# 16 Permanent Water Quality

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# 16 Permanent Water Quality

## 16.1 INTRODUCTION

This section presents detailed design criteria for several types of permanent water quality (PWQ) control measures (CMs) for use on projects owned, operated, or overseen by the Colorado Department of Transportation (CDOT). It is primarily intended for CDOT Project Engineers, Region Hydraulic Engineers, and design consultants. The secondary audience includes CDOT Water Quality Specialists and maintenance staff. This section replaces Chapters 12 and 19 of the *CDOT Drainage Design Manual* (2004) and Chapter 6 of CDOT's *Erosion Control & Stormwater Quality Guide* (2002) entitled "Post Construction Best Management Practices," as applicable.

The term "control measure" has replaced the term "best management practice" as the preferred term to describe permanent facilities that are intended to treat water quality in perpetuity once construction is complete. Throughout CDOT, the abbreviation CM also means Construction Manager. In this document, and throughout the PWQ Program, Construction Manager will be spelled out where it is used, and CM will mean control measure. Textual context should provide clarity as a control measure is a thing and a Construction Manager is a job title. The abbreviations CM or PWQ CM may be used interchangeably.

This section has been created to meet the requirements of CDOT's Colorado Discharge Permit System (CDPS) Permit Number COS000005, CDOT Municipal Separate Storm Sewer System Permit (MS4 permit) effective August 28, 2015 with a modification issued October 16, 2015. The MS4 permit issued by the CDPHE specifies which projects require PWQ CMs to be constructed and the design standards that CMs must meet. The content of this section will be revised when the MS4 permit is updated, or as CDOT's Permanent Water Quality Program is refined, as necessary. Updates will be managed by CDOT Hydrologic Resources and Ecological Design Unit staff. Updates to the PWQ section of the CDOT DDM and the PWQ Program will be posted to the CDOT Permanent Water Quality website.

### 16.1.1 Organization

This section incorporates many CDOT specifications, policies, and design criteria, as well as criteria from outside sources, by reference, with the goal of minimizing the frequency with which this section will need to be updated. Users should refer to the most recent version of referenced documents for the most current information.

A new user should review the entire section before beginning design on a PWQ CM to ensure that all required factors are being considered. Design of PWQ CMs is progressive and if a there is a site factor, such as shallow bedrock or high groundwater, that will limit the use of some CMs, it is far more cost- and time-effective to know this information before CM selection and design begins. The following list summarizes the structure of this chapter and the type of information each section contains.

- Section 16.1 Introduction – Provides background information, location of additional guidance documentation, and roles and responsibilities.
- Section 16.2 Design Considerations and Legal Requirements – Provides general design considerations and legal requirements such as soils, water rights, groundwater, wetlands, maintenance, safety, and other factors, as well as the MS4 permit design standards.
- Section 16.3 CDOT PWQ Design Criteria – Provides specific design criteria for CMs allowed for use without approval. These include extended detention basins; sand filters; media filter drains; proprietary structures that do not use a filter; and treatment swales. This section also discusses treatment trains; complementary practices; designing for maintenance; and SAP categories.
- Section 16.4 Control Measures Requiring Approval – Provides a brief discussion on retention, bioretention, porous landscape detention, swales, constructed wetlands, proprietary structures, and permeable pavement systems, none of which will be allowed without specific approval.
- Section 16.5 Required Documentation – Provides a summary of required documentation including the PWQ Evaluation and Tracking Form and funding application; water quality report; various checklists; as-built information; GIS information; O&M manual; and water rights reporting.
- Section 16.6 Design Examples – Provides design examples for an extended detention basin, sand filter, and media filter drain.
- References – Provides a list of the documents referenced by this section.

### 16.1.2 Additional Guidance

The PWQ Program directs the need for PWQ CMs as well as the design and installation of PWQ CMs. The PWQ Program is referenced frequently in this section, but only as it relates to design of CMs. Additional information on the PWQ Program is available in the following documents:

- **PWQ Program Manual** – The PWQ Program Manual provides guidance on determining when a PWQ CM is required onsite, obtaining Mitigation Pool funding, and other relevant information. It is available on the PWQ Program website.
- **MS4 Permit** – The CDOT MS4 permit is available on the PWQ Program website. Much of the direction in this section resulted from the requirements of the MS4 permit.
- **PWQ Program Description Document (PDD)** – The PWQ PDD describes how CDOT will meet the requirements of the MS4 permit and provides a list of citations for documents and electronic records used to comply with the permit. The PDD will be available by September 1, 2017. It will be posted on the PWQ Program website. The PDD will provide Program history and will discuss the PWQ Program process in detail. It will point to all relevant SOPs, manuals, guidance and specifications. In the meantime, the PWQ Program Manual will serve this function.

### 16.1.3 Roles And Responsibilities

The responsibility for treating the water quality of runoff from CDOT right-of-way lies with all CDOT employees and consultants. Specific roles and responsibilities to meet the goal of water quality treatment are delineated in this section by job title or job description. A PWQ Project

Process document is available on the PWQ Program website that offers more details on roles, responsibilities, and timing for treating water quality from scoping through project closeout.

- **CDOT Maintenance Superintendent** – The CDOT Maintenance Superintendent is responsible for overseeing maintenance staff in their responsibilities to the CDOT PWQ Program. This person also must designate a representative to attend FIR and FOR meetings to ensure maintenance concerns are being addressed.
- **CDOT Maintenance Staff** – CDOT Maintenance is responsible for ensuring the design of PWQ CMs include elements that are required for maintenance.
- **CDOT Project Engineer** –The CDOT Project Engineer is responsible for coordination with the consultant and CDOT specialties. The CDOT Project Engineer is responsible for providing the Water Quality Specialist with design information including an estimate of the percentage of new impervious area at the FIR review and more detailed revisions to this value as the project progresses.
- **CDOT PWQ Program Manager** –The CDOT PWQ Program Manager is available to assist in determining PWQ Program requirements and to assist in determining Mitigation Pool funding eligibility and requirements. The PWQ Program Manager may be consulted for program assistance at dot_pwq@state.co.us or at 303 757-9814.
- **CDOT Region Hydraulic Engineer** – The CDOT Region Hydraulics Engineer is responsible for oversight and review of the design of plans and Hydraulic Design Report.
- **CDOT Water Quality Specialist** – The CDOT Water Quality Specialist is responsible for providing the project team direction regarding PWQ requirements for the project. A Water Quality Specialist will make determinations about whether the project is located within the MS4 boundary and whether it triggers the need for a PWQ CM. If a project requires a PWQ CM, the Water Quality Specialist will give direction regarding the regulatory requirements. They will also give direction regarding 303(d), TMDL, TMAL, and other water quality requirements. Water Quality Specialists are also responsible for oversight of design documentation; and review of PWQ documentation including the construction plans, operations & maintenance manual, PWQ Report, GIS data, and ensuring that design changes to PWQ CMs occurring during construction are reflected in the PWQ documentation.
- **Consultant** – The consultant is responsible for providing design plans, specifications, and PWQ documentation as required by this section, CDOTs PWQ Program, CDOT's MS4 permit, and any other regulatory guidance applicable to PWQ CMs.
- **Local Agency** – The local agency is responsible for providing input on design elements and for calling attention to local agency design standards. If the project is advertised by a local agency, the local agency is responsible for complying with CDOT's MS4 permit requirements within the CDOT MS4 boundary. Outside of CDOT's MS4 boundary the local agency is responsible for complying with its own MS4 permit requirements and must certify to CDOT that they have met those requirements if the project receives federal funding. Any time a local agency will maintain a PWQ CM that treats runoff from CDOT right-of-way, an IGA for maintenance is required.

## 16.2 DESIGN CONSIDERATIONS AND LEGAL REQUIREMENTS

This section provides an overview of factors to be considered when selecting and siting PWQ CMs, including legal requirements that must be met. This is not meant to be a complete list of all design considerations, but represents the most common factors that need to be considered. This section also discusses the three MS4 permit design standards, one of which must be met by all new PWQ CMs.

### 16.2.1 General Design Considerations

Physical site characteristics and location relative to other elements will influence PWQ CM selection and design. Relevant site characteristics include soil type; rainfall and climate; contributing drainage area; depth to groundwater and presence of groundwater contamination; space constraints; and maintenance and safety considerations. Other site characteristics that have associated legal requirements include the presence of wetlands, locations of waters of the state, floodplain location, and water rights considerations. These are discussed in Section 16.2.2.

#### 16.2.1.1 SOILS

Soils with good permeability, typically those in Hydrologic Soil Groups (HSGs) A and B, are well suited for CMs designed to meet the infiltration standard. Depth to bedrock shall always be determined to ensure bedrock will not be an obstacle to construction or function of a CM. When soils with moderate to high swell potential are present, infiltration should be avoided if adjacent structures may be damaged from water-induced swelling. A geotechnical engineer must be consulted during the design process to evaluate native soils, subsurface conditions, and potential impacts to nearby structures.

Karst features, sinkholes, and landslides are additional considerations, although less common. Evaporite karst hazards are present in several areas of the state, including the Roaring Fork River and the Eagle River valleys (CGS, n.d.a). Landslides can result from either destabilizing or overloading slopes (CGS, n.d.b). A geotechnical engineer must be consulted for CMs located near or up gradient from steep slopes. Where karst features, sinkholes, or landslides exist or are likely to exist, infiltration CMs shall be avoided. The Colorado Geological Survey's (CGS) landslide inventory map is available for consultation as a viewer or ESRI shapefile (http://coloradogeologicalsurvey.org/geologic-hazards/landslides/colorado-landslide-inventory/) (CGS, n.d.b).

#### 16.2.1.2 STABILITY OF DRAINAGE AREA

The degree of vegetative cover, or surface stability, in the watershed draining to a CM site can influence the type of CM that should be selected. If the area draining to a CM is not either well vegetated or paved, runoff from the watershed is likely to have a high sediment load. In these cases, infiltration facilities should be avoided, as their long-term performance is sensitive to high sediment load. A *WQCV* facility should be used instead.

#### 16.2.1.3 RAINFALL AND CLIMATE

Average annual rainfall and distribution should be evaluated if vegetation is specified. This will determine whether there is sufficient natural moisture to maintain the vegetation in a sufficiently healthy state for facilitating infiltration or biological uptake. If this is not the case, supplemental irrigation will be necessary to maintain the design vegetation.

The CM must be designed to treat the design flow rate or design volume and accommodate the 100-year event runoff volume or peak flow rate. The design flow rate and/or volume are specific to the MS4 permit design standard being met and are discussed for each design standard in Section 16.2.2.4.1. Drainage calculations for CDOT project must follow CDOT criteria and specifications.

For CDOT, stormwater management includes keeping highways safe and operational during winter months when snow and ice can accumulate. CDOT uses a variety of winter management techniques, including the application of anti-icing / de-icing chemicals and abrasives such as sand. These chemicals and abrasives, which can accumulate and concentrate over the course of the winter season, are often released along with melting snow and ice in the spring. Selection and design of CMs must consider the potential impacts from winter management techniques.

#### 16.2.1.4 WETLANDS

CDOT does not allow PWQ CMs to be used as compensatory mitigation for impacts to wetlands or other aquatic resources because the functions of the two types of facilities conflict at an operational level. CDOT may evaluate incorporating non-jurisdictional wetlands into PWQ CMs on a project-by-project basis, with approval from the Region Biologist. CDOT projects must be permitted under the Clean Water Act, Section 404 (404 permit) if the project will result in the discharge of dredged or fill material to waters of the United States, including wetlands. Information on 404 permit requirements, as well as exemptions and nationwide permits, can be obtained from the CDOT Wetlands Program Manager.

#### 16.2.1.5 WATERSHED SIZE

The contributing drainage area is a major consideration for PWQ CMs. There is a practical minimum size for some CMs, largely related to the ability to drain the *WQCV* over the required drain time. For example, while it is technically possible to size an extended detention basin for a half-acre site, designing a functional outlet to release the *WQCV* over a 40-hour drain time is practically impossible due to the very small orifices that would be required. For a small watershed, it would be more appropriate to use a CM meeting the infiltration design standard, or a CM that uses filtration in combination with subgrade release of the *WQCV*, such as a partial infiltration sand filter. On the other hand, larger watersheds should not use an infiltration CM and should use an EDB instead. As a practical limit, the UDFCD recommends a maximum drainage area of one square mile for any *WQCV* facility.

The presence of upstream, offsite flows are a significant challenge for CDOT and can require purchasing additional right-of-way to accommodate larger PWQ CMs or coordinating with local agencies to construct a bypass route for runoff from areas outside CDOT's MS4 area. A CM will be quickly overwhelmed, and potentially out-of-compliance with MS4 permit treatment standards, if designed to treat only the calculated runoff volume from CDOT right-of-way but actually accepting runoff both from CDOT right-of-way and from area upstream of the project. Projects must take into account any offsite upstream runoff unless it is routed around the PWQ CM. These upstream flows, if they are accepted by the CM, will require construction of larger PWQ CMs and potentially introduce pollutants that would not otherwise be present in runoff from CDOT's right-of-way.

#### 16.2.1.6 GROUNDWATER

The selection and design of PWQ CMs is subject to the legal and regulatory conditions imposed by state groundwater regulations. Shallow groundwater on a site presents challenges for CMs that rely on infiltration and for CMs that are intended to be dry between storm events, such as detention basins. Shallow groundwater may limit the ability to infiltrate runoff or result in unwanted groundwater ponding in the bottom of *WQCV* CMs.

To avoid issues with groundwater, borings are required in areas proposed for *WQCV* CMs. Borings are required at extended detention basins to confirm that groundwater is at least 2 feet below proposed grade 7 days after drilling, or as approved by the Project Manager. For infiltration CMs, groundwater needs to be confirmed to be below the depth required to infiltrate the required volume.

Locations proposed for PWQ CMs that may result in infiltration must be carefully evaluated for the presence of contaminated groundwater plumes beneath the CM site. The CDPHE's Clean Water: GIS Maps website publishes an ArcGIS shapefile that identifies areas with known groundwater contamination. If the CM site is located above an area that has known contamination, CDOT must consult with CDPHE's Water Quality Control Division, Groundwater Program regarding potential permits for PWQ CMs.

#### 16.2.1.7 SPACE CONSTRAINTS

Space constraints are consistently identified by CDOT as a challenge to CM selection and design. CDOT projects, particularly in MS4 areas, have limited right-of-way, and designers are often forced to squeeze the CM into the space remaining after the other physical structures taking precedence, such as roadways, sidewalks, and utilities, have been designed. Space constraints create additional challenges for maintenance crews such as insufficient space to maneuver equipment or requiring closure of traffic lanes during CM maintenance.

The most effective and integrated CM designs begin by determining areas of a site that are best suited for CMs (e.g., natural low areas, areas with well-drained soils) and then designing the layout of roads and other site features around the existing drainage and water quality resources of the site. Allocating a small amount of land to water quality infrastructure during early planning stages will result in better integration of water quality facilities with other site features.

Projects should consider buying additional right-of-way to construct PWQ CMs that meet CDOT MS4 permit design standards. A cost-benefit analysis can balance the cost of additional right-of-way against the expected costs of an undersized PWQ CM or selecting an inappropriate PWQ CM to fit the available space. The latter can include increased maintenance requirements, increased total cost over the 20-to-50-year lifespan of the facility, decreased maintenance crew safety, inundation or undermining of the road surface, and potential non-compliance with the MS4 permit.

#### 16.2.1.8 MAINTENANCE

Long-term maintenance requirements are a critical component of PWQ CM selection and design to ensure ongoing compliance with the MS4 permit. Design requirements for maintenance are discussed in more detail in Section 16.3.5 as well as in the discussion for each specific PWQ CM. CMs that are not properly maintained do not treat stormwater quality. Maintenance considerations that must be evaluated during the CM selection and design process include:

- Accessibility;
- Required frequency of maintenance;
- Complexity of maintenance, including the number tasks and the type of equipment;
- Specialty training required;
- Necessary materials such as filters or filter material and their availability and cost;

- Maintenance crew safety such as avoiding the need for confined space entry or to shut down a lane of traffic; and
- Required equipment being readily available to CDOT maintenance crews.

An operations and maintenance manual must be developed and submitted in accordance with Section 16.5.6. Regional maintenance staff or local agency maintenance staff must be consulted during the PWQ CM selection and design process. CDOT maintenance staff uses a final acceptance checklist to evaluate whether a PWQ CM can be accepted. The checklist includes FIR and FOR components to ensure maintenance staff has been consulted during the design process.

PWQ CMs must be maintained to function properly, and maintenance requirements must be a primary consideration when selecting a CM. The MS4 permit establishes enforceable criteria for ensuring that PWQ CMs are adequately maintained as follows:

- "Control measures shall be selected, designed, installed, implemented, and maintained in accordance with good engineering, hydrologic, and pollution control practices, and the manufacturer's specifications, when applicable. "Pollution" is man-made or man-induced, or natural alteration of the physical, chemical, biological, and radiological integrity of water."
- "Control measures shall be maintained in effective operating condition."
- "A control measure shall be considered an "inadequate control measure" if it is not designed, implemented, or operating in accordance with the requirements of the permit … [or] implemented and maintained to operate in accordance with the design."
- "A control measure shall be considered a 'control measure requiring routine maintenance' if it is still operating in accordance with its design and the requirements of this permit, but requires maintenance to prevent associated potential for failure during a runoff event."

#### 16.2.1.9 SAFETY

CDOT's paramount concern for roadway design is ensuring public safety. PWQ CMs are an integral component of the final roadway design and must not pose safety hazards to roadway traffic. In addition, CMs must not compromise the function of roadway infrastructure. The CM selection and design process also needs to consider non-traffic related safety issues. These can include the use of handrail at an outlet structure to protect nearby children as well as maintenance personnel. The clear zone needs to be maintained for all surface structures.

CMs that require maintenance crews to be exposed to traffic, or close a lane of traffic, should be avoided if possible. Safety aspects of proposed CMs should be discussed with appropriate CDOT or local agency maintenance staff prior to final selection and design. Clear zone and any other requirements included in the *CDOT Roadway Design Guide*, Chapter 3 - Elements of Design must be met by all PWQ CMs. The CDOT Office of Transportation Safety should be consulted to confirm roadway design criteria are met.

### 16.2.2 Legal Requirements

There are several legal requirements to consider when designing PWQ CMs. Some are established by the MS4 permit, and others are imposed by Colorado's prior appropriation system for surface water rights or FEMA.

#### 16.2.2.1 ONLINE VERSUS OFFLINE PWQ CONTROL MEASURES

CDOT's MS4 permit requires CDOT's PWQ CMs to treat runoff prior to it entering a water of the state. Online CMs are designed to treat waters of the state. They are often constructed by effectively damming a water of the state so that water is impounded during a runoff event and then allowed to drain slowly downstream once the storm is over. Because online CMs are located in a water of the state, they cannot be used to meet MS4 permit requirements. The Region Water Quality Specialist and the PWQ Program Manager may be consulted to determine if a proposed PWQ CM location will not allow runoff to be treated prior to entering a water of the state.

#### 16.2.2.2 FLOODPLAINS

The siting of PWQ CMs is subject to local, state, and federal (FEMA) floodplain regulations. CDOT PWQ CMs can generally be constructed within a 100-year floodplain, unless local agency regulations prohibit such siting (e.g., Weld County), provided they are located outside the 10-year floodplain and are designed to withstand the flood event they are expected to encounter. Design elements shall include scour, structure stability, and flotation at a minimum. If a PWQ CM is proposed within a regulatory floodplain, CDOT requires a floodplain development permit from the applicable local agency. The local floodplain manager shall be consulted for all work proposed within a 100-year floodplain to determine if a FEMA CLOMR and/or LOMR are required.

#### 16.2.2.3 SURFACE WATER RIGHTS

The design of PWQ CMs is subject to the legal and regulatory conditions imposed by Colorado's prior appropriation system for surface water rights. Colorado Senate Bill 15-212 became effective on August 5, 2015, as Colorado Revised Statute (CRS) §37-92-602 (8). The provisions of this statute apply to surface waters throughout the state and clarify when stormwater facilities may be subject to water rights administration by the Colorado Division of Water Resources. This statute applies statewide and is not tied to any MS4 permit or area. This statute provides legal protection for stormwater treatment facilities in Colorado that may otherwise be seen as utilizing a water right, provided the facility meets the following criteria:

- It is owned or operated by a government entity or is subject to oversight by a government entity, including those facilities that are privately owned but are required by a government entity for flood control or pollution reduction;
- It operates passively and does not subject stormwater to any active treatment process such as coagulation, flocculation, or disinfection, to name a few;
- It has the ability to continuously release or infiltrate at least 97% of all of the water from a rainfall event that is equal to or less than a five-year storm within 72 hours of the end the rainfall event;
- It has the ability to continuously release or infiltrate at least 99% of all of the water from a rainfall event that is greater than a five-year storm within 120 hours of the end the rainfall event; and
- It is operated solely for stormwater management.

> **Colorado Senate Bill 15-212, Required Reporting**
>
> All stormwater detention and infiltration facilities constructed on CDOT-owned land, anywhere in the State, must be reported using the UDFCD web portal.

Agencies that own or operate certain water quality facilities must report them to the Colorado Division of Water Resources; however, CMs that meet the statutory requirements have been determined not to cause material injury to vested water rights. The statute requires surface water rights or an augmentation plan for CMs that do not meet the statutory requirements. To ensure compliance with the statute, it should be verified that the micropool of an EDB has a volume that is less than 1% of the total runoff volume from a 5-year storm.

CDOT has provided guidance on Senate Bill 15-212 including how to report data through the UDFCD web portal, when reporting is required, and who is responsible for reporting. This guidance is available on the PWQ Program website.

#### 16.2.2.4 MS4 PERMIT REQUIREMENTS

The MS4 permit contains numerous requirements and concepts. Several of them are included in this section for reference.

##### *16.2.2.4.1 MS4 Permit Design Standards*

The MS4 permit establishes three design standards: the *WQCV* design standard, the runoff reduction (infiltration) design standard, and the pollutant removal (TSS) design standard. Each design standard is described in this section, with specific calculations included in Section 16.3. The design of PWQ CMs must meet one of these standards, at a minimum. These standards rely on various processes to remove pollutants from stormwater runoff including flow attenuation, infiltration, sedimentation, and filtration, among others. The UDFCD's *Urban Storm Drainage Criteria Manual,* Volume 3, Chapter 2, Section 1.3 provides a useful description for each of these processes.

All PWQ CMs must be selected, designed, installed, implemented, and maintained in accordance with good engineering, hydrologic, and pollution control practices, and the manufacturer's specifications, when applicable. The *WQCV* design standard is typically met by an extended detention basin; the runoff reduction (infiltration) design standard is typically met with a full infiltration sand filter; and the pollutant removal (TSS) design standard is typically met with a media filter drain or a proprietary structure. The impervious area the CM is required to treat in accordance with each design standard does not have to be comprised solely of the newly added impervious area. The area that must be treated may be comprised of entirely new impervious area, entirely existing impervious area, or some combination of the two. This concept is often referred to as equivalent benefit and is discussed in detail in Section 16.2.2.4.3. The following is a description of the three design standards:

**WQCV Design Standard** – The water quality capture volume (*WQCV*) design standard is defined as follows by the MS4 permit:

"The control measure(s) is designed to provide treatment and/or infiltration from impervious surfaces with a surface area equal to or greater than 90% of the new impervious surface area located within the portion of the project discharging runoff to the 303(d)-listed segment for a roadway pollutant of concern. In addition, the design drain time of the *WQCV* shall be a minimum of 12 hours. Evaluation of the minimum drain time shall be based on the pollutant removal mechanism and functionality of the control measure implemented. Consideration of drain time shall include maintaining vegetation necessary for operation of the control measure." (COS000005 Part I.E.2.a.iii (A)1).

The standard is interpreted to mean that if 2.0 acres of new impervious area are being added to an applicable project site, the CM must treat at least 1.8 acres of impervious area within that applicable project site. Extended detention basins and sand filters are examples of PWQ CMs that can be designed to meet the *WQCV* design standard. Design guidance on both is included in Sections 16.3.1 and 16.3.2. The calculation of the *WQCV* is included in the design guidance for an EDB.

**Runoff Reduction (Infiltration) Design Standard** – The runoff reduction design standard is defined as follows by the MS4 permit:

"The control measure(s) is designed to infiltrate into the ground where site geology permits, evaporate, or evapotranspire a quantity of water equal or greater than 60% of what the calculated *WQCV* would be if [all][90% of new]* impervious area from the applicable portion of the priority development project discharged without infiltration" (COS000005 Part I.E.2.a.iii (A) 2)."

*Which option applies depends on the trigger. Use (all) if the 303(d) trigger applies. Use (90% of new) if the EA/EIS trigger applies. See Section 16.2.2.4.2 for information on triggers.

The standard is currently interpreted to mean that if 2.0 acres of new impervious area are being added to an applicable project site that already had 6.0 acres of impervious area, the CM must infiltrate at least 60% of the *WQCV* calculated for 8.0 acres of 100% impervious area. Runoff from adjacent pervious or impervious areas may also be captured by the CM. The CM will always need to be sized to store at least the *WQCV* for the entire area draining to the CM. Full infiltration sand filters can be designed to meet the infiltration design standard. Design guidance is included in Section 16.3.2.

**Pollutant Removal (TSS) Design Standard** – The pollutant removal design standard is defined as follows by the MS4 permit:

"The control measure(s) is designed to treat at a minimum the 2-year, 1-hour peak runoff flow. The control measure(s) shall be designed to treat to an expected median effluent concentration for total suspended solids (TSS) of 30 mg/L from impervious surfaces with a surface area equal to or greater than 90% of the new impervious surface area located within the portion of the project discharging runoff to the 303(d)-listed segment for a roadway pollutant of concern." (COS000005 Part I.E.2.a.iii (A) 3)."

The standard is interpreted to mean that a CM must fully treat a design flow rate equal to the 2-year peak flow from an impervious area as described for the *WQCV* standard. The standard is interpreted to mean that if 2.0 acres of new impervious area are being added to an applicable project site, the CM must treat the 2-year peak runoff from 1.8 acres of impervious area within that applicable project site. If runoff from pervious or offsite areas drain to the CM, the 2-year peak runoff from these areas must also be treated. Media filter drains and proprietary structures can be designed to meet the TSS design standard. Design guidance for these two CMs is included in Sections 16.3.3 and 16.3.4.

#### *16.2.2.4.2 MS4 Permit Triggers and Area Treated*

All projects that require construction of PWQ CMs must treat a specific impervious area that is dictated by the site characteristic that triggered the need for PWQ treatment. There are three possible triggers: the EA/EIS trigger, the 303(d) trigger, and the Cherry Creek trigger. More than one trigger may apply and the requirements of all triggers must be met. The process for determining which trigger(s) applies is included in the CDOT PWQ Program Manual, available on the PWQ Program website. The treatment requirements that apply to each trigger are shown below. The PWQ Evaluation and Tracking Form Directions on the PWQ Program website provide guidance for completing required calculations, including definitions of existing and new impervious area.

**EA/EIS Trigger -** The *WQCV* design standard, the runoff reduction (infiltration) design standard, and/or the pollutant removal (TSS) design standard shall be met by treating the required portion of impervious area within the project boundary shown in the SWMP. The required impervious area to be treated may be anywhere within the project boundary as shown in the SWMP.

Projects meeting the EA/EIS trigger shall look for opportunities to treat more than the minimum required impervious area where it is practicable and when Mitigation Pool funding is available to aid CDOT in meeting the MS4 permit programmatic requirement.

**303(d) Trigger -** The *WQCV* design standard, the runoff reduction (infiltration) design standard, and/or the pollutant removal (TSS) design standard shall be met by treating the required portion of impervious area within the project boundary that discharges runoff to a waterbody or stream segment on the 303(d) list for a roadway pollutant of concern. The waters on the 303(d) list are available from the CDPHE. The required impervious area to be treated may be located anywhere within the project boundary shown in the SWMP provided it drains to the impaired water. Areas that do not drain to the impaired water may be treated by the CM but may not be credited toward the total impervious area that must be treated.

**Cherry Creek Trigger -** Projects meeting the Cherry Creek trigger must meet the design standards outlined in the Cherry Creek Reservoir Control Regulation (5 CCR 1002-72), Part 72.7.2(c). Only that portion of the project that discharges to the Cherry Creek reservoir drainage basin must meet these requirements. These projects, or portions of them, may also be required to meet the requirements of the EA/EIS or 303(d) triggers. The Cherry Creek Trigger requirements, including the Design Standard requirements, are discussed in more detail in the PWQ Program Manual.

#### *16.2.2.4.3 Equivalent Benefit*

The *WQCV* design standard and the pollutant removal (TSS) design standard state the CM must treat runoff from an area equivalent to 90% of the new impervious area. The following more specific requirements apply:

1. Unless the 303(d) trigger applies, a *WQCV* CM or a TSS CM may treat runoff from impervious surfaces anywhere within the project limits with an area equal to at least 90% of the impervious area being added by the project. The entire area treated must be within the CDOT's MS4 area.

2. If new impervious area will drain to a waterbody on the 303(d) list for a roadway pollutant of concern, a *WQCV* CM or a TSS CM must be constructed that treats runoff from impervious surfaces with an area totaling at least 90% of the new impervious area. Additional conditions apply to the impervious area treated. The impervious area treated must all drain to the impaired water, must be located entirely within the project area, and must be entirely within CDOT's MS4 area.

If a *WQCV* or TSS CM treats runoff from impervious area as required by the second condition above, the area treated may apply towards the total area that must be treated as required by the first condition; however, the reverse is not true. If portions of a project drain to more than one waterbody on the 303(d) list for a pollutant of concern, each portion of the project must be addressed individually in accordance with the requirements of the second condition for *WQCV* and TSS CMs.

The runoff reduction (infiltration) design standard does not require any specific area to be treated. Rather, it requires that a certain volume of water be infiltrated. How this volume of water is calculated depends on the trigger. If the 303(d) trigger applies, the volume to be infiltrated is 60% of the *WQCV* calculated for all impervious area within the applicable portion of the project area. If the EA/EIS trigger applies, the volume to be infiltrated is 60% of the *WQCV* calculated for

90% of new impervious area within the applicable portion of the project area. The following more specific requirements apply:

1. Unless the 303(d) trigger applies, the required volume of water to be treated by an infiltration CM may be runoff from anywhere within the project limits. The entire area treated must be within the CDOT's MS4 area.
2. If new impervious area will drain to a waterbody on the 303(d) list for a roadway pollutant of concern, the required volume of water to be treated by an infiltration CM must be runoff from area that drains to the impaired water, is located entirely within the project area, and is entirely within CDOT's MS4 area.

If an infiltration CM treats a runoff volume as required by the second condition above, the volume treated may apply towards the total volume that must be treated as required by the first condition; however, the reverse is not true. If portions of a project drain to more than one waterbody on the 303(d) list for a pollutant of concern, each portion of the project must be addressed individually in accordance with the requirements of the second condition for infiltration CMs.

#### *16.2.2.4.4 PWQ Treatment Not Required by the MS4 Permit*

Occasionally, CDOT must install PWQ CMs for reasons other than MS4 permit requirements. For example, NEPA may require a PWQ CM be constructed where CDOT is contributing to a TMDL. If a requirement for PWQ treatment exists that does not result from the MS4 permit, the CDOT Water Quality Specialist shall be consulted to determine the appropriate design standards.

#### *16.2.2.4.5 PWQ Only Projects*

If the sole purpose of an entire project is to provide PWQ treatment, the project is known as a PWQ Only project. The size of the area treated by these projects is not dictated by the MS4 permit. The only requirement is that the CM treats runoff from the CDOT MS4 area. The size of the area treated may be determined by the project team. The design of the CM must be in accordance with the requirements of this manual.

## 16.3 CDOT PWQ DESIGN CRITERIA

There are several types of PWQ CMs currently used by CDOT throughout the state. Some types of CMs will continue to be allowed by CDOT without exception. However, several types of CMs are no longer preferred due to maintenance or performance concerns. These will require specific approval prior to being allowed and are discussed in Section 16.4.0. This section discusses design criteria for those PWQ CMs that will be allowed for use by CDOT without exception. PWQ CMs that do not require approval include extended detention basins, sand filters, and media filter drains.

Table 1 below includes additional information including SAP categories; category abbreviations; PWQ CMs that apply to each category; the design standard that each CM is typically designed to meet; and whether approval is required for specific CMs. Detailed criteria for the types of primary CMs allowed without approval are included or referenced in this section. If a CM design meets the design criteria in this section, it has been determined to meet a MS4 permit design standard. Design examples for some types of CMs are included in Section 16.6.

The requirement for approval is based on the experiences and capacity of CDOT maintenance crews; many CMs have been designed and constructed over the years that are difficult or expensive to maintain. The need for approval for some types of CMs is intended to ensure maintenance crews can easily maintain them. Regardless of whether approval is required, all new PWQ CMs must be designed to facilitate maintenance operations in accordance with Section 16.3.5. PWQ CMs that do not require approval will still be subject to review by the CDOT maintenance staff that is responsible for maintaining it. Details on approval procedures can be found on the PWQ Program website.

**Table 1** SAP Categories and Associated PWQ Control Measures Characteristics

| PWQ SAP Category | SAP code | PWQ Control Measures | Typical Permit Design Standard | Approval |
|---|---|---|---|---|
| Extended Detention Basin | EDB | extended detention basin | *WQCV* | No |
| Infiltration Facility | IF | sand filter | *WQCV*/Infiltration | No |
| | | bioretention, porous landscape detention (PLD), biofiltration swale, bioslope | Infiltration | Yes |
| | | media filter drain (MFD) | TSS | No |
| PWQ Inlet/Vault | IV | proprietary structure with filter | TSS | Yes |
| | | separation proprietary structure | TSS | Yes |
| PWQ Swale | TS | treatment swale | Infiltration | Yes |
| Retention Pond | RP | retention pond | *WQCV* | Yes |
| PWQ Constructed Wetland | CW | constructed wetland | *WQCV* | Yes |
| Porous Surface | PS | permeable pavers | Infiltration | Yes |

### 16.3.1 Extended Detention Basins

Extended detention basins (EDBs) are earthen basins constructed by either impoundment in a natural depression or excavation of existing soil. The outlet of an EDB is designed to detain and then release the water quality capture volume (*WQCV*) over a design drain time to promote sedimentation of solids and infiltration. An EDB for water quality is similar to a detention basin used for flood control; however, an EDB for water quality uses a smaller basin and a smaller outlet to extend the drain time for the more frequently occurring runoff events. EDBs shall be designed to meet the MS4 permit *WQCV* design standard by using the design guidance contained herein.

The Urban Drainage and Flood Control District (UDFCD) developed and maintains detailed design guidance for EDBs. Chapter 4 of Volume 3 of the *Urban Storm Drainage Criteria Manual* (USDCM) (2016) includes CM fact sheets, designated with the "T," to indicate treatment, that offer detailed information on several CMs. Fact Sheet T-5, Extended Detention Basin (EDB) includes detailed design procedure and criteria, construction considerations, factors affecting long-term performance, and maintenance concerns for EDBs.

The sizing and design of EDBs for water quality treatment shall be in accordance with the most recent version of the USDCM, with the exception that the aesthetic design elements included in the USDCM are not necessarily required, but should still be considered for CDOT EDBs. The CDOT Landscape Architecture Manual provides guidance for incorporating aesthetics, vegetation, and environmental sustainability into EDBs. Aesthetic elements will also require approval from a local agency, if one will maintain the facility. For convenience, some portions of the most recent version of the USDCM (UDFCD 2016) have been excerpted or modified to be included herein.

CDOT may provide water quality treatment within a larger basin that also provides hydraulic detention for flood control. In these instances, the guidance in the USDCM for EURV facilities shall be followed. It also should be noted that Mitigation Pool funding may only be used for the portion of the basin that provides water quality treatment.

#### 16.3.1.1 WQCV

The *WQCV* is a key component in the design of an EDB. Capturing and treating the *WQCV* is expected to remove between 80 and 90% of the annual TSS load and provides the most benefit per volume of storage area. For example, doubling the capture volume was estimated by the UDFCD to increase the TSS removal rate by only 1 to 2%. Fact Sheet T-5 provides detailed discussion on the origin of the *WQCV* as well as calculations to determine the *WQCV*.

Two variables are required to calculate the *WQCV* to be treated by a CM. The first is the total imperviousness of the area draining to the CM. The total imperviousness is the weighted average of individual areas of like imperviousness. Recommended imperviousness values are in Volume 1 of the USDCM. Select examples include paved areas assigned an imperviousness of 100%; drives, walks and roofs assigned an imperviousness of 90%; and lawn areas assigned an imperviousness of 0%. The total imperviousness of a site can be determined by taking an area-weighted average of all of the impervious and pervious areas.

The second variable required to calculate the *WQCV* is the design drain time of the CM. A design drain time of 40 hours is recommended for all PWQ CMs for CDOT. The general equation for the *WQCV* is expressed as:

$$WQCV = Aa(0.91I^3 - 1.19I^2 + 0.78\,I)/12 \qquad (16.1)$$

where *WQCV* = water quality capture volume, acre-ft; $a$ = coefficient corresponding to *WQCV* design drain time (Table 2); $I$ = imperviousness (decimal percentage less than or equal to 1.0); and, $A$ = area draining to the CM, acres.

**Table 2** Drain Time Coefficients for *WQCV* Calculations

| Drain Time | Coefficient, *a* |
|---|---|
| 12 hours | 0.8 |
| 24 hours | 0.9 |
| 40 hours | 1.0 |

Equation 1 is appropriate for use in the Denver metropolitan area. For other portions of Colorado, the *WQCV* can be adjusted using the following relationship:

$$WQCV_{other} = d_6\,(WQCV/0.43) \qquad (16.2)$$

where $WQCV_{other}$ = water quality capture volume outside the Denver metro area, acre-ft; $WQCV$ = water quality capture volume calculated using equation 16.1, acre-ft; and, $d_6$ = depth of average runoff-producing storm per Figure 1.

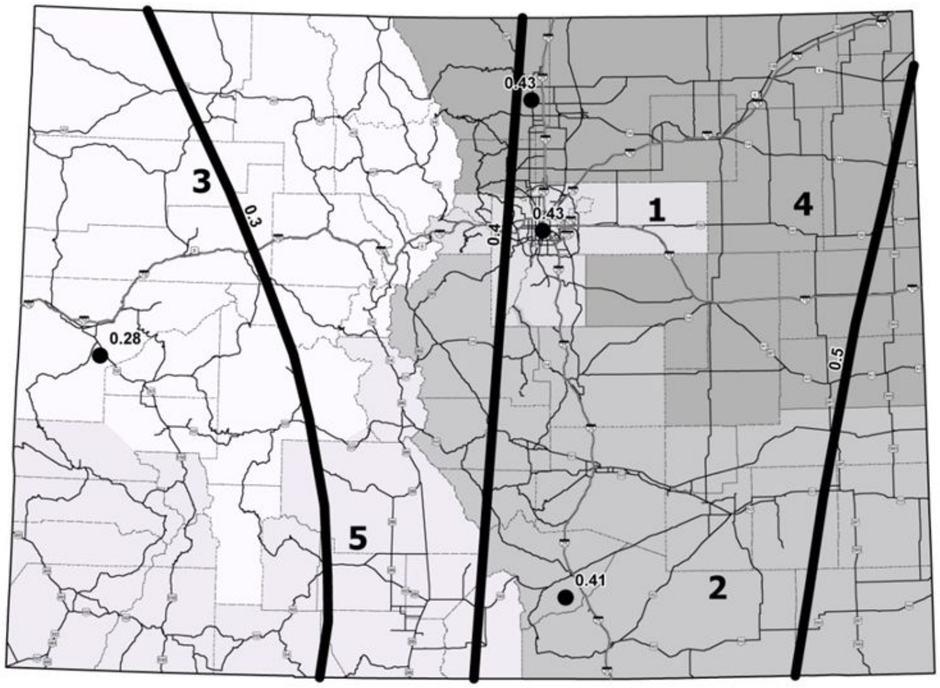


**Figure 1** Map of the Average Runoff Producing Storm's Precipitation Depth in Inches in Colorado (Modified from UDFCD, 2016)

### 16.3.1.2 FACILITY DESIGN

Design of an EDB requires detailed design of several components. These shall include the basin configuration and site grading; the forebay structure or structures; the trickle channel; the outlet structure and overflow spillway; and the maintenance access paths. Information on additional design components can be found in the USDCM. EDB facility design shall be in accordance with USDCM design procedures and recommended structures to treat the *WQCV*, with the exception that any proprietary manufactured components such as grates or well screens can be specified as their generic counterparts.

#### *16.3.1.2.1 Basin Configuration*

EDB geometry for CDOT CMs is often dictated by available right-of-way, roadway locations, and clear zone considerations. Regardless of the constraints, EDB layout will be developed simultaneously with the roadway or maintenance facility improvements. The EDB layout should first be presented with the other proposed improvements at the FIR meeting. As EDBs often have an impact on grading and right-of-way needs, they will be designed concurrently with the primary improvements.

The bottom of an EDB shall be shaped with a gradual expansion from the inlet and a gradual contraction toward the outlet to minimizing short-circuiting of the basin. An EDB shall be at least three times longer from the inlet to the outlet than it is wide. Side slopes should ideally be 4H:1V to allow for mowing; however, 3H:1V side slopes may be allowed with maintenance approval. Side slopes shall also be fully vegetated, but no trees or shrubs should be located on the basin side slopes.

Maintenance access shall be provided to the forebay, micropool, and trickle channel per Section 16.3.5. At least one geotechnical boring shall be completed prior to FIR submittal to ensure that the locations of bedrock and groundwater are appropriate for an EDB. Finally, it is not permitted to construct water quality EDBs with embankments that are considered jurisdictional dams by the DWR.

#### *16.3.1.2.2 Inflow Points*

All points of concentrated inflow into an EDB will be provided with energy dissipation to limit erosion. Typical energy dissipation structures include low tailwater basins, drop structures, or forebays designed in accordance with the most recent version of the USDCM. Other energy dissipation structures may be used, as appropriate. A concrete forebay is required at the point of largest concentrated inflow into each EDB, at a minimum. Concrete forebays allow flow to spread out in a contained space so that coarse sediment is deposited and can be removed before it enters the vegetated portion of the EDB. Riprap basins may be used at points of lower concentrated inflow.

There are nearly limitless possibilities for forebay designs. Figures 2 and 3 below show two examples. Figure 2 is a forebay with a slotted outlet and a weir overflow. It includes a ramp for access by maintenance equipment. Figure 3 is a forebay with several baffles to dissipate energy. Baffles are typically discouraged unless absolutely necessary for energy dissipation due to the difficulty maintenance crews have removing sediment around them. Concrete forebays shall be sloped to drain at between 0.5% and 2.0% and shall not have a permanent pool. If possible, the outlet of the forebay should be offset from the direction of the flow entering the forebay to encourage sediment deposition prior to flow leaving the forebay. Forebay walls should be a minimum of 12-inches high and may be modified as necessary to meet grade constraints as shown in Figure 3. Specific guidance for forebays can be found in Fact Sheet T-5 in the USDCM (2016).

**Figure 2** Example Forebay 1

**Figure 3** Example Forebay 2

#### *16.3.1.2.3 Trickle Channels*

Trickle channels convey low flows from the forebay to the micropool and discourage short-circuiting of the EDB. The trickle channel shall have a flow capacity greater than or equal to the maximum release rate that the concrete forebay was designed to convey to it. Multiple trickle channels may be required for multiple inflow points. Trickle channels must be at least 84-inches wide with a flat bottom. They must be concrete with sides at least 6-inches high to allow access for lightweight maintenance. Trickle channels shall be sloped to drain at between 0.4% and 1.0%.

#### *16.3.1.2.4 Outlets*

All EDB outlets must be designed to detain the *WQCV* and release it over the design drain time. CDOT water quality EDBs should be designed to drain in 40 hours. The slow release of the *WQCV* is typically achieved via a steel plate with a vertical column of small, equally spaced orifices. An easily removable well screen trash rack must be used immediately upstream of the orifice plate to prevent the orifices from becoming clogged. Outlet structures should be located in the downstream embankment of the EDB.

Fact Sheet T-12, Outlet Structures, in the USDCM (2016) includes detailed design procedure and criteria, construction considerations, factors affecting long-term performance, and maintenance concerns for EDB outlet structures. This guidance will be followed for all CDOT water quality CMs with outlet structures. Additionally, each EDB outlet should function passively. Gates, valves, or other mechanical devices shall not be used on EDBs because of maintenance concerns.

#### *16.3.1.2.5 Micropools*

Pollutant removal is enhanced when a small micropool is located upstream of and immediately adjacent to the outlet structure to promote biological uptake. All CDOT water quality EDBs shall have a permanent micropool directly in front of the outlet structure. An initial surcharge volume shall also be provided in accordance with the guidance in the USDCM to avoid frequent inundation of the vegetation and soils surrounding the micropool. The well screen trash rack on the outlet structure should be submerged to the bottom of the micropool. This will reduce clogging and encourage a smaller, deeper permanent pond that is less suitable as mosquito habitat. The bottom of micropools shall be concrete to facilitate maintenance. As discussed in

Section 16.2.2.3, to ensure compliance with CRS §37-92-602 (8), it should be verified that the micropool has a volume that is less than 1% of the total runoff volume from a 5-year event. Fact Sheet T-12 provides additional guidance.

#### *16.3.1.2.6 Spillways*

A spillway is required to convey inflow volumes that exceed the *WQCV* or when the outlet structure becomes blocked with debris. Unless the 100-year concentrated discharge can be diverted prior to entering the EDB, the spillway should be capable of conveying the 100-year peak inflow into the basin.

The EDB spillway controls the location and direction of the overflow. The spillway and the path of the overflow downstream of the spillway should be indicated on the construction plans. Downstream hazards, including critical facilities, should be identified to determine if the spillway should be designed for events larger than the 100-year design storm. Structures are not permitted in the path of the overflow.

There are two general types of EDB spillways, surface and enclosed. Surface spillways may be cut into the crest of the downstream embankment where there is an open channel or other receiving water downstream of the EDB. Soil riprap is the most common method for providing embankment protection for a spillway. Baffle chute spillways are not preferred but may be considered on a case-by-case basis. Enclosed spillways allow flow to pass over the top of a drop box outlet structure and into a downstream conveyance system. A safety grate must be used over the top of a drop box outlet. The grate must be hinged and light enough to be opened without the use of mechanical equipment. The crest of the drop box acts as a weir, and its length, as well as the size of the drop box opening, needs to be oversized to account for flow area reduction and debris blockage caused by the safety grate. The downstream conveyance system must have capacity for the 100-year peak inflow into the EDB.

Regardless of the type of spillway used, there must be at least 1.0 foot of freeboard above the 100-year water surface elevation. If a surface spillway is used, the 100-year water surface elevation through the spillway must be 1.0-foot below the top of the surrounding embankment. No clogging needs to be assumed for a surface spillway, but it should include a cutoff wall in accordance with UDFCD recommendations. If an enclosed spillway is used, the 100-year water surface must remain at least 1.0 foot below the surrounding embankment. If a safety grate is used along the spillway path, such as on the top of a drop box outlet, a clogging factor must be applied.

**Table 3** General EDB Design Criteria

| Design Component | Treats Between 1 and 2 Impervious Acres | Treats Between 2 and 5 Impervious Acres | Treats Between 5 and 20 Impervious Acres | Treats Over 20 Impervious Acres |
|---|---|---|---|---|
| Inflow Points | Inflow energy may be dissipated by low tailwater basins, drop structures, or concrete forebays. | | | |
| Forebay Release & Configuration | 2% of the 100-year inflow releases via a wall notch | | | 2% of 100-year inflow releases via wall notch or pipe |

| | | | |
|---|---|---|---|
| Minimum Forebay Volume | 1% of the *WQCV* | 2% of the *WQCV* | 3% of the *WQCV* |
| Maximum Forebay Depth | 12 inches | 18 inches | |
| Trickle Channel Capacity | Greater than or equal to the forebay outlet capacity | | |
| Micropool | Surface area shall be greater than 10 square feet; bottom shall be concrete. | | |
| Initial Surcharge Volume | Greater than 4 inches deep | | Greater than 4 inches deep; total volume greater than 0.3% of *WQCV* |
| Spillway | Spillway shall be able to pass the 100-year peak inflow into the EDB. | | |
| Basin Geometry | Side slopes should be 4H:1V (3H:1V max); basin length is 3 times basin width. | | |
| Drain Time | 40 hours preferred; may be lower as approved | | |

#### 16.3.1.3 MAINTENANCE REQUIREMENTS AND COST

Orifice and weir flow calculations for surface and enclosed spillways will be in accordance with the USDCM. Chapter 12, Section 5, of Volume 2 of the USDCM (2016) offers several design configurations and associated calculations for EDB spillways. Table 3 below includes many of the design criteria contained within the text of Section 16.3.1.

Maintenance requirements include trash and sediment removal; repairs to outlet structures or embankments; mowing; and repair of any undercut or eroded areas. Nuisance control including identification and removal of undesirable, invasive, or noxious species of weeds, shrubs, or trees may also be necessary. The basin needs to be inspected after significant storm events to identify any signs of erosion or damage to the basin structure. The design requirements to facilitate maintenance are discussed later in this section. Detention ponds rank as medium for design costs and low for construction, operation, and maintenance costs. If additional right-of-way is required, this will be an added cost.

### 16.3.2 Sand Filters

Sand filters, also known as infiltration basins, are basins with a surcharge zone underlain by a sand bed that typically includes an underdrain system. They are typically used for smaller watersheds where an EDB outlet would be impractical. Runoff collects in the surcharge zone and gradually infiltrates into the underlying sand bed, filling the void spaces. The underdrain system gradually dewaters the sand bed and discharges the runoff to a nearby channel, swale, or storm drain. Sand filters shall be designed to meet the MS4 permit *WQCV* or infiltration design standard by using the design guidance contained herein.

The UDFCD has developed and maintains detailed design guidance for sand filters. Chapter 4 of Volume 3 of the USDCM (2016) includes CM fact sheets, designated with the "T," to indicate treatment, that offer detailed information on several CMs. Fact Sheet T-6, Sand Filter, includes detailed design procedures and criteria; construction considerations; factors affecting long-term performance; and maintenance concerns for sand filters.

The sizing and design of sand filters for water quality treatment shall be in accordance with the most recent version of the USDCM, with exceptions as noted. For convenience, some portions of the most recent version of the USDCM (UDFCD 2016) have been excerpted or modified to be included herein. Fact Sheet T-6 contains several figures that can be modified and detailed for use in the construction plans as applicable.

Sand filters are appropriate in areas with sheet or concentrated inflows within ¼ mile of a regulated MS4, sensitive water bodies, or other stakeholder boundaries. Potential locations for sand filters include medians, interchanges, areas adjacent to ramps, and along right-of-way adjacent to roads.

#### 16.3.2.1 BASIN LAYOUT, VOLUME, AND GEOMETRY

Similar to EDBs, geometry for a sand filter is often dictated by available right-of-way, roadway locations, and clear zone considerations. Regardless of the constraints, sand filter layout should be developed simultaneously with the roadway or maintenance facility improvements. The sand filter layout should first be presented with the other proposed improvements at the FIR meeting. It is not sufficient to shoehorn a sand filter into the project site after the proposed improvements have been substantially designed.

When sand filters are located adjacent to buildings or pavement areas, protective measures should be implemented to avoid adverse impacts to these structures. A geotechnical engineer should evaluate the potential impact of a sand filter on adjacent structures based on an evaluation of the subgrade soil, groundwater, and bedrock conditions at the site. In locations with potentially expansive soils or bedrock, placement of a sand filter adjacent to a structure should only be considered if it includes an impervious liner and an underdrain.

A sand filter should be sized to hold the *WQCV*, as calculated in Equation 1, using a drain time of 12 hours from Table 2. The minimum basin floor area, which is the flat surface of the sand filter, should be calculated as:

$$A_F = 0.0125\, AI \tag{16.3}$$

where $A_F$ = minimum filter area (flat surface area), ft$^2$; $A$ = area tributary to basin, ft$^2$; $I$ = imperviousness of the area tributary to the sand filter (decimal percentage).

Increasing the filter area will decrease the frequency of maintenance, as sediment will have more room to disperse, reducing the speed at which the sand filter will clog. The top 18 inches of the filter area should be CDOT Class B or C filter material graded to a flat surface.

Side slopes should ideally be 4H:1V to allow for mowing, however, 3:1 side slopes may be allowed. Side slopes should also be fully vegetated, but no trees or shrubs should be located on the basin side slopes. The bottoms of sand filters are not intended for vegetative growth so that layers of sediment can be easily removed. Vertical walls should be used where side slopes are steeper than 3H:1V. Maintenance access needs to be provided to the bottom, inlets, and outlet of the sand filter.

#### 16.3.2.2 UNDERDRAIN SYSTEM

An underdrain system with cleanouts is required if any of the following applies:

- Existing soils will not infiltrate the *WQCV* within 6 hours,
- An impermeable liner is used, or
- An underdrain system is required to divert water away from structures.

Infiltration tests should be performed or supervised by a licensed professional engineer and conducted at a minimum depth equal to the bottom of the filter material layer. There are three basic types of sand filters discussed in this section: no-infiltration, partial infiltration, and full infiltration.

##### *16.3.2.2.1 No-Infiltration Sand Filter*

The no-infiltration sand filter includes an underdrain and an impermeable liner that prevents infiltration of stormwater into the subgrade soils. A no-infiltration sand filter must meet the MS4 permit *WQCV* design standard and should only be used for the following reasons:

- The site could receive toxic pollutants via stormwater runoff and infiltration could result in contamination of groundwater.
- The site is located over contaminated soils and infiltration could mobilize these contaminants.
- The site is located over potentially expansive soils or bedrock that could swell due to infiltration and potentially damage adjacent structures.

The impermeable liner of a no-infiltration sand filter should be a PVC geomembrane liner, a minimum of 30 millimeters thick along the bottom and sides of the basin, extending up at least to the top of the underdrain layer. Nine to 12 inches of cover should be provided over the liner where it is attached to the wall to protect it from UV deterioration. The liner should be field-seamed using a dual track welder. A small amount of single track or adhesive seaming is allowed in limited areas to seam around pipe perforations, to patch seams removed for destructive seam testing, and for limited repairs.

The liner should be installed with slack to prevent tearing due to backfill, compaction, and settling. CDOT Class B geotextile separator fabric should be placed above the liner to protect it from being punctured during the placement of the filter material. The surface should be smooth-rolled if the subgrade contains angular rocks or other material that could puncture the liner. If smooth rolling the surface does not provide a suitable surface, a layer of separator fabric shall be placed between the liner and the subgrade. If the sand filter has concrete perimeter walls, the liner shall be connected to them to form a watertight seal using a continuous batten bar and anchor connection. Where the need for the impermeable membrane is not as critical, the membrane can be attached with a nitrile-based vinyl adhesive. Watertight PVC boots shall be used for underdrain pipe penetrations through the liner.

##### *16.3.2.2.2 Partial Infiltration Sand Filter*

A partial infiltration sand filter does not include an impermeable liner, and allows some infiltration. Stormwater that does not infiltrate is collected and removed by an underdrain system. This is the most likely scenario for CDOT sand filters and should be used in most cases where the underlying soils cannot drain the *WQCV* in 6 hours or less. A partial infiltration sand filter must meet the MS4 permit *WQCV* design standard.

When an underdrain system is used, a control orifice should be used on the outlet structure to drain the design volume over 12 hours. The control orifice should be easily removable to facilitate maintenance. Cleanouts shall be provided to allow for inspection of the underdrain system immediately after construction to ensure that the pipe was not crushed or disconnected during construction and to allow for maintenance of the underdrain. The operation and maintenance plan should indicate that jetting of the underdrain pipe should be at pressures below 1500 psi to minimize damage to the filter material.

The underdrain pipes should be placed below a minimum of 18 inches of filter material. The underdrain pipes should be placed within an additional, lower section of filter material that allows the pipes to be surrounded by at least 1 inch of filter material. Underdrain pipes shall be spaced a maximum of 20 feet apart. Areas of the underdrain layer closer to the outlet may be thicker to accommodate the slope of the underdrain pipes. If a full infiltration sand filter is used, the minimum section can be reduced to the 18-inch filter material layer. The underdrain system shall use slotted pipe that meets the dimensions in Table 4.

**Table 4** Underdrain Pipe Dimensions

| Pipe Size in | Slot Length in | Maximum Slot Width in | Slot Centers in | Open Area per Foot $in^2$ |
|---|---|---|---|---|
| 4 | 1 - 1/16 | 0.032 | 0.413 | 1.90 |
| 6 | 1 - 3/8 | 0.032 | 0.516 | 1.98 |

Pipe must conform to requirements of ASTM designation F949. There shall be no evidence of splitting, cracking, or breaking when the pipe is tested per ASTM test method D2412 in accordance with F949 section 7.5 and ASTM F794 section 8.5.

#### *16.3.2.2.3 Full Infiltration Sand Filter*

A full infiltration sand filter is designed to infiltrate the water stored in the basin into the subgrade below. An initial infiltration rate that will drain the *WQCV* within 6 hours is required to eliminate the need for an underdrain system. This will allow for long-term functionality of the system given the anticipated slowing of the infiltration rate over time. An underdrain system could still be used, even if it is not initially necessary, to ensure the ability of the basin to drain. For this scenario, a gate or valve could be placed at the underdrain outlet. In the event that infiltration rates do not remain adequate over time, the gate or valve could be opened to allow the basin to drain. It is rare that sand filters can be designed to fully infiltrate. The operation and maintenance plan should require that any gates or valves be returned to their default setting once maintenance activities are completed.

### 16.3.2.3 INLETS, OUTLET, AND SPILLWAY

All points of concentrated inflow into a sand filter should be provided with energy dissipation to limit erosion. Energy dissipation structures include low tailwater basins, impact stilling basins, drop structures, or forebays designed in accordance with the most recent version of the USDCM. Alternately, a riprap blanket underlain with geotextile fabric can be used at the inlet. If a riprap blanket is used, $D_{50}$ shall be 6-to-9 inches, riprap layer thickness shall be two times $D_{50}$, and all rock voids should be filled with Class B or C filter material. Riprap sizing at the basin inlets will be in accordance with the design criteria of this manual based on the 100-year peak flow rate.

When using an underdrain system, a removable control orifice should be used at the outlet structure to drain the design volume in approximately 12 hours or more. A minimum orifice size of 3/8 inch should be used to avoid clogging. Equation 16.4 can be used to size the orifice to provide slow release of the *WQCV*.

$$D = (V/1914\, y^{0.41})^{0.5} \tag{16.4}$$

where $D$ = orifice diameter required to drain basin in 12 hours, in; $y$ = distance from the filter material surface to the center of the orifice, ft; and $V$ = volume to drain in 12 hours (*WQCV*), $ft^3$.

A spillway is required to convey inflow volumes that exceed the *WQCV*. A spillway shall be designed in accordance with the criteria for EDB spillways, including freeboard requirements.

#### 16.3.2.4 MAINTENANCE REQUIREMENTS AND COST

Sand filters require annual or semi-annual inspection to identify clogs or excess sediment material accumulation on the surface of the filter material bed. Inspection should include testing the infiltration rate of the basin using an infiltrometer. Once the infiltration rate falls below what is required to drain the basin in 12 hours, the upper several inches of filter material will need to be replaced to restore filter capacity and remove accumulated pollutants and sediment. The design requirements to facilitate maintenance are discussed later in this section. Sand filters rank as medium-to-high for design, maintenance, and operation costs. Construction costs depend on location; replacement filter material may be costly; and the filter may need expensive concrete walls in urban areas.

### 16.3.3 Media Filter Drains

The media filter drain was developed by the Washington State Department of Transportation (WSDOT) for treatment of sheet flow runoff. It was originally referred to as an ecology embankment, and many documents still use this term. A media filter drain (MFD) is a linear, flow-through water quality device that can be utilized where available right-of-way is limited, including along highway side-slopes and medians, borrow ditches, or other linear depressions. A media filter drain can only be used where runoff from the highway surface is in the form of uninterrupted sheet flow, roadway side slopes are 4H:1V or flatter, and roadway longitudinal slope is 5% or less. A media filter drain shall be designed to meet the MS4 permit TSS design standard by using the design guidance contained herein.

A media filter drain has four basic components: a gravel no-vegetation zone, a vegetated filter strip, the ecology mix bed, and a gravel-filled underdrain trench. A media filter drain removes suspended solids, oil, phosphorus, and metals from highway runoff through physical straining, ion exchange, carbonate precipitation, and biofiltration. The ecology mix bed contains a specific mix of crushed rock, dolomite, gypsum, and perlite.

Comprehensive design guidance and operations and maintenance procedures and requirements for the media filter drain can be found in the latest edition of the *WSDOT Highway Runoff Manual* available at (http://www.wsdot.wa.gov/publications/manuals/fulltext/M31-16/M31-16.04Complete.pdf) or via an internet search for "WSDOT Highway Runoff Manual." This information is contained in RT.07 – Media Filter Drain beginning on page 5-71 of the *WSDOT Highway Runoff Manual* (2014).

All recommended design procedures and parameters shall be adhered to for the media filter drain to function properly, with one exception. The requirement for a vegetated filter strip upstream of the ecology mix bed may be difficult to meet given Colorado's dry climate and the harsh nature of the chemicals applied to CDOT roads in the winter. If it is infeasible to maintain vegetation along a CDOT roadway due to limited precipitation or heavy chemical use, it is acceptable to eliminate the vegetation requirement provided the recommended width of the vegetated filter strip is converted to meet the requirements of the no-vegetation zone. The more distance that can be provided between the traveled way and the ecology mix bed, the less likely an errant vehicle will impact the media filter drain.

One concern is use of the media filter drain adjacent to a guardrail. Guardrail has a tendency to concentrate flows around the support posts, while a media filter drain requires sheet flow to function. If flow cannot be uniformly dispersed downstream of guardrail posts before reaching the ecology mix bed, a media filter drain should not be used.

The *WSDOT Highway Runoff Manual* indicates that media filter drains have low capital costs and low-to-moderate maintenance costs. Maintenance will consist of routine roadside management. Areas of the media filter drain that show signs of physical damage will need to be replaced by maintenance staff.

### 16.3.4 Complementary Components And Practices

Complementary PWQ components and practices should be used in sequence or combination with primary CMs whenever possible to increase the effectiveness of CMs or limit required maintenance. Complementary components and practices will not meet any of the MS4 permit design standards, but rather, will enhance the effectiveness of the CMs that do meet one of those design standards. Complementary practices include dispersion berms or level spreaders, soil amendments, swales, and filter strips.

#### 16.3.4.1 DISPERSION BERMS / LEVEL SPREADERS

Dispersion can be natural or engineered. Dispersion can be effective in mitigating the effects of highway runoff by using existing natural areas to remove pollutants. Natural dispersion requires sheet flow into a naturally vegetated area with characteristics that provide for pollutant removal through vegetative filtration and shallow surface infiltration. The goal is to have stormwater flows dispersed into the surrounding landscape to minimize the likelihood that stormwater runoff will reach a flowing body of water. Natural dispersion is ideal for roadway projects, particularly in rural areas where sheet flow can be maintained.

For engineered dispersion, a constructed conveyance system delivers concentrated runoff to a level spreader that then directs the runoff into a dispersion area in a manner that mimics sheet flow. Engineered dispersion often requires that the dispersion area is enhanced with compost-amended soils and more dense vegetation than what would naturally occur. Safety measures can sometimes be used as engineered dispersion. For example, safety shoulders designed to minimize vehicle rollover could be designed to disperse highway runoff across a media filter drain to enhance infiltration and sediment removal.

Engineered dispersion differs from natural dispersion in that pre-project flows may not have flowed to the dispersion area. As with natural dispersion, the goal is for stormwater flows to be dispersed into the landscape so that stormwater runoff is unlikely to reach a flowing body of water. Site locations for dispersion areas include CDOT rights-of-way, protected areas, agricultural areas, state parks, government-owned forest land, and low density rural areas.

Maintenance requirements include mowing and control of invasive vegetation species; inspection and repair of areas that erode or scour; removal of sediment and other materials to ensure even distribution of flow over the length of the dispersion areas; and removal of litter and debris. Dispersion typically ranks low for design, construction, and maintenance costs; however, costs may increase if right-of-way or easements must be purchased to protect natural dispersion areas from future development.

#### 16.3.4.2 SOIL AMENDMENTS

Soil amendments, including soil conditioners and organic fertilizers, make the soil more suitable for native plant establishment and increase water retention capabilities. Compost amendments and soils for water quality enhancement are also used to enhance native or disturbed and compacted soils. Soil amendments are valuable in areas with poor soils because the added nutrients will sustain vegetative cover, thereby reducing long-term erosion and promoting infiltration. Soil amendments can be used on medians and roadway setbacks. For information on plant selection and establishment to achieve restoration, see the planting section in the most recent edition of the CDOT Landscape Architecture Manual.

Compost as a soil conditioner is an excellent filtration medium for highway runoff. Compost has a high cation exchange capacity (CEC) that chemically traps dissolved heavy metals and binds them to the compost material. Compost also removes oil, grease, and floatables from highway runoff. It should be noted compost-amended soils might cause an increase in nutrients in stormwater runoff until the amended soil stabilizes; therefore, compost should not be used if a project’s receiving water is impaired for a nutrient.

Maintenance activities for areas with soil amendments revolve around establishing and maintaining a robust vegetative cover to minimize erosion and invasive species. Maintenance activities should avoid using equipment that will compact the amended soil, adversely affecting infiltration rates and water holding capacity. Amended soils can be clogged with sediment and fines, in which case the amended soils and associated vegetation must be replaced. Areas with amended soils should be periodically observed after wet weather events as excessive ponding may indicate the need for replacement. Soil amendments are a low added cost to any CM that utilizes vegetation.

#### 16.3.4.3 TREATMENT SWALES

A treatment swale is not allowed to be used on its own to meet MS4 permit requirements without specific approval, but it may still be used as a complementary component to a PWQ CM that does fully meet one of the design standards, or as part of a treatment train that will meet one of the design standards (with approval). Treatment swales and treatment trains are both discussed in Section 16.4.

#### 16.3.4.4 FILTER STRIPS

Filter strips are strips of vegetation and topsoil in the right-of-way, parallel to the road, to treat sheet flow from adjacent impervious area. Treatment occurs as the stormwater runoff flows through the grass and soil surface. Filter strips are good for highway application because of their low maintenance requirements. Vegetated filter strips are only for water quality improvement because they are ineffective peak flow reducers.

Vegetated filter strips cannot be used as a standalone control measures to treat highway runoff but they can be part of a treatment train to provide additional removal of nutrients and dissolved metals.

Maintenance considerations for vegetated filter strips include removal of sediment that accumulates in the grass, mowing, control of nuisance or invasive vegetation, removal of trash and debris, repair of eroded or scoured areas, and sediment removal and cleaning of any flow spreaders to ensure even flow along the length of the vegetated filter strip. Vegetated filter strips rank low for design, construction, and operation and maintenance costs.

### 16.3.5 Design For Maintenance

Countless variations of PWQ CMs have been installed by CDOT over the years, many without input from maintenance crews. All new PWQ CMs must include specific components that will facilitate maintenance. Every CM must be accessible by the size and type of equipment required to maintain it, and the required equipment must be available to CDOT region maintenance crews or local agency maintenance crews if they are responsible for long-term maintenance. Both physical access and maintenance crew safety must be addressed in the CM design. Even if a PWQ CM is located in a local agency's MS4 area, an easement or other means of legal access must be provided to allow CDOT maintenance to access the facility if it treats runoff from the CDOT MS4 area. This is

> CDOT region or local agency maintenance crews must be consulted when designing CMs to ensure they are maintainable with readily available equipment and maintenance crew expertise. If a project will rely on a local agency for long-term maintenance, local agency maintenance staff must be consulted.

required even if an IGA is in place requiring that the local agency maintain the CM. Minimum required maintenance considerations are presented below; local agencies may have additional or different maintenance requirements.

#### Access Roads

- Access roads must be provided to all structures including forebays, outfalls, inlets, micropools, and outlet structures.
- Access roads must support an 80,000-pound vehicle load and be at least 10 feet wide.
- Inside turning radius must be at least 25 feet or as approved to allow equipment to maneuver within the site.
- Access ramps must have a slope no steeper than 10:1.
- Concrete ramps must be scored for wet weather traction.
- To the extent possible, CMs should not be installed in locations where closing a lane of traffic is necessary to perform routine maintenance.

#### Forebays

- Retention and detention CMs must have a forebay, accessible to maintenance crews, to retrieve accumulate sediment and floatables.
- The forebay must be sized for the larger of the sediment load or the hydraulic load recognizing that sediment load is extremely difficult to predict.
- Base flow velocity leaving the forebay must be less than 5 feet/second.

#### Media Filter Drains

- A coarse gravel surface should be provided over media filter drains. Such a surface will prevent damage to the media filter from vehicles and equipment while still allowing runoff to drain to the filter.

#### Stockpile Areas

- PWQ CMs should be designed with a stockpile area for temporary storage and drying of mucked out material. The stockpile area should be directly adjacent to the structures being cleaned out. Erosion control measures such as erosion control logs will likely be required during routine maintenance.
- Stockpile areas must be sited in upland areas to avoid wetland regulatory issues.
- Stockpile areas should be as flat as possible to minimize erosion of the stockpiled material.
- Stockpile areas must be at least twice the combined square footage of the all forebays and the micropool.

#### Extended Detention Basins

- Micropools must be accessible to a vacuum truck or backhoe and have a hard bottom against which to excavate. Without a hard bottom, maintenance operations may inadvertently over-excavate the bottom of the micropool.

- Trickle channels must be at least 84 inches wide and flat. They must have a concrete bottom and concrete sides at least 6 inches high to allow access for lightweight maintenance equipment.

**Infiltration/Sand Filters**

- Sand filters have a short lifespan and must include pretreatment to remove trash and larger sediment.
- Infiltration practices must have a barrier to prevent degradation of the roadway subgrade.
- Cleanouts should be provided every 300 feet where underdrains are used.
- Underdrain piping must be capable of withstanding jetting operations with a jet pressure of 1500 psi.
- Infiltration facilities will require maintenance approval, loading evaluation, and suitable underdrain design if a full infiltration basin is not used. Infiltration testing will be conducted after construction and prior to acceptance to ensure the facility functions as intended.

**Proprietary Structures**

- PWQ CMs that do not require confined space entry procedures are preferred. Careful design of access to vaults and use of a vacuum truck may eliminate confined space entry requirements.
- PWQ CMs that require filters should be avoided if possible. The use of filters increases the cost and frequency of maintenance.

Selection and design of CMs must be coordinated with the applicable CDOT regional maintenance crew or local agency maintenance crew. Specific CMs, such as infiltration practices, require approval by the Region Maintenance Superintendent, before construction, that acknowledges that the equipment and expertise necessary to maintain the CM is available.

## 16.4 CONTROL MEASURES REQUIRING APPROVAL

PWQ CMs falling under the PWQ SAP categories of Retention Pond; PWQ Constructed Wetland; PWQ Inlet/Vault; and Porous Surface are only permitted with specific approval. PWQ CMs falling under the SAP category of Infiltration Facility that require approval include treatment swale, bioretention, porous landscape detention (PLD), bioslope, and biofiltration swale.

These control measures may be used in limited circumstances when approval is obtained. There are two types of approval, Region approval and Mitigation Pool Committee (MPC) approval. Region approval requires the approval of the Region Hydraulic Engineer, the Region Water Quality Specialist, and the Region Maintenance Superintendent. MPC approval requires the approval of the MPC in addition Region approval. Region approval must be submitted to the MPC prior to the MPC granting approval. Details on approval procedures and requirements can be found on the PWQ Program website. Approvals are more likely to be granted when a local agency has agreed to be responsible for completing maintenance operations on a regularly scheduled basis via an IGA. The types of CMs requiring approval, their SAP category, and the type of approval required are shown in Table 5 below. Approval procedures and requirements may be updated over time. Guidance on the PWQ Program website will supersede information in this section.

Detailed design criteria for these types of control measures are not included. Detailed design of these types of CMs must be included in the approval request as described under each of the specific CM headings below. The design must clearly meet one of the three MS4 permit design standards presented in Section 16.2.2.4.1. This section offers a brief discussion of each of these types of CMs and the type of approval required. Details on approval procedures and specific requirements can be found on the PWQ Program website.

### 16.4.1 Proprietary Structures

A wide range of proprietary structures, also known as manufactured systems, is available for water quality treatment. There are two general types of proprietary structures – separation structures and filtration structures. Separation structures use underground vaults and manholes to remove coarse sediment, pollutants absorbed by sediment, oil, and floatables from stormwater runoff via gravity centrifugal separation. If a proprietary structure must be used, a separation structure is preferred. Filtration structures, also known as media filters (not to be confused with the media filter drain), use a special media mix in underground vaults, manholes, or catch basins to remove sediment, metals, and oil from stormwater runoff. Due to the need to replace the filter, filtration structures are not preferred over separation structures. Details on approval procedures for proprietary structures can be found on the PWQ Program website.

**Table 5** Control Measures Requiring Approval

| PWQ Control Measures | SAP Category | SAP Code | Type of Approval | Typical Permit Design Standard |
|---|---|---|---|---|
| Proprietary Structure | PWQ Inlet/Vault | IV | Region | TSS |
| Treatment Swale | Infiltration Facility | TS | Region | Infiltration |
| Bioretention | Infiltration Facility | IF | Region/MPC | Infiltration |
| Porous Landscape Detention | Infiltration Facility | IF | Region/MPC | Infiltration |
| Bioslope | Infiltration Facility | IF | Region/MPC | Infiltration |
| Biofiltration swale | Infiltration Facility | IF | Region/MPC | Infiltration |
| Constructed Wetlands | PWQ Constructed Wetland | CW | Region | *WQCV* |
| Permeable Pavement | Porous Surface | PS | Region/MPC | Infiltration |
| Retention Pond | Retention Pond | RP | Region/MPC | *WQCV* |
| New Technologies | Varies | N/A | Region/MPC | Varies |
| Treatment Trains | Varies | N/A | Region/MPC | Varies |

Proprietary structures are typically compact and installed underground, which makes them a preferred method for treatment in space-limited settings with low design flow rates. However, not all proprietary structures will meet the MS4 permit TSS design standard. In the absence of a complex, expensive, and time-consuming testing program of its own, CDOT has determined that proprietary structures meeting certain protocol established by other public agencies can be assumed to meet the MS4 permit TSS design standard. There are several provisions to this determination discussed in this section.

#### 16.4.1.1 APPROVED TESTING PROTOCOLS

Proprietary structures that have been tested and approved by programs from New Jersey and Washington are acceptable for use on CDOT projects. The New Jersey Department of Environmental Protection (NJDEP) Division of Science, Research & Technology (DSRT) is responsible for certifying final pollutant removal rates for all manufactured treatment devices. The certification process includes verification of a device's pollutant removal rates by the New Jersey Corporation for Advanced Technology (NJCAT). A proprietary structure must be a field verified stormwater technology in the technology verification database maintained by NJCAT to be acceptable for use as a CDOT CM.

Alternately, the Washington State Department of Ecology (WSDOE) maintains a program called the Technology Assessment Protocol – Ecology (TAPE) that has established a testing protocol and a process for evaluating and reporting on the performance and appropriate uses of emerging stormwater treatment technologies. Proprietary structures with a conditional or general use level designation (CULD or GULD) or higher for basic or enhanced treatment are acceptable for use as a CDOT CM.

#### 16.4.1.2 DESIGN FLOW RATE

Another provision for approval of a proprietary structure is that its design must be completed by the manufacturer to treat the water quality flow rate and to pass the flow expected to arrive at the structure during the 100-year event. This does not have to be the 100-year peak flow rate from the area draining to the CM if these peak flows can be bypassed around the structure. The water quality flow rate cited by the current MS4 permit is the 2-year peak flow rate, which shall be calculated in accordance with Chapter 7 – Hydrology of this manual. The 2-year event will yield a volume much larger than the *WQCV*, the measure on which the other two MS4 permit design standards is based.

#### 16.4.1.3 MAINTENANCE REQUIREMENTS AND COST

Proprietary structures are generally expensive to construct and maintain given the flow rate treated, but they can be invaluable where space is too limited to construct a larger CM. Proprietary systems are not recommended for rural locations or any location where maintenance access is limited or restricted.

The use of proprietary structures that use filters must be approved by CDOT or local agency maintenance staff prior to installation to confirm they are willing to accept the cost associated with purchasing and replacing the filters. Maintenance requirements for all proprietary structures include inspections in accordance with the manufacturer's recommended frequency, and removal of floatable debris and trash. A vacuum truck is likely required to maintain a proprietary structure. Confined space entry requirements and the need for lane closures during maintenance should be considered when specifying a proprietary structure.

### 16.4.2 Treatment Swales

Swales are aboveground, shallow, open channels engineered to treat stormwater runoff using sedimentation, filtration, and infiltration as runoff is conveyed through the vegetated surface, typically grass, and the upper soil layer. Unless local soils are in hydrologic soil group A, it is critical that swales be vegetated as the root structure of the vegetation provides a pathway for runoff to infiltrate into the ground. Only if a treatment swale can be designed to meet the requirements of a full infiltration sand filter as discussed in Section 16.3.2 will it meet the runoff reduction (infiltration) design standard from the MS4 permit. If this cannot be achieved, an underdrain system must be installed. Alternately, treatment swales may be used as a complementary component or in a treatment train as discussed later in this section.

Grassed swales are popular because of their low construction and maintenance costs and minimal design limitations. Required maintenance includes periodic removal of litter and debris. Mowing within the bottom of the swale is not recommended unless the vegetation becomes too dense or it is required for safety reasons such as visibility or sight distance. Mowing along the edge of the road, outside the invert of the swale is recommended. Swales rank low-to-moderate for design, construction, and operation and maintenance costs.

### 16.4.3 Bioretention/PLD/Bioslopes/Biofiltration Swales

These types of PWQ CMs require a high level of vegetation maintenance. They require consultation with a licensed landscape architect to ensure that appropriate vegetation is selected for the CM and an operation and maintenance plan is in place to maintain the vegetation, including irrigation if base flows are not present. CDOT does not typically have the resources required for intensive routine landscape maintenance along roadways and at maintenance facilities. A local agency or a unique CDOT facility however, may have these resources and a strong interest in CM aesthetics in addition to functional processes. Region and Mitigation Pool Committee approvals are required to construct these types of PWQ CMs. Details on approval procedures and specific requirements can be found on the PWQ Program website.

### 16.4.4 Constructed Wetlands

Constructed wetlands require base flows and ongoing maintenance of vegetation in Colorado’s climate. Additionally, the presence of de-icing chemicals and other pollutants in runoff from CDOT MS4 area requires coordination with a licensed landscape architect and careful selection of robust vegetation to ensure long-term success of the constructed wetland vegetation. CDOT will not allow constructed wetlands without approval. Additionally, CDOT does not allow mitigated wetlands to be constructed within a PWQ CM. Constructed wetlands can never be located in a water of the state. A Region approval is required to construct these types of PWQ CMs. Details on approval procedures and specific requirements can be found on the PWQ Program website.

### 16.4.5 Permeable Pavement Systems

Permeable pavement includes a variety of stabilized surfaces that can be used for the movement and parking of various types of vehicles as well as storage of materials and equipment. Permeable pavement is designed to infiltrate stormwater runoff instead of shedding it off the surface like a conventional pavement. Permeable pavement offers the advantage of decreasing the effective imperviousness of an urbanizing or redeveloped site, thereby reducing runoff and pollutant loads leaving the site (City of Aspen, 2014).

Permeable pavement has been demonstrated to be an effective CM in parking lots and other areas with a low design speed and light traffic load. Issues including structural design, water quality, surface clogging, cold weather performance, and required maintenance present challenges to this CM. CDOT has not endorsed permeable pavement for use on roadway projects but may consider test applications at maintenance yards or headquarters or region office parking lots. Region and Mitigation Pool Committee approvals are required to construct these types of PWQ CMs. Details on approval procedures and specific requirements can be found on the PWQ Program website.

### 16.4.6 Retention Ponds

Senate Bill 15-212 requires a retention facility have a surface water right or augmentation plan to ensure that it will not injure downstream surface water rights. CDOT has not historically held surface water rights; CDOT also expects that it would be cost prohibitive to obtain surface water rights with sufficient seniority to make retention feasible. However, a local agency with senior water rights may be in a position to construct and maintain a retention-based PWQ CM. Both Region and MPC approvals are required to construct these types of PWQ CMs. Details on approval procedures and specific requirements can be found on the PWQ Program website.

### 16.4.7 New And Innovative Technologies

CDOT recognizes the need to explore new or innovative technologies and may allow new or innovative technologies on a pilot basis. These types of CMs must be approved through a pilot process, and approvals must be obtained. Project teams that want to use new or innovative technologies should consider applying to the Division of Transportation Development (DTD) Applied Research and Innovation Branch to fund a study of the new or innovative technology. Information on the Research Program can be found at the Research Program website.

The project team must prepare a report at the end of design and construction that documents whether the design and installation met expectations and whether there were unforeseen costs. A program to track the performance of the CM as well as maintenance requirements for the first several years must be established, reviewed, and accepted. All of the records from this program must be submitted to the PWQ Program Manager for evaluation by the MPC so that a decision can be made on future use of the technology. Region and Mitigation Pool Committee approvals are required to construct these types of PWQ CMs. Details on approval procedures and specific requirements can be found on the PWQ Program website.

### 16.4.8 Treatment Trains

Treatment trains are multiple CMs in series that provide complementary or redundant water quality treatment. One example of a treatment train is a complementary or incidental pretreatment CM constructed upstream of the primary CM to allow the primary CM to function more effectively and to limit maintenance. They offer the following benefits:

- Expanded pollutant removal: Treatment trains link together complementary processes and expand the range of pollutants that can be treated by the system. They increase the overall efficiency of the system for pollutant removal. A sand filter, for example, could be placed downstream from an EDB to remove any pollutants remaining in the discharge.

- Redundancy: Multiple practices in a treatment train can provide more consistent treatment of runoff than a single practice and provide redundancy in the event that one component of a treatment train is not functioning as intended.
- Pretreatment: CMs that remove trash, debris, coarse sediment, and other gross solids are a common first stage of a treatment train. They are also often easier to maintain because pretreatment concentrates larger debris in one area for easier cleaning. Pretreatment extends the service life of downstream components by reducing the potential for clogging and accumulation of trash and debris.

PWQ CMs that are well suited to be included in a treatment train may not achieve one of the MS4 permit design standards on their own. Instead, they can be used to enhance the function or limit maintenance of primary PWQ CMs that do meet an MS4 permit design standards. If a designer believes that multiple CMs in sequence can be shown to achieve one of the MS4 permit design standards, in lieu of a single CM, that designer must receive Region and Mitigation Pool Committee approvals to construct them. Details on approval procedures and specific requirements can be found on the PWQ Program website.

## 16.5 REQUIRED DOCUMENTATION

When a PWQ CM is constructed, regardless of the category the project is in, several documents must be submitted prior to project advertisement. Guidance for all required documentation is included on the PWQ Program website. Required documents include the following:

- PWQ Evaluation and Tracking Form;
- PWQ Funding Application;
- Water Quality Report;
- Required Plan Information Checklist;
- Maintenance Checklist;
- As-Built Plans;
- Operations and Maintenance Manual;
- GIS Information; and
- Water Rights Reporting.

Additional information is included in the subsections below. All documents including, but not limited to, construction plans, operation and maintenance plans, as-built plans, and all reports should indicate both the SAP category and the specific type of PWQ CM being designed. Table 1 in Section 16.3 includes this information.

### 16.5.1 PWQ Evaluation And Tracking Form

The PWQ Evaluation and Tracking Form, previously the NDRD Evaluation and Tracking Form, must be completed for all projects, regardless of whether a PWQ CM is required. This form is required for evaluation and tracking of PWQ CMs within the PWQ Program. This form is also used to determine whether PWQ is required for a project and to track specific PWQ requirements. Projects using PWQ Mitigation Pool funds must also complete the PWQ Cost Estimate and Design Expenditure spreadsheet. These are all available on the PWQ Program website.

### 16.5.2 PWQ Funding Application

CDOT projects that require PWQ CMs as a result of MS4 permit or that include PWQ CMs that treat runoff from the MS4 area are often eligible to receive funding from the PWQ Mitigation Pool. The requirements to obtain funding differ depending on a variety of criteria. The PWQ Program Manual as well as various application guidance and flow charts are available on the PWQ Program website to aid in determining project eligibility and the applicable funding process.

### 16.5.3 Water Quality Report

A Water Quality Report is required to be included as an appendix to the Hydraulic Design Report when a project includes one or more PWQ CMs. The required outline and contents of the report can be found on the PWQ Program website.

### 16.5.4 Checklists

Several checklists must be completed over the course of design and construction of a PWQ CM. They include the following:

- **Required Plan Information Checklist** – A Required Plan Information Checklist must be included as an attachment to the Water Quality Report for every PWQ CM included on a project. There is a checklist for an extended detention basin; a checklist for a sand filter, which can also be used for a treatment swale; and checklist for a proprietary structure. The information included on the applicable checklist must be included on the construction plans. The checklists can be found on the PWQ Program website.
- **Maintenance Checklist** – The Maintenance Final Acceptance Checklist for Project Closeout for Permanent Water Quality Control Measures must be completed prior to project closeout. This checklist ensures that maintenance staff will be involved throughout the entire design and construction process and that maintenance concerns have been addressed. The checklist can be found on the PWQ Program website.

### 16.5.5 As-Built Plans

There are specific requirements for as-built plans, also called as-constructed plans, for PWQ CMs, in addition to what is required by the CDOT Construction Manual. Specific requirements for PWQ CM as-built plans can be found on the PWQ Program website. Revisions to the operations and maintenance manual must be included as part of the as-built submittal if field or change orders were issued to revise the PWQ CM design during construction.

### 16.5.6 Operations And Maintenance Manual

An operations and maintenance manual must be completed for each PWQ CM concurrent with construction plans. Guidance on how to complete the operations and maintenance manual, including required information and example manuals is included on the PWQ Program website. If as-built conditions necessitate a revision of the operations and maintenance manual, those revisions must be made as part of the as-built submittal.

### 16.5.7 GIS Information

A GIS shapefile indicating the area treated by each PWQ CM must be submitted and incorporated into the PWQ database. Specific requirements for GIS information and submittal protocols can be found on the PWQ Program website.

### 16.5.8 Water Rights Reporting

If a CM is a detention or infiltration facility, it must follow the design and reporting requirements indicated in Section 16.2.2.3.

## 16.6 DESIGN EXAMPLES

Design examples have been developed to walk the designer through the process of the three most common types of PWQ CMs – the extended detention basin, the sand filter, and the media filter drain. A common project example will be used for each with slight variations as noted.

CDOT is improving a one-mile stretch of an existing two-lane roadway located within CDOT's MS4 area in the Denver metropolitan area. The existing roadway section includes two 12-foot lanes with an 8-foot paved shoulder on each side within a 130-foot right-of-way, all of which drains to existing roadside ditches. The roadway section will be widened by 12 feet to accommodate a center turn lane, which increases the imperviousness of the project site by 30%. The total width of disturbance is anticipated to be 40 feet, including roadway widening and ditch work. This results in a total disturbed area of 4.85 acres over the project length. Table 6 presents existing and post-construction project area dimensions.

The proposed roadway will be crowned in the center and drain to the reconstructed roadside ditches on either side. The entire project length has a generally constant grade of approximately 2%, draining from north to south. This project meets the criteria of the 303(d) trigger and requires a PWQ CM in accordance with the guidance on the PWQ website. The examples in this section will all reference these project characteristics.

**Table 6** Project Data

| Element | Description | Width (feet) | Area (acres) |
|---|---|---|---|
| a | Right-of-way (R/W) | 130 | 15.76 |
| b | Existing impervious roadway area | 40 | 4.85 |
| c | Existing undeveloped R/W (a - b) | 90 | 10.91 |
| d | New impervious roadway area | 12 | 1.45 |
| e | Post-construction impervious area (b + d) | 52 | 6.30 |
| f | Post-construction undeveloped R/W (a-e) | 78 | 9.45 |

### 16.6.1 Extended Detention Basin

For this example, CDOT was able to acquire enough right-of-way adjacent to the east side of the roadway right-of-way at the south end of the project to be able to accommodate an open basin. A geotechnical investigation indicated that groundwater was too high to accommodate a sand filter. An extended detention basin (EDB) will be evaluated to determine if it can be designed to meet the *WQCV* design standard and is appropriate for this site.

The *WQCV* design standard requires that treatment be provided for runoff from a total impervious area equal to or greater than 90% of the new impervious area. With a new impervious area of 1.45 acres, a minimum of 1.31 acres of impervious area must be treated.

The project area draining to the CM site includes 7.88 acres on the east side of the crown, of which 3.15 acres will be impervious once the project is complete. This exceeds the 1.31 acres of impervious area that must be treated to achieve the *WQCV* design standard, and CDOT is not required to convey runoff from the west half of the roadway to the EDB for treatment.

However, surface runoff from an additional 7.12 acres outside the project area drains into the east ditch, 4.35 acres of which are impervious. The EDB must be designed to treat runoff from the entire area draining to the CM site because flows from within and from outside the project area cannot reasonably be separated. A total of 15.0 acres will be treated by the EDB, 7.5 of which are impervious. Table 7 presents the areas to be treated by the EDB.

Fact Sheet T-5 from the USDCM indicates that EDB drainage areas should include a minimum of 2 acres of impervious area, and that EDBs are best suited for watersheds with at least 5 impervious acres. The area to be treated by the proposed CM indicates an EDB is appropriate for this project.

The first step in designing an EDB is calculating the *WQCV* using equation 1. While the minimum drain time is 12 hours, longer drain times result in better removal of pollutants. Because there is adequate area within the drainage easement, a 40-hour drain time is used for this example.

$$WQCV = Aa(0.91I^3 - 1.19I^2 + 0.78I)/12$$

where $a$ = 1.0 for a drain time of 40 hours (Table 2); $I$ = 0.50; and $A$ = 15.0 acres.

$$WQCV = 15(1.0)[(0.91(0.50)^3 - 1.19(0.50)^2 + 0.78(0.50)] /12 = 0.26 \text{ acre-feet}$$

**Table 7** Area Treated by the EDB

| Element | Description | Width (ft) | Area (ac) |
|---|---|---|---|
| g | East side of the R/W within the project area | 65 | 7.88 |
| h | East side proposed total impervious area | 26 | 3.15 |
| i | Offsite area draining to the CM | varies | 7.12 |
| j | Offsite impervious area draining to the CM | varies | 4.35 |
| k | Total area to be treated by the CM (g + i) | varies | 15.00 |
| l | Total impervious area to be treated (h + j) | varies | 7.50 |

The EDB must be designed to treat a *WQCV* of 0.26 acre-feet. The next design steps for the EDB include determining geometry of the basin itself, and sizing the initial surcharge volume (ISV), micropool, outlet structure, and spillway. The USDCM provides guidelines for each design element. The UDFCD also publishes the spreadsheet tools “UD-Detention” and “UD-BMP” that may aid in the design. Hydraulic modeling software such as EPA SWMM may be used iteratively route flows through the basin to achieve an acceptable design. However, the limitations of any design aid must be understood by the designer, and output must be evaluated by a competent engineer. Every project will require consideration for specific details beyond those produced by design aids. For this example, UD-Detention will be used to develop general dimensions and outlet configurations.

Once the required *WQCV* is known, the basin must be developed to fit the available space. Side slopes should be 4:1 to allow for mowing. A general length-to-width ratio of at least 3:1 should be used with an expansion from the inlet and contraction toward the outlet. The ultimate configuration of the basin will likely need to be developed by iterating configurations until the required volume, including freeboard, is achieved within the available footprint.

The EDB must include a permanent micropool with a minimum depth of 2.5 feet and minimum surface area of 10 square feet. In UD-Detention, a stage of 0.0 feet should coincide with the top of the micropool. The initial surcharge volume (ISV) is calculated as 0.3% of the *WQCV* and is located on top of the micropool. For this example, the ISV is calculated to be 34 cubic feet and will be set to a depth of 0.5 feet. The trickle channel slope should be between 0.4% and 1.0%, and typical depths range from 0.5 to 1.5 feet. The trickle channel for this example will be 0.5 feet deep and have a slope of 0.5%. An available detention depth of 3.0 feet has been selected to store the *WQCV*. When entered into UD-Detention, these dimensions result in a basin floor that is approximately 127 feet long by 47 feet wide with an area of 5,936 square feet. The final layout of the basin must be determined after sizing the outlet to account for required freeboard. Variations to the floor dimensions will require a user-input stage-storage definition.

The *WQCV* outlet for this EDB will use an orifice plate to release the *WQCV* over 40 hours. Using the UD-Detention spreadsheet, the ideal configuration for this *WQCV* outlet is three 1-1/16-inch-diameter circular orifices, spaced at 12 inches on center vertically, with the lowest orifice being located even with the top of the micropool. This results in a maximum depth of 3.0 feet during the *WQCV* event.

The final step is to size an emergency spillway for the EDB. The EDB spillway must be designed to pass the 100-year peak inflow with at least 1.0 feet of freeboard in the basin. As the design depth of flow through the spillway increases, so too must the height of the embankments of the basin. Spillway overflow depths should be limited to the extent possible to limit the size of the basin and the energy required to be dissipated downstream of the spillway.

The 100-year peak flow is calculated to be 24.2 cfs. A trapezoidal spillway will be set at a stage of 3.0 feet, equal to the depth of the *WQCV*. The crest length will be 6.0 feet and side slopes 3:1. Using the UD-Detention spillway sizing application, this results in a 100-year flow depth of almost one foot. This yields a peak stage of nearly 4.0 feet. Adding one foot of freeboard requires a total minimum basin depth of 5.0 feet. The EDB spillway must be designed and stabilized in accordance with the USDCM. The overflow should be located where flows can best be routed downstream and provide capacity for the 100-year discharge from the EDB.

While UD-Detention offers a helpful way to develop a preliminary design, a detailed stage-storage relationship must be developed for each EDB in CAD to account for the specific geometry of the basin. The specific project site geometry will include variations for maintenance access and other site constraints. This specific relationship can be entered into UD-Detention to size the *WQCV* orifice plate and the outlet and the overflow spillway, but all other calculations must be completed by hand.

### 16.6.2 Sand Filter

For this example, CDOT was able to acquire a drainage easement on the west side of the highway at the south end of the project. The area draining to the CM site from within the project boundary is the same as for the east side, 7.88 acres including 3.15 impervious acres. However, 3.62 acres of offsite area also drains to the CM site, including 0.85 acres of imperviousness. The total area that will drain to the CM is 11.5 acres, 4.0 acres of which are impervious. This site will be considered as an alternative to the EDB at the east CM site. Table 8 shows the area to be treated by the sand filter.

The geotechnical investigation of the proposed CM site indicates that groundwater is deep enough to accommodate a sand filter. Because a sand filter may achieve greater pollutant reduction than an EDB, the Project Manager would like to evaluate the feasibility of constructing a sand filter at this location. Site conditions do not allow for peak or offsite flows to be bypassed around the CM site, so the entire drainage area of 11.5 acres must be treated.

**Table 8** Area Treated by the Sand Filter

| Element | Description | Width (ft) | Area (ac) |
|---|---|---|---|
| m | West side of the R/W within the project area | 65 | 7.88 |
| n | West side proposed total impervious area | 26 | 3.15 |

| | | | |
|---|---|---|---|
| o | Offsite area draining to the CM | varies | 3.62 |
| p | Offsite impervious area draining to the CM | varies | 0.85 |
| q | Total area to be treated by the CM (m + o) | varies | 11.50 |
| r | Total impervious area to be treated (n + p) | varies | 4.00 |

The sand filter will be designed to meet the runoff reduction (infiltration) design standard. This design standard requires that the sand filter infiltrate, evaporate, or evapotranspirate a quantity of water equal to or greater than 60% of the *WQCV* calculated for all impervious area from within the project area. The first step is to calculate the *WQCV* for the impervious portion of the project area using equation 1 with the minimum drain time of 12 hours.

$$WQCV = Aa(0.91I^3 - 1.19I^2 + 0.78\,I)/12$$

where $a$ = 0.8 for a drain time of 12 hours (Table 2); $I$ = 1.00 (6.3 impervious acres for the entire project site); and $A$ = 6.3 acres from entire project area (both sides of the crown).

$$WQCV = 6.3(0.8)[(0.91(1.00)^3 - 1.19(1.00)^2 + 0.78(1.00)]\ /12 = 0.21 \text{ acre-feet}$$

The minimum volume that must be treated by the sand filter is calculated as 60% of this value, or 0.13 acre-feet. The next step is to calculate the *WQCV* for the area that will physically drain to the new CM to ensure that it will function as intended under the hydraulic conditions presented by the water quality event.

$$WQCV = Aa(0.91I^3 - 1.19I^2 + 0.78\,I)/12$$

where $a$ = 0.8 for a drain time of 12 hours (Table 2); $I$ = 0.35 (4.0 impervious acres divided by 11.5 total acres); and $A$ = 11.5 acres, including offsite area.

$$WQCV = 11.5(0.8)[(0.91(0.35)^3 - 1.19(0.35)^2 + 0.78(0.35)]\ /12 = 0.13 \text{ acre-feet}$$

It is a coincidence that the volume to be infiltrated that is required by the permit is equal to the *WQCV* of the area draining to the CM. If the *WQCV* of the area draining to the sand filter had been higher than the volume required by the permit, the sand filter would need to be designed to infiltrate that larger volume of water to ensure proper treatment of the design runoff event. The sand filter will be designed to infiltrate 0.13 acre-feet. The minimum basin floor area is determined using Equation 3 for the area draining to the CM, 11.5 acre-feet.

$$A_F = 0.0125\,AI$$

where $A$ = (11.5)(43560) = 500,890 $ft^2$; I = 0.35(4 impervious acres / 11.5 total acres); and
AF = 0.0125(500,890)(0.35) = 2,180 $ft^2$

Next, it must be determined whether a no-infiltration, partial infiltration, or full infiltration design is appropriate. No structures are nearby and the edge of the CM site is located far enough from the edge of the roadway that no soil stability issues are anticipated. No toxic pollutants are expected to enter the sand filter, and there is no known existing contamination of soils under the CM site. The geotechnical investigation found no expansive soils or bedrock, and determined a soil infiltration rate of 3.0 inches per hour. Using the minimum basin floor area of 2,180 square feet and the volume to be treated of 0.13 acre-feet, the design depth is 31.2 inches. Note that this "design depth" is not equivalent to the expected ponding depth within the basin due to the some of the treatment volume being stored over the side slopes of the basin.

Given the infiltration rate of the soil of 3.0 inches per hour, it would take 10.4 hours for the design treatment volume to infiltrate via the floor of the basin. Sand filters must infiltrate the design volume within 6 hours, so either the basin floor area must be increased, a partial infiltration design must be used, or both. For this example, the basin floor area will be kept at approximately 2,180 square feet and a partial infiltration sand filter will be designed.

The next steps for design of the sand filter include determining geometry of the basin itself, sizing the underdrain system, and designing the overflow spillway. The USDCM provides guidelines for each design element, and the spreadsheet design tools UD-Detention and UD-BMP may both be used as aids to approximate a preliminary design values.

UD-Detention was used to iterate the design ponding depth using 4:1 side slopes and a 3:1 basin length-to-width ratio to achieve the minimum floor area of 2,180 square feet within the spreadsheet.
UD-Detention yielded a design ponding depth of 1.8 feet, a basin floor length of 81 feet, a basin floor width of 27 feet, and a final basin floor area of roughly 2,200. While UD-Detention can be used in this manner to approximate basin dimensions, the final design of the basin will need to reflect the actual stage-storage relationship that will be constructed before proceeding with the outlet and underdrain design. This actual stage-storage relationship can be entered into UD-Detention to determine orifice and spillway parameters.

The outlet for the design event will be an underdrain system located below a layer of filtration media that must be a minimum of 18 inches deep. The invert of the underdrain will be 2 feet below the surface of the filtration media and be underlain by at least 1 inch of filter media. The underdrain system will converge at an accessible outlet structure where a control orifice will be located. The slotted underdrain pipes and control orifice at the downstream end of the underdrain system must be sized so that the design volume fully releases over 12 hours or up to 72 hours.

UD-Detention was used to determine the design orifice size by selecting the outlet type, the underdrain invert depth, and clicking the “Calculate Underdrain Orifice Diameter to match *WQCV* Drain Time” button. Time to drain is then shown as 12 hours in the spreadsheet for this example. If a longer drain time is desired, the orifice size may be slightly reduced to achieve the desired drain time. Using a 12-hour drain time resulted in an orifice diameter of 1-3/4 inches. This size orifice can be accommodated by 4-inch diameter underdrain pipes. Underdrain pipe sizes should be able to convey the design volume to the outlet within the design drain time. Underdrain pipes should be spaced no farther than 20 feet from each other or the edge of the basin floor. The USDCM includes dimensions for the slots on the underdrain pipe.

The final step in the design of a sand filter is to size an emergency spillway to provide passage for up to the 100-year peak inflow to the basin. The spillway elevation will be placed at the design ponding depth, and at least 1 foot of freeboard will be provided above the 100-year water surface elevation.

The 100-year peak inflow into the basin is 15.5 cfs, and a dropbox overflow with a sloping grate will be used. Within UD-Detention, the overflow weir edge was set to the design ponding depth of 1.8 feet. The front edge of the dropbox weir will be 3.5 feet long; the sides will be sloped at 4H:1V to match the embankment slope; and the sides will 3.5 feet long. A 24-inch outlet pipe will be used to convey overflow from the box to the downstream ditch. Its invert will be set 2 feet below the basin floor to be level with the underdrain system. Inlet or outlet control nomographs may be used to size the outlet pipe as needed. Using the UD-Detention-recommended grate open area ratio of 70% and debris clogging ratio of 50%, the maximum depth of the 100-year event is calculated to be 3.0 feet. A quick check of velocity through the grate shows a maximum of 1.8 feet per second, which is less than recommended maximum of 2 feet per second. Accounting for one foot of freeboard, the basin must be 4 feet deep, with an approximate length of 113 feet, width of 59 feet, and area of 6,700 square feet. These dimensions do not account for embankments or maintenance access and are preliminary only.

### 16.6.3 Media Filter Drain

For this example, CDOT was unable able to acquire any additional drainage easements or right-of-way, eliminating the possibility of using an open basin CM. The Project Manager would like to evaluate the feasibility of using a Media Filter Drain (MFD) to meet the pollutant removal (TSS) design standard. This design standard requires that the CM be designed to treat the 2-year peak runoff.

Effective MFDs require that runoff enters the CM as sheet flow, and that embankment slopes perpendicular to the highway are between 2% and 25%. To increase the chances of maintaining sheet flow and to reduce the risk of the MFD being damaged by errant vehicles, the shoulder on the side the MFD will be constructed will be widened from 8 feet to 10 feet.

Sheet flow from the roadway to the MFD should occur when the paved flow path is less than 150 feet and the resultant roadway slope, combining longitudinal slope and cross slope, does not exceed 9.4%. For this project, the flow path from the crown to the edge of pavement will be 28 feet. The longitudinal slope of the highway is 2.0% and the cross slope is 2.0%. The resultant roadway slope is calculated using the equation below.

$$S_{CFS} \leq (G^2 + e^2)^{0.5}$$

where $S_{CFS}$ = resultant roadway slope, %; $e$ = cross slope (including superelevation), % = 2%; $G$ = longitudinal slope (grade), % = 2%; and $S_{CFS} \leq (2.0^2 + 2.0^2)^{0.5} = 2.8\%$.

Both the flow path and resultant roadway slope are within the requirements for MFD.

The flowline of the ditches along the highway are offset 36 feet horizontally and 6 feet vertically below the existing edge of pavement, and they must not be moved in order to avoid earthwork outside the right-of-way. After widening the paved width of the roadway by 8 feet on the side of the new MFD, the new embankment slope for the MFD will be 20.9%, which is within the allowable 4H:1V maximum for a simple MFD application.

The required amount of impervious area to treat in order to meet the pollutant removal (TSS) design standard is equal to or greater than 90% of the new impervious area. This was determined to be 1.31 impervious acres in the example in Section 16.6.1. The MFD will be treating 28 feet of roadway pavement width. Dividing the required treatment area of 1.31 acres by a paved width of 28 feet yields a required MFD length of 2,038 feet. The 2,038 feet of MFD could be located anywhere along the length of the project. It is preferable to place the MFD where its discharge point would have the shortest flow path to receiving waters.

The next step is to select an MFD design type. The Type 1 and Type 3 designs from WSDOT are both suited for side slope applications like the one required in this example. A Type 1 MFD includes an underdrain pipe for conveying treated runoff to a downstream concentrated discharge point, while a Type 3 MFD disperses treated runoff through a toe comprised of crushed base course material. For both types, the 50-year water surface elevation in the adjacent ditch must be known. For this example, treated runoff does not need to be conveyed to a particular location, so a Type 3 MFD will be used. Because the receiving stream is impaired for phosphorus, the MFD must be designed without a compost blanket.

The final steps are to determine the design flow rate and the required width of the MFD. The Rational Method may be used to determine the peak 2-year flow rate from the impervious area to be treated. A time of concentration of five minutes should be assumed to determine the 2-year rainfall intensity, and a C value of 1.0 should be used for all paved areas. Area will be the total contributing area in acres. In this example, the area is 1.31 acres. The 2-year, 5-minute rainfall intensity for the project area is 3.36 inches per hour, resulting in a 2-year peak flow rate of 4.74 cfs. The equation to determine the MFD mix bed width is as follows:

$$W = QC(SF) / L(LTIR)$$

where $W$ = width of MFD mix bed, feet; $Q$ = design peak flow rate for treated area, cfs; $C$ = conversion factor of 43,200; (in/hr)/(ft/sec); $SF$ = safety factor (equal to 1.0) unless unusually heavy sediment loading is expected); $L$ = length of MFD (parallel to roadway), ft; and $LTIR$ = long-term infiltration rate of the MFD mix (use 10), in/hr.

Applying the equation to this example with a total MFD length of 2,038 feet and a Safety Factor of 1.0, the minimum width of the mix bed is 10.0 feet. With a non-vegetation zone of 3 feet and a 3-foot wide grass strip, the horizontal distance from the edge of pavement to the downslope edge of the MFD is 16.0 feet. At the downslope edge of the MFD, the mix bed must be 12 inches deep, and the crushed base course toe for the MFD must extend 6 inches below the mix bed and daylight horizontally. At a slope of 20.9%, the width of the base course toe is 7.2 feet. A total horizontal width of 23.2 feet is required for the MFD. The edge of the crushed base course toe will be 4.8 feet away horizontally and 1.0 feet away vertically from the ditch invert. For this example, it will be assumed that this keeps the edge above the 50-year WSE of the ditch.

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## Appendix A – Acronyms and Definitions

**303(d)** – refers to a section of the Clean Water Act that requires states to submit a list of impaired and threatened waters (i.e. the 303(d) list) to the EPA for approval every two years. For each water on the list, the state identifies the pollutant causing the impairment, when known, initiating a TMDL analysis.

**ADOT** – Arizona Department of Transportation

**CDOT** – Colorado Department of Transportation

**CDPHE** – Colorado Department of Public Health and Environment; state agency that that dictates water quality management requirements via the issuance of MS4 permits to achieve reduction of pollutants in the stormwater discharges from CDOT's MS4 area.

**CDPS** – Colorado Discharge Permit System; the system under which individual MS4 permits are issued by the CDPHE to allow discharge of runoff to surface waters. CDOT's MS4 permit number COS000005 is issued under the CDPS.

**CEC** – Cation Exchange Capacity; the total capacity of a soil to hold exchangeable cations. CEC influences the soil's ability to hold onto essential nutrients and provides a buffer against soil acidification.

**CGS** – Colorado Geologic Survey; a state government agency within the Colorado School of Mines whose science-driven mission is to help reduce the impact of geologic hazards on the citizens of Colorado.

**CLOMR** – Conditional Letter of Map Revision; FEMA's comment on a proposed project that would, upon construction, affect the hydrologic or hydraulic characteristics of a flooding source and thus result in the modification of the existing regulatory floodway, the effective Base Flood Elevations (BFEs), or the Special Flood Hazard Area (SFHA).

**CM** – control measure; this term replaces the term "best management practice" (BMP) as the preferred term to refer to permanent facilities that are intended to treat water quality in perpetuity once construction is complete.

**CRS** – Colorado Revised Statute

**CWA** – Clean Water Act; a federal law implemented in 1972 and administered by the CDPHE in the form of MS4 permits.

**CWCB** – Colorado Water Conservation Board; a state agency that provides policy direction on water issues. The CWCB's responsibilities are wide-ranging, but include protecting Colorado's streams and lakes, watershed protection, and stream restoration.

**CWQCA** – Colorado Water Quality Control Act; an act adopted in 1966, creating authority to establish water quality standards consistent with the Federal Clean Water Act. The CWQCA is the analog of the federal CWA but includes special provisions to assure that water quality control efforts in Colorado are refined to meet the specific needs of Colorado's waterways.

**CWQD** – Colorado Water Quality Division; the division within the CDPHE that is tasked with administering water quality control programs to protect waters of the state through delegated authority by both the CWQCA and the federal CWA. The CWQD provides education, compliance assistance, permits, inspections and enforcement to promote prevention, control and abatement of water pollution.

**DDM** – Drainage Design Manual; the CDOT-authored document that provides guidance and detailed design criteria for multiple aspects of drainage design including PWQ CMs.

**DSRT** – Division of Science, Research & Technology; a division of the NJDEP that is responsible for certifying final pollutant removal rates for all manufactured treatment devices.

**DTD** – Division of Transportation Development; a CDOT division that includes the Applied Research and Innovation Branch whose mission is to save Colorado citizens' money, time, and lives while preserving the environment and quality of life through the research, development and deployment of innovative products, materials, and methods in transportation.

**DWR** – Colorado Division of Water Resources; also known as the Office of the State Engineer, the DWR administers water rights and oversees dam safety, among many other services in Colorado.

**EA** – Environmental Assessment; a document prepared under NEPA to provide sufficient evidence and analysis to determine whether a proposed agency action would require preparation of an environmental impact statement or a finding of no significant impact.

**EDB** – Extended Detention Basin; a facility that provides temporary storage of stormwater runoff. It has an outlet structure that detains and attenuates inflows and promotes the settlement of pollutants.

**EIS** – Environmental Impact Statement; a document prepared under NEPA to describe the effects of proposed activities on the environment.

**EPA** – Environmental Protection Agency; Federal agency in charge of implementing the federal Clean Water Act. In Colorado EPA has delegated the implementation of the CWA to CDPHE. Ultimately, EPA is the overreaching governing agency of the MS4.

**EURV** – Excess Urban Runoff Volume; the difference in runoff volume between the developed condition and the undeveloped (i.e., natural) condition.

**HSG** – Hydrologic Soil Group; one of four soil classifications created by the Natural Resource Conservation Service (NRCS) based on a soil's runoff potential. The four HSGs are A, B, C and D. Type A soils generally have the smallest runoff potential and Type D the greatest.

**LOMR** – Letter of Map Revision; FEMA's modification to an effective Flood Insurance Rate Map (FIRM), or Flood Boundary and Floodway Map (FBFM), or both.

**Mitigation Pool** – In order to meet the requirements of the MS4 permit, CDOT contributes $6.5 million annually to the PWQ Mitigation Pool. Funding is to construct PWQ CMs that will treat runoff from CDOT MS4 area.

**MnDOT** – Minnesota Department of Transportation

**MPC** – Mitigation Pool Committee; the MPC is a committee that evaluates projects' proposed PWQ CMs to determine if funding from the Mitigation Pool can be allocated to them. The MPC also may grant variances for CMs that require them.

**MS4** – Municipal Separate Storm Sewer System; a conveyance or system of conveyances that is owned by a state, city, town, village, or other public entity that discharges to waters of the U.S.; designed or used to collect or convey stormwater (e.g., storm drains, pipes, ditches); not a combined sewer; and not part of a sewage treatment plant, or publicly owned treatment works.

**NDRD** – New Development Redevelopment; NDRD refers to CDOT's program to treat water quality using PWQ CMs. Also known as the NDRD Interim Program, this program is the precursor to the PWQ Program.

**NEPA** – National Environmental Policy Act; a US environmental law that promotes the enhancement of the environment enacted on January 1, 1970.

**NJCAT** – New Jersey Corporation for Advanced Technology; the entity that verifies CM pollutant removal rates and maintains a database of verified CMs. NJDEP – New Jersey Department of Environmental Protection.

**PLD** – Porous Landscape Detention; a low lying vegetated area underlain by a sand bed with an underdrain pipe. The underdrain gradually dewaters the sand bed to a nearby channel, swale, or storm sewer.

**PWQ** – Permanent Water Quality; a general acronym. It is also a designation for CMs that are intended to be in service indefinitely as opposed to facilities that are intended to treat water quality during construction.

**PWQ Program** – one of the seven programs required by CDOT's MS4 permit, which requires CDOT to reduce the discharge of pollutants to the MS4 area that come from new development and redevelopment (NDRD). The PWQ Program requirements are outlined in the PWQ Program Guidance.

**RPEM** – Regional Planning and Environmental Manager; the CDOT employee responsible for managing environmental and planning staff and projects for a Region. The RPEM signs the 128 form and is responsible for ensuring environmental clearances are met on projects.

**RWPCM** – Region Water Pollution Control Manager; a CDOT position originally created as a result of a notice of violation from the CDPHE. The main intent of the position is to perform audits on CDOT construction sites.

**SAP** – CDOT's database system into which all PWQ CMs must be entered.

**SWMP** – Stormwater Management Plan; a document that delineates how erosion and sediment control will be handled during construction.

**TMDL** – Total Maximum Daily Load; the maximum amount of a pollutant allowed to enter a waterbody so that the waterbody will meet and continue to meet water quality standards for that particular pollutant. A TMDL determines a pollutant reduction target and allocates load reductions necessary to the source(s) of the pollutant.

**TSS** – Total Suspended Solids; the dry-weight of particles that can be trapped by a glass fiber filter. It is a common parameter used to assess water quality. It is listed as a conventional pollutant in the Clean Water Act.

**UDFCD** – Urban Drainage and Flood Control District; a cooperative district covering 1608 square miles of the Denver Metropolitan area, including parts of the 6 surrounding counties, and all or parts of 33 incorporated cities and towns with a total population of approximately 2.8 million people. Their purpose is to assist local governments within the Denver metropolitan area with drainage and flood control challenges. The UDFCD maintains a criteria manual that is widely considered to be an industry standard nationwide.

**USACE** – United States Army Corps of Engineers; the federal agency responsible for administering and enforcing Section 404 of the Clean Water Act. The USACE issues 404 permits.

**WQCC** – Water Quality Control Commission; the administrative agency responsible for developing specific water quality policy in Colorado, in a manner that implements the broader policies set forth by the CWQCA. The WQCC adopts water quality classifications and standards to protect beneficial uses of waters of the state, as well as various regulations aimed at achieving compliance with those classifications and standards.

**WQCV** – Water Quality Capture Volume; the volume of water equal to the runoff from a drainage basin during the 80th percentile runoff event.

**WSDOT** – Washington State Department of Transportation