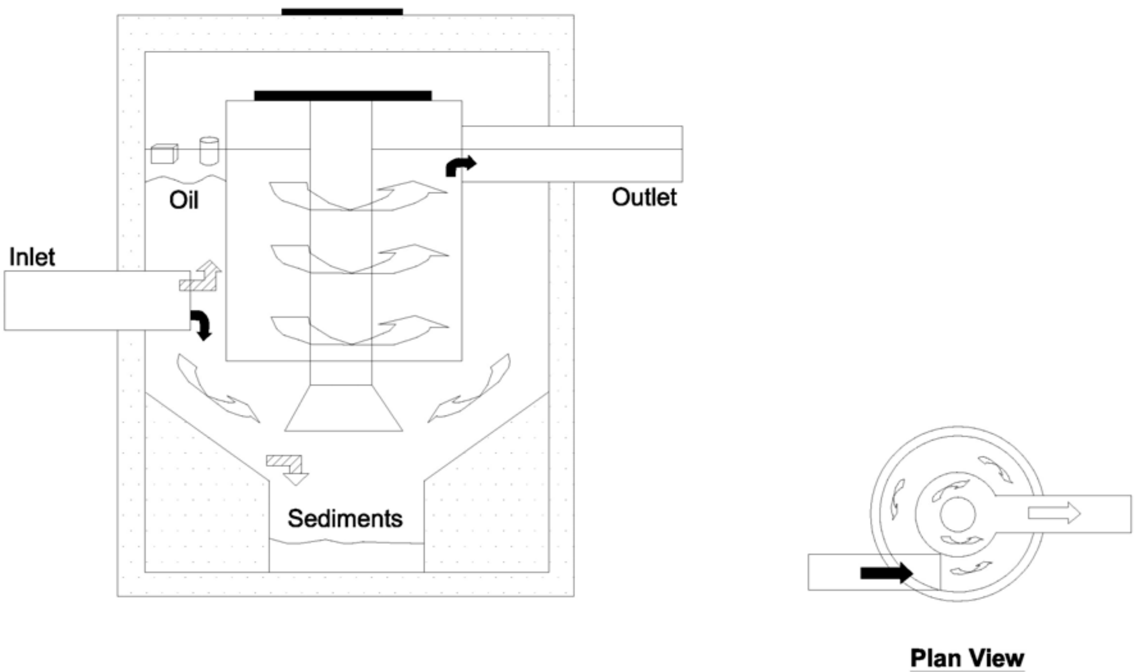
3. Manufacturer recommends the use of sorbent material within CDS separation chamber to improve capture of oil and grease. Usage rate is typically several pounds of sorbent pre acre per year.

Schematic of a Hydrodynamic Oil Water Separator

Notes:

1. This figure shows a single unit to treat stormwater runoff, manufactured, by H.I.L Technologies, Inc.

2. Unit consists of polyethylene components supported by a stainless frame, inserted into a standard concrete manhole. Concrete manhole sizes vary from 4' to 10'.



REFERENCES AND RESOURCES

Arizona Department of Transportation (ADOT), *Standard Specifications for Road and Bridge Construction*, 2008.

Arizona Department of Transportation (ADOT), *Construction Standard Drawings C-15.10 to 92*

Arizona Department of Transportation (ADOT), *Highway Drainage Design Manual (draft),* 2006.

California Department of Transportation (Caltrans), *Storm Water Quality Handbooks: Project Planning and Design Guide,* April 2003.

City of Knoxville, TN. City of Knoxville Stormwater Engineering Division, *Knoxville Best Management Practices Manual,* March 2003.

Virginia Department of Conservation and Recreation, *Division of Soil and Water Conservation, Virginia Stormwater Management Handbook, Volume I, First Edition* 1999.

Bioretention

DEFINITION

Bioretention areas are engineered structures consisting of a grass buffer strip, ponding area, organic or mulch layer, planting soil, and vegetation. An optional sand bed can also be included in the design to provide aeration and drainage of the planting soil. The filtered runoff can either be discharged through an underdrain system to a receiving water body, conveyance system or other BMP, or it can infiltrate to the underlying soils. They can be configured in an on-line and off-line configuration.

OVERVIEW

GENERAL INFORMATION
Key design factors: ▪ Maximum contributing drainage area of 5 acres. ▪ Typically requires 5 feet of elevation difference from inflow to outflow.
Maintenance needs: ▪ Periodic inspections. ▪ Repair/replace treatment area components.
Most effective when used with: ▪ Pretreatment (i.e. Vegetated Filter Strips or Decomposed Granite Cover).
Alternative BMPs to consider: ▪ Infiltration Trench or Infiltration Basin. ▪ Retention and Detention Basins (pond-in-place).

RATINGS	H	M	L
Associated Costs			
Design		X	
Construction	X		
Maintenance		X	
BMP Objective			
Erosion control			X
Drainage conveyance			X
Water Quality/Treatment	X		
DOT Target Pollutants Removal			
Dissolved or suspended sediment	X		
Biological constituents	X		
Nutrients and pesticides		X	
Heavy metals	X		
Organics	X		

PHOTOGRAPHS

PURPOSE

Bioretention and biofiltration areas are structural stormwater controls that capture and temporarily store stormwater runoff using soils and vegetation in shallow basins or landscaped areas to provide enhanced removal of dissolved stormwater pollutants, including nutrients, pesticides, organics, metals, and biological constituents.

APPROPRIATE APPLICATIONS

Bioretention and biofiltration are suitable for many types of development where there is a discharge (not sheetflow) within 1/4 mile of a sensitive water body. The use of bioretention is extremely flexible and can easily be incorporated into various types of new or existing landscapes including roadway median strips, along road drainage swales, and as landscaped islands in impervious or high-density environments. Refer below for additional design considerations.

LIMITATIONS

Bioretention basins are ***NOT*** appropriate in the following conditions:

- Along slopes greater than 4:1;
- Shallow groundwater (less than 4 feet below the bottom of the basin or channel) to allow proper draining; and
- Climates where soil can freeze.

DESIGN CONSIDERATIONS

Consider the following bioretention basin design factors:

<u>Soil characteristics</u> – If infiltration is intended for this system, ensure an infiltration rate of at least 0.5 inches per hour. Refer to geotechnical data to ensure that the permeability is sufficient at depths below the bottom of the basin. Do not locate the basin above collapsible soils. Karst areas may require a liner. If infiltration is not intended for this system, there are no restrictions on soil types.

<u>Footprint/geometry</u> – The total storage volume must be able to contain the runoff from the design storm corresponding to ADOT's local drainage design requirement. Offline configurations (runoff is concentrated and conveyed to another location) can be used to accommodate larger drainage areas and/or footprint geometries. Contributing drainage areas should be less than 0.5 acres for on-line systems and 5.0 acres for off-line systems.

<u>Local government code</u> – Refer to local municipal code for any local holding and infiltration requirements, such as the amount of time allowed for standing water. Also, verify any applicable setback requirements. Setbacks from infiltration practices are typically set for building foundations, private and public supply wells, septic systems, and downstream surface water bodies.

Basin safety and stability – Basins excavated more than 4 feet deep should be properly stabilized through benching. A geotechnical engineering analysis should be conducted to ensure side slope stability.

Construction sequencing – After the system is constructed, install temporary controls around the perimeter until the project has been established to prevent excessive, premature sediment loading into the basin.

Pretreatment – In areas where dense vegetation can be maintained, **Vegetated Filter Strips** should be installed along the perimeter of the infiltration basin for pretreatment. Otherwise, **Decomposed Granite Cover** should be used between the contributing roadway drainage area and the basin.

MATERIAL SPECIFICATIONS

Planting soil bed – shall be at least 4 feet in depth when trees are planted in the bioretention area but can be a minimum of 2 feet deep in facilities that will utilize plants other than trees. Planting soils shall consist of a sandy loam, loamy sand, or loam texture with a clay content ranging from 10 to 25%. The soil must have an infiltration rate of at least 0.5 inches per hour and a pH between 5.5 and 6.5. In addition, the planting soil must have a 1.5 to 3% organic content and a maximum 500 ppm concentration of soluble salts.

Mulch layer – must consist of 2 to 4 inches of commercially available fine shredded hardwood mulch or shredded hardwood chips.

Sand bed – must be 12 to 18 inches thick. Sand shall be clean and have less than 15% silt or clay content.

Pea gravel – for the diaphragm and curtain, when used, should be ASTM D 448 size No. 6 (1/8” to 1/4”).

Underdrain collection system – shall include a 4 to 6 inch pipe wrapped in a 6 to 8 inch gravel layer. The pipe shall have 3/8-inch perforations, spaced at 6-inch centers, with a minimum of 4 holes per row around the circumference of the pipe. The pipe spacing shall be at a maximum of 10 feet on center and a minimum grade of 0.5% must be maintained. A permeable filter fabric shall be required between the gravel layer and the planting soil bed.

DESIGN STANDARDS

A. General components of a bioretention area include:

- A grass filter strip (or grass channel) between the contributing drainage area and the ponding area,
- A ponding area containing vegetation with a planting soil bed,

- An organic/mulch layer,
- A gravel and perforated pipe underdrain system to collect runoff that has filtered through the soil layers (bioretention areas can optionally be designed to infiltrate into the soil – see description of infiltration trenches for infiltration criteria).

B. A bioretention area design may also include some of the following:

- An optional sand filter layer with geotextile fabric to spread flow, filter runoff, and aid in aeration and drainage of the planting soil, located between the underdrain and planting soil.
- A pea gravel diaphragm at the beginning of the grass filter strip to reduce runoff velocities and spread flow into the grass filter.
- Energy dissipation techniques will be required for contributing drainage areas that have a 6% slope or greater.

C. The bioretention footprint is dependent on the drainage area being treated and should be determined per the methods described in Section 15.4 of the ADOT Highway Drainage Design Manual. Dimensions of other components of the system include:

- The planting soil filter bed shall be sized using the Darcy's Law equation with a filter bed drain time of 48 hours and a coefficient of permeability (k) of 0.5 feet per day.
- The maximum ponding depth of a bioretention area is 6 inches.

D. Adequate pretreatment and inlet protection for bioretention systems shall be provided, such as a Vegetated Filter Strip or a Decomposed Granite Cover. For off-line applications, a grass channel with proper outlet protection shall be used for pretreatment. The length of the grass channel depends on the drainage area, land use, and channel slope. The minimum grassed channel length shall be 20 feet.

E. An outlet discharge pipe shall be provided from the underdrain system if infiltration is not to be used.

F. Emergency spillway

- An overflow structure and nonerosive overflow channel must be provided to safely pass flows that exceed the storage capacity of the bioretention area to a stabilized downstream area or watercourse. If the system is located off-line, the overflow shall be set above the shallow ponding limit.
- A high flow overflow system <u>within</u> a bioretention structure may consist of a yard drain catch basin, though any number of conventional systems could be used. The throat of the catch basin inlet located in a bioretention facility must be no more than 6 inches above the mulch layer at the elevation of the shallow ponding area.

G. Maintenance Access

- A minimum 20 foot wide maintenance right-of-way or easement shall be provided from a driveway, public or private road. The maintenance access easement shall have a maximum slope of no more than 15% and shall have a minimum unobstructed drive path having a width of 12 feet, appropriately stabilized to withstand maintenance equipment and vehicles.
- The maintenance access shall be designed such that all areas of the bioretention area can be easily accessed, and shall be designed to allow vehicles to turn around.

H. Landscaping

- Landscaping is critical to the performance and function of bioretention areas. A dense and vigorous vegetative cover that is appropriate for use in a bioretention area shall be established over the contributing pervious drainage areas before runoff can be accepted into the facility. When the contributing drainage area is completely or partially disturbed or unstabilized, sediment laden runoff reaching the bioretention area can clog the soils and cause the bioretention area to fail.
- In general, any vegetation used in the bioretention area should be native, resistant to drought, tolerant of pollutants, have low fertilization requirements, and be easily maintained. Grasses, shrubs, and trees are all permissible vegetation types for bioretention areas, as long as the species used meet the general guidance provided herein.
- After the trees and shrubs are established, the ground cover and mulch should be established.

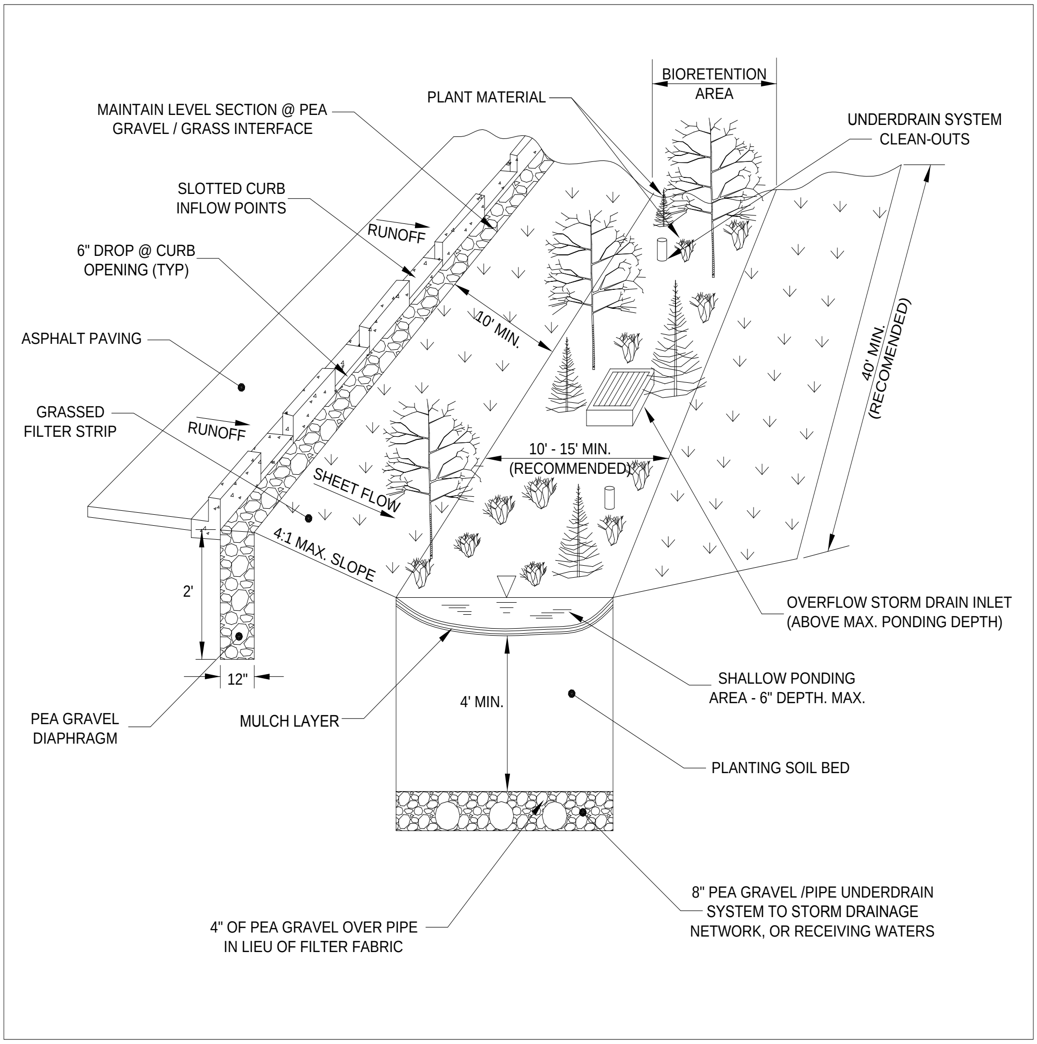
MAINTENANCE AND INSPECTION REQUIREMENTS

<u>Inspections</u> – Perform inspections regularly to confirm the system is draining within 48 hours of a storm. Static water beyond 48 hours of a storm could be indicative of an ineffective, clogged basin.

<u>Trash and sediment removal</u> – Trash and other miscellaneous debris should be regularly removed from the basin. The bottom sand layer may need to be replaced if water does not completely drain after 48 hours of a storm.

<u>Nuisance Control</u> – Inspect for standing water at the end of each rain event. No additional nuisance control is necessary if the infiltration basin drains properly.

SCHEMATICS



(Source: Claytor and Schueler, 1996)

REFERENCES AND RESOURCES

Arizona Department of Transportation (ADOT), *Standard Specifications for Road and Bridge Construction*, 2008.

Arizona Department of Transportation (ADOT), *Highway Drainage Design Manual (draft)*, 2006.

California Department of Transportation (Caltrans), *Storm Water Quality Handbooks: Project Planning and Design Guide*, April 2003.

Knox County, *Knox County Tennessee Stormwater Management Manual, Volume 2 (Technical Guidance),* 2007.

Minnesota Pollution Control Agency (MPCA), *Protecting Water Quality in Urban Areas, Chapter 4: BMPs for Stormwater Systems,* 2000.

Filtration Structures

DEFINITION

Stormwater filtration structures utilize a filtering media (sand, soil, gravel, peat, or compost) to remove pollutants from stormwater runoff. Filtration structures can vary in design, but should all generally comprise of the following: (a) inflow regulation that diverts a defined flow volume into the filtration system, (b) pretreatment to remove coarse sediments, (c) filter media, specific to one or more target pollutants, and (d) an outflow mechanism to discharge flows to a conveyance system or directly to a receiving water body.

OVERVIEW

GENERAL INFORMATION
Key design factors: ▪ Sediment pre-treatment must be included to prevent premature clogging. ▪ Proper selection of filter bed media, surface area, depth, and profile.
Maintenance needs: ▪ Removal of accumulated debris and replacement of exhausted filter media.
Most effective when used with: ▪ Vegetated filter strips or decomposed granite as pre-treatment.
Alternative BMPs to consider: ▪ Infiltration or storage practices. ▪ ADOT-Approved Vendor Treatment Devices.

RATINGS	H	M	L
Associated Costs			
Design	X		
Construction	X		
Maintenance	X		
BMP Objective			
Erosion control			X
Drainage conveyance			X
Water Quality/Treatment	X		
DOT Target Pollutants Removal*			
Dissolved or suspended sediment	X		
Biological constituents		X	
Nutrients and pesticides			X
Heavy metals		X	
Organics	X		

*Removal efficiencies are highly dependent on filter media and filtration structure dimensions.

PHOTOGRAPHS

PURPOSE

Filter structures are designed strictly for water quality treatment; they are not effective for handling peak storm flows. Special consideration should be given to the kind of media that is selected to target specific pollutants in the runoff.

APPROPRIATE APPLICATIONS

Due to the complexity and cost of design and construction, filtration structures should only be considered when infiltration or storage practices are not feasible (see limitations for **Infiltration Trench, Infiltration Basin,** and **Detention and Retention Basins**) and treatment is necessary (i.e. within a 1/4 mile of a regulated MS4, other stakeholder boundaries, or a sensitive water body.) Most filtration structures are constructed off-line where runoff is diverted from the main conveyance system.

LIMITATIONS

Filtration structures are ***NOT*** appropriate in the following conditions:

- If infiltration or storage practices are feasible;
- Un-stabilized areas or construction sites. No runoff should enter the filtration structure until all contributing drainage areas from the right-of-way have been stabilized; and,
- When considering an on-line treatment configurations. On-line filtration structures are located within the conveyance system and are exposed to the full range of flow events, including 100-year events. Filtration structures are most effective for specific ranges of flows. For small drainage areas (i.e. < 1.0 acre), consider using **ADOT-Approved** (filtration) **Vendor Devices**.

DESIGN CONSIDERATIONS

Consider the following infiltration trench design factors:

<u>Pollutants of concern</u> – Identifying the pollutant(s) of concern to treat in the stormwater runoff influent is important for selecting the filtration media with the associated highest removal efficiencies. Identifying the pollutants of concern is particularly important when discharging to a sensitive water body. Compare the pollutants for which the surface water body is impaired to ADOT roadway generated pollutants.

<u>Footprint/geometry</u> – Most filtration structures are constructed off-line where runoff is diverted from the main conveyance system. The pan area footprint or surface area of the filtration structure is dictated by the impervious cover in the upstream drainage area.

<u>Aesthetics</u> – Municipalities or other stakeholders (i.e. tribal lands or forest service lands) may require or prefer that filtration structures and devices not be visible to the public.

Excavation practices – Trenches are best constructed with a backhoe to the desired depth. The excavated material may be used elsewhere on the project. During excavation, when possible, scarify the sides and bottom of the trench to correct for any smearing of the interface.

Construction sequencing – No runoff should enter the filtration structure until all contributing drainage areas from the right-of-way have been stabilized.

Secondary pretreatment – In areas where dense vegetation can be maintained, vegetated filter strips should be installed upstream from the filtration structure for *secondary* pretreatment. Otherwise, **Decomposed Granite Cover** should be used between the contributing roadway drainage area and the filtration structure.

Perimeter curbs – Curbing along the filtration structure perimeter may be used to protect the structure from vehicular traffic.

MATERIAL SPECIFICATIONS

Sand Filter Media – Clean AASHTO M-6 or ASTM C-33 concrete sand (0.02 to 0.04" nominal diameter).

Peat Filter Media – Uncompacted, uniform and clean peat, with an ash content < 15%, a pH range between 4.9 and 5.2 and a loose bulk density of 7.5 to 9.5 lb/ft^3.

Underdrain Gravel - The underdrain gravel (0.25 to 0.75" nominal diameter) should meet AASHTO M-43 requirements.

Geosynthetic Filter Fabric – If used, the filter fabric should comply with Section 1014 of the ADOT Standard Specifications for Road and Bridge Construction.

Impermeable Liner – ASTM D 751, 412, 624 and 471.

Underdrain piping – 6" diameter schedule 40 PVC pipe. 3/8" perforations at 6" on center.

Concrete – refer to Section 601 – Concrete Structures of the ADOT Standard Specifications for Road and Bridge Construction.

DESIGN STANDARDS

A. **Inflow Volume Control** – Inflow regulators convey runoff from a conduit, open channel or impervious surface into the filtration structure and divert excess flow away from the system.

B. **Pretreatment** – Pretreatment is needed in every design to prevent coarse sediment particles from prematurely clogging the filter bed. The most common technique of pretreatment is a dry settling chamber. Geotextile screens, pea gravel diaphragms, and vegetated filter strips may also be used for additional pretreatment measures.

C. Filter Bed and Filter Media - Filter media may consist of sand, gravel, peat, grass, soil, or compost to filter target pollutants. The proper selection of filter media is important; each has different hydraulic and pollutant removal characteristics. The filter media is incorporated into the filter bed. Key properties of the filter bed are:

1. Surface area – dictated by the impervious drainage area treated and the type of media used.
2. Depth - range from 18 inches to 4 feet. Filter beds are typically shallow; most pollutants are removed in the top few inches of the filter bed.
3. Filter profile – there are a variety of filter profiles, as shown in the schematic.

D. Outflow Mechanism – Filtration structures must have a proper outflow mechanism, which is achieved by installing an impermeable liner at the bottom of the filter bed, capturing the filtered runoff through perforated pipes and discharging it to a conveyance system or directly to a receiving water body.

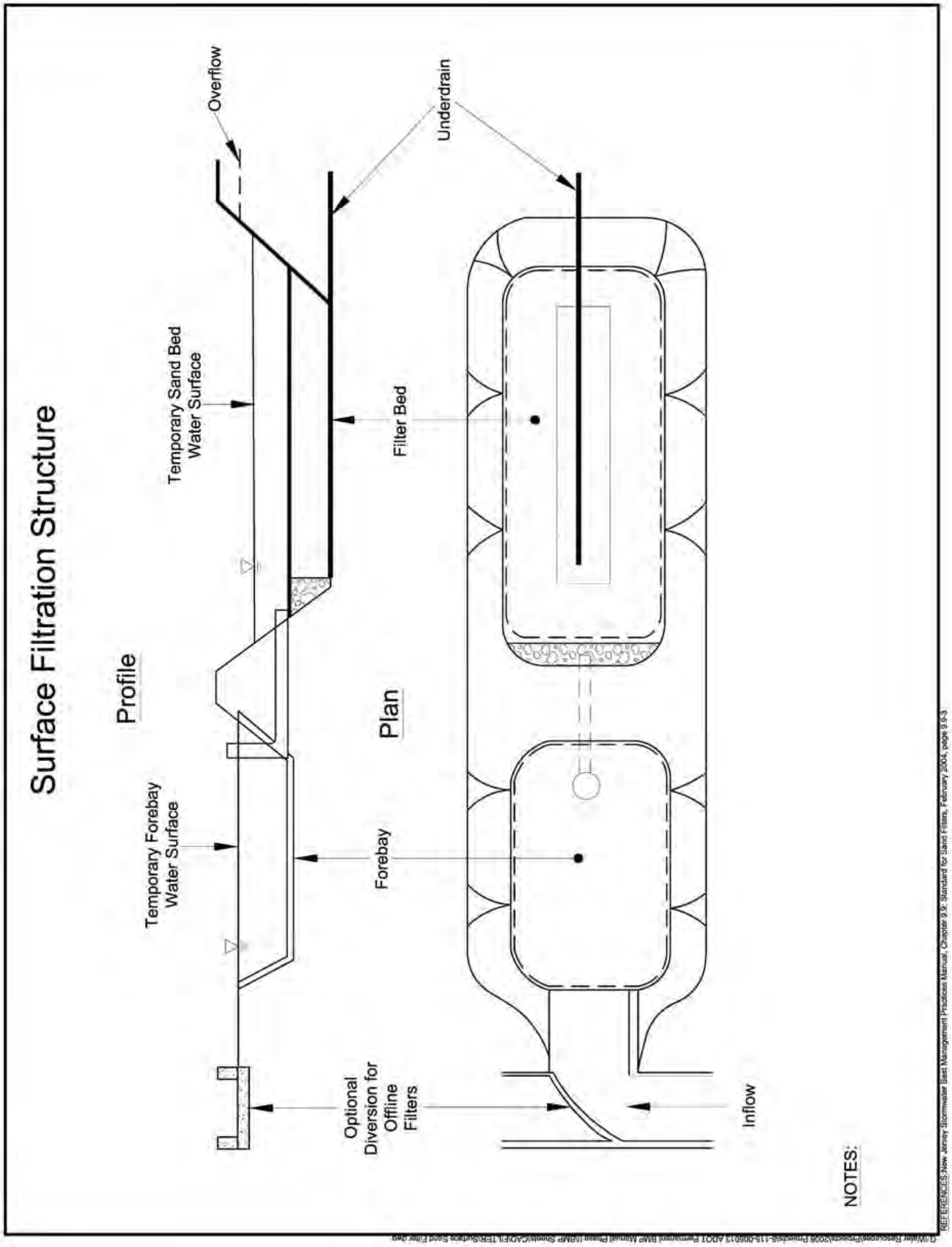
MAINTENANCE AND INSPECTION REQUIREMENTS

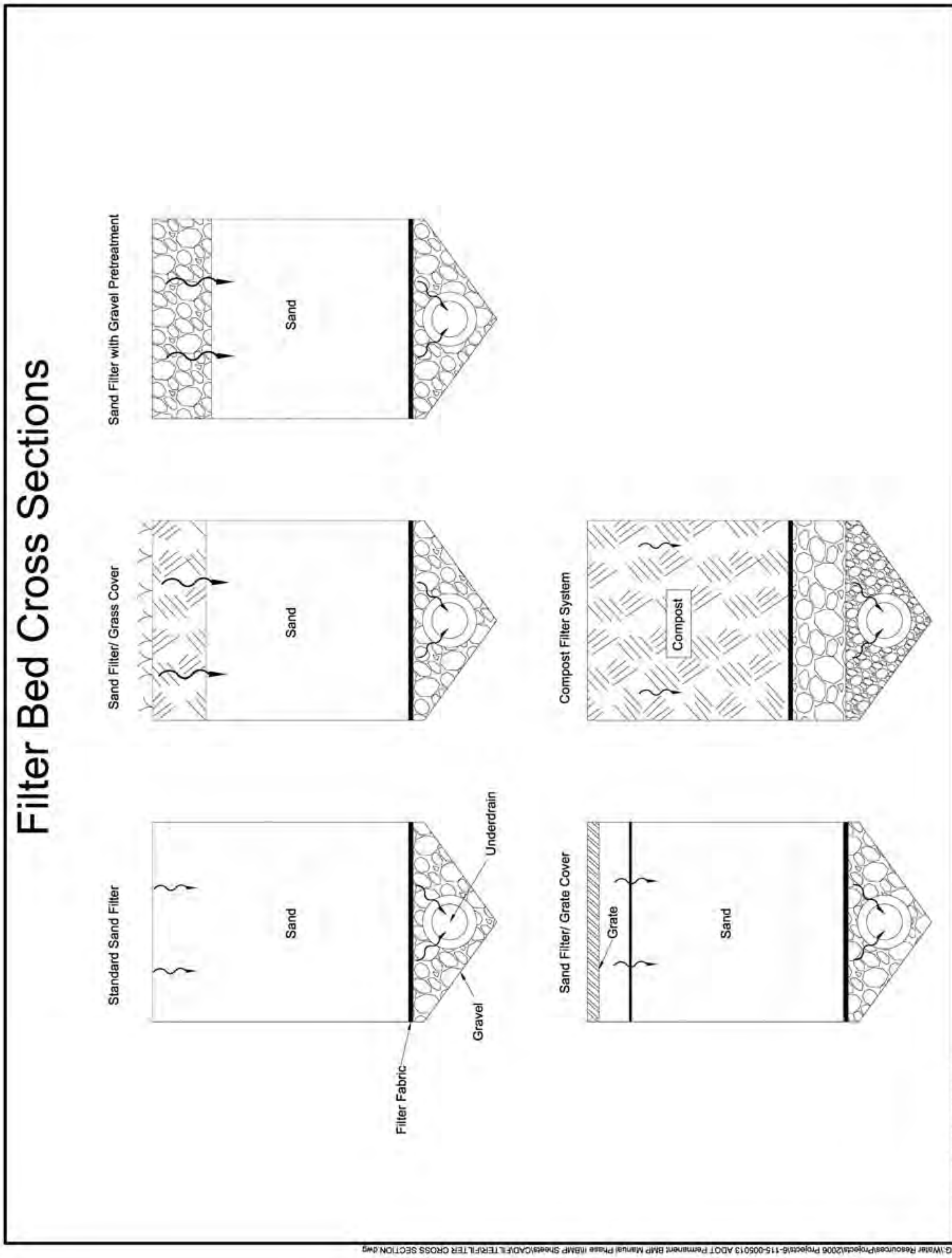
Inspections – Perform inspections regularly to confirm the filter is draining properly after a storm event. If standing water is observed after 24 hours of a storm event, the filter media is exhausted and should be replaced.

Trash and Sediment Removal – Floatable trash and debris should be removed on a routine basis. Exhausted filter media should be replaced with new filter media (same type).

Nuisance Control – Inspect for standing water following each storm event. No additional nuisance control is necessary.

SCHEMATICS


Surface Filtration Structure
Profile
Plan
Overflow
Underdrain
Temporary Sand Bed Water Surface
Filter Bed
Temporary Forebay Water Surface
Forebay
Optional Diversion for Offline Filters
Inflow
NOTES:
REFERENCES: New Jersey Stormwater Best Management Practices Manual, Chapter 9.9: Standard for Sand Filters, February 2004, page 9.9-3


Filter Bed Cross Sections
Standard Sand Filter
Sand
Underdrain
Gravel
Filter Fabric
Sand Filter/ Grass Cover
Sand
Sand Filter with Gravel Pretreatment
Sand
Sand Filter/ Grate Cover
Grate
Sand
Compost Filter System
Compost

REFERENCES AND RESOURCES

Arizona Department of Transportation (ADOT)*, Standard Specifications for Road and Bridge Construction*, 2008*.*

Arizona Department of Transportation (ADOT), *Highway Drainage Design Manual (draft)*, 2006.

California Department of Transportation (Caltrans), *Storm Water Treatment BMP New Technology Report, SW-04-069.04.02*, April 2004.

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http://www.fhwa.dot.gov/environment/ultraurb/index.htm

Minnesota Pollution Control Agency (MPCA), *Protecting Water Quality in Urban Areas, Chapter 4: BMPs for Stormwater Systems,* 2000.

Infiltration Basin

DEFINITION

Infiltration basins are facilities typically constructed below the roadway shoulder where the appropriate footprint is available to hold and infiltrate runoff. Infiltration basins (also known as recharge basins) are considered a treatment BMP because they can remove pollutants from surface discharges by capturing the stormwater runoff volume (typically, larger volumes than an infiltration trench) and infiltrating it directly to the soil rather than discharging it to an above-ground drainage system. Basins are excavated in most any configuration to meet footprint restrictions and can be vegetated.

OVERVIEW

GENERAL INFORMATION
Key design factors: ▪ Moderately to highly permeable soils needed (0.5 – 2.5 in/hr) for infiltration. ▪ Large footprint area is required in order to retain the design storm.
Maintenance needs: ▪ Periodic inspections of the basin surface. ▪ Removal of floatable debris and trash.
Most effective when used with: ▪ Pretreatment (i.e. Vegetated Filter Strips or Decomposed Granite Cover).
Alternative BMPs to consider: ▪ Infiltration Trench ▪ Retention/Detention Basins

RATINGS	H	M	L
Associated Costs			
Design		X	
Construction		X	
Maintenance			X
BMP Objective			
Erosion control			X
Drainage conveyance		X	
Water Quality/Treatment	X		
DOT Target Pollutants Removal			
Dissolved or suspended sediment	X		
Biological constituents	X		
Nutrients and pesticides	X		
Heavy metals	X		
Organics	X		

PHOTOGRAPHS

PURPOSE

Infiltration basins are effective in managing and treating a wide range of runoff volumes (relative to other treatment BMPs) by collecting and percolating stormwater runoff below ground surface through the surrounding and underlying native soil matrix, rather than discharging it to an above-ground drainage system.

APPROPRIATE APPLICATIONS

Infiltration basins are appropriate in areas where there is a discharge (not sheetflow) within 1/4 mile of regulated MS4s, sensitive water bodies, or other stakeholder boundaries ***and*** the existing soils have an infiltration rate between 0.5 to 2.4 inches per hour. Refer below for additional design considerations.

LIMITATIONS

Infiltration basins are ***NOT*** appropriate in the following conditions:

- Within low permeability soils (less than 0.5 inches per hour), fill soil, compacted soil, or along slopes greater than 4:1;
- Shallow groundwater (less than 4 feet below the bottom of the basin) to allow proper draining;
- Basins require a significant footprint, relative to other treatment BMPs. If there is not sufficient footprint, consider an offline configuration at a more convenient location.

If not properly maintained, infiltration basins will prematurely clog and will result in costly maintenance. Pretreatment (**Vegetated Filter Strips, Decomposed Granite Cover** or other erosion control practices) can help to reduce influent sediment.

In the cases where infiltration basins are not appropriate, consider implementing a **Detention/ Retention basin** and the appropriate pumpout or discharge pipe infrastructure.

DESIGN CONSIDERATIONS

Consider the following infiltration basin design factors:

<u>Soil characteristics</u> – Ensure an infiltration rate of at least 0.5 inches per hour. Refer to geotechnical data to ensure that the permeability is sufficient at depths below the bottom of the basin. Do not locate the basin above collapsible soils.

<u>Footprint/geometry</u> – The total storage volume must be able to contain the runoff from the design storm corresponding to ADOT's local drainage design requirement. Offline configurations can also be designed to accommodate larger footprint geometries. The maximum depth of the infiltration basin should be 12 feet.

Local government code – Refer to local municipal code for any local holding and infiltration requirements, such as the amount of time allowed for standing water. Also, verify any applicable setback requirements. Setbacks from infiltration practices are typically set for building foundations, private and public supply wells, septic systems and downstream surface water bodies.

Excavation practices – During construction, the excavated material from the basin may be used elsewhere on the project. During excavation, when possible, scarify the sides and bottom of the trench to correct for any smearing of the interface. Avoid compaction of the soils below the basin, whenever possible.

Basin safety and stability – Basins excavated more than 4 feet deep should be properly stabilized through benching. A geotechnical engineering analysis should be conducted to ensure the stability of the trench walls and supports.

Construction sequencing – After the basin is constructed, install temporary controls around the basin perimeter until the project has been established to prevent excessive, premature sediment loading into the basin.

Pretreatment – In areas where dense vegetation can be maintained, vegetated filter strips should be installed perimeter of the infiltration basin for pretreatment. Otherwise, decomposed granite should be used between the contributing roadway drainage area and the basin. A 6-inch sand layer at the bottom of the basin can intercept silt and debris that could potentially clog the soil underlying the basin and facilitates the cleanout of these materials.

MATERIAL SPECIFICATIONS

Soils – Minimum acceptable infiltration rate of the surrounding soil is 0.5 inches per hour.

Sand layer – Must consist of sand with a maximum 15% fines and a minimum permeability rate of 20 inches per hour.

DESIGN STANDARDS

A. Design the basin geometry per the design criteria in Section 15.4 of the ADOT Hydraulics Manual and the allowable footprint. Use side slopes less than 4:1.

B. Furnish a 6-inch layer of clean sand (refer to material specifications above) for the bottom of the basin.

C. Furnish a bypass or overflow for the design check discharge.

D. If feasible, include vehicle access to the basin for maintenance.

E. Vegetate the sides of the basin in accordance with ADOT Standard Specifications for Road and Bridge Construction, Section 805.

F. Observations wells should be located at the point of lowest elevation within the basin. The well design consists of a 6-inch diameter perforated stand pipe that extends the entire basin depth with a weatherproof cap to monitor water levels and sediment accumulation within the infiltration basin.

MAINTENANCE AND INSPECTION REQUIREMENTS

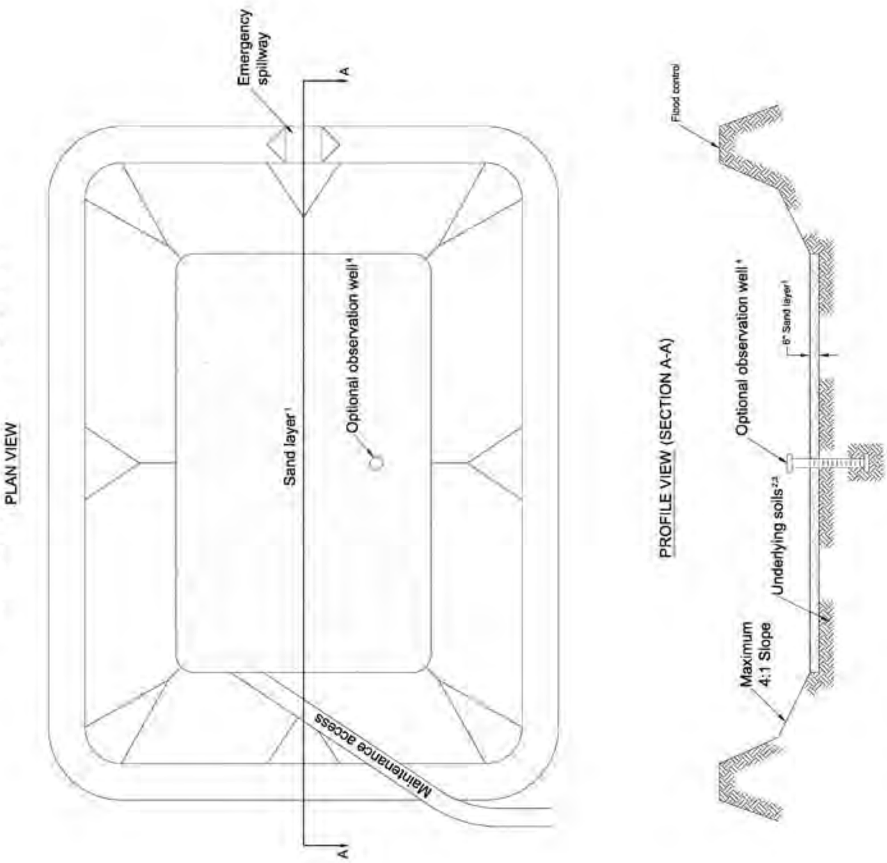
Inspections – Perform inspections regularly to confirm the basin is draining within 48 hours of a storm. Static water beyond 48 hours of a storm could be indicative of an ineffective, clogged basin (see trash and sediment removal).

Trash and sediment removal – Trash and other miscellaneous debris should be regularly removed from the basin. The bottom sand layer may need to be replaced if water does not completely drain after 48 hours of a storm.

Nuisance Control – Inspect for standing water following each storm event. No additional nuisance control is necessary if the infiltration basin drains properly.

SCHEMATICS

Infiltration Basin



NOTES:

[1]Optional sand layer should have less than 15% fines and a minimum infiltration rate of 20 inches per hour.

[2]Underlying soils should have a minimum infiltration rate of 0.5 inches per hour.

[3]Basin construction should not compact the soils below the basin, whenever possible.

[4]Observation well should contain 6" diameter perforated pipe (1" slot size). Flanged at the bottom to anchor it, and a removable cover.

G:\Water Resources\Projects\2006 Projects\6-115-005013 ADOT Permanent BMP Manual Phase II\BMP Sheets\CAD\INFILTRATION\INFILTRATION BASIN2.dwg

REFERENCES AND RESOURCES

Arizona Department of Transportation (ADOT), *Standard Specifications for Road and Bridge Construction,* 2008.

Arizona Department of Transportation (ADOT), *Highway Drainage Design Manual (draft),* 2006.

California Department of Transportation (Caltrans) *Storm Water Quality Handbooks: Project Planning and Design Guide,* April 2003,.

Minnesota Pollution Control Agency (MPCA), *Protecting Water Quality in Urban Areas, Chapter 4: BMPs for Stormwater Systems,* 2000.

Infiltration Trench

DEFINITION

An infiltration trench is a structural BMP, constructed below ground surface, within the median and/or below a shoulder of relatively flat stretches of roadway. It is considered a treatment BMP because it can remove pollutants from surface discharges by capturing stormwater runoff volume and allowing it to infiltrate directly into the soil (through the bottom and the sides of the trench) rather than discharging it to an above-ground drainage system. Infiltration trenches are excavated, lined with a geotextile fabric (optional), and backfilled with aggregate.

OVERVIEW

GENERAL INFORMATION
Key design factors: ▪ Moderately to highly permeable soils needed (0.5 – 2.5 in/hr). ▪ Most effective when used with sediment pretreatment to prevent premature clogging.
Maintenance needs: ▪ Periodic inspections of trench surface and its observation well. ▪ Removal of floatable debris and trash.
Most effective when used with: ▪ Pretreatment (i.e. vegetated filter strips or decomposed granite).
Alternative BMPs to consider: ▪ Infiltration Basin ▪ Bioretention

RATINGS	H	M	L
Associated Costs			
Design		X	
Construction		X	
Maintenance			X
BMP Objective			
Erosion Control			X
Drainage conveyance		X	
Water Quality/Treatment	X		
DOT Target Pollutants Removal			
Dissolved or suspended sediment		X	
Biological constituents	X		
Nutrients and pesticides	X		
Heavy metals	X		
Organics	X		

PHOTOGRAPHS

PURPOSE

Infiltration trenches are effective in managing and treating drainage by collecting and percolating stormwater runoff below ground surface through the surrounding and underlying native soil matrix, rather than discharging it to an above-ground drainage system.

APPROPRIATE APPLICATIONS

Infiltration trenches are appropriate in relatively flat areas where sheetflow discharges from roadway surfaces occur. They are particularly effective within regulated MS4s or other stakeholder boundaries, including discharges within 1/4 mile of sensitive water bodies in Arizona.

LIMITATIONS

Infiltration trenches are ***NOT*** appropriate where the following conditions occur:

- Within low permeability soils (less than 0.5 inches per hour), fill soil, compacted soil, or along slopes greater than 4:1; and
- Shallow groundwater (less than 4 feet below the trench bottom) to allow proper draining.
- Areas with high sediment loading (i.e. unstabilized construction sites).

If not properly designed and/or maintained, infiltration trenches may prematurely clog. This will result in costly maintenance (removal and replacement of the aggregate matrix). Pretreatment (**Vegetated Filter Strips, Decomposed Granite Cover**, erosion control, etc.) measures are required to reduce potential influent sediment.

DESIGN CONSIDERATIONS

Consider the following infiltration trench design factors:

Soil characteristics – Ensure an infiltration rate of at least 0.5 inches per hour. Refer to geotechnical data to ensure that the permeability is sufficient at depths below the bottom of the trench. Do not locate the trench above collapsible soils.

Footprint/geometry – The total trench storage volume must be able to contain the runoff from the design storm corresponding to ADOT's local drainage design requirement. Offline configurations can also be designed to accommodate larger footprint geometries. The maximum depth of the infiltration trench should be 12 feet.

Local government code – Refer to municipal code for any local holding and infiltration requirements, such as the amount of time allowed for standing water. Also, verify any applicable setback requirements from infiltration systems. Setbacks from infiltration systems are typically designated for building foundations, private and public supply wells, septic systems, and downstream surface water bodies.

Excavation practices – Trenches are best constructed with a backhoe to the desired depth. The excavated material may be used elsewhere on the project. During excavation, when possible, scarify the sides and bottom of the trench to correct for any smearing of the interface.

Trench safety and stability – Trenches over 4 feet deep should be properly stabilized with a trench box and/or other trench supports. Refer to the Occupational Safety and Health Administration (OSHA) trench safety standards: 29 CFR 1926.650, 651, and 652. A geotechnical engineering analysis should be conducted to ensure the stability of the trench walls and supports.

Earthen partitions – To minimize the impacts of the ground surface slope (longitudinal to the trench), the trench design can include earthen partitions to shorten trench lengths. The earthen partitions should be wide enough to prevent collapse into the subsequent trench (see trench safety and stability above).

Construction sequencing – After the trench is constructed, install temporary controls around the trench perimeter until the pretreatment measure has been established to prevent excessive, premature sediment loading into the trench.

Pretreatment – In areas where dense vegetation can be maintained, vegetated filter strips should be installed on the sides of the infiltration trench for pretreatment measure. Otherwise, decomposed granite cover should be used between the contributing roadway drainage area and the infiltration trench.

Perimeter curbs – Optional curbing along the trench perimeter (with openings to allow sheetflow passage) may be used to delineate the boundary of the trench.

MATERIAL SPECIFICATIONS

Soils – Minimum acceptable infiltration rate of surrounding soil is 0.5 inches per hour.

Aggregate Fill – The aggregate fill in the trench should be clean (washed of fines), 1.5 to 2.5 inches in diameter, and have a void space of approximately 40%. Specify as Class 6 Aggregate of the ADOT Standard Specifications for Road and Bridge Construction.

Geosynthetic Filter Fabric – A geosynthetic filter fabric can be used to line the sides of the trench to prevent soil piping. It can also be used 2 to 6 inches from the top of the trench to prevent sediment from passing into the underlying aggregate in areas with particularly high sediment loading. Note, however, that filter fabric will likely necessitate more frequent maintenance. If used, the filter fabric should comply with Section 1014 of the ADOT Standard Specifications for Road and Bridge Construction.

DESIGN STANDARDS

A. Design the trench geometry based on the runoff volume per unit length of roadway. The drainage area should include the contributing width of roadway and the subsequent pretreatment (vegetated filter strip or decomposed granite cover). Deep and narrow infiltration trenches are most efficient (3 to 4 feet wide and 3 to 12 feet deep) because they provide more static pressure head.

B. Once the design depth has been established, an additional 6 inches can be excavated and filled with clean sand at the trench bottom. The sand will absorb the impact from the overlying aggregate fill so that the underlying soil is not compacted.

C. Observation wells should be located at the downgradient end of the infiltration trench. The well design consists of a 6-inch diameter perforated stand pipe that extends the entire trench depth with a weatherproof cap to monitor water levels and sediment accumulation within the infiltration trench. Label the trench depth on the monitor well cap.

D. Provide pretreatment whenever possible using a vegetated filter strip where dense vegetation can be maintained. Otherwise, decomposed granite cover should be used between the contributing roadway drainage area and the infiltration trench.

MAINTENANCE AND INSPECTION REQUIREMENTS

<u>Inspections</u> – Trained ADOT Maintenance personnel should perform regular inspections to confirm the trench is draining within 72 hours. Trash and debris should be regularly removed from the trench surface. Two critical aspects to monitor are draining capacity and sediment accumulation, which should be evaluated as follows:

- After 72 hours of a design (significant) storm event, evaluate whether the trench has drained. Drop a groundwater sounder in the observation well and record the depth of static water (if any) below the ground surface. Static water could be indicative of an ineffective (clogged) trench and maintenance may be required.

- To evaluate sediment accumulation, the trench must be completely drained and dry. Feed a tape measure to the bottom of the observation well until the tape hits the well bottom and record the depth at the top edge of the well. ***Do not force the tape further down after the first sign of resistance.*** Compare this depth to the total well depth, which is labeled on the underside of the observation well cap. The depth of sediment accumulation can be calculated and recorded as:

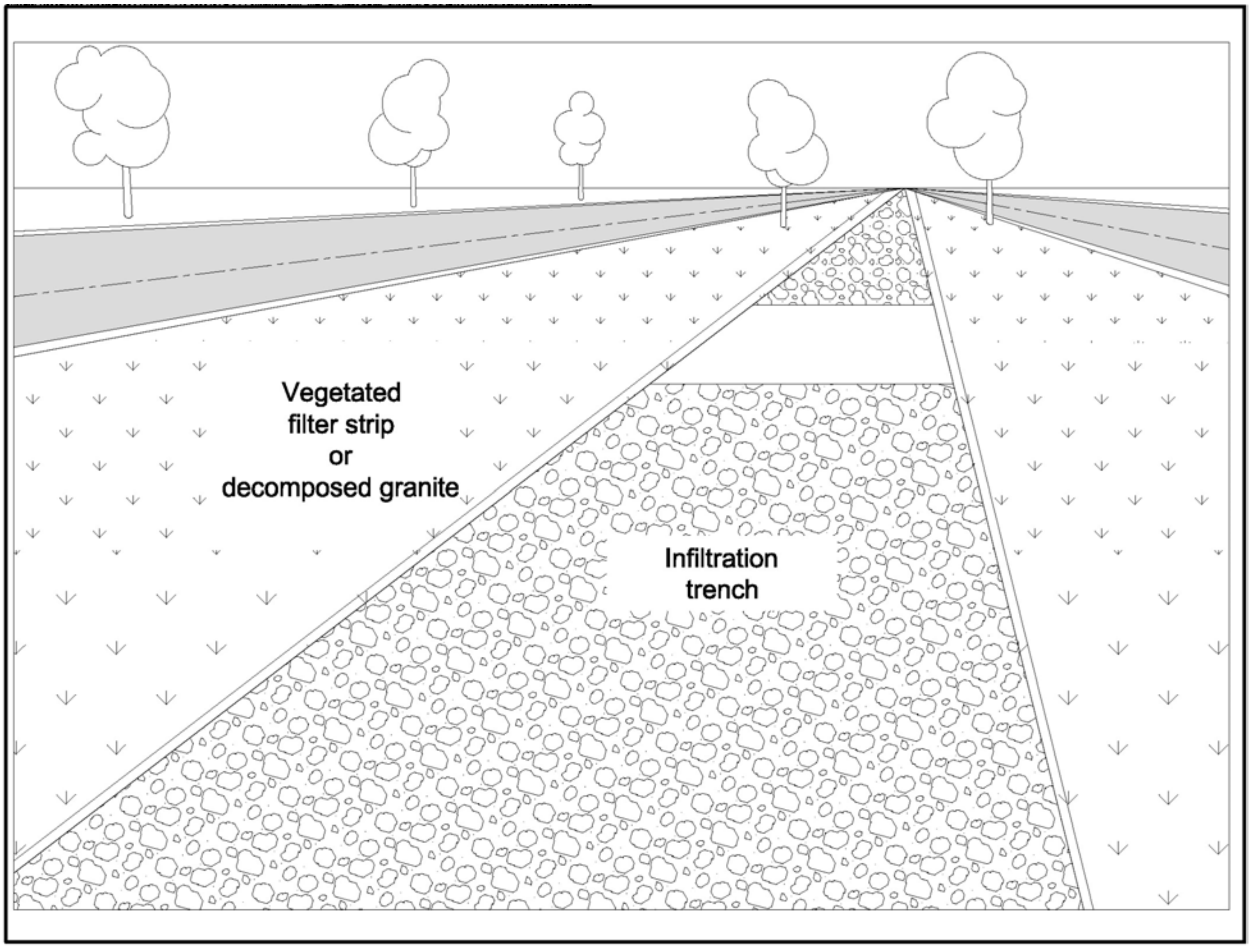
  Sediment Accumulation = Well Depth - Measured Depth

<u>Sediment Removal</u> – If ADOT decides that the infiltration trench was effective and that a new infiltration trench should be reconstructed, sediment should be removed after the depth of sediment accumulation has reached the slope of the trench; refer to the Infiltration Trench schematic (Side View). Sediment can be removed from the trench by removing the aggregate, screening out the accumulated sediment and other debris, reconstructing the trench with the clean aggregate.

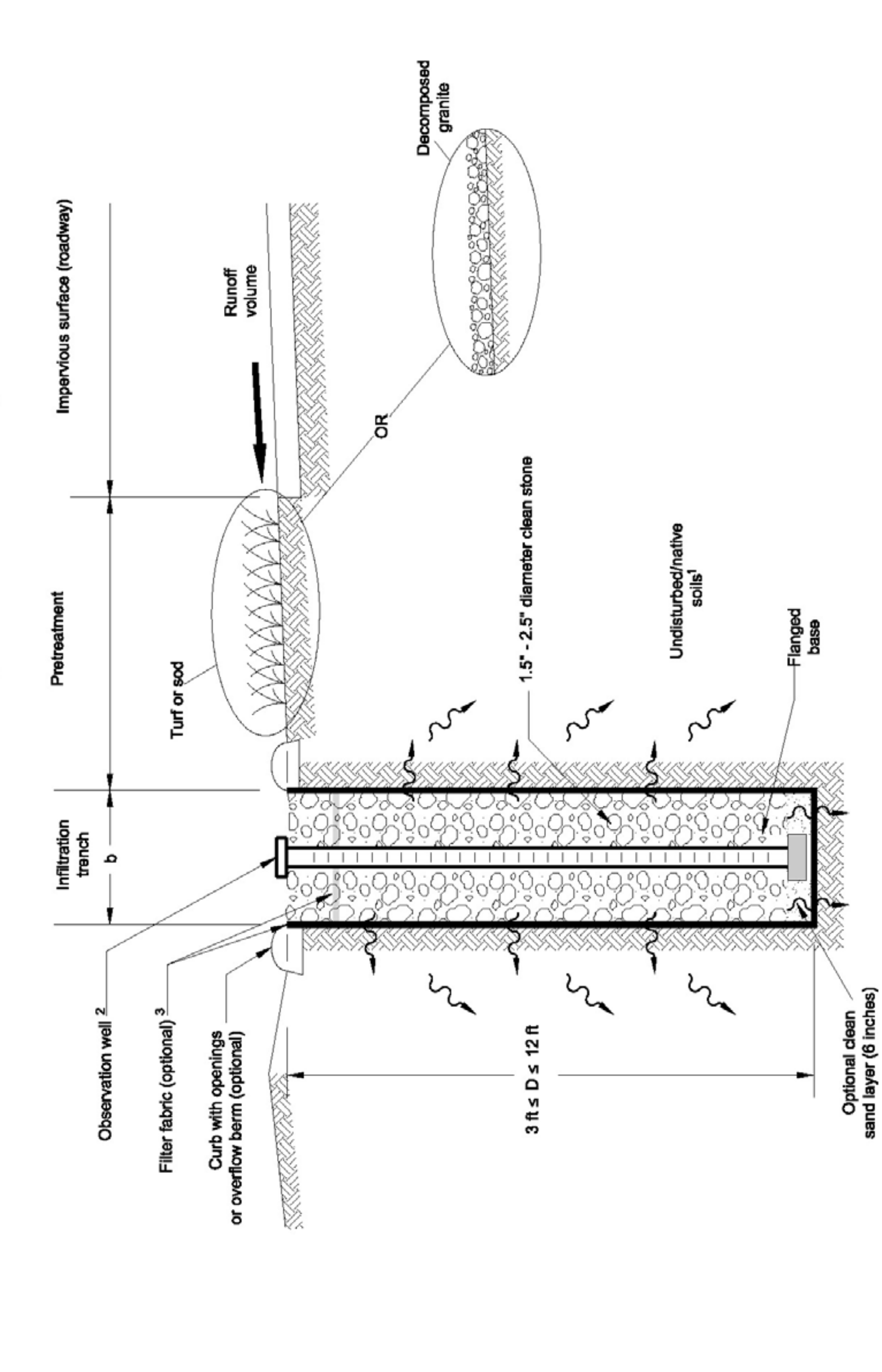
<u>Nuisance Control</u> – Inspect for standing water at the end of each storm event. No additional nuisance control is necessary if the infiltration trenches drain properly.

<u>Traffic Control</u> – Implement standard ADOT maintenance traffic control if located along a shoulder or median.

SCHEMATICS


Vegetated
filter strip
or
decomposed granite
Infiltration
trench

Infiltration Trench (Profile View)



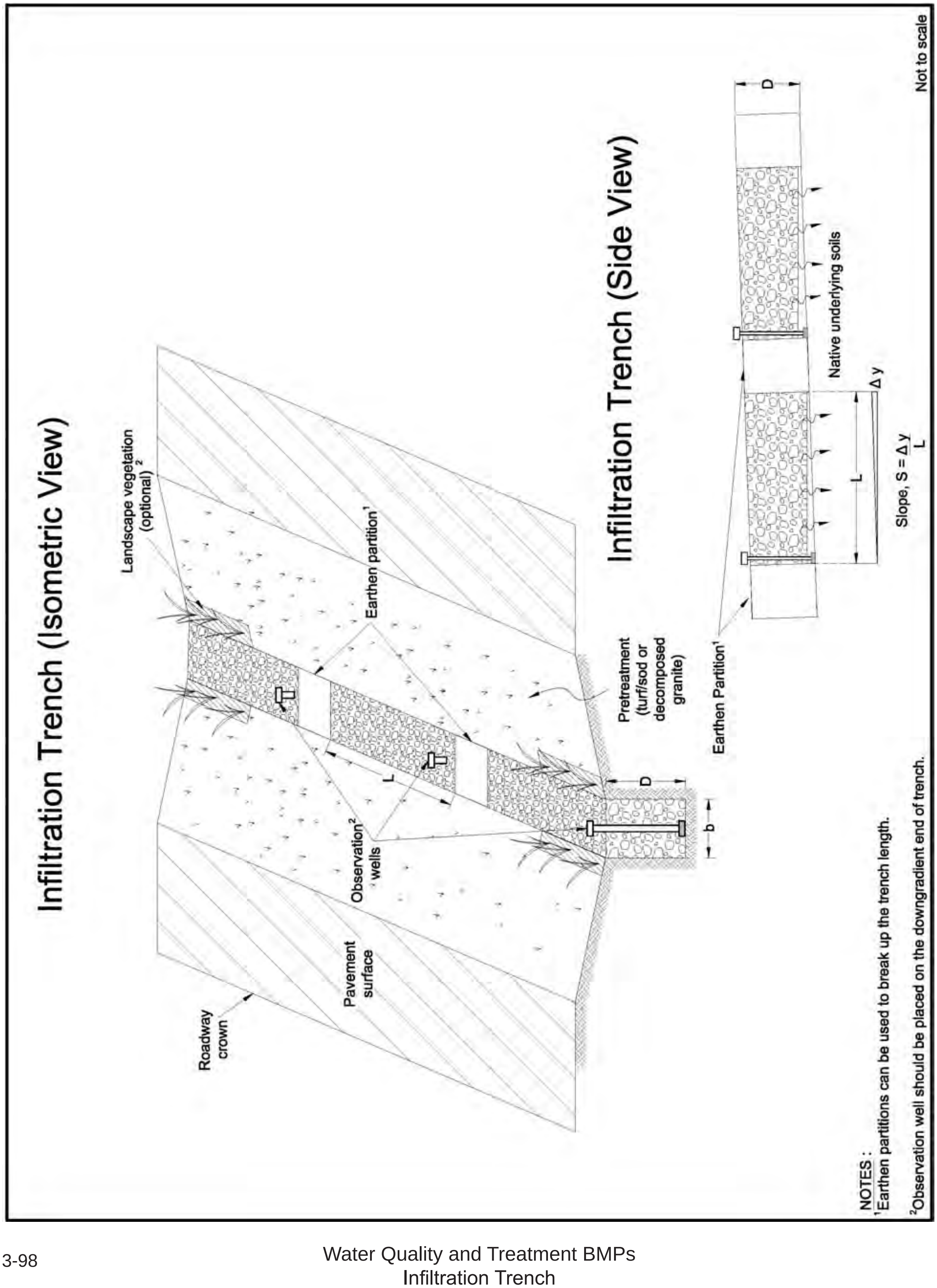
NOTES:

[1]Maximum infiltration rate of surrounding/ underlying soils should be 0.5 inches per hour.

[2]Observation well should contain 6" diameter perforated pipe (1" slot size), flanged at the bottom to anchor it, and a removeable cover.

[3]The filter fabric can be folded over 6" from the top of the trench and completed with aggregate fill for additional pre-treatment.

Not to scale


Infiltration Trench (Isometric View)
Landscape vegetation (optional)2
Earthen partition1
Roadway crown
Pavement surface
Observation2 wells
L
D
b
Pretreatment (turf/sod or decomposed granite)
Earthen Partition1
Infiltration Trench (Side View)
D
Native underlying soils
Δ y
L
Slope, S = Δ y / L
Not to scale
NOTES :
1Earthen partitions can be used to break up the trench length.
2Observation well should be placed on the downgradient end of trench.

REFERENCES AND RESOURCES

Arizona Department of Transportation (ADOT), *Standard Specifications for Road and Bridge Construction*, 2008.

California Department of Transportation (Caltrans), *Storm Water Quality Handbooks: Project Planning and Design Guide*, April 2003.

California Department of Transportation (Caltrans), *Storm Water Treatment BMP New Technology Report, SW-04-069.04.02*, April 2004

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Minnesota Pollution Control Agency (MPCA), *Protecting Water Quality in Urban Areas, Chapter 4: BMPs for Stormwater Systems*, 2000.

Ohio Department of Transportation (ODOT), Division of Highway Operations, Office of Structural Engineering, Hydraulic Section, *Location and Design Manual, Volume 2, Drainage Design Procedures, Chapter 1100*, January 2006.

Retention and Detention Basins

DEFINITION

Retention and detention basins are facilities typically constructed below the roadway shoulder where the appropriate footprint is available to hold runoff, and are also referred to as pond-in-place practices. Retention and detention basins are excavated in most any configuration to meet footprint restrictions and can be vegetated. The difference between retention and detention is explained further in the **Purpose** section below.

OVERVIEW

GENERAL INFORMATION
Key design factors: ▪ A sediment forebay or equivalent upstream pretreatment must be provided. ▪ Typical minimum length:width ratio is 1.5:1.
Maintenance needs: ▪ Periodic inspections of the sediment forebay, outlet structure, spillway, and vegetation. ▪ Removal of floatable debris/trash and sediment.
Most effective when used with: ▪ Pretreatment (i.e. Vegetated Filter Strips or Decomposed Granite Cover).
Alternative BMPs to consider: ▪ Infiltration Basin ▪ Filtration Structures

RATINGS	H	M	L
Associated Costs			
Design		X	
Construction			X
Maintenance			X
BMP Objective			
Erosion control		X	
Drainage conveyance	X		
Water Quality/Treatment	X		
DOT Target Pollutants Removal			
Dissolved or suspended sediment	X		
Biological constituents	X		
Nutrients and pesticides		X	
Heavy metals		X	
Organics	X		

PHOTOGRAPHS

PURPOSE

Retention and detention basins can manage and treat a wide range of runoff volumes (relative to other treatment BMPs). Retention and detention basins are both intended to mitigate stormwater runoff quantity and quality (refer to Section 15.3 of the ADOT Highway Drainage Design Manual for more details). They differ by their intended function, as described below:

- Retention Basin – a structural BMP that impounds all stormwater flows from a design storm until the storm has passed. A retention basin is considered a treatment BMP because it can remove suspended pollutants through settling and being slowly released.
- Detention Basin – a structural BMP that impounds stormwater for a set period of time sufficient to reduce the peak discharge. Similar to retention, a detention basin is considered a treatment BMP because it can remove suspended pollutants through settling, before the water is slowly released to a receiving waterbody, conveyance, or other BMP.

APPROPRIATE APPLICATIONS

Retention and detention basins are appropriate in areas where there is a discharge (not sheetflow) within 1/4 mile of regulated MS4s, sensitive water bodies, or other stakeholder boundaries and the existing soils are ***not*** suitable for infiltration.

LIMITATIONS

Retention and detention basins are ***NOT*** appropriate in the following conditions:

- Do not locate retention or detention basins on unstable slopes or slopes greater than 4:1;
- Basins require a significant footprint relative to other treatment BMPs. If there is not a sufficient footprint, consider an offline configuration at a more convenient location; and
- Retention and detention basins have the potential for thermal impacts/downstream warming.

DESIGN CONSIDERATIONS

Consider the following detention and retention basin design factors:

Soil characteristics – Underlying soils of hydrologic group “C” or “D” are typically adequate to maintain a permanent pool. Retention and detention basins constructed in group “A” soils and some group “B” soils require a pond liner. Evaluation of underlying soils should be based upon an actual subsurface analysis and permeability tests.

Footprint/geometry – The total storage volume must be able to contain the runoff from the design storm corresponding to ADOT’s local drainage design requirement. Offline configurations can also be designed to accommodate larger footprint geometries. As a rule of thumb, a footprint of approximately 2 to 3% of the contributing drainage area is typically required for most retention basins.

Local government code – Refer to local municipal code for local storage requirements and the amount of time allowed for standing water. Also, verify any applicable easement or setback requirements. Setbacks from pond-in-place practices are typically set for building foundations, private and public supply wells, septic systems, and downstream surface water bodies.

Excavation practices – During construction, the excavated material from the basin may be used elsewhere on the project.

Basin safety and stability – Basins excavated more than 4 feet deep should be properly stabilized through benching. A geotechnical engineering analysis must be conducted to ensure the stability of the side slopes.

Construction sequencing – Temporary desilting basins and/or sediment traps (see Section 5.3.3 of the ADOT Erosion and Pollution Control Manual) can be converted into permanent detention or retention basins, where appropriate, after construction has been completed.

Pretreatment – In areas where dense vegetation can be maintained, **Vegetated Filter Strips** should be installed along the perimeter of the basin for pretreatment. Otherwise, **Decomposed Granite Cover** should be used between the contributing roadway drainage area and the basin.

MATERIAL SPECIFICATIONS

Refer to construction material specifications referenced in the **Outlet Protection**, **Spillways**, **Catch Basins and Downdrain Conduits,** and **Culverts** BMP sheets if they are being incorporated into the retention and detention basin design.

DESIGN STANDARDS

Consider the following design factors:

- Design the basin geometry per the design criteria in Section 15.4 of the ADOT Highway Drainage Design Manual and the allowable footprint;
- Furnish a bypass or overflow for the design event discharge;
- Whenever feasible, include vehicle access to the basin for maintenance;
- Vegetate the sides of the basin in accordance with Section 805 of the ADOT Standard Specifications for Road and Bridge Construction.

MAINTENANCE AND INSPECTION REQUIREMENTS

Inspections – After significant storm events, inspect for bank stability, signs of erosion, and damage to outlet structures. Look for signs of pollution such as oil sheens, discolored water, or odors. Measure sediment accumulation in the sediment forebay.

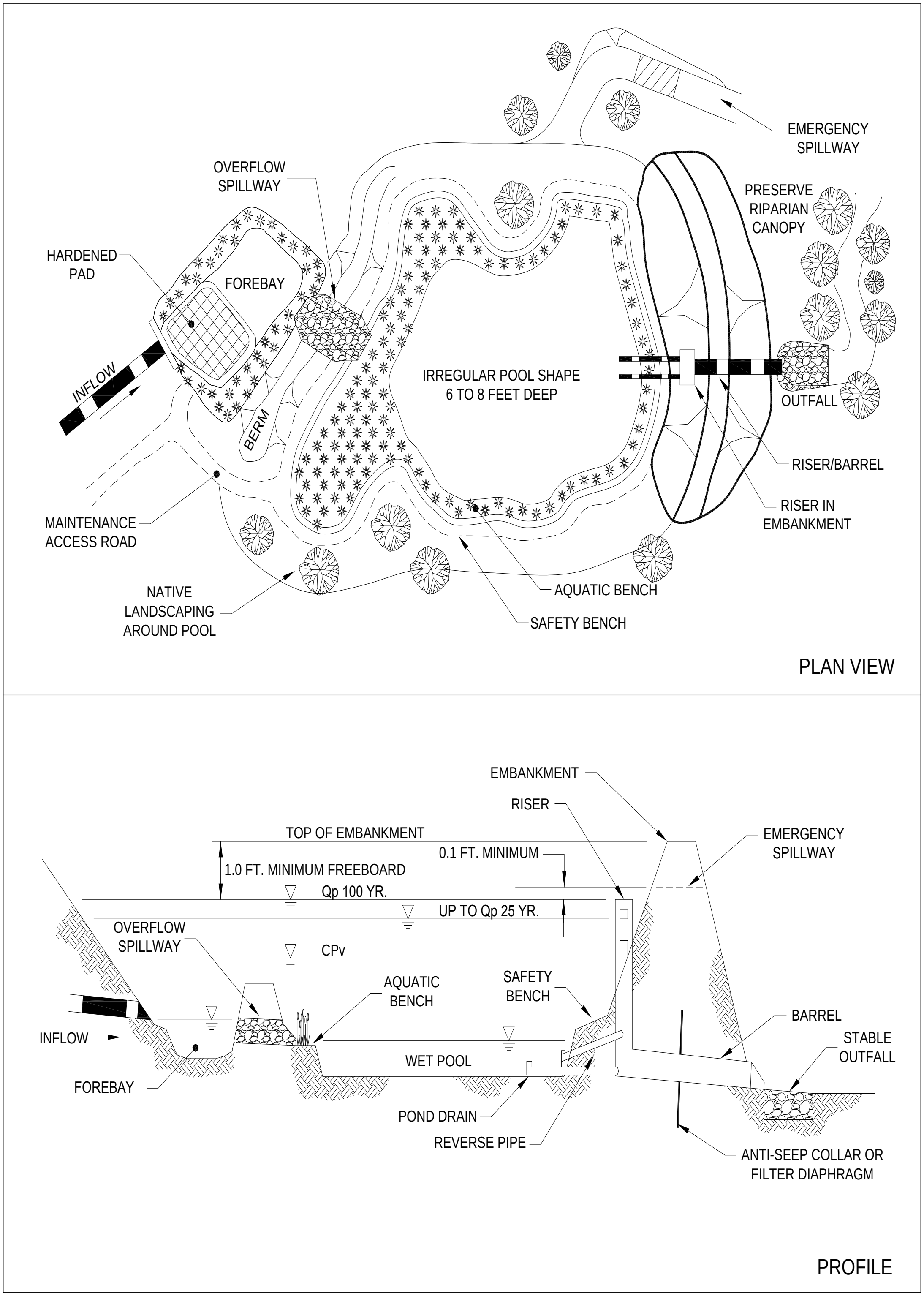
Trash and sediment removal - Trash and other miscellaneous debris should be regularly removed from the basin.

Structural repairs – Repair damage to the basin outlet structures, embankments, control gates, valves, or other mechanical devices. Repair undercut or eroded areas.

Nuisance Control – Inspect for standing water at the end of each storm event. Check for undesirable or invasive vegetation growth. No additional nuisance control is necessary if the basin drains and evaporates properly.

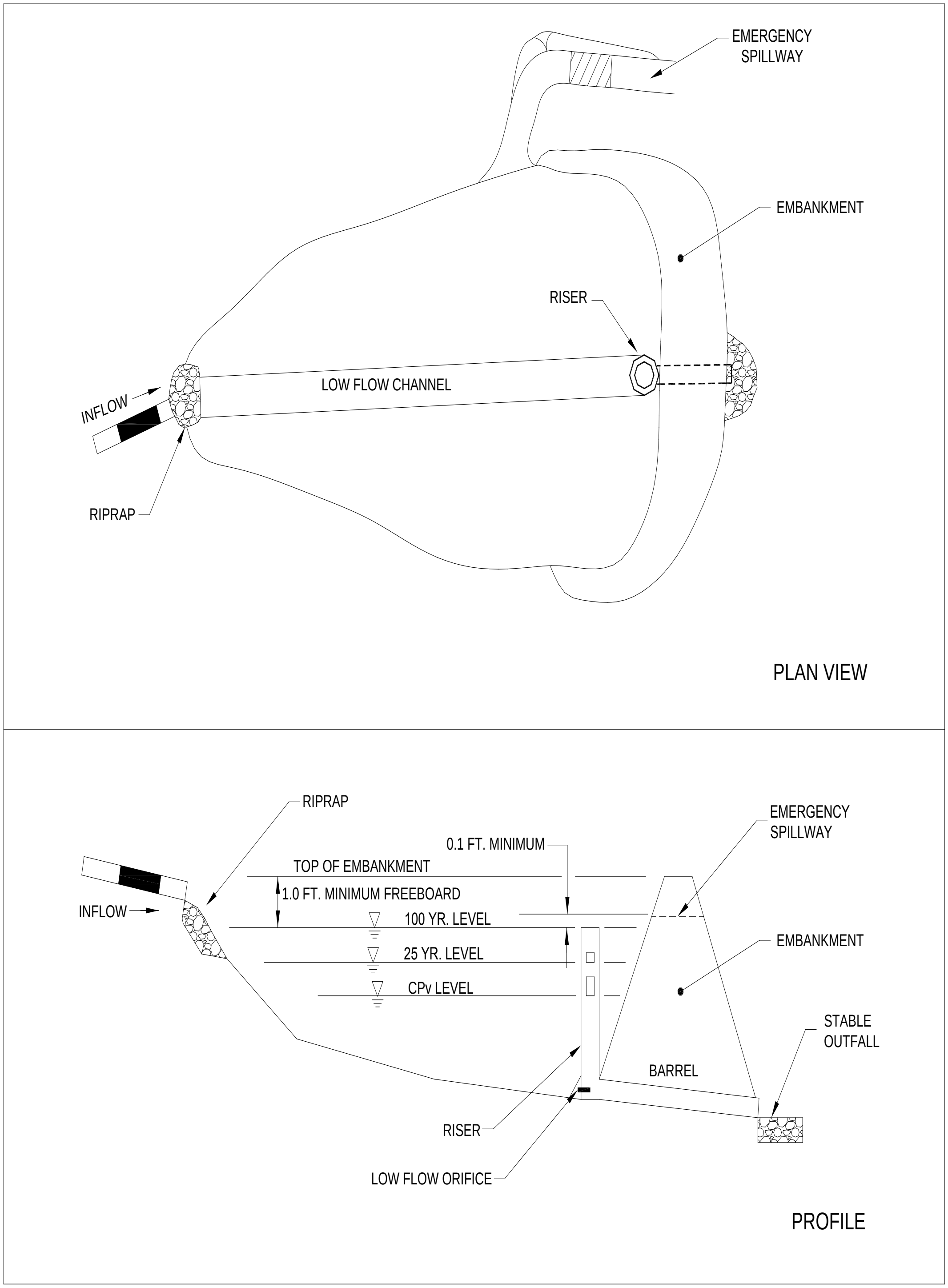
SCHEMATICS

Standard Retention Basin



(Source: adapted from CWP, 2005)

Dry Extended Detention Basin



(Source: adapted from CWP, 2005)

REFERENCES AND RESOURCES

Arizona Department of Transportation (ADOT), *Standard Specifications for Road and Bridge Construction*, 2008.

Arizona Department of Transportation (ADOT), *Highway Drainage Design Manual (draft),* 2006.

California Department of Transportation (Caltrans), *Storm Water Quality Handbooks: Project Planning and Design Guide,* April 2003.

Center for Watershed Protection. *Manual Builder.* Stormwater Manager's Resource Center, Accessed July 2005. www.stormwatercenter.net

Knox County, *Knox County Tennessee Stormwater Management Manual, Volume 2 (Technical Guidance)*, 2007.

Minnesota Pollution Control Agency (MPCA), *Protecting Water Quality in Urban Areas, Chapter 4: BMPs for Stormwater Systems,* 2000.

Vegetated Filter Strips

DEFINITION

Vegetated Filter Strips (VFSs) are typically long but relatively narrow areas of natural (undisturbed) or planted vegetation (ground cover, sod, or grasses). They are used to retard stormwater runoff and consequently settle or trap sediment and other pollutants; hence protecting surface waterbodies or adjacent, downslope properties. They are designed for overland sheet flow and are often well suited to provide pretreatment to other best management practices (BMPs), such as infiltration, filtration, or storage practices.

OVERVIEW

GENERAL INFORMATION
Key design factors: ▪ Mild slopes and uniformly graded surfaces. ▪ Drainage areas less than 5 acres.
Maintenance needs: ▪ Periodic inspections, particularly if irrigated. ▪ May require trash removal. ▪ Routine maintenance of vegetation (i.e. mowing and thatching).
Most effective when used with: ▪ Filtration, Infiltration or pond-in-place treatment practices.
Alternative BMPs to consider: ▪ Decomposed Granite Cover.

RATINGS	H	M	L
Associated Costs			
Design		X	
Construction			X
Maintenance	X		
BMP Objective			
Erosion control	X		
Drainage conveyance			X
Water Quality/Treatment		X	
DOT Target Pollutants Removal			
Dissolved or suspended sediment	X		
Biological constituents			X
Nutrients and pesticides		X	
Heavy metals		X	
Organics		X	

PHOTOGRAPHS

PURPOSE

VFSs achieve several benefits as a BMP, including (1) reduce sediment and other pollutants in sheetflow runoff, (2) retard and reduce (via infiltration) the total volume of runoff, (3) prevent downslope erosion, and (4) enhance biological diversity and aesthetics. VFSs are considered a treatment BMP because they can remove pollutants through filtration, adsorption, infiltration, and biological uptake.

APPROPRIATE APPLICATIONS

VFSs are appropriate when it is necessary to pretreat stormwater before it reaches a downslope BMP, regulated MS4s, or is within ¼ mile of an impaired, unique, or not attaining waterbody, or other sensitive area requiring stormwater runoff treatment.

LIMITATIONS

VFSs are not appropriate in the following conditions:

- In urban areas, use decomposed granite cover to achieve similar results;
- VFSs do not effectively treat concentrated flows; they are better suited for sheetflow discharges;
- Slopes greater than 8% and non-uniformly graded surfaces are not appropriate for VFSs. Both the VFS and the upland drainage area must also be relatively flat and uniformly graded for VFSs to function properly;
- Research by other DOTs has shown that VFS can not treat a drainage area greater than 5 acres and do not provide significant attenuation of peak discharges;
- VFSs are better suited for suspended pollutants and sediment than for dissolved pollutants;
- VFSs require irrigation or sufficient precipitation to sustain growth; and
- VFSs need to be accessible for maintenance.

DESIGN CONSIDERATIONS

VFSs consist of the following design factors:

<u>Soil characteristics</u> – Fine grained soils within the drainage area will require wider filter strips than coarse grained soils.

<u>Drainage area</u> – The upslope drainage area, soil properties, and percent imperviousness all dictate the required width (footprint) of the VFS to achieve effective pollutant removal from the runoff. Impervious upslope drainage areas will require wider filter strips compared to pervious surfaces.
<u>Local government code</u> – Refer to local municipal code or other agency requirements for restrictions

on the use of vegetation along the right-of-way.

Construction sequencing – VFSs are likely to be installed during the landscaping phase, although they can be installed at other points during the construction project to help stabilize and protect key areas of the site.

Perimeter curbs – Optional curbing prior to the VFS can be used for protection from roadway traffic.

Vegetation cover – Native grass (seeding) or turf vegetation (sodding) is typically used in the VFSs. Consider the following when selecting vegetation:

- *Salt tolerance* – vegetation should be able to withstand high salt concentrations in regions of the state where winter weather treatment is used.
- *Nutrient needs* – turfs with low nitrogen demand are preferred to minimize the amount of supplemental nitrogen (fertilizer) that must be applied, which in turn minimizes the chances of releases or spills to downstream receiving water bodies.
- *Water needs* – drought resistant vegetation are preferable to avoid the need for supplemental irrigation, when possible.

For optimal performance, the vegetation cover should be dense. Refer to the **Erosion Control Blanket** BMP for design guidance on blankets and mats that can be used to enhance the seedling growth, uniformity, and density.

Slope – The VFS should be mildly sloped and uniformly graded to maintain sheet flow whenever possible. Research data shows that VFSs are not appropriate if the slope exceeds 8%.

MATERIAL SPECIFICATIONS

Refer to Section 805 of the ADOT Standard Specifications for Road and Bridge Construction for ADOT-approved or preferred seed mix specifications to be used within the vegetated filter strip. Consult with the ADOT Roadside Development Section for guidance on selecting single-specie seed or sod.

DESIGN STANDARDS

A. The VFS **width** must be oriented perpendicular to the discharge source and the receiving body (natural waterbody, channel, open area or other BMP).

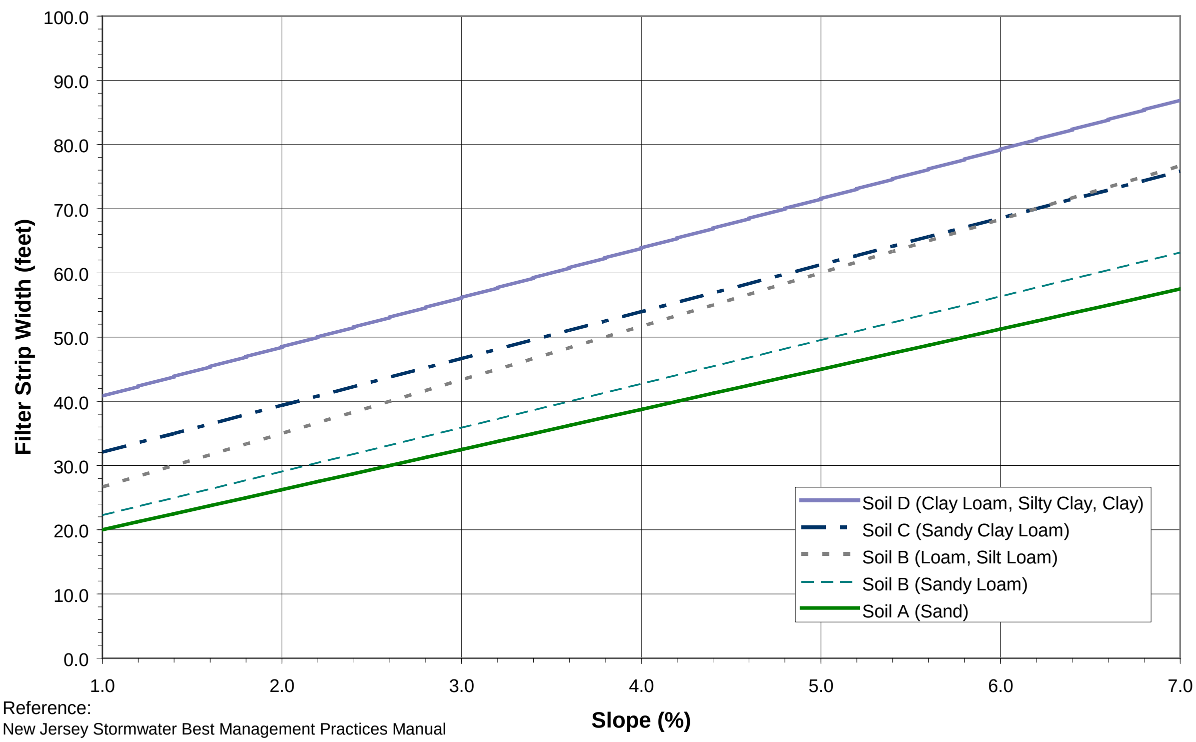
B. Determine the hydrologic soil group of the drainage area soil, based on a soil survey map.

C. Determine the maximum slope of the filter strip width.

D. Based on the hydrologic soil group and the maximum slope, determine the design filter strip width, using the figure on the following page.

E. Refer to Section 805 of the ADOT Standard Specifications for Road and Bridge Construction for specifications and/or guidance on soil preparation and seed application/establishment within the VFS. Consult with the ADOT Roadside Development Section for guidance on installing single-species seed or sod.

Filter Strip Width vs. Slope



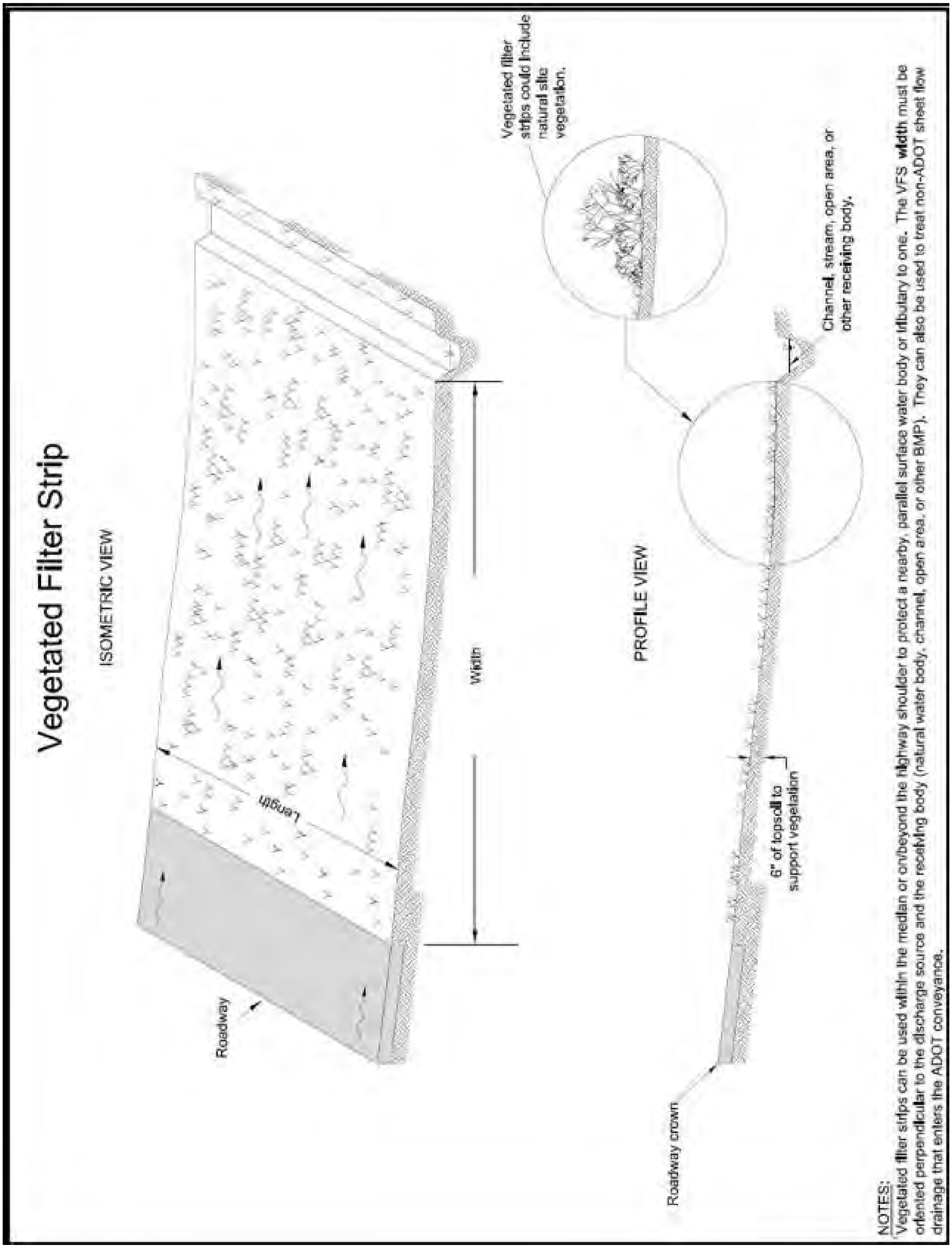
Reference:
New Jersey Stormwater Best Management Practices Manual

MAINTENANCE AND INSPECTION REQUIREMENTS

Inspections – VFSs should be inspected for excessive buildup of the vegetated mat and/or accumulated sediment at the road/VFS interface, growth of unwanted vegetation (weeds or invasive species), and pests. All these things may disrupt the runoff sheetflow, reduce the effectiveness of the VFS and negatively impact natural receiving water bodies. Irrigation infrastructure, if used, should be inspected for leaks and malfunctions.

Maintenance – Vegetation should be routinely maintained to ensure optimal pollutant removal efficiency, maximize the design life of the VFS, and keep the roadside aesthetically pleasing. Vegetation maintenance may include mowing, aerification or other thatch management practices, removing excess clippings, and appropriate application of nutrients. Clippings can be added back into the turf stand to recycle nutrients. Floatable trash and debris should be manually removed, ideally after significant storm events.

SCHEMATICS


Vegetated Filter Strip
ISOMETRIC VIEW
Roadway
Length
Width
Vegetated filter strips could include natural site vegetation.
PROFILE VIEW
Roadway crown
6" of topsoil to support vegetation
Channel, stream, open area, or other receiving body.
NOTES:
Vegetated filter strips can be used within the median or on/beyond the highway shoulder to protect a nearby, parallel surface water body or tributary to one. The VFS width must be oriented perpendicular to the discharge source and the receiving body (natural water body, channel, open area, or other BMP). They can also be used to treat non-ADOT sheet flow drainage that enters the ADOT conveyance.

REFERENCES AND RESOURCES

California Stormwater BMP Handbook, New Development and Redevelopment, 2003

Knox County, *Knox County Tennessee Stormwater Management Manual, Volume 2 (Technical Guidance),* 2007.

Minnesota Pollution Control Agency (MPCA), *Protecting Water Quality in Urban Areas, Chapter 4: BMPs for Stormwater Systems*, 2000.

New Jersey Stormwater Best Management Practices Manual, Chapter 9.10: Standard for Vegetative Filters, February 2004.

POST-CONSTRUCTION BEST MANAGEMENT PRACTICE SELECTION GUIDE

INTRODUCTION

To keep up with construction and regulatory requirements, ADOT has developed a process diagram with guidelines for determining where, when, and how post-construction (permanent) best management pratices (BMPs) are applied during the design process (installation or expansion) of roadways in Arizona. The flow chart included in this document captures and maps out the decisions and considerations that ADOT roadway designers should follow in order to select post-construction BMPs. The flowchart is not laid out in the chronological order followed during design, but rather organized into four categorical sections:

Section I: Applicability Analysis - to assess whether or not post-construction BMPs are applicable to the project of interest.

Section II: Offroad, Overland Flow Erosion Control - to identify and select control post-construction BMPs that minimize or eliminate the release and transport of sediment in stormwater.

Section III: Roadway Drainage Conveyance - to identify and select post-construction BMPs that collect and convey stormwater from the roadway.

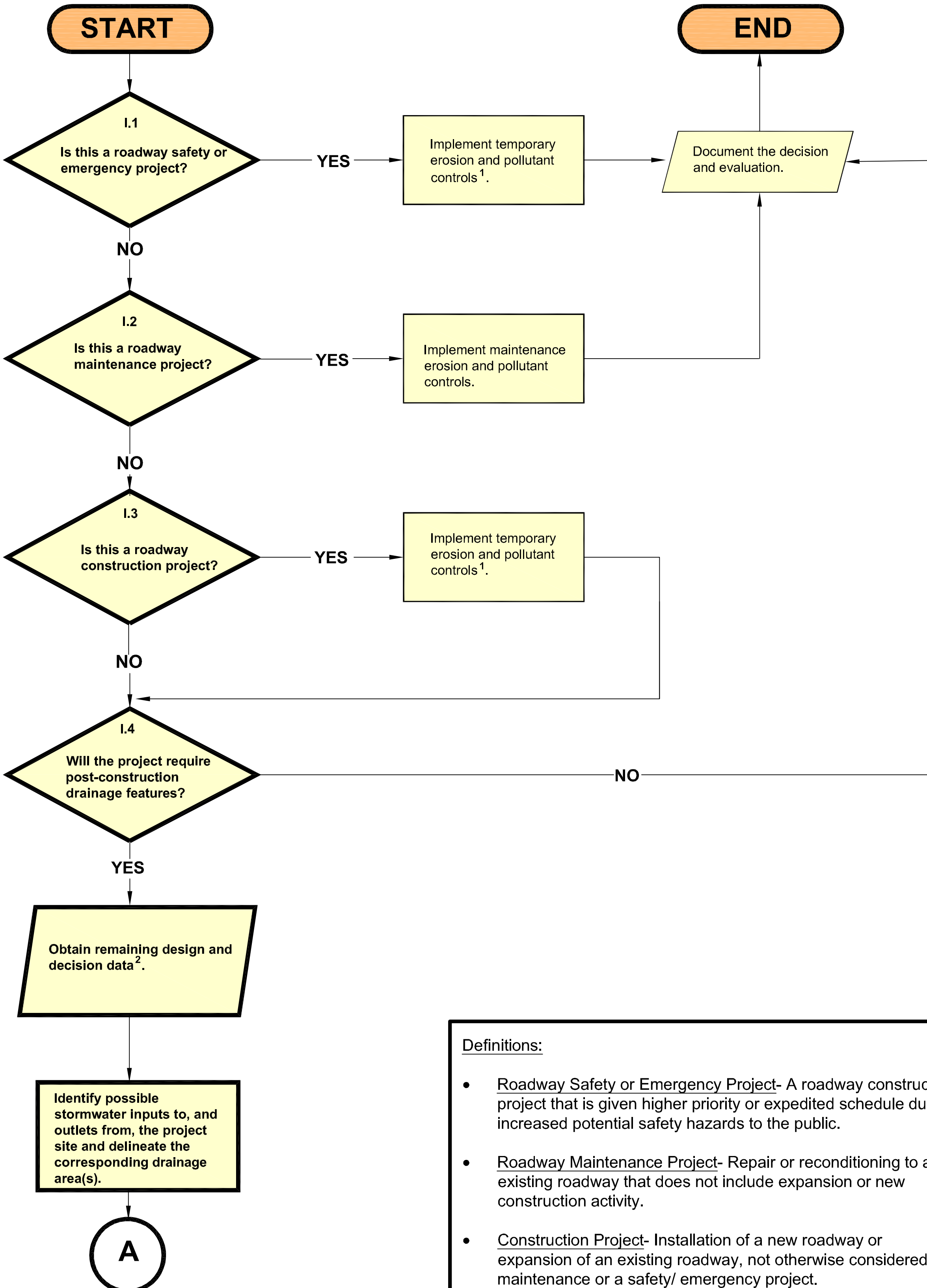
Section IV: Water Quality and Treatment - to identify and select post-construction BMPs that treat (pollutant displacement / removal) stormwater before discharging to a receiving water body conveyance, or other BMP.

Throughout the selection process, the roadway designer should document each of the decisions made (and the associated justification or back-up rationale).

LIMITATIONS

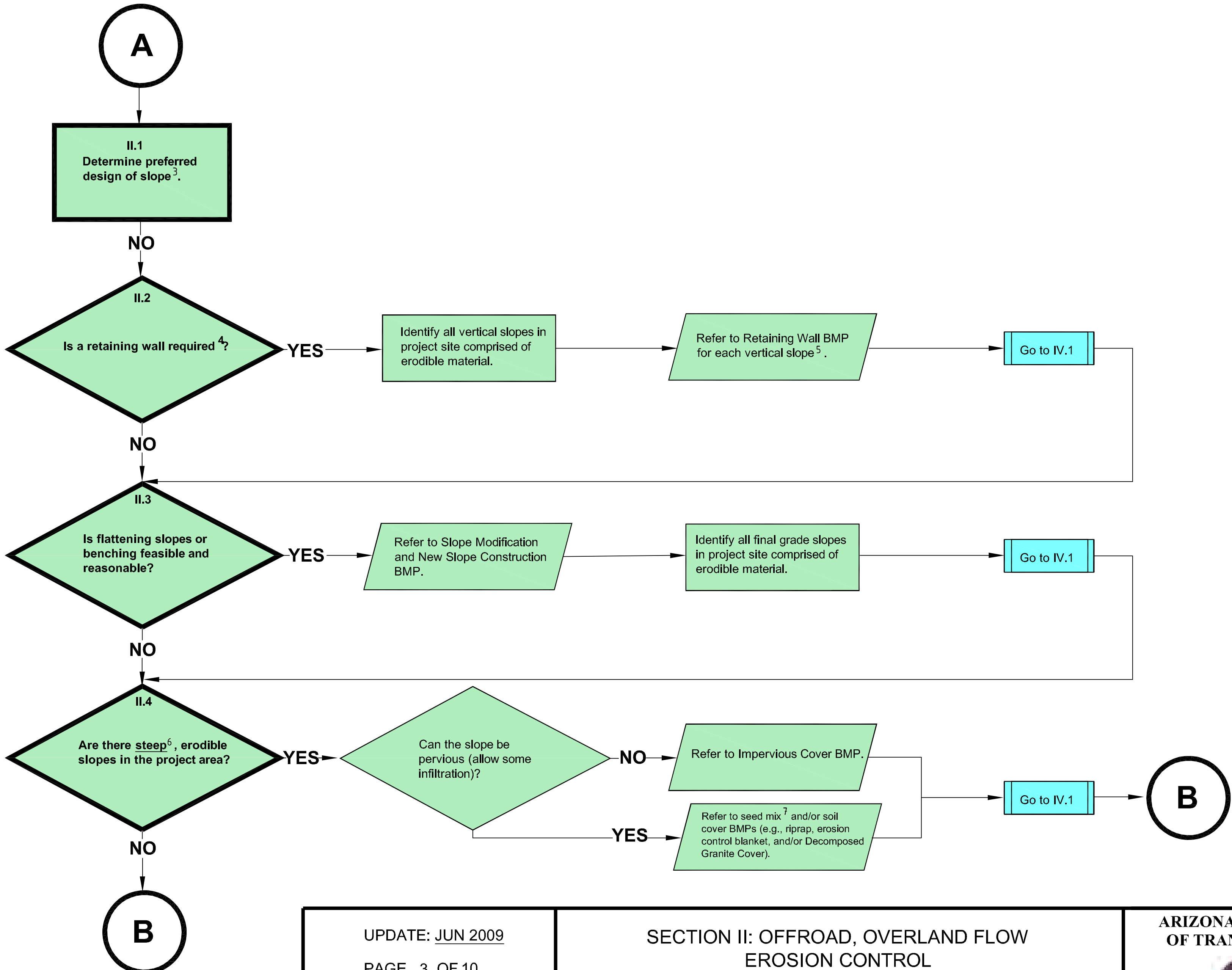
The flow chart in this document has been developed as a general selection methodology based on typical roadway layouts, but it is not necessarily inclusive of all potential project conditions or scenarios. Moreover, the flow chart is only intended to guide the roadway designer through important decision-making steps, not to serve as a "cookbook" for BMP selection. The actual design process may follow a different path/sequence based on specific project constraints and conditions.

NOTE: Superscripts shown in symbols throughout the following pages are defined immediately after the flow chart, starting on page 8.



Definitions:

- Roadway Safety or Emergency Project- A roadway construction project that is given higher priority or expedited schedule due to increased potential safety hazards to the public.
- Roadway Maintenance Project- Repair or reconditioning to an existing roadway that does not include expansion or new construction activity.
- Construction Project- Installation of a new roadway or expansion of an existing roadway, not otherwise considered a maintenance or a safety/ emergency project.

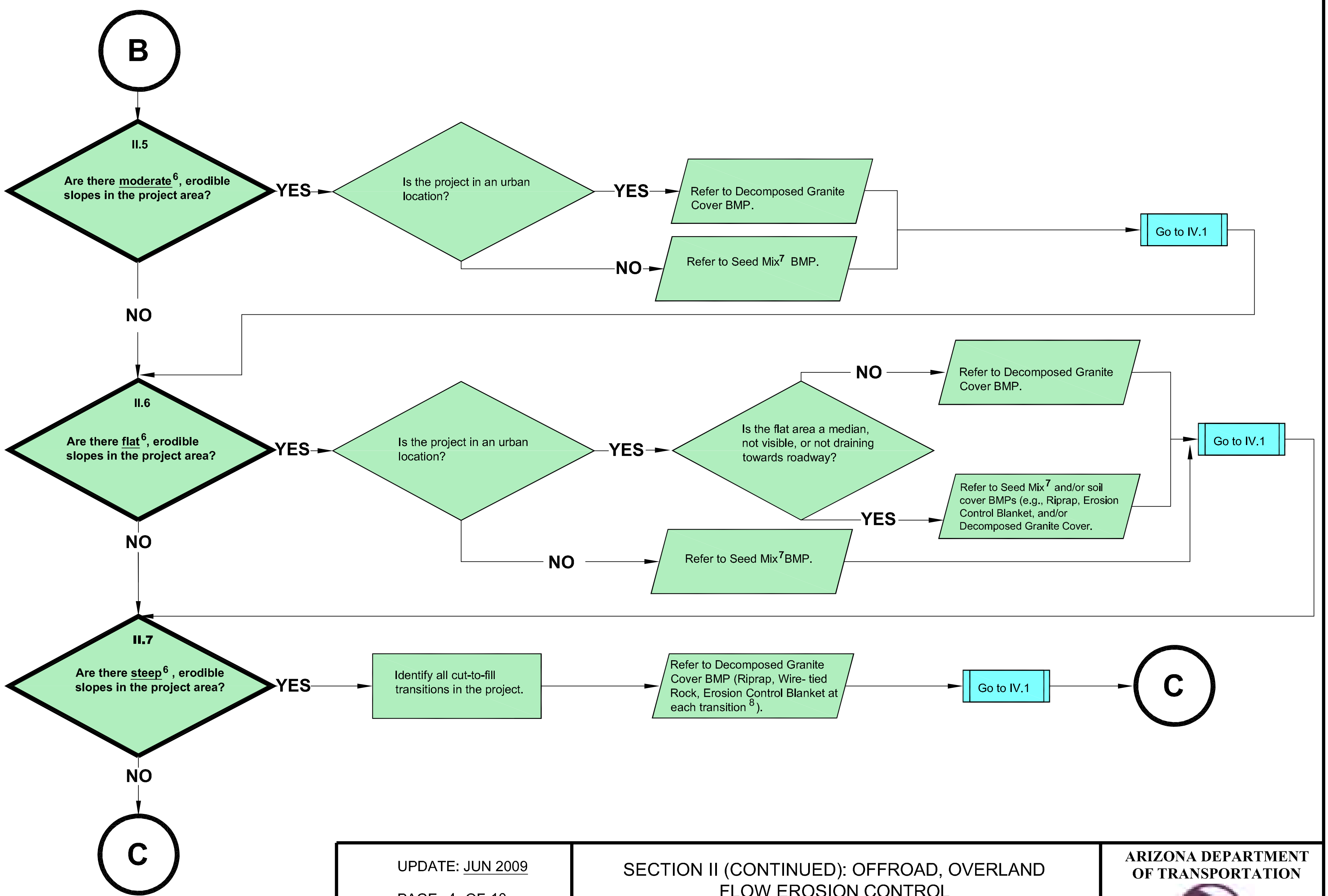


SECTION II: OFFROAD, OVERLAND FLOW EROSION CONTROL

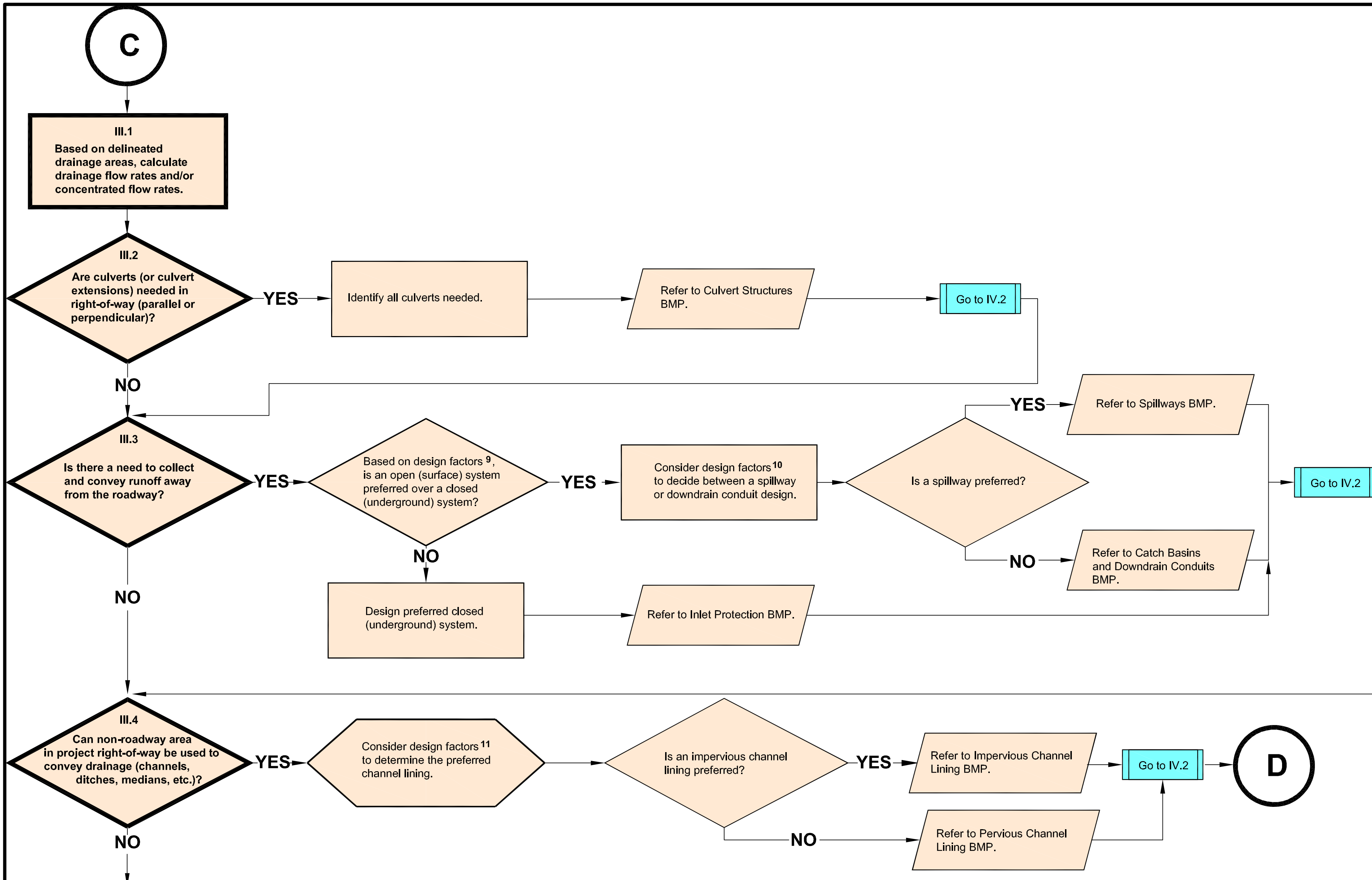
INTERMODAL TRANSPORTATION DIVISION

POST- CONSTRUCTION BEST MANAGEMENT PRACTICE SELECTION GUIDE

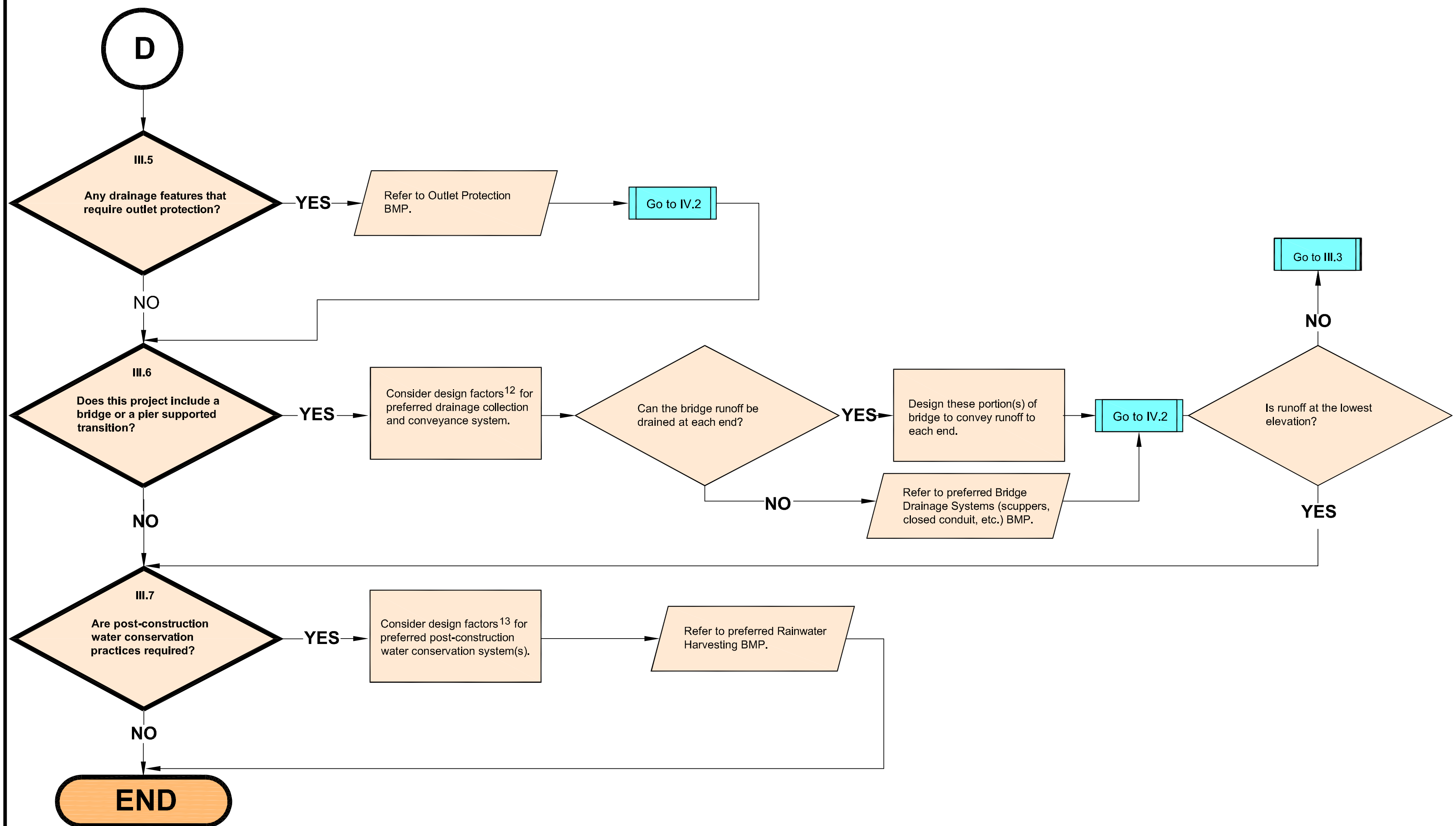
ARIZONA DEPARTMENT OF TRANSPORTATION



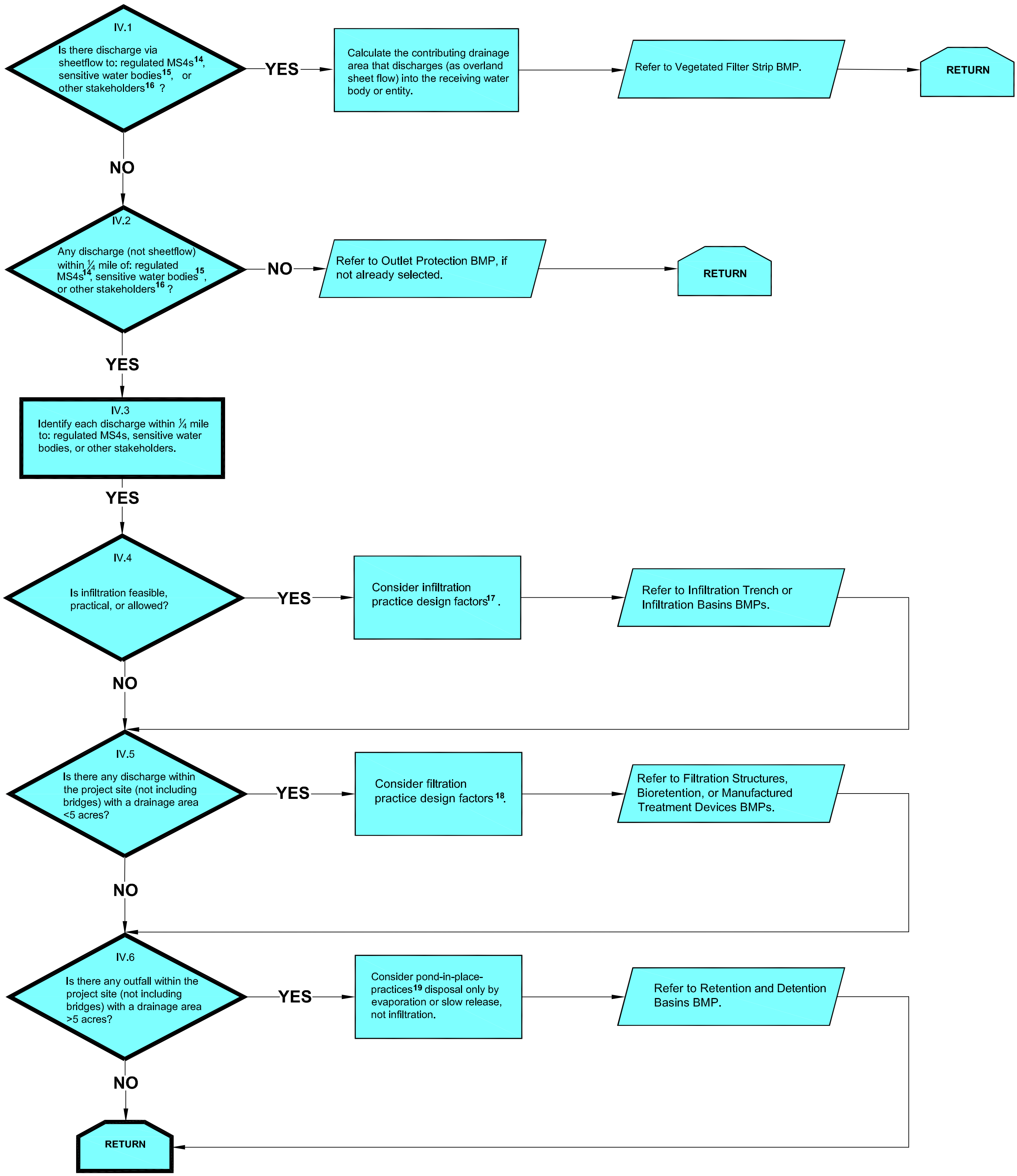
UPDATE: JUN 2009 PAGE 4 OF 10	SECTION II (CONTINUED): OFFROAD, OVERLAND FLOW EROSION CONTROL	ARIZONA DEPARTMENT OF TRANSPORTATION
INTERMODAL TRANSPORTATION DIVISION	**POST- CONSTRUCTION BEST MANAGEMENT PRACTICE SELECTION GUIDE**	



UPDATE: JUN 2009 PAGE 5 OF 10	SECTION III : ROADWAY DRAINAGE CONVEYANCE	ARIZONA DEPARTMENT OF TRANSPORTATION ADOT
INTERMODAL TRANSPORTATION DIVISION	**POST- CONSTRUCTION BEST MANAGEMENT PRACTICE SELECTION GUIDE**	



UPDATE: JUN 2009 PAGE 6 OF 10	SECTION III (CONTINUED): ROADWAY DRAINAGE CONVEYANCE	ARIZONA DEPARTMENT OF TRANSPORTATION ADOT
INTERMODAL TRANSPORTATION DIVISION	**POST- CONSTRUCTION BEST MANAGEMENT PRACTICE SELECTION GUIDE**	



SECTION IV: WATER QUALITY AND TREATMENT

ARIZONA DEPARTMENT OF TRANSPORTATION

ADOT

INTERMODAL TRANSPORTATION DIVISION

POST- CONSTRUCTION BEST MANAGEMENT PRACTICE SELECTION GUIDE

FOOTNOTES:

[1] Some temporary controls can be modified to be "permanent" or post-construction in nature and can be addressed at any time during the project.

[2] Decision data may include (but not limited to) the following information:

Topographic
- Detailed terrain map of the project site

Drainage
- Drainage report(s)
- Hydrologic and hydraulic analysis

Soils/Geology
-Geotechnical report(s)
- Soil type/texture map(s)
- Karst geology map(s)

Climatic
- Temperature data
- Annual precipitation

Water Quality*
- Water Quality Standards
- TMDLs
- 303(d) list
- Impaired unique surface waters
- Other stakeholders (MS4s)

Additional Data
- Land use map(s)
- Well location map(s)
- Septic system locations
- Utility easements

*Refer to the following website for some of this data: www.azdot.gov/adot_and/storm_water/stormwater.asp (external)

[3] Consider the following slope design factors in determining appropriate post-construction erosion control BMP(s):

Long-term maintainability - includes cost, time, labor, and equipment required to maintain erosion control BMP.

Soil erodibility - based on soil type and slope angle/length.

Stakeholders - aesthetic and visual considerations, including compliance with MOUs and agreements with other public entities (BLM, Forest Service and Indian Tribes).

Urban vs. Rural - in most cases, use decomposed granite in urban areas and seeding in rural areas.

Vegetation - seed mix is determined by biozone.

Right-of-way - the feasibility and practicality of slope flattening often depends on available right-of-way.

[4] ADOT uses retaining walls for slope stability on erodible slopes ranging from vertical to the lowest allowable angle of repose among other purposes (stakeholder requirements, nearby Superfund sites, etc.).

[5] Retaining wall designs should include consideration of how best to divert drainage flows that occur behind and above the retaining wall and minimize erosion.

[6] Identifiy slopes* in project within the following categories:

Steep - between 2:1 and lowest allowable angle of repose.

Moderate - between 4:1 and 2:1

Flat - less than 4:1

*Note that earth balancing may increase or decrease some slopes within project.

[7] Refer to ADOT guidance/specifications for proper seed mix, mulches, tackifier, soil amendments, and other requirements for the given biozone.

[8] The ADOT Erosion and Pollution Control Manual does not cover deep or unique cut-to-fill transitions.

[9] Consider the following design factors in deciding between a closed vs. open system:

Existing infrastructure - match or tie into what already exists.

Urban area - more likely to require a closed system.

Topography - closed systems required for roadways below surrounding elevation.

Other factors - stakeholders, aesthetics, etc.

[10] Consider the following design factors in deciding between spillways vs. downdrain conduits:

Slope angle and length - the steeper or longer the slope, the more likely a downdrain conduit should be used.

Elevation differential - spillways are preferable for shorter elevation differentials.

Costs and maintenance - select the system that requires the least long-term maintenance.

Rural vs. urban - spillways are typically installed in rural areas while downdrain conduits are generally used in urban areas.

Other factors - stakeholders, aesthetics, etc.

[11] Consider the following design factors in deciding between impervious vs. pervious channel lining:

Erosivity - select appropriate lining for maximum anticipated velocity and shear stress.

Bends and alignment - impervious lining required for abrupt changes in channel alignment.

Maintenance - select the lining that requires the least long-term maintenance.

Site-specific issues - subsurface contamination, aesthetics, shallow groundwater, etc.

[12] Consider the following design factors in deciding between collecting/conveying water on the bridge or on either end of the bridge:

Width - as the width and/or number of lanes on a bridge increases, the more economical and feasibile it is to collect drainage along multiple locations, rather than draining to the ends of the bridge.

Span of bridge - the longer the bridge span, the more economical and feasibile it is to collect drainage along multiple locations, rather than draining to the ends of the bridge.

Slope/pitch of bridge - if the slope or pitch causes all or most of the drainage to be collected and conveyed on one side of the bridge, it is likely to be more economical and feasibile to collect drainage along multiple locations, rather than draining to the ends of the bridge.

[13] Consider the following design factors for selecting the appropriate rainwater harvesting practice(s):

Regulatory/stakeholder requirements - state, local government, and other stakeholder requirements may specify rainwater harvesting requirements.

Integration with other post-construction BMPs selected for the project - some BMPs, such as infiltration basins, are inherently suited for rainwater harvesting.

Installation and maintenance costs - may be an important factor in the rainwater harvesting methodology used.

Conservation volume - the rainwater harvesting BMP must be sized properly to handle the required stormwater volume to be conserved.

14 Regulated MS4s boundaries refer to:

Phase I - current incorporated boundaries.

Phase II - urbanized area (UA), based on most recent census data.

Other designated MS4s - municipalities designated by ADEQ (40 CFR 122.32(a)(2)).

Refer to the MS4 boundary areas map at the following website: www.azdot.gov/adot_and/storm_water/stormwater.asp (external)

15 Sensitive water bodies refer to:

Unique (outstanding) waters - as defined by ADEQ as waters of exceptional recreational or ecological significance because of unique attributes, including but not limited to geology, flora, fauna, water quality, and/or aesthetic values, or waters that sustain threatened or endangered species. Refer to current ADEQ list.

Impaired waters - are defined by ADEQ as routinely exceeding the Total Maximum Daily Load (TMDL) for pollutants. The TMDL is the amount of pollutant a body of water can receive and still meet surface water quality standards. Refer to current ADEQ list.

Not attaining waters - a surface water for which: (1) a TMDL has been completed and approved by EPA, but the water standards are not yet attained, (2) other pollution control requirements are expected to result in the attainment of water quality standards by the next regularly scheduled listing cycle, or (3) the impairment is not related to pollutant loading, but is caused by pollution (e.g., hydromodification).

Refer to the ADOT Receiving Waters map at the following website: www.azdot.gov/adot_and/storm_water/stormwater.asp (external)

16 Other stakeholders may include tribal lands, Forest Service land, and other third party public entities that require sheetflow water quality treatment.

View maps of stakeholder lands that the project will impact at the following website: www.azdot.gov/adot_and/storm_water/stormwater.asp (external)

17 Consider the following infiltration practice design factors:

Footprint/geometry - based on design drainage volume. Offline configurations can also be designed to accomodate larger footprints.

Local government code - several cities and counties stipulate infiltration requirements, such as the maximum amount of time allowed for standing water.

Soil permeability - to determine percolation rate and avoid infiltrating above collapsible soils.

Vegetation - in areas where vegetation can be maintained, bioretention should be considered.

18 Consider the following filtration practice design factors:

Pollutant of concern - particularly important if discharging to a sensitive water body. Compare the pollutants for which the surface water body is impaired to ADOT roadway generated pollutants. If applicable to ADOT, select the filtration media/BMP with the highest removal efficiency of the target pollutant.

Footprint/geometry - based on design drainage volume. For MS4s, underground filters or smaller footprint filters may be preferred. Offline configurations can also be designed to accomodate larger footprints.

Aesthetics - stakeholders may require or prefer that filtration structures and devices not be highly visible.

19 Consider the following pond-in-place practice (retention and detention basins) design factors:

Footprint/geometry - based in design drainage volume. Offline configurations can also be designed to accomodate larger footprints.

Climate - detention is more appropriate over retention in arid regions.

Other requirements - stakeholders, vector control, aesthetics, etc.

Water Quality or Treatment BMP	Area typically served (acres)	Percent of site area required for BMP (%)	Configuration	Soils	Minimum Hydraulic Head (ft)	Maximum upstream slopes (%)	Fracturing geology present	Minimum depth to groundwater	Approximate percent (%) removal efficiencies[1] for select parameters[2]					Safety	Reference(s)
									Total Suspended Solids (TSS)	Metals	Total Phosphorous (TP)	Total Nitrogen (TN)	Total Petroleum Hydrocarbons (TPH)		
Manufactured Treatment Devices	< 1	None	Offline/Online	Independent	1-2	N/A	N/A	N/A	20-40	<10	<10	<10	N/A	Good	FHWA, 2000 NJDA, et al., 2000
Bioretention	1.0 – 4.0	4-10	Offline/Online	Independent, when equipped with an underdrain system	2-4	5	Impermeable liner required	2 feet	75-80	75-80	50-60	50	75	Good	FHWA, 2000 CDOT, 2004 NJDA, et al., 2000
Filtration Structures	2-5	2-3	Offline	Independent	1-8	6-10	Impermeable liner required if not lined with concrete.	2 feet	70-95	20-90	27-80	25-70	N/A to 90	Good	FHWA, 2000 NJDA, et al., 2000
Infiltration Basin	2 - 20	2-4	Offline	Dependant	3-4	15	Not practical due to sinkhole formation	2 – 5 feet	75-99	50-90	50-70	45-70	75	Good	FHWA, 2000 NJDA, et al., 2000
Infiltration Trench	2 – 4	2-4	Offline/Online	Dependant	3-8	15	Not practical due to sinkhole formation	2 – 5 feet	75-99	75-99	50-75	45-70	75	Good	FHWA, 2000 NJDA, et al., 2000
Retention and Detention Basins	>20	10-20	Offline/Online	Independent	3-8	15	Impermeable liner and geologic tests required	2-4 feet, if aquifer is contaminated	45-98	25-90	20-95	10-60	N/A	Poor, unless fenced, to Fair	CDOT, 2004 NRML, 2002 FHWA, 2000 NJDA, et al., 2000
Vegetated Filter Strip (VFS)	0-5	> 25	Offline	Dependant	Negligible	2-10	Not practical due to sinkhole formation	2 – 4 feet	25-70	-15 - 55	20-40	20-40	2-80	Good	FHWA, 2000 CDOT, 2004 NJDA, et al., 2000

[1] Removal efficiencies are based on the references cited.
[2] There are other pollutants (not included in the table) equally important to consider from transportation systems, such as litter and traffic debris.

<table>
<tr><th>Water Quality or Treatment BMP</th><th>Urban Areas</th><th>Setback Requirements</th><th>Streambank Erosion</th><th>Sensitive Waterbodies</th><th>Sensitive Wildlife Habitats</th><th>References</th></tr>
<tr><td>Manufactured Treatment Devices.</td><td>o Water quality inlets can fit inside drain lets; ideal for bridges and ultra urban settings.</td><td>o N/A</td><td>o Water quality inlets should always discharge to a structural BMP downstream from the drain to prevent streambank erosion.</td><td>o Ideal for online treatment on bridges over sensitive waterbodies.</td><td>o No information for these BMPs specifically related to sensitive wildlife habitats.</td><td rowspan="7">NJDA, et al., 2000
Clar, et al., 2003
FHWA, 2000
NRML, 2002</td></tr>
<tr><td>Bioretention</td><td rowspan="2">o Standing water is a safety concern for children nearby.
o Standing water may breed mosquitoes during the warmer months, posing a public health concern.
o Standing water may become eutrophic.
o Space may be limited in ultra-urban settings (see columns 2 and 3)</td><td rowspan="6">o Any storage devices that discharge to a coldwater stream should be placed offline from the outfall to the stream.

o Install storage devices and infiltration basin/trench in a flat area; it may need to be placed off-line to accommodate the BMP footprint.

o Move all infiltration devices 100 feet from drinking water wells; all other BMPs must be 50 feet away.

o Structural BMPs (excluding vegetation) should be > 25 feet from a streambank.

o Structural BMPs (excluding vegetation) should be > 25 feet from jurisdictional wetlands.

o Structural BMPs (excluding vegetation) should be > 25 feet of the critical root zone of state protected tree species.

o Structural BMPs (excluding vegetation) should be > 50 feet from the edge of a septic drain system.</td><td rowspan="5">If a structural BMP is located within 25 feet of a streambank…

o Retention, detention, and infiltration practices may require additional design volume.

o Retention and detention practices must be installed in combination with velocity dissipation BMP(s).</td><td rowspan="2">o May release water with a temperature above temperature of the receiving coldwater streams.</td><td rowspan="5">o No information for these BMPs specifically related to sensitive wildlife habitats.
o No information for these BMPs specifically related to sensitive wildlife habitats.</td></tr>
<tr><td>Retention and Detention Basins</td></tr>
<tr><td>Infiltration Basin</td><td rowspan="2">o Space may be limited in ultra-urban settings (see columns 2 and 3)</td><td rowspan="2">o Ideal BMP for sensitive waterbodies if all runoff is collected and infiltrated.</td></tr>
<tr><td>Infiltration Trench</td></tr>
<tr><td>Filtration Structures</td><td>o Underground filters are often well suited for urban settings.</td><td>o Can provide relatively advanced water treatment for a discharge to a sensitive waterbody when infiltration is not practicable (see column 9 in Table 3).</td></tr>
<tr><td>Vegetated Filter Strip (VFS)</td><td>o Aesthetically pleasing to public.
o Space may be limited in ultra-urban settings (see columns 2 and 3)</td><td>o When practicable, VFS is the most appropriate practice to prevent/minimize streambank erosion.</td><td>o VFS ideally suited to provide buffer zone between one of the structural treatment BMPs above and the sensitive waterbody.</td><td>o Desirable species of emergent vegetation can be planted and encouraged through the VFS.</td></tr>
</table>

Water Quality or Treatment BMP	Urban Areas	Setback Requirements	Streambank Erosion	Sensitive Waterbodies	Sensitive Wildlife Habitats	References
Vegetated Filter Strip (VFS) *(Continued)*		o Structural BMPs (excluding vegetation) should not be installed within utility easements or non-ADOT right-of-ways. o Satisfy any other applicable setbacks from ADOT or other jurisdictions.				

<table>
<tr><th rowspan="2">Water Quality or Treatment BMP</th><th rowspan="2">Peak flow reduction</th><th colspan="2">Temperature extremes</th></tr>
<tr><th>Cold Climate</th><th>Arid and Semi-Arid Climates</th></tr>
<tr><td>Manufactured Treatment Devices.</td><td>o No peak flow reduction.</td><td>o None</td><td>o None</td></tr>
<tr><td>Bioretention</td><td>o Low to moderate; 40% reduction in the total runoff volume (influent to effluent).</td><td rowspan="5">o Protect inlet/outlet pipes
o Use large diameter (> 8 in) gravel in underdrain of outfall protection
o Provide ice storage volume
o Use freeze and salt tolerant vegetation</td><td>o Minor modifications may be necessary.</td></tr>
<tr><td rowspan="4">Retention and Detention Basins</td><td rowspan="4">o Ideally suited for peak flow reduction and flood control.
o Retention and detention ponds may increase the risk of downstream flooding in some cases.</td><td>o Acceptable in arid and semi-arid areas.</td></tr>
<tr><td>o Preferred in arid and acceptable in semi-arid areas.</td></tr>
<tr><td>o Not recommended in arid areas and of limited use in semi-arid areas.</td></tr>
<tr></tr>
<tr><td>Infiltration Basin</td><td rowspan="2">o Moderate; when designed with sufficient capacity, all runoff collected is infiltrated.</td><td rowspan="2">o Monitor groundwater for chlorides and do not allow infiltration if chlorides are a concern for the groundwater in the area.
o Increase soil permeability requirements
o Use a 20 foot minimum setback between the road subgrade and the BMP structure.</td><td rowspan="2">o Soil limitations often exist in arid areas.</td></tr>
<tr><td>Infiltration Trench</td></tr>
<tr><td>Filtration Structures</td><td>o None to low peak flow reduction.</td><td>o Reduced filtration occurs during cold weather
o Underground filters are only effective if placed below the frost line.
o Peat/compost (organic) media is ineffective during cold weather and may become impervious if frozen.</td><td>o Preferred in both arid and semi-arid areas.
o Arid area filters require greater pretreatment.</td></tr>
<tr><td>Vegetated Filter Strip (VFS)</td><td>o Low to moderate; 30-40% reduction in the total runoff volume (influent to effluent).</td><td>o Small setback may be required between the VFS and the edge of the road if frost heave is a concern.
o Use cold and salt-tolerant vegetation.
o Plowed snow can be stored in the VFS.</td><td>o Use drought tolerant vegetation.</td></tr>
</table>

Water Quality or Treatment BMP	Costs		Maintenance	Effective Life (years)	References
	Capital	O&M			
Manufactured Treatment Devices.	Low - Moderate	Moderate - High	High; Frequent cleanouts	10 - 50	
Bioretention	Moderate	Low	Mowing/plant replacement	5-20	FHWA, 2000 CDOT, 2004 NRML, 2002
Retention and Detention Basins	Moderate-High	Low	Moderate; annual inspection and debris removal	20-50	
Infiltration Basin	Moderate	Moderate	High; sediment and debris removal from the surface	5-10, before deep tilling is required	
Infiltration Trench	Moderate -High	Moderate	High; sediment and debris removal from the top	10-15	
Filtration Structures	Moderate-High	Moderate-High	High; biannual to annual media removal	5-20	
Vegetated Filter Strip (VFS)	Low	Low	Low; mowing and edge debris removal, scraping to maintain sheet flow	20-50	

BMP	Description	Treatment mechanism	Advantage	Critical Limitations	Recommended for ADOT?
Manufactured Treatment Devices	Vendor treatment devices include trapping catch basins and oil/grit separators that prompt sedimentation of particulate materials with sorbed oil and the separation of free oil. WQIs also contain screens to retain larger or floating debris. WQIs can also include coalescing units to help promote oil/water separation.	Filtration and adsorption	Highly effective for trapping litter, oil, and grease.	o Sediment can be resuspended in vendor treatment devices and released to surface waters. o Standing water in vendor treatment devices is breeding ground for mosquitoes.	**Yes.** Vendor treatment devices are useful treatment BMPs to install at the drain or outlet from the edge of bridge decks or in curb/gutter systems.
Bioretention	A combination of a (1) vegetated buffer strip, (2) ponding area, (3) organic mulch layer, (4) planting soil bed, (5) sand bed, and (6) surrounding plants.	Sedimentation, filtration, adsorption, and biodegradation.	Ideally suited for impervious areas and widely applicable to different climatic zones. Can be very effective for removing fine sediments, trace metals, nutrients, bacteria and organics.	o Not recommended for upstream slopes greater than 20%; o Not suitable for aquifers less than 6 feet; o Pretreatment is necessary to avoid clogging; o Not suitable in climates where soil can freeze; o Bioretention BMPs can attract mosquitoes and other environmental nuisances.	**In some cases.** Bioretention cells may be applicable to highway facilities, such as along the perimeter of port-of entries and rest areas.
Chemical Treatment	Still considered an experimental practice, injecting alum can promote fine, suspended particles to flocculate and settle out.	Flocculation and sedimentation	Best to be applied for high flows at the end of combined sewer overflows and POTWs.	High cost and still an experimental application.	**No.** This BMP is still in research and development and does not have well documented data on operation and maintenance costs. It is therefore not advisable to implement this BMP for a long-term (permanent) time frame.
Constructed Wetland	A wet retention basin that incorporates natural biodegradation/removal of dissolved pollutants.	Sedimentation of particulate pollutants and biodegradation (dissolved pollutants)	o High aesthetic value o Improved treatment over dry detention and retention. o Flood attenuation, reduction of peak flows o Limits downstream bank erosion.	o Possible release of nutrients during the fall season o Discharges from constructed wetlands may be warmer than the temperature of receiving surface waterbody (heat sink effect).	**No.** Constructed wetlands are not applicable in any of the climatic zones of Arizona.
Continuous Deflective Separator (CDS)	Deflects the inflow (and suspended pollutants) into a separation chamber. The separation chamber consists of a screen at the top and a sump at the bottom for the heavier solids.	Enhanced sedimentation and filtration	In addition to the advantages for vortext separators, CDSs incorporate a filtration mechanism.	Same limitations as vortex separators. CDS may allow limited decomposition of dissolved organic matter in the water contained in the sump.	**No.** CDSs may be an over-design for ADOT's needs.
Exfiltration Trench	A permeable concrete pavement that captures roadway drainage at the outside edge of the shoulder. The exfiltration trench is placed parallel to the roadway against a concrete curb structure.	Filtration	Requires minimal space in high density urban settings.	Still considered to be an experimental application.	**No.** This BMP is still in research and development and does not have well documented data on operation and maintenance costs. It is therefore not advisable to implement this BMP for a long-term (permanent) time frame.
Filtration Structures	Systems that may consist of a pretreatment basin, water storage reservoir, flow spreader, sand, and under-drain piping. Liners can be installed if the treated runoff is not allowed to infiltrate to groundwater. Structures can be constructed above or below ground with a sand or peat moss media.	Filtration and absorption	o Filters are useful in high density, impervious drainage areas. o High removal efficiencies for suspended solids. o In addition to the benefits of surface sand filters, underground filters can be placed *below* the right of way when space is limited.	o Pretreatment required to prevent filter media from clogging. o Requires complete stabilization of upstream drainage area.	**Yes.** Filtration structures have high removal efficiencies for suspended particles.
Infiltration Basin	An open surface pond that collects stormwater from impervious areas and infiltrates water to the subsurface; requires highly permeable soils for efficient recharge.	Sedimentation of particulate pollutants and filtration through native soil strata.	o Theoretically, infiltration achieves 100% removal of dissolved and colloidal pollutants to surface waterbodies. o Flood attenuation, reduction of peak flows o Eliminates downstream bank erosion	o High failure rates due to improper siting, design, and lack of maintenance, especially when no pretreatment is included. o Clogging likely under high suspended solid loading; o Not suitable below steep slopes; o Possible groundwater contamination or exacerbation; violation of Aquifer Protection Permit (APP) standards. o Requires complete stabilization of upstream drainage area.	**Yes.** Infiltration is a preferable practice to consider for treating runoff collected at a single point.
Infiltration Trench	An excavated trench lined with aggregate. Stormwater infiltrates through the sides and the bottom of the trench.	Sedimentation of particulate pollutants and filtration through native soil strata.	In addition to the benefits of an infiltration basin, trenches can have a linear footprint.		

BMP	Description	Treatment mechanism	Advantage	Critical Limitations	Recommended for ADOT?
Isolation and Diversion Structures	Isolation/Diversion Structures divert and isolate first flush (more polluted) runoff away from the additional (less polluted) runoff.	Sedimentation, filtration, adsorption, and/ or biodegradation (within the diversion chamber).	The preferred approach to specifically treat first flush runoff.	Each diversion must have a stabilized outlet with adequate capacity.	**Yes.** Isolation/Diversion Structures are necessary if it is desired to divert and isolate first flush (more polluted) runoff away from the additional (less polluted) runoff.
Multi-Chambered Treatment Trains (MCTTs)	A series of three treatment mechanisms, each in a separate chamber: sump, sedimentation chamber with tube settlers and sorbent pads, and a filter media chamber.	Sedimentation, filtration, and adsorption	Can be used in areas where site conditions prevent the use of other BMPs such as infiltration, and retention/ detention practices.	MCTTs provide minimal attenuation of peak flows or runoff volumes.	**No.** MCTTs may be an over-design for ADOT's needs.
Pervious Channel Lining	A vegetated or loose-rock lined swale that allows some infiltration in addition to conveyance.	Filtration, adsorption, and biodegradation in surface vegetation and soil matrix.	o Control peak discharges by reducing runoff velocity; o Provides effective pretreatment for BMPs in series. o Good option for replacing existing drainage ditches. o Linear nature is convenient for highway runoff. o Runoff has comparably short detention time, so useful for cold water streams.	o Impractical in areas with extremely flat or steep grades or wet/poorly drained soils; o Requires substantial linear area.	**Yes.** Pervious channel lining is useful to DOT roadways because they (1) intercept, collect, and convey sheet runoff, (2) effectively reduce runoff volume prior to the outlet, and (3) provide moderate treatment.
Porous Pavement	A permeable pavement surface with an underlying reservoir, and the water eventually infiltrates. Also allows highways to prevent hydroplaning.	Filtration	Porous pavements are a material substitution…requiring no additional footprint.	o Not effective with high suspended sediment laden runoff; o Requires diligent maintenance to remove sediment from pores.	**No.** Although porous pavement may be applicable to highway facilities, such as port-of entries and rest area parking lots, they are not recommended for typical highways and roadways.
Retention and Detention Basins	A dry or wet pond that impounds stormwater and allows suspended pollutants to settle. They may or may not permanently retain water.	Predominately sedimentation of particulate pollutants and biodegradation.	o Can perform in both arid and cold environments. o Can limit downstream bank erosion. o May have high aesthetic value. o Retention basins improve treatment, flood attenuation, and reduce peak flows.	o Not suitable for drainage areas less than 10 acres. o Potential for clogging outlets and sediment resuspension (if not properly maintained). o Discharges from dry detention basins may be warmer than the temperature of receiving surface waterbody (heat sink effect). o Can not be placed on steep or unstable slopes and require a base flow or supplemental source of water to maintain ponded water level. o Improper design of retention basins can result in stratification and release of nutrients and metals.	**Yes.** Retention and detention basins are common practice for a wide range of applications.
Vegetated Filter Strip (VFS)	Long, relatively narrow area of undisturbed or planted vegetation used to retard or collect sediment for the protection of surface waterbodies or adjacent properties. They are designed for overland sheet flow.	Filtration, adsorption, and biodegradation. It also prevents streambank erosion.	o VFSs help maintain riparian zones along streams, reduce streambank erosion, and provide wildlife habitat. o VFSs can be installed/enhanced during construction and easily maintained afterward.	o VFS can not treat a large drainage area and do not provide significant attenuation of peak discharges o Vegetative buffers offer minimal treatment for dissolved constituents.	**Yes.** Vegetated filter strips are one of the primary forms of treatment for sheet flow.
Vortex Separators	Vortex separators or swirl concentrators create a swirling path of stormwater collected within the inlet to allow suspended sediment and floatables to settle out.	Enhanced sedimentation	Provides cost-effective pre-treatment compared to traditional wet or dry basins. Mosquito and other vector control may not be as necessary as for retention basins with standing water.	Vortex separators are not as effective as wet valuts for fine sediment particles (50 - 100 um in diameter). Non-steady inflows of stormwater decrease the capture efficiency compared to controlled flows during laboratory tests. Votex separators do not remove dissolved pollutants.	**Yes.** Vortex separators may be included, pending ADOT's approval.

BMP	Upfront Construction Costs[1]	Annual Maintenance Costs[1]
Offroad, Overland Flow Erosion Control		
Retaining wall	N/A[2]	N/A
Slope Modification and New Slope Construction	Terraces \$1.20 - \$14.50 / lineal foot	N/A
Impervious Cover	N/A	N/A
Seed Mix	\$0.05 - \$0.25 / yd^2	15% - 25% of installation
Riprap	\$100 / check dam	N/A
Erosion Control Blanket	Biodegradable \$0.50 - \$0.57 / yd^2	N/A
Decomposed Granite Cover	\$25/ton	N/A
Wire-tied Rock	N/A	N/A
Roadway Drainage Conveyance		
Culvert Structures	N/A	N/A
Spillways	N/A	N/A
Downdrain Conduits	Slope drain \$5 / lineal foot for flexible PVC pipe	N/A
Inlet Protection	\$65 - \$131 / inlet	N/A
Impervious Channel Lining	Concrete \$60 - \$100 / yd^3	N/A
Pervious Channel Lining	N/A	N/A
Outlet Protection	N/A	N/A
Bridge Drainage Systems	N/A	N/A
Rainwater Harvesting Practices	N/A	N/A
Water Quality and Treatment		
Vegetated Filter Strip	Established from: • Using existing vegetation - \$0 • Seeding - \$530/acre-VFS • Sodding - \$14,190/acre-VFS	N/A
Infiltration Basin	\$0.55/ft^3 of storage	\$0.04/ft^3 of storage
Infiltration Trench	\$4.36/ft^3 of storage	\$0.04/ft^3 of storage
Bioretention	\$6.83/ft^3 of storage	N/A
Filtration Structures	\$2.63/ft^3 of storage	N/A
Manufactured Treatment Devices	\$2,200 each	\$164 each
Retention and Detention Basins	\$0.55/ft^3 of storage	\$0.009 – \$0.08/ft^3 of storage (retention) \$0.008 – \$0.33/ft^3 of storage (detention)

Notes:

[1] Unit costs are very approximate and should only be used for comparison and informational purposes. Do not use these costs for construction cost estimates.

[2] N/A – Unit cost data is either not available or is not an appropriate measurement of costs for the BMP.

REFERENCES AND RESOURCES

California Department of Transportation, (CALTRANS) April 2003, Storm Water Quality Handbooks: Project Planning and Design Guide.

Environmental Protection Agency (EPA), November 2005, National Management Measures to Control Nonpoint Source Pollution from Urban Areas, www.epa.gov/owow/nps/urbanmm

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Appendix C: Design Calculations, Tables and References

DESIGN CALCULATIONS

Water Quality Volume Calculation

WQv = T(P A* Cq)/12*

where:

WQv = Water Quality Volume (Ac-ft)
T = Treatment Percent
P = Precipitation
A = Contributing Drainage Area to an outfall (acres)
Cq = $0.858i^3 – 0.78i^3 + 0.774i + 0.04$
i = impervious area divided by the total area

Treatment Percent

*Treatment = [(Aix * 20) + (Ain * 100)] / (Aix + Ain)*

where:

Treatment = Treatment percent
Aix = Existing impervious area (acrea)
Ain = New impervious area (acres)

Bioretention Cell Sizing

*A = WQv * D / [3600 * K * T * (h+D)]*

where:

WQv = Water Quality volume
T = Drain time of the cell
K = permeability of the soil
A = Top surface area of the trench
D = Depth of the planting soil
h = Maximum height of water above the cells top layer of the WQv

Infiltration Trench

$L_t = 43560 * WQv / (3600 * K * T * (b+2D) + 0.4 [D^2 + (b * D)])$

where:

WQv = Water Quality volume
T = Drain time through the sides of the trench, 24 hours
K = permeability of the surrounding soil (ft/sec)
D = Trench Depth
b = Bottom width of the trench (ft)

Infiltration Basin (invert area)

$A = (WQv * S.F. * 12) / (k * t)$

where:

A = area of invert of the basin (acres)
WQv = Water Quality volume
S.F. = Safety Factor of 1.5
k = Infiltration Rate (in/hr)
t = Drawdown time of 48 hours

Infiltration Basin (depth)

$D = WQv / A$

where:

A = area of invert of the basin
WQv = Water Quality volume
D = Required depth of the basin

REFERENCES

Arizona Department of Transportation (ADOT), *Highway Drainage Design Manual (draft)*, 2006.

Arizona Department of Transportation (ADOT), *Highway Drainage Design: Chapter 600*, May 1996.

California Department of Transportation, (CALTRANS), *Storm Water Quality Handbooks: Project Planning and Design Guide, Appendix A: Approved Design Pollution Prevention BMPs and Appendix B: Approved Treatment BMPs*, April 2003.

Ohio Department of Transportation (ODOT), Division of Highway Operations, Office of Structural Engineering, Hydraulic Section, *Location and Design Manual, Volume 2, Drainage Design Procedures, Chapter 1100*, January 2006.

ODOT, Division of Highway Operations, Office of Structural Engineering, Hydraulic Section, *ODOT Storm Water BMP Updates*, January 24, 2006.

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Appendix D: Abbreviations, Acronyms, and Definitions

Acronym/Term	*Definition*
303(d) List:	Under Section 303(d) of the 1972 Clean Water Act, states, territories and authorized tribes are required to develop a list of water quality limited segments. These waters on the list do not meet water quality standards, even after point sources of pollution have installed the minimum required levels of pollution control technology. The law requires that these jurisdictions establish priority rankings for water on the lists and develop action plans, called as Total Maximum Daily Loads (TMDLs to improve water quality.
AASHTO:	Association of State Highway and Transportation Officials
ADEQ:	Arizona Department of Environmental Quality
ADOT:	Arizona Department of Transportation
ADWR:	Arizona Department of Water Resources
Apron:	A lining of the bed of the channel upstream or downstream from a lined or restricted waterway. A floor or lining concrete, rock, etc., to protect a surface from erosion such as the pavement below chutes, spillways, at the toes of dams, or along the toe of bank protection.
Bank:	The lateral boundary of a stream confining water flow. The bank on the left side of a channel looking downstream is called the left bank, etc.
Bank Protection:	Revetment, or other armor protecting a bank of a stream from erosion, includes devices used to deflect the forces of erosion away from the bank.
Base Flow:	The flow contribution to a creek by groundwater. During dry periods, base flow constitutes the majority of stream flow.
Basin:	Space above or below ground capable of retaining or detaining runoff.
Best Management Practice:	Structural devices or nonstructural practices that are designed to prevent pollutants from entering into stormwater flows, to direct the flow of stormwater or to treat polluted stormwater flows.
Biological Uptake:	Process by which an organism metabolizes an organic compound for energy, growth and/or reproduction.
Bioretention:	Engineered facilities consisting of a grass buffer strip, ponding area, organic or mulch layer, planting soil, and vegetation. An optional sand bed can also be included in the design to provide aeration and drainage of the planting soil. The filtered runoff can either be discharged through an underdrain system to a receiving waterbody, conveyance system or other BMP, or it can infiltrate to the underlying soils. They can be configured in an on-line and off-line configuration.
BMP:	Best Management Practices.

BOD:	Biological Oxygen Demand
Bridge Drainage System:	Infrastructure that conveys runoff from the bridge deck. This may include channeling water through gutters to either end of the bridge for short bridge spans or immediately off of the deck through scuppers or closed conduit systems. Inlet drain systems may function either by gravity or in combination with a pumping system.
Capacity:	The effective stormwater carrying ability of a drainage structure. Generally measured in cubic feet per second.
Catch Basin and Downdrain Conduits:	A drainage structure that collects water. May be either a structure where water enters from the side or through a grate inlet.
CFR:	Code of Federal Regulations
Channel:	The space above the bed and between banks occupied by a stream.
Check Dam:	A temporary dam across a swale or gully to reduce gully erosion, or placed bank to bank downstream from a headcut; often used in series. A small dam generally placed in steep ditches for the purpose of reducing the velocity in the ditch.
Chemical Oxygen Demand:	A test used to indirectly measure the amount of organic compounds in water.
Concentrated Flow:	Drainage that has accumulated into a single narrow width, with greater velocity than sheetflow.
Concentration:	Mass per unit volume of a pollutant.
Conduit:	Any channel or pipe for directing the flow of water.
Construction Project:	Installation of a new roadway or expansion of an existing roadway, not otherwise considered a maintenance or a safety/emergency project.
Conveyance:	Any natural or man-made channel or pipe in which concentrated water flows.
Corrosion:	Erosion by chemical action.
Cultipacker Seeder:	A seeding device with 2 corrugated rollers with the seed box mounted between the rollers. The first roller makes a groove into which the seed is dropped. The second roller covers the seed by packing soil around it.
Culvert Structure:	A closed conduit or underpass, other than a bridge, that allows water to drain from and pass under a roadway. Culverts must be designed with proper inlet/outlet protection and headwalls.
DDD, DDE, DDT:	Organo-chlorinated constituents, historically developed and used as pesticides. These constituents are banned in the United States, but are still prevalent in the environment.
Debris:	Any material including floating woody material and other trash, suspended sediment, or bed load moved by a flowing stream.
Decomposed Granite Cover:	Granite rock, ranging from ¼" to 2" nominal diameter, used for drains, erosion control, and a temporary driving surface.
Depth:	Vertical distance, (1) from surface to bed of a body of water, or (2) from crest or crown to invert of a conduit.

Design Storm: That particular storm that contributes runoff that drainage facilities were designed to handle. This storm is selected for design on the basis of its probability of exceedance or average recurrence interval.

Detention/ Retention Basin: Facilities typically constructed below the roadway shoulder where the appropriate footprint is available to hold runoff, and are also referred to as pond-in-place practices. Retention and detention basins are excavated in most any configuration to meet footprint restrictions and can be vegetated.

Diversion Dike: Embankment to confine or control water, often built along the banks of a river to prevent overflow of lowlands; a levee.

Discharge: A release or flow of stormwater or other substance from a conveyance or storage container.

Dissipate: Expend or scatter harmlessly, as of energy of moving water.

Ditch: Small artificial channel, usually unlined.

DOC: Dissolved Organic Compound

Drainage: (1) The process of removing surplus ground or surface water by artificial means. (2) The system by which the waters of an area are removed. (3) The area from which waters are drained; a drainage basin.

Drainage Area: Portion of the earth's surface upon which falling precipitation flows to a given location.

Drainage System: Usually a system of underground conduits and collector structures that flows to a single point of discharge.

Easement: Right to use the land of others.

Embankment: Soil surface adjacent to a stream, lake, or body of water where the soil elevation adjacent to the water is higher than the water level; usually referred to as the bank.

Emulsified Asphalt: A suspension of small asphalt cement globules in water, which is assisted by an emulsifying agent (such as soap). Emulsions have lower viscosities than neat (plain) asphalt and can thus be used in low temperature applications. After an emulsion is applied the water evaporates away and only the asphalt cement is left.

Energy Dissipater: A structure for the purpose of slowing the flow of water and reducing the erosive forces present in any rapidly flowing body of water.

Entrance: The upstream approach transition to a constricted waterway.

EPA: Environmental Protection Agency. Issued regulations to control pollutants in stormwater runoff discharges (The Clean Water Act and NPDES permit requirements).

Erosion Control Blankets: A protective blanket or soil stabilization mat installed to reduce soil erosion by wind or water. Erosion control blankets usually consist of photodegradable mesh filled with straw, excelsior, coconut fiber, wood fiber, or jute.

Excavation: The process of removing earth, stone, or other materials.

Excelsior:	Thin wood shavings used for packing or stuffing
Existing Vegetation:	Any vegetated area that has not already been cleared and grubbed.
Fecal Coliform:	Bacteria that indicate the presence of sewage contamination of a waterway and the possible presence of other pathogenic organisms.
Fertilizer:	Any of a large number of natural or synthetic compounds including organic material, nitrogen, phosphorus, and potassium, applied to the soil to promote its plant growth capabilities.
FHWA:	Federal Highway Administration
Filter Bed:	Filter consisting of a layer of sand or gravel for filtering water
Filter Structures:	Structures that utilize a filtering media (sand, soil, gravel, peat, or compost) to remove pollutants from stormwater runoff. Filtration structures can vary in design, but should all generally comprise of the following: (a) inflow regulation that diverts a defined flow volume into the filtration system, (b) pretreatment to remove coarse sediments, (c) filter media, specific to one or more target pollutants, and (d) an outflow mechanism to discharge flows to a conveyance system or directly to a receiving waterbody.
Filter Fabric:	Textile of relatively small mesh or pore size that is used to (a) allow water to pass through while keeping sediment out (permeable), or (b) prevent both runoff and sediment from passing through (impermeable).
First Flush	The initial half (0.5) inch of runoff from a storm event. The first flush of runoff, typically contains the highest concentration of pollutants.
Flow:	A term used to define the movement of water, silt, sand, etc.; discharge; total quantity carried by a stream.
Footprint Area:	The plan view or surface area that a structure occupies.
Furrrow:	A long, narrow, shallow trench made in the ground.
Gabion:	Baskets (usually made of wire) filled with rock or broken pieces of concrete, used for building erosion control structures.
Geosynthetic:	Manufactured (inorganic/organic) fabric material.
Geotextile:	Textiles in the traditional sense, but consist of synthetic fibers rather than natural ones. Thus biodegradation is not a problem. These synthetic fibers are made into a flexible, porous fabric by standard weaving machinery or are matted together in a random, or nonwoven, manner. The fabric performs at least one of five discrete functions separation, reinforcement, filtration, drainage or as a moisture barrier when impregnated.
Girders:	A beam, as of steel, wood, or reinforced concrete, used as a main horizontal support in a building or bridge.
Grading:	The cutting and/or filling of the land surface to a desired slope or elevation.
Gradient:	See definition for "**Slope**"

Gravel: Soil particles ranging from 1/5 inch to 3 inches in diameter.

Grout: A thin, coarse mortar poured into various narrow cavities, as masonry joints or rock fissures, to fill them and consolidate the adjoining objects into a solid mass.

"H": High rating (in terms of Costs, BMP Objective, and DOT Target Pollutants Removal)

Head: Represents an available force equivalent to a certain depth of water. This is the motivating force in effecting the movement of water. The height of water above any point or plane of reference. Used also in various compound expressions, such as energy head, entrance head, friction head, static head, pressure head, lost head, etc.

Heavy Metals: Any metallic chemical element that has a relatively high density and is toxic or poisonous at low concentrations. Examples of heavy metals include mercury (Hg), cadmium (Cd), arsenic (As), chromium (Cr), thallium (Tl), and lead (Pb).

Hydraulic: Pertaining to water in motion and the mechanics of the motion.

Hydrologic: Pertaining to the cyclic phenomena of waters of the earth; successively as precipitation, runoff, storage and evaporation, and quantitatively as to distribution and concentration.

Impaired Waterbody: Defined by ADEQ as routinely exceeding the TMDL for pollutants. Refer to the current ADEQ list.

Impervious Surface: Artificial surfacing of a soil surface to resist erosion or scour. Impervious cover can consist of soil cement (a dry mix of sand, cement and admixtures, compacted to the required density); shotcrete (mortar or concrete applied, pneumatically, through a hose); grouted riprap (rock voids filled with concrete grout); concrete slope pavement (cast-in-place or pre-cast and place concrete monolithic armor) and grouted fabric slope pavement (sand-cement mortar, injected between two layers of double-woven fabric).

Impervious Channel: A rigid facing for a drainage swale, ditch, or channel that is typically constructed out of concrete or grouted riprap for minimal infiltration and erosion.

Inlet: An entrance into a ditch, storm sewer, or other waterway.

Inlet Protection: A decomposed granite cover or riprap surface surrounding a storm drain inlet, culvert, spillway, channel, or other BMP structure. It can also refer to slots or screens to prevent floatable debris from entering a culvert or a storm drain system.

Infiltration Basin: Facilities typically constructed below the roadway shoulder where the appropriate footprint is available to hold and infiltrate runoff. Infiltration basins (also known as recharge basins) are considered a treatment BMP because they can remove pollutants from surface discharges by capturing the stormwater runoff volume (typically, larger volumes than an infiltration trench) and infiltrating it directly to the soil rather than discharging it to an above-ground drainage system. Basins are excavated in most any configuration to meet footprint restrictions and can be vegetated.

Infiltration Trench: A structural BMP, constructed below ground surface, within the median and/or below a shoulder of relatively flat stretches of roadway. It is considered a treatment BMP because it can remove pollutants from surface discharges by capturing stormwater runoff volume and allowing it to infiltrate directly into the soil (through the bottom and the sides of the trench) rather than discharging it to an above-ground drainage system. Infiltration trenches are excavated, lined with a geotextile fabric (optional), and backfilled with aggregate.

Jute: A long, soft, shiny plant fiber that can be spun into coarse, strong threads.

Karst Geology: Refers to subsurface geologic features found in various parts of Arizona, including sinkholes, fissures and subsidence can form crevices and enlarged joints in the soil.

"L": Low rating (in terms of Costs, BMP Objective, and DOT Target Pollutants Removal)

Level Spreader: A device used to spread out stormwater runoff uniformly over the ground surface as sheet flow (i.e., not through channels). The purposes of level spreaders are to prevent concentrated erosive flows from occurring and to enhance infiltration.

LID: Low Impact Development

Loam: Soil composed of a mixture of sand, clay, silt, and organic matter.

Low Impact Design: stormwater management and land development strategy applied at the parcel and subdivision scale that emphasizes conservation and use of on site natural features integrated with engineered, small-scale hydrologic controls to more closely mimic pre-development hydrologic functions.

"M": Medium rating (in terms of Costs, BMP Objective, and DOT Target Pollutants Removal)

Median Cable Barrier: A flexible traffic barrier that is ideally suited for use as a retrofit design in existing relatively wide and flat medians to prevent cross-over crashes.

MAG: Maricopa Association of Governments

Minibenches: Small furrows, serrations or stair-steps along the face of a slope.

MOU: Memorandum of Understanding

MPCA: Minnesota Pollution Control Agency

MS4: Municipal Separate Stormwater Sewer System

Mulch: A natural or artificial layer of plant residue or other materials covering the land surface which conserves moisture, holds soil in place, aids in establishing plant cover, and minimizes temperature fluctuations.

Municipal Separate Storm Sewer System: All separate storm sewers defined as "large," "medium," or "small" municipal separate storm sewer systems or any municipal separate storm sewers on a system-wide or jurisdiction-wide basis as determined by the Director under 18-9-C902(A)(1)(g)(i) through (iv). [A.A.C. R18-9-A901(23)]

Not Attaining Waterbody: A surface water for which: (1) a TMDL has been completed and approved by EPA, but the water standards are not yet attained, (2) other pollution control requirements are expected to result in the attainment of water quality standards by the next regularly scheduled listing cycle, or (3) the impairment is not related to pollutant loading, but is caused by pollution (e.g., hydromodification). Refer to the current ADEQ list.

Nuisance Control: Control and/or eradication of vectors and pests, including mosquitoes, insect larvae, and rodents.

Nutrients: A substance that provides nourishment for growth or metabolism. Plants absorb nutrients mainly from the soil in the form of minerals and other inorganic compounds.

ODOT: Ohio Department of Transportation

Oil Sheen: A thin, glistening layer of oil on water.

Open Channel: Any conveyance in which water flows with a free surface.

Organic: Involving organisms or the products of their life processes.

OSHA: Occupational Safety and Health Administration

Outfall: The point, location, or structure where wastewater or drainage discharges from a sewer pipe, ditch, or other conveyance to a receiving body of water.

Outlet Protection: Outlet protection consists of loose or grouted riprap placed at the outlet ends of culverts, conduits, spillways, or channels to reduce erosion along the soil interface and at the toe of concrete and metal structures.

Permeability: The property of soils that permits the passage of any fluid. Permeability depends on grain size, void ratio, shape and arrangement of pores.

Pervious Channel Lining: A pervious channel lining is typically a vegetated or rock-lined (non-grouted) swale, ditch, or channel that allows some infiltration in addition to providing a means for conveyance.

Pesticides: A chemical used to control/eradicate pests, especially invasive insect and plant species.

pH: An expression of the intensity of the basic or acidic condition of a waterbody. pH is calculated as the negative log of the hydronium ($H3O+$) concentration present within the natural waterbody (i.e. the higher the pH, the lower the concentration of hydronium ions present.). The measurement range for pH is between 1 (very acidic) to 14 (very basic or alkaline), and neutral pH is defined as 7. Natural waters usually have a pH between 6.5 and 8.5.

Pollutant: Fluids, contaminants, toxic wastes, toxic pollutants, dredged spoil, solid waste, substances and chemicals, pesticides, herbicides, fertilizers and other agricultural chemicals, incinerator residue, sewage, garbage, sewage sludge, munitions, petroleum products, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt and mining, industrial, municipal and agricultural wastes or any other liquid, solid, gaseous or hazardous substances. [A.R.S. § 49-201(29)]

Precipitation: Discharge of atmospheric moisture as rain, snow, or hail, measured in depth of fall or in terms of intensity of fall in unit time.

Pretreatment: Robust displacement of pollutants (typically suspended sediment) in stormwater prior to reaching a water quality/treatment BMP.

Pump Out: Mechanical displacement or removal of stormwater to a point of higher elevation.

Rainfall Harvesting: The practice of collecting and storing rainwater for use in irrigation or any application where surface or groundwater resources would traditionally be consumed. Rainwater harvesting also acts as a retention/detention practice from a stormwater management perspective.

Retaining Wall: A wall structure, built along soil slopes ranging from vertical to the angle of repose.

Retention Basin: A structural BMP that impounds all stormwater flows from a design storm until the storm has passed. A retention basin is considered a treatment BMP because it can remove suspended pollutants through settling and being slowly released.

Retrofit: The modification of stormwater management systems in developed areas through the construction of wet ponds, infiltration systems, wetland plantings, stream bank stabilization, and other BMP techniques for improving water quality. A retrofit can consist of the construction of a new BMP in the developed area, the enhancement of an older stormwater management structure, or a combination of improvement and new construction.

Revegetation: Reestablishing vegetative cover on ground that has been disturbed, such as a construction site.

Revetment: A stone or concrete facing to sustain an embankment.

Riprap: A controlled placement of erosion-resistant ground cover of large, loose, angular stone with a geotextile or granular underlining.

Roadway: Infrastructure for vehicles to use to travel from one point to another. Roadways include interstates, highways, freeways, on-ramps, off-ramps, intersections, bridges, tunnels under the jurisdiction of ADOT.

Roadway Maintenance Project: Repair or reconditioning to an existing roadway that does not include expansion or new construction activity.

Roadway Safety or Emergency Project: A roadway construction project that is given higher priority or expedited schedule due to increased potential safety hazards to the public.

Rock Mulch: Rock mulch typically has a nominal diameter of less than 3 inches and is used for pipe inlet and outlet protection and headwall and wingwall erosion control.

Runoff: That portion of precipitation, snowmelt, or irrigation water that runs off the land into streams or other surface water. It can carry pollutants from the air and land into the receiving waters.

SAF Stilling Basin Saint Anthony Falls stilling basin.

Scour: The clearing and digging action of flowing water, especially the downward erosion caused by stream water in sweeping away mud and silt from the stream bed and outside bank of a curved channel.

Scuppers: An opening for draining off water, as from a floor or the roof of a building.

Sedimentation: The process of depositing soil particles, clays, sands, or other sediments that were picked up by runoff.

Sediments: Soil, sand, and minerals washed from land into water usually after rain, that pile up in reservoirs, rivers, and harbors, destroying fish-nesting areas and holes of water animals and clouding the water so that needed sunlight might not reach aquatic plants. Careless farming, mining, and building activities will expose sediment materials, allowing them to be washed off the land after rainfalls.

Sediment Forebay: A pretreatment mechanism, installed prior to basins and infiltration/filtration structures.

Seed Mix: The application of native vegetation seeds to a previously disturbed soil surface, seeding can be mixed with fiber, fertilizers, mulch, or stabilizing emulsions to enhance the seed germination.

Sensitive Waterbody: See definition for "**Impaired or Unique Waterbody**". See also definition for **"Not Attaining Waterbody"**.

Sheet Flow: The portion of precipitation that moves initially as overland flow in very shallow depths before eventually reaching a stream channel.

Shotcrete: Mortar or concreted applied pneumatically through a hose.

Slide: Gravitational movement of an unstable mass of earth from its natural position.

Slope The rate of ascent or descent expressed as a percent or as decimal; determined by the ratio of the change in elevation to the length.

Slope Modification Construction: Slope modification practices may include minibenches, creating furrows, terraces, serrations, stair-steps, or track-marks on the face of the slope. Existing and new slopes should also be flattened to the lowest extent possible, whenever feasible, to reduce erosive runoff velocities and increase infiltration time.

Soil: The unconsolidated mineral and organic material on the immediate surface of the earth that serves as a natural medium for the growth of land plants.

Sorbed Oil: Petroleum hydrocarbons that attach or "sorb" to the soil particle matrix.

Spillway: Spillways drain roadway surface runoff through an open channel down an embankment or side slope. Spillways must be designed with proper riprap inlet/outlet protection and headwalls.

SSWMP: Statewide Stormwater Management Plan

Storage: Detention, or retention of water for future flow, naturally in channel and marginal soils or artificially in reservoirs.

Storm Drain: A slotted opening leading to an underground pipe or an open ditch for carrying surface runoff.

Stormwater: Stormwater runoff, snow melt runoff, and surface runoff and drainage; rainfall that does not infiltrate the ground or evaporate because of impervious land surfaces but instead flows onto adjacent land or watercourses or is routed into drain/sewer systems.

Subsoil: The bed or stratum of earth lying below the surface soil.

Surface Water: All water naturally open to the atmosphere (rivers, lakes, reservoirs, streams, wetlands impoundments, seas, estuaries, etc.); also refers to springs, wells, or other collectors which are directly influenced by surface water.

Suspended Solids: Organic or inorganic particles that are suspended in and carried by the water. The term includes sand, silt, and clay particles as well as solids in wastewater.

Swale: A vegetated channel; can be either “wet” or “dry”. Wet swales can temporarily store water and can act as a linear and shallow wetland treatment system. Dry swales have an underlying filterbed and eliminate standing water.

SWAT Storm Water Advisory Team

Tackifier: A material used to bond seed to the soil surface. It is commonly used as an additive for hydro-seeding mixtures.

TDS: Total Dissolved Solids

TKN: Total Kjeldahl Nitrogen

TMDL: Total Maximum Daily Load

TOC: Total Organic Carbon

TPH: Total Petroleum Hydrocarbons

Transport: To carry solid material in a stream in solution, suspension, saltation, or entrainment.

Treatment: Displacement and removal of undesirable pollutants from stormwater.

TSS: Total Suspended Solids

Turbidity: A measure of the amount of material suspended in water. Increasing the turbidity of the water decreases the amount of light that penetrates the water column. High levels of turbidity are harmful to aquatic life.

Turf Reinforced Mats: A combination of vegetation and a geosynthetic material used to prevent soil erosion due to stormwater runoff. The mat can be made from such material as polypropylene, nylon, and polyvinyl chloride, and is used to enhance vegetative root and stem development.

UA: Urbanized Area

Unique Waterbody: Defined by ADEQ as waters of exceptional recreational or ecological significance because of unique attributes, including but not limited to geology, flora, fauna, water quality, and/or aesthetic values, or waters that sustain threatened or endangered species. Refer to the current ADEQ list.

Vadose Zone: The region between the water table and the land surface, where the moisture content is typically unsaturated. The soil pore space is a combination of moisture and air.

Velocity: The rate of motion of objects or particles, or of a stream of particles.

Vegetative Filter Strip: Vegetated Filter Strips (VFSs) are typically long but relatively narrow areas of natural (undisturbed) or planted vegetation (ground cover, sod, or grasses). They are used to retard stormwater runoff and consequently settle or trap sediment and other pollutants; hence protecting surface waterbodies or adjacent, downslope properties. They are designed for overland sheet flow and are often well suited to provide pretreatment to other best management practices (BMPs), such as infiltration, filtration, or storage practices.

VFS: See definition for “**Vegetated Filter Strip**”.

Wire-tied Rock: A wire mesh structure, filled with rock, that can be constructed in the form of wire-tied rock mattresses or gabions. In wire-tied rock mattress designs, the individual wire mesh units are laid end-to-end and side-to-side to form a mattress layer along the channel bed or side slope. Generally, the depth is much smaller than the width or length. Gabions, in contrast, are typically rectangular or trapezoidal in shape. The depths are approximately the same as the widths and are stacked vertically.

WQV: Water Quality Volume

WSE: Water Surface Elevation

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