

Storm Water Post-Construction Best Management Practices Manual

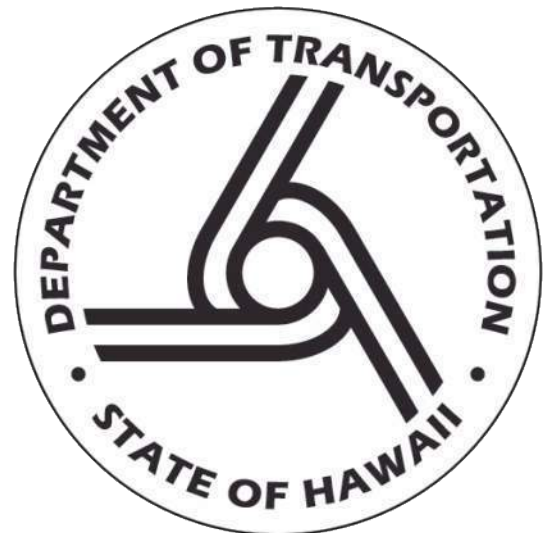
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PROTECT
OUR WATER

MĀLAMA I KA WAI

STATE OF HAWAII DEPARTMENT OF TRANSPORTATION



State of Hawaii
Department of Transportation
Highways Division
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ACRONYMS AND ABBREVIATIONS

BMPs	Best Management Practices
CCH	City and County of Honolulu
CWA	Clean Water Act
DA	Disturbed Area
DOH	State of Hawaii, Department of Health
DOT	State of Hawaii, Department of Transportation
DOT-HWYS	State of Hawaii, Department of Transportation, Highways Division
EA	Environmental Assessment
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
HAR	Hawaii Administrative Rules
HSG	Hydrologic Soil Group
IDIQ	Indefinite Delivery/Indefinite Quantity
LID	Low Impact Development
LOS	Lines of Study
MEP	Maximum Extent Practicable
MS4	Municipal Separate Storm Sewer System
NCHRP	National Cooperative Highway Research Program
ND	New Development
NJCAT	New Jersey Corporation for Advanced Technology
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
O&M	Operations and Maintenance
RD	Redevelopment
SWMP	DOT-HWYS Storm Water Management Plan
TAPE	Technology Assessment Protocol-Ecology
TMDL	Total Maximum Daily Load

ACRONYMS AND ABBREVIATIONS (continued)

WLA	Waste Load Allocation
WQV	Water Quality Volume
WQFR	Water Quality Flow Rate

DEFINITIONS OF KEY TERMS

BEST MANAGEMENT PRACTICE (BMP) – Schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of waters of the United States. BMPs also include treatment requirements, operating procedures, and practices to control site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage. [40 CFR § 122.2]

CLEAN WATER ACT (CWA) – Formerly referred to as the Federal Water Pollution Control Act of 1972 or Federal Water Pollution Control Act Amendments of 1972. Public Law 92-500, as amended by Public Law 95-217, Public Law 95-576, Public Law Public 96-483 and Public Law 97-117, 33 U.S.C. 1251 *et seq.* [40 CFR § 122.2]

CLEARING – Removal of vegetation without disturbing the root structure including grass or weed cutting, bush or tree trimming or felling.

CODE OF FEDERAL REGULATIONS (CFR) – The codification of the general and permanent rules published in the Federal Register by the executive departments and agencies of the Federal Government. It is divided into 50 titles that represent broad areas subject to Federal Regulation. Title 40 of the CFR (referenced as 40 CFR) lists all environmental regulations.

CONNECTION PERMIT – A permit issued by DOT-HWYS for a physical connection into the MS4.

CONSTRUCTION ACTIVITY – Any construction or demolition activity, clearing, grading, grubbing, or excavation or any other activity that results in a land disturbance. Construction does not include emergency construction activities required to immediately protect public health and safety or routine maintenance to maintain original line and grade, hydraulic capacity, or original purpose of the facility.

CWA SECTION 303(d) LIST – A state's list of impaired and threatened waters. States are required to submit their list for EPA approval every two years. For each water on the list, the state identifies the pollutant causing the impairment, when known. In addition, the state assigns a priority for development of TMDLs based on the severity of the pollution and the sensitivity of the uses to be made of the waters, among other factors.

DETENTION VOLUME – The volume of runoff that is held and treated in a BMP structure.

DISCHARGE – Any liquid, semi-solid, or solid substance that is released into and from the MS4.

DISCHARGE PERMIT – A permit issued by DOT-HWYS to discharge storm water runoff into the MS4.

DISCHARGE RATE – The rate at which water is discharged out of the BMP after being stored and treated.

DISTURBANCE OF LAND – Any construction-related activity that results in the penetration, turning, or moving of soil including roadway construction, demolition, grading, grubbing, and reconstruction of pavement which exposes the underlying base course or bare soil. Disturbance does not include clearing that leaves soil intact nor does it include the operation of vehicles, staging, and storage of materials and equipment on paved surfaces.

DRAINAGE AREA – Any area of land where precipitation collects and drains to a common outlet, such as into a river, stream, or other body of water. Other terms for drainage area are catchment area, drainage basin, and drainage watershed.

EROSION CONTROL – Stabilizing a disturbed or exposed surface area to prevent soil particles from being detached and causing sediment accumulation in nearby surface waters.

EXEMPT PROJECT – A project that only consists of exempt types of construction activities and is not required to implement post-construction BMPs.

FREEBOARD – The vertical distance between the water surface of the design discharge and a point of interest such as a low chord of a bridge or top of a channel bank.

GOOD HOUSEKEEPING – A common practice related to the storage, use, or cleanup of materials performed in a manner that minimizes the discharge of pollutants.

GROUNDWATER RECHARGE – The process of surface water infiltrating into the ground to replenish the groundwater supply.

GRUBBING – The process of uprooting or dislodging vegetation from the ground surface including removal of tree stumps.

HYDROLOGIC CYCLE – The cycle of water movement from the atmosphere to the earth and returning to the atmosphere through various stages or processes such as precipitation, interception, runoff, infiltration, percolation, storage, evaporation, and transportation.

IMPERVIOUS SURFACE – Surface area which allows little or no infiltration such as asphalt and concrete pavements, bridge decks, sidewalks, walkways, concrete slabs, and roofs.

INFILTRATION – The downward movement of water from the surface to the subsoil.

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

LAND USE – The way land is developed and used in relation to the types of allowable activities (agriculture, residences, industries, etc.) and the sizes of buildings and structures permitted. Certain types of pollution problems are often associated with particular land uses such as sedimentation from construction activities.

LINE OF STUDY (LOS) – Lines used for drainage calculations where storm water runoff leaves the DOT-HWYS right-of-way as sheet flow.

LOW IMPACT DEVELOPMENT (LID) – A comprehensive land planning and engineering design approach with a goal of mimicking or replicating the pre-development hydrologic regime of urban and developing watersheds.

MAXIMUM EXTENT PRACTICABLE (MEP) – For the purpose of this manual, the extent to which every option to achieve the full water quality treatment requirement has been thoroughly evaluated and found to be infeasible due to constraints permissible by DOT-HWYS.

MS4 PERMIT – A permit issued by the State of Hawaii, Department of Health which requires permittees to control the quality of storm water discharge to their MS4.

MUNICIPAL SEPARATE STORM SEWER SYSTEM (MS4) – A conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, manmade channels, or storm drains) owned by a state, city, town, or other public body, that is designed or used for collecting or conveying storm water, that is not a combined sewer, and that is not part of a publicly owned treatment works [40 CFR § 122.26(b)(8)].

NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM (NPDES) – The national program for issuing, modifying, revoking and reissuing, terminating, monitoring and enforcing permits, and imposing and enforcing pretreatment requirements, under Sections 307, 318, 402, and 405 of the CWA. [40 CFR § 122.2]

NEW DEVELOPMENT - Any construction of new impervious surface over existing pervious area.

NUTRIENTS – Any substance assimilated by living things that promotes growth. The term is generally applied to nitrogen and phosphorus in wastewater, but is also applied to other essential and trace elements.

OUTFALL – A point source where the MS4 discharges to state waters and does not include open conveyances connecting two MS4s, pipes, tunnels, or other conveyances which connect segments of the same stream or state waters and are used to convey state waters [40 CFR 122.26(b)(9)].

PERCOLATION – The movement of water through soil.

PERVIOUS SURFACE – Surface area which allows infiltration of water.

POLLUTANTS – Refer to the waste material that contaminates air, soil, or water. In the context of storm water quality, typical highway pollutants are:

Sediment – particles that settle or are suspended in liquid;

Nutrients - phosphorous and nitrogen;

Oils and Grease - organic carbon and hydrocarbons;

Metals;
Trash and Debris; and
Bacteria

POROSITY – The measurement of the void space of a material or media expressed as a fraction of the volume of voids over the total volume.

POST-CONSTRUCTION BMP – A specific practice intended to reduce storm water volume and/or the pollution typically associated with storm water runoff. Such practices may include LID design features, source control methods, or manufactured devices designed to capture pollutants and is synonymous with the terms Permanent BMP (PBMP) and Permanent Post-construction BMP.

PRETREATMENT – Treatment of storm water that occurs upstream of a treatment control BMP to remove gross solids, sediment, or other pollutants that may otherwise reduce the pollutant removal efficiency of the BMP. Examples of pretreatment facilities include vegetated buffer strips, vegetated swales, sediment forebays, and pretreatment chambers.

PRIVATE CONSTRUCTION PROJECT – A project not under the authority (funding) of or administered by DOT-HWYS that is located within or adjacent to DOT-HWYS right-of-way and drains to the DOT-HWYS right-of-way. Not necessarily a privately-funded project, also includes projects funded by the City and County of Honolulu and other counties. Private construction projects are required to obtain a Permit to Perform Work Upon State Highways prior to commencing construction activities. Private construction projects that drain to the DOT-HWYS right-of-way are required to submit an Application for a Private Storm Drain Connection and/or Discharge Permit to the State of Hawaii Highways Division Storm Drain System and a Permit to Discharge into the State Highways Drainage System. Also known as an Encroachment Permit Project or Encroachment Contract project.

PROPRIETARY BMP – A commercially available pre-manufactured or partially manufactured post-construction BMP that treats water through filtration or settling methods. Such examples include drain inlet inserts, modified catch basins, oil/grit separators, and hydrodynamic separators.

PUBLIC CONSTRUCTION PROJECT – A project funded by DOT-HWYS, designed either by personnel of DOT-HWYS or engineering consultant firms, and constructed by DOT-HWYS or a private contractor. Includes contract construction projects and maintenance construction projects.

REDEVELOPMENT - Any construction, reconstruction, alteration, or improvement performed on existing impervious area in which the underlying soil or pervious subgrade is exposed, penetrated, or replaced during construction. Cold planing (also known as “mill and fill” and some variations of pavement resurfacing) which removes a thin layer of pavement without exposing the underlying pervious subgrade is not considered redevelopment. Redevelopment results in no net increase in impervious surface.

REQUIRED TREATMENT AREA – The impervious area resulting from New Development and Redevelopment that is required to be treated by post-construction BMPs.

RESURFACING – Removal of existing asphalt pavement to a specified depth to remove worn asphalt without penetrating into the underlying base course or soil although may result in exposing the underlying base course or soil. Resurfaced areas do not increase the amount of impervious surface. Also known as “cold planing” or “mill and fill”.

RETROFIT – Modifying an existing BMP to increase effectiveness at improving water quality or constructing a new BMP in a previously developed area in which no BMP previously existed.

RUNOFF VOLUME – The volume of water that flows off of a surface during a storm event.

SEDIMENT – Organic or inorganic material that is carried by or is suspended in water and that settles out to form deposits in the storm drain system or receiving waters.

SENSITIVE RECEIVING WATERS – State waters that are listed on the State Clean Water Act (CWA) Section 303(d) list or state waters with EPA approved Total Maximum Daily Loads (TMDLs).

SHEET FLOW – Flow that occurs overland in places without defined channels. The flood water spreads out over a large area at a uniform depth. Also referred to as overland flow.

SHORT-CIRCUITING – The minimizing of “dead spaces” (areas where little or no exchange occurs during a storm event) to minimize the distance between the inlet and outlet.

SOURCE CONTROL BMP – Operational or structural measures that prevent or reduce pollutants from entering storm water. Examples of operational source control BMPs include good housekeeping practices, spill prevention, and employee training. Structural source control BMPs consist of enclosures or roofs for working areas where pollutants are present or installing devices that direct contaminated storm water to appropriate treatment control BMPs.

STATE WATERS – As defined by Section 342D-1, HRS, means all waters, fresh, brackish, or salt around and within the state, including, but not limited to, coastal waters, streams, rivers, drainage ditches, ponds, reservoirs, canals, ground waters, and lakes; provided that drainage ditches, ponds, and reservoirs required as part of a water pollution control system are excluded. In accordance with HAR 11-54-1, this definition applies to all state waters, including wetlands, subject to the following exceptions: (1) This chapter [HAR 11-54-1] does not apply to groundwater, except the director may in the director’s discretion take appropriate actions when the director believes that the discharge of pollutants to the ground or groundwater has adversely affected, is adversely affecting, or will adversely affect the quality of any state water other than groundwater. (2) This chapter does not apply to drainage ditches, flumes, ponds and reservoirs that are required as part of a water pollution control system. (3) This chapter does not apply to drainage ditches, flumes, ponds, and reservoirs that are used solely for irrigation and do not overflow into or otherwise adversely affect the quality of any other state waters, unless such ditches,

flumes, ponds, and reservoirs are waters of the United States as defined in 40 C.F.R. section 122.2. The State of Hawaii has those boundaries stated in the Hawaii Constitution, art. XV § 1.

STORM WATER – Storm water runoff, snow melt runoff, and surface runoff and drainage. [40 CFR § 122.26(b)(13)]

STORM WATER RUNOFF – The portion of precipitation that does not naturally percolate into the ground or evaporate, but flows via overland flow, interflow, channels, or pipes.

SWALE – An elongated depression in the land surface that is at least seasonally wet, usually vegetated, and normally without flowing water. Swales discharge storm water into primary drainage channels and may provide some groundwater recharge.

TEMPORARY PROJECT – A project that is not intended to be permanent and will be removed or restored to match existing conditions within a specified period.

TOPOGRAPHIC MAP – A type of map depicting a limited set of features but including at the minimum information about elevations or landforms. Topographic maps are commonly used for navigation and reference purposes.

TOTAL MAXIMUM DAILY LOAD (TMDL) – A water quality assessment that determines the source or sources of pollutants of concern for a particular waterbody, considers the maximum amount of pollutants the waterbody can assimilate, and then allocates to each source a set level of pollutants that it is allowed to discharge (i.e., a waste load allocation).

TREATMENT CONTROL BMP – An engineered system, also known as a structural BMP, designed and constructed to remove pollutants from storm water runoff by infiltration, sedimentation, biological uptake, media absorption, or other physical, biological, or chemical process.

VARIANCE – An allowance of less than the minimum storm water treatment requirement due to exceptional constraints that would result in physical infeasibility or unnecessary hardship. A full or partial variance may be granted with the remaining treatment addressed by other type of BMPs or via Alternative Compliance.

WASTE LOAD ALLOCATION (WLA) – The portion of a receiving water's total maximum daily load that is allocated to one of its existing or future point sources of pollution.

WATER QUALITY STANDARDS – Provisions of state, territorial, authorized tribal or federal law approved by EPA that describe the desired condition of a waterbody and the means by which that condition will be protected or achieved. Water quality standards consist of three core components: designated uses, criteria, and antidegradation requirements.

WATERS OF THE UNITED STATES – All waters which are currently used, or were used in the past, or may be susceptible to use in interstate or foreign commerce, including all waters which are subject to the ebb and flow of the tide, all interstate waters and wetlands, tributaries of these waters, and the territorial seas.

WATERSHED – A drainage area or basin in which all water drains or flows toward a central collector such as a stream, river, or lake at a lower elevation.

WETLANDS – Areas that are inundated or saturated by surface or ground water all year or for varying periods of time during the year. Under normal circumstances, wetlands support aquatic life and vegetation typically adapted for life in saturated soil conditions.

1. ENVIRONMENTAL BACKGROUND AND INTRODUCTION

1.1 ENVIRONMENTAL BACKGROUND

Historically, the design of roadway storm sewer systems has facilitated quick and efficient storm water drainage from the road surface. This design approach, combined with increased urban development, prevents storm water infiltration, increases the intensity of peak flow rates, and disrupts natural hydrologic cycles. Furthermore, untreated storm water runoff generated from impervious areas may carry surface pollutants into Hawaii's state waters resulting in negative environmental impacts.

Post-construction Best Management Practices (BMPs) mitigate these negative environmental impacts and include Low Impact Development (LID) design techniques that attempt to mimic predevelopment hydrology, and non-LID proprietary or custom-designed storm water treatment systems. Post-construction BMPs can include activities, prohibitions, procedures, or structural and non-structural systems which provide positive impacts to water quality and/or reduce storm water runoff volumes.

1.2 INTRODUCTION

The State of Hawaii, Department of Transportation, Highways Division (DOT-HWYS) operates a Municipal Separate Storm Sewer System (hereinafter referred to as the "MS4") on the Island of Oahu and the Island of Maui. The operation and discharge of each MS4 on the island of Oahu, and the MS4 within the Kahului-Paia urbanized area on the island of Maui are authorized and governed by a National Pollutant Discharge Elimination System (NPDES) Permit (hereinafter referred to as "MS4 Permit") which are issued by the State of Hawaii, Department of Health (DOH). The Oahu MS4 Permit (No. HI S000001) became effective on September 1, 2020 and the Maui MS4 Permit (Permit File No. HI 15KE674) became effective on April 2, 2015 and was administratively extended on November 22, 2016. Per the MS4 Permit requirements, DOT-HWYS does not advertise or award any public construction project, nor award any construction contract, until the project plans have been reviewed and accepted to ensure the appropriate post-construction BMPs, prioritizing LID BMPs, have been included in the project design and bid package in accordance with the standards and criteria set forth in this manual. For the purpose of this manual, the island of Oahu and the entire island of Maui are referred to as the "MS4 Permit areas".

DOT-HWYS also owns and operates drainage systems in less urbanized areas on the islands of Hawaii, Kauai, Lanai, and Molokai, which are not subject to MS4 Permits. These areas are referred to as "non-MS4 Permit areas" and are subject to less restrictive storm water quality guidelines due to their rural characteristics. For further discussion of non-MS4 Permit areas, please refer to Section 4.

Regardless of a project's location, district, or island, careful consideration should be given to new development and redevelopment projects during the planning and design phases to implement storm water quality controls that improve overall water quality and protect Hawaii's receiving waters. Any required post-construction BMPs and measures shall be designed and constructed in accordance with the applicable sections of this manual to the maximum extent practicable (MEP).

1.3 APPLICABILITY

The purpose of this manual is to provide procedures and guidelines to ensure that post-construction BMPs are considered and implemented, as applicable, throughout all phases of DOT-HWYS new development, redevelopment, and private construction projects, including planning, design, permitting, construction, and maintenance.

Post-construction BMP implementation requirements apply to the following types of projects:

- Public construction projects - Projects that are funded by DOT-HWYS, designed by personnel of DOT-HWYS or by engineering consultant firms, and constructed by DOT-HWYS or a private contractor. Public construction projects may be located within DOT-HWYS right-of-way or a parcel owned by DOT-HWYS and include traditional design-bid-build projects or design-build projects.
- Private construction projects - Projects that are not under the authority (funding) of or administered by DOT-HWYS that are located within or adjacent to DOT-HWYS right-of-way and drains to the DOT-HWYS right-of-way. Not necessarily a privately-funded project, also includes projects funded by the City and County of Honolulu and other counties. Private construction projects that drain to the DOT-HWYS right-of-way are required to obtain a DOT-HWYS discharge or connection permit. Although encouraged by DOT-HWYS, private construction projects outside of DOT-HWYS right-of-way have no requirements for post-construction BMPs other than what is required by the respective county.

The DOT-HWYS Storm Water Management Program (SWMP) takes an iterative approach to reach water quality standards. Several factors were taken into consideration in the development of the post-construction BMP criteria presented in this manual to identify opportunities to implement storm water treatment controls across various types of improvements. The criteria will be reevaluated and revised, as necessary, to meet the conditions set forth in subsequent MS4 Permit renewals.

An electronic version of this revised manual will be available on the DOT-HWYS storm water website (www.stormwaterhawaii.com). Future revisions to the manual will also be

released through the website. Always consult with DOT-HWYS to ensure that the latest revisions to this manual are being incorporated.

1.4 HOW TO USE THIS MANUAL

This manual consists of the following sections:

Section 1: ENVIRONMENTAL BACKGROUND AND INTRODUCTION. A general overview of the storm water regulatory requirements governing treatment quality of storm water runoff and how the manual applies to projects draining to the MS4.

Section 2: STORM WATER POST-CONSTRUCTION BEST MANAGEMENT PRACTICES. Introduces the various types of post-construction BMPs commonly used for water quality treatment. The post-construction BMPs presented represent only a sample of available options. The designer may elect to use other post-construction BMPs not mentioned based upon their engineering judgment and pending approval from DOT-HWYS.

Section 3: CRITERIA FOR MS4 PERMIT AREAS. Identifies the criteria for implementation of post-construction BMPs and provides a step-by-step procedure for applying the criteria to projects within MS4 Permit areas.

Section 4: CRITERIA FOR NON-MS4 PERMIT AREAS. Identifies the criteria for implementation of post-construction BMPs and provides a step-by-step procedure for applying the criteria to projects within non-MS4 Permit areas.

Section 5: EXEMPTIONS AND VARIANCES. Lists types of projects, improvements, or construction activities that are exempt from post-construction BMP requirements. Also included in this section are constraints that may impact the feasibility of implementing post-construction BMPs, thereby necessitating a variance.

Section 6: ALTERNATIVE COMPLIANCE. Outlines the Alternative Compliance process for public construction projects within MS4 Permit areas in which the full Required Treatment Area cannot be addressed to the MEP. The deficit in water quality treatment will need to be addressed via Alternative Compliance. This section also provides information about the credit tracking program used to document water quality credits and debits.

Section 7: POST-CONSTRUCTION BMP DESIGN METHODOLOGY. Provides guidance on determining the Required Treatment Area subject to water quality treatment and sizing criteria for volume-based and flow-based treatment control BMPs.

Section 8: POST-CONSTRUCTION BMP DEVELOPMENT IN PLANNING PHASE. Provides DOT-HWYS requirements and general considerations for the development of a post-construction BMP strategy during the planning phase.

Section 9: POST-CONSTRUCTION BMP DEVELOPMENT IN DESIGN PHASE. Provides DOT-HWYS requirements and general considerations for the further development of the post-construction BMP strategy during the design phase.

Section 10: INSPECTIONS, OPERATION, AND MAINTENANCE. Explains procedures for inspections, BMP acceptance, and long-term maintenance to ensure that construction post-construction BMPs perform as intended.

Section 11: REFERENCES. List of resources used as reference in preparation of this manual.

Appendix A: TREATMENT CONTROL BEST MANAGEMENT PRACTICES. Examples of commonly used treatment control BMPs for pollutant reduction and water quality treatment. Includes both LID and non-LID treatment control devices.

Appendix B: RAIN STATIONS ANALYZED FOR QUANTITATIVE CRITERIA. Provides graphical references regarding the rain gauge stations used in determining the quantitative criteria.

2. STORM WATER POST-CONSTRUCTION BEST MANAGEMENT PRACTICES

Urban development continues to have a profound impact on the quality of state waters. Large impervious surfaces result in increased storm water runoff volumes and peak discharge rates. Impervious surfaces also reduce infiltration and groundwater recharge due to loss of vegetative cover (NCHRP 2012). These effects on storm water runoff may have adverse impacts upon the surrounding environment, including water quality, streambank erosion, soils disturbance, land cover, and wildlife habitat.

DOT-HWYS faces unique challenges when addressing highway runoff: primarily linear roadways within limited rights-of-way, projects that span multiple watersheds, and the need to adhere to roadway safety guidelines. A variety of options are available to reduce pollutant discharge and improve the quality of storm water runoff. These options are collectively known as post-construction BMPs, which are comprised of treatment control and source control BMPs. Both types may be used separately or in combination, as applicable, to effectively reduce pollutant discharge into the DOT-HWYS MS4. Unlike temporary construction activity BMPs, the design and implementation of post-construction BMPs provides long-term storm water treatment following project completion.

2.1 TREATMENT CONTROL BMPs

Treatment control BMPs, otherwise known as structural BMPs, are the primary means for addressing storm water quality and quantity issues resulting from land development. Treatment control BMPs are physical systems that generally target removal of pollutants based upon one or more of the following processes or mechanisms:

- **Infiltration** – Storm water that infiltrates the ground surface and percolates into the underlying soil is treated through biological, chemical, and physical processes to capture sediment and pollutants that would otherwise be transported further downstream within the MS4. Infiltration facilities provide for some reduction in runoff volume and peak flow attenuation for downstream drainage facilities and replenishes groundwater aquifers.
- **Detention** - Detention systems are defined as facilities that intercept storm water runoff and temporarily store the runoff volume which is subsequently released to the surface or downstream facilities with the MS4. Examples include detention basins, ponds, and underground storage vaults. These systems allow for settling of particulate matter and may also include an infiltration component when constructed with pervious underlying surfaces.

- **Retention** - Although sometimes used interchangeably with detention, retention systems are intended for storage of runoff with no provisions for subsequent release to downstream facilities. Retention systems rely on infiltration or evaporation for storm water volume dissipation and also allow for pollutants to settle via gravity. Retention systems are designed to feature a permanent pool for the majority of the year and often promote natural aquatic and wildlife habitats.
- **Filtration** - Filtration systems rely on a mix of natural or manufactured proprietary porous media or membranes to physically filter pollutants from storm water runoff. These systems can be designed to target specific pollutants and are often restricted to relatively small drainage areas since they provide only limited storage volume for runoff. Pretreatment considerations are critical to prevent sediment and debris from clogging the media filter thereby extending the useful life of the system.
- **Biofiltration** – Biofiltration uses vegetated surfaces to reduce storm water runoff velocities and filter out pollutants. Examples of biofiltration include grassed swales and vegetated buffer strips.
- **Adsorption** – Adsorption can occur in infiltration systems as soluble pollutants such as dissolved metals adhere to soil and organic matter as storm water percolates through the soil or media.
- **Vegetative Uptake** – Vegetative uptake is a process through which nutrients such as nitrogen and phosphorus are removed from storm water by vegetative growth. Microorganisms in the plants and soil capture and convert pollutants into a food source for the vegetation. This process occurs in treatment facilities with established plant growth such as bioretention facilities, ponds, and wetlands.
- **Bioretention** – Bioretention systems are designed to capture and store the required Water Quality Volume in vegetated areas and rely on infiltration and adsorption through vegetative uptake for treatment. Benefits also include groundwater recharge and aesthetic properties.
- **Rainwater Harvesting** – Following capture of storm water runoff, rainwater harvesting allows for storm water to be used for irrigation or mechanical systems in lieu of potable water. These methods are rarely used in highway projects but may be incorporated in construction projects outside of DOT-HWYS right-of-way for water reuse in industrial or commercial usages.

Treatment control BMPs generally fall into the categories of LID or non-LID, depending upon the type of process used for water quality treatment.

2.1.1 LID Treatment Control BMPs

LID is a storm water management strategy that attempts to maintain pre-development hydrology by minimizing impervious areas and preserving or recreating natural landscape features. LID BMPs, which commonly constitute green infrastructure, include retention practices that typically do not allow flow discharge and rely on treatment of storm water runoff via infiltration, bioretention, evapotranspiration, or rainwater harvesting.

In accordance with the Oahu MS4 Permit requirements, projects that require post-construction BMPs must prioritize using LID BMPs. Other options for water quality treatment may be considered only if implementation of LID BMPs is deemed infeasible. Although not required in the Maui MS4 Permit, projects on the island of Maui will also prioritize using LID BMPs for water quality treatment. Commonly used LID BMPs that may be applicable to DOT-HWYS projects include:

- Vegetated Buffer Strip
- Vegetated Swale
- Enhanced Swale
- Infiltration Trench
- Infiltration Basin
- Bioretention Facility
- Permeable Pavement
- Pocket Wetland
- Rainwater Harvesting
- Tree Box Filter

A summary of LID BMPs and individual fact sheets, which provide descriptions, limitations, design criteria, construction considerations, and guidelines for maintenance and inspection, are included in Appendix A.

2.1.2 Non-LID Treatment Control BMPs

In highly urbanized areas, existing constraints may pose challenges to implementing LID BMPs, which typically require a larger footprint to store and treat the required storm water runoff volume. If deemed infeasible, a viable option is to incorporate non-LID treatment control measures to address pollutant discharge.

Traditional Methods remove solids through settling or media filtration prior to discharge. These systems do not typically provide adequate storage volume for storm water runoff, and may require more long-term maintenance to ensure pollutant removal effectiveness. Some examples include:

- Wet Pond
- Wet Extended Detention Pond
- Sand Filter

Proprietary Methods are typically patented technologies installed within new or existing drainage structures that rely on dynamic settling of solids or filtration using media, screens, or cartridges for treatment prior to discharge. A wide variety of proprietary systems is available and is constantly changing based on technological advancements and research. A few of the proprietary methods mentioned in this manual include the following:

- Drain Inlet Filter
- Modified Catch Basin
- Oil/Grit Separator
- Centrifugal Hydrodynamic Separator
- Multi-Stage Hydrodynamic Separator

Proprietary BMPs are rapidly changing with new and advanced technologies, regulatory requirements, and storm water treatment objectives. DOT-HWYS does not endorse or promote any specific type or brand of proprietary BMP device and will review its application and performance on a case-by-case basis for applicability. More information regarding the technological verification requirements for proprietary BMPs is provided in Section 9.1.4.

A summary of non-LID BMPs and individual fact sheets which provide descriptions, limitations, design criteria, construction considerations, and guidelines for maintenance and inspection are included in Appendix A.

2.1.3 Online vs. Offline Treatment Control BMPs

Treatment control BMPs may be designed with an online or offline configuration. The size of online facilities must convey the full range of storm events, as higher flows may scour bare or vegetated surfaces, resuspend settled particles, and flush oils and debris downstream.

An offline facility with a flow splitter or flow diversion upstream of the treatment control BMP may be a good solution when adequate space is available. The flow diversion will convey a specified amount of flow through the treatment device and combine with the main flow further downstream.

2.2 SOURCE CONTROL BMPs

Source control BMPs are management techniques and tools that reduce storm water runoff and pollutants at the source. They primarily aim to prevent pollutants from being released into storm water rather than using treatment control BMPs for pollutant removal. Although source control BMPs contribute to pollutant reduction, they are not technically considered post-construction BMPs.

Source control BMPs are often used during construction but may also be implemented before and after construction as part of the overall strategy for improving water quality. If a project does not meet the threshold for implementing post-construction BMPs, source control BMPs may still be required, at the discretion of DOT-HWYS, for projects with a higher potential for pollutant discharge or those that drain to sensitive receiving waters. A few source control BMP categories include the following:

- Land Management Techniques
- Soil Stabilization Methods
- Sediment Control Methods
- Storm Water Flow Control Methods
- Trash Management Practices
- Good Housekeeping Measures
- Spill Prevention Techniques

Refer to the DOT-HWYS *Construction BMP Field Manual* which is available on the DOT-HWYS storm water website (www.stormwaterhawaii.com) for more information on allowable source control BMPs, including descriptions, installation and implementation considerations, guidelines for maintenance and inspection, and BMP limitations.

2.3 POST-CONSTRUCTION BMPs NOT COVERED IN THIS MANUAL

The post-construction BMPs presented in this manual are frequently utilized by other municipalities and are considered applicable for Hawaii's climatic and geologic conditions. DOT-HWYS does not promote or endorse any specific post-construction BMP. The designer may elect to implement other post-construction BMPs not included in this manual based upon their professional due diligence, design expertise, and judgment subject to DOT-HWYS approval.

3. CRITERIA FOR MS4 PERMIT AREAS

Urbanized areas are densely developed regions with a high percentage of impervious surfaces. Therefore, storm water discharges from roadways in Oahu and parts of Maui are subject to more stringent programmatic requirements of their respective MS4 Permits. For the purpose of this manual, the criteria for MS4 Permit areas apply to the island of Oahu and the entire island of Maui.

This section (Section 3) highlights the criteria for areas subject to an MS4 Permit while Section 4 presents criteria for non-MS4 Permit areas.

3.1 CRITERIA

The Oahu and Maui MS4 Permits require the inclusion of post-construction BMPs to address storm water runoff from projects that result in land disturbance of one (1) acre or more. This criterion applies to all non-exempt projects that discharge runoff to the DOT-HWYS right-of-way. However, projects that disturb less than one (1) acre, but impact sensitive water bodies or those that have a high potential for pollutant discharge may also be required to include post-construction BMPs.

The criteria for implementing post-construction BMPs varies depending upon the type of project funding and its location with respect to the DOT-HWYS right-of-way as described in the subsections that follow.

3.1.1 Public Construction Projects

Public construction projects are funded by DOT-HWYS and designed by personnel of DOT-HWYS or an engineering consultant and may be within DOT-HWYS right-of-way or a parcel owned by DOT-HWYS. To reduce the impact of increased storm water runoff and pollutants from entering the MS4, public construction projects that result in one (1) acre or more of land disturbance are required to implement LID BMPs and/or non-LID BMPs.

It is important to note that this manual defines “disturbance” as any construction activity that results in the penetration, turning, or moving of soil including roadway construction, demolition, grading, grubbing, and reconstruction of pavement that exposes the underlying base course or bare soil. Construction activities excluded from the disturbed area definition include clearing that leaves soil intact and the operation of vehicles, staging, and storage of materials and equipment on paved surfaces. As such, a project's Disturbed Area for construction NPDES Permitting may differ from the Disturbed Area applicable to this manual.

Some public construction projects such as parking lots or those intended for industrial use, such as base yards and maintenance facilities, have a higher potential for generating pollutant runoff due to the anticipated level of traffic or proposed land use. DOT-HWYS may require the implementation of post-construction BMPs at these Priority Projects (sometimes referred to as "stormwater hotspots") because of the presence of pollutants such as oils, grease, and sediment.

All public construction projects that result in one (1) acre or more of Disturbed Area are required to implement LID BMPs.

Priority Projects that have a high potential for pollutant discharge may be required to implement post-construction BMPs at the discretion of DOT-HWYS regardless of the amount of Disturbed Area.

3.1.2 Private Construction Projects

A private construction project is a construction project undertaken by a non-DOT-HWYS entity (i.e., a third party) that is located within or adjacent to DOT-HWYS right-of-way and that has the potential to discharge storm water runoff to DOT-HWYS right-of-way. DOT-HWYS administers a permitting program for any business (industrial or commercial), agency, or project that wishes to establish a permanent connection or release storm water runoff to DOT-HWYS right-of-way. Private construction projects require a permit (e.g., Permit to Perform Work Upon State Highways, Permit to Discharge into the State Highways Drainage System, Permit to Connect to the State Highways Drainage System, etc.), as applicable.

Typically, private construction projects occur within private or public lands outside of DOT-HWYS right-of-way and are subject to applicable County storm water quality requirements. If the project meets all County post-construction BMP requirements, as determined by DOT-HWYS, the project is considered to be in compliance and there are no additional requirements for post-construction BMPs. However, private construction projects that also include improvements within the DOT-HWYS right-of-way may require additional post-construction BMPs.

The permittee will be responsible for maintaining any post-construction BMPs installed within DOT-HWYS right-of-way in accordance with the maintenance agreement established with the state, when applicable. Further details regarding maintenance and record keeping requirements are provided in Section 10.

Post-construction BMPs may be required at the discretion of DOT-HWYS regardless of project size for private construction projects located within the DOT-HWYS right-of-way if the project has the potential to discharge storm water runoff to the DOT-HWYS right-of-way.

Private construction projects located outside the DOT-HWYS right-of-way are considered to be in compliance with post-construction BMP requirements if the project complies with the storm water quality requirements of the applicable county.

Regardless of whether post-construction BMPs are required, the permittee must apply for applicable permits that allow for permanent connection or the release of storm water runoff to the DOT-HWYS right-of-way, which may include the following:

- Application for a Private Storm Drain Connection and/or Discharge Permit to the State of Hawaii Highways Divisions Storm Drain System
- Permit to Discharge into the State Highways Drainage System
- Permit for Connection to the State Highways Drainage System

3.1.3 Projects Draining to Sensitive Receiving Waters

The DOH and U.S. Environmental Protection Agency (EPA) assess and identify impaired water bodies that do not meet state water quality standards. These sensitive receiving waters include designated Total Maximum Daily Load (TMDL) watersheds and 303(d)-listed water bodies.

Pollutants such as nitrogen, phosphorus, and sediment may further degrade sensitive receiving waters and adversely impact aquatic organisms and natural habitats. Therefore, public or private construction projects that are located within or drain to a TMDL or 303(d)-listed watershed may be subject to stringent criteria to reduce pollutant loads depending upon targeted pollutants and the regulatory status of the water body.

Projects which are located within or drain to sensitive receiving waters may be required to implement LID and/or non-LID BMPs at the discretion of DOT-HWYS regardless of the amount of Disturbed Area.

The list of sensitive water bodies is updated regularly. The designer shall consult the most recent version of the *State of Hawaii Water Quality Monitoring and Assessment Report* to determine if the project is located within or drains to a TMDL or 303(d)-listed watershed. This report is published by DOH and provided at the following website:

<https://health.hawaii.gov/cwb/clean-water-branch-home-page/integrated-report-and-total-maximum-daily-loads/>.

Table 3-1. Criteria Summary for MS4 Permit Areas (Islands of Oahu and Maui)

Item	Description
<i>Public Construction Projects</i>	<p>All public construction projects that result in one (1) acre or more of Disturbed Area are required to implement LID BMPs.</p> <p>Priority Projects that have a high potential for pollutant discharge may be required to implement post-construction BMPs at the discretion of DOT-HWYS regardless of the amount of Disturbed Area.</p>
<i>Private Construction Projects</i>	<p>Post-construction BMPs may be required at the discretion of DOT-HWYS regardless of project size for private construction projects located within the DOT-HWYS right-of-way if the project has the potential to discharge storm water runoff to the DOT-HWYS right-of-way.</p> <p>Private construction projects located outside the DOT-HWYS right-of-way are considered to be in compliance with post-construction BMP requirements if the project complies with the storm water quality requirements of the applicable county.</p>
<i>Sensitive Receiving Waters</i>	<p>Projects which are located within or drain to sensitive receiving waters may be required to implement LID and/or non-LID BMPs at the discretion of DOT-HWYS regardless of the amount of Disturbed Area.</p>

3.2 APPLICATION OF CRITERIA FOR MS4 PERMIT AREAS

This section presents a step-by-step guide for evaluating the applicability of MS4 Permit projects on the islands of Oahu and Maui. Further explanation of terminology and concepts used can be found in subsequent sections of this manual. Since each project varies in size, composition, and complexity, consultation with DOT-HWYS may be required to make a final determination on post-construction BMP project requirements.

Refer to the flow chart provided in Figure 3-1 for assistance with navigating the process.

Step 1: Is the project a private construction project?

Private construction projects located outside the DOT-HWYS right-of-way are required to comply with the applicable storm water quality requirements of the respective county. If the project meets the applicable county storm water requirements, the project will be considered to be in compliance with post-construction BMP requirements. The designer must submit all county-approved documentation to DOT-HWYS demonstrating that all runoff that may discharge to the DOT-HWYS right-of-way has been addressed (i.e., drainage report) and that post-construction BMPs have been designed to meet or exceed the minimum requirements (e.g., Storm Water Quality Report).

Post-construction BMPs may be required for private construction projects located within or that extend into DOT-HWYS right-of-way if the project discharges storm water runoff to the DOT-HWYS right-of-way. For example, projects meeting these criteria may include vehicular auxiliary lanes for large developments or paved frontage areas. The permittee will be responsible for maintaining any required post-construction BMPs installed within DOT-HWYS right-of-way in accordance with any maintenance agreement established with the state.

Step 2: Does the project qualify for an exemption?

Exemptions are allowed for projects that are not anticipated to discharge significant amounts of pollutants to the DOT-HWYS right-of-way. If the project only consists of construction activities identified in the exemption list in Section 5.1, the project is exempt from implementation of post-construction BMPs. However, post-construction BMPs are required if the project contains other ancillary improvements that are subject to the other criteria in this manual.

For example, a project that only involves the installation of a median guardrail would be exempt from having to implement post-construction BMPs. However, if the project also includes road widening that results in over an acre of land disturbance, LID BMPs would be required.

If the project is exempt from implementation of post-construction BMPs, proceed to Step 9.

Step 3: Does the public construction project result in one (1) acre or more of Disturbed Area?

Public construction projects that result in one (1) acre or more of Disturbed Area are required to implement LID BMPs.

Step 4: Does the project have a high potential for pollutant discharge to the DOT-HWYS right-of-way?

If the Disturbed Area is less than an acre, post-construction BMPs may still be required at the discretion of DOT-HWYS due to the potential for pollutant discharge to the DOT-HWYS right-of-way. Projects that may require evaluation by DOT-HWYS include parking lots or those intended for industrial use, such as base yards and maintenance facilities.

Step 5: Does the project drain to a sensitive receiving water?

Projects located within or that drain to a TMDL or 303(d)-listed watershed may be required to implement post-construction BMPs subject to the discretion of DOT-HWYS. The designer shall consult the most recent version of the *State of Hawaii Water Quality Monitoring and Assessment Report* to determine if the project is located within or drains

to a TMDL or 303(d)-listed watershed. This report is published by DOH and provided at the following website: <https://health.hawaii.gov/cwb/clean-water-branch-home-page/integrated-report-and-total-maximum-daily-loads/>.

Required post-construction BMPs may consist of either LID BMPs or non-LID BMPs. For TMDL watersheds, the selected post-construction BMP(s) must specifically address the target pollutant(s) of concern.

Step 6: Implement LID BMPs and/or non-LID BMPs to the MEP.

Projects that require LID BMPs must implement them to the MEP (defined in Section 5.4). If full treatment with LID BMPs is not practicable, the designer must then attempt to address the remainder of the Required Treatment Area using non-LID BMPs to the MEP.

Step 7: Has the Required Treatment Area been met?

If the designer cannot address the Required Treatment Area to the MEP using either LID BMPs or non-LID BMPs, the designer shall submit a Variance Request Form to demonstrate that all possible options have been exhausted. The procedure for submitting a Variance Request Form is explained in further detail in Section 9.

If DOT-HWYS concurs that the project has been designed to the MEP, the designer is relieved of providing any further treatment. Proceed to Step 9.

Step 8: How will additional treatment be provided?

If DOT-HWYS determines that MEP has not been met, the designer shall evaluate other onsite treatment options or devices.

If other onsite options are deemed infeasible, DOT-HWYS will require that the treatment deficit be addressed offsite by another public construction project in a higher priority watershed via Alternative Compliance. The designer of the treatment-deficit project is relieved of providing any further treatment for that specific project. The Alternative Compliance process is detailed in Section 6.

Private construction projects that require post-construction BMPs, are only obligated to address the Required Treatment Area to the MEP. Alternative Compliance is not an option for private construction projects. Thus, if DOT-HWYS concludes that the Required Treatment Area has been addressed to the MEP, the designer is relieved of implementing any additional water quality treatment measures.

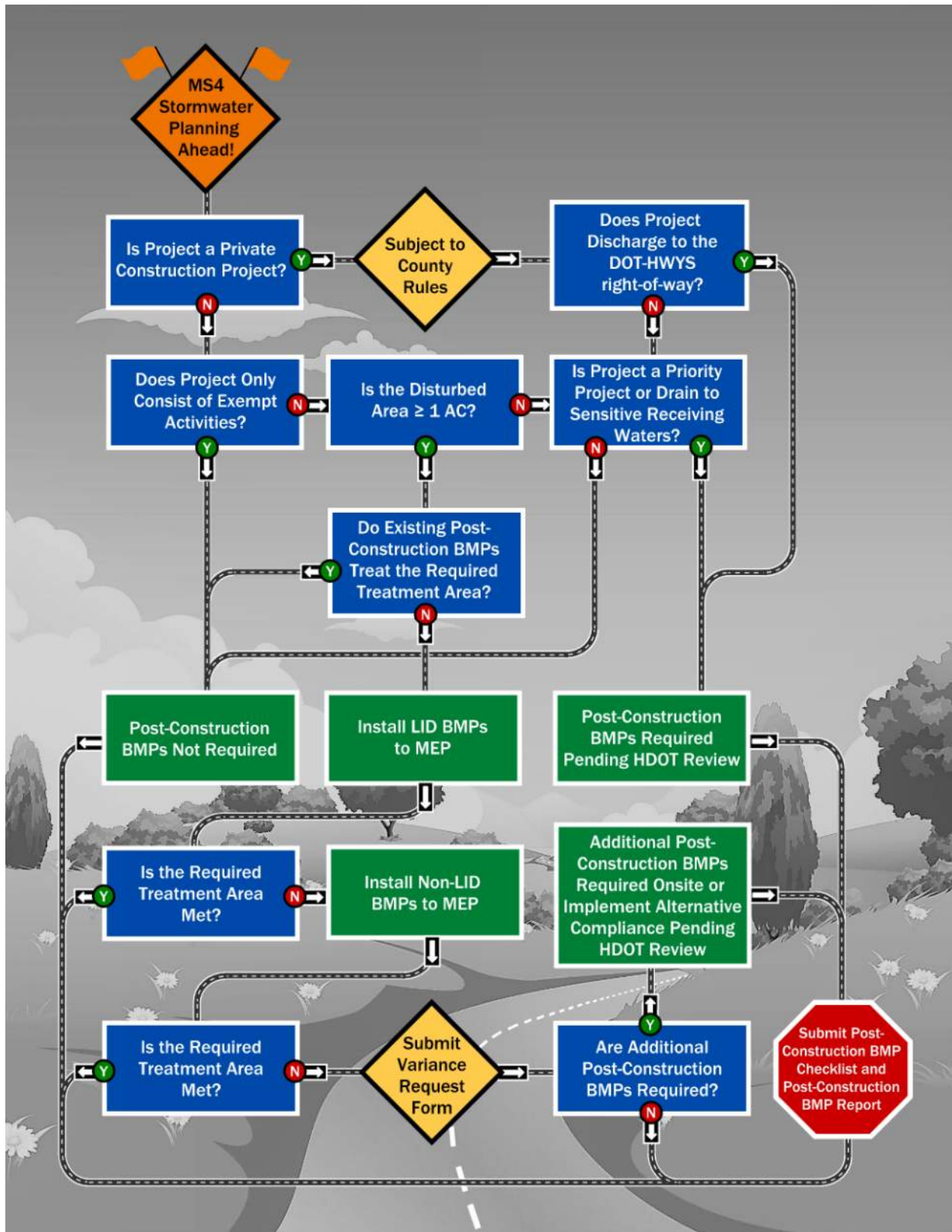
Step 9: Submit the Post-Construction BMP Design Checklist.

All construction projects subject to DOT-HWYS review must submit a Post-Construction BMP Design Checklist regardless of whether it is a public or private construction project or whether any post-construction BMPs are required. The checklist (included in Section 9) must be filled out by a civil engineer licensed in the State of Hawaii and submitted to DOT-HWYS. DOT-HWYS will review the submittal for completeness and log data for recordkeeping.

Step 10: Submit the Storm Water Post-Construction BMP Design Report.

If post-construction BMPs are required, submit a Storm Water Post-Construction BMP Design Report to DOT-HWYS indicating all post-construction BMPs incorporated into the design. Include, at a minimum, sizing criteria, calculations, maintenance requirements, and any applicable manufacturer's data sheets. Additional information regarding the Storm Water Post-Construction BMP Design Report is provided in Section 9.3.

Figure 3-1: MS4 Permit Area Flowchart



4. CRITERIA FOR NON-MS4 PERMIT AREAS

Improving storm water quality is a statewide goal. Although storm water discharges on the islands of Hawaii, Kauai, Molokai, and Lanai are currently not covered under any MS4 Permit, it is advantageous for these non-MS4 Permit areas to implement post-construction BMPs to the MEP to reduce storm water runoff and pollutants.

The following criteria is applicable to the non-MS4 Permit areas. Several of the terms used in this section are defined in Section 3.

4.1 CRITERIA

4.1.1 Public Construction Projects

The threshold at which criteria are applied to post-construction BMP requirements differs between MS4 Permit areas and non-MS4 Permit areas. Non-MS4 Permit areas are more rural and typically feature less impervious surfaces. Because large-scale redevelopment of existing impervious surfaces is infrequent, the criteria for public construction projects within these non-MS4 Permit areas focus on new impervious surfaces.

For non-MS4 Permit areas, public construction projects that result in one (1) acre or more of new impervious surface are required to implement LID BMPs and/or non-LID BMPs. Post-construction BMPs are not required for redevelopment of existing impervious surfaces.

Priority Projects such as baseyards, maintenance facilities, or parking lots that have a higher potential to discharge pollutants to the DOT-HWYS MS4 due to their proposed land use or anticipated level of vehicular traffic may be required to implement post-construction BMPs at the discretion of DOT-HWYS regardless of the amount of new impervious surface created.

All public construction projects that result in one (1) acre or more of new impervious surface are required to implement LID BMPs and/or non-LID BMPs.

Priority Projects that have a high potential for pollutant discharge may be required to implement post-construction BMPs at the discretion of DOT-HWYS regardless of the amount of new impervious surface created.

4.1.2 Private Construction Projects

For non-MS4 Permit areas, private construction projects are only required to implement post-construction BMPs if one (1) acre or more of new impervious surface is created within DOT-HWYS right-of-way.

Although not required for private construction projects located outside of DOT-HWYS right-of-way, implementation of post-construction BMPs is highly encouraged to reduce storm water runoff and pollutants that may negatively impact water quality.

Post-construction BMPs are only required for private construction projects if one (1) acre or more of new impervious surface is created within DOT-HWYS right-of-way.

Post-construction BMPs are highly encouraged for private construction projects located outside of DOT-HWYS right-of-way.

Maintenance of any required post-construction BMPs installed within DOT-HWYS right-of-way will be the responsibility of the project owner.

4.1.3 Projects Draining to Sensitive Receiving Waters

TMDL watersheds and 303(d)-listed water bodies have been identified as having impaired water quality with respect to specific pollutants. Public construction projects that are located within or drain to these sensitive receiving waters may be subject to more stringent criteria to reduce additional pollutant loads depending upon the specific pollutants being targeted and the regulatory status of the water body.

Public construction projects that are located within or drain to sensitive receiving waters may be required to implement LID and/or non-LID BMPs at the discretion of DOT-HWYS regardless of the amount of new impervious surface created.

The list of sensitive water bodies is updated regularly. The designer shall consult the most recent version of the *State of Hawaii Water Quality Monitoring and Assessment Report* to determine if the project is located within or drains to a TMDL or 303(d)-listed watershed. This report is published by DOH and provided at the following website: <https://health.hawaii.gov/cwb/clean-water-branch-home-page/integrated-report-and-total-maximum-daily-loads/>.

Table 4-1. Criteria Summary for Non-MS4 Permit Areas (Islands of Hawaii, Kauai, Molokai, and Lanai)

Item	Description
<i>Public Construction Projects</i>	<p>All public construction projects that result in one (1) acre or more of new impervious surface are required to implement LID BMPs and/or non-LID BMPs.</p> <p>Priority Projects that have a high potential for pollutant discharge may be required to implement post-construction BMPs at the discretion of DOT-HWYS regardless of the amount of new impervious surface created.</p>
<i>Private Construction Projects</i>	<p>Post-construction BMPs are not required for private construction projects unless one (1) acre or more of new impervious surface is created within DOT-HWYS right-of-way.</p> <p>Post-construction BMPs are highly encouraged for private construction projects located outside of DOT-HWYS right-of-way.</p>
<i>Sensitive Receiving Waters</i>	<p>Public construction projects that are located within or drain to sensitive receiving waters may be required to implement LID and/or non-LID BMPs at the discretion of DOT-HWYS regardless of the amount of new impervious surface created.</p>

4.2 APPLICATION OF CRITERIA FOR NON-MS4 PERMIT AREAS

The following step-by-step procedure details how the criteria should be evaluated for projects located in areas not covered by an MS4 Permit. Non-MS4 permit areas are located on the islands of Hawaii, Kauai, Molokai, and Lanai.

Refer to the flow chart provided in Figure 4-1 for assistance with navigating the process.

Step 1: Is the project a private construction project?

Private construction projects are only required to implement post-construction BMPs if the project results in the creation of one (1) acre or more of new impervious surface within DOT-HWYS right-of-way.

Although not required, post-construction BMPs are highly encouraged for private construction projects located outside of DOT-HWYS right-of-way.

If the project is a private construction project and does not result in one (1) acre or more of new impervious surface within DOT-HWYS right-of-way, post-construction BMPs are not required. Proceed to Step 8.

Step 2: Does the project qualify for an exemption?

Projects that do not discharge significant amounts of pollutants to the DOT-HWYS right-of-way may qualify for exemptions. If the project only consists of construction activities identified in the exemption list in Section 5.1, the project is exempt from implementation of post-construction BMPs. However, post-construction BMPs are required if the project contains other ancillary improvements that are subject to the other criteria in this manual.

For example, a project that only involves the installation of a median guardrail would be exempt from having to implement post-construction BMPs. However, if the project also includes road widening that results in over an acre of new impervious surface, LID BMPs would be required.

If the project is exempt from implementation of post-construction BMPs, proceed to Step 8.

Step 3: Does the public construction project result in one (1) acre or more of new impervious surface?

Public construction projects that result in (1) acre or more of new impervious surface are required to implement LID BMPs.

Step 4: Does the project have a high potential for pollutant discharge to the DOT-HWYS right-of-way?

If the project has a high potential to discharge pollutants to the DOT-HWYS right-of-way, DOT-HWYS may require post-construction BMPs, even if the project results in less than an acre of new impervious surface.

These projects should, at a minimum, apply source control BMPs which are further discussed in Section 2.2.

Step 5: Does the project drain to a sensitive receiving water?

Projects within or that drain to a TMDL or 303(d)-listed watershed may be required to implement post-construction BMPs subject to the discretion of DOT-HWYS regardless of the amount of new impervious surface created. The degree of post-construction BMP requirements will depend on the potential for pollutant discharge and the location of the watershed.

Required post-construction BMPs may consist of either LID BMPs or non-LID BMPs. For projects located within a TMDL watershed, the selected post-construction BMP must specifically address the target pollutant. The designer shall consult the most recent version of the *State of Hawaii Water Quality Monitoring and Assessment Report* to

determine if the project is located within or drains to a TMDL or 303(d)-listed watershed. This report is published by DOH and provided at the following website:
<https://health.hawaii.gov/cwb/clean-water-branch-home-page/integrated-report-and-total-maximum-daily-loads/>.

Step 6: Implement LID BMPs and/or non-LID BMPs to the MEP.

Projects that require LID BMPs must implement them to the MEP (defined in Section 5.4). If full treatment with LID BMPs is not reasonable, the designer must then attempt to address the remainder of the Required Treatment Area using non-LID BMPs to the MEP.

Step 7: Has the Required Treatment Area been met?

If the designer cannot address the Required Treatment Area to the MEP using either LID BMPs or non-LID BMPs, the designer shall submit a Variance Request Form to demonstrate that all possible options have been exhausted. The procedure for submitting a Variance Request Form is explained in further detail in Section 9.

If DOT-HWYS concurs that the project has been designed to the MEP, the designer is relieved of providing any further treatment. Proceed to Step 8.

Rural districts that are representative of non-MS4 Permit areas typically receive less funding and have fewer resources to administer, enforce, implement, track, and maintain an Alternative Compliance program to address deficits in water quality treatment. Thus, if DOT-HWYS concludes that it is infeasible to treat the remainder of the Required Treatment Area, the designer is relieved of providing any further treatment.

Step 8: Submit the Post-Construction BMP checklist.

All projects subject to DOT-HWYS review must submit a Post-Construction BMP Design Checklist regardless of whether it is a public or private construction project and regardless of whether post-construction BMPs are required. The checklist (included in Section 9) must be filled out by a civil engineer licensed in the State of Hawaii and submitted to DOT-HWYS. DOT-HWYS will review the submittal for completeness and log data for recordkeeping.

Step 9: Submit the Storm Water Post-Construction BMP Design Report.

If post-construction BMPs are required, submit a Storm Water Post-Construction BMP Design Report to DOT-HWYS indicating all post-construction BMPs incorporated into the design. Include, at a minimum, sizing criteria, calculations, maintenance requirements, and any applicable manufacturer's data sheets. Additional information regarding the Storm Water Post-Construction BMP Design Report is provided in Section 9.3.



5. EXEMPTIONS AND VARIANCES

5.1 EXEMPTIONS

Some proposed improvements or construction activities are not considered significant generators of pollutants. Such activities may qualify for an exemption from implementing post-construction BMPs unless the project includes other improvements that trigger the requirement for post-construction BMPs as described in previous sections of this manual. Projects that include post-construction BMP-exempt activities may exclude the disturbed areas resulting from the exempt improvements when determining the post-construction BMP Required Treatment Area.

The following types of projects, improvements, or construction activities are exempt from post-construction BMP requirements since they have minimal or no adverse impact on storm water runoff entering the DOT-HWYS MS4. These exemptions shall apply to projects in both MS4 Permit areas and non-MS4 Permit areas:

- Projects that do not result in storm water discharge into DOT-HWYS MS4 or state waters
- Operations and Maintenance Activities
 - Structural Repairs
 - Baseyard Maintenance and Repairs
 - Installation or Replacement of Pavement Striping and Pavement Markers
- Pavement Preservation Treatments
 - Pavement Resurfacing, Restoration, or Rehabilitation projects in which improvements do not expose or disturb the underlying aggregate or subgrade layer such as Pavement Overlays, Cold Planing, Crack Sealing, or Similar Treatments
- Guardrail and Underground Utility Projects
 - Guardrail Installation or Replacement
 - Utility Installation or Relocation
- Water Quality Improvements or Preservation
 - Shoreline Protection
 - Landscaping
 - Culvert Rehabilitation or Replacement
 - Installation of Post-Construction BMPs

- Erosion and Sediment Control
 - Rockfall Mitigation
- Pedestrian Walkways or Bicycle Paths
- Bridges or Roads constructed above or below existing impervious areas
- “Minor” Disturbance Project
 - Signage
 - ADA Ramps
- Emergency Project
- Temporary Project
- Projects that are currently in the design phase in which timing and scheduling of the project for advertising may make it infeasible to comply with this revised manual.
- Federal-aid city or county projects

5.2 LID CONSTRAINTS

In accordance with Oahu MS4 Permit requirements, implementation of LID BMPs that provide water quality treatment via infiltration, bioretention, evapotranspiration, or rainwater harvesting must be prioritized to maintain predevelopment hydrologic conditions. However, LID BMPs are typically land-intensive and implementation may be infeasible in highly urbanized areas.

The following types of constraints may pose challenges for the implementation of LID BMPs:

- Hydrogeological Constraints - e.g., infiltration; depth to groundwater; slope stability; structural impacts to buildings/roadbed (shown in Table 5-1),
- Physical Constraints - e.g., space constraints; site slope; lack of right-of-way; impacts to structural foundations (shown in Table 5-2).
- Operational Constraints - e.g., strength/loading requirements for pavement; no application for water reuse (shown in Table 5-3).
- Environmental/Cultural Constraints - e.g., contaminated sites; impacts to archaeological or historic properties (shown in Table 5-4).

Table 5-1. Hydrogeological Constraints

Constraints	Feasibility Concern
Soil Permeability	Soil beneath LID BMP invert must have a minimum infiltration rate of 0.5 in/hr for infiltration facilities
Depth to Groundwater Table	Vertical clearance between LID BMP invert and seasonally high groundwater table is less than required depths indicated in Appendix A
Distance to Drinking Water	LID BMP is closer than 50 ft to nearest groundwater well for drinking
Relative Location to Septic System	LID BMP shall be located upstream of and no closer than 35 ft from any septic system
Sensitive Downstream Areas	Instituting LID BMPs would adversely affect downstream habitats

Table 5-2. Physical Constraints

Constraints	Feasibility Concern
Space Constraints	Physical objects such as retaining walls or existing utilities limit the usable space available for implementing LID BMPs
Site Slope	Usable flat area doesn't yield adequate space for required treatment
Slope Stability	LID BMP and infiltration would adversely impact slope stability
Lack of Right-of-Way	Project is closer than 10 ft to the nearest property line and no memorandum of understanding or joint ownership has been established
Structural Impacts to Buildings/Roadbed	LID BMP is close to the existing or proposed building foundation or roadbed. Proximity is dependent on BMP type, but minimum distance is 10 feet

Table 5-3. Operational Constraints

Constraints	Feasibility Concern
Strength/Loading Requirements for Pavement	LID BMPs that direct runoff into underlying soil may compromise adjacent pavement structure
Hazardous Operations	Location of proposed LID BMP poses a public safety hazard to vehicles, pedestrians, or DOT-HWYS workers
Inaccessible Maintenance	LID BMP is located along a high-volume roadway and limited or no access is available for inspections and maintenance without costly or challenging lane closures

Table 5-4. Environmental/Cultural Constraints

Constraints	Feasibility Concern
Contaminated Subsoil	Project is near a contaminated (or “brownfield” site)
Ecological Site	Construction of LID BMP would permanently damage a community resource (e.g., wildlife refuge)
Culturally Sensitive Site	Excavation for LID BMP would result in disturbance of archaeological remains or historic artifacts

5.3 VARIANCE REQUESTS

The designer shall attempt to treat the full Required Treatment Area through the use of LID BMPs to the MEP. If existing constraints prohibit addressing the full Required Treatment Area through the use of LID BMPs, the designer shall attempt to treat the remaining amount using non-LID BMPs. If the Required Treatment Area cannot be met using a combination of LID BMPs and non-LID BMPs, the designer shall submit a completed Variance Request Form to DOT-HWYS (see Section 9).

The Variance Request Form must identify the project constraints and justify why the full Required Treatment Area cannot be met using LID BMPs and non-LID BMPs. Upon review, DOT-HWYS will determine whether the project has been designed to the MEP or if additional post-construction BMPs will be required. For MS4 Permit areas only, DOT-HWYS may require that the deficit in water quality treatment is addressed at an offsite location through Alternative Compliance, as discussed in Section 6.

5.4 MAXIMUM EXTENT PRACTICABLE

The designer must reduce pollutant discharge to state waters to the MEP in accordance with the MS4 Permit, which references Section 402(p)(3)(B) of the Clean Water Act (CWA). The CWA definition for MEP is constantly evolving with improved treatment technologies, storm water management programs, permit requirements, and water quality standards. The general understanding is that EPA has intentionally not provided a precise definition of MEP to allow flexibility in MS4 permitting based upon the discretionary judgment of the implementing municipality (National Research Council 2009).

For the purpose of this manual, MEP is generally defined as having been met if every option to achieve the full water quality treatment requirement has been thoroughly evaluated and found to be infeasible due to constraints permissible by DOT-HWYS.

6. ALTERNATIVE COMPLIANCE

In ultra-urban areas, space constraints within the DOT-HWYS right-of-way often pose a challenge to storm water compliance. Slope embankments, retaining walls, utility lines and structures, limited shoulder areas, and other constraints are a few of the potential obstacles for siting post-construction BMPs. Adequate open space outside the DOT-HWYS right-of-way for constructing post-construction BMPs is rarely available or may be costly to acquire.

A storm water program that allows an alternative means for compliance provides flexibility to better meet MS4 Permit requirements. If implementing post-construction BMPs within the project limits are deemed infeasible, DOT-HWYS has the opportunity to incorporate post-construction BMPs in an alternative watershed of similar or higher priority using a strategy called Alternative Compliance.

The EPA recognizes Alternative Compliance as a practicable method for storm water compliance. Environmental benefits include reaching water quality objectives at an accelerated rate or targeting specific watersheds. Potential economic benefits are lower overall costs as smaller post-construction BMPs from multiple projects can be combined into a larger single treatment device. Benefits may improve economies of scale regarding administrative, construction, and maintenance costs (EPA November 2008).

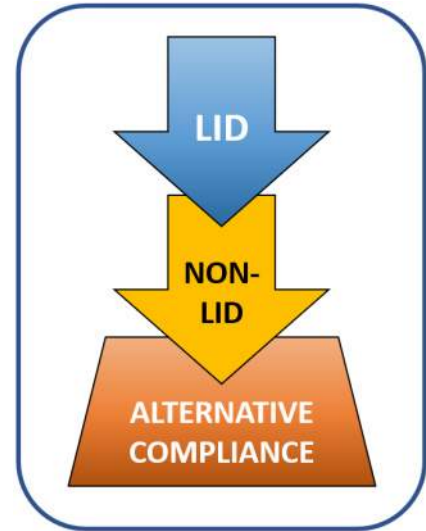
6.1 PRINCIPLES AND GUIDELINES

The Alternative Compliance strategy is an option for public construction projects within MS4 Permit areas only. Typically, rural districts that are representative of non-MS4 Permit areas do not have the resources to maintain an Alternative Compliance program and therefore cannot utilize this option to achieve water quality goals.

Alternative Compliance is based on the following principles and guidelines:

1. A designer must first attempt to implement on-site LID BMPs to the MEP. LID BMPs are the preferred post-construction BMP type.
2. If LID BMPs are infeasible due to constraints within the project limits, non-LID BMPs will be allowed to treat the remainder of the required treatment.
3. If limitations exist such that both LID BMPs and non-LID BMPs cannot fulfill the required water quality treatment, the designer must submit a Variance Request Form to DOT-HWYS for review.

4. If DOT-HWYS determines that post-construction BMPs have been implemented to the MEP, no additional treatment is required.
5. Otherwise, the deficit in water quality treatment will need to be addressed onsite with additional BMPs or by a separate project via Alternative Compliance in an alternative watershed.
6. Post-construction BMPs for Alternative Compliance may be fulfilled by a stand-alone BMP retrofit project or included in a subsequent public construction project. If handled under a subsequent public construction project, post-construction BMPs must be designed to treat the public construction project-required treatment before Alternative Compliance measures can be applied for the deficient project.
7. Alternative Compliance relies on a tracking system with credits and debits assigned to water quality treatment on a watershed basis. Additional information regarding the credit tracking system is provided in Section 6.2
8. DOH and EPA have identified sensitive receiving waters including 303(d)-listed water bodies and TMDL watersheds which shall be used to prioritize alternate watersheds. The designer shall consult the most recent version of the State of Hawaii Water Quality Monitoring and Assessment Report for a listing of the sensitive receiving waters at the following website:
<https://health.hawaii.gov/cwb/clean-water-branch-home-page/integrated-report-and-total-maximum-daily-loads/>.
9. Alternative Compliance is only allowed to occur within an alternate watershed having an equal or higher priority and may be applied to multiple watersheds to fulfill the Required Treatment Area.
10. Alternative Compliance addresses water quality only. Projects must still be designed to handle peak flow rates on-site.



DOT-HWYS regularly issues pavement preservation contracts for projects designated as having “indefinite delivery/indefinite quantity” (IDIQ) scopes of work. These IDIQ projects solely consist of pavement preservation treatments such as pavement resurfacing, reconstruction, overlays, and striping. This narrow scope of work allows for increased work efficiencies and lower unit costs for construction. Ancillary types of work, including utility improvements, grading, guardrail installation, and construction of post-construction BMPs, are excluded from the project. Any IDIQ-contracted projects that trigger the requirement for post-construction BMPs would therefore rely on Alternative Compliance for appropriate water quality treatment.

6.2 CREDIT TRACKING PROGRAM

A credit tracking program is essential for tracking the generation, spending, and transfer of credits. It ensures that treatment requirements are adequately addressed and provides a system that can be easily verified for program compliance.

DOT-HWYS has established a credit tracking system based on the following guidelines:

1. Credits and debits are measured in units of “treatment area”.
2. Each project must submit a completed Water Quality Summary Sheet to DOT-HWYS at the final design phase. This form is provided in Figure 6-1 and is also available as a fillable spreadsheet from DOT-HWYS. The form must be submitted regardless if credits or debits are created.
3. Projects that result in water quality treatment in excess of what is required will generate a credit. Credits are created when a qualifying project features any of these conditions:
 - a. Post-construction BMPs are sized to treat an impervious area larger than the Required Treatment Area.
 - b. A reduction in the amount of impervious surface area within the project limits is realized. For example, replacing an acre of asphalt concrete with grass would result in a credit of an acre of treated area.
 - c. Existing highway facilities are retrofitted to reduce the impact of runoff on water quality via enhancement of existing drainage systems or post-construction BMPs.
 - d. A stand-alone post-construction BMP project that does not involve any New Development or Redevelopment is designed to target a specific area with known pollutant discharge.
4. Projects that result in water quality treatment below what is required will generate a debit. Debits are created when a qualifying project features any of these conditions:
 - a. Hydrogeological, physical, or other constraints prohibit implementation of appropriately sized post-construction BMPs for the Required Treatment Area.
 - b. The project results in an increase in the amount of impervious surface area.
 - c. Existing post-construction BMPs are removed or no longer provide treatment to the previously intended drainage tributary area. Calculations are required to determine the resulting debit equal to the amount of reduction in treatment.

5. If a project creates more debits than credits, the designer must prepare and submit a Variance Request Form to justify that all other options were evaluated and deemed infeasible.
6. Credits and debits are tracked for each watershed separately.
7. Credits become available for use (and debits are cleared) once the post-construction BMP has been constructed and accepted by DOT-HWYS.
8. Credits and debits do not expire.
9. DOT-HWYS must initiate a project to address deficits within a specific watershed once the deficit amount for that watershed exceeds five (5) acres of Required Treatment Area or within five (5) years from when the deficit was created.

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7. POST-CONSTRUCTION BMP DESIGN METHODOLOGY

Post-construction BMPs shall be designed and installed following the guidelines presented in this manual. However, the design guidelines are minimum requirements. DOT-HWYS may require additional treatment controls to meet specific water quality needs in watersheds that drain to sensitive receiving waters or those that have other project-specific conditions. Design requirements may result in larger facilities or additional types of structural or non-structural controls; the design solution will be contingent upon the pollutants of concern that impact the water body and the regulatory status of the water body.

This section introduces the variables used and the general concepts involved in the methodology for sizing post-construction BMPs.

7.1 REQUIRED TREATMENT AREA

Special attention has been given to the effects of impervious surfaces upon storm water runoff in recent decades. Vehicular traffic on roads, highways, and bridges releases heavy metals, oils, and other toxic substances into the environment. Urban highways often generate higher amounts of trash and debris compared to rural areas. This manual focuses on treating impervious surfaces intended for vehicular use associated with New Development and Redevelopment to address the impacts of urban development. Impervious surfaces intended for non-vehicular use, such as sidewalks and bicycle paths, are considered negligible generators of pollutant discharge and do not require treatment. Pervious areas disturbed during construction require permanent stabilization following construction also do not require treatment.

For New Development and/or Redevelopment projects, the calculation for sizing Required Treatment Area is below. If the equation yields a zero or negative result, no treatment is required.

$$A_T = ND + (F \times RD) - A_{TE}$$

Where A_T = Required Treatment Area (acres)

ND = New Development resulting in new impervious surface (acres)

RD = Redevelopment of existing impervious surface (acres)

F = Redevelopment Treatment Fraction

= 0.25 for MS4 Permit areas

= 0 for non-MS4 Permit areas

A_{TE} = Area Treated by Existing BMPs (acres)

New Development is any construction of new impervious surface intended for vehicular use. The limits should extend to the edge of pavement (or curb face for roadways or facilities with curbs). Examples of New Development include:

- Roadway corridors
- Roadway intersections
- Roadway access ramps
- Roadway realignment
- Roadway widening
- Baseyard facilities
- Parking lots

Redevelopment occurs when any construction, reconstruction, alteration, or improvement is performed on existing impervious surfaces in which the underlying untreated aggregate or pervious subgrade is exposed or penetrated during construction. This results in no net increase of impervious surface.

Pavement preservation treatments, such as asphalt overlays, crack sealing, pavement resurfacing or rehabilitation, extend the useful life of existing pavements while leaving a layer of the impervious pavement surface intact. These pavement repair methods are not considered Redevelopment and do not factor into the Required Treatment Area calculation because underlying untreated aggregate or pervious subgrade are not exposed or disturbed.

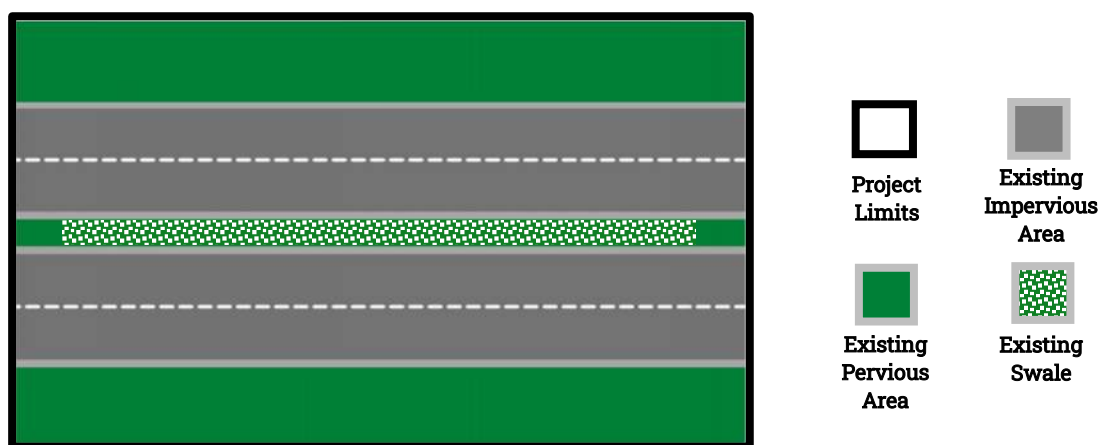
Only a fraction of the Redeveloped Area requires treatment since the effects of Redevelopment upon the MS4 and surrounding environment are less impactful than newly created impervious surfaces.

- MS4 Permit Areas – 25 percent of the Redevelopment area requires treatment since DOT-HWYS employs other BMP housekeeping methods such as an effective street sweeping program that reduces pollutant runoff from highways.
- Non-MS4 Permit Areas – The Redevelopment Treatment Fraction is equal to zero since post-construction BMPs are only required for new impervious surfaces.

If post-construction BMPs have been constructed or installed and already provide water quality treatment for the Disturbed Area, the area treated by the existing post-construction BMP may be subtracted from the Required Treatment Area. In order for the existing post-construction BMPs to qualify for a reduction in the required treatment, its current condition must meet the design parameters provided for the specific BMP listed in Appendix A. For example, an existing vegetated swale may be used to reduce the Required Treatment Area if it meets the design criteria for the WQFR, design flow velocity, swale length, footprint area, etc. Existing BMPs may be retrofitted to meet the sizing criteria or to provide additional water quality treatment.

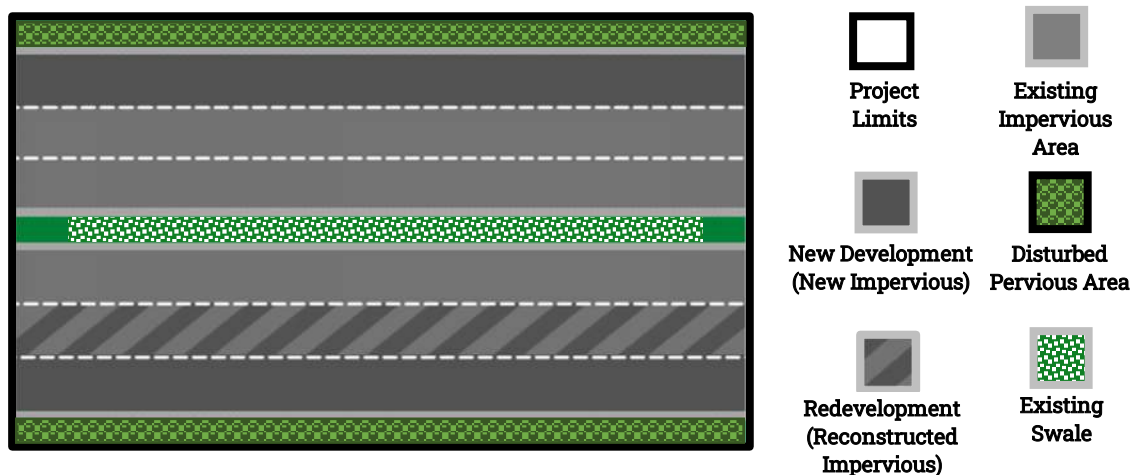
An example of how to determine the Required Treatment Area for a highway widening project is provided below. The sample project area occurs within an MS4 Permit area and within the DOT-HWYS right-of-way. The example project does not drain to sensitive receiving waters and does not qualify for a project exemption from providing post-construction BMPs. The project limits fall within a single tributary drainage basin.

7.1.1 Existing Condition



The existing project site consists of a 4-lane divided highway with a grassed median containing a vegetated swale as shown in the figure above. The total existing impervious area is 4 acres. The existing treatment area served by the vegetated swale is 1 acre.

7.1.2 Proposed Condition



A new lane is proposed in both directions. One existing lane will undergo full-depth reconstruction, as shown in the figure above. The New Development (ND) resulting in new impervious surface is 2 acres and the Redevelopment (RD) of existing impervious surface

is 1 acre. A total of 1 acre of pervious surface will also be disturbed along the roadside for grading work. The total area which will result in exposing the underlying base course, penetrating and moving soil, is 4 acres. Since the Disturbed Area (DA) will be greater than one (1) acre, the project is subject to implementing post-construction BMPs to address storm water runoff.

Although the DA is used to determine whether post-construction BMPs are required, sizing post-construction BMPs is based upon the Required Treatment Area. The Required Treatment Area only considers impervious surfaces associated with New Development and Redevelopment within the project area.

The Required Treatment Area (A_T) is calculated as shown below.

$$A_T = ND + (F \times RD) - A_{TE} = 2 + (0.25 \times 1) - 1 = 1.25 \text{ acres}$$

Where A_T = Required Treatment Area (acres)

ND = New Development resulting in new impervious surface (acres)

RD = Redevelopment of existing impervious surface (acres)

F = Redevelopment Treatment Fraction

= 0.25 for MS4 Permit areas

A_{TE} = Area Treated by Existing BMPs (acres)

If the project limits span multiple drainage areas, the Required Treatment Area must be calculated separately for each tributary drainage area. Post-construction BMPs must then be designed to address the Required Treatment Area associated with drainage area separately.

7.1.3 Stand-Alone BMP Retrofit Projects

In addition to New Development and Redevelopment projects, DOT-HWYS funds stand-alone BMP retrofit projects to address areas that drain to sensitive receiving waters to reduce targeted pollutants. For example, a stand-alone BMP retrofit project may be designed to treat runoff from an existing roadway within a designated TMDL watershed.

For stand-alone BMP retrofit projects, since there are no new or reconstructed impervious areas, the treatment control BMP should be sized based on the existing impervious surface within the tributary drainage area.

7.2 DESIGN STORM RUNOFF DEPTH

Pollutant discharge from runoff is considerably higher during the “first flush” of storm events. Post-construction BMPs treat this first flush, which typically makes up

approximately 80 percent of the average annual runoff. Determination of these quantitative criteria is essential when designing and sizing post-construction BMPs to enhance storm water runoff quality through infiltration, evapotranspiration, rainwater harvesting, or other activities that treat and release storm water.

DOT-HWYS determined that a 1-inch runoff depth correctly models the volume required for post-construction BMP treatment. The City and County of Honolulu (CCH) conducted research and analysis of the 85th percentile values for 24-hour cumulative depths over 0.10 inches for the island of Oahu. The resulting research, presented in the CCH Standards Revision Plan (dated December 2011), demonstrated the 24-hour 85th percentile value of one (1) inch equaling or exceeding the total for 89 percent of the stations analyzed.

DOT-HWYS conducted an independent study to confirm rainfall data for Oahu and the rest of the counties in the State of Hawaii with 24-hour 85th percentile values. DOT-HWYS evaluated rainfall stations within a margin of seven (7) miles to the left and right of state routes across all counties. Stations were primarily selected for having 35 years of recent continuous monitoring data. Some stations did not have 35 years of data but provided useful rainfall information. Through the analysis of these stations, no more than half of the stations in the state exceeded the one (1) inch value, with most county averages at or close to the one (1) inch value. This summary of storm averages is presented in Table 7-1. Appendix C of this manual shows the rain gauge station locations analyzed for each island.

Table 7-1. Summary of Statewide 85th Percentile Storm Averages

Island Name	No. of Stations Analyzed	Average From All Stations (in.)
Hawaii	107	1.101
Maui	45	1.059
Lanai	3	1.105
Molokai	8	0.989
Oahu	62	0.889
Kauai	38	0.939

Designers may elect to use a higher value than the 1-inch design storm based on actual site conditions, technical expertise, safety concerns, or other reasons.

7.3 SIZING CRITERIA FOR TREATMENT CONTROL BMPs

Section 2 discussed how the Required Treatment Area improves stormwater quality with the use of treatment control BMPs. Sizing treatment control BMPs is dependent upon several factors, including project constraints, land use, soil types, depth to groundwater, maintenance requirements, and pollutants of concern. If a project consists of multiple tributary drainage areas, a treatment control BMP must be sized for each drainage area.

In accordance with the MS4 Permit requirements, projects that require post-construction BMPs must first prioritize using LID treatment measures. If implementation of LID is deemed infeasible for some or all of the treatment required, the project shall utilize non-LID BMPs or seek Alternative Compliance for the remaining treatment amount as determined by DOT-HWYS.

Unlike typical flood control measures that are designed to handle peak flows of larger infrequent storms, treatment control BMPs are designed to treat lower flow volumes associated with more frequent storm events or the “first flush” that occurs with larger storm events. Depending upon the type of treatment process employed, treatment control BMPs may generally be classified as either volume-based or flow-based BMP devices.

7.3.1 Volume-Based Water Quality Control

Volume-based water quality control measures incorporate storage to achieve water quality treatment through retention and infiltration of storm water runoff. By sizing for a specified runoff volume, these BMPs may become overwhelmed by long-duration or high-intensity storm events that result in large runoff volumes. The BMP design should accommodate excess flows via a bypass or overflow configuration. Examples of these types of post-construction BMPs include ponds, wetlands, infiltration trenches, and bioretention facilities.

Sizing of volume-based facilities is based upon the required Water Quality Volume (WQV) which is calculated using the following formula. The WQV volume is based on a 1-inch Design Storm Runoff Depth (P) representing the 85th percentile, 24-hour storm as discussed in the previous section.

$$\text{WQV} = P \times C \times A_T \times 3630$$

Where WQV = Water Quality Volume (ft³)

P = Design Storm Runoff Depth (inches) = 1 inch

C = Volumetric Runoff Coefficient = 0.95

A_T = Treatment Area (ac)

3630 = conversion factor

The volumetric runoff coefficient represents the fraction of rainfall that becomes runoff and is expressed as:

$$C = 0.05 + 0.009I$$

Where C = Volumetric Runoff Coefficient

I = Percent of Impervious Cover

Since this manual focuses on treating impervious surfaces, the value for the volumetric runoff coefficient (C) is 0.95 for volume-based water quality control measures.

7.3.2 Flow-Based Water Quality Control

Flow-based water quality control measures treat storm water by capturing pollutants as they pass through filtration media, via infiltration, or sedimentation. In addition, some devices utilize hydraulic particle separation techniques ("hydrodynamic separator" BMPs). However, these alone are typically not capable of removing smaller sized fractions of solids that may have absorbed metals such as copper and zinc.

Flow-based water quality control measures are sized based on specified peak flow rates and required treatment flow rates. Short-duration storm events with high peak flows which exceed the design flow rates should also be considered in the design.

The sizing of flow-based facilities is based upon the required Water Quality Flow Rate (WQFR) which is calculated using the following formula. The WQFR is the runoff that would be produced from a rainfall intensity of 0.4 inches per hour. This rate must be maintainable for a minimum of three hours. Flow rate calculation shall be based upon the Rational Method as follows:

$$\text{WQFR} = C \times i \times A_T$$

Where WQFR = Water Quality Flow Rate (cfs)

C = Runoff Coefficient (from Table 7-2)

i = Rainfall Intensity (in/hr) = 0.4 in/hr

A_T = Treatment Area (ac)

The runoff coefficient (C) used for sizing flow-based facilities is slightly less than for volume-based facilities since some runoff is lost as flow passes through the flow-based treatment control device. Typical runoff coefficients for various surfaces are presented in Table 7-2.

Since the manual criteria focus on treatments for newly created or reconstructed impervious surfaces, only runoff coefficients for paved surfaces are applicable in the sizing computation of the post-construction BMPs. Runoff coefficient values for pervious surfaces are included for comparative purposes.

Table 7-2. Recommended Runoff Coefficient Values

Type of Surface or Condition	Runoff Coefficient (C)
Concrete pavement	0.80
Asphalt pavement	0.70
Gravel roadways or shoulders	0.50
Pervious concrete	0.10 - 0.60
Porous asphalt	0.10 - 0.55
Grass	0.10
Grid pavements with grass or aggregate	0.10

If a highway project involves multiple types of pavements such as a combination of concrete and asphalt, a weighted runoff coefficient based upon each surface type shall be used:

$$C = (\sum C_i \times A_i) / A_T$$

Where C = Weighted Runoff Coefficient

$C_{1,2,...,n}$ = Runoff Coefficient for each pavement type

$A_{1,2,...,n}$ = Area for each pavement type (ac)

A_T = Required Treatment Area (ac)

7.3.3 Combined Volume-Based and Flow-Based Water Quality Control

If volume-based BMPs cannot treat the entire Required Treatment Area, flow-based BMPs may be used in combination to treat the remaining deficit. Scenarios in which a combination of volume-based and flow-based systems would provide better hydraulic or treatment performance should also be evaluated. When multiple BMPs are arranged in a “treatment train”, treatment options should be in order of ascending pollution removal rates for nutrients and total suspended solids (TSS) as well as maintenance requirements for the removal of trash and debris. In other words, the removal efficiencies should increase moving downstream in a treatment train to avoid clogging at the beginning or upstream end.

7.4 HYDRAULIC DESIGN CRITERIA

While the primary purpose of this Post-Construction BMP Manual is to address storm water quality impacts of highway runoff to the DOT-HWYS MS4, post-construction BMPs also need to be designed in accordance with the respective drainage design standards concerning hydraulic conveyance of the post-development peak design flows.

The designer shall refer to the most current version of the DOT-HWYS *Design Criteria for Highway Drainage* standards, which is available upon request from DOT-HWYS. For private construction projects, refer to the applicable County drainage standards.

8. POST-CONSTRUCTION BMP DEVELOPMENT IN PLANNING PHASE

To achieve the desired water quality goals of the DOT-HWYS SWMP, personnel of DOT-HWYS, designers, and contractors need to adopt a comprehensive strategy for post-construction BMPs throughout every phase of a project. Early consideration of post-construction BMPs will help identify right-of-way limitations, physical constraints, potential community and environmental impacts, design conflicts, permitting requirements, and future maintenance needs. Any significant hurdle may adversely impact the feasibility of the project.

Projects with a planning phase will typically need an Environmental Assessment (EA) or Environmental Impact Statement (EIS). Sufficient information should be provided to determine whether post-construction BMPs are required. The design team, including the civil engineers, planners, and landscape architects should begin developing the post-construction BMP strategy during the EA or EIS preparation process.

If a project does not include a planning phase, EA, or EIS, a separate post-construction BMP planning report will not be required. The Storm Water Post-Construction BMP Design Report, written during the design phase, should document any proposed water quality treatment controls. More information regarding the Storm Water Post-Construction BMP Design Report is provided in Section 9.3.

8.1 POST-CONSTRUCTION BMP CONCEPT DEVELOPMENT

It is understood that not all information will be available to fully design the post-construction BMPs during the planning phase. However, a concept should be developed based on the best information available. At a minimum, the following information should be referenced or taken into consideration to develop an initial post-construction BMP conceptual plan.

8.1.1 Record Drawings

Record drawings identify site improvements that were previously constructed or may still exist within the project limits. The presence of underground utilities and other obstacles may affect the size and location of required post-construction BMPs. The designer should check the availability of record drawings from all possible sources, including DOT-HWYS, other state agencies, counties, utility companies, and private developers and landowners.

8.1.2 Subsurface Information

The existing soil profile is critical in identifying possible post-construction BMP solutions. Available soils reports or boring log information should be referenced to determine site soil characteristics and groundwater conditions that may dictate whether a specific type of post-construction BMP is feasible.

If subsurface information is unavailable, the general Hydrologic Soil Group (HSG) class can be identified using the interactive features found on the United States, Department of Agriculture, Natural Resources Conservation Service (NRCS) Web Soil Survey website (<https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm>). The four HSG classes are identified as A, B, C, and D with A soils generally having the smallest runoff potential and D soils the greatest. An HSG classification may not be provided for areas developed on fill material or where insufficient information was available to make an HSG determination.

Table 8-1. Hydrologic Soil Groups

Soil Group	Soil Types	Runoff Potential	Infiltration Rate
A	sand, loamy sand, or sandy loam	Low	High
B	silt loam or loam	Moderately Low	Moderate
C	sandy clay loam	Moderately High	Low
D	clay loam, silty clay loam, sandy clay, silty clay, or clay	High	Very Low

The HSG classification should be used as an initial screening tool to select an appropriate post-construction BMP for the project. For example, an infiltration facility may be infeasible for an area with seasonally high groundwater or high clay content. More in-depth subsurface investigation is required during the design phase to verify site soil conditions as detailed in Section 9.1.3.

8.1.3 Pollutants of Concern

The water quality of highway runoff is generally similar to other urban land uses but tend to be higher in TSS, oils, grease, and metals and lower in bacteria and nutrients (NCHRP 2012). Depending on the proposed project location, or if located within a WLA or TMDL watershed, the presence of specific pollutants may already be known. Many post-construction BMP devices are not designed or have adequate testing data to confirm reduction efficiencies in TSS or nutrients such as nitrogen and phosphorus. The designer must evaluate the capacity of each post-construction BMP to remove pollutants. The designer should also consider using multiple treatment control BMPs (aka a “treatment train”) to achieve the necessary storm water quality treatment.

- **Sediment** - Primarily found in highway runoff as either suspended solids or dissolved solids. Overabundance of solids negatively impacts water quality of streams and oceans and its fish and wildlife habitat. Heavy sedimentation transforms natural waterways and requires costly dredging to reestablish stream capacities. A common term used in measuring treatment efficiency is TSS which is typically sediment and particles larger than 2 micrometers in size.
- **Nutrients** - High levels of phosphorus and nitrogen can lead to algal blooms in downstream waters which reduces oxygen levels and results in water discoloration and odors. Nutrients may be of particular concern in watersheds with large agricultural or landscaped areas due to the presence of fertilizers and organic matter. Nutrients, where mentioned in this manual, collectively refers to both total nitrogen and total phosphorus.
- **Oils and Grease** - Oils and grease are typically present in runoff from roads and parking lots and may be of significant concern for industrial or commercial land uses. In low concentrations, hydrocarbons present in oils and grease become toxic and threaten aquatic life. Once released into water bodies, they may take several years or more to decompose naturally without human intervention and treatment.
- **Metals** - Metals are released from a variety of manmade products and when transported in storm water runoff, becomes toxic to aquatic life and has the potential to contaminate potable water sources if infiltrated into groundwater. Metals most often detected are lead, copper, and zinc, although arsenic, mercury, and cadmium are also commonly found in urban runoff samples.
- **Trash** – Trash consists of solid waste material and floatables that is intentionally or unintentionally disposed of in the environment. Large accumulations within drainage culverts and structures may reduce drainage capacities and eventually end up in streams and oceans.
- **Bacteria** - Bacteria multiplies faster in warm weather so is well-equipped to thrive in Hawaii's tropical climate. During large storm events, excessive levels of bacteria carried by storm runoff may result in closures of affected beaches.

Appendix A provides general information for various treatment control BMPs including typical targeted pollutants for removal, limitations, design criteria, construction and landscaping considerations, and maintenance requirements.

8.1.4 Post-Construction BMP Treatment Type

No single BMP can be applied to all scenarios. Whether a volume-based, flow-based, or a BMP treatment train is chosen will determine space and maintenance requirements.

Volume-based BMPs typically require a larger footprint than flow-based BMPs but the amount of space required is dependent on the amount of contributory runoff requiring treatment and hydraulic conveyance through the post-construction BMP.

8.1.5 Pretreatment

Sediment accumulation is often the cause of premature failure of post-construction BMPs, especially those that rely on infiltration for storm water treatment. Pretreatment should be considered for all treatment control devices that may be susceptible to sediment and debris to extend their service life and minimize the need for frequent maintenance or replacement. Designers should incorporate provisional space for pretreatment features such as vegetated buffer strips, vegetated swales, sediment forebays, or pretreatment chambers upstream of the post-construction BMP.

8.1.6 Preliminary Sizing and Layout

Calculate the approximate Required Treatment Area and resulting value for WQV or WQFR based on the criteria in Section 7 of this manual. Use the BMP fact sheets in Appendix A to select and configure an appropriate post-construction BMP device. Provide a conservative estimate of the required footprint of the post-construction BMP to allow for some flexibility in the design layout, as it may affect the rights-of-way required and influence the BMP selection.

Once the estimated size of the post-construction BMP is determined, evaluate potential locations and layouts by conducting a site visit or referencing the record drawings to identify any potential conflicts with the terrain or surrounding improvements. Include a schematic layout of the post-construction BMPs with the planning documents. Complete the concept development before any public informational meetings in which project impacts and alternatives may affect decisions.

8.1.7 Cost-Effectiveness

The cost to implement post-construction BMPs shall be taken into consideration when defining project budgets and design scopes. Factors including post-construction BMP type, Required Treatment Area, and project site constraints, may escalate overall project costs. For project initiation budgetary purposes, it may be assumed that incorporating source control BMPs and treatment control BMPs range between \$100,000 and \$250,000 per lane mile for new roadway construction or major reconstruction projects (Caltrans, 2019).

The lower end of this range would apply to projects that are in rural areas with adequate space to install vegetated LID BMPs. The higher end of this range would apply to projects in

more urbanized areas, where implementation of proprietary non-LID BMPs may be necessary.

8.1.8 Maintenance Requirements

Maintenance requirements impact manpower and financial resources for the entire duration that the post-construction BMP device is in operation. Common maintenance activities include removal of sediment, trash, and debris, repair and replacement of worn or defective components, cleaning and inspection of filtration devices, vegetative maintenance, and repair of eroded areas. At the planning stage, general maintenance issues need to be considered such as site accessibility, maneuvering space for vector trucks and service vehicles, and traffic impacts including possible lane closures.

8.2 POST-CONSTRUCTION BMP PLANNING INFORMATION

Adequate information shall be provided in the applicable planning report, EA or EIS to allow DOT-HWYS to properly plan and budget for the post-construction BMPs. The following information shall be provided, at a minimum:

- Post-Construction BMP Information
 - Description and intended treatment
 - Regulatory requirements
 - TMDL or WLA requirements
 - Impacted drainage outfall(s)
 - Right-of-way requirements
 - Maintenance requirements (activity, frequency, and cost)
 - Construction cost estimate
- Figures
 - Existing and proposed drainage maps
 - Proposed post-construction BMP types and locations
 - Flood Zone designations, floodplain and floodway boundaries
- Supporting Documentation
 - BMP sizing calculations and worksheets
 - Proposed product data information
 - Hydrologic and hydraulic calculations
 - Site photos (if critical to BMP selection)

- References

The applicable planning report, EA, EIS, and any other required documents shall be submitted to DOT-HWYS for review and concurrence. Further evaluation to finalize the post-construction BMP design and feasibility will be performed in the design phase.

9. POST-CONSTRUCTION BMP DEVELOPMENT IN DESIGN PHASE

The post-construction BMP concept should be further developed during the design phase. For projects that have a planning report, EA, or EIS, the post-construction BMP planning concept should be used as the basis for developing the design. Otherwise, the development of post-construction BMP design concepts starts at the initiation of project design.

9.1 POST-CONSTRUCTION BMP DESIGN DEVELOPMENT PROCESS

During the design development stage, more in-depth analysis is required to confirm the types, sizes, and details of post-construction BMPs to implement in the project. For projects where storm water runoff is discharged from the right-of-way in a sheet flow fashion, lines of study (LOS) should be identified. Care should be taken to follow the drainage patterns within and outside the right-of-way to identify correct study points and lines of study. Topographic survey maps and desktop surveys rarely provide an accurate depiction of actual site conditions, so field investigation is required for verification.

The post-construction BMP design is to be updated throughout the design process as necessary based on revisions to the project design, site hydrology, grading, or other design factors. The designer should include or consider the following, at a minimum, when developing the design of the post-construction BMPs.

9.1.1 Topographic Survey

The topographic survey limits should extend an adequate distance beyond the proposed roadway or site improvements to identify potential locations for post-construction BMP facilities. The topographic mapping should identify rights-of-way, property lines, easements, surface features and elevations, utility locations and inverts, and other site features that may impact the post-construction BMP design.

9.1.2 Hydrology and Hydraulics

In addition to addressing water quality treatment, post-construction BMPs must also be sized in accordance with the hydrologic and hydraulic guidelines of the DOT-HWYS *Design Criteria for Highway Drainage* which is available upon request from DOT-HWYS.

Projects in MS4 Permit areas and non-MS4 Permit areas shall be designed such that the post-development peak flow and runoff volume do not exceed the pre-development condition. Check water surface elevations for all design storm events to ensure the post-

construction BMPs can safely pass the design flows. Discharge velocities at outfalls, spillways, and pipe outlets shall be non-erosive for peak design flows. Energy dissipators such as riprap aprons or concrete baffles shall also be considered to further prevent scour

When connecting to an existing storm drain system, considerations should also be given to online or offline post-construction BMP configurations, high-flow bypass, inlet and outlet sizing, and downstream capacities.

9.1.3 Infiltration Testing and Subsurface Investigation

In-depth subsurface investigation and testing during the design phase is essential to verify HSG classifications or previously obtained geotechnical data and to ultimately determine the rate at which storm water can percolate through the underlying soil. Infiltration tests are required for any volume-based treatment control BMP that utilizes infiltration as a means for water quality treatment (e.g., infiltration trenches, infiltration basins, bioretention facilities, etc.).

The feasibility and size of some LID BMPs are based upon the long-term infiltration rate, which is typically expressed in inches per hour. Allowable testing methods include the double-ring infiltration test and falling head infiltration test. The tests shall be conducted under the supervision of a professional engineer licensed in the State of Hawaii with expertise in geotechnical engineering. Tests shall be conducted in accordance with industry standard testing procedures applicable to the selected testing method. Testing shall occur at the proposed bottom elevation of the infiltration device and extend to a depth as determined by the geotechnical engineer.

Infiltration Test Requirements

1. Infiltration Basins and Bioretention Facilities: A minimum of one (1) test for every 2,500 square feet of treatment area.
2. Infiltration Trenches: A minimum of one (1) test for every 100 linear feet of trench.
3. Enhanced Swales: A minimum of one (1) test for every 100 linear feet of trench.
4. Safety Factor: Minimum safety factor of 2 should be applied to measured infiltration rates to account for reduced infiltration over time.

Design infiltration rates should be greater than 0.5 inches per hour to avoid clogging of the filtration media. Infiltration rates should also not exceed 8.0 inches per hour to prevent overly rapid infiltration, which would diminish the treatment effectiveness of the infiltration facility. Generally, infiltration facilities are not applicable in soils having 20

percent or greater clay content or 40 percent or greater silt/clay content (Minnesota 2020). Soils with infiltration rates above 8.0 inches per hour may be amended to a certain depth with organic matter or other soil types to decrease the infiltration rate to an acceptable level. Additional infiltration tests must be conducted after amending the soils to confirm that the desired infiltration rate has been achieved.

Boring logs should also be taken to determine site soil conditions and the presence of groundwater. Soil boring depths should extend a minimum of five (5) feet beyond the bottom of any proposed infiltration facility or as recommended by the licensed geotechnical engineer.

Some factors to consider during the subsurface investigation or which may impact the infiltration test results include:

- Highly variable test results – If test results indicate significant variance of soil properties across the site, the designer may be required to conduct additional tests to resolve the differences.
- Seasonally high groundwater – Areas may be susceptible to seasonal fluctuations in groundwater levels. The geotechnical engineer should take this into consideration when scheduling the tests and for assessing the subsurface soil characteristics and test results. Similar considerations should also be applied for low lying areas influenced by tidal fluctuations.
- Artesian conditions – Infiltration devices are typically not allowed where artesian conditions are anticipated or encountered.
- Contaminated site conditions – Infiltration devices are typically not allowed on sites with soil or groundwater contamination.

9.1.4 Technological Verification

If non-LID BMPs are to be used as part of the post-construction BMP strategy, the designer may choose from several available proprietary treatment control BMP devices. These proprietary devices use patented technologies to target specific pollutants. The field of proprietary treatment control BMPs is constantly changing with technological advances, regulatory requirements, and storm water treatment objectives. DOT-HWYS does not endorse any particular type or brand of proprietary treatment control BMP device and will review its application and performance on a case-by-case basis.

At a minimum, each proposed proprietary device must have a current verification from the New Jersey Corporation for Advanced Technology (NJCAT), the State of Washington Department of Ecology Technology Assessment Protocol-Ecology (TAPE), or a national

testing and verification program. The verification must apply to the targeted pollutants of concern and the selected device must provide sufficient capacity for both the required WQFR and design peak flow rate. It is the designer's responsibility to consult with the device manufacturer and confirm the effectiveness of pollutant removal for each proprietary device.

The designer shall submit the following information to DOT-HWYS for each proposed treatment control BMP:

- Name/Brand of proprietary device
- Manufacturer's product literature
- Expected pollutant removal effectiveness
- Technological verification
- Warranty information
- Operations and maintenance (O&M) requirements

9.1.5 BMP Retrofits

In highly urbanized areas, space is limited for installations of new LID BMPs. It may be possible to achieve some level of water quality treatment and gain treatment credits by retrofitting the existing drainage system or treatment control BMPs. However, retrofit costs are typically much higher than the construction cost for new post-construction BMPs. An evaluation must be done to ensure retrofitted drainage structures can still adequately pass the design storm flows and will not create flooding conditions.

9.1.6 Plant Selection

The introduction of invasive species within an ecosystem diminishes Hawaii's ecological heritage and reduces natural pollutant retention and remediation. Therefore, public construction projects that include vegetated post-construction BMPs in public spaces must comply with Hawaii Revised Statutes (HRS) Section 103D-408, Act 233 which requires a minimum percentage of landscaping to be composed of native Hawaiian plants. More information regarding Act 233 can be found at the following website:
https://spo.hawaii.gov/wp-content/uploads/2018/12/Act-233-Hawaiian-Plants_Info_12-26-18.pdf.

Where possible, select plant species that may adapt to the project habitat without the need for permanent irrigation.

9.1.7 Maintenance Requirements

During the design phase, the post-construction BMP design should be sufficiently developed to establish a draft maintenance plan including anticipated inspection intervals, maintenance frequencies, and costs. Costs should be estimated based on theoretical quantities of pollutants removed, monitoring, inspection, hauling and disposal, repairs and replacement, and traffic control. More information regarding maintenance requirements is provided in Section 9 of this manual and the DOT-HWYS *Post-Construction BMP Operations and Maintenance Manual*.

9.1.8 Cost Implications

Expand upon any planning level cost estimates as more detailed information becomes available during the design process. The designer must take into consideration the cost implications of the various treatment control BMPs being evaluated. Post-construction BMPs that treat large areas or volumes are generally more cost-effective than several smaller facilities. If space is available, vegetated LID BMPs are typically less costly to construct and maintain than proprietary non-LID BMPs.

9.2 DESIGN SUBMITTALS

Each design submittal shall provide sufficient information to convey the proposed project components, potential impacts to water quality, and proposed measures to mitigate such impacts. The submittal at each design phase should include the following information, as applicable:

- Construction drawings
 - Project limits
 - Limits of disturbance
 - New impervious surfaces
 - Existing impervious surfaces to be removed or reconstructed
 - New and existing drainage outfalls
 - New and existing culverts and drainage structures
 - Existing and proposed contour and elevation data
 - Direction of drainage flow and surface runoff
 - Proposed post-construction BMP types and locations
 - Dimensions and elevations of post-construction BMPs
 - Plant and tree schedule

- Soil boring logs
- Specifications
 - Post-construction BMP minimum performance requirements
 - Allowable proprietary treatment control BMP models or brands
 - Post-construction BMP installation and protection procedures
 - Maintenance requirements
- Construction cost estimate
- Calculations
 - Sizing calculations and worksheets
 - Hydrologic and hydraulic calculations
- Proposed product data information
- Drainage report
- Storm Water Post-Construction BMP Design Report (see Section 9.3)
- Storm Water Post-Construction BMP Design Checklist (see Section 9.5)
- Post-Construction BMP O&M Plan
- Variance Request Form, if applicable (see Section 9.6)
- Copies of files submitted to DOH for projects that require coverage under the NPDES General Permit Authorizing Discharges of Storm Water Associated with Construction Activities
- Other information as requested by DOT-HWYS

9.3 STORM WATER POST-CONSTRUCTION BMP DESIGN REPORT

A Storm Water Post-Construction BMP Design Report shall be submitted to DOT-HWYS for review at the preliminary submittal phase. The report should include the following, at a minimum:

- Executive Summary
- Introduction
 - Project background
 - Scope of proposed improvements
- Figures

- Location and Vicinity Maps
 - Flood Zone designations, floodplain and floodway boundaries
 - Existing and proposed drainage maps
- Post-Construction BMP Information
 - Description and intended treatment
 - Justification for any treatment variances
 - Regulatory requirements
 - TMDL or WLA requirements
 - Impacted drainage outfall(s)
 - Right-of-way requirements
 - Maintenance requirements (activity, frequency, and cost)
 - Construction cost estimate
- 30% Conceptual Plans
 - Site location with respect to DOT-HWYS right-of-way, easements, and property lines
 - Topographic survey with existing and proposed contour data
 - Limits of Disturbance
 - Development and/or Redevelopment entities
 - Proposed post-construction BMP types and locations
- Storm Water Post-Construction BMP Design Checklist (see Section 9.5)
- Appendix
 - Sizing calculations and worksheets
 - Hydrologic and hydraulic calculations
 - Site photos (if critical to post-construction BMP selection)
 - Proposed product data information
 - Soil infiltration test results
- References

9.4 REVIEW AND APPROVAL

Projects may be initiated from different departments within DOT-HWYS on Oahu or from outer islands depending upon project type, funding mechanisms, targeted watersheds, and

jurisdictional priorities. It is essential that all design projects, regardless of size, applicability of post-construction BMPs, island location, or departmental source, follow a standard protocol for reviewing, approving, and documenting post-construction BMP designs. Following protocol ensures proper tracking of project water quality requirements and compliance with the MS4 Permits.

For both conventional design-bid-build projects and design-build projects, DOT-HWYS shall not advertise any construction project or award any construction contract or issue work permits until the project design has been reviewed and accepted by the applicable DOT-HWYS department. This process will ensure that appropriate post-construction BMPs have been included in the project design in accordance with this manual.

9.5 STORM WATER POST-CONSTRUCTION BMP DESIGN CHECKLISTS

For all public construction projects, a Storm Water Post-Construction BMP Design Checklist should be completed by the designer, subject to review and approval by DOT-HWYS. A separate checklist has been created for projects within MS4 Permit areas and non-MS4 Permit areas.

The applicable checklist should be submitted with other required items to DOT-HWYS at the 30% preliminary design submittal regardless of whether post-construction BMPs are required for the project. Evaluating post-construction BMP requirements at the beginning of the design phase ensures that ample time is available to address issues with space constraints, land acquisitions, and/or property easements.

If significant design changes occur after the 30% preliminary design submittal, a revised Storm Water Post-Construction BMP Design Checklist should be submitted to DOT-HWYS for re-evaluation of the applicability of post-construction BMP implementation. A revision should be submitted if any of the following scenarios occur:

- Post-construction BMP exemptions become applicable or no longer apply due to added/deleted types of improvements.
- Disturbance Area has changed.
- Areas of new or reconstructed impervious surfaces have changed.
- Proposed drainage areas, grading conditions, or design elements have changed resulting in changes to the proposed drainage system in terms of drainage quantity or drainage patterns.
- The size or type of proposed post-construction BMP has changed.

The Storm Water Post-Construction BMP Design Checklists for MS4 Permit areas and non-MS4 Permit areas are included at the end of this section.

9.6 STORM WATER POST-CONSTRUCTION BMP VARIANCE REQUEST FORM

A Storm Water Post-Construction BMP Variance Request Form is required for all projects that do not meet the Required Treatment Area and result in more debits than credits. The designer must justify that all other options to maximize water quality treatment have been evaluated and are deemed infeasible.

Possible options to consider may include the following:

- Selection of alternate types or a combination of post-construction BMPs to better fit site conditions or constraints.
- Reduction of proposed or existing impervious surfaces.
- Increase amount of grassed or vegetated pervious surfaces.
- Amendment or replacement of existing site soils to increase effectiveness of infiltration facilities.
- Retrofit an existing post-construction BMP to increase its pollutant removal efficiency.
- Implementation of a different type or model of manufactured treatment device where non-LID BMPs are allowed.
- Other design concepts or practices based on designer's professional judgement.

The Storm Water Post-Construction BMP Variance Request Form is included at the end of this section.

STORM WATER POST-CONSTRUCTION BMP DESIGN CHECKLIST FOR MS4 PERMIT AREAS		<input type="checkbox"/> New Submittal <input type="checkbox"/> Resubmittal
Project Information		
Project Name: _____		
Project Number: _____		Island: _____
Project Route Name(s): _____		Milepost Begin/End: _____
Watershed Location(s): _____		
Disturbance Area (acres): _____		New Impervious Area (acres): _____
Applicant Name: _____		Company: _____
Email: _____		Telephone: _____
Applicability		
1. Check "Yes" if project entirely consists of one or more of the following activities or conditions below. The project may be exempt from Post-Construction BMPs if it includes these exempted activities ONLY . Otherwise, if the project includes other types of improvements not listed below, continue to Step 2.		Yes
a. Project does not result in storm water discharge into the MS4 or state waters		<input type="checkbox"/>
b. Operations and Maintenance activities		<input type="checkbox"/>
b.1 Structural repairs		<input type="checkbox"/>
b.2 Baseyard maintenance and repairs		<input type="checkbox"/>
b.3 Installation or replacement of pavement striping and pavement markers		<input type="checkbox"/>
b.4 Other _____		<input type="checkbox"/>
c. Pavement Preservation Treatment which does not expose or disturb underlying aggregate or subgrade layer		<input type="checkbox"/>
d. Guardrail and Underground Utility Projects		<input type="checkbox"/>
d.1 Guardrail installation or replacement		<input type="checkbox"/>
d.2 Utility installation or relocation		<input type="checkbox"/>
e. Water Quality Improvements or Preservation		<input type="checkbox"/>
e.1 Shoreline protection		<input type="checkbox"/>
e.2 Landscaping		<input type="checkbox"/>
e.3 Culvert rehabilitation or replacement		<input type="checkbox"/>
e.4 Installation of Post-Construction BMPs		<input type="checkbox"/>
e.5 Erosion and sediment control		<input type="checkbox"/>
e.6 Rockfall mitigation		<input type="checkbox"/>
f. Pedestrian walkways or bicycle paths		<input type="checkbox"/>
g. Bridges or roads constructed above or below existing impervious areas		<input type="checkbox"/>

h. "Minor" Disturbance Project	Yes
h.1 Signage	<input type="checkbox"/>
h.2 ADA ramps	<input type="checkbox"/>
i. Emergency project	<input type="checkbox"/>
j. Temporary project	<input type="checkbox"/>
If project ONLY consists of exempt activities, go to Step 7. Otherwise, continue to Step 2.	
<p>2. Is project a private construction project?</p> <p><input type="checkbox"/> Yes; project is outside the DOT-HWYS right-of-way. Post-construction BMPs must comply with the applicable county storm water requirements. Identify any county-required documentation below. Continue to Step 7.</p> <p>_____</p> <p><input type="checkbox"/> Yes; project is within DOT-HWYS right-of-way. Post-construction BMPs may be required if project has the potential to discharge storm water to the DOT-HWYS right-of-way. Continue to Step 3.</p> <p><input type="checkbox"/> No; Continue to Step 3.</p>	
<p>3. Does project result in one (1) acre or more of Disturbed Area?</p> <p><input type="checkbox"/> Yes; LID BMPs are required. Continue to Step 6.</p> <p><input type="checkbox"/> No; continue to Step 4.</p>	
<p>4. Is project a Priority Project with a high potential for pollutant discharge?</p> <p><input type="checkbox"/> Yes; Post-Construction BMPs may be required at the discretion of DOT-HWYS regardless of the amount of Disturbed Area. Continue to Step 6.</p> <p><input type="checkbox"/> No; continue to Step 5.</p>	
<p>5. Is project located within or drain to sensitive receiving waters?</p> <p><input type="checkbox"/> Yes; Post-Construction BMPs may be required at the discretion of DOT-HWYS regardless of the amount of Disturbed Area. Continue to Step 6.</p> <p><input type="checkbox"/> No; post-construction BMPs are not required. Continue to Step 7.</p>	
<p>6. Does project treat the full Required Treatment Area?</p> <p><input type="checkbox"/> Yes; continue to Step 7.</p> <p><input type="checkbox"/> No; acceptance of water quality treatment to be determined pending DOT-HWYS review. Submit a Variance Request Form. Continue to Step 7.</p>	
<p>7. Additional project information (optional):</p> <p>Signature: _____ Date: _____</p>	
<p><u>For Department Use Only:</u></p> <p>Does project adequately address post-construction BMP requirements?</p> <p><input type="checkbox"/> Yes; the project treats the full Required Treatment Areas or is designed to the MEP.</p> <p><input type="checkbox"/> No; the project is not designed to the MEP. Provide additional post-construction BMPs.</p> <p><input type="checkbox"/> No; the project will result in a debit for water quality treatment and Alternative Compliance will be required for the remainder of the Required Treatment Area.</p> <p>Reviewed By: _____ Reviewed Date: _____</p>	

STORM WATER POST-CONSTRUCTION BMP DESIGN CHECKLIST FOR NON-MS4 PERMIT AREAS		<input type="checkbox"/> New Submittal <input type="checkbox"/> Resubmittal
Project Information		
Project Name: _____ Project Number: _____ Island: _____ Project Route Name(s): _____ Milepost Begin/End: _____ Watershed Location(s): _____ Disturbance Area (acres): _____ New Impervious Area (acres): _____		
Applicant Name: _____ Company: _____ Email: _____ Telephone: _____		
Applicability		
1. Check "Yes" if project entirely consists of one or more of the following activities or conditions below. The project may be exempt from Post-Construction BMPs if it includes these exempted activities ONLY . Otherwise, if the project includes other types of improvements not listed below, continue to Step 2.	Yes	
a. Project does not result in storm water discharge into the MS4 or state waters	<input type="checkbox"/>	
b. Operations and Maintenance activities	<input type="checkbox"/>	
b.1 Structural repairs	<input type="checkbox"/>	
b.2 Baseyard maintenance and repairs	<input type="checkbox"/>	
b.3 Installation or replacement of pavement striping and pavement markers	<input type="checkbox"/>	
b.4 Other _____	<input type="checkbox"/>	
c. Pavement Preservation Treatment which does not expose or disturb underlying aggregate or subgrade layer	<input type="checkbox"/>	
d. Guardrail and Underground Utility Projects	<input type="checkbox"/>	
d.1 Guardrail installation or replacement	<input type="checkbox"/>	
d.2 Utility installation or relocation	<input type="checkbox"/>	
e. Water Quality Improvements or Preservation	<input type="checkbox"/>	
e.1 Shoreline protection	<input type="checkbox"/>	
e.2 Landscaping	<input type="checkbox"/>	
e.3 Culvert rehabilitation or replacement	<input type="checkbox"/>	
e.4 Installation of Post-Construction BMPs	<input type="checkbox"/>	
e.5 Erosion and sediment control	<input type="checkbox"/>	
e.6 Rockfall mitigation	<input type="checkbox"/>	
f. Pedestrian walkways or bicycle paths	<input type="checkbox"/>	
g. Bridges or roads constructed above or below existing impervious areas	<input type="checkbox"/>	

STORM WATER POST-CONSTRUCTION BMP VARIANCE REQUEST FORM

Project Information

Project Name: _____

Project Number: _____ Island: _____

Project Route Name(s): _____ Milepost Begin/End: _____

Watershed Location(s): _____

Required Treatment Area (acres): _____ Provided Treatment Area (acres): _____

Applicant Name: _____ Company: _____

Email: _____ Telephone: _____

Justification for Project Water Quality Debit

1. Check "Yes" for any applicable project conditions below which will incur a debit(s).

<p>a. Where Low Impact Development (LID) BMPs are required, the designer shall implement LID BMPs to the Maximum Extent Practicable. Indicate any site constraints that will result in providing less than the required water quality treatment. Refer to Section 5.2 of the manual for further descriptions of the various types of constraints.</p>	Yes
<p>a.1 Hydrogeological Constraint</p>	<input type="checkbox"/>
<p>a.2 Physical Constraint</p>	<input type="checkbox"/>
<p>a.3 Operational Constraint</p>	<input type="checkbox"/>
<p>a.4 Environmental/Cultural Constraint</p>	<input type="checkbox"/>
<p>a.5 Other Constraint Type _____</p>	<input type="checkbox"/>
<p>b. Project results in an increase in impervious area</p>	<input type="checkbox"/>
<p>c. Project will remove an existing post-construction BMP or reduce the treatment effectiveness of an existing post-construction BMP (reduction in associated WQV or WQFR)</p>	<input type="checkbox"/>
<p>d. Other _____</p>	<input type="checkbox"/>

2. Provide detailed information regarding the resulting project debits and indicate why full treatment cannot be met by using post-construction BMPs.

3. Indicate other information that will be provided to evaluate the justification of this variance request.

a. Design drawings or details	Yes <input type="checkbox"/>	No <input type="checkbox"/>
b. Calculations	Yes <input type="checkbox"/>	No <input type="checkbox"/>
c. Photos	Yes <input type="checkbox"/>	No <input type="checkbox"/>
d. Other	Yes <input type="checkbox"/>	No <input type="checkbox"/>

4. Applicant signature and date

Signature: _____ Date: _____

For Department Use Only:

Variance Approved: ☐ Denied: ☐

Notes:

Reviewed By: _____ Reviewed Date: _____

10. INSPECTIONS, OPERATION, AND MAINTENANCE

Maintenance of post-construction BMPs is critical to ensure they perform as intended to achieve storm water management goals. The anticipated effectiveness of treatment control BMPs is based upon the designer's expertise, technical literature, historical information, and/or manufacturer's data. Its realized effectiveness will be dependent upon several factors including actual site conditions, construction techniques, and proper O&M.

10.1 PUBLIC CONSTRUCTION PROJECTS

Inspections are required for all post-construction BMPs installed for public construction projects. This section provides guidance on the following activities which are essential components of an effective O&M plan:

- Regular site inspections;
- Acceptance of post-construction BMPs and as-built certification;
- Proper BMP maintenance; and
- Good record keeping.

Since O&M of post-construction BMPs that are installed outside of DOT-HWYS right-of-way are the responsibility of the adjacent landowner, the recommended actions listed in this section only apply to public construction projects. However, post-construction BMPs located outside of DOT-HWYS right-of-way should also be inspected and maintained by the owner to minimize the risk of pollutants being discharged to the DOT-HWYS MS4. Suggested inspection and maintenance guidelines for private construction projects are provided in Section 10.2.

10.1.1 Site Inspections and Maintenance During Construction

The contractor is responsible for inspecting and maintaining the post-construction BMPs during construction in accordance with the contract documents. Any damages or deficiencies identified that may ultimately affect the performance of the post-construction BMPs should be identified, documented, and addressed. The contractor is typically required to handle and dispose of all accumulated debris, sediment, trash, or stored volume of storm water in accordance with state, county, and federal regulations for the duration of construction.

An inspection should also be conducted and documented during the following critical construction activities as applicable to the project or as determined by the designer.

- During excavation to subgrade or sub-foundation especially for infiltration facilities to ensure subgrade remains uncompacted.
- During placement of underdrain systems and observation wells.
- During backfill for foundations, trenches, underdrain systems and observation wells.
- During placement of geotextile and filter media.
- During the placement of structural fill beneath drainage structures.
- During embankment construction.
- During construction and installation of components of the treatment process such as diversion structures, pretreatment forebays, inlets, outlets, media filters, overflow pipes, outfalls, and flow distribution structures.
- Upon completion of final grading.
- Upon establishment of permanent stabilization.
- During and upon completion of any adjacent paved surfaces.
- During vegetative planting and plant maintenance periods.
- At any critical construction stage highlighted by the manufacturer for proprietary treatment control BMPs.

The maintenance period typically begins after the pre-final inspection has been completed and ends after the duration specified in the contract documents.

10.1.2 Acceptance of Post-Construction BMPs

At the end of the designated post-construction BMP maintenance period, a final site inspection will be held with DOT-HWYS, the contractor, subcontractors, maintenance supervisor/superintendent, and members of the design team. If the post-construction BMPs are determined to be operational in accordance with the requirements in the plans and specifications, and other construction activities have been adequately completed and approved, the project will be officially accepted by DOT-HWYS. After this point, maintenance of post-construction BMPs will become the responsibility of DOT-HWYS.

10.1.3 As-Built Drawings for Post-Construction BMPs

Once a public construction project has been accepted by DOT-HWYS, the contractor shall prepare and submit as-built plans to DOT-HWYS. Accurate documentation is critical since modifying the overall layout, dimensions, or elevations of a post-construction BMP may significantly affect its effectiveness and performance.

The as-built plans should identify any changes or modifications made to the original design during construction and include an as-built topographic survey conducted by a land surveyor licensed in the State of Hawaii to verify critical components of the installed post-construction BMPs. As-built plans shall include, but not be limited to, verification of the following information:

- Drainage Structures – Top and bottom elevations for structures; structure lengths, widths, and depths; sizes and invert elevations for pipes, cleanouts, orifices, weirs, flow splitters, level spreaders, headwalls, and spillways.
- Embankments – Embankment heights, widths, top elevations, and side slopes.
- If the project limit was revised for work done beyond the original project limits, the revised limits should be indicated on the plans.

Upon receiving the contractor's as-built plans, the designer is responsible for preparing a set of record drawings to document the as-built plan information and for submitting them to DOT-HWYS for proper documentation.

10.1.4 Post-Construction BMP Inspections After Construction

Post-construction BMPs for public construction projects shall be inspected in accordance with the construction specifications of the Post-Construction BMP O&M Plan. Inspections shall occur once per year at a minimum. During the first year after construction, post-construction BMPs shall be inspected after an exceedance of the design storm event, if applicable, to assess performance and maintenance requirements for peak flow events.

Inspections should include visual observations at the surface level to identify general deficiencies such as ponding water which may indicate clogged filter media. More in-depth inspections of monitoring wells or overflow pipes may detect issues with the infiltration properties of the underlying soil.

Post-construction BMP inspections must be documented using an inspection form or checklist that is acceptable to DOT-HWYS. If deficiencies are observed during the inspections, follow-up procedures must be performed promptly to ensure that the required repair, maintenance, or modification activity adequately addresses the deficiency. The allotted period varies depending on the identified deficiency but shall be done in a timely manner to avoid potential pollutant discharges.

10.1.5 Long-Term Post-Construction BMP Operation and Maintenance

The effectiveness of a post-construction BMP is highly dependent upon its continual maintenance and upkeep. Maintenance of post-construction BMPs are comprised of routine or major activities. The following activities pertain to post-construction BMPs installed for public construction projects only. O&M of private construction projects are discussed in Section 10.2.

- **Routine Maintenance Activities** - Routine maintenance tasks are performed at set intervals or as determined by site inspections and prolong the longevity of the post-construction BMP. Routine maintenance activities may include the following:
 - Inspection of monitoring wells and cleanouts.
 - Removal of accumulated sediment, trash, and debris.
 - Removal of grease and oil.
 - Cleaning underdrain pipes to remove sediment and debris.
 - Redistribution of mulch, sand, topsoil, or other surface materials.
 - Replenishment of mulch, aggregate, topsoil, media filter, or other materials.
 - Mowing vegetated areas or clearing overgrowth.
 - Replacement of dead or diseased plants. Removal of invasive species.
 - Testing of valves and equipment.
 - Assessment of embankments and spillways.
 - Checking for ponding water and presence of mosquitoes.
- **Major Maintenance Activities** - Major maintenance activities are sometimes required to address more severe deficiencies that may progressively appear over time such as:
 - Adjustment or replacement of level spreaders.
 - Replacement or repair of broken pipes, underdrains, or system components.
 - Reseeding or replanting of bare or damaged vegetated areas.
 - Repairing eroded embankments, slopes, spillways, or conveyance areas.
 - Replacement of sand, riprap, aggregate, media filter material, or other materials.
 - Clearing clogged pipes or storage chambers.
 - Replacement or repair of damaged flow control structures or devices.

Recommended maintenance activities for each post-construction BMP are identified in Appendix A.

10.1.6 Record Keeping

Records of all post-construction inspections and follow-up activities for addressing deficiencies undertaken by DOT-HWYS are to be retained by DOT-HWYS for a minimum of five (5) years. This information can be used to track and improve upon the post-construction BMP performance for future applications. In addition to the inspection forms, records of routine and major maintenance activities for any post-construction BMP shall also be kept. These records track maintenance activities, record observations of maintenance personnel, and document future maintenance requirements for a particular treatment device.

Proper record-keeping is critical for DOT-HWYS to maintain their database of post-construction BMPs and to satisfy regulatory requirements.

10.2 PRIVATE CONSTRUCTION PROJECTS

Although post-construction BMPs located outside of DOT-HWYS right-of-way are beyond the jurisdiction of DOT-HWYS, pollutants discharged from improperly maintained devices may still enter the DOT-HWYS MS4, impact quality of state waters, and possibly jeopardize compliance with the MS4 Permit.

10.2.1 Maintenance Agreements

For private construction projects in which post-construction BMPs are required, a long-term maintenance agreement should be executed, when appropriate, between DOT-HWYS and the owner to ensure proper BMP maintenance. Each district is encouraged to develop its own maintenance agreement based upon storm water management program priorities, funding, and resources.

At a minimum, a maintenance agreement should include the following:

- Owner's name, title, signature, telephone number, and email address.
- Property address.
- Contact person's name, title, telephone number, and email address (to schedule future site inspections).
- Date of post-construction BMP installation.

- O&M Plan that clearly defines roles and responsibilities for maintenance and inspection of post-construction BMPs including:
 - Types of post-construction BMPs.
 - Make and model of proprietary treatment devices.
 - Schematic diagram showing locations of post-construction BMPs including distances from property lines, easements, buildings, structures, utilities, pavements, and vegetation.
 - Scheduled maintenance activities (to be conducted by owner) including maintenance frequency.
- Additional information, as required by DOT-HWYS, which may include:
 - Application for a Private Storm Drain Connection and/or Discharge Permit to the State of Hawaii Highways Divisions Storm Drain System
 - Permit to Discharge into the State Highways Drainage System
 - Permit for Connection to the State Highways Drainage System
 - Use and Occupancy Agreement

The O&M Plan shall be executed prior to the installation of any post-construction BMPs.

10.2.2 Maintenance

The owner or owner's representative shall maintain all post-construction BMPs in accordance with the approved O&M Plan. Document all maintenance activities and include remedial actions taken to address any deficiencies.

10.2.3 Inspections

The owner or owner's representative shall conduct inspections of all post-construction BMPs in accordance with the Post-Construction BMP O&M Manual, or annually at a minimum. Inspection reports shall be made available to DOT-HWYS upon request.

DOT-HWYS may conduct an inspection every five (5) years or more frequently, if necessary. The owner shall grant access to DOT-HWYS to perform the inspection.

10.2.4 Record Keeping

The owner shall keep all maintenance logs and inspection reports for a minimum of five (5) years. Copies shall be provided to DOT-HWYS upon request.

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APPENDIX A

TREATMENT CONTROL BEST MANAGEMENT PRACTICES



The effectiveness of a treatment control BMP is site-specific and dependent upon several variables. The cells marked with an “x” in Table A-1 indicate those devices that may achieve at least 50 percent removal of a specific pollutant based upon research of various resources. An unmarked entry does not necessarily mean that it cannot be used, but that it may need to be used in conjunction with another device to meet the desired treatment quality for a specific targeted pollutant.

Design criteria, sizing procedures, and figures are for guidance only and the designer shall ultimately rely upon their due diligence, design expertise, and professional judgement.

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Table A-1. Post-Construction BMP Summary Matrix

Treatment Control BMP		Typical Targeted Pollutants for Removal						Notes
		Sediment ¹	Nutrients ¹	Oil & Grease ²	Metals ¹	Trash ²	Bacteria ¹	
LID	Vegetated Buffer Strip	x		x		x		
	Vegetated Swale	x		x		x		
	Enhanced Swale	x	x	x	x	x		
	Infiltration Trench	x	x	x	x	x	x	
	Infiltration Basin	x	x	x	x	x	x	
	Bioretention Facility	x	x	x	x	x	x	
	Permeable Pavement	x	x	x	x		n/a	
	Pocket Wetland	x	varies	x	x	x	x	
	Rainwater Harvesting	varies	varies	n/a	varies	n/a	varies	Primarily for runoff reduction
	Tree Box Filter	x	x	x	n/a	x	x	
TRADITIONAL NON-LID	Wet Pond	x	x	x	x	x	x	
	Wet Extended Detention Pond	x	x	x	x	x	x	
	Sand Filter	x	varies	x	x	x		
PROPRIETARY NON-LID	Drain Inlet Filter	x				x		Results vary depending on type/model. Refer to manufacturer's data for targeted pollutant removal efficiencies.
	Modified Catch Basin	x				x		
	Oil/Grit Separator	x		x	n/a	x	n/a	
	Centrifugal Hydrodynamic Separator	x		x	x	x		
	Multi-Stage Hydrodynamic Separator	x		x	x	x		

¹ Source: State of Georgia Stormwater Management Manual 2016

² Source: North Carolina DOT 2020

Vegetated Buffer Strip



SOURCE: Ohio Department of Transportation 2019

Typical Targeted Pollutants for Removal	
Sediment	x
Nutrients	
Oil & Grease	x
Metals	
Trash	x
Bacteria	

Other Considerations ¹	
Construction Cost	Low
Maintenance Cost	Low
Effective Life	20-50 years

¹ Source: Washington State DOT, Highway Runoff Manual 2019

Description & Purpose

A vegetated buffer strip, or filter strip, is a grassy slope located adjacent and typically parallel to roadways or other impervious surfaces. Often vegetated with turf or native grasses, pollutants are removed primarily through sedimentation as sheet flow passes over and through the grassed surface. Permeable soils (HSG classification A or B) are more conducive to infiltration.

Applications

Vegetated buffer strips are primarily used as a pretreatment device upstream of infiltration and biofiltration-type BMPs such as infiltration trenches and vegetated swales. To be effective, sheet flow must be established across the buffer strip.

Limitations

- The lateral slope (perpendicular to flow) of the area immediately downstream of the impervious area should not exceed 2 percent to promote even flow distribution (King County 2021).
- Longitudinal slope (in the direction of flow) should range between 1 and 15 percent (King County 2021).
- Flow velocities should not exceed 1 ft/sec across the vegetated surface.
- Not intended for treatment of concentrated flows.
- Vegetated swales shall be located in areas with adequate sunlight. For healthy vegetation, a minimum 6 hours of daily sunlight is recommended (King County 2021).
- Vegetation needs to be well-established to prevent rilling and erosion along the slope.

Design Criteria

SIZING PROCEDURE

1. Determine the Water Quality Flow Rate (WQFR).
2. Determine the buffer strip width (w) which is typically equal to the width of the adjacent impervious surface contributing flow to the buffer strip. If the width of the buffer strip (w) is less than the adjacent impervious surface, provide a transition structure to direct the runoff evenly across the buffer strip width.
3. Determine the longitudinal slope (s) based upon the proposed site conditions.
4. Compute the design flow depth (y) based upon the width (w) and longitudinal slope (s) of the buffer strip using a simplified form of Manning's Equation as follows:

$$y = \left[\frac{WQFR \times n}{1.49 \times w \times \sqrt{s}} \right]^{0.6}$$

Where y = Depth of Flow (ft)

WQFR = Water Quality Flow Rate (ft³/s)

n = Manning's roughness coefficient

w = Width perpendicular to direction of flow (ft)

s = Longitudinal Slope parallel to direction of flow (ft/ft)

Assumptions:

- Manning's roughness coefficient (n): 0.15 for medium grass, 0.25 for dense grass, and 0.35 for very dense Bermuda-type grass
- Maximum depth of flow (y): 1 inch

If depth of flow (y) exceeds the maximum depth allowed, reduce the tributary drainage area of the impervious surface, increase the buffer width (w) or longitudinal slope (s) and recalculate.

5. Calculate the design flow velocity (V) across the buffer strip based on the following equation:

$$V = \frac{WQFR}{wy}$$

Design Criteria *(continued)*

Where V = Design Flow Velocity (ft/s)
WQFR = Water Quality Flow Rate (cfs)
 w = Design Width (ft)
 y = Depth of Flow (ft)

Assumptions:

- Maximum design flow velocity (V): 1 ft/s

If the design flow velocity (V) is greater than 1 ft/s, redesign the buffer strip by adjusting one or more design parameters and recalculate. A velocity greater than 1 ft/s is shown to flatten grass, thereby reducing filtration (Washington State DOT 2019).

6. Calculate the buffer strip length (L) based on the following equation:

$$L = 60VT$$

Where L = Design Length (ft)
 V = Design Flow Velocity from Step 5 (ft/s)
 T = Hydraulic Residence Time (min)

Assumptions:

- Hydraulic residence time (T): 9 minutes (Washington State DOT 2019)
- Minimum length (L): 15 feet to provide filtration and contact time (Georgia 2016)
- Maximum length (L): 100 feet

Ensure that the proposed site can accommodate the required buffer strip length (L); otherwise, redesign the buffer strip or explore other post-construction BMP options.

ADDITIONAL DESIGN PARAMETERS

- A level spreader should be provided at the upper edge of the buffer strip to evenly distribute the runoff across the width of the buffer strip. Level spreader options include a gravel trench, porous pavement strips, slotted curbing, or concrete headers.
- The top of the level spreader should be approximately 1 inch below the pavement surface.

Vegetated Buffer Strip

Construction Considerations

- Aggregates used in level spreader trench should be washed and open graded with a non-woven geotextile fabric along trench sides and bottom.
- Minimize all traffic across the site of the buffer strip to prevent soil compaction.

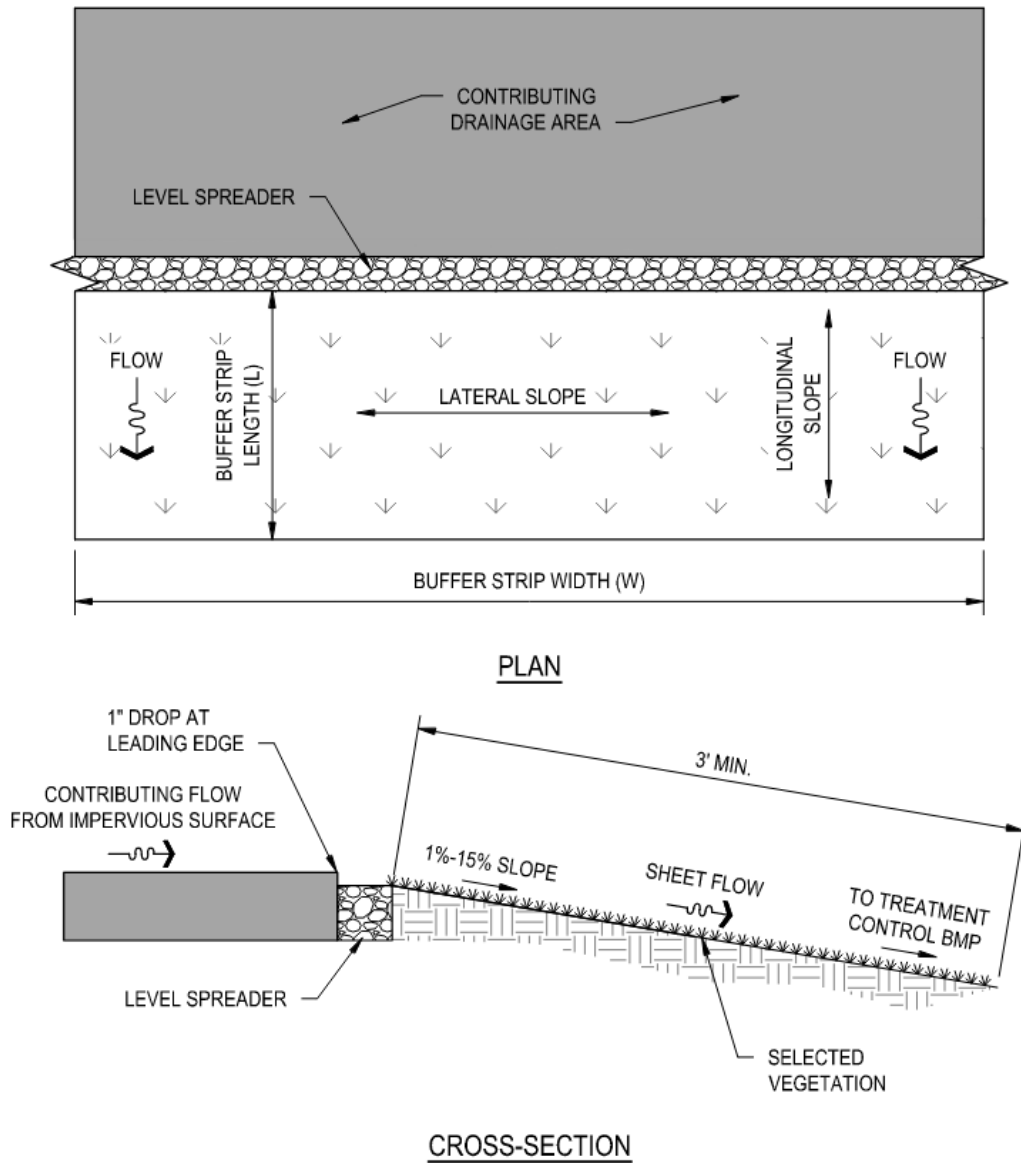
Landscaping Considerations

- Dense grass (preferably native grass) should be selected based on climactic, soil, and hydraulic conditions to promote sedimentation and filtration and to limit flow velocities and rilling.
- Seed should be flood and drought-resistant grasses.
- If sod tiles are used, ensure no gaps exist between tiles. Stagger the tiles so that channels are not formed along the strip. Use a roller to ensure there are no air pockets between sod and soil.
- If seeds are used, install erosion control measures as needed to protect seeds from washing away during storm events.
- Avoid the use of fertilizer nutrients and amendments that have the potential to be washed into receiving waters.
- Protect buffer strips with temporary erosion control BMPs until vegetation has been stabilized.

Maintenance and Inspections

- Research indicates that grass height and mowing frequency have little impact on pollutant removal. Thus, buffer strips should be mowed only as required for safety and aesthetics or to suppress weeds and woody vegetation (CASQA 2003).
- Maintain a minimum of 90 percent grass coverage to ensure continued effectiveness.
- Trim overhanging tree growth and branches to allow adequate sunlight for vegetation.
- Sediment buildup should be removed when:
 - Deposited sediment creates channelized flow through the filter strip;
 - Sediment reaches the level of the contributing ground surface or level spreader; or
 - Sediment increases water depth above height of the vegetation.
- Remove trash and debris as required to prevent clogging of downstream facilities.
- Repair eroded areas or scour holes caused by high flow velocities or channelization.
- Adjust or replace level spreader if flows are not being evenly distributed over entire width of buffer strip.

Vegetated Buffer Strip



VEGETATED BUFFER STRIP

Vegetated Swale



H-3 Freeway Median, Kaneohe, Hawaii

Typical Targeted Pollutants for Removal	
Sediment	x
Nutrients	
Oil & Grease	x
Metals	
Trash	x
Bacteria	

Other Considerations ¹	
Construction Cost	Low to Moderate
Maintenance Cost	Low to Moderate
Effective Life	5-20 years

¹ Source: Washington State DOT, Highway Runoff Manual 2019

Description & Purpose

A vegetated swale (also known as a “dry swale”) removes pollutants by filtration as storm water runoff is conveyed along its length through the vegetation. Grassed surfaces also reduce flow velocities thereby allowing pollutants to be removed via sedimentation, adsorption, and infiltration into the underlying soil.

Applications

Vegetated swales are applicable for land uses such as roads, highways, residential development, and pervious areas. They are often installed parallel to roads or within medians and used for flow conveyance as well as water quality treatment.

Limitations

- Excessive oils and grease may hinder grass growth resulting in lower reduction of pollutants.
- Flow velocities should not exceed 1 ft/sec for the water quality flow rate and 3 ft/sec for the design peak flow rate, respectively.
- Vegetated swales shall be located in areas with adequate sunlight. For healthy vegetation, a minimum 6 hours of daily sunlight is recommended (King County 2021).
- If heavy sediment is anticipated, consider including a pretreatment device upstream such as a sediment forebay, vegetated buffer strip, or level spreader.
- Longitudinal slope should be between 2 to 6 percent. On steeper slopes, check dams may be used to reduce the slope to within acceptable limits (CASQA 2013).

Design criteria

SIZING PROCEDURE

1. Determine the Water Quality Flow Rate (WQFR).
2. Assuming a trapezoidal swale, determine initial dimensions based on rearrangement of the Manning's equation:

$$AR^{2/3} = \frac{WQFR \times n}{1.49s^{1/2}}$$

Where A = Cross Sectional Area (ft²)
 R = Hydraulic Radius (ft)
 WQFR = Water Quality Flow Rate (cfs)
 n = Manning's roughness coefficient
 s = Longitudinal Slope (ft/ft)

Assumptions:

- Manning's roughness coefficient (n): 0.15 for medium grass, 0.25 for dense grass, and 0.35 for very dense Bermuda-type grass
 - Longitudinal slope (s): 2 to 6 percent
3. Use the following equations to calculate the cross-sectional area (A) and hydraulic radius (R) and solve for the bottom width (b) which will be the only remaining unknown variable (Washington State DOT 2019).

$$A = (b + zy)y$$

$$R = \frac{(b + zy)y}{b + 2y\sqrt{1 + z^2}}$$

Where b = Bottom Width (ft)
 z = Swale Side Slope (length per unit height)
 y = Depth of Flow (ft)

Assumptions:

- Minimum bottom width (b): 2 feet to ensure adequate surface area for filtration and to facilitate mowing during maintenance.
- Maximum bottom width (b): 10 feet to reduce land disturbance area.
- Swale side slope (z): 3H:1V (typical) and 2H:1V (max.)
- Depth of flow (y): 4 inches (0.33 ft) for swales that are mowed infrequently (Washington State DOE 2019)

Design Criteria *(continued)*

If the calculated bottom width falls outside of this range, decrease the tributary area and/or adjust one or more swale dimensions and repeat the calculations.

4. Calculate the design flow rate (Q) based on the resulting bottom width (b) and assumed swale dimensions from Steps 2 and 3 using Manning's equation:

$$Q = \frac{1.49}{n} AR^{2/3} S^{1/2}$$

5. Determine the design flow velocity (V) using the flow continuity equation:

$$V = \frac{Q}{A}$$

Where V = Design Flow Velocity (ft/s)

Q = Design Flow Rate (cfs)

A = Cross-Sectional Area (ft²)

Assumptions:

- Maximum design flow velocity (V): 1 ft/s at WQFR.

If the design flow velocity (V) is greater than 1 ft/s, include check dams with vertical drops of no more than 12 inches or revise swale dimensions and recalculate. A velocity greater than 1 ft/s is shown to flatten grass, thereby reducing filtration (Washington State DOT 2019).

6. Calculate the swale length (L) based on the following equation:

$$L = 60VT$$

Where L = Swale Length (ft)

V = Design Flow Velocity from Step 5 (ft/s)

T = Hydraulic Residence Time (min)

Assumptions:

- Hydraulic residence time (T): 9 minutes (Washington State DOT 2019)
- Minimum swale length (L): 100 ft

Adjust the swale dimensions as needed to achieve the recommended minimum swale length (L). If necessary, the bottom width (b) may be increased as long as the hydraulic residence time (T) remains greater than 9 minutes.

Design Criteria *(continued)*

- Calculate the total area required (A_{BMP}) to ensure adequate space is available.

$$A_{BMP} = \left[b + 2z \left(f + \frac{y}{12} \right) \right] \times L$$

Where A_{BMP} = Total Surface Area (ft²)

b = Bottom Width (ft)

z = Swale Side Slope: length per unit height

f = Freeboard (ft)

y = Depth of Flow from Step 3 (inches)

L = Swale Length from Step 6 (ft)

- Lastly, if the swale will convey the design peak flow (no high-flow bypass), check that the swale can adequately convey the design peak flow using Manning's equation while maintaining a minimum 1-foot freeboard. Adjust swale dimensions and recalculate, if necessary.

ADDITIONAL DESIGN PARAMETERS

- The inflow should be directed towards the upstream end of the swale but should occur evenly over the swale.
- If the longitudinal slope is less than 1.5 percent, a perforated underdrain (minimum 6 inches in diameter) surrounded by a gravel bed may be provided beneath the swale bottom to reduce the chance of standing water in saturated conditions.
- Check dams (maximum 12 inches in height) may be used to achieve velocity requirements, decrease runoff volume, rate, and velocity, and promote filtration and settling of nutrients and other pollutants.

Pretreatment Considerations

- For vegetated swales that receive concentrated runoff directly from impervious surfaces, a sediment forebay, gravel trench, level spreader, or proprietary device may be considered to reduce incoming velocities and sediment entering the swale.

Construction Considerations

- Avoid running equipment over the swale to prevent soil compaction.
- Install swales when there is a reasonable chance of successful establishment without irrigation when possible.
- Keep erosion and sediment controls in place until swale vegetation is established. Remove any accumulated sediment at the end of construction.

Construction Considerations *(continued)*

- If used to capture sediment during construction, overexcavate the bottom area a minimum of 6 inches and reconstruct as initially designed.

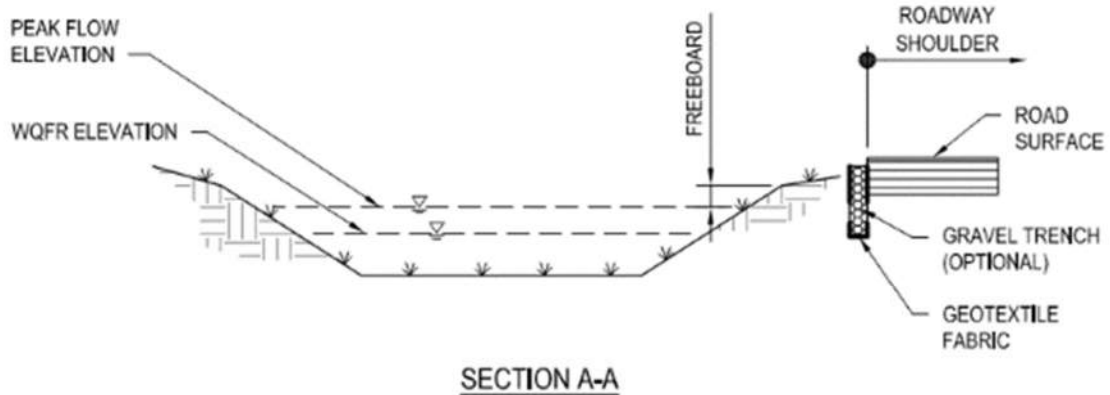
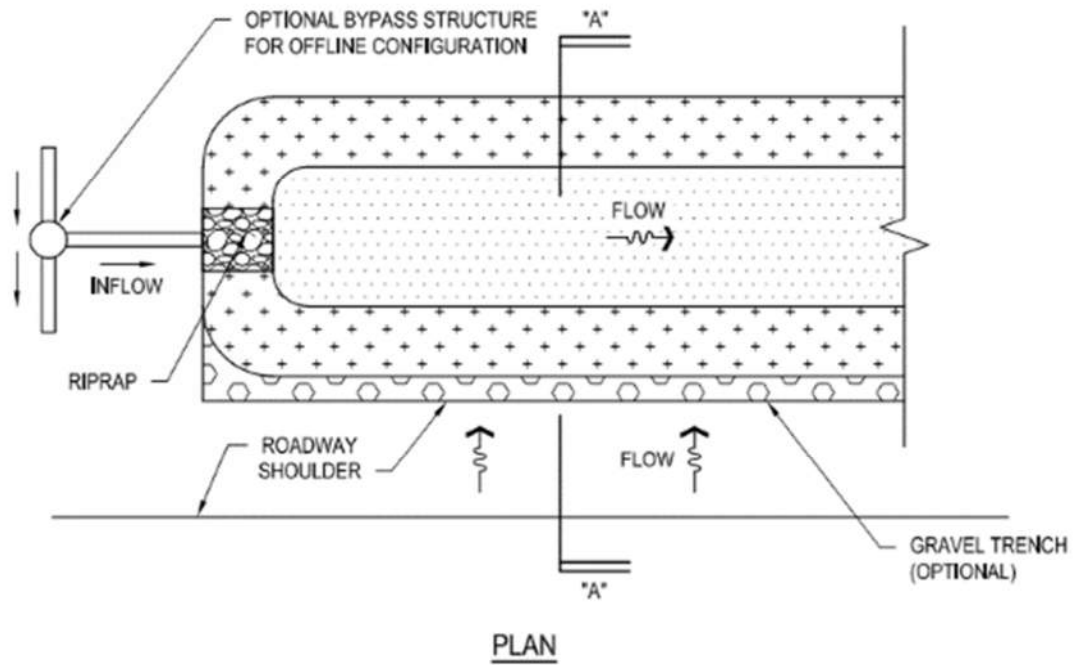
Landscaping Considerations

- Landscape design should specify proper grass species (preferably native) based on the specific site, soils and hydric conditions.
- Dense grass should be used to promote sedimentation, filtration, and nutrient uptake and reduce flow velocities.
- Seed should be flood and drought-resistant grasses.
- If sod tiles are used, install tiles so that no gaps exist between tiles. Stagger the ends of the tiles so that channels are not formed along the swale.
- Use a roller on the sod to ensure there are no air pockets between sod and soil.
- If seeds are used, install erosion controls to protect seeds for at least 75 days after the first rainfall of the season.
- Avoid the use of fertilizer nutrients and amendments that have the potential to be washed into receiving waters.

Maintenance and Inspections

- Research indicates that grass height and mowing frequency have little impact on pollutant removal. Thus, vegetated swales should be mowed only as required for safety and aesthetics or to suppress weeds and woody vegetation (CASQA 2003).
- Maintain a minimum of 90 percent grass coverage to ensure continued effectiveness.
- Trim overhanging tree growth and branches to allow adequate sunlight for vegetation.
- Remove sediment when depth exceeds 2 inches or as needed if restricting flow conveyance.
- Remove trash and debris as required to prevent clogging of downstream facilities.
- Repair eroded areas or scour holes caused by high flow velocities or channelization.

Vegetated Swale



VEGETATED SWALE



H-1 Freeway Eastbound Onramp Cloverleaf, Mo'ili'ili, Hawaii

Typical Targeted Pollutants for Removal	
Sediment	x
Nutrients	x
Oil & Grease	x
Metals	x
Trash	x
Bacteria	

Other Considerations ¹	
Construction Cost	Low to Moderate
Maintenance Cost	Low to Moderate
Effective Life	5-20 years

¹ Source: Washington State DOT, Highway Runoff Manual 2019

Description & Purpose

An enhanced swale may look similar to a vegetated swale at the surface but features a permeable planting media beneath the swale bottom to allow for capture and treatment of the Water Quality Volume. Also referred to as a bioretention swale or bioswale, an enhanced swale functions similarly to a bioretention facility but also provides storm water conveyance.

Applications

Enhanced swales are applicable for land uses such as roads, highways, residential development, and impervious areas. They are often installed parallel to roads or within medians and used for flow conveyance as well as water quality treatment and flow attenuation.

Limitations

- Excessive oils and grease may hinder plant growth resulting in lower reduction of pollutants.
- Typically requires a pretreatment device upstream such as a sediment forebay, vegetated buffer strip, or level spreader.
- Flow velocities should not exceed 1 ft/sec for the water quality flow rate and 3 ft/sec for the design peak flow rate, respectively.
- Maintain at least 3 feet clearance between the bottom of the drainage layer and the seasonally high groundwater table.
- Ponding may create a breeding environment for mosquitoes.

Design Criteria

SIZING PROCEDURE

1. Determine the Water Quality Volume (WQV).
2. Pretreatment is critical to capture sediment that may otherwise lead to premature failure of the facility. Size the pretreatment forebay assuming a volume equal to 10 percent of the WQV (DOEE 2020). The forebay volume counts toward the WQV requirement.

$$V_P = 0.1WQV$$

Where V_P = Pretreatment Forebay Volume (ft³)
WQV = Water Quality Volume (ft³)

3. Select a design ponding depth (d_p) and determine the thickness and porosity for the planting media and drainage layer. Calculate the total effective storage depth (d_t), which is a function of the depth and porosity of the storage layers, using the following equation:

$$d_t = d_p + d_m n_m + d_d n_d$$

Where d_t = Total Effective Storage Depth (ft)
 d_p = Design Ponding Depth (ft)
 d_m = Planting Media Depth (ft)
 n_m = Planting Media Porosity
 d_d = Drainage Layer Depth (ft)
 n_d = Drainage Layer Porosity

Assumptions:

- Total effective storage depth (d_t) is based on the storage capacity using the void space in the planting media and drainage layer and the ponding depth.
- Maximum ponding depth (d_p), if check dams are used: 1 foot
- Average ponding depth: 0.5 feet (half of maximum ponding depth).
- Planting media depth (d_m): 1.5 to 3 feet (typ.)
- Planting media porosity (n_m): 0.2 to 0.35 (typ.) (NCHRP 2019)
- Drainage layer depth (d_d): 8 to 12 inches (typ.)
- Drainage layer porosity (n_d): 0.3 to 0.4 (typ.) (NCHRP 2019)

Design Criteria *(continued)*

- Calculate the required swale bottom area (A_b). Since the pretreatment forebay is sized for 10 percent of the WQV, the surface is calculated based on the remaining 90 percent of the WQV.

$$A_b = \frac{0.9WQV}{d_t}$$

Where A_b = Swale Bottom Area (ft^2)

WQV = Water Quality Volume from Step 1 (ft^3)

d_t = Total Effective Water Storage Depth from Step 3 (ft)

- Calculate the total area required (A_{BMP}) to ensure adequate space is available.

$$A_{BMP} = \left[b + 2z \left(f + \frac{d_p}{12} \right) \right] \times \frac{A_b}{b}$$

Where A_{BMP} = Total Surface Area (ft^2)

b = Bottom Width (ft)

z = Swale Side Slope: length per unit height

f = Freeboard (ft)

d_p = Design Ponding Depth from Step 3 (inches)

A_b = Swale Bottom Area from Step 4 (ft^2)

Assumptions:

- Minimum bottom width (b): 2 feet to ensure adequate surface area for filtration and to facilitate mowing during maintenance.
 - Maximum bottom width (b): 10 feet to reduce land disturbance area.
 - Swale side slope (z): 3H:1V (typical) and 2H:1V (max.)
 - Minimum freeboard (f): 1 foot
- Lastly, if the swale will convey the design peak flow (no high-flow bypass), check that the swale can adequately convey the design peak flow using Manning's equation while maintaining a minimum 1-foot freeboard. Adjust swale dimensions and recalculate, if necessary.

ADDITIONAL DESIGN PARAMETERS

- Check dams (maximum 12-inch height) may be used to achieve velocity requirements, decrease runoff volume, rate, and velocity, and promote filtration and settling of nutrients and other pollutants.

Design Criteria *(continued)*

- Underdrain System
 - Underdrain pipe (minimum 4-inch diameter) should be perforated PVC Schedule 40 pipe or equivalent corrugated HDPE pipe encased in a layer of #57 washed stone, 8- to 12-inches thick. Perforations should be 3/8-inch diameter at a minimum 6-inch on center spacing with a minimum of 4 holes per row (DOEE 2020).
 - Underdrain pipes shall be placed in the middle of the aggregate layer with perforations on the bottom side of the pipe.
 - Underdrain pipes shall be placed with a minimum slope of 0.5 percent.
 - Provide an observation well at every 250 to 300 feet along the underdrain system and a cleanout at the end of all underdrain pipe runs for cleaning and observation. Observation wells and cleanouts should be made of solid-wall PVC Schedule 40 pipe (minimum 4-inches in diameter).
 - Mark the depth of the trench on the observation well cap as reference for future maintenance.
- Provide a 2- to 4-inch filter layer of #7 washed stone between the planting media and the drainage layer.
- Place a non-woven filter fabric along the walls of the facility to reduce lateral flows.

Pretreatment Considerations

- If receiving concentrated runoff directly from impervious surfaces, a pretreatment facility such as a sediment forebay or vegetated buffer strip is recommended to reduce incoming velocities and reduce the amount of sediment entering the treatment device.
- Provide a sediment forebay at the inlet sized to contain 0.1 inches per impervious acre of contributing drainage (10 percent of WQV). The storage in the forebay counts toward the total required WQV to be treated.
- A gravel trench or level spreader may be provided along the top edge of the enhanced swale to accommodate pretreatment for lateral sheet flows.

Construction Considerations

- Avoid running equipment over the swale to prevent soil compaction.
- Install swales when there is a reasonable chance of successful establishment without irrigation when possible.
- Keep erosion and sediment controls in place until swale vegetation is established. Remove any accumulated sediment at the end of construction.
- If used to capture sediment during construction, overexcavate the bottom area a minimum of 6 inches and reconstruct as initially designed.

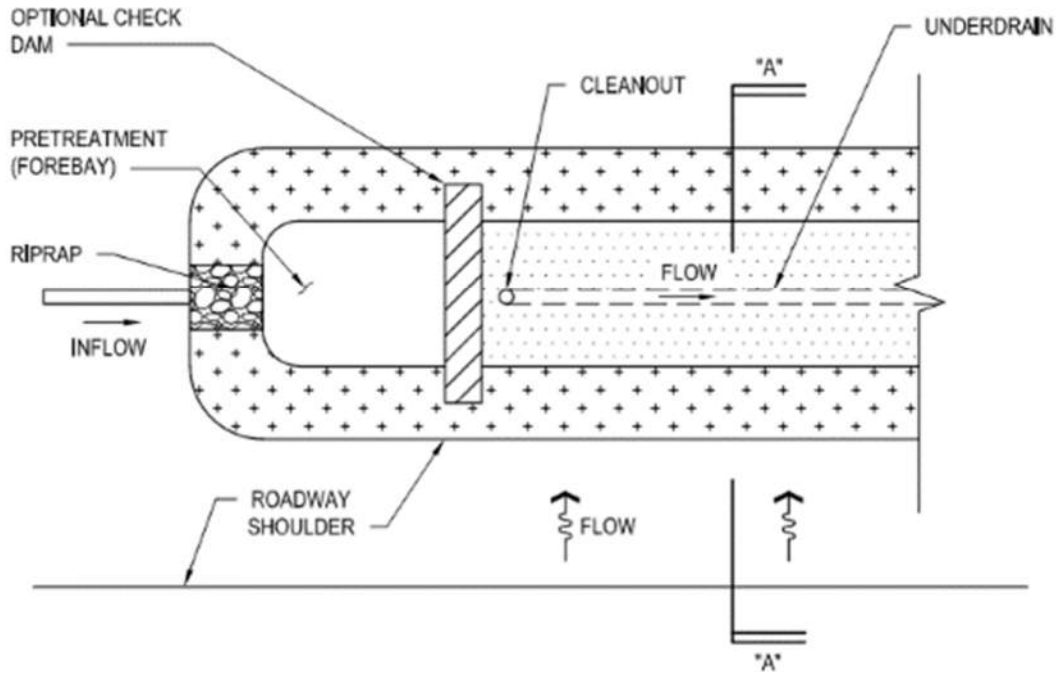
Landscaping Considerations

- Landscape design should specify proper plant species (preferably native) based on the specific site, soils and hydric conditions.
- Plants should be flood and drought-resistant.
- If grass is used, provide dense species to promote sedimentation, filtration, and nutrient uptake and to reduce flow velocities. Install erosion controls to protect seeds for at least 75 days after the first rainfall of the season.
- Avoid the use of fertilizer nutrients and amendments that have the potential to be washed into receiving waters.

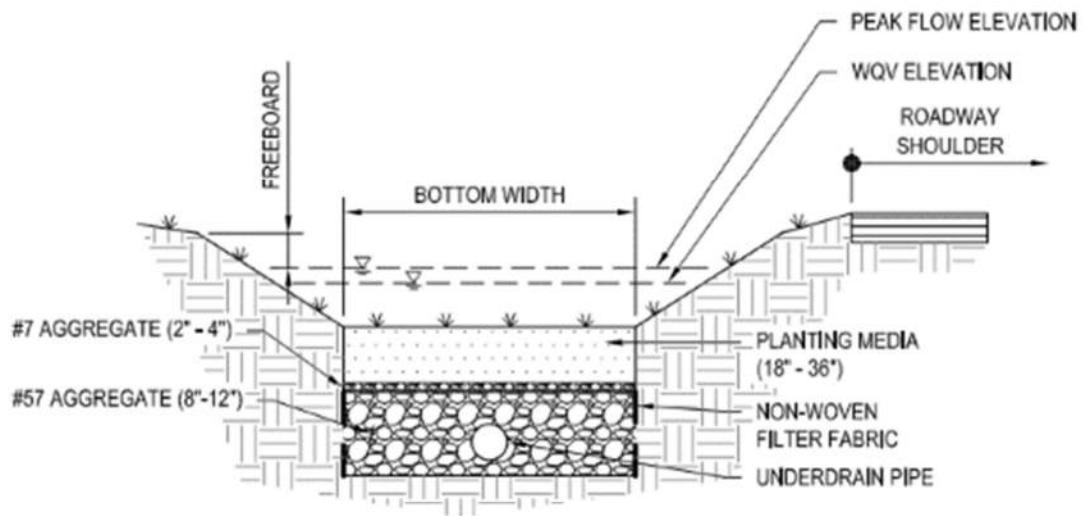
Maintenance and Inspections

- Research indicates that grass height and mowing frequency have little impact on pollutant removal. Thus, enhanced swales should be mowed only as required for safety and aesthetics or to suppress weeds and woody vegetation (CASQA 2003).
- Remove sediment as needed if restricting conveyance of the swale.
- Remove trash and debris as required to prevent clogging of downstream facilities.
- Inspect observation wells at least once a year to ensure the enhanced swale is operating properly.
- Clean underdrain pipes to remove sediment and debris.

Enhanced Swale



PLAN



SECTION A-A

ENHANCED SWALE

Infiltration Trench



SOURCE: Virginia Association of Soil and Water Conservation District

Typical Targeted Pollutants for Removal	
Sediment	x
Nutrients	x
Oil & Grease	x
Metals	x
Trash	x
Bacteria	x

Other Considerations ¹	
Construction Cost	Low
Maintenance Cost	Low
Effective Life	20-50 years

¹ Source: Washington State DOT, Highway Runoff Manual 2019

Description & Purpose

An infiltration trench is a rock-filled trench with no surface outlet, where storm water runoff is stored in the void space between rocks and infiltrates through the bottom into the underlying soil matrix.

Applications

Appropriate in locations where space is limited and adequate clearance exists above the seasonally high groundwater table. The linear nature of infiltration trenches make them very suitable for roadway applications.

Limitations

- Requires pretreatment upstream to capture sediment loadings which would otherwise lead to clogging and premature failure.
- The tributary drainage area should typically be less than 5 acres (CASQA 2003).
- Soil infiltration rate should be between 0.5 and 8 in/hr to provide adequate treatment.
- Should not be used in karst terrain where it may result in sinkholes or groundwater contamination or on sites constructed of fill material.
- Should not be used for treatment of industrial runoff to avoid groundwater contamination.
- Infiltration facility shall be located at least 100 feet from any water supply well or septic system leach field.

Limitations (continued)

- Infiltration facility should not be placed in locations that cause water problems to adjacent properties or roadways and should be setback (10 ft) downgrade from structures.
- Maintain at least 3 feet clearance between the bottom of the infiltration trench and the seasonally high groundwater table to avoid groundwater contamination.
- Infiltration facility cannot be located on slopes greater than 15 percent.

Design criteria

SIZING PROCEDURE

1. Determine the Water Quality Volume (WQV).
2. Pretreatment is critical to capture sediment that may otherwise lead to premature failure of the facility. Size the pretreatment forebay assuming a volume equal to 10 percent of the WQV (DOEE 2020). The forebay volume counts toward the WQV requirement.

$$V_P = 0.1WQV$$

Where V_P = Pretreatment Forebay Volume (ft³)

WQV = Water Quality Volume (ft³)

3. Calculate the maximum storage depth (d_{max}) of the infiltration trench.

$$d_{max} = \frac{kt}{12FS}$$

Where d_{max} = Maximum Storage Depth (ft)

k = Soil Infiltration Rate from testing (in/hr)

t = Drawdown Time (hours)

FS = Infiltration Rate Factor of Safety

Assumptions:

- Trench depth (d_{max}): 2 to 10 ft
- Maximum drawdown time (t): 48 hours
- Minimum factor of safety (FS): 2 (to account for long-term reduction in infiltration rate due to clogging)

Design Criteria *(continued)*

- Determine the thickness and porosity for the top aggregate layer, rock storage layer, and bottom sand layer. Calculate the total effective storage depth (d_t), which is a function of the depth and porosity of the storage layers, using the following equation:

$$d_t = d_g n_g + d_r n_r + d_s n_s$$

Where d_t = Total Effective Storage Depth (ft)

d_g = Top Aggregate Layer Depth (ft)

n_g = Top Aggregate Layer Porosity

d_r = Rock Storage Layer Depth (ft)

n_r = Rock Storage Layer Porosity

d_s = Sand Layer Depth (ft)

n_s = Sand Layer Porosity

Assumptions:

- Aggregate layer porosity (n_g): 0.2 to 0.35 (typ.) (NCHRP 2019)
 - Rock storage layer depth (d_r): 2 to 10 ft (typ.)
 - Rock storage layer porosity (n_r): 0.3 to 0.4 (typ.) (NCHRP 2019)
 - Sand layer depth (d_s): 6 to 12 inches to avoid compaction of soil during placement of rock storage layer
 - Sand layer porosity (n_s): 0.25 to 0.45 (typ.) (NCHRP 2019)
- Confirm that the total effective storage depth (d_t) is less than the maximum storage depth (d_{max}) calculated in Step 3.
 - Calculate the required surface area of the infiltration trench (A_{BMP}).

$$A_{BMP} = \frac{WQV}{\left(d_t + \frac{kT}{12FS}\right)}$$

Where A_{BMP} = Trench Surface Area (ft²)

WQV = Water Quality Volume (ft³)

d_t = Total Effective Water Storage Depth (ft)

k = Soil Infiltration Rate from Step 3 (in/hr)

T = Fill Time (hours)

FS = Infiltration Rate Factor of Safety from Step 3

If the required surface area does not fit in the allowable space, adjust the design variables and repeat the calculations as necessary.

Design Criteria *(continued)*

7. Based upon the required surface area (A_{BMP}), determine the infiltration trench top width (W) and corresponding top length (L).

$$L = \frac{A_{BMP}}{W}$$

Where L = Trench Top Length (ft)

A_{BMP} = Trench Surface Area from Step 5 (ft²)

W = Trench Top Width (ft)

ADDITIONAL DESIGN PARAMETERS

- Avoid standing water to reduce opportunity for vector problems.
- Trench media should be clean, washed material free from clay, silt, and organic matter.
- Do not cover the trench with vegetation or impervious material.
- Provide an observation well at 50-ft intervals along the underdrain system and a cleanout at the end of all underdrain pipe runs to monitor water drawdown and measure sediment buildup. Observation wells and cleanouts should be made of solid-wall PVC Schedule 40 pipe (minimum 4-inches in diameter).
- Mark the depth of the trench on the observation well cap as reference for future maintenance.
- Place a non-woven filter fabric along the walls of the facility to reduce lateral flows.
- A non-erosive overflow spillway for high storm water flows must be provided.

Pretreatment Considerations

- If receiving concentrated runoff directly from impervious surfaces, a pretreatment facility such as a sediment forebay or vegetated buffer strip is recommended to reduce incoming velocities and reduce the amount of sediment entering the treatment device.
- Provide a sediment forebay at the inlet sized to contain 0.1 inches per impervious acre of contributing drainage (10 percent of WQV). The storage in the forebay counts toward the total required WQV to be treated.
- If flow enters at multiple locations, provide a sediment forebay at each inlet location.
- Forebays should contain a fixed vertical marker to measure sediment depth.
- A gravel trench or level spreader may be provided along the top edge of the enhanced swale to accommodate pretreatment for lateral sheet flows.

Infiltration Trench

Construction Considerations

- Avoid running equipment within the trench footprint to prevent soil compaction.
- Infiltration facilities should be constructed towards the end of a project to avoid sediment runoff from adjacent construction activities. Upstream areas should be stabilized prior to construction of the infiltration trench.
- Keep erosion and sediment controls in place until surrounding vegetation is established. Remove any accumulated sediment at the end of construction.

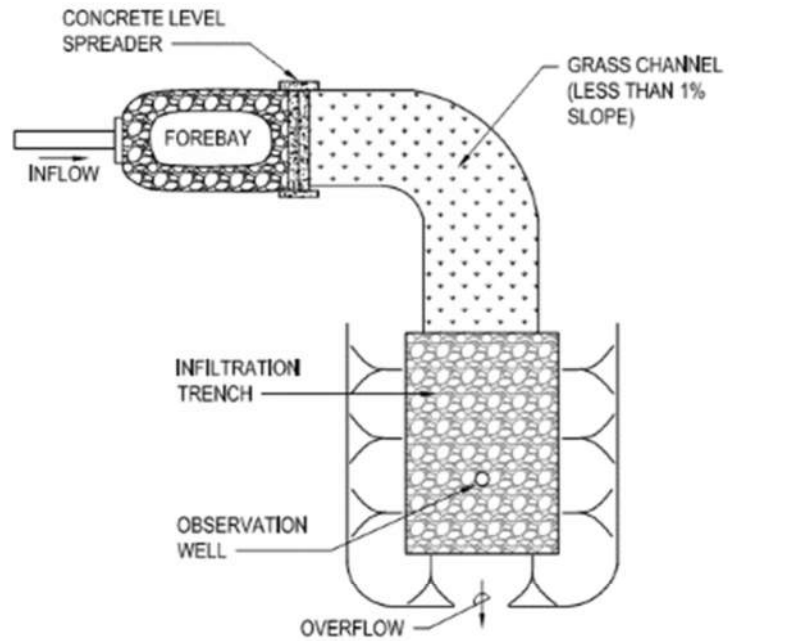
Landscaping Considerations

- Vegetative cover must be established over the contributing pervious drainage areas upstream before runoff can be accepted into the facility.
- Do not allow grass or vegetation to grow within the infiltration trench.

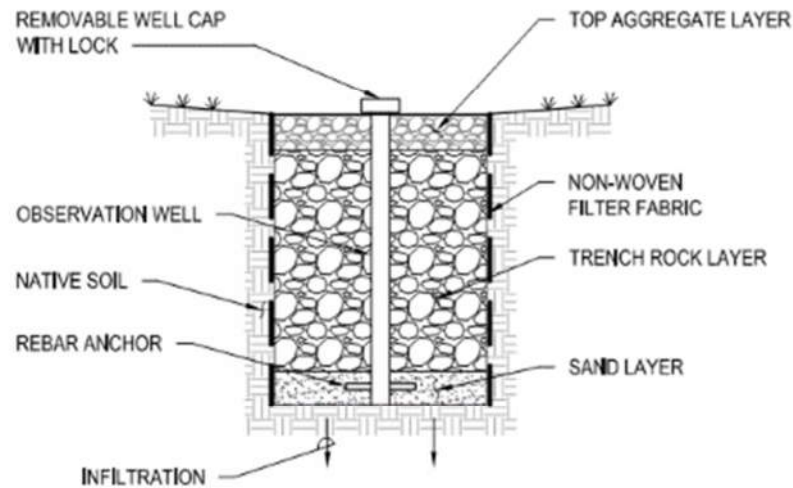
Maintenance and Inspections

- Regularly remove sediment, trash, and debris from the facility
- Remove sediment from the forebay when it reaches a depth of 12 inches or if the performance of the facility is affected.
- Replace drainage media when a reduction in infiltration rate is observed to remove accumulated sediment and restore infiltration properties.

Infiltration Trench



PLAN



CROSS-SECTION

INFILTRATION TRENCH

Infiltration Basin



SOURCE: Google Earth (I-5 Exit 102, Tumwater, Washington)

Typical Targeted Pollutants for Removal	
Sediment	x
Nutrients	x
Oil & Grease	x
Metals	x
Trash	x
Bacteria	x

Other Considerations ¹	
Construction Cost	Moderate
Maintenance Cost	Moderate
Effective Life	5-10 years before deep tilling required

¹ Source: Washington State DOT, Highway Runoff Manual 2019

Description & Purpose

An infiltration basin is a relatively large, shallow surface depression with relatively little vegetation where storm water runoff infiltrates into the underlying soil matrix. Infiltration basins differ from bioretention basins because they do not include an engineered soil media and vegetation typically consists of simple grass cover.

Applications

Appropriate in locations where adequate space is available and adequate clearance exists above the seasonally high groundwater table.

Limitations

- Requires pretreatment upstream to capture sediment loadings which would otherwise lead to clogging and premature failure.
- Soil infiltration rate should be between 0.5 and 8 in/hr to provide adequate treatment.
- Should not be used in karst terrain where it may result in sinkholes or groundwater contamination or on sites constructed of fill material.
- Should not be used for treatment of industrial runoff to avoid groundwater contamination.
- Infiltration facility shall be located at least 100 feet from any water supply well or septic system leach field.
- Infiltration facility should not be placed in locations that cause water problems to adjacent properties or roadways and should be setback (10 ft) downgrade from structures.

Limitations *(continued)*

- Maintain at least 3 feet clearance between the bottom of the infiltration basin and the seasonally high groundwater table to avoid groundwater contamination.

Design Criteria

SIZING PROCEDURE

1. Determine the Water Quality Volume (WQV).
2. Pretreatment is critical to capture sediment that may otherwise lead to premature failure of the facility. Size the pretreatment forebay assuming a volume equal to 10 percent of the WQV (DOEE 2020). The forebay volume counts toward the WQV requirement.

$$V_p = 0.1WQV$$

Where V_p = Pretreatment Forebay Volume (ft³)
WQV = Water Quality Volume (ft³)

3. Calculate the maximum storage depth (d_{max}) of the infiltration basin.

$$d_{max} = \frac{kt}{12FS}$$

Where d_{max} = Maximum Storage Depth (ft)
 k = Soil Infiltration Rate from testing (in/hr)
 t = Drawdown Time (hours)
FS = Infiltration Rate Factor of Safety

Assumptions:

- Maximum drawdown time (t): 48 hours
 - Minimum factor of safety (FS): 2 (to account for long-term reduction in infiltration rate due to clogging)
4. Calculate the required bottom surface area of the infiltration basin (A_b). Since the pretreatment forebay is sized for 10 percent of the WQV, the surface is calculated based on the remaining 90 percent of the WQV.

$$A_b = \frac{0.9WQV}{d_{max}}$$

Design Criteria *(continued)*

Where A_b = Basin Bottom Surface Area (ft^2)

WQV = Water Quality Volume (ft^3)

d_{max} = Maximum Storage Depth from Step 3 (ft)

- For a rectangular-shaped basin, select a bottom width (w_b) and calculate the resulting bottom length (l_b).

$$l_b = \frac{A_b}{w_b}$$

Where l_b = Bottom Length (ft)

A_b = Bottom Surface Area from Step 3 (ft^2)

w_b = Bottom Width (ft)

- Calculate the total surface area (A_{BMP}) occupied by the BMP (excluding pretreatment area) to ensure adequate space is available.

$$A_{\text{BMP}} = (w_b + 2zf) \times (l_b + 2zf)$$

Where A_{BMP} = Total Surface Area, excluding pretreatment (ft^2)

w_b = Bottom Width from Step 4 (ft)

z = Basin Side Slope (length per unit height)

f = Freeboard (ft)

l_b = Bottom Length from Step 4 (ft)

Assumptions:

- Basin side slope (z): 3H:1V (typical) and 2H:1V (max.)
- Minimum freeboard (f): 1 foot

ADDITIONAL DESIGN PARAMETERS

- Avoid standing water to reduce opportunity for vector problems.
- Bottom of infiltration basin should have less than 3 percent slope in any direction (WSDOT 2019) and not consist of fill soils.
- Basins may be lined with a 6-to-12-inch layer of filter material such as coarse sand or a non-woven filter fabric to help prevent the buildup of impervious deposits. The filter layer or filter fabric can be readily replaced or cleaned when clogged (WSDOT 2019).
- Flow path and outlet velocities for peak flows should be non-erosive.

Design Criteria *(continued)*

- Embankments (WSDOT 2019)
 - Embankments shall be designed in accordance with applicable federal and state guidelines for dam safety.
 - Interior basin side slopes up to the spillway elevation should not be steeper than 3H:1V unless a fence is provided.
 - Exterior basin side slopes shall not be steeper than 2H:1V unless analyzed for stability by a geotechnical engineer.
 - For embankments up to 6 feet, the minimum top width should be 6 feet or as recommended by a geotechnical engineer.
- Emergency Overflow Spillway (WSDOT 2019)
 - Provide an emergency overflow spillway designed to pass the 100-year peak design flow.
 - Use non-erosive materials such as grouted riprap.
- Access Road (WSDOT 2019)
 - Provide access for maintenance, cleaning, and inspections to critical components of the facility.
 - Access roads shall be a minimum of 12 feet wide (15 feet on curves) and be designed to support anticipated vehicular loads applicable to the site.
 - Provide a turnaround area for any dead ends.
 - Provide an access ramp having a maximum slope of 15 percent to the bottom of the basin unless all portions of the facility can be accessed and maintained from the top of bank (Washington State DOE 2019).
- Since infiltration basins are fixed obstacles and include side slopes that may exceed 3H:1V, they should be located outside of the roadside clear zone or protected with guardrails.

Pretreatment Considerations

- If receiving concentrated runoff directly from impervious surfaces, a pretreatment facility such as a sediment forebay or vegetated buffer strip is recommended to reduce incoming velocities and reduce the amount of sediment entering the treatment device.
- Provide a sediment forebay at the inlet sized to contain 0.1 inches per impervious acre of contributing drainage (10 percent of WQV). The storage in the forebay counts toward the total required WQV to be treated.
- If flow enters at multiple locations, provide a sediment forebay at each inlet location.
- Forebays should contain a fixed vertical marker to measure sediment depth.

Construction Considerations

- Avoid running equipment within the basin footprint to prevent soil compaction.
- Infiltration facilities should be constructed towards the end of a project to avoid sediment runoff from adjacent construction activities. Upstream areas should be stabilized prior to construction of the infiltration trench.
- After the completion of final grading, the basin should be well-aerated and have a highly porous surface texture.
- Remove all accumulated sediment and debris at the end of construction.

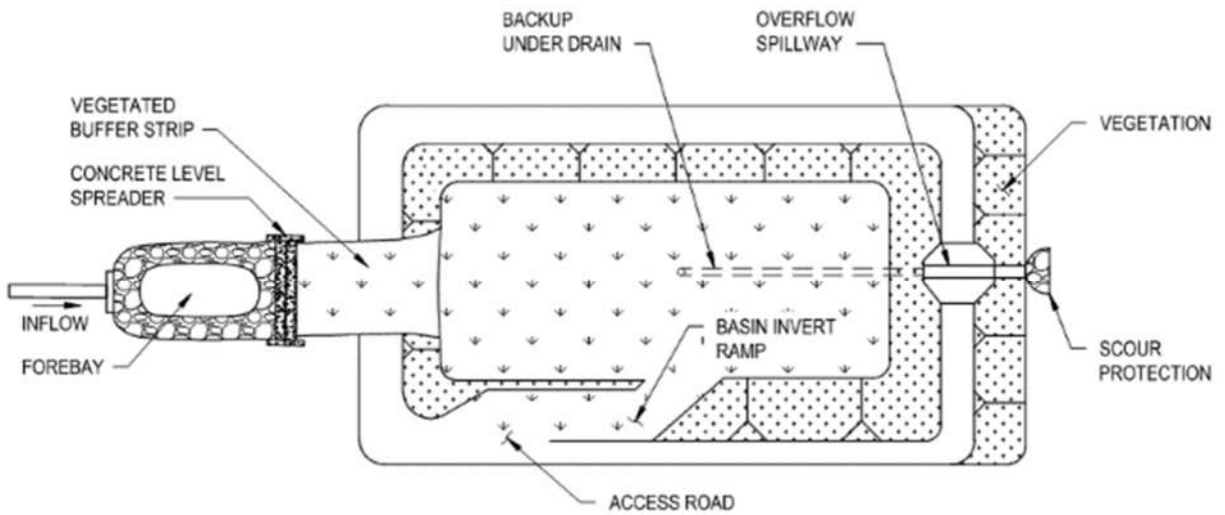
Landscaping Considerations

- Establish dense vegetation on basin side slopes and floor, preventing erosion, sloughing, and a natural means of maintaining high infiltration rates.
- Vegetative cover must be established over the contributing pervious drainage areas before runoff can be accepted into the facility.

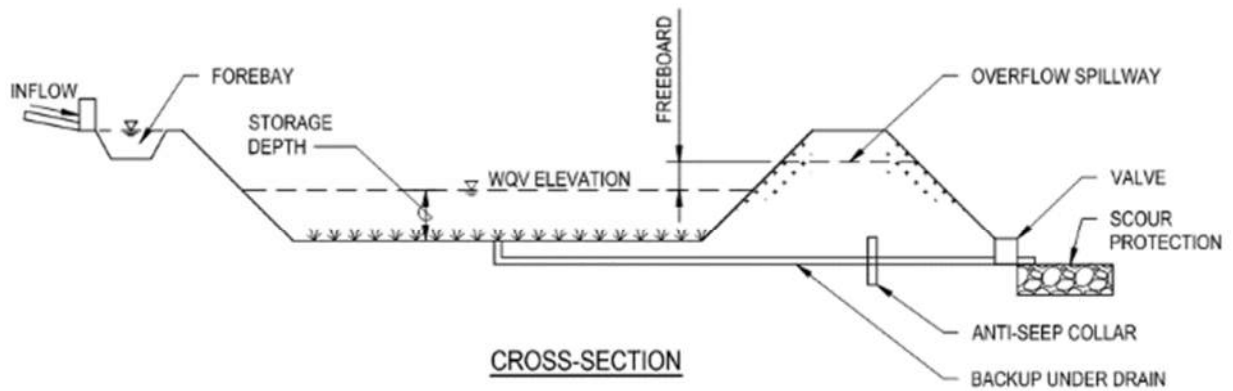
Maintenance and Inspections

- Regularly remove sediment, trash, and debris from the facility
- Remove sediment from the forebay when it reaches a depth of 12 inches or if the performance of the facility is affected.
- Aerate or replace soils at bottom of basin when a reduction in infiltration rate is observed.
- Maintain vegetation on the basin floor and side slopes. Remove all invasive species.
- Stabilize any eroded banks with appropriate measures such as grassing, riprap, or permanent matting. Remove any trees or vegetation that affect integrity of slopes or structures.
- Assess embankments annually and after large storm events to identify potential leaks.
- Replace any missing riprap from spillway.

Infiltration Basin



PLAN



CROSS-SECTION

INFILTRATION BASIN

Bioretention Facility



SOURCE: New Jersey Developers Green Infrastructure Guide 2018

Typical Targeted Pollutants for Removal

Sediment	x
Nutrients	x
Oil & Grease	x
Metals	x
Trash	x
Bacteria	x

Other Considerations ¹

Construction Cost	Moderate
Maintenance Cost	Moderate
Effective Life	5-20 years

¹ Source: Washington State DOT, Highway Runoff Manual 2019

Description & Purpose

Bioretention facilities are vegetated depressions where storm water runoff is directed through vegetation and designed soil mixes for infiltration and treatment. Soil mix may include a combination of sand, organic matter, soil, or other media. Excess flows may be bypassed to drainage structures further downstream. Design variations include bioretention cells, bioretention swales, and bioretention planters. Smaller facilities are also commonly referred to as rain gardens.

Applications

A bioretention facility is a versatile post-construction BMP that provides water quality treatment, storm water volume reduction, and flow attenuation. Appropriate in locations where adequate space is available. The overall shape can be adjusted to fit within the allotted space so is well suited in a variety of urban settings including roadway applications, parking lots, and curb extensions for smaller devices.

Limitations

- Requires pretreatment upstream to capture sediment loadings which would otherwise lead to clogging and premature failure.
- Edge protection such as a raised curb or a covered grate is recommended for public safety when constructed adjacent to pedestrian walkways.
- The tributary drainage area should typically be less than 1 acre. Larger drainage areas may require multiple bioretention areas (CASQA 2003).
- Should not be used in karst terrain where it may result in sinkholes or groundwater contamination or on sites constructed of fill material.

Limitations (continued)

- Should not be used for treatment of industrial runoff to avoid groundwater contamination.
- Bioretention facility shall be located at least 100 feet from any water supply well or septic system leach field.
- Bioretention facility should not be placed in locations that cause water problems to adjacent properties or roadways and should be setback (10 ft) downgrade from structures.
- Maintain at least 3 feet clearance between the bottom of the bioretention facility and the seasonally high groundwater table to avoid groundwater contamination.

Design Criteria

SIZING PROCEDURE

1. Determine the Water Quality Volume (WQV).
2. Pretreatment is critical to capture sediment that may otherwise clog the soil media layer. Size the pretreatment forebay assuming a volume equal to 10 percent of the WQV (DOEE 2020). The forebay volume counts toward the WQV requirement.

$$V_p = 0.1WQV$$

Where V_p = Pretreatment Forebay Volume (ft³)
WQV = Water Quality Volume (ft³)

3. Calculate the maximum storage depth (d_{max}) based upon the underlying soil infiltration rate (k) and the required drawdown time (t).

$$d_{max} = \frac{kt}{12FS}$$

Where d_{max} = Maximum Storage Depth (ft)
 k = Soil Infiltration Rate from testing (in/hr)
 t = Drawdown Time (hours)
FS = Infiltration Rate Factor of Safety

Assumptions:

- Maximum drawdown time (t): 48 hours
- Minimum factor of safety (FS): 2 (to account for long-term reduction in infiltration rate due to clogging)

Design Criteria *(continued)*

4. Select a design ponding depth (d_p) and determine the thickness and porosity for the planting media and drainage layer. Calculate the total effective storage depth (d_t), which is a function of the depth and porosity of the storage layers, using the following equation:

$$d_t = d_p + d_m n_m + d_d n_d$$

Where d_t = Total Effective Storage Depth (ft)

d_p = Ponding Depth (ft)

d_m = Planting Media Depth (ft)

n_m = Planting Media Porosity

d_d = Drainage Layer Depth (ft)

n_d = Drainage Layer Porosity

Assumptions:

- Maximum ponding depth (d_p): 6 inches (typ.)
 - Planting media depth (d_m): 2 to 4 feet (typical)
 - Planting media porosity (n_m): 0.2 to 0.35 (typ.) (NCHRP 2019)
 - Drainage layer depth (d_d): 8 to 12 inches (typ.)
 - Drainage layer porosity: 0.3 to 0.4 (typ.) (NCHRP 2019)
5. Confirm that the total effective storage depth (d_t) is less than the maximum storage depth (d_{max}) calculated in Step 3.
 6. Calculate the required bottom surface area of the bioretention facility (A_b). Since the pretreatment forebay is sized for 10 percent of the WQV, the surface is calculated based on the remaining 90 percent of the WQV.

$$A_b = \frac{0.9WQV}{d_t + kT/12FS}$$

Where A_b = Bottom Surface Area (ft²)

WQV = Water Quality Volume (ft³)

d_t = Total Effective Storage Depth (ft)

k = Soil Infiltration Rate from Step 3 (in/hr)

T = Fill Time (hours)

FS = Infiltration Rate Factor of Safety from Step 3

Design Criteria *(continued)*

- For a rectangular-shaped facility, select a bottom width (w_b) and calculate the resulting bottom length (l_b).

$$l_b = \frac{A_b}{w_b}$$

Where l_b = Bottom Length (ft)

A_b = Bottom Surface Area from Step 6 (ft²)

w_b = Bottom Width (ft)

- Calculate the total surface area (A_{BMP}) occupied by the BMP (excluding pretreatment area) to ensure adequate space is available.

$$A_{BMP} = [w_b + 2z(d_p + f)] \times [l_b + 2z(d_p + f)]$$

Where A_{BMP} = Total Surface Area, excluding pretreatment (ft²)

w_b = Bottom Width from Step 7 (ft)

z = Side Slope (length per unit height)

l_b = Bottom Length (ft)

d_p = Design Ponding Depth (ft)

f = Freeboard (ft)

Assumptions:

- Side slope (z): 3H:1V (typical) and 2H:1V (max.)
- Minimum freeboard (f): 1 foot

ADDITIONAL DESIGN PARAMETERS

- Mulch Thickness: 2 to 4 inches (typical)
- Avoid standing water to reduce opportunity for vector problems.
- Flow path and outlet velocities for peak flows should be non-erosive.
- Underdrain System
 - If infiltration capacity is inadequate to meet required drawdown time, provide underdrain system consisting of central collector pipe and lateral feeder pipes to collect and discharge storm water runoff to the drainage system. Except as noted herein, underdrain system shall be in accordance with the information provided in the fact sheet for Enhanced Swales.
 - Provide an observation well at every 250 to 300 feet along the underdrain system and a cleanout at the end of all underdrain pipe runs for cleaning and observation. Observation wells and cleanouts should be made of solid-wall PVC pipe (minimum 4-inches in diameter).

Design Criteria *(continued)*

- Place a non-woven filter fabric along the walls of the facility to reduce lateral flows.
- Consider loss of parking stalls, street width, and vehicle turning radii for installations in ultra-urban settings.
- Since bioretention facilities are fixed obstacles and include side slopes that may exceed 3H:1V, they should be located outside of the roadside clear zone or protected with guardrails.

Pretreatment Considerations

- If receiving concentrated runoff directly from impervious surfaces, a pretreatment facility such as a sediment forebay or vegetated buffer strip is recommended to reduce incoming velocities and reduce the amount of sediment entering the treatment device.
- Provide a sediment forebay at the inlet sized to contain 0.1 inches per impervious acre of contributing drainage (10 percent of WQV). The storage in the forebay counts toward the total required WQV to be treated.
- If flow enters at multiple locations, provide a sediment forebay at each inlet location.
- Forebays should contain a fixed vertical marker to measure sediment depth.

Construction Considerations

- Avoid running equipment within the facility footprint to prevent soil compaction.
- Keep erosion and sediment controls in place until vegetation is established. Remove any accumulated sediment at the end of construction.
- Adjacent landscaping and construction activities should be completed before constructing bioretention facility to avoid sediment runoff onto pavement.

Landscaping Considerations

- Landscaping is critical to the function and performance of the bioretention areas.
- Landscape design should specify proper plant species (preferably native) based on the specific site, soils and hydric conditions.
- Plants should be flood and drought-resistant.
- If grass is used, provide dense species to promote sedimentation, filtration, and nutrient uptake and to reduce flow velocities. Install erosion controls to protect seeds for at least 75 days after the first rainfall of the season.
- Avoid the use of fertilizer nutrients and amendments that have the potential to be washed into receiving waters.

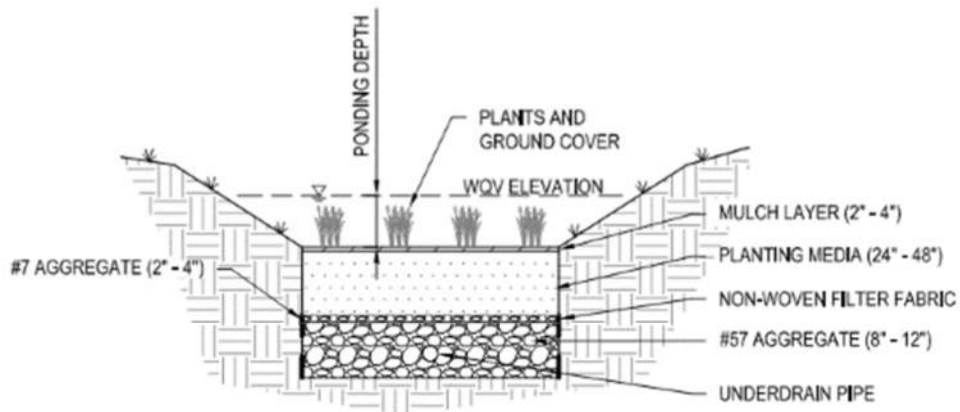
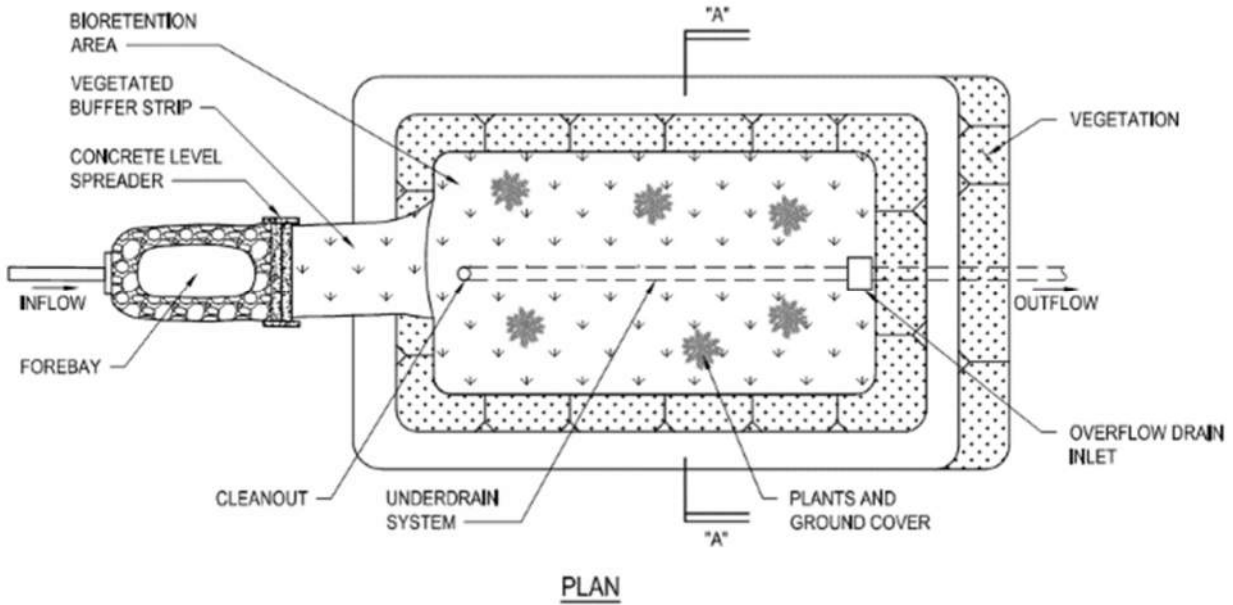
Landscaping Considerations *(continued)*

- A mulch layer (2 to 3 inches thick) may be provided to reduce the risk of erosion and retain moisture for plants. Avoid the use of mulches that may increase nutrient levels or where higher flow velocities may cause mulch material to float and wash away.
- Vegetative cover must be established over the contributing drainage area before runoff can be accepted into the facility.
- Vegetation must accommodate adequate sight distances along roads and at intersections within urbanized areas.

Maintenance and Inspections

- Regularly remove sediment, trash, and debris from the facility
- Remove sediment from the forebay when it reaches a depth of 12 inches or if the performance of the facility is affected.
- Replace dead or diseased plants. Remove all invasive species.
- Stabilize any eroded banks with appropriate measures such as grassing or permanent matting. Remove any trees or vegetation that affect integrity of slopes or structures.
- Replenish or redistribute mulch as necessary.
- Inspect observation wells at least once a year to ensure the facility is operating properly.
- Clean underdrain pipes to remove sediment and debris.

Bioretention Facility



BIORETENTION FACILITY

Permeable Pavement



Kahuku Police Station, Kahuku, Hawaii

Typical Targeted Pollutants for Removal	
Sediment	x
Nutrients	x
Oil & Grease	x
Metals	x
Trash	
Bacteria	n/a

Other Considerations ¹	
Construction Cost	Moderate
Maintenance Cost	High
Effective Life	Varies

¹ Source: Washington State DOT, Highway Runoff Manual 2019

Description & Purpose

Permeable pavement consists of pavement or interlocking paver blocks designed to allow storm water to infiltrate through voids in the pavement surface into an underlying stone layer, thereby reducing storm water runoff and pollutant discharge. Also known as pervious or porous pavement, several types include porous asphalt, pervious concrete, and permeable pavers.

Applications

Typically used in low-volume, low-speed applications such as parking lots, driveways, minor roads, and roadway shoulders for light-vehicle loads. In addition to storing storm water runoff, may also be designed for infiltration into the underlying soil. May also be used in conjunction with impervious surfaces or as overlays over existing pavements.

Limitations

- Not applicable for use on highways and high-volume roads due to heavy traffic and sediment loads, and potential for oils and grease to infiltrate into the underlying soils.
- Not applicable downstream of landscaped or pervious areas where sediment may lead to premature failure.
- The ratio of the contributing impervious area to pervious concrete should be 1:1 (max). The ratio of the contributing impervious area to porous asphalt or permeable pavers should be 3:1 (max) (Georgia 2016).
- Not applicable for storage of materials where silt, sediment, or spillage may occur.

Limitations *(continued)*

- If the system is also designed as an infiltration facility, the infiltration rate of the underlying soil should be greater than 0.5 in/hr. Slower infiltration rates may be acceptable due to the large surface area being used for infiltration as long as any flood risks are addressed (Caltrans 2013).

Design Criteria

SIZING PROCEDURE

1. Determine the Water Quality Volume (WQV).
2. If the permeable pavement is also designed as an infiltration facility, calculate the maximum storage depth (d_{max}).

$$d_{max} = \frac{kt}{12FS}$$

Where d_{max} = Maximum Storage Depth (ft)

k = Soil Infiltration Rate from testing (in/hr)

t = Drawdown Time (hrs)

FS = Infiltration Rate Factor of Safety

Assumptions:

- Maximum drawdown time (t): 48 hours
 - Minimum factor of safety (FS): 2 (to account for long-term reduction in infiltration rate due to clogging)
3. Calculate the total effective storage depth (d_t), which is a function of the depth and porosity of the pavement and storage layers, using the following equation:

$$d_t = d_{pave}n_{pave} + d_r n_r$$

Where d_t = Total Effective Storage Depth (ft)

d_{pave} = Pavement Course Depth (ft)

n_{pave} = Pavement Course Porosity

d_r = Rock Storage Layer Depth(ft)

n_r = Rock Storage Layer Porosity

Design Criteria *(continued)*

Assumptions:

- Porous asphalt porosity (n_{pave}): 0.16 to 0.25 (typ.) (Washington State DOE 2019)
 - Pervious concrete porosity (n_{pave}): 0.15 to 0.35 (typ.) (Washington State DOE 2019)
 - Rock storage layer porosity (n_r): 0.3 to 0.4 (typ.) (NCHRP 2019)
4. Confirm that the total effective storage depth (d_t) is less than the maximum storage depth (d_{max}) calculated in Step 2.
 5. Calculate the required surface area of the permeable pavement (A_{BMP}).

$$A_{BMP} = \frac{WQV}{\left(d_t + \frac{kT}{12FS}\right)}$$

Where A_{BMP} = Total Surface Area (ft²)

WQV = Water Quality Volume (ft³)

d_t = Total Effective Water Storage Depth from Step 3 (ft)

k = Soil Infiltration Rate from Step 2 (in/hr)

T = Fill Time (hours)

FS = Infiltration Rate Factor of Safety from Step 2

6. Based upon the allowable space, determine the permeable pavement width (W) and corresponding length (L).

$$L = \frac{A_{BMP}}{W}$$

Where L = Pavement Length (ft)

A_{BMP} = Trench Surface Area from Step 5 (ft²)

W = Pavement Width (ft)

ADDITIONAL DESIGN PARAMETERS

- Must be able to safely convey surface runoff without creating ponding issues in parking lots or along roadways when the storage volume is exceeded.
- For parking lot applications, the subgrade should have less than 2 percent slope in any direction to enable even distribution and infiltration of flows (Caltrans 2013).
- For applications with subgrade slopes greater than 2 percent, incorporate subsurface check dams or underdrains to minimize flow conveyance beneath the pavement layer.

Design Criteria *(continued)*

- Perforated underdrains may be used along the bottom of the storage layer to evenly distribute flow throughout the limits of the permeable pavement or where on-site soils have low infiltration rates. Underdrain pipes should be laid level and may also provide additional storage volume. Underdrain system shall consist of materials as detailed in the fact sheet for Enhanced Swales.
- If the system is also designed as an infiltration facility, provide at least 3 feet clearance between the bottom of the pavement subgrade and the seasonally high groundwater table to avoid groundwater contamination.
- Permeable pavements must also be designed to provide structural support for anticipated vehicular loads.
- Voids between blocks or pavers may be filled with sand or aggregate material.
- Many proprietary permeable pavement products are available. Refer to the product data and manufacturer's recommendations for specific guidelines on design, construction, maintenance, and inspection.
- Additional design details on specific pavement systems are available from other organizations including the National Asphalt Pavement Association, the National Ready Mix Concrete Association, the Interlocking Concrete Pavement Institute, and the American Association of State Highway and Transportation Officials.

Pretreatment Considerations

- Pretreatment is not required as long as the contributing drainage area consists of impervious or stabilized surfaces.
- If the area may experience sediment loading, provide pretreatment to prevent clogging with fine sediment which may lead to premature failure.
- Possible methods of pretreatment include gravel filter strips, vegetated buffer strips, or vegetated swales.

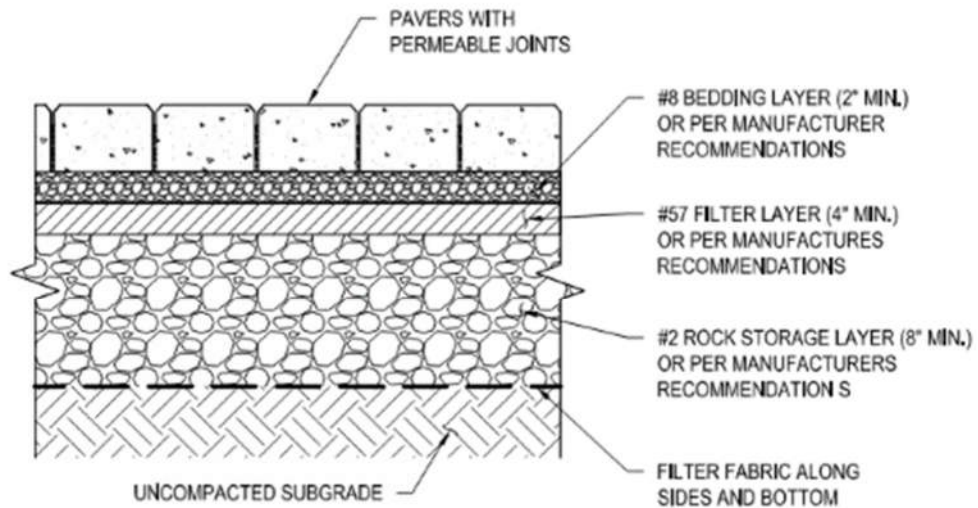
Construction Considerations

- Avoid running equipment within the pavement area to prevent soil compaction.
- Permeable pavement should be constructed in a single operation, as one of the last items on a development site. Adjacent landscaping and construction activities should be completed before pavement construction to avoid sediment runoff onto pavement. If necessary, cover constructed permeable pavements with plastic sheeting until adjacent areas have been permanently stabilized.

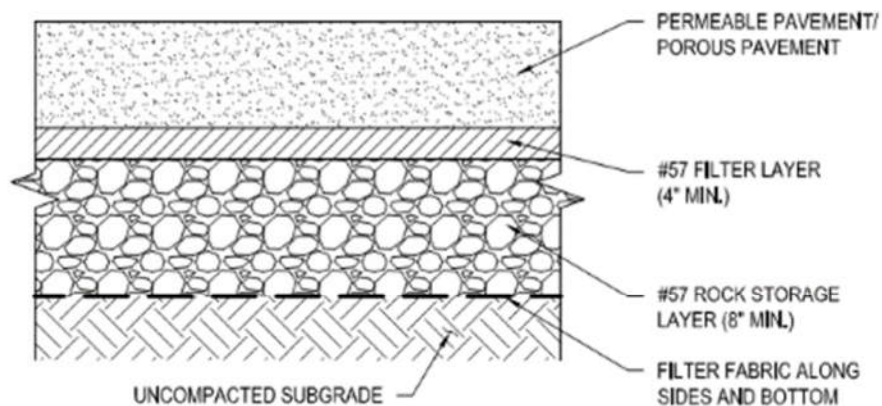
Maintenance and Inspections

- Prevent soil from washing or flowing onto the pavement. Do not store sand, soil, mulch or other landscaping materials on or near permeable pavement surfaces.
- Check for sediment and debris accumulation within pavement voids.
- Perform vacuum sweeping or power washing to remove sediment and debris from the surface and to restore surface permeability, as needed.
- Inspect for signs of pavement failure. Repair any surface deformations and replace broken pavers or section of pavement.
- Check for standing water on pavement or between blocks between storm events.
- Clean underdrain pipes to remove sediment and debris.
- Replenish aggregate in joints or paver grids as needed.
- Remove any weeds that may grow through open joints. Mow vegetation in grid pavement as needed.
- Ensure contributing drainage area is stabilized and free from sediment and debris.
- If system no longer performs as required, remove, clean, and replace pavement, and pavers, including rock storage layer. Scarify subgrade and remove any accumulated sediment.

Permeable Pavement



PERMEABLE CONCRETE PAVER



PERVIOUS CONCRETE AND POROUS ASPHALT

PERMEABLE PAVEMENT



SOURCE: Athens-Clark County, GA 2021

Typical Targeted Pollutants for Removal	
Sediment	x
Nutrients	varies
Oil & Grease	x
Metals	x
Trash	x
Bacteria	x

Other Considerations ¹	
Construction Cost	Moderate to High
Maintenance Cost	Moderate
Effective Life	20-50 years

¹ Source: Washington State DOT, Highway Runoff Manual 2019

Description & Purpose

Pocket wetlands are shallow marsh areas designed to remove pollutants primarily via sedimentation and vegetative uptake. Pocket wetlands have a permanent pool of water for most of the year. Temporary storage is provided for the Water Quality Volume and additional capacity may be provided for flow attenuation of larger storm events.

Applications

Pocket wetlands are applicable in open spaces where high groundwater or perennial base flows may be present to maintain wetland vegetation.

Limitations

- Requires an adequate supply of water to maintain aquatic vegetation.
- Suitable for sites with HSG classification C or D. Sites with HSG A or B soils may have difficulty maintaining a permanent pool (DOEE 2020).
- Without proper maintenance, overaccumulation of nutrients may lead to algae blooms, unpleasant odors, and unaesthetic conditions.
- Shallow pockets of water may become breeding grounds for mosquitoes.
- May be a public safety hazard if located near populated areas.
- To avoid seepage damage, pocket wetland must be at least 20 feet away from structures and foundations. If adequate clearance cannot be provided, an impermeable liner may be installed vertically along the edge to prevent lateral movement of water.

Design Criteria

SIZING PROCEDURE

1. Determine the Water Quality Volume (WQV) which is equal to the volume of the pocket wetland (V_{BMP}).

$$WQV = V_{BMP}$$

Where WQV = Water Quality Volume (ft^3)

V_{BMP} = Pocket Wetland Volume (ft^3)

2. Determine the surface area of the pocket wetland (A_{BMP}) by dividing the Water Quality Volume (WQV) by the average water depth (d_{BMP}).

$$A_{BMP} = \frac{V_{BMP}}{d_{BMP}}$$

Where A_{BMP} = Pocket Wetland Surface Area (ft^2)

V_{BMP} = Pocket Wetland Volume from Step 1 (ft^3)

d_{BMP} = Pocket Wetland Average Depth (ft)

Assumptions:

- Pocket wetland average depth: 3 feet (Washington State DOE 2019)

3. A pocket wetland consists of two cells: a pretreatment forebay (at the inlet) and a wetland cell. The pretreatment forebay prevents sediment, trash, and debris from entering the permanent pool.

Determine the volume of the pretreatment forebay (V_P). If flow enters at multiple locations, provide a sediment forebay at each inlet location. The forebay volume counts toward the WQV requirement.

$$V_P = 0.1V_{BMP}$$

Assumptions:

- Pretreatment forebay volume (V_P): 10 percent of the pocket wetland volume (V_{BMP}) (DOEE 2020)

Design Criteria *(continued)*

- Determine the surface area of the pretreatment forebay (A_P) by dividing the volume of the pretreatment forebay by its water depth (d_P).

$$A_P = \frac{V_P}{d_P}$$

Where A_P = Pretreatment Forebay Surface Area (ft²)

V_P = Pretreatment Forebay Volume (ft³)

d_P = Pretreatment Forebay Depth (ft)

Assumptions:

- Forebay water depth (d_P): 3 to 6 feet (DOEE 2020)

- Determine the surface area of the wetland cell (A_W) by subtracting the surface area of the pretreatment forebay (A_P) from the pocket wetland surface area (A_{BMP}).

$$A_W = A_{BMP} - A_P$$

Where A_W = Wetland Cell Surface Area (ft²)

A_{BMP} = Pocket Wetland Surface Area from Step 2 (ft²)

A_P = Pretreatment Forebay Surface Area from Step 4 (ft²)

- Determine the water depth distribution in the wetland cell. The berm separating the forebay and wetland cell may be designed to either be at the WQV water surface or submerged approximately 1 foot below the WQV water surface.

Grade the wetland cell such that the distribution of water depths in the wetland cell are in accordance with the following table:

Dividing Berm at WQV Water Surface		Dividing Berm at Submerged 1-Foot Below WQV Water Surface	
Depth Range (ft)	Percent	Depth Range (ft)	Percent
0.1 to 1.0	25	1.0 to 1.5	40
1.0 to 2.0	55	1.5 to 2.0	40
2.0 to 2.5	20	2.0 to 2.5	20

- Perform a water balance calculation to check that the pocket wetland will have sufficient water following a 30-day summer drought.

$$d_{BMP} > (E + INF + RES)/12$$

Design Criteria *(continued)*

Where d_{BMP} = Pocket Wetland Average Depth from Step 2 (ft)

E = Highest Monthly Evaporation (in)

INF = Monthly Infiltration Loss (in)

RES = Reservoir of Water (in)

Assumptions:

- Highest monthly evaporation (E): 7.9 inches (data from Ekern 1985)
- Monthly infiltration loss (INF): 7.2 inches (0.01 in/hr) (DOEE 2020)
- Reservoir of Water (RES) is a factor of safety assumed to be 6 inches for wetlands (DOEE 2020).

8. Design the outlet structure in accordance with design parameters below.

ADDITIONAL DESIGN PARAMETERS

- Microtopography which is the creation of shallow and deep zones is encouraged to maximize internal flow paths and enhance diversity in the wetland.
- A longer flow path from the inlet to the outlet will increase water residence time and improve pollutant removal. A flow path having a minimum length-to-width ratio of 2:1 shall be provided for pocket wetlands (DOEE 2020).
- Embankments
 - Embankments shall be designed in accordance with applicable federal and state guidelines for dam safety.
 - Side slopes should generally have gradients of 4H:1V or flatter which helps to promote growth of wetland vegetation and facilitate maintenance (DOEE 2020).
 - Exterior basin side slopes shall not be steeper than 2H:1V unless analyzed for stability by a geotechnical engineer.
 - For embankments up to 6 feet, the minimum top width should be 6 feet or as recommended by a geotechnical engineer.
- An aquatic bench (typically 15 feet wide) shall be provided around the inside perimeter of the wetland pool for public safety. The aquatic bench shall have a maximum depth of 18 inches (DOEE 2020).
- Dividing Berm
 - The top of the berm separating the forebay and wetland cell shall be sloped to drain towards the wetland cell.
 - The side slopes of the berm shall meet the following criteria:
 - Top of berm at WQV water surface: 3H:1V (max.)
 - Top of berm submerged 1-foot below WQV water surface: 2H:1V (max.)

Design Criteria *(continued)*

- If the dividing berm will also be used for vehicular access, it shall be designed to withstand applicable vehicular loads.
- Outlet Control Structure (WSDOT 2019)
 - Provide an outlet control structure with a restrictor device (pipe, orifice, or weir) for controlling outflow to meet the desired flow discharge.
 - The pool outlet pipe shall be back-sloped or have a turned-down elbow to trap oils and floatables in the wet pool. The outlet pipe shall extend 1 foot below the WQV water surface at the lower pipe end and discharge into the outlet structure at the WQV water surface at the upper pipe end. Size the pipe based on inlet control and determine required upstream water surface elevation (head) necessary to convey the flow.
 - Provide a screen protector over orifices to help prevent plugging.
 - Take into consideration the backwater effect of downstream water surface elevations, which may affect outlet capacities and basin storage volumes.
 - Provide a primary overflow within the outlet structure to allow bypassing of the 100-year peak flow in case the outlet becomes plugged or during high inflows.
 - Provide a secondary overflow as additional protection. This is often provided with a grated opening on the face or top of the outlet structure.
- Emergency Overflow Spillway (WSDOT 2019)
 - In addition to primary and secondary overflows, provide an emergency overflow spillway designed to pass the 100-year peak design flow.
 - Use non-erosive materials such as grouted riprap.
- Access Road (WSDOT 2019)
 - Provide access for maintenance, cleaning, and inspections to critical components of the facility.
 - Access roads shall be a minimum of 12 feet wide (15 feet on curves) and be designed to support anticipated vehicular loads applicable to the site.
 - Provide a turnaround area for any dead ends.
 - Provide an access ramp having a maximum slope of 15 percent to the bottom of the basin unless all portions of the facility can be accessed and maintained from the top of bank (Washington State DOE 2019).
- If pocket wetland is designed to also provide storm water detention:
 - Volume of the wetland must be sufficient to provide flow attenuation and reduce peak outflow rates to pre-development levels.
 - Detention volume shall not comprise more than 50 percent of the total wetland volume and its maximum water surface elevation shall not extend more than 3 feet above the WQV water surface (DOEE 2020).

Design Criteria *(continued)*

- The wetland must draw down to WQV levels in 2-5 days (3 days typical) after a storm event to avoid prolonged inundation of wetland vegetation (Washington State DOE 2019).
- Since pocket wetland facilities are fixed obstacles and include side slopes that may exceed 3H:1V, they should be located outside of the roadside clear zone or protected with guardrails.

Pretreatment Considerations

- If receiving concentrated runoff directly from impervious surfaces, a pretreatment facility such as a sediment forebay or vegetated buffer strip is recommended to reduce incoming velocities and reduce the amount of sediment entering the treatment device.
- Provide a sediment forebay at the inlet sized to contain 0.1 inches per impervious acre of contributing drainage (10 percent of WQV). The storage in the forebay counts toward the total required WQV to be treated.
- If flow enters at multiple locations, provide a sediment forebay at each inlet location.
- Forebays should contain a fixed vertical marker to measure sediment depth.

Construction Considerations

- Upstream areas that contribute runoff to the pocket wetland should be stabilized prior to wetland construction.
- Divert storm water runoff away from the wetland during construction to avoid sediment accumulation.
- Perimeter slopes and vegetated areas must be stabilized within 14 days of construction.
- Remove all accumulated sediment and debris at the end of construction.

Landscaping Considerations

- Landscape design should specify proper plant species (preferably native) based on the specific site, soils and hydric conditions.
- Wetland plants are encouraged either along the aquatic bench, safety bench and side slopes, or within shallow areas of the pool.
- Select plant types based on the anticipated inundation levels.
- Avoid planting trees or woody vegetation on or near embankments since root system may undermine the structural integrity of the embankment.
- Plants should be flood- and drought-resistant.
- Avoid the use of fertilizer nutrients and amendments that have the potential to be washed into receiving waters.

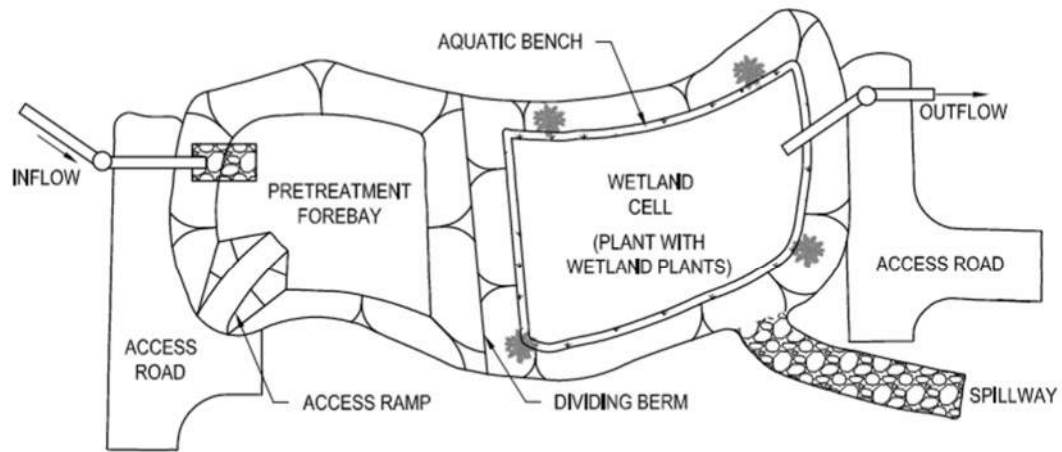
Landscaping Considerations *(continued)*

- Vegetate the shelf region to discourage waterfowl (a direct source of nutrients and bacteria) and protect the shoreline from erosion. Vegetated shelves also increase safety by discouraging children from accessing the water pool.

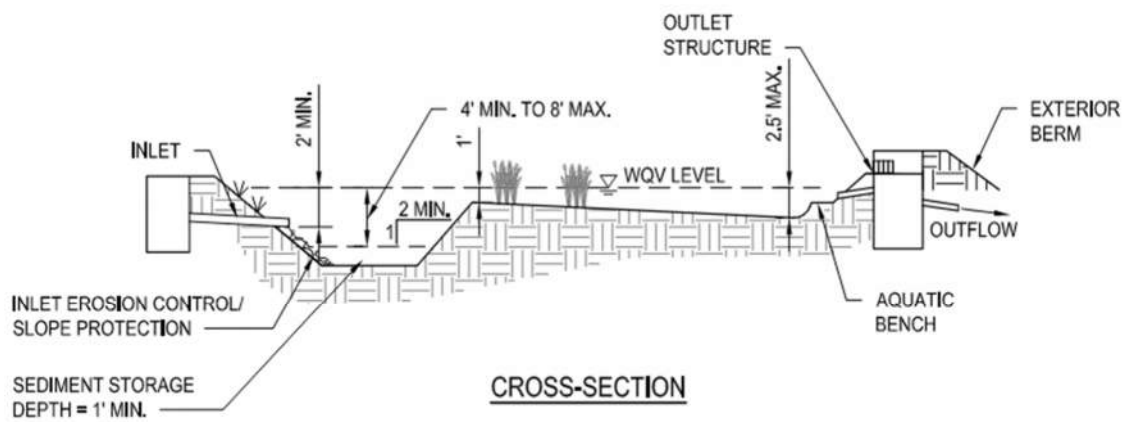
Maintenance and Inspections

- Water levels must be managed appropriately. Frequent soil saturation is needed for plants to survive; however excessively deep water may be detrimental.
- Regularly remove trash, and debris from the facility
- Remove sediment from the forebay when it reaches a depth of 12 inches or if the performance of the facility is affected.
- Remove algal growth when 50 percent of the pool surface area is covered.
- Stabilize any eroded banks with appropriate measures such as grassing, riprap, or permanent matting. Remove any trees or vegetation that affect integrity of slopes or structures.
- Assess embankments annually and after large storm events to identify potential leaks.
- Dead or diseased plants shall be replaced. Remove all invasive species.
- Test valves and mechanical components annually and repair or replace as needed.
- Replace any missing riprap from spillway.

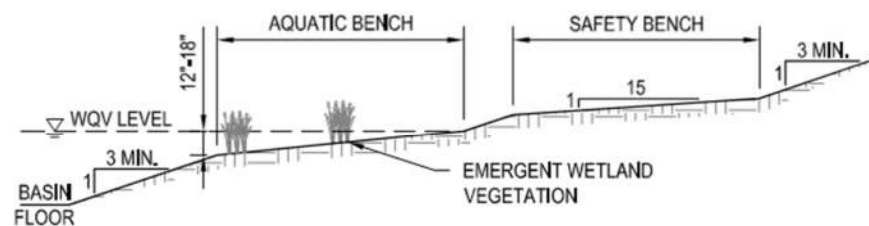
Pocket Wetland



PLAN



CROSS-SECTION



BENCH DETAIL

POCKET WETLAND

Rainwater Harvesting



Nawahiokalani'opu'u Laboratory Public Charter School, Hawaii

Typical Targeted Pollutants for Removal	
Sediment	varies
Nutrients	varies
Oil & Grease	n/a
Metals	varies
Trash	n/a
Bacteria	varies

Other Considerations	
Construction Cost	Varies
Maintenance Cost	Varies
Effective Life	Varies

Description & Purpose

Rainwater harvesting is the capture and storage of rainwater from roofs and downspouts in above-ground cisterns or underground vaults for subsequent reuse.

Applications

Storm water runoff stored using rainwater harvesting may be reused in place of potable water for uses such as irrigation, mechanical systems, or toilet flushing typically in rural areas. Although not applicable for roadway projects, rainwater harvesting may help to reduce peak storm water flows and volumes for smaller DOT-HWYS facilities such as maintenance and office buildings.

Limitations

- Drainage areas are typically small and limited to rooftop areas or overpass downspouts.
- Uses for storm water reuse need to be identified.
- Amount of storm water available for reuse may be inconsistent and unreliable so a source for makeup water may also be required.
- Pumping system is needed if collected storm water is to be discharged at higher pressure or elevation.
- Needs to comply with local building and plumbing codes.

Design Criteria

SIZING PROCEDURE

Sizing a rainwater harvesting system is an iterative process and sizing calculations may need to be done multiple times to determine the appropriate cistern volume.

1. For the project site, determine the corresponding Monthly Rainfall Rate (R) in inches using NOAA rainfall data or other sources.
2. Determine the Monthly Pan Evaporation Rate (E_{pan}) (Reference: "Pan Evaporation: State of Hawaii, 1894-1983; Report R74, State of Hawaii, Department of Land and Natural Resources, Division of Water and Land Development, website: https://files.hawaii.gov/dlnr/cwrmp/publishedreports/R74_PanEvap.pdf) or other sources.
3. Calculate the Volumetric Runoff Coefficient using the following equation developed by the EPA for smaller storms in urban areas:

$$C = 0.05 + 0.009I$$

Where C = Volumetric Runoff Coefficient

I = Impervious Cover (%)

4. Calculate the tributary drainage area (A_d) of the cistern.
5. Determine the flow entering the cistern each month assuming the entire runoff volume will be stored for reuse based on the following equation:

$$Q = 3630RCA_d$$

Where Q = Monthly Runoff Volume (ft^3)

R = Monthly Rainfall Rate from Step 1 (in)

C = Volumetric Runoff Coefficient from Step 3

A_d = Tributary Drainage Area from Step 4 (ac)

6. Calculate the monthly water demand based on identified reuse applications which may include irrigation or other industrial uses.

- i) Calculate the design evaporation rate (E_o) associated with irrigation:

$$E_o = E_{pan} \times K_p \times K_l$$

Design Criteria *(continued)*

Where E_0 = Design Evaporation Rate (in)

E_{pan} = Monthly Pan Evaporation Rate from Step 2 (in)

K_p = Pan Evaporation Coefficient

K_l = Landscape Coefficient

Assumptions:

- Pan evaporation coefficient (K_p): 0.8 for Hawaiian climate (Ekern 1985)
- Landscape coefficient (K_l): 0.6 (average)

- ii) Subtract the flow entering system (rainfall) from the flow exiting system via irrigation and other demands (total reuse) to determine the monthly total demand (D_T).

$$D_T = D_{IRR} + D_R$$

$$= [(E_0 - R)/e] \times A_i \times 3630 + D_R$$

Where D_T = Monthly Total Demand (ft³)

D_{IRR} = Monthly Irrigation Demand (ft³)

D_R = Monthly Other Demand (ft³)

E_0 = Design Evaporation Rate from Step 6i (in)

R = Monthly Rainfall Rate from Step 1 (in)

e = System Efficiency

A_i = Irrigated Area (ac)

Assumptions:

- System efficiency factor (e): 0.9 to account for water loss due to leakage, splash, etc.

Perform a monthly water balance analysis starting with January and ending with December using the difference between the monthly rainfall (Q) and the monthly demands (D_T) from Steps 5 and 6.

The storage volume at the beginning of the month (V_b) is the same as the storage volume at the end of the previous month (V_e). For the first month of the analysis (January), V_b is set to 0.

Design Criteria *(continued)*

If Q exceeds D_T for a given month, the difference is added to the storage volume at the beginning of the next month (V_b), and the storage volume at the end of the month (V_e) is computed.

$$V_e = V_b + Q - D_T$$

Where V_e = Storage Volume at the end of the month (ft³)
 V_b = Storage Volume at the beginning of the month (ft³)
 Q = Monthly Runoff Volume (ft³)
 D_T = Monthly Total Demand (ft³)

If D_T exceeds Q for a given month, the difference is subtracted from the storage volume at the beginning of the month (V_b), and the storage volume at the end of the month (V_e) is computed. The process is continued for the remaining months until December. If the computed storage volume at the end of the month is negative, a value of 0 is shown for V_e .

- iii) Size the cistern volume to be greater than the highest value of (V_e) over the course of the entire year. Include any freeboard requirements or additional volume required as a factor of safety. If the cistern is designed to have a volume less than the maximum V_e due to cost or space constraints, the system needs to also incorporate a bypass system or other means to manage the excess storm water flows.

ADDITIONAL DESIGN PARAMETERS

- If the cistern or vault is located at a lower elevation than the intended discharge point for reuse, a pump system will be necessary.
- For underground vaults, the bottom of the structure must be no lower than the seasonally high groundwater table unless buoyancy calculations are provided to show that floatation will not occur and that groundwater will not seep into the structure.
- If located under areas of high vehicular volume or loading areas, design vault to handle traffic and design loads applicable to the site.
- Overflow of tanks during storm events or for maintenance purposes must be safely discharged downstream without impacting hydraulic capacities or creating erosion.
- Choose a tank or cistern material that is appropriate for the proposed use. Common materials include fiberglass, polyethylene, concrete or steel. Aboveground tanks should be UV and impact resistant.
- Any connection to a water supply shall have a proper backflow prevention device to prevent cross-contamination.

Pretreatment Considerations

- Screening or filtration is required upstream of the storage tank to prevent leaves and debris from entering and clogging the system.
- First flush diverters are required to prevent stormwater runoff containing initial surface contaminants from entering the system.

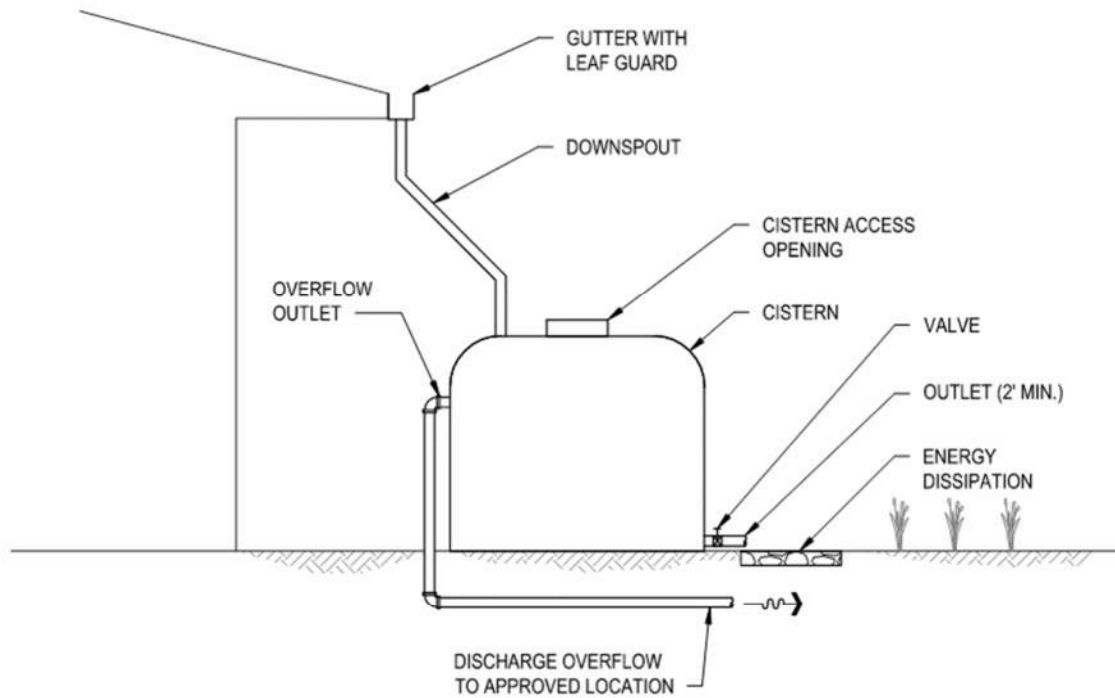
Construction Considerations

- Tanks shall be constructed with strong, durable, and corrosion-resistant materials.
- Verify that all necessary permits and approvals have been obtained prior to conducting work on any plumbing systems.
- For underground systems, ensure that proper buoyancy protection measures are installed, if necessary.
- Inspect and clean all storage and conveyance components prior to system testing of pumps, valves, and piping.
- Stabilize the area downstream of the overflow discharge prior to filling the tank.

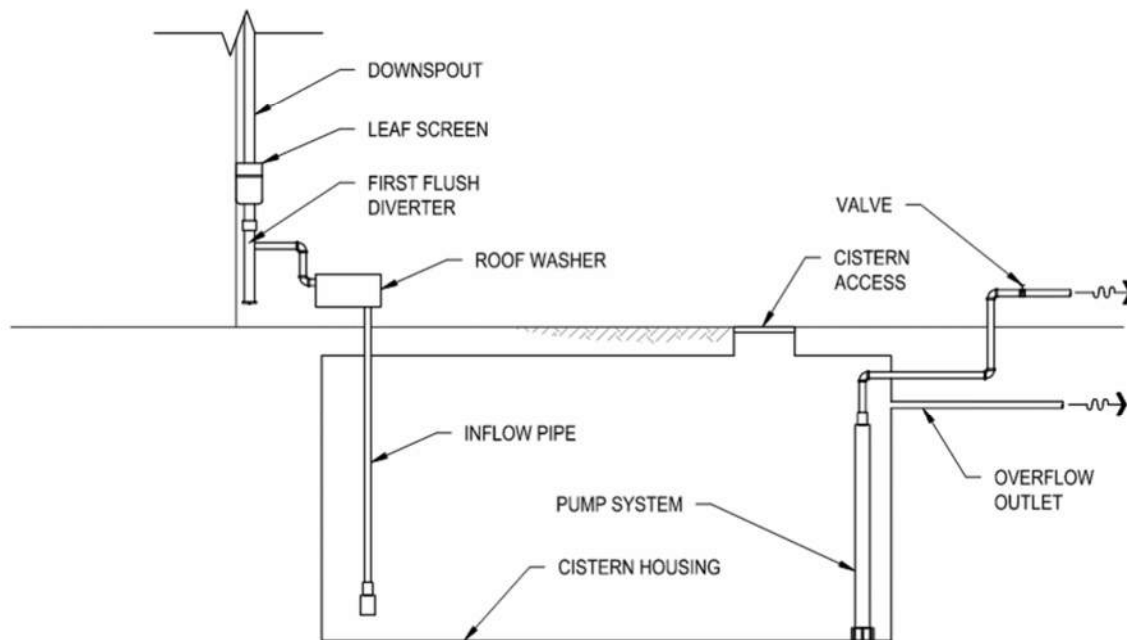
Maintenance and Inspections

- Inspect cisterns and vaults at least every 6 months.
- Note any damage to the exterior and interior of structures (e.g., concrete, manhole lids, screens, etc.).
- Clean and inspect all inlets, filters, outlets, and overflow pipes for blockages and sediment accumulation.
- Clean out leaves and debris from gutters and drainage paths upstream of structure.
- Clear overhanging trees and vegetation above roof drainage area as necessary.
- Inspect and test pumping systems and lubricate all valves.
- Check for mosquitoes and prevent breeding by adjusting screens or adding larvicide pellets (for non-potable use only).
- For proprietary systems, perform any additional maintenance activities in accordance with the manufacturer's recommendations.

Rainwater Harvesting



ABOVE GROUND CISTERN



BELOW GROUND CISTERN

Tree Box Filter



SOURCE: NYC Environmental Protection

Typical Targeted Pollutants for Removal	
Sediment	x
Nutrients	x
Oil & Grease	x
Metals	n/a
Trash	x
Bacteria	x

Other Considerations	
Construction Cost	High ¹
Maintenance Cost	Moderate ¹
Effective Life	Varies

¹ Source: State of Georgia, Georgia Stormwater Management Manual 2016

Description & Purpose

Tree box filters are vaulted treatment devices filled with engineered soil media typically located within a sidewalk area, median, or parking lot. Storm water runoff is directed from the adjacent impervious area into the tree box filter and percolates through the soil media before being conveyed back into the drainage system. During large storm events, excess runoff can bypass the tree box filter at the ground surface and enter adjacent downstream BMP devices or drainage structures. Pollutant removal is accomplished via filtration by the soil media and evapotranspiration similar to a bioretention BMP.

Applications

Typically used in urban areas. Requires a relatively small footprint and can accommodate vertical elevation drops along its edges. It is common for multiple tree pits to be installed in series in order to treat the entire water quality volume.

Limitations

- Requires pretreatment upstream to capture sediment loadings which would otherwise lead to clogging and premature failure.
- Not applicable downstream of landscaped or pervious areas where heavy sediment loadings may lead to premature failure.
- Avoid using adjacent to structures and foundations that may be impacted by subsurface infiltration.
- In highly urbanized areas, size of structure may be limited by underground utilities and root growth may damage sidewalks.

Limitations *(continued)*

- If an open-bottomed structure is used, maintain at least 3 feet clearance between the bottom of the tree box filter and the seasonally high groundwater table to avoid groundwater contamination.

Design Criteria

SIZING PROCEDURE

1. Determine the Water Quality Volume (WQV).
2. If an open-bottom structure is used, calculate the maximum storage depth (d_{max}) based upon the underlying soil infiltration rate (k) and the required drawdown time (t). Otherwise, if a closed-bottom structure is used, continue to Step 3.

$$d_{max} = \frac{kt}{12FS}$$

Where d_{max} = Maximum Storage Depth (ft)

k = Soil Infiltration Rate from testing (in/hr)

t = Drawdown Time (hours)

F_s = Infiltration Rate Factor of Safety

Assumptions:

- Maximum drawdown time (t): 48 hours (although a shorter period may be used for high-pedestrian traffic areas where ponding may be a nuisance)
 - Minimum factor of safety (F_s): 2 (to account for long-term reduction in infiltration rate due to clogging)
3. Select a design ponding depth (d_p) and determine the thickness and porosity for the engineered soil media. Calculate the total effective storage depth (d_t), which is a function of the depth and porosity of the soil media and drainage layer, using the following equation:

$$d_t = d_p + d_s n_s + d_d n_d$$

Where d_t = Total Effective Storage Depth (ft)

d_p = Design Ponding Depth (ft)

d_m = Engineered Soil Media Depth (ft)

n_m = Engineered Soil Media Porosity

d_d = Drainage Layer Depth (ft)

n_d = Drainage Layer Porosity

Design Criteria *(continued)*

Assumptions:

- Maximum ponding depth: 6 inches (typ.)
 - Engineered soil media porosity: 0.25 (typ.) (Georgia 2016)
 - Drainage layer porosity: 0.3 to 0.4 (typ.) (NCHRP 2019)
4. Confirm that the total effective storage depth (d_t) is less than the maximum storage depth (d_{max}) calculated in Step 2. If a closed-bottom structure is used, continue to Step 5.
 5. Calculate the required surface area (A_{BMP}) of the tree box filter.

$$A_{BMP} = \frac{WQV}{\left(d_t + \frac{kT}{12FS}\right)}$$

Where A_{BMP} = Tree Box Filter Surface Area (ft^2)

WQV = Water Quality Volume (ft^3)

d_t = Total Effective Water Storage Depth (ft)

k = Soil Infiltration Rate from Step 2 (in/hr)

T = Fill Time (hours)

FS = Infiltration Rate Factor of Safety from Step 2

If the required surface area does not fit in the allowable space, adjust the design variables and repeat the calculations as necessary.

6. Based upon the required surface area (A_{BMP}), determine the top width (W) and corresponding top length (L) of the tree box filter.

$$L = \frac{A_{BMP}}{W}$$

Where L = Top Length (ft)

A_{BMP} = Tree Box Filter Surface Area from Step 5 (ft^2)

W = Top Width (ft)

7. Design a bypass system to convey peak flows in excess of the WQV to adjacent downstream BMP devices or drainage structures. Evaluate resulting gutter spread and impact upon surface street flooding, where applicable.

Design Criteria *(continued)*

ADDITIONAL DESIGN PARAMETERS

- Footprint area is typically about 5 percent of the contributing drainage area (Georgia 2016).
- Provisions shall be provided to bypass peak flows to downstream drainage systems when the device capacity is exceeded. Assess impact of flow bypass on gutter spread and localized flooding.
- Underdrain System
 - Underdrain pipe (minimum 4-inch diameter) should be perforated PVC Schedule 40 pipe or equivalent corrugated HDPE pipe encased in a layer of #57 washed stone, 8- to 12-inches thick. Perforations should be 3/8-inch diameter at a minimum 6-inch on center spacing with a minimum of 4 holes per row (DOEE 2020).
 - Underdrain pipes shall be placed in the middle of the aggregate layer with perforations on the bottom side of the pipe.
 - Provide an overflow drain to allow excess flow to enter the underdrain system and that can also be used as an observation well. Vertical pipe section should be made of solid-wall PVC Schedule 40 pipe (minimum 4-inches in diameter).
- Provide a 2- to 4-inch filter layer of #7 washed stone between the planting media and the drainage layer.
- Provide energy dissipation devices at inflow points to reduce erosion.
- Consider providing edge protection for pedestrian safety where elevation difference between pavement surface and planting media exceeds 6 inches.
- Vegetation must accommodate adequate sight distances at intersections.

Pretreatment Considerations

- For devices that receive concentrated runoff directly from impervious surfaces, a pretreatment sediment chamber may be provided to capture sediment, trash, and debris from entering the tree box filter.

Construction Considerations

- Tree box filters should be installed after adjacent construction activities have been completed.
- Divert storm water around the tree box filter until contributing drainage areas have been permanently stabilized.
- Trim large roots from all sides of excavated area prior to backfilling.
- Top of soil media shall be graded relatively flat to evenly distribute storm water runoff over the soil surface.

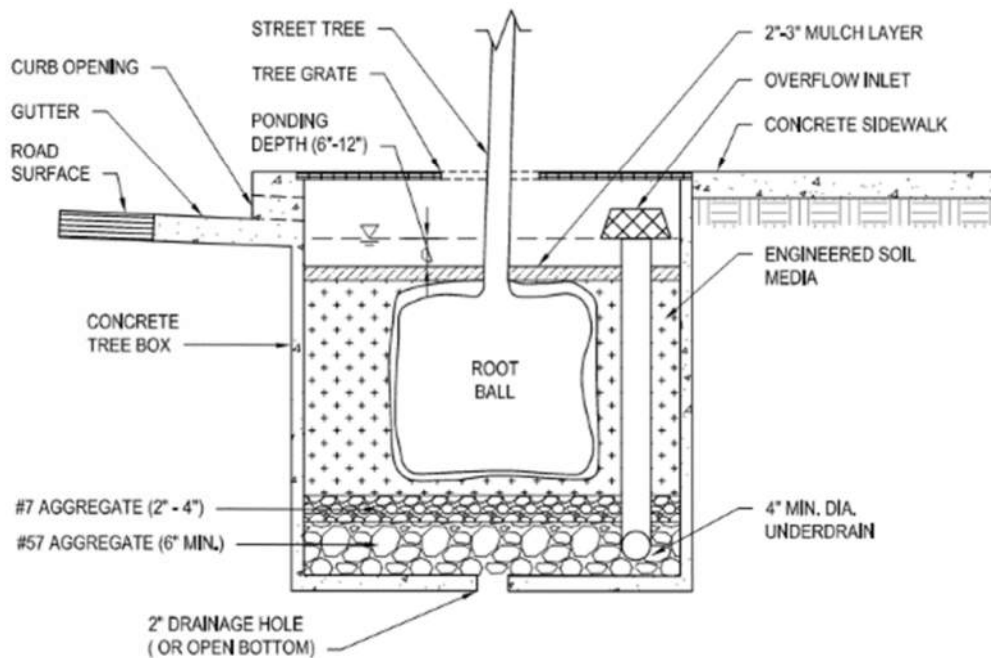
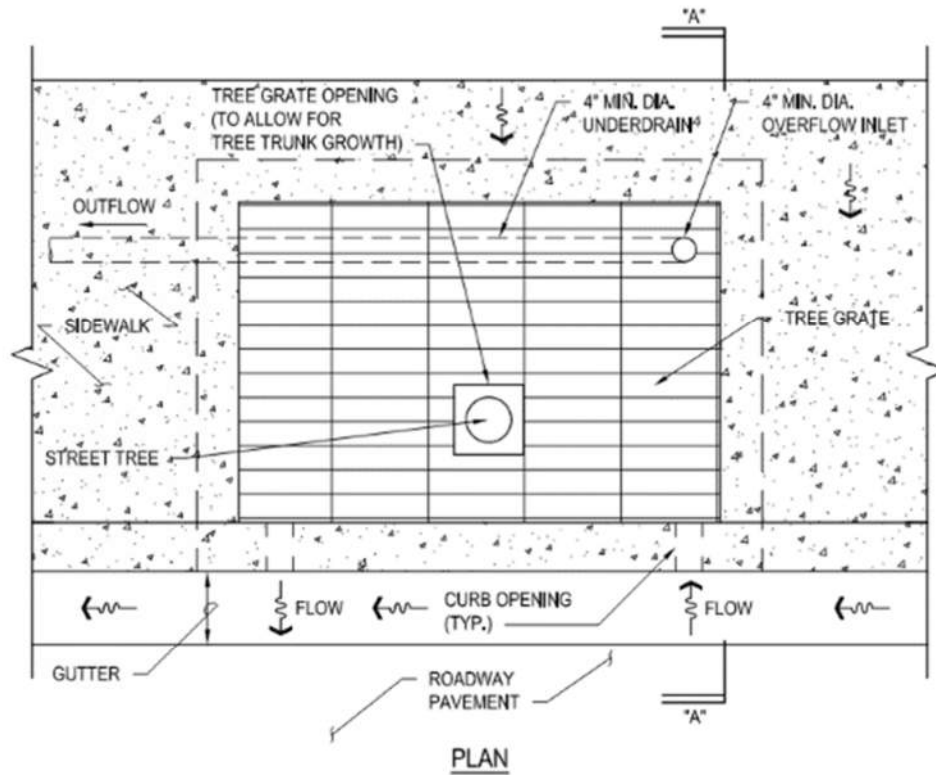
Landscaping Considerations

- Landscape design should specify proper plant species (preferably native) based on the specific site, soils and hydric conditions.
- Select vegetation of an appropriate size for the available soil volume.
- Avoid the use of fertilizer nutrients and amendments that have the potential to be washed into receiving waters.
- A mulch layer (2 to 3 inches thick) may be provided to retain moisture for plants.
- Avoid the use of mulches that may increase nutrient levels or where higher flow velocities may cause mulch material to float and wash away.
- Stabilize newly planted trees with stakes or guywires for support.

Maintenance and Inspections

- Regularly remove sediment, trash, and debris from the facility
- Evaluate overall health of trees and inspect for insect damage or disease.
- Replace dead or diseased trees. Prune damaged, dead, or diseased branches as needed.
- Determine if tree stakes are needed or require adjustment for tree stability.
- Replenish or redistribute mulch as necessary.
- Remove sediment from the pretreatment chamber (if applicable) if the performance of the facility is affected.
- Inspect observation wells at least once a year to ensure the facility is operating properly.
- Clean underdrain pipes to remove sediment and debris.
- For proprietary systems, perform any additional maintenance activities in accordance with the manufacturer's recommendations.

Tree Box Filter



SECTION A-A
TREE BOX FILTER

Wet Pond



SOURCE: Minnesota Stormwater Manual, 2020

Typical Targeted Pollutants for Removal	
Sediment	x
Nutrients	x
Oil & Grease	x
Metals	x
Trash	x
Bacteria	x

Other Considerations ¹	
Construction Cost	Moderate to High
Maintenance Cost	Low to Moderate
Effective Life	20-50 years

¹ Source: Washington State DOT, Highway Runoff Manual 2019

Description & Purpose

A wet pond is a constructed storm water pond with a permanent pool of water that removes pollutants primarily via sedimentation and vegetative uptake. The volume of the permanent pool is equal to the Water Quality Volume. Wet ponds are generally not considered LID BMPs since incoming runoff displaces water from the permanent pool.

Applications

Wet ponds are applicable in mostly rural areas where ample open space is available. If properly designed, constructed, and maintained, it may provide aesthetic value and create a wildlife habitat.

Limitations

- Requires an adequate supply of water to maintain aquatic vegetation.
- Depth to groundwater is not a major constraint since high groundwater can help maintain a permanent pool. However, high groundwater may reduce the pollutant removal effectiveness (DOEE 2020).
- Suitable for sites with Hydrologic Soil Group (HSG) classification C or D. Sites with HSG A or B soils may have difficulty maintaining a permanent pool so a geotextile or clay liner may be used for water retention (DOEE 2020).
- Without proper maintenance, overaccumulation of nutrients may lead to algae blooms, unpleasant odors, and unaesthetic conditions.
- Mosquitoes are typically not a problem with deeper ponds that support aquatic wildlife since fish help to eradicate mosquitoes.
- May be a public safety hazard if located near populated areas.

Limitations (continued)

- To avoid seepage damage, wet pond must be at least 20 feet away from structures and foundations. If adequate clearance cannot be provided, an impermeable liner may be installed vertically along the edge to prevent lateral movement of water.

Design Criteria

SIZING PROCEDURE

- Determine the Water Quality Volume (WQV).
- A wet pond consists of two cells: a pretreatment forebay (at the inlet) and a permanent pool. For a wet pond, the volume of the permanent pool (V_{PP}) is equal to the WQV.

$$WQV = V_{PP}$$

Where WQV = Water Quality Volume (ft³)

V_{PP} = Permanent Pool Volume (ft³)

- Determine the volume of the pretreatment forebay (V_P) which prevents sediment, trash, and debris from entering the permanent pool. If flow enters at multiple locations, provide a sediment forebay at each inlet location. The forebay volume counts toward the WQV requirement.

$$V_P = 0.1WQV$$

Where V_P = Pretreatment Forebay Volume (ft³)

WQV = Water Quality Volume (ft³)

Assumptions:

- Pretreatment forebay volume (V_P): 10 percent of WQV (DOEE 2020).
- Conduct storage-volume calculations to establish the preliminary geometry and elevations of the wet pond based on the following design parameters:

Pretreatment. The water depth in the pretreatment forebay shall be between 4 to 6 feet (DOEE 2020). Provide for a 1-foot depth of sediment storage.

Permanent Pool. The maximum depth of the permanent pool should not exceed 8 feet (DOEE 2020).

Design Criteria *(continued)*

Side Slopes. Side slopes should generally have gradients of 3H:1V or flatter (DOEE 2020). Flatter slopes provide for easier maintenance and promote growth of vegetation.

Benches. The perimeter of all storm water ponds shall be surrounded by two benches:

- **Safety bench:** Provide around the outer perimeter of the pond (typically 8 to 15 feet wide) to reduce hazards of a deep pool except where pond side slopes are 5H:1V or flatter. Safety bench shall have a maximum slope of 5 percent (DOEE 2020).
 - **Aquatic bench:** Provide around the inside perimeter of the pond (typically 15 feet wide) to promote growth of aquatic plants and wetland plants. The aquatic bench shall have a maximum depth of 18 inches (DOEE 2020).
5. Perform a water balance calculation to check that the wet pond will have sufficient water following a 30-day summer drought.

$$d_{BMP} > (E + INF + RES)/12$$

Where d_{BMP} = Wet Pond Average Depth (ft)

E = Highest Monthly Evaporation (in)

INF = Monthly Infiltration Loss (in)

RES = Reservoir of Water (in)

Assumptions:

- Wet pond average depth: 6 feet (DOEE 2020)
 - Highest monthly evaporation (E): 7.9 inches (data from Ekern 1985)
 - Monthly infiltration loss (INF): 7.2 inches (0.01 in/hr) (DOEE 2020)
 - Reservoir of Water (RES) is a factor of safety assumed to be 24 inches for ponds (DOEE 2020).
6. Design the outlet structure in accordance with design parameters below.

ADDITIONAL DESIGN PARAMETERS

- A longer flow path from the inlet to the outlet will increase water residence time and improve pollutant removal. A flow path having a minimum length-to-width ratio of 1.5:1 shall be provided for wet ponds (DOEE 2020). The recommended ratio is 3:1 (Georgia 2016).

Design Criteria *(continued)*

- Embankments
 - Embankments shall be designed in accordance with applicable federal and state guidelines for dam safety.
 - Side slopes should generally have gradients of 3H:1V or flatter.
 - Exterior basin side slopes shall not be steeper than 2H:1V unless analyzed for stability by a geotechnical engineer.
 - For embankments up to 6 feet, the minimum top width should be 6 feet or as recommended by a geotechnical engineer.
- Outlet Control Structure (WSDOT 2019)
 - Provide an outlet control structure with a restrictor device (pipe, orifice, or weir) for controlling outflow to meet the desired flow discharge.
 - The pool outlet pipe shall be back-sloped or have a turned-down elbow to trap oils and floatables in the wet pool. The outlet pipe shall extend 1 foot below the WQV water surface at the lower pipe end and discharge into the outlet structure at the WQV water surface at the upper pipe end. Size the pipe based on inlet control and determine required upstream water surface elevation (head) necessary to convey the flow.
 - Provide a screen protector over orifices to help prevent plugging.
 - Take into consideration the backwater effect of downstream water surface elevations, which may affect outlet capacities and basin storage volumes.
 - Provide a primary overflow within the outlet structure to allow bypassing of the 100-year peak flow in case the outlet becomes plugged or during high inflows.
 - Provide a secondary overflow as additional protection. This is often provided with a grated opening on the face or top of the outlet structure.
- Emergency Overflow Spillway (WSDOT 2019)
 - In addition to primary and secondary overflows, provide an emergency overflow spillway designed to pass the 100-year peak design flow.
 - Use non-erosive materials such as grouted riprap.
- Access Road (WSDOT 2019)
 - Provide access for maintenance, cleaning, and inspections to critical components of the facility.
 - Access roads shall be a minimum of 12 feet wide (15 feet on curves) and be designed to support anticipated vehicular loads applicable to the site.
 - Provide a turnaround area for any dead ends.
 - Provide an access ramp having a maximum slope of 15 percent to the bottom of the basin unless all portions of the facility can be accessed and maintained from the top of bank (Washington State DOE 2019).

Design Criteria *(continued)*

- Since wet ponds are fixed obstacles and include side slopes that may exceed 3H:1V, they should be located outside of the roadside clear zone or protected with guardrails.

Pretreatment Considerations

- If receiving concentrated runoff directly from impervious surfaces, a pretreatment facility such as a sediment forebay or vegetated buffer strip is recommended to reduce incoming velocities and reduce the amount of sediment entering the treatment device.
- Provide a sediment forebay at the inlet sized to contain 0.1 inches per impervious acre of contributing drainage (10 percent of WQV). The storage in the forebay counts toward the total required WQV to be treated.
- If flow enters at multiple locations, provide a sediment forebay at each inlet location.
- Forebays should contain a fixed vertical marker to measure sediment depth.

Construction Considerations

- Upstream areas that contribute runoff to the storm water pond should be stabilized prior to pond construction.
- Divert storm water runoff away from the pond during construction to avoid sediment accumulation.
- Perimeter slopes and vegetated areas must be stabilized within 14 days of construction.
- Remove all accumulated sediment and debris at the end of construction.

Landscaping Considerations

- Landscape design should specify proper plant species (preferably native) based on the specific site, soils and hydric conditions.
- Wetland plants are encouraged either along the aquatic bench, safety bench and side slopes, or within shallow areas of the pool.
- Select plant types based on the anticipated inundation levels.
- Avoid planting trees or woody vegetation on or near embankments since root system may undermine the structural integrity of the embankment.
- Plants should be flood- and drought-resistant.
- Avoid the use of fertilizer nutrients and amendments that have the potential to be washed into receiving waters.
- Vegetate the shelf region to discourage waterfowl (a direct source of nutrients and bacteria) and protect the shoreline from erosion. Vegetated shelves also increase safety by discouraging children from accessing the water pool.



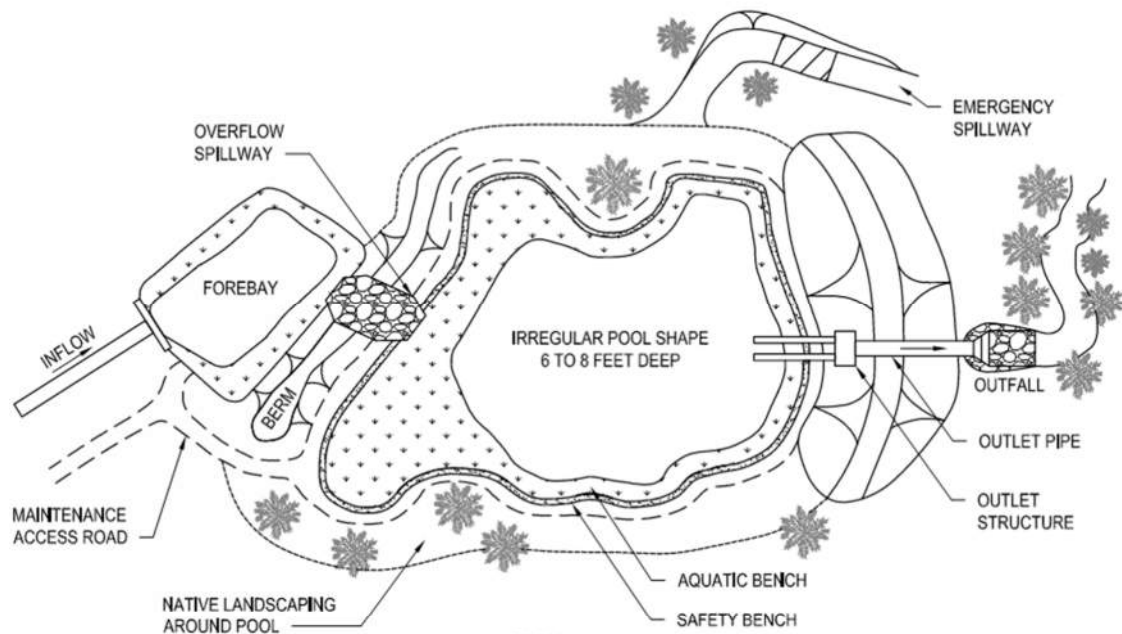
Wet Pond

T-11

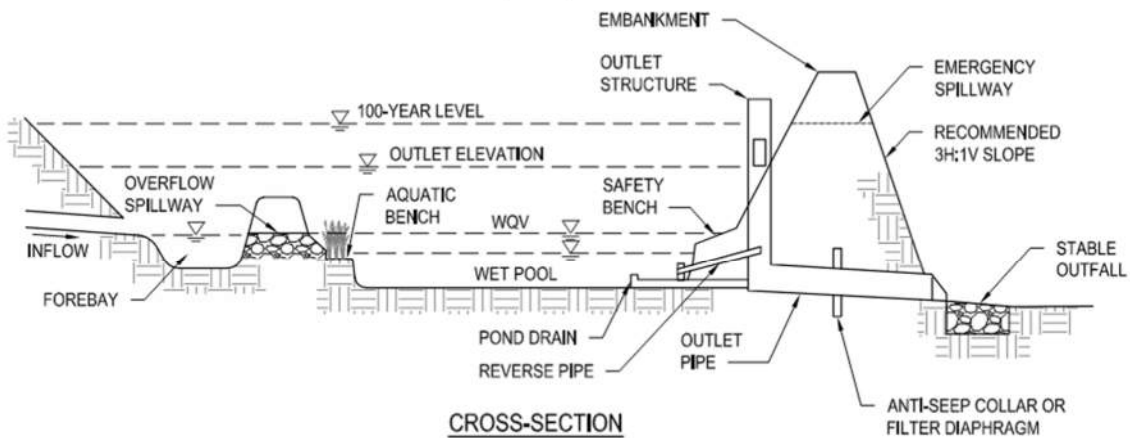
Maintenance and Inspections

- Regularly remove trash, and debris from the facility
- Remove sediment from the forebay when it reaches a depth of 12 inches or if the performance of the facility is affected.
- Remove algal growth when 50 percent of the pool surface area is covered.
- Stabilize any eroded banks with appropriate measures such as grassing, riprap, or permanent matting. Remove any trees or vegetation that affect integrity of slopes or structures.
- Assess embankments annually and after large storm events to identify potential leaks.
- Dead or diseased plants shall be replaced. Remove all invasive species.
- Test valves and mechanical components annually and repair or replace as needed.
- Replace any missing riprap from spillway.

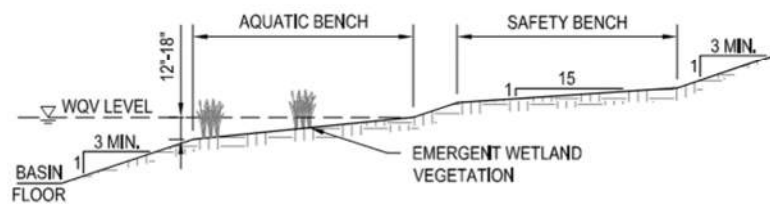
Wet Pond



PLAN



CROSS-SECTION



BENCH DETAIL

WET POND

Wet Extended Detention Pond



SOURCE: Staten Island, NY 2019

Typical Targeted Pollutants for Removal	
Sediment	x
Nutrients	x
Oil & Grease	x
Metals	x
Trash	x
Bacteria	x

Other Considerations ¹	
Construction Cost	Moderate
Maintenance Cost	Low to Moderate
Effective Life	20-50 years

¹ Source: Washington State DOT, Highway Runoff Manual 2019

Description & Purpose

A wet extended detention (ED) pond is a constructed storm water pond that is similar to a wet pond except that it provides additional storage capacity above the permanent pool for flow attenuation of larger storm events. Wet ED ponds are generally not considered LID BMPs since runoff that enters the pond displaces water from the permanent pool.

Applications

Wet ED ponds are applicable in mostly rural areas where ample open space is available and where flow attenuation is desired in addition to water quality treatment. A wet ED pond results in a smaller footprint area than a detention basin with a separate downstream treatment facility. If properly designed, constructed, and maintained, it may provide aesthetic value and create a wildlife habitat.

Limitations

- Requires an adequate supply of water to maintain aquatic vegetation.
- Depth to groundwater is not a major constraint since high groundwater can help maintain a permanent pool. However, high groundwater may reduce the pollutant removal effectiveness (DOEE 2020).
- Suitable for sites with Hydrologic Soil Group (HSG) classification C or D. Sites with HSG A or B soils may have difficulty maintaining a permanent pool so a geotextile or clay liner may be used for water retention (DOEE 2020).
- Without proper maintenance, overaccumulation of nutrients may lead to algae blooms, unpleasant odors, and unaesthetic conditions.
- Mosquitoes are typically not a problem with deeper ponds that support aquatic wildlife since fish help to eradicate mosquitoes.

Limitations (continued)

- May be a public safety hazard if located near populated areas.
- To avoid seepage damage, wet ED pond must be at least 20 feet away from structures and foundations. If adequate clearance cannot be provided, an impermeable liner may be installed vertically along the edge to prevent lateral movement of water.

Design Criteria

SIZING PROCEDURE

The procedure for sizing a wet ED pond is similar to that for a wet pond except that additional storage is provided for storm water detention above the permanent pool.

1. Determine the Water Quality Volume (WQV).
2. A wet ED pond consists of two cells: a pretreatment forebay (at the inlet) and a permanent pool. For a wet ED pond, the WQV is split evenly between the permanent pool and the ED volume above the permanent pool.

$$0.5WQV = V_{PP}$$

Where WQV = Water Quality Volume (ft³)

V_{PP} = Permanent Pool Volume (ft³)

3. Determine the volume of the pretreatment forebay (V_P). If flow enters at multiple locations, provide a sediment forebay at each inlet location. The forebay volume counts toward the WQV requirement.

$$V_P = 0.1WQV$$

Where V_P = Pretreatment Forebay Volume (ft³)

WQV = Water Quality Volume (ft³)

Assumptions:

- Pretreatment forebay volume (V_P): 10 percent of WQV (DOEE 2020).
4. Conduct storage-volume calculations to establish the preliminary geometry and elevations of the wet ED pond based on the design parameters used to size a wet pond.

Design Criteria *(continued)*

5. Perform a water balance calculation to check that the wet ED pond will have sufficient water following a 30-day summer drought. Use the same procedure used for a wet pond.
6. Design the outlet structure in accordance with a wet pond. However, since storm water detention is also provided, include a flow restrictor such as an orifice, weir, or flow diverter to ensure that the discharge from the outlet structure does not exceed the predevelopment runoff. The flow restrictor shall also be sized to release the detention volume over a 24-hour period.

ADDITIONAL DESIGN PARAMETERS

- A longer flow path from the inlet to the outlet will increase water residence time and improve pollutant removal. A flow path having a minimum length-to-width ratio of 1.5:1 shall be provided for wet ponds (DOEE 2020). The recommended ratio is 3:1 (Georgia 2016).
- Embankments
 - Embankments shall be designed in accordance with applicable federal and state guidelines for dam safety.
 - Side slopes should generally have gradients of 3H:1V or flatter.
 - Exterior basin side slopes shall not be steeper than 2H:1V unless analyzed for stability by a geotechnical engineer.
 - For embankments up to 6 feet, the minimum top width should be 6 feet or as recommended by a geotechnical engineer.
- Outlet Control Structure (WSDOT 2019)
 - Provide an outlet control structure with a restrictor device (pipe, orifice, or weir) for controlling outflow to meet the desired flow discharge.
 - The pool outlet pipe shall be back-sloped or have a turned-down elbow to trap oils and floatables in the wet pool. The outlet pipe shall extend 1 foot below the WQV water surface at the lower pipe end and discharge into the outlet structure at the WQV water surface at the upper pipe end. Size the pipe based on inlet control and determine required upstream water surface elevation (head) necessary to convey the flow.
 - Provide a screen protector over orifices to help prevent plugging.
 - Take into consideration the backwater effect of downstream water surface elevations, which may affect outlet capacities and basin storage volumes.
 - Provide a primary overflow within the outlet structure to allow bypassing of the 100-year peak flow in case the outlet becomes plugged or during high inflows.

Design Criteria *(continued)*

- Provide a secondary overflow as additional protection. This is often provided with a grated opening on the face or top of the outlet structure.
- Emergency Overflow Spillway (WSDOT 2019)
 - In addition to primary and secondary overflows, provide an emergency overflow spillway designed to pass the 100-year peak design flow.
 - Use non-erosive materials such as grouted riprap.
- Access Road (WSDOT 2019)
 - Provide access for maintenance, cleaning, and inspections to critical components of the facility.
 - Access roads shall be a minimum of 12 feet wide (15 feet on curves) and be designed to support anticipated vehicular loads applicable to the site.
 - Provide a turnaround area for any dead ends.
 - Provide an access ramp having a maximum slope of 15 percent to the bottom of the basin unless all portions of the facility can be accessed and maintained from the top of bank (Washington State DOE 2019).
- To account for storm water detention:
 - Volume of the wet ED pond must be sufficient to provide flow attenuation and reduce peak outflow rates to predevelopment levels.
 - Detention volume shall not comprise more than 50 percent of the total wet ED pond volume and its maximum water surface elevation shall not extend more than 3 feet above the WQV water surface (DOEE 2020).
 - The wetland must draw down to WQV levels in 2-5 days after a storm event to avoid prolonged inundation of wetland vegetation (Washington State DOE 2019).
- Since wet ED ponds are fixed obstacles and include side slopes that may exceed 3H:1V, they should be located outside of the roadside clear zone or protected with guardrails.

Pretreatment Considerations

- If receiving concentrated runoff directly from impervious surfaces, a pretreatment facility such as a sediment forebay or vegetated buffer strip is recommended to reduce incoming velocities and reduce the amount of sediment entering the treatment device.
- Provide a sediment forebay at the inlet sized to contain 0.1 inches per impervious acre of contributing drainage (10 percent of WQV). The storage in the forebay counts toward the total required WQV to be treated.
- If flow enters at multiple locations, provide a sediment forebay at each inlet location.
- Forebays should contain a fixed vertical marker to measure sediment depth.

Construction Considerations

- Upstream areas that contribute runoff to the storm water pond should be stabilized prior to pond construction.
- Divert storm water runoff away from the pond during construction to avoid sediment accumulation.
- Perimeter slopes and vegetated areas must be stabilized within 14 days of construction.
- Remove all accumulated sediment and debris at the end of construction.

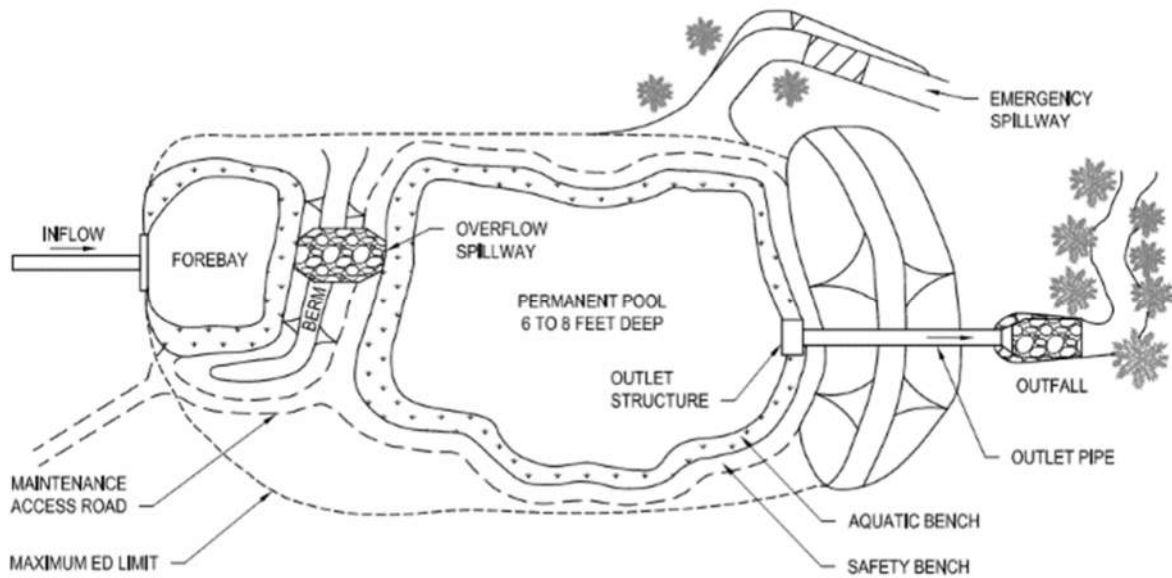
Landscaping Considerations

- Landscape design should specify proper plant species (preferably native) based on the specific site, soils and hydric conditions.
- Wetland plants are encouraged either along the aquatic bench, safety bench and side slopes, or within shallow areas of the pool.
- Select plant types based on the anticipated inundation levels.
- Avoid planting trees or woody vegetation on or near embankments since root system may undermine the structural integrity of the embankment.
- Plants should be flood- and drought-resistant.
- Avoid the use of fertilizer nutrients and amendments that have the potential to be washed into receiving waters.
- Vegetate the shelf region to discourage waterfowl (a direct source of nutrients and bacteria) and protect the shoreline from erosion. Vegetated shelves also increase safety by discouraging children from accessing the water pool.

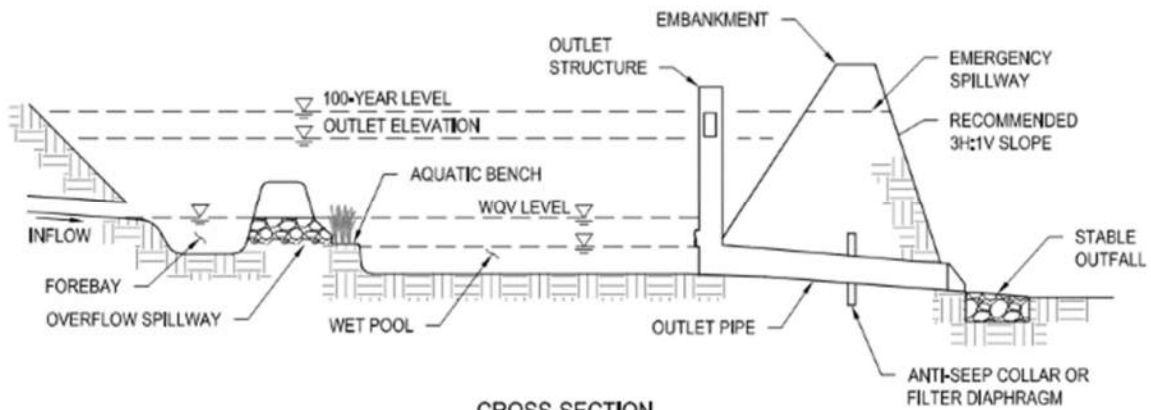
Maintenance and Inspections

- Provide maintenance access to the entire pond including the forebay, access and safety benches, and inlet and outlet structures for maintenance, cleaning, and inspections.
- Routine maintenance such as mowing and trash/debris removal should be done several times a year.
- Remove sediment from the forebay when it reaches a depth of 12 inches or if the performance of the facility is affected.
- Remove algal growth when 50 percent of the pool surface area is covered.
- Stabilize bare or eroding areas with grass cover, riprap, or erosion control matting.
- Dead or diseased plants shall be replaced. Remove all invasive species.
- Test valves and mechanical components annually and repair or replace as needed.
- Assess embankments annually and after large storm events to identify potential leaks.

Wet Extended Detention Pond



PLAN



CROSS-SECTION

WET EXTENDED DETENTION POND



SOURCE: North Carolina Department of Environmental Quality
Stormwater BMP Manual, 2012

Typical Targeted Pollutants for Removal	
Sediment	x
Nutrients	varies
Oil & Grease	x
Metals	x
Trash	x
Bacteria	

Other Considerations	
Construction Cost	Varies
Maintenance Cost	Varies
Effective Life	Varies

Description & Purpose

Sand filters are systems that operate similarly to an infiltration basin except that instead of infiltrating into underlying soil, treatment occurs as storm water filters through a media bed consisting primarily of sand material. As flows increase, ponding increases until it can percolate into the sand or be conveyed by an overflow spillway.

Applications

Sand filters have been used extensively for potable water treatment and have been shown to be effective at removing a variety of pollutants. The overall shape can be varied to fit within the allotted space since treatment is achieved vertically and not horizontally along a conveyance path. Design variations include a surface sand filter (open basin system), perimeter sand filter, or an underground system with either an open-bottom or closed-bottom configuration. Sand filters may be used in an online or offline arrangement.

Limitations

- Applicable for flows evenly distributed across the filter (no concentrated flows).
- Applicable where the difference between the inlet and outlet elevations is between 3 and 6 feet to provide adequate hydraulic head to operate by gravity (Caltrans 2019).
- For open-bottom systems, maintain at least 3 feet clearance between the bottom of the sand filter and the seasonally high groundwater table to avoid groundwater contamination.

Limitations (*continued*)

- For closed-bottom systems, the bottom of the structure must be no lower than the seasonally high groundwater table unless buoyancy calculations are provided to show that floatation will not occur and that groundwater will not seep into the structure.
- Not applicable in areas where heavy sediment or leaves may block or clog the filter bed.
- Not applicable in areas where high groundwater may flood the underdrain system.

Design Criteria

SIZING PROCEDURE

The following procedure is to size a surface sand filter:

1. Determine the Water Quality Volume (WQV).
2. A surface sand filter consists of two chambers: a pretreatment forebay (at the inlet) and the filter bed. The volume of the sand filter (V_{BMP}) shall be sized to treat 75 percent of the WQV. This “discount” is allowed due to the rapid infiltration into the sand media during the storm event (NC DEQ 2020).

$$V_{BMP} = 0.75WQV$$

Where V_{BMP} = Sand Filter Volume (ft³)
WQV = Water Quality Volume (ft³)

3. Determine the volume of the pretreatment forebay (V_P) which shall be equal to 25 percent of the WQV (Georgia 2016).

$$V_P = 0.25WQV$$

Where V_P = Pretreatment Forebay Volume (ft³)
WQV = Water Quality Volume (ft³)

4. Calculate the minimum required surface area of the pretreatment forebay (A_P) based on the Camp-Hazen equation which accounts for turbulent flow. Assume a length-to-width ratio of 2:1 (Maryland DOE 2000).

$$A_P = \frac{Q_o}{W} \times E'$$

Design Criteria *(continued)*

Where A_P = Pretreatment Forebay Surface Area (ft²)
 Q_o = Discharge rate from filter (cfs)
 W = Particle Settling Velocity (ft/sec)
 E' = Sediment Trapping Efficiency Constant

Assumptions:

- Discharge rate from filter (Q_o) assumes the WQV is discharged over 24 hours
- Particle settling velocity (W)
 - 0.0004 ft/sec (particle size=20 microns) for site imperviousness $\leq 75\%$,
 - 0.0033 ft/sec (particle size=40 microns) for site imperviousness $> 75\%$
- Sediment Trapping Efficiency Constant (E'): 2.30 for a sediment trapping efficiency of 90 percent

The equation reduces to:

$$A_P = 0.066 WQV \text{ (for site imperviousness } \leq 75 \text{ percent)}$$

$$A_P = 0.0081 WQV \text{ (for site imperviousness } > 75 \text{ percent)}$$

- Determine the dimensions of the pretreatment forebay based on the length-to-width ratio of 2:1.

$$w = \sqrt{A_s/2}$$

Where w = Pretreatment Forebay Width (ft)
 A = Pretreatment Forebay Surface Area from Step 4 (ft²)

- Based on the available space at the site, determine the required filter bed depth (d_t) based on the filter bed surface area (A_B):

$$A_B = (WQV \times d_t) / [k \times (d_p + d_t) \times t]$$

Where A_B = Filter Bed Surface Area (ft²)
 WQV = Water Quality Volume (ft³)
 d_t = Filter Bed Depth (ft)
 d_p = Average Ponding Depth above Filter Bed (ft)
 k = Filter Coefficient of Permeability (ft/day)
 t = Drawdown Time (hours) = 48 hours (max.)

Design Criteria *(continued)*

Assumptions:

- Minimum filter media depth (d_f): 1 ft (Maryland DOE 2000)
- Filter coefficient of permeability (k): 3.5 ft/day for partially clogged sand (DOEE 2020)
- Maximum ponding depth (d_p): 6 to 12 inches
- Maximum drawdown time (t): 48 hours

ADDITIONAL DESIGN PARAMETERS

- The surface slope of the filter bed should be less than 6 percent in any direction (Georgia 2016).
- Provide a level spreader to evenly distribute flows across the surface of the sand filter.
- Sand filter material shall be clean, washed sand such as ASTM C33 or equivalent with average diameter less than 2 mm and free from clay, silt, and organic matter.
- Provide a 2- to 4-inch filter layer of #7 washed stone between the sand layer and the aggregate layer.
- A non-erosive overflow spillway for high storm water flows must be provided.
- Underdrain System
 - Provide an underdrain system consisting of central collector pipe and lateral feeder pipes to collect and discharge treated runoff to the drainage system.
 - Underdrain pipe (minimum 4-inch diameter) should be perforated PVC Schedule 40 pipe or equivalent corrugated HDPE pipe encased in a layer of #57 washed stone, 8- to 12-inches thick. Perforations should be 3/8-inch diameter at a minimum 6-inch on center spacing with a minimum of 4 holes per row (DOEE 2020).
 - Underdrain pipes shall be placed in the middle of the aggregate layer with perforations on the bottom side of the pipe.
 - Underdrain pipes shall be placed with a minimum slope of 0.5 percent.
 - Provide an observation well at every 250 to 300 feet along the underdrain system and a cleanout at the end of all underdrain pipe runs for cleaning and observation. Observation wells and cleanouts should be made of solid-wall PVC Schedule 40 pipe (minimum 4-inches in diameter).
 - To prevent the underdrain system from backing up into the sand filter, the maximum distance between parallel feeder pipes or between the edge of filter and a feeder pipe shall be 15 feet (King County DNRP 2021)

Pretreatment Considerations

- Pretreatment is critical for infiltration facilities to avoid clogging of the filtration media. Possible methods for pretreatment include vegetated buffer strips, grassed swales, plunge pools, or forebays. For vaulted systems, a separate pretreatment chamber adjacent to the filtration may be provided.
- Forebays should contain a fixed vertical marker to measure sediment depth.

Construction Considerations

- For open-bottomed systems, avoid running equipment within the footprint to prevent soil compaction.
- Filtration facilities should be constructed towards the end of a project to avoid sediment runoff from adjacent construction activities. Upstream areas should be stabilized prior to construction of the sand filter.
- If necessary, phase the work such that placement of the sand and underdrains is done after the project site has been stabilized.

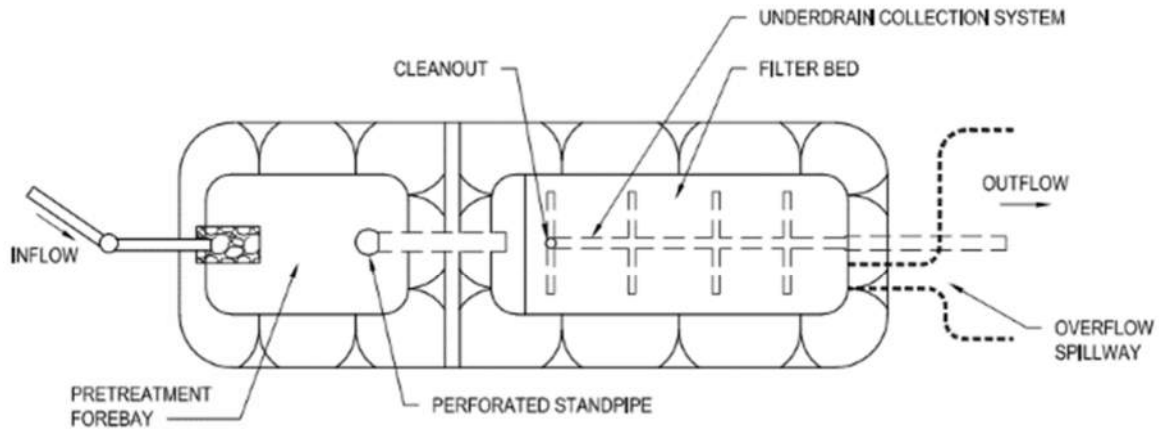
Landscaping Considerations

- Keep adequate buffer space between the sand filter and vegetation to avoid leaves from blocking or clogging the filter bed.

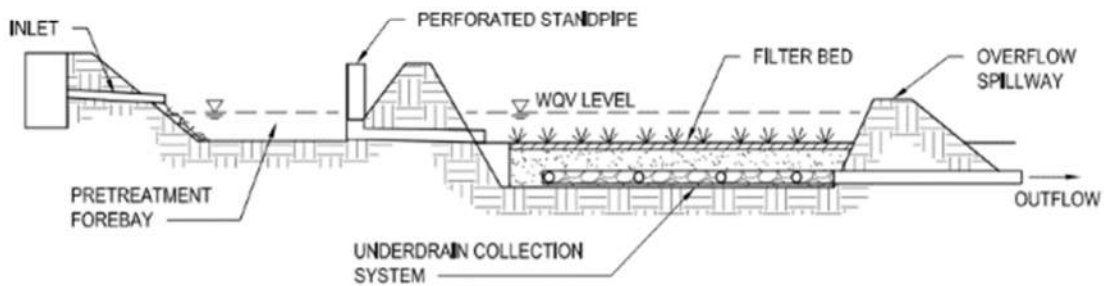
Maintenance and Inspections

- Remove and replace top 2 to 3 inches of sand media when drain time after a storm event exceeds 72 hours.
- Replenish sand media when overall media depth drops more than 6 inches from its original depth.
- Clean or repair pretreatment sediment chamber outlet devices when drawdown times within the chamber exceed 36 hours.
- Remove trash and debris as required to prevent clogging.
- Remove sediment from the forebay or pretreatment chamber when it reaches a depth of 12 inches or if the performance of the facility is affected.
- Filters with a grass cover should be mowed at least 3 times per growing season to maintain grass heights of less than 4-6 inches.
- Herbicides may be required once per year to keep weeds out of the filter.

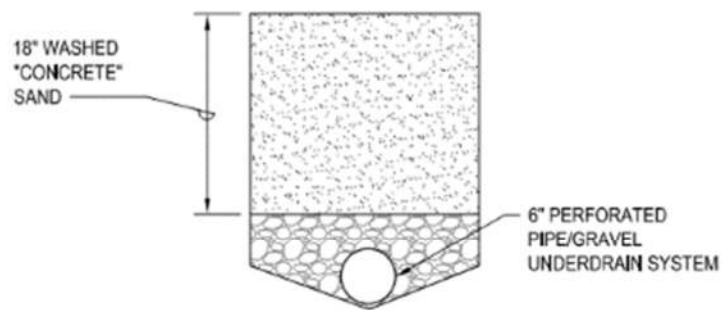
Sand Filter



PLAN



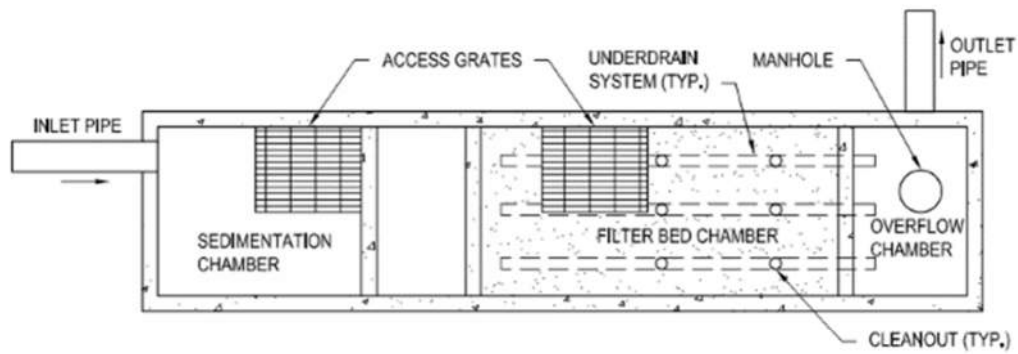
PROFILE



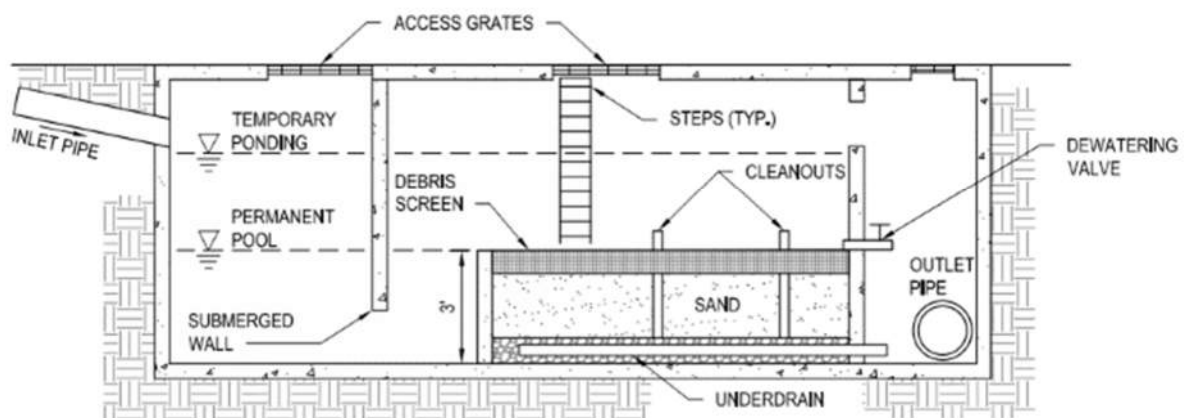
TYPICAL SECTION

SURFACE SAND FILTER

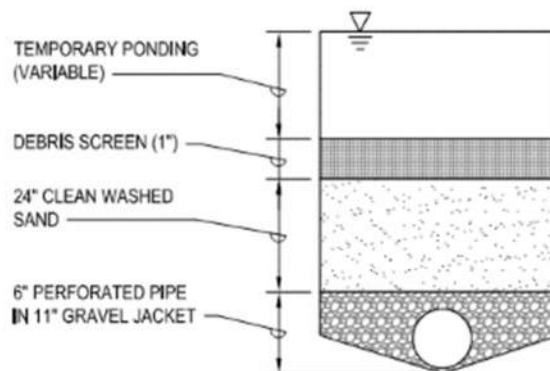
Sand Filter



PLAN



PROFILE



TYPICAL SECTION

UNDERGROUND SAND FILTER



8.6 PROPRIETARY TREATMENT CONTROL BMPs

In highly constrained urbanized areas where LID BMPs are infeasible, a viable option for treatment control is to utilize proprietary non-LID BMPs which are stand-alone treatment devices or installed within new or existing drainage structures. These proprietary devices rely on various manufactured processes to achieve the required water quality treatment. A wide variety of proprietary BMPs exist, not all of which could be included here. The designer must evaluate each device with regards to pollutant removal, hydraulic capacities, pretreatment, construction, and maintenance requirements to determine its applicability. Types of proprietary BMPs discussed here include:

- Drain inlet filter
- Modified catch basin
- Oil/grit separator
- Centrifugal hydrodynamic separator
- Multi-stage hydrodynamic separator

Many of these BMP devices are not able to decrease Total Suspended Solids (TSS), Total Nitrogen (TN), and/or Total Phosphorus (TP) to meet water quality standards and some lack adequate independent testing data or long-term records. In some cases, these devices are used for pretreatment or as part of an overall storm water quality treatment system ("treatment train"). For example, they may be helpful in removing a portion of the pollutants present in storm water runoff before it enters an infiltration basin or other LID practice.

Since these devices are proprietary in nature, sizing procedures are not provided in this manual since it varies depending upon the type of device. Refer to the manufacturer's guidelines for specific design criteria.

Drain Inlet Filter



SOURCE: United Storm Water, Inc.

Typical Targeted Pollutants for Removal	
Sediment	x
Nutrients	
Oil & Grease	
Metals	
Trash	x
Bacteria	

Other Considerations	
Construction Cost	Low
Maintenance Cost	Varies
Effective Life	20-50 years

Description & Purpose

Drain inlet filters consist of a frame and basket that hangs below the inlet grate of a drain inlet that filters out particles through physical screening. The filter may also contain a variety of media to absorb hydrocarbons and pollutants in soluble form.

Applications

Drain inlet filters are typically used for smaller drainage areas with limited space available. Drain inlet filters should be used only for retrofit situations or as a pretreatment where other treatment BMPs are used.

Limitations

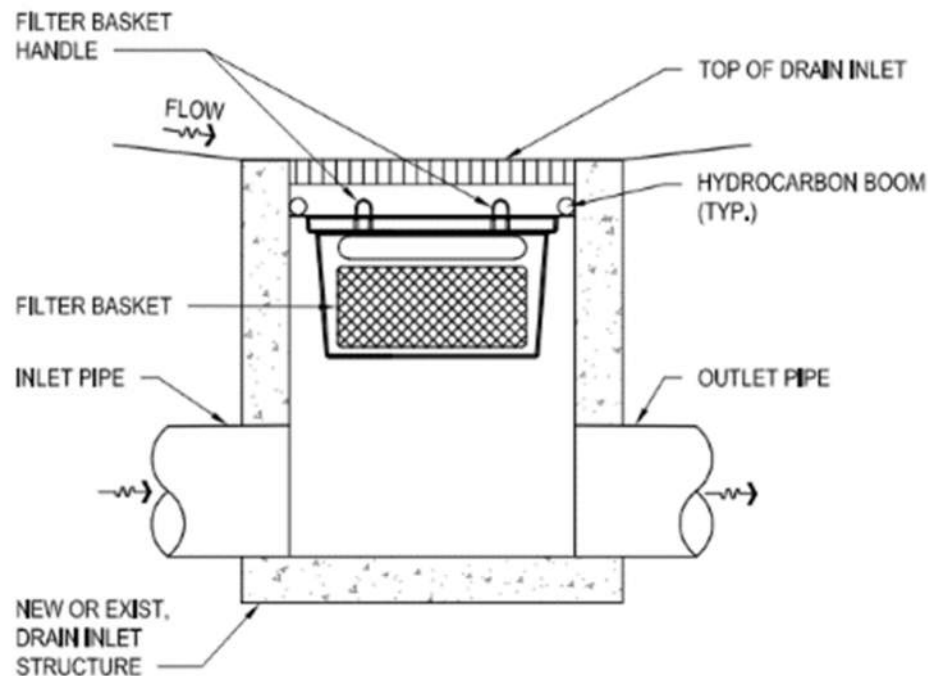
- Treatment level is limited by the physical size of the drain inlet.
- Installation in shallow drain inlets will impact system hydraulic capacity and restrict flows entering and exiting the structure.
- Large quantities of sediment accumulation in the basket or insufficient maintenance may direct storm water through the high flow bypass, therefore circumventing the treatment process.
- The media requires routine maintenance for replacement and cleaning.

Maintenance and Inspections

- Inspect condition monthly and after large storm events.
- Note any damage to the exterior and interior of structures (e.g., concrete or basket).
- Note condition of hydrocarbon boom (if present).

Maintenance and Inspections *(continued)*

- Conditions warranting cleaning of the unit:
 - Recent oil spill or fuel spill;
 - Water ponding (may indicate significant clogging in the unit or downstream structures);
 - Output flow is significantly dirty and filled with trash and debris; and/or
 - If the unit is greater than 50 percent full of debris or sediment.
- Perform any additional maintenance activities in accordance with the manufacturer's recommendations.



ELEVATION

DRAIN INLET FILTER

Modified Catch Basin



Typical Targeted Pollutants for Removal	
Sediment	x
Nutrients	
Oil & Grease	
Metals	
Trash	x
Bacteria	

Other Considerations	
Construction Cost	Low
Maintenance Cost	Varies
Effective Life	20-50 years

Description & Purpose

A modified catch basin consists of retrofitting a new or existing catch basin to add a screening and/or capture device to target sediment, trash, and debris. A media filter may also be added to absorb hydrocarbons and pollutants in soluble form.

Applications

Modified catch basins are mostly used in urban areas along roads with curbs and gutters which direct the storm water runoff into the catch basins.

Limitations

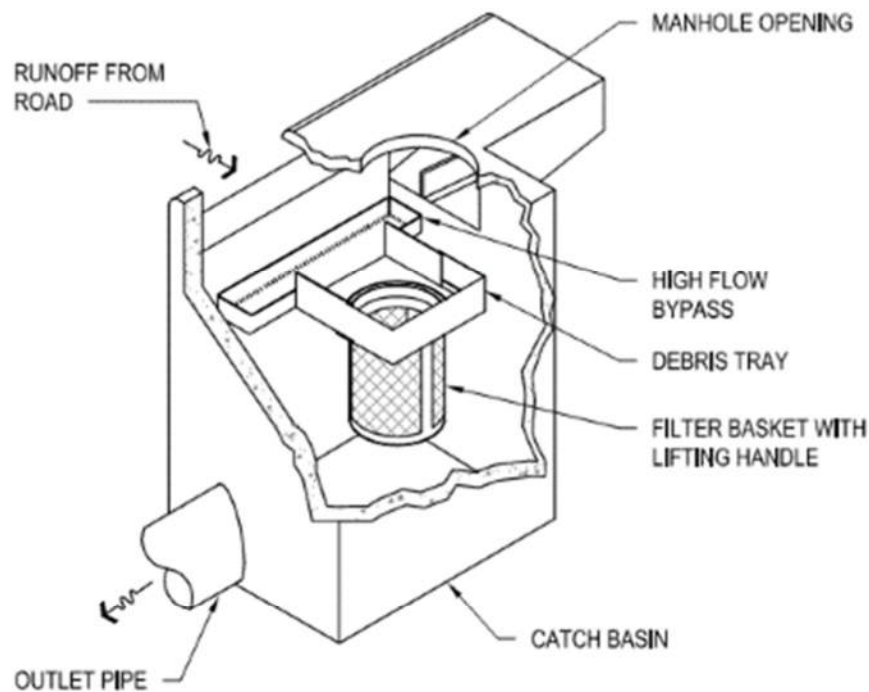
- Treatment level is limited by the physical size of the catch basin.
- The device requires routine maintenance for replacement and cleaning.
- Large quantities of sediment accumulation in the basket or insufficient maintenance may direct storm water through the high flow bypass, therefore circumventing the treatment process.
- Excessive accumulation of trash and debris may affect flows along the gutter line and create localized flooding within the adjacent travel lanes.

Maintenance and Inspections

- Inspect condition monthly and after large storm events.
- Note any damage to the exterior and interior of structures (e.g., concrete or basket).
- Note condition of hydrocarbon boom (if present).

Maintenance and Inspections (continued)

- Conditions warranting cleaning of the unit:
 - Sediment, trash, and debris is visible at catch basin opening;
 - Output flow is significantly dirty and filled with trash and debris; and/or
 - If the unit is greater than 50 percent full of debris or sediment.
- Perform any additional maintenance activities in accordance with the manufacturer's recommendations.



ISOMETRIC

MODIFIED CATCH BASIN

Oil and Grit Separator



Typical Targeted Pollutants for Removal	
Sediment	x
Nutrients	
Oil & Grease	x
Metals	x
Trash	x
Bacteria	n/a

Other Considerations	
Construction Cost	Moderate to High
Maintenance Cost	Varies
Effective Life	20-50 years

Description & Purpose

Oil and grit separators are typically concrete structures with multiple chambers that remove sediment, trash, debris, and oil from storm water. Often designed as an offline pretreatment device, oil and grit separators have limited storage capacity and do not effectively remove nutrients and metals.

Applications

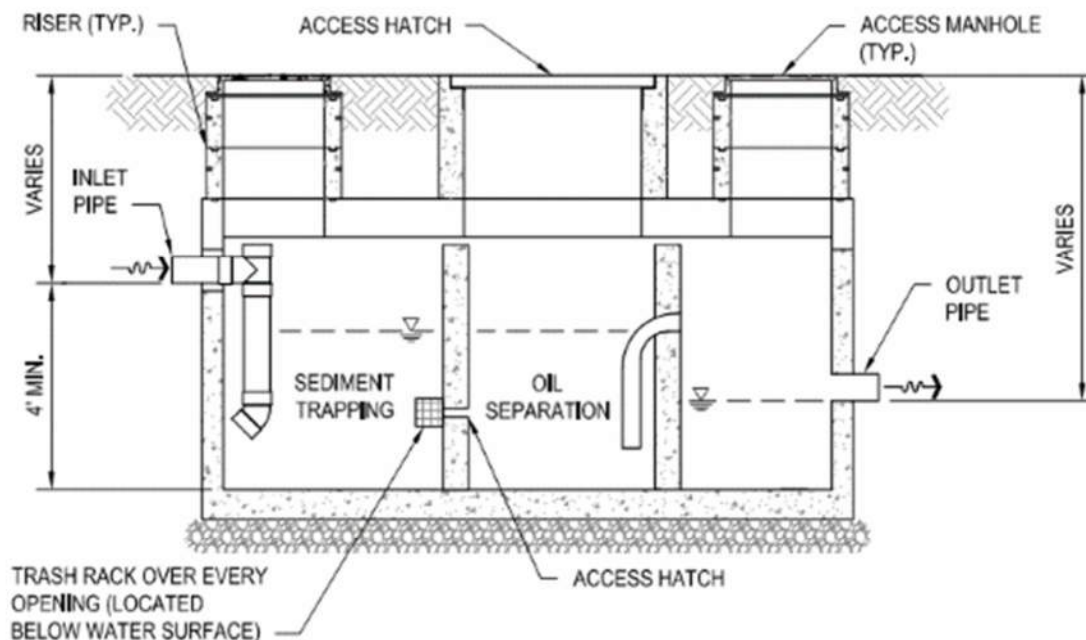
Oil and grit separators are used in highly urbanized areas where oils and sediment are the main pollutants of concern such as in parking lots, industrial facilities, gas stations, and maintenance base yards.

Limitations

- A significant percentage of petroleum products are attached to fine suspended solids and not easily removed by settling.
- Oil and grit separators are typically cost-effective for smaller drainage areas and smaller storm events.
- Reduce or avoid directing storm water from other areas of the site through the oil and grit separator to maintain its efficiency and minimize maintenance requirements.
- Requires frequent periodic maintenance; otherwise, sediment may be resuspended and released back into the drainage system downstream.
- Oil spills must be cleaned up quickly to avoid downstream contamination.

Maintenance and Inspections

- Inspect condition at least every 3 months.
- Note any damage to the exterior and interior of structures (e.g., concrete or grate).
- Conditions warranting cleaning of the unit:
 - Recent oil spill or fuel spill;
 - Floatables cover more than 50 percent of surface area or impedes proper functioning of system; and/or
 - If the depth of deposits exceeds 50 percent of the distance from the bottom to the invert of the outlet pipe.
- Use vacuum hoses to remove floatables and sediments.
- Both sediments and floatables may contain heavy metals or toxic substances and should be handled as hazardous waste.
- Replace oil absorbent pads as necessary; however, at a minimum, replace pads in the fall prior to the rainy season and in the spring (King County 2021).
- Comply with confined-space procedures as required by OSHA regulations.
- Perform any additional maintenance activities in accordance with the manufacturer's recommendations.



ELEVATION

OIL/GRIT SEPARATOR



Typical Targeted Pollutants for Removal	
Sediment	x
Nutrients	
Oil & Grease	x
Metals	x
Trash	x
Bacteria	

Other Considerations	
Construction Cost	Moderate to High
Maintenance Cost	Varies
Effective Life	20-50 years

Description & Purpose

A centrifugal hydrodynamic separator is a flow-through structure that uses centrifugal motion to separate and retain heavier sediment and floatables from storm water runoff before discharging to the downstream drainage system.

Applications

Centrifugal hydrodynamic separators are most applicable in areas that receive heavy sediment, trash, and debris loads. These devices use a vertical centrifugal process which allows for a relatively small footprint area but results in a larger depth.

Limitations

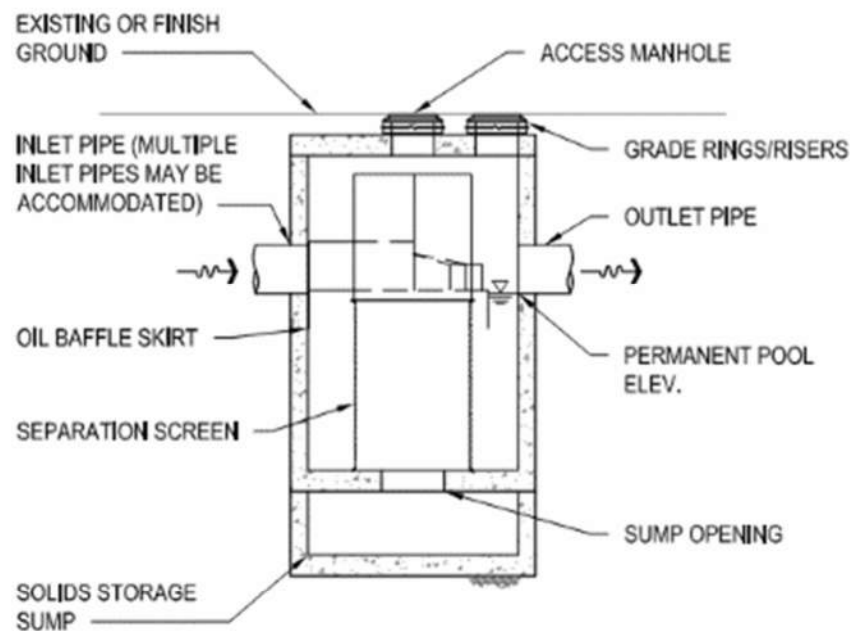
- Centrifugal hydrodynamic separators are not effective at removing fine particles (< 50 microns) that remain in suspension or dissolved pollutants.
- Regular maintenance to remove captured trash and sediments is required.
- Vactor trucks are typically used to remove accumulated sediment, trash, and debris which may impact traffic and require lane closures.

Maintenance and Inspections

- Inspect at least every 6 months.
- Note any damage to the exterior and interior of structures (e.g., concrete, manhole lids or cylinder and screens).
- Check inlet for debris accumulation.
- Take note of floatables and if there are any outside of the separation screen that would indicate a bypass event.

Maintenance and Inspections (continued)

- Conditions warranting cleaning:
 - Recent oil spill or fuel spill
 - Floatables cover more than 50 percent of surface area
 - Output flow is significantly dirty and filled with trash and debris
 - Evidence of vectors, such as mosquito larva in the basin or adults in area
 - The unit is more than 75 percent full of debris or sediment
- Perform any additional maintenance activities in accordance with the manufacturer's recommendations.



ELEVATION

CENTRIFUGAL
HYDRODYNAMIC SEPARATOR

Multi-Stage Hydrodynamic Separator



Kamehameha Highway Median, Kaneohe, Hawaii

Typical Targeted Pollutants for Removal	
Sediment	x
Nutrients	
Oil & Grease	x
Metals	x
Trash	x
Bacteria	

Other Considerations	
Construction Cost	Moderate to High
Maintenance Cost	Varies
Effective Life	20-50 years

Description & Purpose

A multi-stage hydrodynamic separator is a flow-through structure that directs storm water runoff horizontally through a concrete structure and uses baffle boxes to separate and retain heavier sediment. Optional screens can retain floatables before discharging storm water to the downstream drainage system. Hydrocarbon booms may also be installed within the system to absorb hydrocarbons and other soluble pollutants.

Applications

Multi-stage hydrodynamic separators are primarily used where sediment, trash, and debris are main concerns and may also be used in areas that are expected to discharge a variety of pollutants.

Limitations

- Frequent maintenance to remove captured trash and sediments is required; otherwise, subsequent storm events may resuspend sediments and release them into the downstream system.
- Vactor trucks are typically used to remove accumulated sediment, trash, and debris which may impact traffic and require lane closures.
- Significant accumulation of trash and debris may block incoming flow and result in backups further upstream.

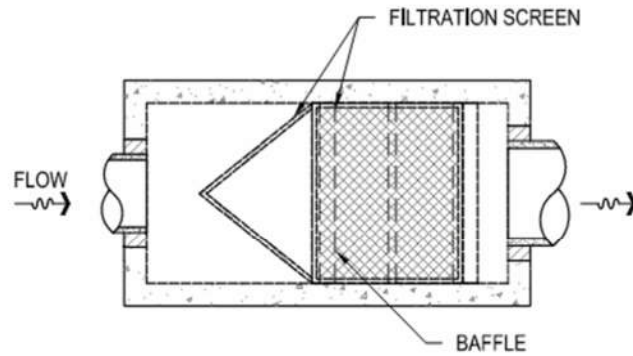


Multi-Stage Hydrodynamic Separator

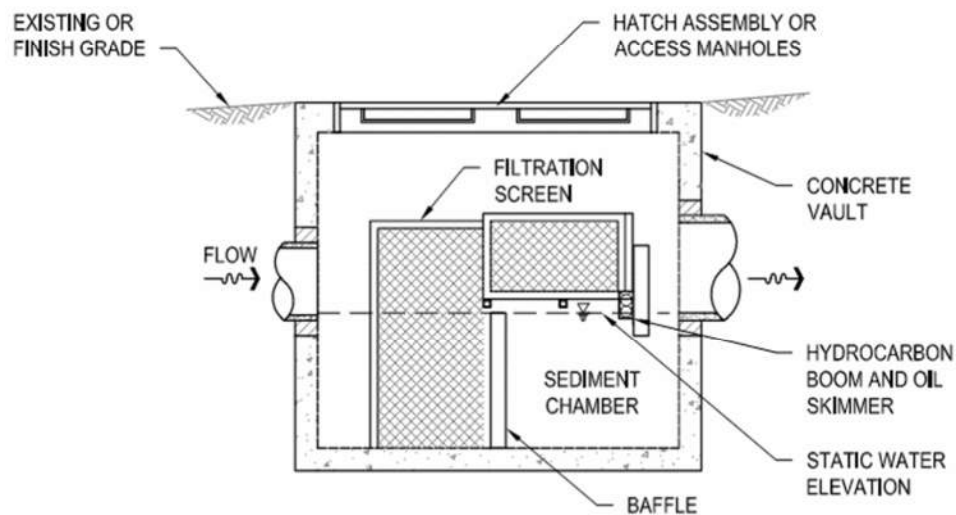
T-18

Maintenance and Inspections

- Inspect at least every 6 months.
- Note any damage to the exterior and interior of structures (e.g., concrete, manhole lids or cylinder and screens).
- Check inlet for debris accumulation.
- Take note of floatables and if there are any outside of the separation screen that would indicate a bypass event.
- Conditions warranting cleaning:
 - Recent oil spill or fuel spill
 - Floatables layer covers more than 50 percent of surface area
 - Output flow is significantly dirty and filled with trash and debris
 - Evidence of vectors, such as mosquito larva in the basin or adults in area
 - The unit is more than 75 percent full of debris or sediment
- Perform any additional maintenance activities in accordance with the manufacturer's recommendations.



PLAN



ELEVATION

MULTI-STAGE
HYDRODYNAMIC SEPARATOR





APPENDIX B

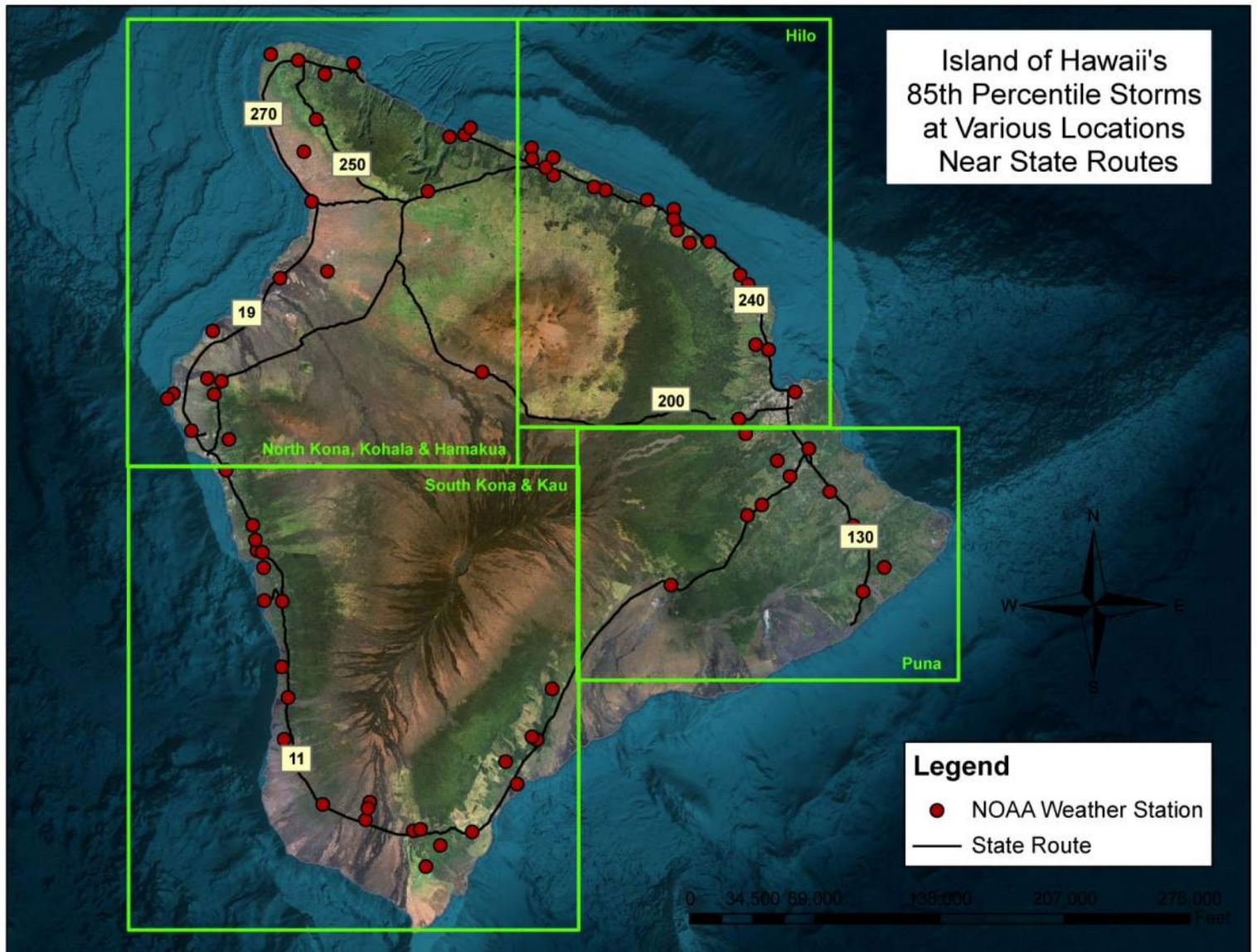
RAIN STATIONS ANALYZED FOR QUANTITATIVE CRITERIA



Introduction

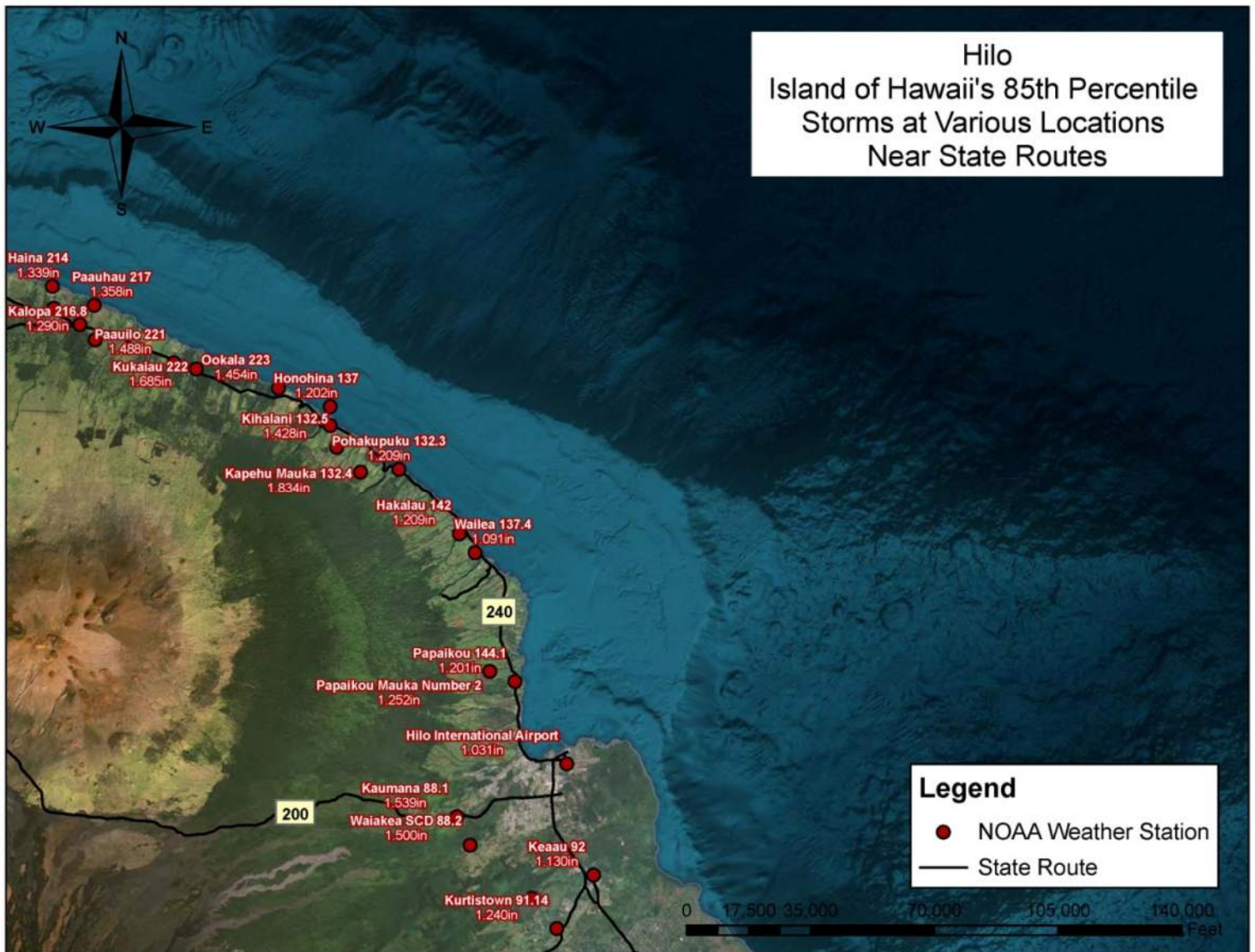
This appendix provides graphical references regarding the rain gauge stations used in determining the quantitative criteria. These references are not to be used in local estimation of reducing the water quality design volume.

Hawaii County



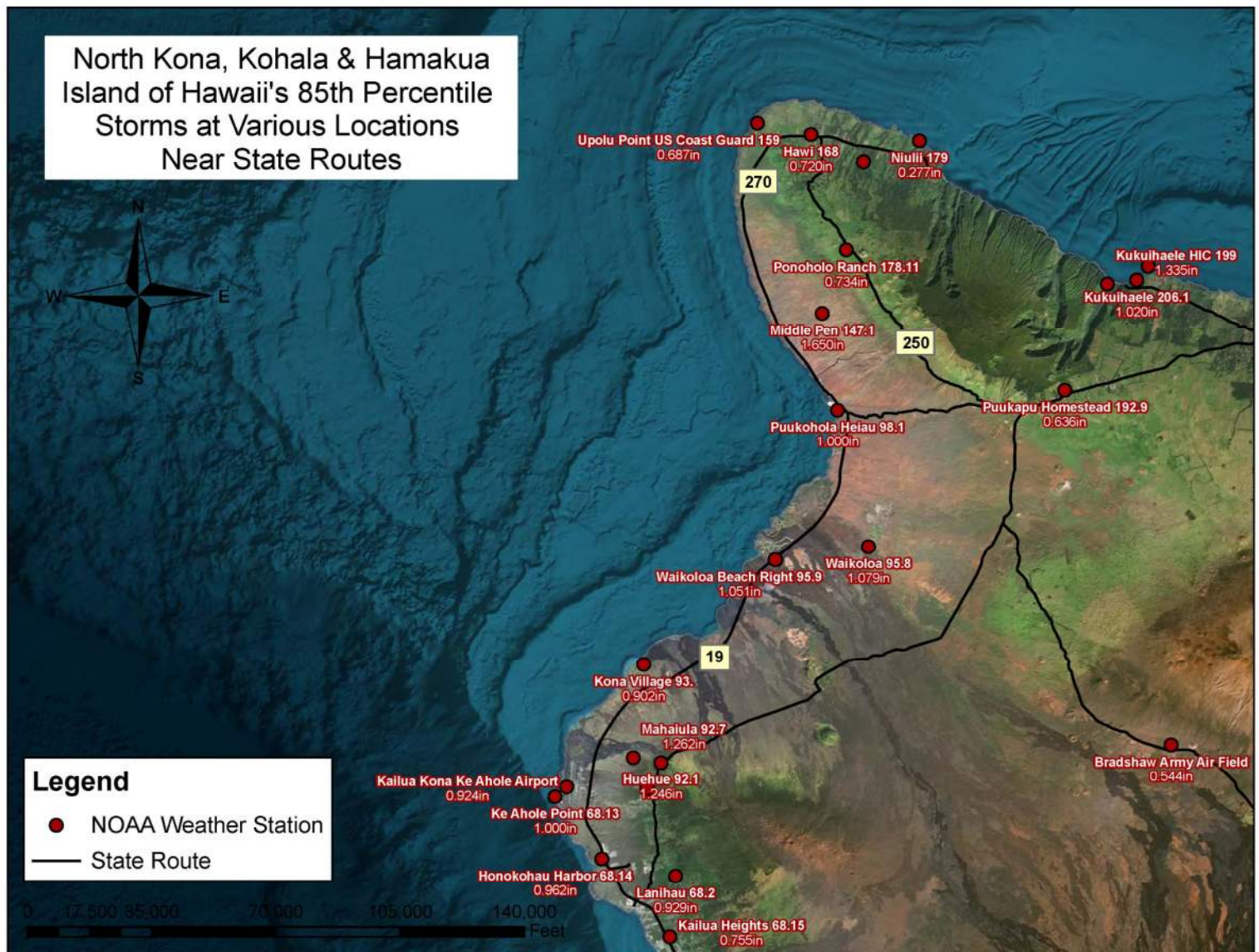


Hawaii County (Hilo Area)



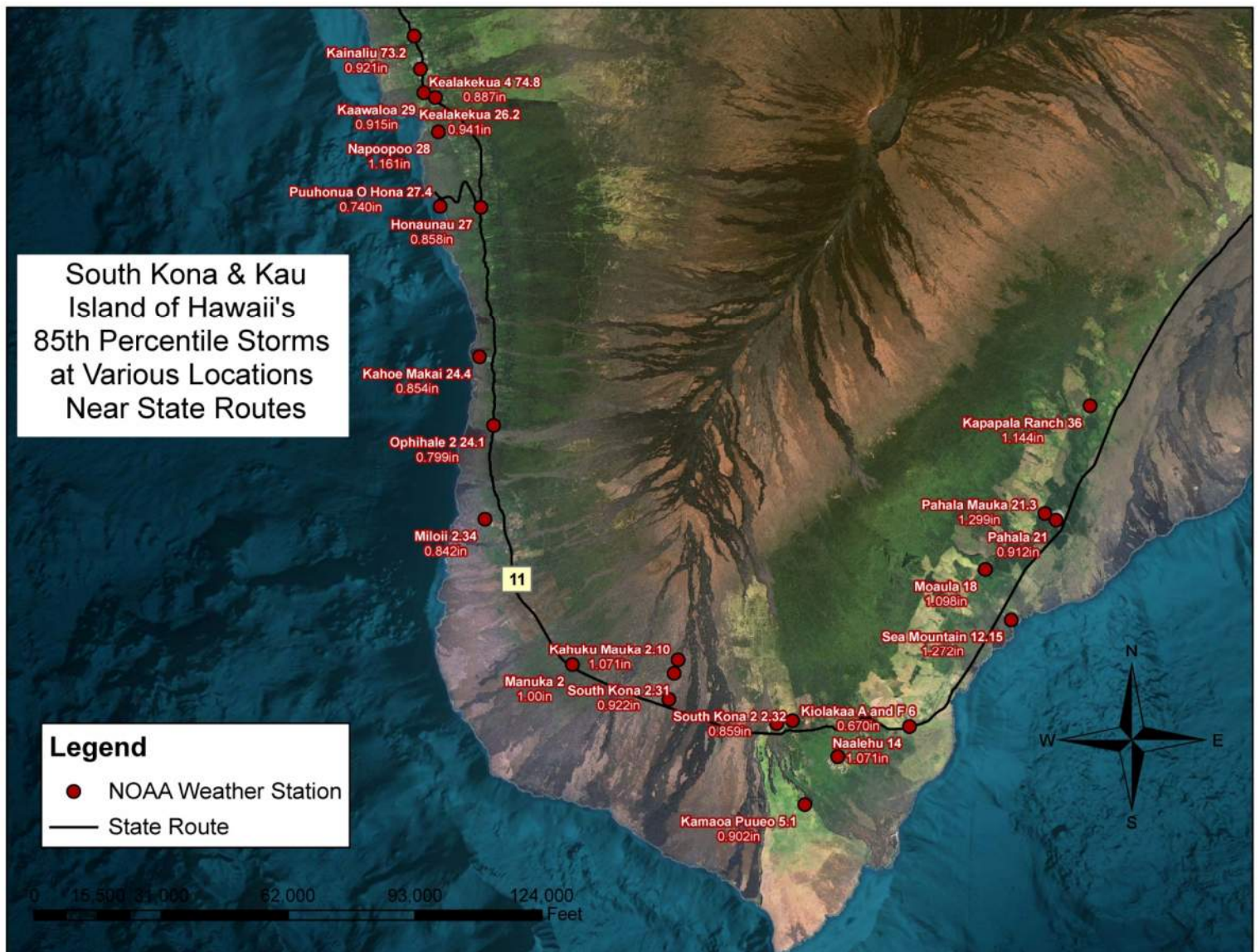


Hawaii County (North Kona, Kohala, & Hamakua Area)



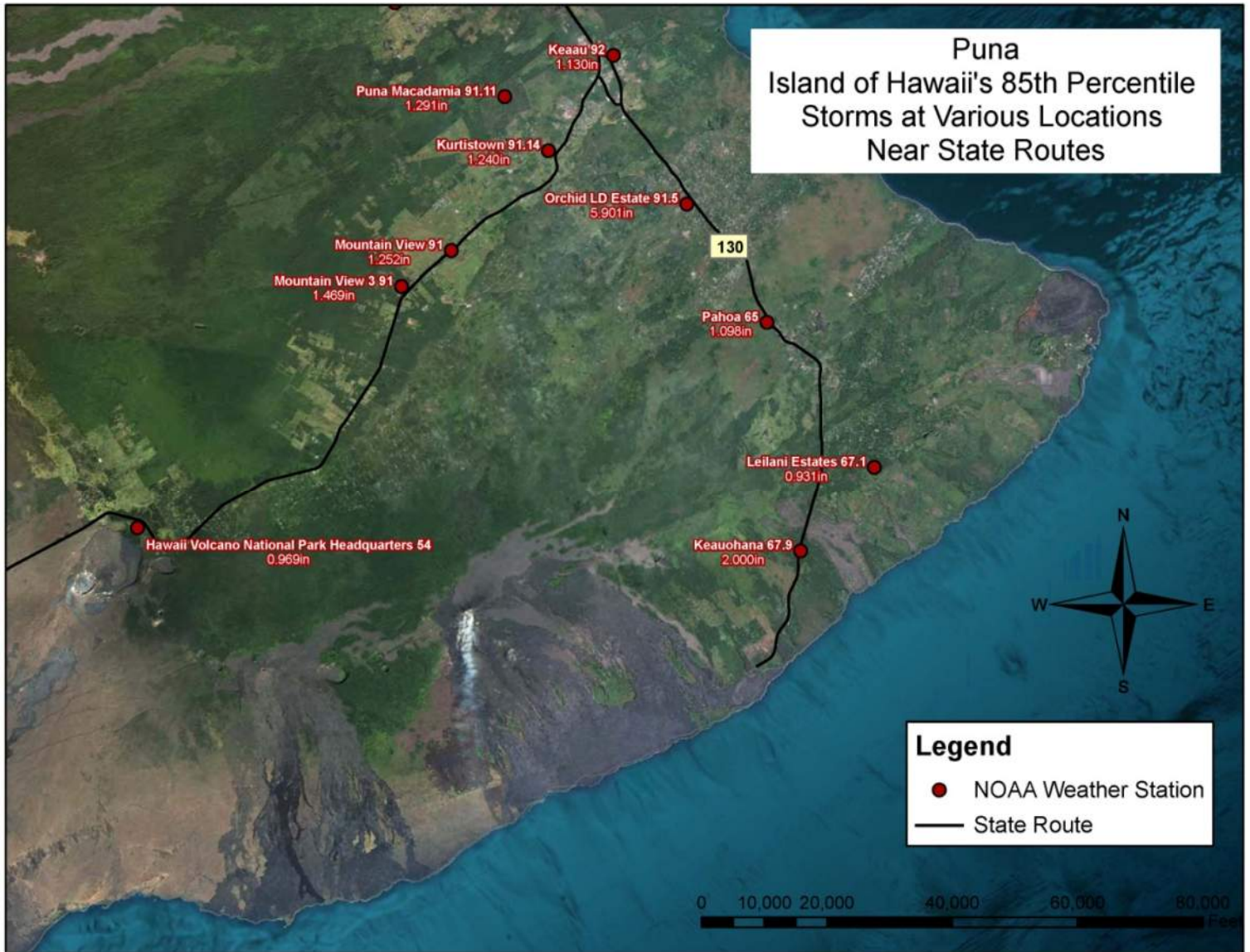


Hawaii County (South Kona & Ka'u Area)





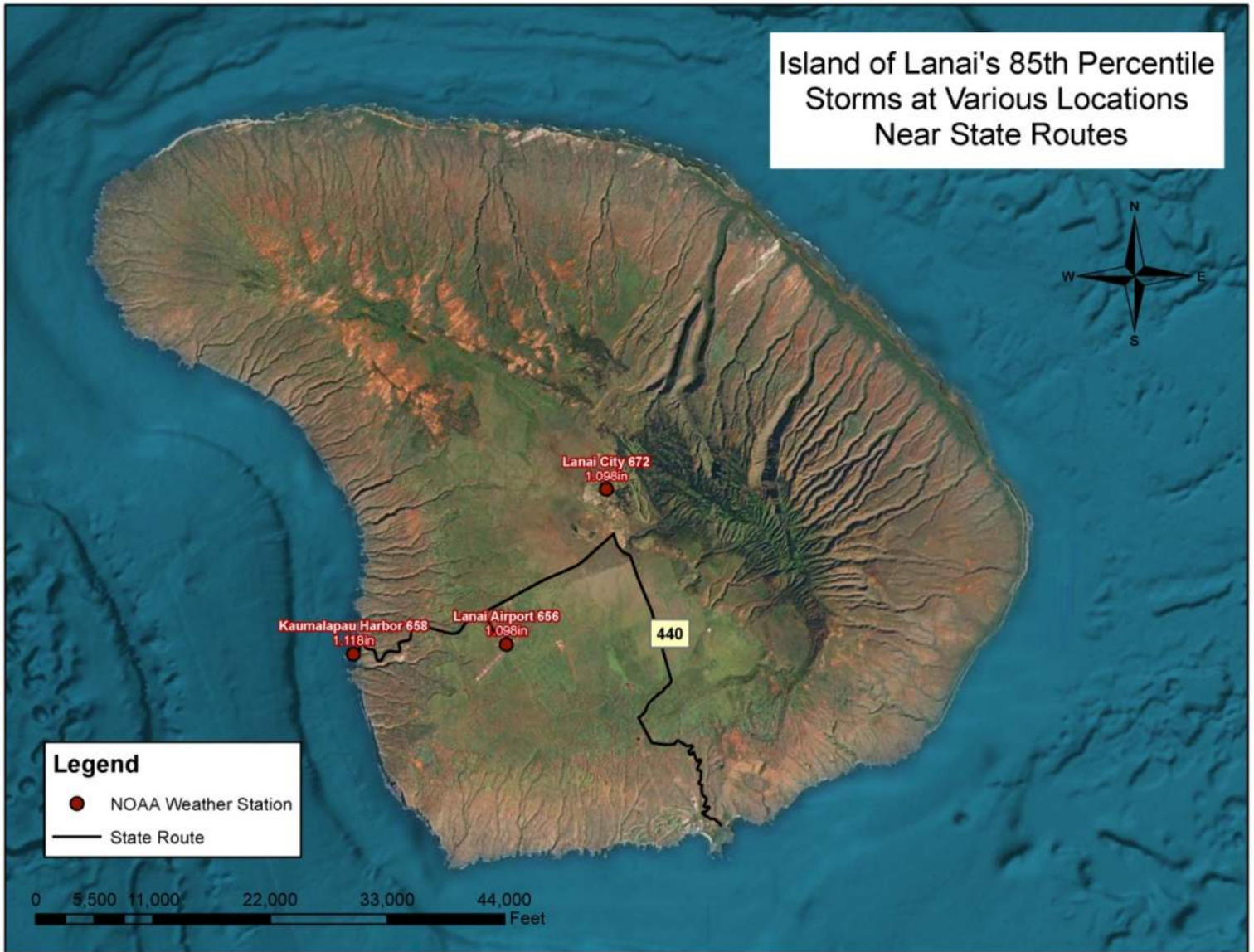
Hawaii County (Puna Area)





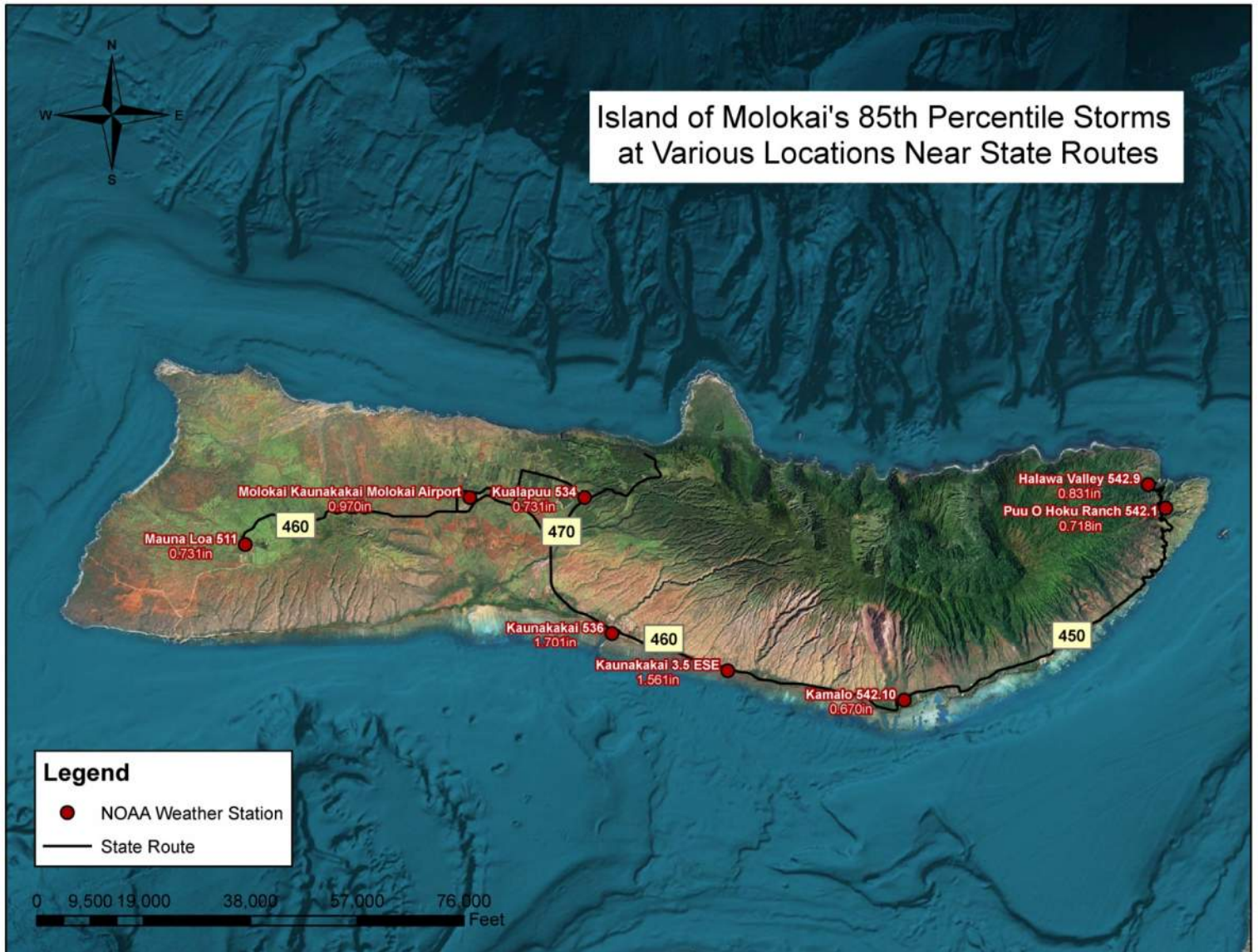


Maui County (Lana'i)

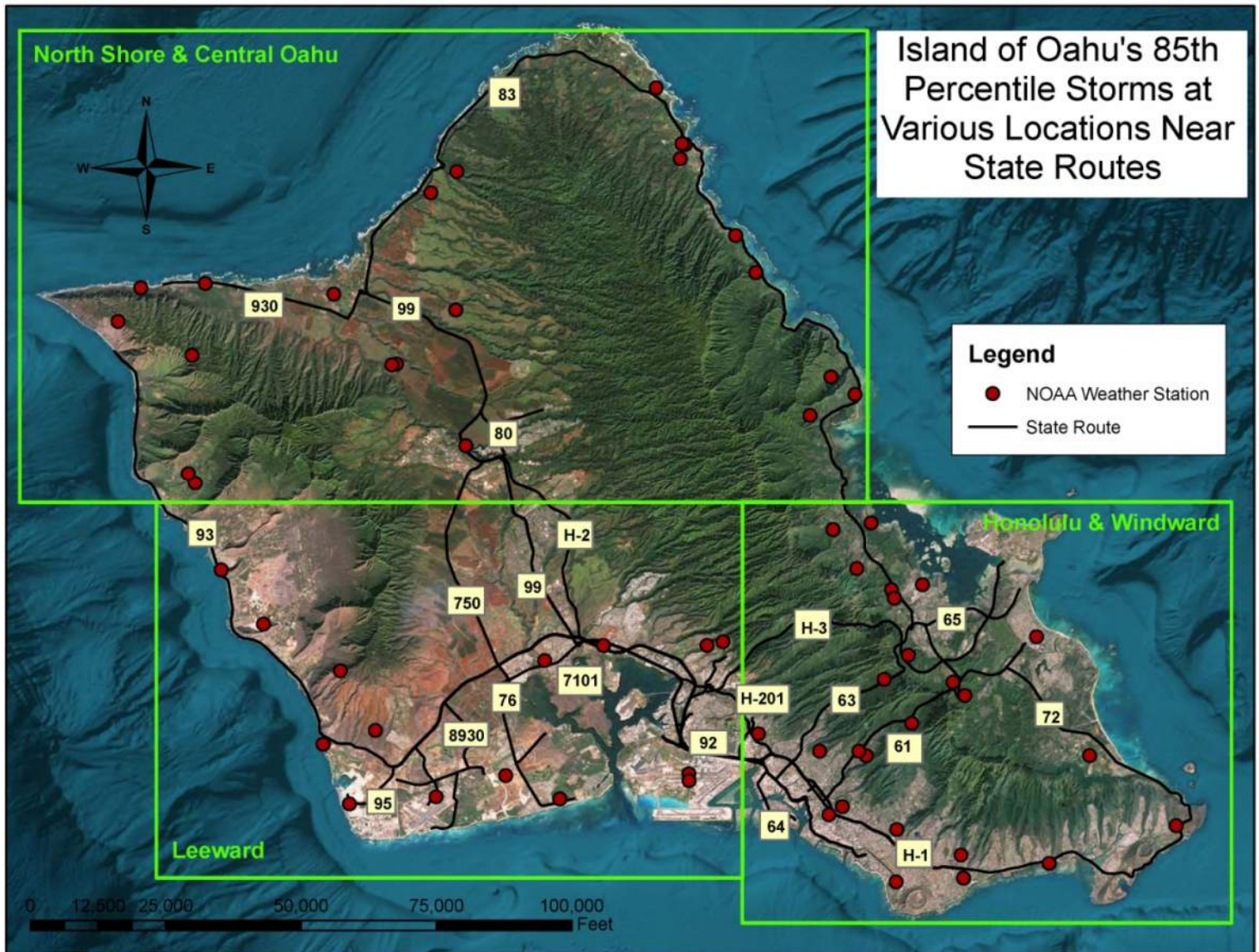




Maui County (Moloka'i)

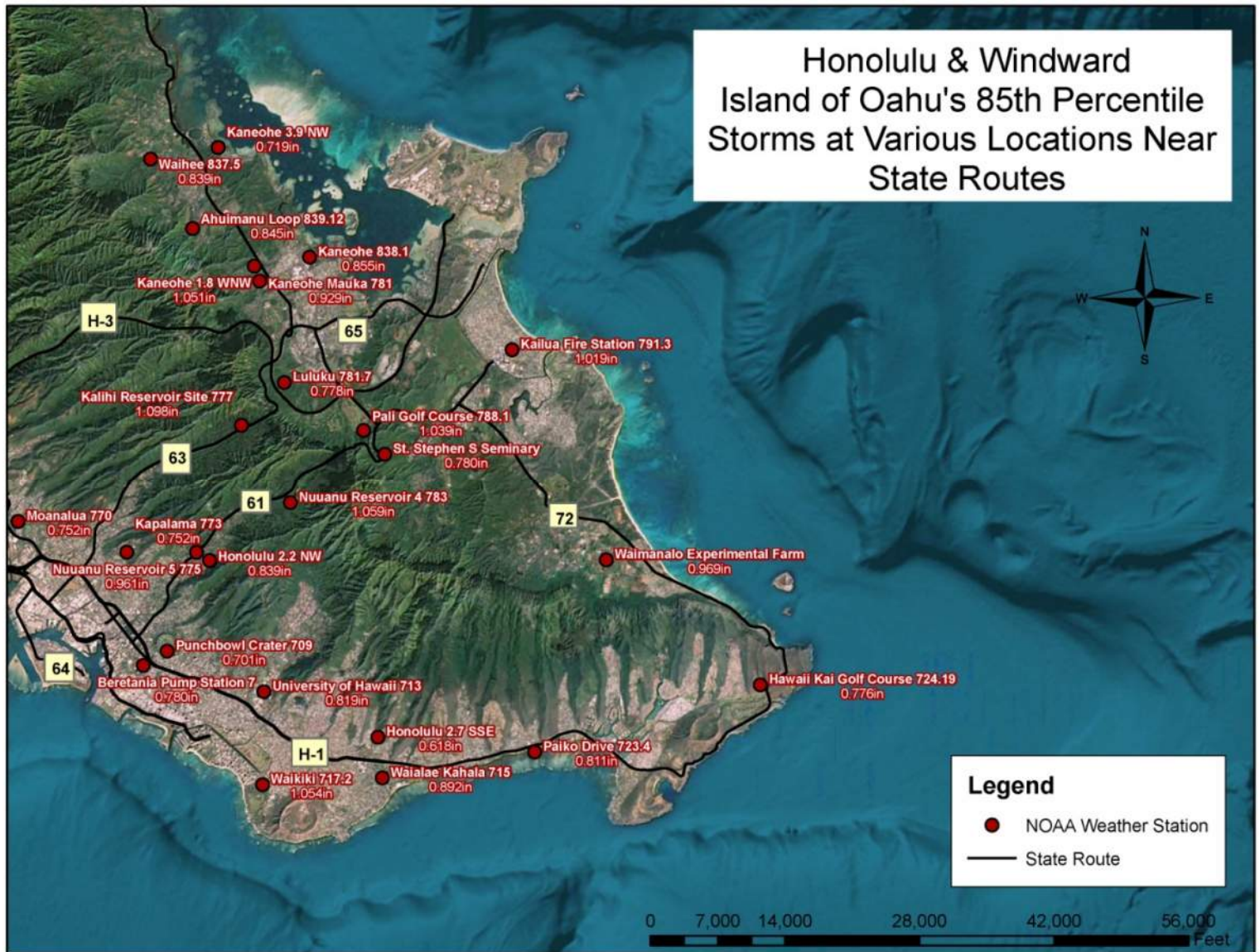


Honolulu County



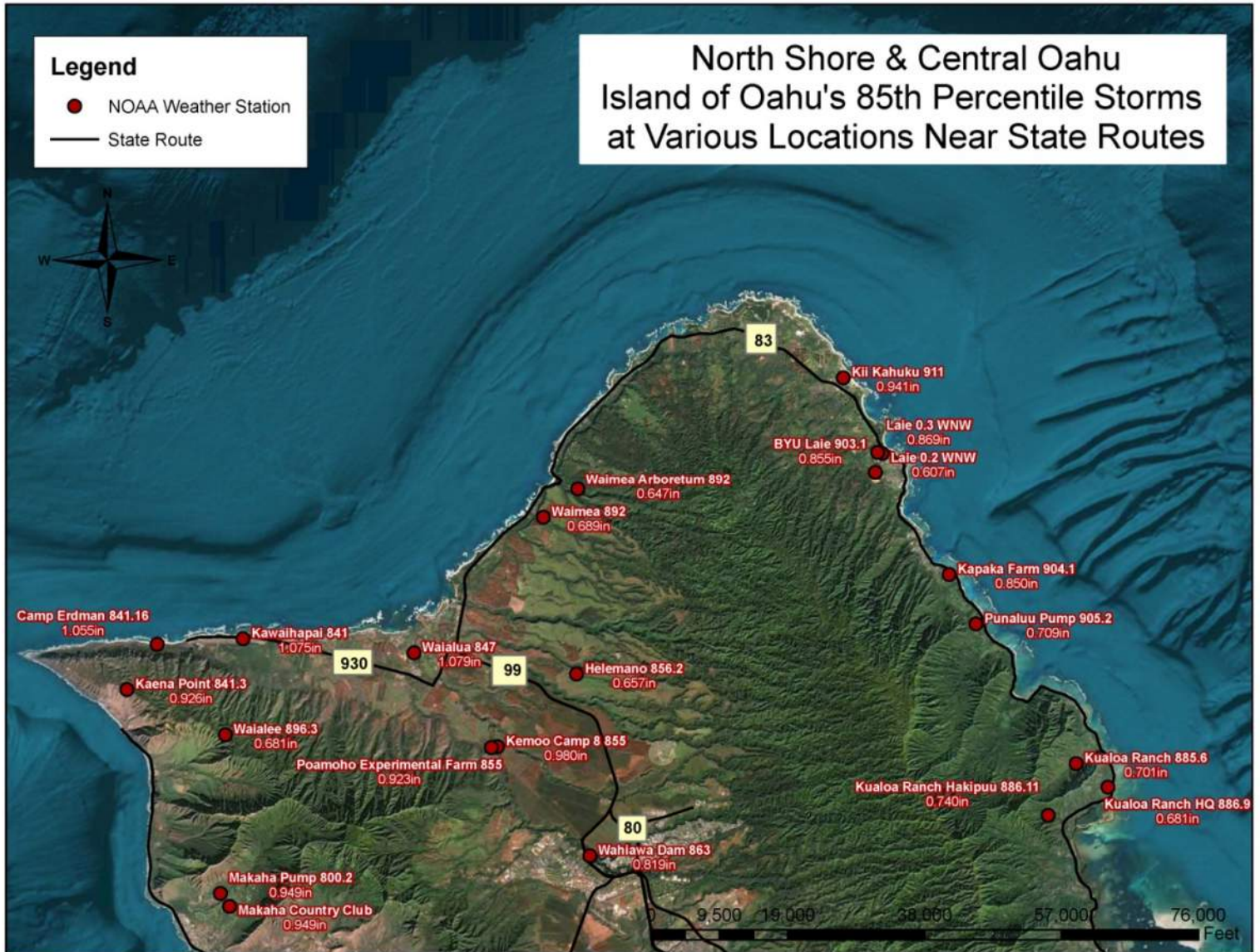


Honolulu County (Honolulu & Windward Area)



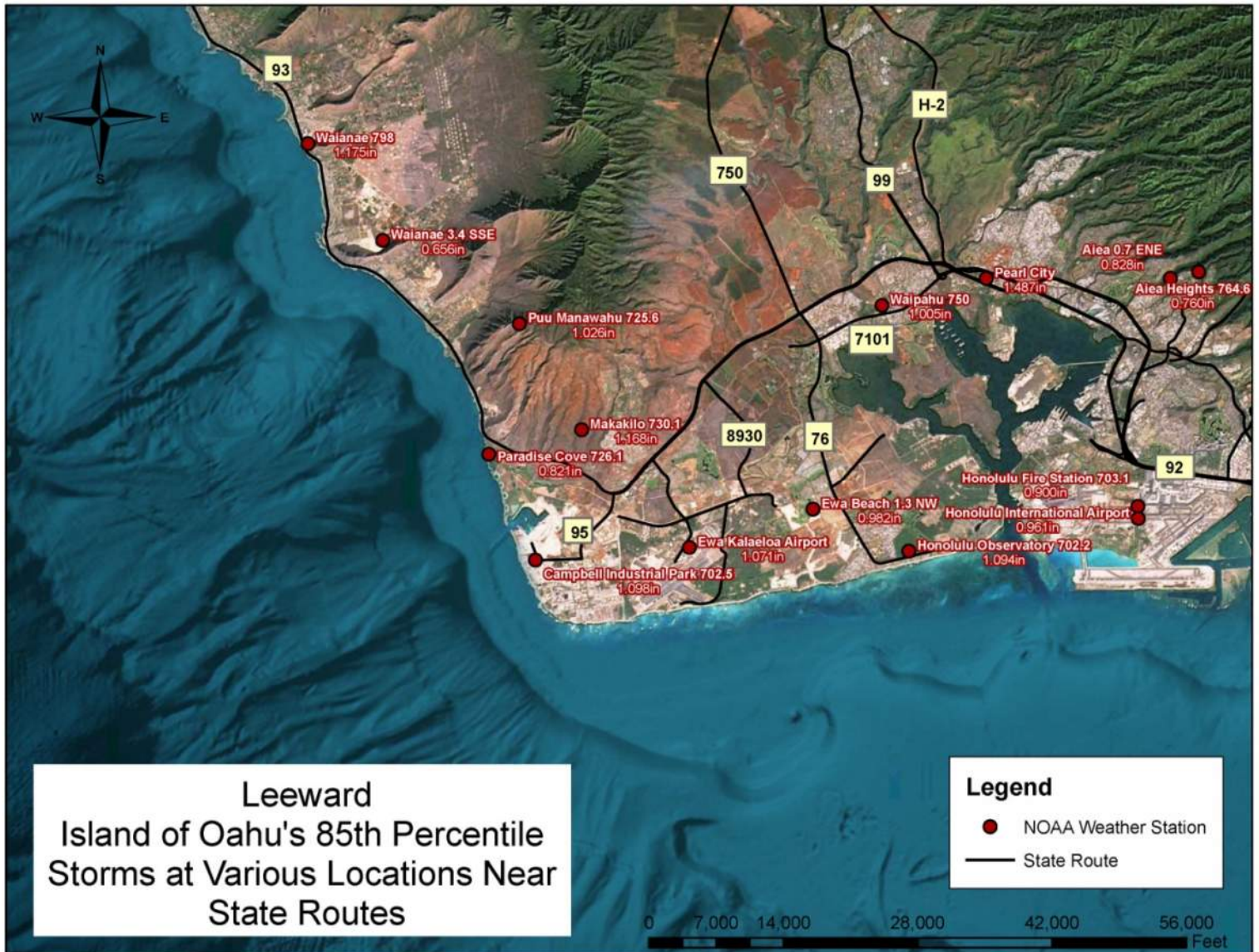


Honolulu County (North Shore & Central Oahu)





Honolulu County (Leeward Oahu)



Kauai County

