Post-Construction/Permanent Best Management Practice Manual

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LIST OF ACRONYMS

AC	Advisory Circular
AIR-E	State of Hawaii, Department of Transportation, Airports Engineering Branch
AIR-EE	State of Hawaii, Department of Transportation, Airports Engineering Branch, Environmental Section
AOA	Aircraft Operations Area
BMP	Best Management Practice
CCH	City and County of Honolulu
CFR	Code of Federal Regulations
CWA	Clean Water Act
DOH	State of Hawaii, Department of Health
DOH SDWB	State of Hawaii, Department of Health, Safe Drinking Water Branch
DOT	State of Hawaii, Department of Transportation
DOTA	State of Hawaii, Department of Transportation, Airports
EPA	U.S. Environmental Protection Agency
FAA	Federal Aviation Administration
GIS	Geographic Information System
GPS	Global Positioning System
HAR	Hawaii Administrative Rules
HDS	Hydrodynamic Separator
HNL	Daniel K. Inouye International Airport
HRS	Hawaii Revised Statutes
HSG	Hydrologic Soil Group
LID	Low Impact Development
MS4	Municipal Separate Storm Sewer System
NPDES	National Pollutant Discharge Elimination System
NRCS	National Resources Conservation Service
O&M	Operations and Maintenance
OWS	Oil Water Separator
PBMP	Post-Construction/Permanent Best Management Practice
SPM	State Project Manager
SWPPP	Stormwater Pollution Prevention Plan
TMDL	Total Maximum Daily Load
UIC	Underground Injection Control
USDA	U.S. Department of Agriculture
WQF	Water Quality Flow Rate
WQV	Water Quality Volume

GLOSSARY

303(d) List – Under *CWA § 303(d)*, States are required to compile a list of impaired and threatened waters that fail to meet applicable water quality standards or cannot support designated or existing uses. The 303(d) list is required to be submitted for EPA approval every two years. States are required to develop a TMDL for each pollutant causing impairment for water bodies on the list.

Best Management Practices or BMPs – Stormwater management practices utilized to reduce or eliminate the negative impacts of stormwater runoff.

HAR § 11-54 defines BMPs as, "schedules of activities, prohibitions or designations of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of state waters. Best management practices also include treatment requirements, operating procedures, and practices to control plant site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage. BMPs include methods, measures, or practices selected by the department to meet nonpoint source pollution control needs. BMPs also include but are not limited to structural and non-structural controls. BMPs can be applied before, during, and after pollution-producing activities."

Biofiltration – A sustainable method of stormwater treatment that utilizes natural biological processes to remove pollutants from stormwater runoff. It typically involves the use of engineered vegetative systems where stormwater is directed to filter through layers of soil, vegetation, and microbial communities. These systems work by facilitating physical, chemical, and biological interactions that help capture, absorb, degrade, and transform pollutants, including sediment, nutrients, heavy metals, and organic compounds, before the water is discharged offsite.

Clean Water Act or CWA – (*33 USC 1251 et seq*.) Requirements of the NPDES program are defined under *CWA § 307, 402, 318, and 405*.

Construction Activity – Refer to *HAR § 11-55, Appendix C*.

Detention – The capture and subsequent release of stormwater runoff from a site at a slower rate than it is collected, the difference being held in temporary storage.

Detention Volume – The volume of runoff that is held in a temporary storage structure.

Disturbed Area/Disturbance of Land – Refer to *HAR § 11-55, Appendix C*.

Drainage Area – The specific land area that contributes stormwater runoff into a defined point. Drainage area also refers to the drainage basin or watershed.

Drain or drawdown – Lowering of the water surface resulting from a withdrawal or release of water.

Drain or drawdown time – The time it takes for a PBMP to completely empty the WQV, i.e., there should be no ponded or standing water in the PBMP past the drain or drawdown time after a rain event.

Erosion – The wearing of land surface by wind or water. Erosion occurs naturally from weather or runoff but can be intensified by land-clearing practices related to farming, new development, redevelopment, road building, or timber cutting.

Evapotranspiration – The combined loss of water into the atmosphere by evaporation (water changing from a liquid to vapor from soil, water, or plant surfaces) and transpiration (water taken up by plant roots and transpired through plant tissue and leaves).

Filter Fabric – A synthetic material used to filter potential pollutants from stormwater runoff.

Flood or Flooding – The inundation to a depth of 3 inches or more of any property not ordinarily covered by water. The terms do not apply to inundation caused by tsunami wave action.

Grading – Any excavation, leveling, or fill, or combination thereof.

Hydrologic Soil Group or HSG – A measure of soil types ranging from A (very permeable, lowest runoff potential) to D (low permeability, highest runoff potential). These parameters can be determined from soil maps prepared by the USDA for any county or using the NRCS Web Soil Survey website.[1]

Impervious Surface – A surface that prevents the land's natural ability to absorb and infiltrate rainfall/stormwater. Man-made impervious surfaces include, but are not limited to, asphalt, concrete, patios, and rooftops. For the purposes of this Manual, this definition does not include soil or rock that are impervious in nature.

Infiltration – The process by which water penetrates the soil surface and moves downward into the subsoil.

Infiltration PBMPs – Practices that capture and temporarily store stormwater at a volume equal to or greater than the design storm volume until it infiltrates into the soil.

Infiltration Rate – The infiltration rate or permeability (inch per hour) is the rate at which water passes through the soil profile during saturated conditions.

Inlet – A permanent structure designed to capture and direct stormwater runoff from the surface into a drainage system or PBMP.

Invert – The lowest point inside a drainage structure, conveyance system, or PBMP.

Low Impact Development or LID – A stormwater and land use management strategy that strives to mimic pre-development hydrologic processes of infiltration, filtration, storage, evaporation, and transpiration by emphasizing conservation, use of on-site natural features, site planning, and distributed stormwater management practices that are integrated into a project design.

Maximum Extent Practicable or MEP – The highest level of effort or action that is reasonable and economically achievable to implement measures to reduce the quantity and improve the quality of stormwater runoff to the greatest extent possible through applying the best available non-point source pollution control practices, technologies, processes, siting criteria, and operating methods.

[1] https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

Municipal Separate Storm Sewer System or MS4 – A conveyance or system of conveyances (including roads with drainage systems, streets, catch basins, curbs, gutters, ditches, man-made channels, or storm drains) that is designed or used for collecting or conveying stormwater and is owned or operated by a city, county, or other governmental entity (including federal and state entities). The term "MS4" specifically excludes combined sewers and systems that are part of a Publicly Owned Treatment Works.

New Development – The creation or addition of impervious surface in a previously undeveloped area.

National Pollutant Discharge Elimination System or NPDES – The national program for issuing, modifying, revoking and reissuing, terminating, monitoring and enforcing permits, and imposing and enforcing pretreatment requirements, under the *CWA § 402*.

On-line Facility – A water quality treatment facility that receives stormwater runoff from a drainage area and **is directly integrated into the main path of stormwater**. Flows above the water quality design flow rate or volume are passed through at a lower percent removal efficiency.

Off-line Facility – A water quality treatment facility that is connected to the stormwater system in such a way that it only receives a portion of the runoff, usually through a diversion structure. In volume-based applications, off-line facilities can receive the design storm volume while excess flows are bypassed. In flow-based applications, off-line facilities can be designed to receive a controlled design flow rate through the diversion structure.

On-site – The area within the boundaries of a specific site or property.

Operational Source Control PBMPs – Schedules of activities, prohibition of practices, and other practices used to prevent or reduce pollutants from entering stormwater. Operational PBMPs can include the formation of a pollution prevention team, good housekeeping, preventive maintenance procedures, spill prevention and clean-up, employee training, inspections of pollutant sources and BMPs, and record keeping. They can also include process changes, raw material/product changes, and recycling wastes.

Overflow – A component or mechanism integrated into a PBMP design to convey stormwater when the system's design capacity is exceeded to prevent flooding, property damage, and infrastructure failure.

Permeable Pavement – Pervious concrete, porous asphalt, permeable pavers, or other forms of pervious or porous paving material intended to allow passage of water through or between the pavement section. Permeable pavement often includes an aggregate base that provides structural support and acts as a stormwater reservoir.

Pollutant – Any substance or agent introduced into the environment that may cause harm or disrupts the natural balance of ecosystems, human health, or property.

Pollution – The introduction of contaminants into stormwater runoff, which can adversely affect water quality, including change in temperature, taste, color, turbidity, or odor of the water, or such discharge of any liquid, gaseous, solid, radioactive or other substance into a receiving water that will or is likely to create a nuisance or render such waters harmful, detrimental or injurious to the public health, safety or welfare, or to domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or livestock, wild animals, birds, fish or other aquatic life.

Pollution Prevention – Practices and actions that reduce or eliminate the generation of pollutants at the source.

Post-Construction Best Management Practice, Permanent Best Management Practice, or PBMP – A BMP designed to reduce the stormwater volume or improve stormwater quality after construction is completed and over the life of a property's use. Permanent BMPs may also include source control BMPs to address certain operations that may generate activities, such as the use or storage of hazardous substances, that do not relate to construction.

Pre-treatment – A practice or device designed to remove or reduce pollutants from stormwater runoff before it enters a downstream PBMP. Pretreatment is important to the design of PBMPs. Properly designed pretreatment systems help to sustain the required PBMP function, extend service life, and reduce maintenance costs. The primary goal of most pretreatment systems is to capture sediment, trash, and debris, which is most commonly achieved by decreasing peak stormwater velocities to allow sediment to settle or by filtering stormwater to remove sediment or trash before it reaches a downstream PBMP.

Project Proponent – Designers, contractors, construction managers, and tenants responsible for ensuring that PBMPs are implemented at new development and redevelopment project sites.

Proprietary PBMP – A commercially available pre-manufactured or partially manufactured PBMP that treats stormwater through filtration, separation, or settling methods.

Receiving Water – A water body that receives discharges from point sources, non-point sources, or stormwater runoff.

Redevelopment – The creation, addition, or replacement of impervious surfaces on an existing site.

Retention – The permanent storage of stormwater to prevent it from leaving a site.

Retrofit – Upgrades and alterations to the existing regulated MS4 that provide stormwater treatment, pollutant reduction (e.g., improve the quality of stormwater runoff), trash or floatable reduction, runoff volume reduction, and/or address specific objectives at an existing site. Retrofits can also include opportunities that remedy past design and/or performance deficiencies.

Reuse – Planned capture and treated reuse of stormwater runoff that would otherwise be discharged without being put to direct use.

Runoff – The movement of water over the land surface to drainage facilities, rivers, streams, springs, seeps, ponds, lakes, and wetlands.

Runoff Coefficient or C – A dimensionless coefficient relating the amount of runoff to the amount of precipitation received. It represents the interaction of multiple factors, including water storage in surface depressions, infiltration, antecedent moisture, ground cover, ground slopes, and soil types. Since the runoff coefficient may vary with respect to prior wetting and seasonal conditions, the use of average values is typically applied for simplicity. The runoff coefficient is a larger value for areas with low infiltration and high runoff (e.g., pavement, steep gradient) and a lower value for permeable, well-vegetated areas (e.g., forest, flat land).

Rainfall Intensity or i – The rate at which rain falls over a specific area during a given period. The rainfall intensity is often used to describe the severity or strength of rainfall events and is used to calculate the peak flow in the Rational Method.

Run-on – Off-site stormwater surface flow or other surface flow onto a project site.

Seasonal High Groundwater – Seasonal high groundwater is the highest annual groundwater elevation as determined by a qualified soil scientist, geohydrologist, or licensed engineer in the State of Hawaii based on monitoring wells or other recognized methods.

Secondary Containment – A structure, barrier, or system (e.g., dike, berm) surrounding tanks or other storage containers, designed to capture and contain leaked or spilled materials, preventing them from spreading into the surrounding environment.

Sedimentation – The process of depositing soil particles, clays, sands, or other sediments that were picked up by runoff.

Sediment – Soil, sand, and minerals washed from land into water, usually after rain, which collects in reservoirs, rivers, lagoons, and harbors.

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

Source Control PBMP – Measure that prevents pollutants from contacting stormwater runoff or prevents the discharge of contaminated runoff. Source Control PBMPs can be categorized as operational or structural and are further defined individually in this glossary.

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

State waters – As defined by *HRS § 342D-1*, State waters means all waters, fresh, brackish, or salt around and within the State, including, but not limited to, coastal waters, stream, rivers, drainage ditches, ponds, reservoirs, canals, groundwaters, and lakes; provided that drainage ditches, ponds, and reservoirs required as part of a water pollution control system are excluded. *HAR § 11-54* applies to all State waters, including wetlands, subject to the following exceptions:

> HAR § 11-54 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.
>
> HAR § 11-54 does not apply to drainage ditches, flumes, ponds, and reservoirs that are required as part of a water pollution control system.

> HAR § 11-54 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 U.S. as defined in 40 CFR § 122.2.

The term “receiving water” is indicative of the particular State water that a project discharges to and this term is used throughout this Manual. The terms, State waters and receiving waters are used interchangeably in this Manual.

Storm Drain – Above- and below-ground structures for transporting stormwater to streams or outfalls for flood control purposes.

Storm Frequency – The time interval between major storms of predetermined intensity and runoff volumes for which storm sewers and other structures are designed and constructed to hydraulically accommodate flow without surcharging and/or back flooding (e.g., a 2-year, 10-year, or 100-year storm).

Stormwater – According to *40 CFR § 122.26 (b)(13)*, stormwater means stormwater runoff, snow melt runoff, and surface runoff and drainage.

Structural Source Control PBMPs – Physical, structural, or mechanical devices or facilities intended to prevent pollutants from entering stormwater. Structural Source Control PBMPs typically include enclosing or covering the pollutant source (e.g., a building or other enclosure, a roof over storage and working areas, temporary tarp, etc.) or segregating the pollutant source to prevent stormwater run-on and direct only contaminated stormwater to appropriate treatment control PBMPs.

Swale – A shallow drainage conveyance with relatively gentle side slopes.

Time of Concentration or T_c – The time it takes for runoff to travel from the hydraulically most distant point in the watershed to the point of reference downstream.

Treatment Control PBMP – Engineered technology designed to remove pollutants from stormwater runoff prior to discharge to a storm drainage system or receiving waters.

Tributary Drainage Area – A geographic area where precipitation collects and runoff drains into a common outlet or a PBMP.

Underdrain – A pipe with holes drilled through the top, installed on the bottom of a PBMP, used to collect and remove captured runoff.

Underground Injection Control or UIC Program – A federal regulatory program established to protect underground sources of drinking water from contamination by regulating the injection of fluids into underground wells. The EPA has granted the DOH SWDB authority to regulate the UIC Program.

Drainage Well – According to *HAR § 11-23* a well is defined as “a bored, drilled or driven shaft, or dug hole whose depth is greater than its widest surface dimension.” If drainage wells are deeper than their widest surface dimension, they are regulated under the State’s UIC program.

Waters of the United States –EPA and the Department of Army published the *CWA: Revised Definition of 'Waters of the U.S.' Final Rule* effective August 29, 2023. However, court decisions may affect regulatory definitions; refer to the current guidance by EPA and the Department of Army. Additional information can be obtained from EPA Waters of the United States web page, which can be accessed using the following webpage: https://www.epa.gov/wotus.

Wildlife – Any wild animal, including without limitation any wild mammal, bird, reptile, fish, amphibian, mollusk, crustacean, arthropod, coelenterate, or other invertebrates, including any part, product, egg, or offspring thereof.

Wildlife Attractants – Any man-made structure, land-use practice, or man-made or natural geographic feature that can attract or sustain hazardous wildlife within the landing or departure airspace or the airport's aircraft operations area. These attractants can include architectural features, landscaping, waste disposal sites, wastewater treatment facilities, agricultural or aquaculture activities, surface mining, or wetlands.

Wildlife Hazard – A potential for a damaging aircraft collision with wildlife on or near an airport. Species of wildlife (birds, mammals, reptiles), including feral and domesticated animals, not under control that may pose a direct hazard to aviation (i.e., strike risk to aircraft) or an indirect hazard such as an attractant to other wildlife that poses a strike hazard or is causing structural damage to airport facilities (e.g., burrowing, nesting, perching).

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INTRODUCTION

This Post-Construction/Permanent BMP Manual (herein referred to as "Manual") was developed to provide guidance for assessing the requirements, applicability, and technical feasibility of implementing PBMPs at airports owned or operated by DOTA. DOTA is required to comply with federal, state, and county regulations to protect water resources by treating and controlling stormwater runoff flow rates for new development and redevelopment projects at its airports. However, airports are different from other industrial, commercial, or MS4 project sites, and DOTA must manage stormwater in a way that will not compromise aircraft safety. Wildlife attractants at airports are a major concern because of the potential for collisions between wildlife and aircraft that threaten human safety. Many traditional PBMPs, such as ponds, may provide wildlife habitat and, thereby, attract wildlife species that can be hazardous to aircraft. As a result, such traditional PBMPs must be individually considered and appropriately selected for use at airports to reduce or eliminate hazardous wildlife attractants. This Manual focuses on the technical and safety issues related to stormwater management within the airport environment.

This Manual requires that specified new development and redevelopment projects include PBMPs. PBMPs are designed to provide water quantity control and improve water quality after construction is completed. PBMPs are further classified into the following categories based on priority:

- LID PBMPs
- Source Control PBMPs
- Treatment Control PBMPs

The purpose of PBMPs is to mimic pre-construction hydrologic processes, reduce or prevent stormwater runoff, retain stormwater on-site, control the source of potential pollutants, treat stormwater, or prevent the discharge of pollutants that enter the DOTA drainage system or receiving waters after the Project is completed.

This Manual has been developed to prioritize and promote LID PBMPs that favor infiltration, biofiltration, evapotranspiration, or harvesting/reuse of stormwater, followed by other practices that treat and release stormwater. This Manual guides the selection, installation, inspection, and maintenance of PBMPs.

The target audience for this Manual includes:

- Project Proponents
- DOTA Staff (including Planners, Engineers, and Maintenance staff)
- Consultants (including designers and Construction Managers)
- Contractors and subcontractors
- DOTA Tenants and users

Project designers may also utilize PBMPs not listed in this Manual, provided they are approved by AIR-E and AIR-EE.

DISCLAIMER

The information presented in this Manual was taken from available and most recent sources deemed to be representative of the acceptable PBMPs and stormwater runoff control measures. This Manual has been prepared as a reference guide for PBMP design and is not intended to replace the applicable storm drain design standards. The selection of appropriate PBMPs shall be made by the design engineer in conjunction with best professional judgment and sound engineering principles to assure the proper function and performance of the PBMPs and associated DOTA drainage system.

DOTA does not guarantee the accuracy or completeness of this document and will not assume any liability or responsibility for the use of, or for any damages resulting from, any information contained herein. The detail and the wording in this Manual will not necessarily result in compliance with any Standard Specifications.

The design criteria in this Manual are recommendations and not intended to conflict with federal, state, county, and other regulations that dictate airport operations and safety. The design engineer is responsible for the selection and implementation of PBMPs and their compliance with all applicable regulations.

1. BACKGROUND

DOTA requires specified construction projects to include PBMPs and verify that they are in place to prevent or minimize water quality impacts to the maximum extent practicable after construction is completed.

DOTA conducts training and outreach to clarify requirements; reviews design plan to verify appropriate PBMPs have been included, where required; and tracks PBMP inspection and maintenance data. When a PBMP is constructed and brought online, it requires inspection and maintenance for proper operation to continue to function as designed to provide water quality treatment. PBMP O&M is necessary and provides for the routine inspection practices based on the type of PBMP installed and the preventive and corrective maintenance needed to properly maintain the PBMP and should be considered during design (refer to sections 5.1 and Appendix VI for additional information on the PBMP O&M requirements and DOTA provided information).

1.1 REGULATORY REQUIREMENTS

There are several federal, state, and county requirements that affect stormwater management and may apply to a given new development and redevelopment project. Potential applicable requirements for DOTA projects may include the following:

- 303(d) list (regulated under CWA § 303(d))
- NPDES Permits for discharges from construction activities (regulated under CWA § 402, 40 CFR § 122 and HAR § 11-55, Appendix C)
- FAA Regulations 14 CFR § 139 and ACs
- UIC Authorization (regulated under HAR § 11-23)
- Hawaiian plants use in public landscaping (regulated under HRS § 103D-408)
- Other – CCH Industrial Wastewater Discharge Permit (regulated under Revised Ordinances of Honolulu § 14), county code related to construction, building permits, fire code, county fire department flammable finishes permits, storm drainage standards, etc.

2. POST-CONSTRUCTION BEST MANAGEMENT PRACTICE APPLICABILITY

2.1 PROJECTS REQUIRING PBMPS

DOTA has developed criteria to determine which new development and redevelopment construction projects need to incorporate PBMPs.

Projects that fall under one or more of the following categories require PBMPs:

- Disturbing one acre or more of land
- Containing steep earthen slopes (i.e., grade of 20 percent or more)
- Modifying, replacing, or installing new drainage structures, as appropriate
- Parking lots and buildings adding 5,000 square feet or more of impervious area
- Aircraft, vehicle, or equipment washing areas
- Aircraft, vehicle, or equipment fueling areas or container and material storage areas
- Determined to have activities that would pose a potential risk to discharge pollutants to the DOTA drainage system or State waters

If none of the categories above apply, or if the project is solely a water quality improvement or preservation project (e.g., shoreline protection, landscaping, permanent erosion control) that will not include any PBMP installation, the project may qualify for a PBMP Variance. To apply for a PBMP Variance, the Designer shall complete the PBMP Variance step in the Construction Design Review workflow in Veoci® along with any supporting documentation. A project that meets the criteria to receive a PBMP Variance may still be required to install PBMPs at the discretion of AIR-EE.

When redeveloping existing areas that require source control PBMPs (e.g., fueling area, washing area, etc.), all applicable design criteria must be incorporated into the redevelopment design.

2.2 FAA EXEMPTION ZONE FOR PBMP INSTALLATION

The types of PBMPs that can be implemented may be limited in certain airport areas due to FAA regulations and exclusions related to aircraft safety concerns or safety zones. Certain BMPs can provide an attractive food source, water source, or shelter for wildlife and can pose a risk to aviation safety (refer to *FAA AC 150/5200-33C*). Effective food source, water source, and shelter management on and near airports to reduce hazards to aviation is dependent on PBMP limitations to eliminate or minimize wildlife attractants to meet the complex safety and regulatory requirements facing airports.

FAA has several regulations and FAA ACs that define the specific design standards (e.g., grading, surface and drainage features) and prescribe airfield layout standards, which result in a high level of passenger and aircraft safety around the runway and taxiway operational surfaces.

FAA regulations define several on-airfield operational zones that ensure the safety of airfield operations should aircraft deviate from the defined runway and taxiway surfaces. In addition, FAA mandates protection zones for near-airfield areas, which extend outside of the airfield AOA boundary, and are designed to protect the aircraft approach and departure airspace.

The FAA specified zones of interest (both on-airfield and near-airfield zones) related to a PBMP implementation strategy include the following:

- Runway Safety Area[2]
- Runway Object Free Area[2]
- Runway Protection Zone[2]
- Taxiway Object Free and Taxiway Safety Areas[2]
- Object Free Area[2]
- Object Free Zone[2]
- Runway Obstacle Free Zone[2]
- Building Restriction Line[2]
- Apron Restrictions[2]
- Aircraft Operations Area or AOA[2]
- Wildlife Hazard Areas[2]

FAA design standards for these zones have direct implications for the design and location of the PBMPs. The layers for FAA restriction zones listed above were used to delineate and establish the FAA Exemption Zones for PBMP Installation. FAA Exemption Zone for PBMP installation maps for all 15 airports statewide are provided in Appendix I and also available within Veoci®. The project proponent can use the interactive maps within Veoci® to review their project location to determine whether they fall within the FAA Exemption Zone.

2.3 LID WAIVER

As described in further detail below, DOTA requires LID PBMPs to be installed, unless the project receives a LID Waiver. Project proponents may request a LID Waiver if a project meets one or more DOTA established criteria:

- The project is located within the FAA Exemption Zone for PBMP Installation (refer to Appendix I and in Veoci®)
- The post-construction runoff rate will be equal to or less than the pre-construction[3] runoff rate before factoring in any reductions attributed to PBMPs
- The project contains conditions that would result in infiltration, biofiltration, and harvesting/reuse infeasibility (see Section 3.3)

To apply for a LID Waiver, the Designer shall complete the LID PBMP Infeasibility & Waiver Screening step in the Construction Design Review workflow in Veoci® along with any supporting documentation. A project that meets the criteria to receive a LID Waiver may still be required to install Source Control or Treatment Control PBMPs.

[2] Found in FAA Advisory Circular: AC 150/5200-33C.
[3] Pre-construction conditions is defined as the existing conditions prior to improvements associated with this project.

3. PBMP IMPLEMENTATION

3.1 PBMP CATEGORIES AND PREFERENCE

Projects that are required to install PBMPs must select the PBMP type in accordance with the following three priorities: (1) LID, (2) Source Control, and (3) Treatment Control. The following criteria must be met for projects on DOTA properties as follows:

- Retain stormwater on-site by infiltration, evapotranspiration, or harvesting/reuse, as much of the WQV as feasible, with appropriate LID PBMPs.
- Implement applicable source control practices for the following activities and areas:
  - Areas with concentrated flows
  - Aircraft, vehicle, and equipment fueling
  - Outdoor loading and unloading operations
  - Aircraft, vehicle, and equipment maintenance and repair
  - Material storage areas
  - Triturator facilities
  - Aircraft, vehicle, and equipment washing
  - Outdoor waste storage
- If LID is demonstrated to be infeasible and a LID Waiver is obtained (see Section 2.3), treat discharge with appropriate Treatment Control PBMPs. If LID PBMPs are only feasible for a portion of the site or WQV, appropriate Treatment Control PBMPs can be used to treat and discharge the remaining portion of the WQV.

For projects where LID PBMPs are feasible, source control and/or treatment control PBMPs should also be considered as pretreatment to the LID PBMP. Figure 3-1 establishes DOTA's priority of designing and installing PBMPs for stormwater management at its airports Statewide.

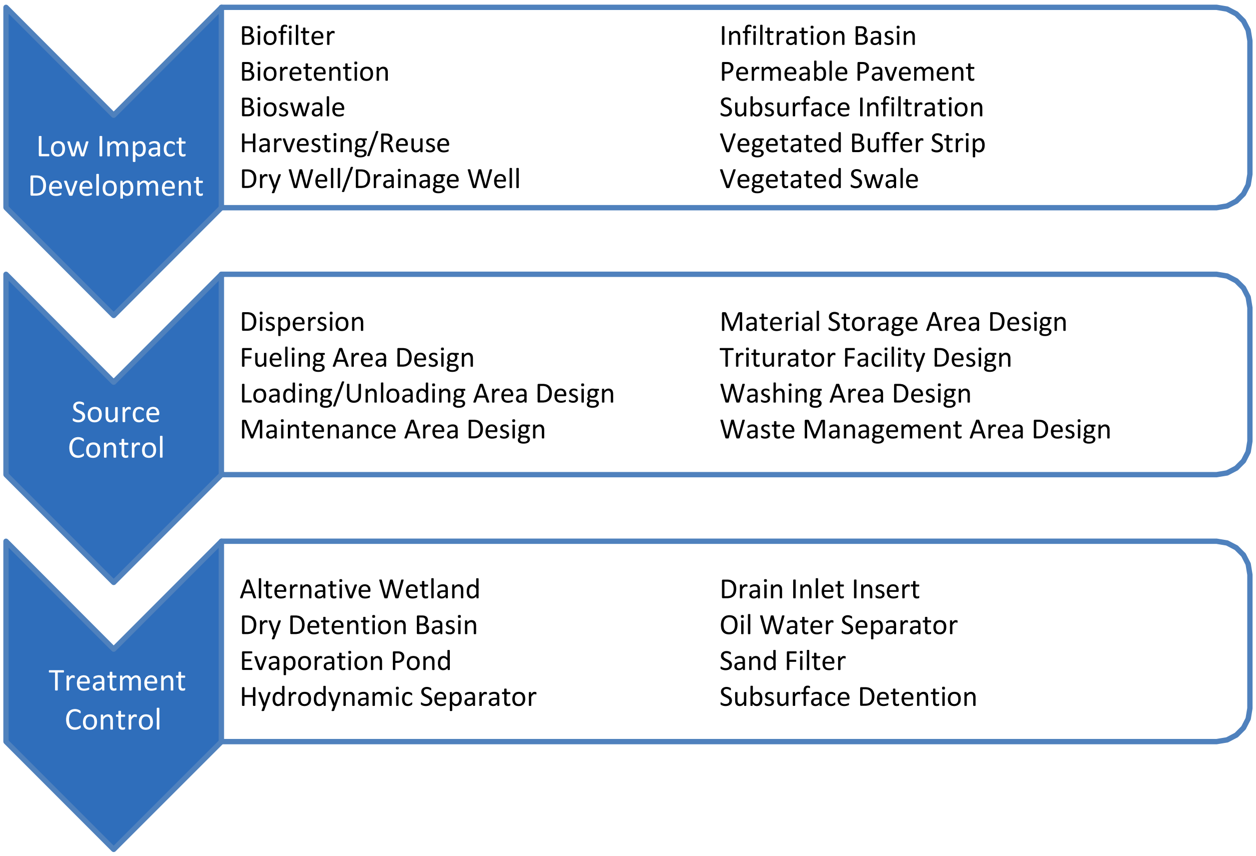

Figure 3-1. PBMP Categories in Order of Preference

3.2 LOW IMPACT DEVELOPMENT PBMP REQUIREMENTS

LID PBMPs seek to mimic pre-development hydrology by minimizing disturbed areas and impervious cover. LID promotes infiltration, detention, evapotranspiration, and biotreatment of stormwater runoff close to its source.

All non-exempt new development or redevelopment projects that do not qualify for a LID Waiver (refer to Section 2.3) must implement LID PBMPs.

Table 3-1 presents a list of acceptable LID PBMPs with references to the corresponding LID PBMP Design Fact Sheets provided in Appendix III and their primary function. LID PBMPs not included herein may be proposed by the designer, subject to DOTA review and approval.

Table 3-1. Low Impact Development PBMPs		
PBMP Design Fact Sheet Identifier	**LID PBMP Name**	**Primary Function**
LC-1	Biofilter	Biofiltration
LC-2	Bioretention	Retention[1]
LC-3	Bioswale	Biofiltration
LC-4	Harvesting/Reuse	Retention
LC-5	Dry Well/Drainage Well	Retention
LC-6	Infiltration Basin	Retention[1]
LC-7	Infiltration Trench	Retention[1]
LC-8	Permeable Pavement	Retention[2]
LC-9	Subsurface Infiltration	Retention[2]
LC-10	Vegetated Buffer Strip	Biofiltration
LC-11	Vegetated Swale	Biofiltration

Notes:
[1] Can be designed as a biofiltration PBMP if there are site constraints to capture and infiltrate the entire WQV.
[2] Can be designed as a biofiltration PBMP depending on the type and model of the proprietary product selected for the project.

3.3 INFILTRATION REQUIREMENTS

LID PBMPs rely on the soil's ability to infiltrate stormwater runoff; these PBMPs may use the filtration, adsorption, and biological properties of the soil matrix, with or without amendments, to remove pollutants as stormwater infiltrates into the ground. Infiltration can provide multiple benefits, including pollutant removal, peak flow control, groundwater recharge, and flood control.

This section outlines the design requirements applicable to infiltration PBMPs.

3.3.1 Estimating Infiltration Rates

Soil lithology and the depth to groundwater are key factors in assessing the feasibility of infiltration PBMPs. An investigation should adequately evaluate soil lithology and groundwater conditions to determine if soil percolation rates would support infiltration, and to identify potential adverse impacts to structures, slopes, or groundwater.

The infiltration rate or permeability of the soil types within the subsoil profile shall be field test verified, extending a minimum of 3 feet below the bottom of the proposed PBMP. Where no previous data are available, an industry-accepted infiltration field test should be conducted. A licensed professional engineer with geotechnical expertise should determine the testing protocols and methods used for each project.

DOTA utilizes the CCH recommendation for the minimum number of permeability tests: 1 test per 100 linear feet for an infiltration trench and 1 test per 2,500 square feet for an infiltration basin, subsurface infiltration system, dry well/drainage well, bioretention, and permeable pavement (City and County of Honolulu, Storm Water BMP Guide for New and Redevelopment, July 2017).

To account for uncertainties and variability in testing and assumptions from previous studies, a correction/safety factor shall be applied to the measured infiltration rate to produce a design infiltration rate for the PBMP sizing calculations. The minimum safety factor for infiltration PBMPs is 2 but the licensed engineer may apply a greater safety factor depending on the data quality.

3.4 LOW IMPACT DEVELOPMENT WAIVER AND PBMP INFEASIBILITY CRITERIA

LID PBMP implementation may not be feasible at a project site depending on the location suitability constraints, including soil infiltration rate, depth to the seasonal high groundwater table, setbacks, drawdown requirements, depth of bedrock, and the proposed activities on the site. A project may qualify for a LID Waiver if it contains conditions that would result in infiltration, biofiltration, and harvesting/reuse infeasibility or has a special condition deeming LID BMPs infeasible.

3.4.1 Infiltration Infeasibility Evaluation Criteria

Infiltration PBMPs are infeasible and shall not be used if any of the following conditions exist:

- Soils beneath the PBMP invert have a measured infiltration rates of less than 0.50 inch per hour.
- Soils beneath the PBMP invert are classified as HSG C or D as reported by the USDA NRCS Web Soil Survey webpage.[4]
- The seasonal high groundwater table is within 3 feet from the PBMP invert.
- There is a documented concern that there is known soil or groundwater contamination on site with the potential to be mobilized.
- The project area is prone to geotechnical hazards such as soil movement or slope failure that would affect the PBMP or that excavation for the PBMP could trigger.
- The PBMP would be situated within the setbacks established in Table 3-2 below:

Table 3-2. Setbacks for Infiltration PBMPs

Setback from nearest	Distance [feet]
Drinking water well	50
Septic system	35
Property line	10
Building foundation	20
Down-gradient building foundation	100

- There are proposed activities/land uses that pose a high threat to water quality, including a high potential for chemical spills (including oil and grease) or high levels of sediment.
- The location of the infiltration PBMP facility/facilities would conflict with the location of existing or proposed underground utilities or easements, including their placement or orientation such that they would discharge to utility trenches, restrict access, or cause stability concerns.

3.4.2 Biofiltration Infeasibility Evaluation Criteria

Biofiltration PBMPs must be evaluated individually as each type has different criteria for infeasibility.

3.4.2.1 Vegetated Biofilters and Bioswales Infeasibility Evaluation Criteria

Vegetated Biofilters are infeasible and shall not be used if any of the following conditions exist:

- The invert of the underdrain layer is below the seasonally high groundwater table.

[4] https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx

- The amount of sunlight received by the site is inadequate or irrigation is infeasible to support vegetation.
- The site lacks a sufficient hydraulic head to support PBMP operation by gravity.
- The PBMP is unable to operate off-line with bypass, and unable to operate in-line with a safe overflow mechanism.

3.4.2.2 Vegetated Swale and Vegetated Filter Strip Infeasibility Evaluation Criteria

Vegetated Swales are infeasible and shall not be used if any of the following conditions exist:

- The amount of sunlight received by the site is inadequate or irrigation is infeasible to support vegetation.
- The PBMP is unable to operate off-line with bypass, and unable to operate in-line with a safe overflow mechanism.

3.4.3 Harvesting/Reuse Infeasibility Evaluation Criteria

Harvesting/reuse PBMPs are infeasible and shall not be used if any of the following conditions exist:

- The harvested water cannot be reused at the project site (landscape irrigation or other non-potable use).
- The demand is inadequate to reuse the collected volume of water at the project site.
- Site constraints, such as a slope above 10 percent or lack of available space, make it infeasible to locate a cistern of adequate size to collect and reuse the required demand amount of water for the site.
- The harvesting/reuse of stormwater runoff conflicts with county, state, or federal ordinances and building codes.
- The cistern would be located within the setbacks established in Table 3-3 below:

Table 3-4. Setbacks for Harvesting/Reuse PBMPs

Setback from nearest	Distance [feet]
Septic system	10
Property line	5
Building foundation	5

- The cistern would restrict access to underground utilities or easements.
- The harvesting/reuse system would conflict with a reclaimed water system.

3.5 SOURCE CONTROL PBMP REQUIREMENTS

Source Control PBMPs are measures that prevent pollutants from contacting stormwater runoff or prevent discharge of contaminated runoff to a drainage system or State waters. While Source Control PBMPs are categorized as either “operational” or “structural,” this manual only includes a discussion on Structural Source Control PBMPs.

Source Control PBMPs are physical, structural, or mechanical devices or facilities intended to prevent stormwater from contacting surfaces, work areas, and activities that can generate pollutants. Examples of these PBMPs include enclosures or covers for work areas where pollutants are present, secondary containment, or devices that direct contaminated stormwater to appropriate LID or Treatment Control PBMPs.

Table 3-4 presents a list of acceptable Source Control PBMPs with references to the corresponding Source Control PBMP Design Fact Sheets provided in Appendix IV. PBMPs not included herein may be proposed by the designer, subject to DOTA review and approval.

Table 3-4. Source Control PBMPs

PBMP Design Fact Sheet Identifier	Source Control PBMP Name
SC-1	Dispersion
SC-2	Fueling Area Design
SC-3	Loading/Unloading Area Design
SC-4	Maintenance Area Design
SC-5	Material Storage Area Design
SC-6	Triturator Facility Design
SC-7	Washing Area Design
SC-8	Waste Management Area Design

Source Control PBMPs such as enclosures, roofs, secondary containment, etc., while permanent, are not subject to the PBMP inspection and maintenance requirements. However, Source Control PBMPs may be subject to inspections under the DOTA Tenant Inspection and Enforcement program or the DOTA Facility Inspection program.

At sites that are subject to a Multisector General Permit for discharge of industrial stormwater, project designers should coordinate source control PBMPs required by DOTA and those included in their Industrial SWPPP.

3.6 TREATMENT CONTROL PBMP REQUIREMENTS

Treatment Control PBMPs are engineered technologies designed to remove pollutants from stormwater runoff prior to discharge to a drainage system or State waters.

Table 3-5 presents a list of acceptable Treatment Control PBMPs with references to the corresponding Treatment Control PBMP Design Fact Sheets provided in Appendix V. PBMPs not included herein may be proposed by the designer, subject to DOTA review and approval.

Table 3-5. Treatment Control PBMPs

PBMP Design Fact Sheet	Treatment Control PBMP Name
TC-1	Alternative Wetland
TC-2	Dry Detention Basin
TC-3	Evaporation Pond
TC-4	Hydrodynamic Separator (HDS) Unit
TC-5	Drain Inlet Insert
TC-6	Oil Water Separator (OWS)
TC-7	Sand Filter
TC-8	Subsurface Detention

4. PBMP DESIGN CRITERIA

To effectively address DOTA stormwater management objectives, the consideration of PBMPs should be integrated into the site planning and design process. In addition to standard engineering design practices, project designers should evaluate the project site conditions and planned future use to determine which PBMPs would be the most effective. The basic steps in the PBMP planning, decision-making, and design processes are presented in Figure 4-1.

Figure 4-1. PBMP Design Process

4.1 POLLUTANTS OF CONCERN

Pollutants of concern should be identified based on pollutants that are anticipated or potentially could be generated by the project based on the planned site activities of the project and receiving water impairments and sensitivities. Project designers must select PBMPs that will target the pollutants of concern most effectively.

4.1.1 Pollutants of Concern Associated with Planned Site Activities

Pollutants in stormwater runoff are typically related to site activities. Pollutants that are expected to be generated or have a potential to be generated from a project based on the project's proposed site activities must be identified. In addition, site-specific conditions, such as legacy pollutants in site soils resulting from past activities, must also be considered for potential pollutant sources. If a previously contaminated site was remediated, obtained a No Further Action letter from DOH, and does not pose a current or future threat to stormwater quality, the pollutants for which it was previously contaminated are no longer considered a pollutant of concern for that site unless additional information is gained that negates this assumption.

Project proponents must assess planned site activities to determine the potential pollutants likely associated with the project's proposed site activities using Table 4-1

Table 4-1. Pollutants of Concern for Site Activities at DOT Airports								
Site Activity	**Bacteria**	**Metals**	**Nutrients**	**Oil & Grease**	**Organic Compounds**	**Pesticides**	**Sediment**	**Trash**
Aircraft, Vehicle, or Equipment Parking Area or Travel Corridor (e.g., roadway, runway, taxiway)		X		X	X		X	X*
Aircraft, Vehicle, or Equipment Fueling		X		X	X			X
Aircraft, Vehicle, or Equipment Maintenance and Repair		X		X	X			X
Aircraft, Vehicle, or Equipment Washing		X	X	X	X		X	X
Outdoor Loading and Unloading of Materials		X	X	X	X	X	X	X
Outdoor Container Storage of Liquids		X	X	X	X	X		
Outdoor Storage of Raw Materials			X	X	X	X	X	X
Waste Handling and Disposal	X	X	X	X	X	X	X	X
Buildings	X		X				X	X
Landscaping	X		X			X	X	X
** If outside of the AOA, otherwise not expected.*								

4.1.2 Pollutants of Concern based on Receiving Waters

Project proponents shall identify the nearest and first receiving water that has the potential to receive runoff from the project site and determine pollutants for which each receiving water is listed as impaired on the 303(d) list, as depicted on the Table Depicting Minimum Pollutants of Concern Based on Receiving Water Bodies.[5]

4.2 PBMP SELECTION

PBMPs should be selected based on the identified pollutants of concern; sensitivity of receiving waters to changes in stormwater discharge flow rates, velocities, durations, and volumes; site restrictions; PBMP pollutant removal performance; and other requirements imposed by other permits, TMDLs, etc.

Table 4-2 lists PBMPs that can be selected for identified pollutants of concern or volume reduction.

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[5] https://hidot.hawaii.gov/airports/doing-business/engineering/environmental/construction-site-runoff-control-program/table-depicting-minimum-pollutants-of-concern/

Table 4-1. Acceptable PBMPs to Target Pollutants of Concern

PBMP	Bacteria	Metals	Nutrients	Oil & Grease	Organic Compounds	Pesticides	Sediment	Trash	Volume Reduction
LC-1 Biofilter	X	X	X		X		X	X	
LC-2 Bioretention	X	X	X		X	X	X	X	X
LC-3 Bioswale		X	X				X	X	
LC-4 Harvesting/Reuse							X	X	X
LC-5 Dry Well/Drainage Well*									X
LC-6 Infiltration Basin	X	X	X		X	X	X	X	X
LC-7 Infiltration Trench	X	X	X		X	X	X	X	X
LC-8 Permeable Pavement		X	X	X	X	X	X		X
LC-9 Subsurface Infiltration		X	X		X	X	X	X	X
LC-10 Vegetated Buffer Strip		X			X		X	X	
LC-11 Vegetated Swale		X			X		X		
TC-1 Alternative Wetland	X	X	X		X		X	X	
TC-2 Dry Detention Basin	X						X	X	X
TC-3 Evaporation Pond	X				X		X	X	X
TC-4 Hydrodynamic Separator				O			X	X	
TC-5 Drain Inlet Insert		O		O			X	X	
TC-6 Oil Water Separator				X			X	X	
TC-7 Sand Filter	X	X			X		X	X	
TC-8 Subsurface Detention	X				X		X	X	X

Notes:
X = PBMP is acceptable to target this pollutant of concern.
O = Pollutant performance may vary depending on the type and model of the proprietary product selected.
** Dry Wells/Drainage Wells should only be used for volume reduction. Other PBMPs must be incorporated as pretreatment to target pollutants of concern while protecting groundwater.*

PBMPs not included herein may be proposed by the designer, subject to DOTA review and approval.

4.3 PBMP DESIGN FACT SHEETS

A PBMP Design Fact Sheet contains information on the PBMP design criteria and guidelines, limitations, construction considerations, cut sheet examples, and sizing guidelines. Refer to Sections 3.2, 3.4, and 3.5 and Appendices III, IV, and V for the information included within the LID PBMP Design Fact Sheets, Source Control PBMP Fact Sheets, and Treatment Control PBMP Design Fact Sheets, respectively.

The sizing procedures provided within the PBMP Design Fact Sheets for LID and Treatment Control PBMPs are based on simple dynamic and static principles and may result in conservatively large PBMPs. Other sizing methods (such as detailed routing methods or continuous simulation models) may be proposed by the project designer, subject to DOTA's approval.

4.4 RETROFITS

Retrofits include drainage system upgrades/alterations that provide stormwater treatment, pollutant reduction (e.g., improve the quality of stormwater runoff), trash or floatable reduction, etc. Where possible, project designers should identify opportunities to upgrade the existing drainage system or PBMPs in their redevelopment projects.

4.5 PRELIMINARY DESIGN

The primary objectives of the preliminary design phase are to gather key information and develop a preliminary site layout that considers all the site characteristics and constraints for PBMP design. Every construction project and facility activity has unique design goals and constraints. As such, there is no one-size-fits-all PBMP that meets DOTA requirements. Preliminary sizing of PBMPs will be necessary to determine if the post-construction performance can be achieved with a single PBMP or if several PBMPs need to be applied in series, using a "treatment train" approach. The selection and sizing process will likely be iterative as multiple options may need to be considered to determine the most efficient and effective PBMP(s) for the site.

4.5.1 Site Assessment

The site assessment provides information about the site and its surroundings, forming the basis to make decisions about PBMP location and selection. The site assessment should include an inventory and analysis of natural and developed conditions that would affect the project design. Information that may be needed from the site assessment includes:

- Topography
- Hydrologic patterns and features
- Soils and groundwater information
- Native vegetation and soil protection areas
- Environmentally sensitive features
- Site access
- Land use controls
- Utility availability and conflicts

4.5.2 Identify Stormwater Standards and Requirements

Project designers should identify and review the DOTA engineering standards and any applicable state and federal requirements that can influence the PBMP design. This typically involves coordination with AIR-E and AIR-EE to discuss the project and proposed approach to meeting the standards and requirements. DOTA standards and requirements that may influence site design include:

- Stormwater requirements, including PBMP requirements
- Infeasibility criteria for LID PBMPs
- Setback requirements for structures, drinking wells, foundations, etc.
- Soil and subsurface hydrology evaluation and reporting requirements
- PBMP sizing methodologies to be used
- DOTA engineering design standards
- Maintenance requirements for DOTA drainage system and PBMPs
- FAA regulations and design standards

4.5.3 Sizing Criteria

While the basic hydrologic and hydraulic principles are the same when designing a storm drainage system or a PBMP, these two systems have very different design goals and performance objectives. The design goal for storm drainage systems is to protect human health and property from flooding, whereas the design goal for PBMPs is to reduce runoff volume and/or pollutants.

DOTA requires specific criteria for PBMP sizing using both volume-based and flow-based PBMP design. Volume-based PBMPs must be sized for a 1-inch design storm depth and flow-based PBMPs must be designed to handle a velocity of 0.4 inch per hour.[6]

4.5.3.1 Volume–Based Designs

Volume-based designs include PBMPs, such as infiltration basins, infiltration trenches, dry wells/drainage wells, harvesting/reuse, permeable pavement, vegetated biofilters, bioretention systems, bioswales, dry detention ponds, and sand filters, that will hold a certain volume of runoff.

For volume-based PBMP designs, a design storm depth of 1 inch or larger must be used and the WQV must be sized based on the following equation:

$$\boldsymbol{WQV} = \boldsymbol{PCA}\,\mathbf{x}\,\mathbf{3630}$$

Where: WQV = Water Quality Volume (cubic feet)
P = Design Storm Runoff Depth (inch)
C = Volumetric Runoff Coefficient
A = Drainage Area (acre)

C is an empirically derived value that indicates the fraction of rainfall converted into runoff for that land use. Using data from the Nationwide Urban Runoff Program[7] data collected at 44 monitored development sites with various percentages of impervious area, it was concluded that the primary

[6] Design criteria is in alignment with other similar manuals across the State (City and County of Honolulu. 2017, July. Storm Water BMP Guide for New and Redevelopment; County of Maui, Department of Public Works. 2012, November 9. Maui County Code Chapter 15-111, Rules for the Design of Storm Water Treatment Best Management Practices; State of Hawaii, Department of Transportation, Highways. 2015, April. Permanent Best Management Practices Manual).
[7] Environmental Protection Agency, Water Planning Division. 1983, December. Results of the Nationwide Urban Runoff Program, Volume I - Final Report.

influence on C is the impervious area within the contributing drainage area.[8] Schueler used a simple linear regression to derive an equation to calculate C based on the percent impervious cover. The volumetric runoff coefficient is calculated using the following equation for storms less than 2 inches in urban areas:[7]

$$\boldsymbol{C = 0.05 + 0.009(I)}$$

Where: C = Volumetric Runoff Coefficient
I = Impervious Cover (%)

Offsite existing impervious areas may be excluded from the calculation of the WQV by diverting any offsite flows to minimize the offsite runoff contribution to the new development or redevelopment construction project. When a new development or redevelopment construction project contains multiple drainage areas feeding to different PBMPs, the WQV volume shall be addressed for each drainage area.

4.5.3.2 Flow-Based Designs

Examples of flow-based designs include vegetated buffer strips, vegetated swales, subsurface infiltration systems, alternative wetlands, evaporation ponds, HDS units, MTDs, OWSs, and subsurface detention facilities.

The design must be able to accommodate a peak rainfall intensity of 0.4 inch per hour, based on the following equations:

$$\boldsymbol{WQF = CiA}$$

Where: WQF = Water Quality Flow Rate (cubic feet per second)
C = Runoff Coefficient
I = Peak Rainfall Intensity (inch/hour)
A = Drainage Area (acre)

For drainage areas containing multiple land use cover types, compute the composite weighted runoff coefficient using the following equation:

$$\boldsymbol{C_c = [(\sum_{i=1}^{n} C_i A_i)/A_t]}$$

Where: C_c = Composite Weighted Runoff Coefficient
$C_{1,2,\ldots n}$ = Runoff Coefficient for each Land Use Cover Type
$A_{1,2,\ldots n}$ = Drainage Area for each Land Use Cover Type (acre)
n = Number of Land Use Cover Types within the Drainage Area
A_t = Total Drainage Area (acre)

Table 4-3 provides the runoff coefficients for various drainage surface areas. Where ranges are given, design engineers should use professional judgment to select the appropriate C value within the range. Generally, larger areas with permeable soils, flat slopes, and dense vegetation should have the lower C

[8] Schueler, T.R., Department of Environmental Programs, Metropolitan Washington Council of Governments. Washington, DC. 1987, July. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs.

values. Smaller areas with dense soils, moderate to steep slopes, and sparse vegetation or impermeable surfaces should have higher C values.

Table 4-3. Runoff Coefficients

Type of Drainage Surface Area	Runoff Coefficient
Roofs	0.75 – 0.95
Concrete	0.80 – 0.95
Asphalt	0.70 – 0.95
Stone, brick, or concrete pavers with mortared joints and bedding	0.80
Stone, brick, or concrete pavers with sand joints and bedding	0.70
Pervious Concrete	0.10
Porous Asphalt	0.10
Permeable interlocking concrete pavement	0.10
Grid pavements with grass or aggregate surface	0.10
Crushed aggregate	0.10
Grass	0.10
Grass over Porous Plastic	0.05
Gravel over Porous Plastic	0.05
Light industrial	0.50 – 0.80
Heavy Industrial	0.60 – 0.90
Unimproved areas	0.10 – 0.30

4.5.3.3 Combined Volume-Based and Flow-Based Designs

Volume-based and flow-based PBMP designs do not necessarily treat the same stormwater runoff quantity. For example, an on-line volume-based PBMP, such as a detention basin will treat the design runoff volume and is not greatly affected by runoff entering the basin at a high rate, say from a short but intense storm that produces the design volume of runoff. However, a flow-based PBMP might be overwhelmed by the same short but intense storm if the storm intensity results in runoff rates that exceed the flow-based PBMP design flow rate. Additionally, a flow-based PBMP such as a swale will treat the design flow rate of runoff and is not greatly affected by the duration of the design flow, say from a long, low-intensity storm; however, a volume-based PBMP such as a detention basin subjected to this same rain event will begin to provide less treatment or will go into bypass or overflow mode after the design runoff volume is received.

Therefore, there may be situations where both volume-based and flow-based PBMP design criteria should be considered. An example of the application of both criteria is an off-line detention basin where the capacity of the diversion structure could be designed to comply with the flow-based criteria, while the detention basin itself could be designed to comply with the volume-based criteria.

When both volume-based and flow-based criteria apply, the design engineer should determine which of the criteria apply to each element of the PBMP system and then size the elements accordingly.

4.5.3.4 Pan Evaporation Rates and Rainfall Data

For designing PBMPs that rely on evaporation (e.g., TC-3 Evaporation Pond), use the Evaporation Rates and Rainfall Data for Statewide Airports provided in Appendix II. Pan evaporation rate data are used to determine the potential evapotranspiration of a project area.[9] The potential evapotranspiration directly influences soil moisture conditions and runoff. Pan evaporation is not as highly variable as rainfall.

To convert the pan evaporation values to potential evapotranspiration values, the pan evaporation values need to be multiplied by a correction factor or the Pan Evaporation Coefficient, K_p. If site-specific data are not available, a K_p value of 0.80 can be used (representative of Hawaiian climate).

4.5.3.5 Drain or Drawdown Time

The drain or drawdown time, t, for PBMPs to drain the WQV must be set to 48 hours or less for all surface PBMPs. This period was selected to minimize the wildlife attractant and address aircraft safety requirements in accordance with the *FAA AC 150/5200-33C*. Flows to surface PBMPs that cannot be infiltrated or drained in 48 hours or less should be routed to bypass the PBMP through a stabilized discharge point. Subsurface PBMPs where standing water aboveground is not anticipated can be designed with a drawdown time, t, of up to 72 hours.

4.5.3.6 Permeability Coefficients

Project designers can use site-specific data where available or conduct in-situ measurements to determine the coefficient of permeability for the planting soil or media, k_m. If specific data is unavailable, a value of 1 foot/day for k_m is commonly used.

Project designers can use site-specific data where available or conduct in-situ measurements to determine the coefficient of permeability for the sand, k_s. If specific data are unavailable, a value of 3.50 feet/day for k_s is commonly used.

4.5.3.7 Porosity Values

Project designers can use site-specific data where available for the porosity values of various media, n. If site-specific data are unavailable, the following values of n provided in Table 4-4 can be used; where ranges are listed, refer to the PBMP Design Fact Sheets provided in Appendices III, IV, and V for more guidance.

Table 4-4. Porosity Values

Type of Media	Porosity Abbreviation	Porosity
Backfill Material	n_{bf}	0.30 – 0.95
Backfill Material – trench rock for infiltration trenches	n_{bf}	0.35
Drainage Layer	n_d	0.25 – 0.40
Gravel Layer	n_g	0.30 – 0.35
Media Layer	n_m	0.25
Pavement Course	n_p	0.15
Reservoir Course	n_r	0.30 – 0.35
Sand	n_s	0.40

[9] Pan Evaporation: State of Hawaii 1894-1983 (Ekern, P.C. and Chang, J.H., 1985).

4.5.3.8 Landscape Coefficient

The landscape coefficient, K_l, was derived specifically to estimate water loss from landscape plantings. The following factors are used to determine K_l:

- Species
- Density
- Microclimate

Project designers can use site-specific data where available for K_l. If site-specific data are not available, a value of 0.60 for K_l can be used. This value is for turfgrass in warm weather.[10]

4.5.3.9 Irrigation Efficiency

Irrigation efficiency, e, can be defined as the beneficial use of applied water (by landscaping). An e value of 100 percent would mean that all applied water was used by the planting. This rarely occurs and additional water may need to be applied to account for efficiency losses.

Irrigation efficiency values can be obtained by three approaches: calculated, estimated, or goal setting. All three methods are highly approximate. Project designers can use site-specific data where available for the e value. If site-specific data are unavailable, a value of 0.90 for e can be used, assuming the new landscape can achieve 90 percent irrigation efficiency.[10]

4.5.3.10 Fill Time

The *Maryland Stormwater Design Manual Volumes I & II* (Center for Watershed Protection and the Maryland Department of the Environment, 2000) states that the effective fill time for most infiltration trenches and infiltration basins will generally be less than two hours and, therefore, uses two hours. Unless another value can be justified, project designers should use a fill time value of two hours for sizing bioretention facilities, dry wells/drainage wells, infiltration basins, infiltration trenches, and permeable pavements.

4.5.3.11 Manning's n Values

The roughness coefficient, Manning's n value, varies with the type of vegetative cover and flow depth. Unless another value can be justified, project designers should use a Manning's n value of 0.25 and 0.20 for vegetated buffer strip and vegetated swale sizing calculations, respectively.

4.5.3.12 Freeboard

Project designers should typically use a freeboard of 1 foot except for evaporation ponds. For evaporation ponds, 2 feet should be used since there is no outlet structure.

[10] A Guide to Estimating Irrigation Water Needs of Landscape Plantings in California (University of California Cooperative Extension, California Department of Water Resources, 2000).

4.5.4 Preliminary Site Layout

Developing the preliminary site layout is an iterative process intended to optimize site development and consider the site requirements and constraints, including PBMPs. This process typically takes place after the site assessment has occurred.

4.5.5 Pre-Design Meeting

After the preliminary site layout is determined, project designers should request a pre-design meeting with AIR-EE to discuss the preliminary PBMP design, the O&M required for long-term effectiveness, accessibility, and options for any innovative PBMP design. Project designers can also provide information on the potential for PBMP variance, LID waivers, or other site constraints that limit PBMP implementation.

The goal of the pre-design meeting is to establish a collaboration between the project designer and AIR-EE to design PBMPs effectively, communicate any issues early, and consider PBMPs that serve the best interest of DOTA over time.

4.6 PBMP REPORT

A report that summarizes and describes each of the PBMPs (e.g., type, sizing calculations, manufacturer-recommended maintenance requirements, maintenance contracts prior to turnover to state, etc.), with references to project drawing sheets that include information on each individual PBMP shall be submitted to AIR-EE for review and approval.

4.7 PBMP MAINTENANCE

Project designers must consider PBMP maintenance during the design phase. Documentation of the PBMP maintenance requirements can be provided either by developing and submitting a PBMP O&M Plan or utilizing the PBMP O&M Fact Sheets within this Manual (refer to Appendix VI). The O&M costs for the designed PBMPs shall be provided. See Section 5.0 for more information on PBMP maintenance.

For DOTA projects, DOTA will be responsible for long-term maintenance. For tenant improvement projects, tenants will be responsible for long-term maintenance.

4.8 PBMP FINAL ACCEPTANCE

The contractor shall submit as-built drawings, product sheets, maintenance requirements, product specifications if applicable, and the O&M Plan to AIR-EE.

Additionally, DOTA will need the following information:

- GPS coordinates or GIS location data
- Contractor warranty period
- Product or equipment warranty information, if applicable
- PBMP turnover date

5. INSPECTIONS, OPERATIONS, AND MAINTENANCE

After installation, PBMPs require inspection and maintenance to continue to function as designed (i.e., meeting the criteria for stormwater flow rate, volume, and water quality) such that the effectiveness of the PBMP does not decrease. Routine and timely scheduled PBMP maintenance will help avoid more costly rehabilitative maintenance or replacement when PBMPs have not been maintained regularly.

All LID and Treatment Control PBMPs will be inspected at least annually (or as prescribed by the manufacturer) and after significant storm events to verify they are functioning properly, and maintenance is performed as necessary. These inspections will verify proper operation in accordance with the Project's PBMP O&M Plans and/or the PBMP O&M Fact Sheets provided in Appendix VI.

5.1 PBMP INSPECTIONS, OPERATIONS, & MAINTENANCE

Every PBMP constructed shall have a PBMP O&M Plan or use the DOTA PBMP O&M Fact Sheets provided in Appendix VI. If PBMP-specific O&M Manuals are not available, the DOTA PBMP O&M Fact Sheets can be utilized as a resource in conducting inspections of PBMPs on DOTA property, including those in tenant leased spaces.

DOTA is responsible for the maintenance of PBMPs on DOTA-owned and -operated spaces. Tenants are responsible for the maintenance of PBMPs on tenant leased spaces.

For PBMPs on tenant leased spaces, mechanisms used to assign responsibility for maintenance may include:

- Lease agreements
- Covenants
- Maintenance agreements
- Conditional Use Permits
- Other legal agreements

AIR-EE and DOTA Maintenance personnel verifies inspections and maintenance of PBMPs on DOTA property, including those on tenant leased spaces.

5.2 PBMP DATABASE INVENTORY

Inspections and maintenance of PBMPs are tracked in Veoci®. The following information is tracked:

- PBMP identification information
- PBMP Category (i.e., LID, Source Control, Treatment Control)
- Latitude and longitude coordinates
- Photographs
- PBMP O&M Plan
- Date of inspection and/or maintenance

- Inspection frequency
- Maintenance frequency

5.3 ENFORCEMENT AND RESPONSE PLAN FOR TENANT PBMPS

During the tenant inspection process, AIR-EE verifies annual inspection/maintenance records and visually observes aboveground accessible PBMPs. If a deficiency is identified, enforcement actions follow the DOTA Tenant Inspection and Enforcement Manual.

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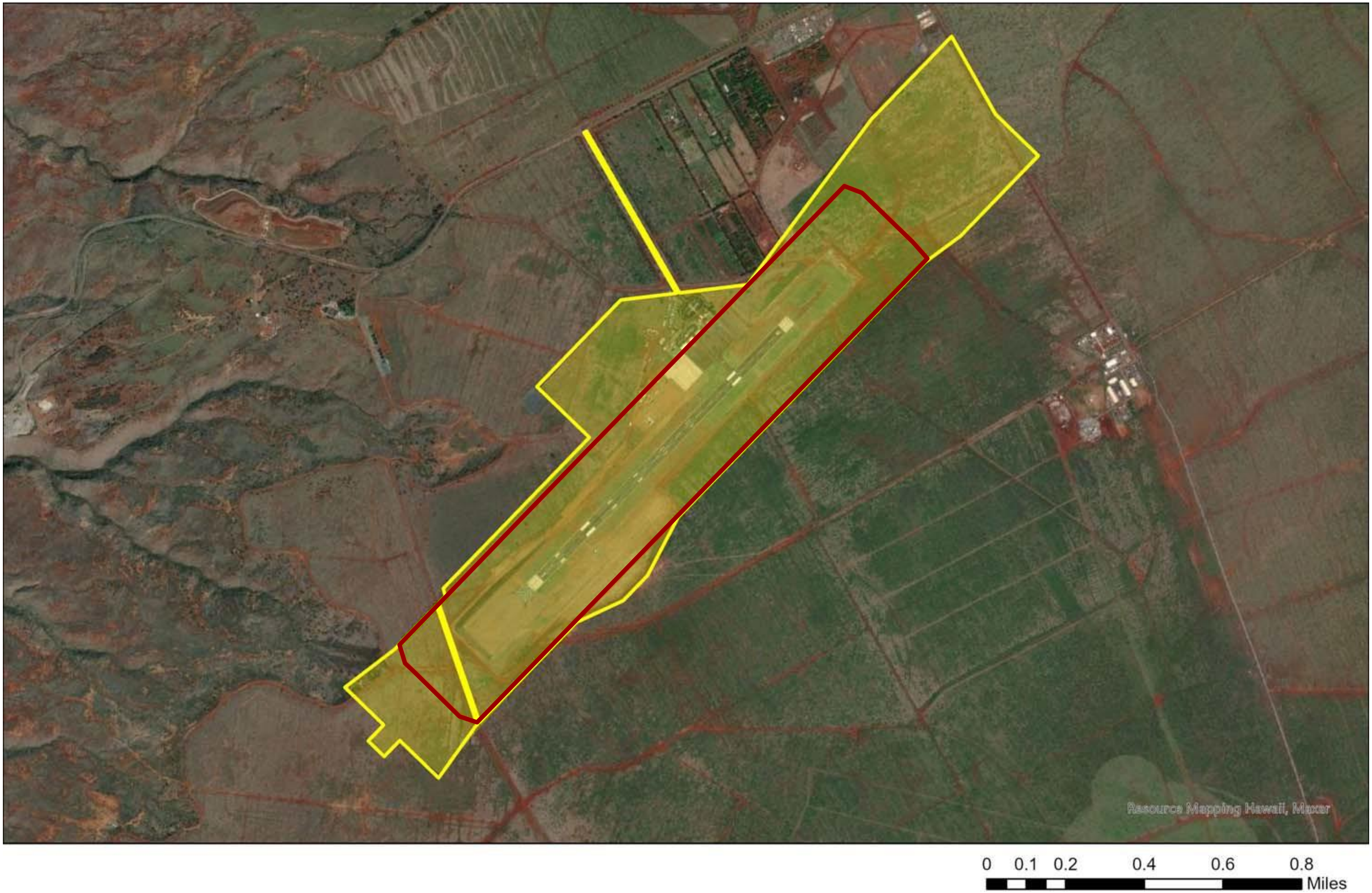
APPENDIX I
FAA EXEMPTION ZONE FOR PBMP INSTALLATION MAPS



FAA Exemption Zone for PBMP Installation Lanai Airport (LNY)

Legend

FAA PBMP Exemption Zone

Airport Property Line

FAA Exemption Zone for PBMP Installation Dillingham Air Field (HDH)

Legend

FAA PBMP Exemption Zone

Airport Property Line

0 0.07 0.15 0.3 0.45 0.6 Miles

N

FAA Exemption Zone for PBMP Installation Daniel K. Inouye International Airport (HNL)

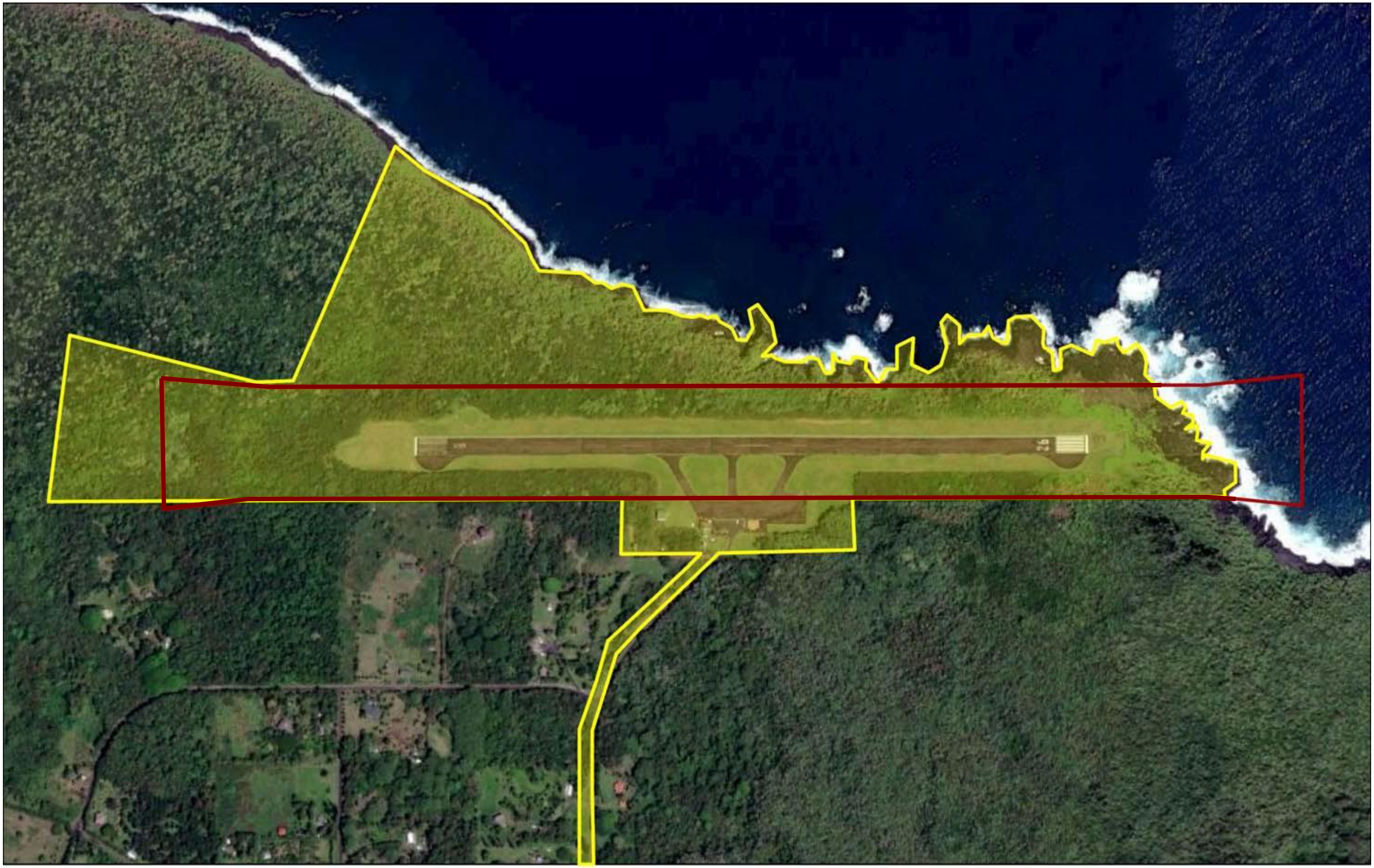
Legend

FAA PBMP Exemption Zone

Airport Property Line

0 0.1 0.2 0.4 0.6 0.8 Miles

N

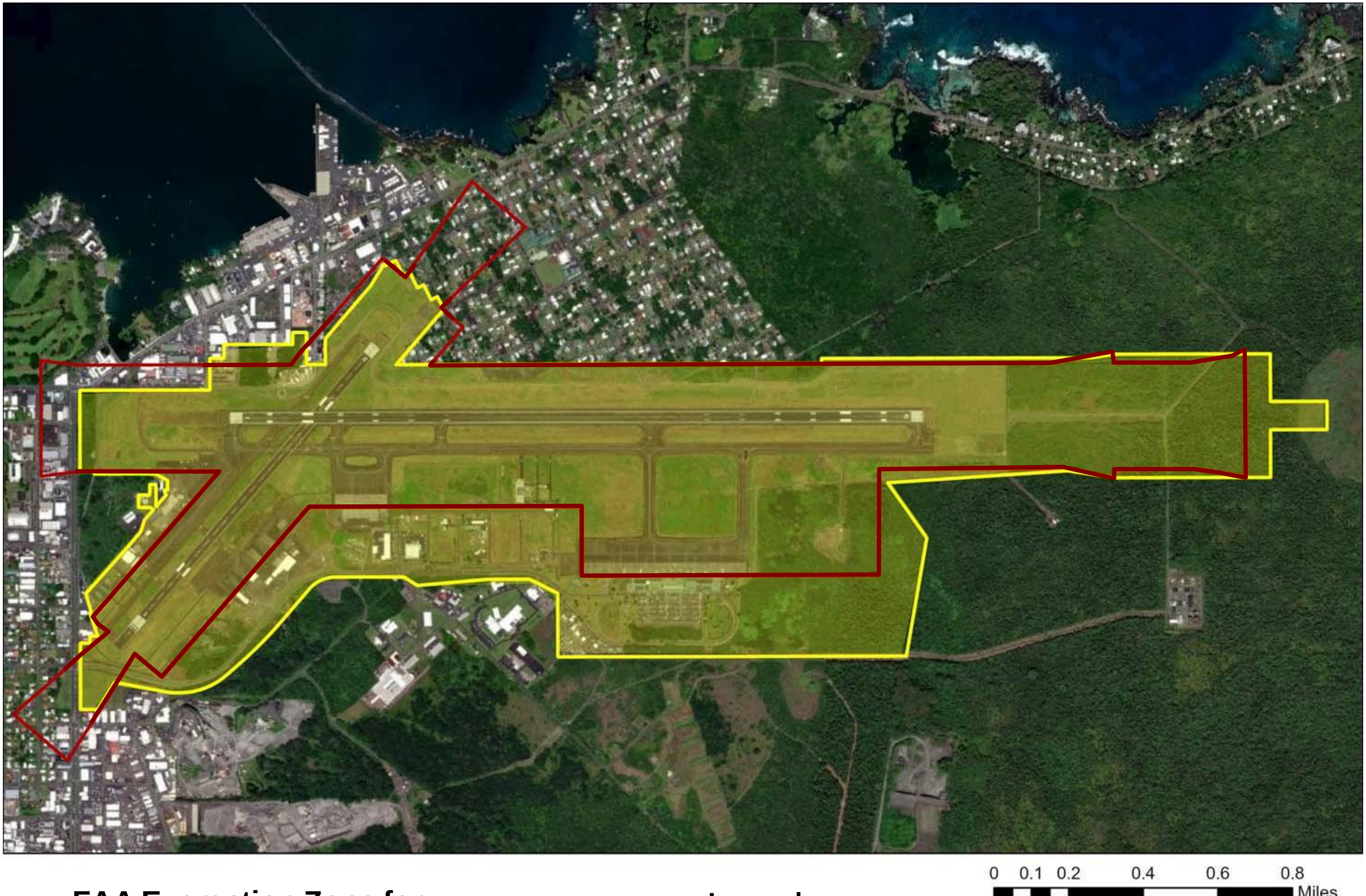


FAA Exemption Zone for PBMP Installation Hana Airport (HNM)

Legend

FAA PBMP Exemption Zone

Airport Property Line



FAA Exemption Zone for PBMP Installation Hilo International Airport (ITO)

Legend

FAA PBMP Exemption Zone

Airport Property Line

FAA Exemption Zone for PBMP Installation Kapalau Airport (JHM)

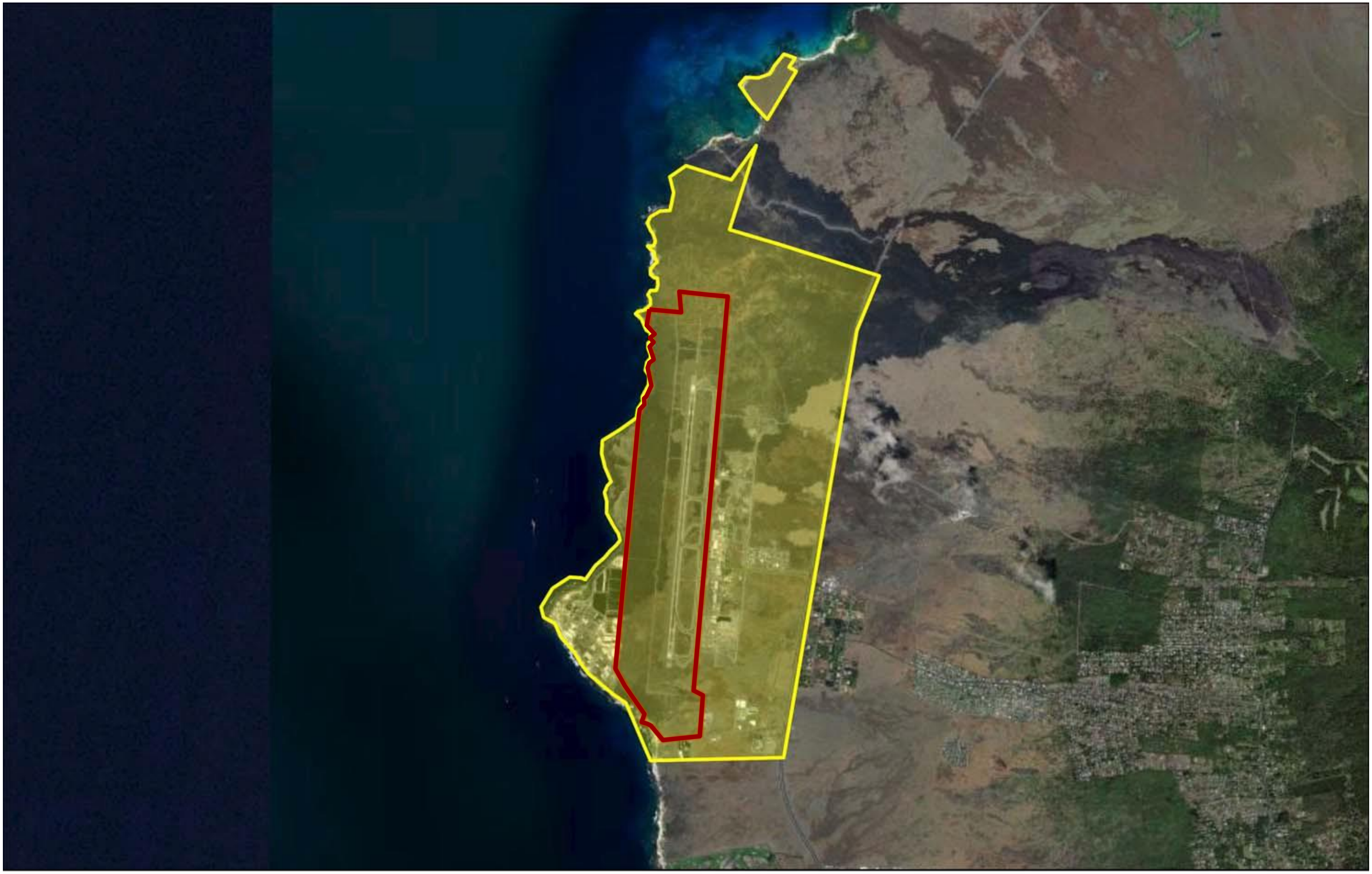
Legend

- FAA PBMP Exemption Zone
- Airport Property Line

FAA Exemption Zone for PBMP Installation Kalaeloa Airport (JRF)

Legend

- FAA PBMP Exemption Zone
- Airport Property Line

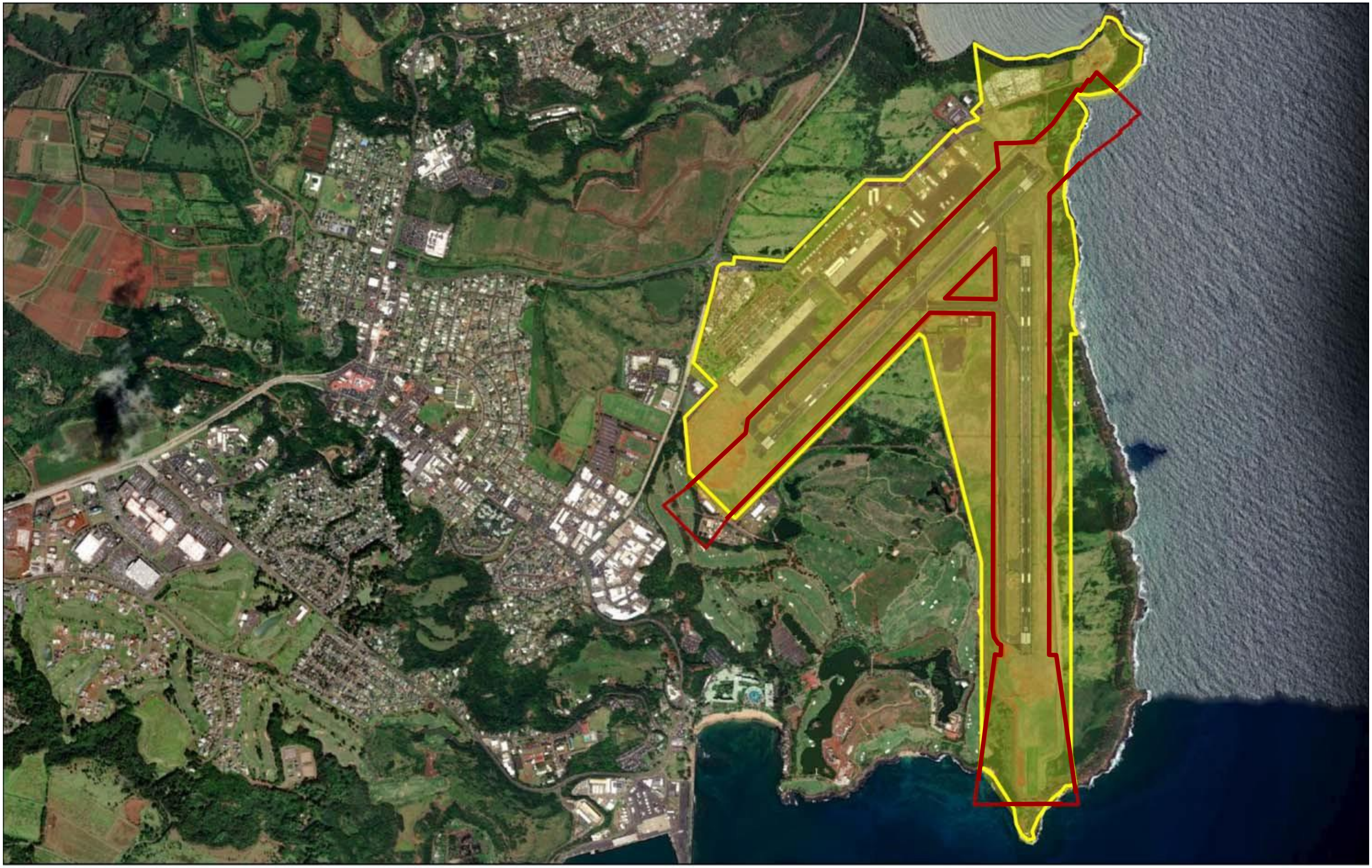


FAA Exemption Zone for PBMP Installation International Airport at Keahole (KOA)

Legend

FAA PBMP Exemption Zone

Airport Property Line

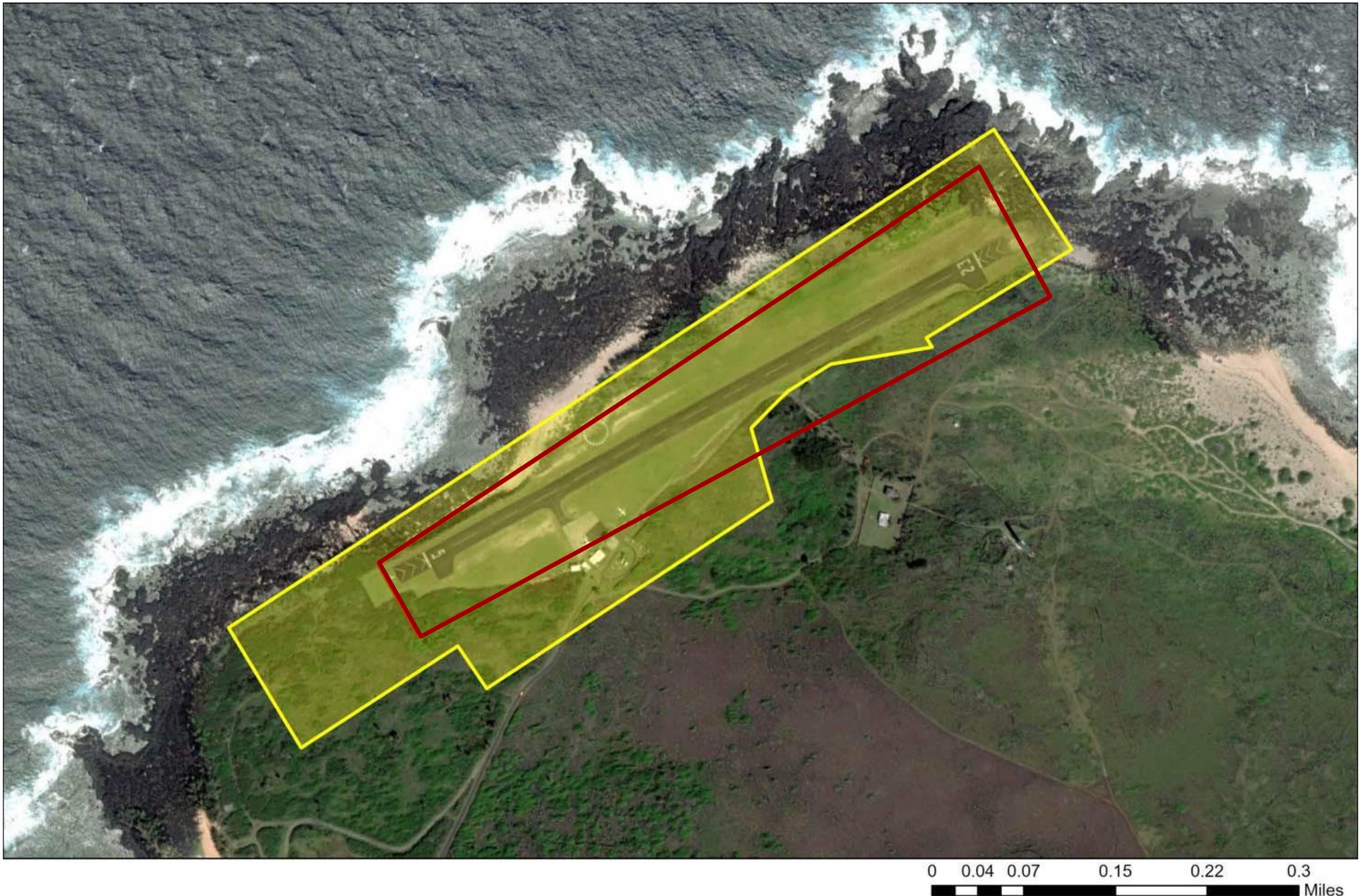


FAA Exemption Zone for PBMP Installation Lihue Airport (LIH)

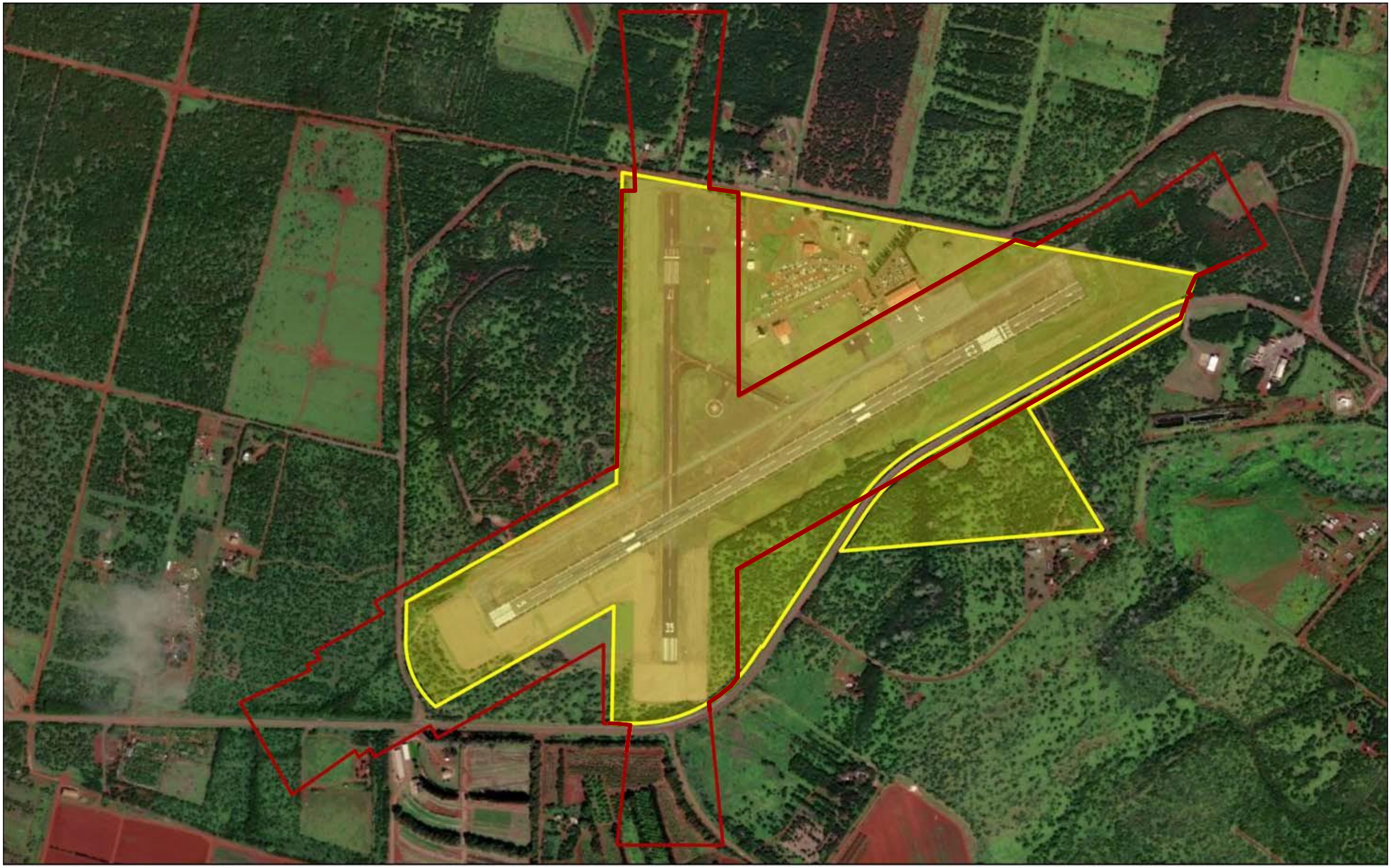
Legend

FAA PBMP Exemption Zone

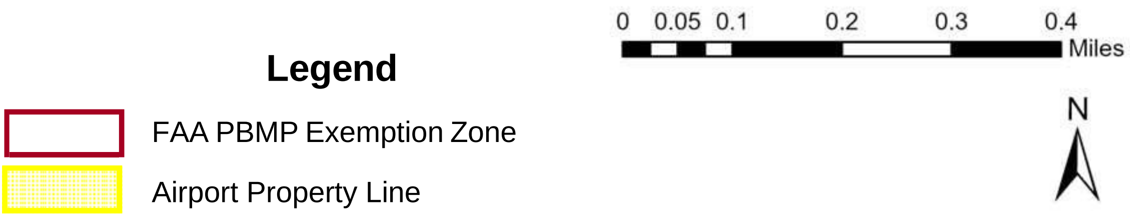
Airport Property Line

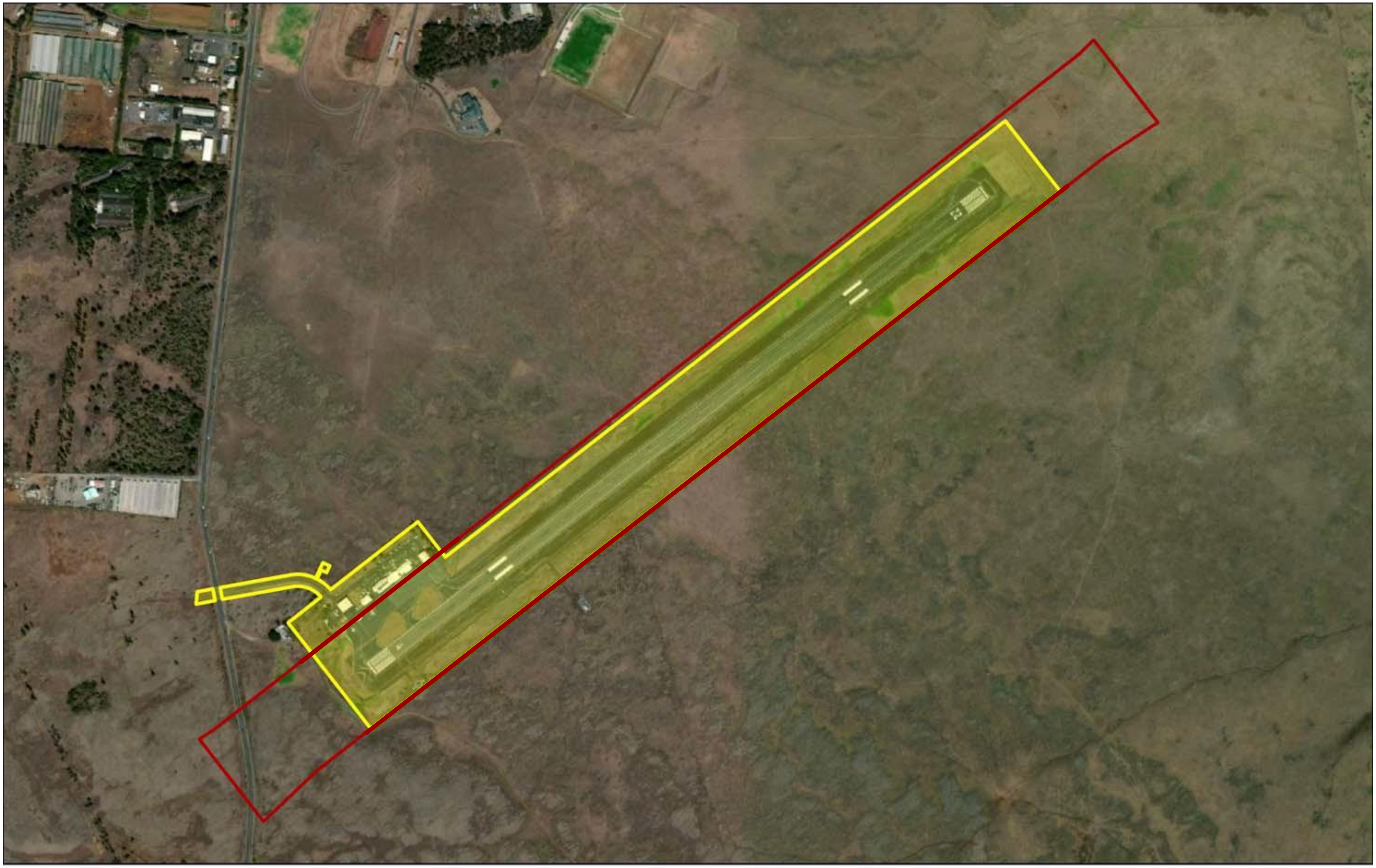


FAA Exemption Zone for PBMP Installation Kalaupapa Airport (LUP)



FAA Exemption Zone for PBMP Installation Molokai Airport (MKK)





FAA Exemption Zone for PBMP Installation Waimea-Kohala Airport (MUE)

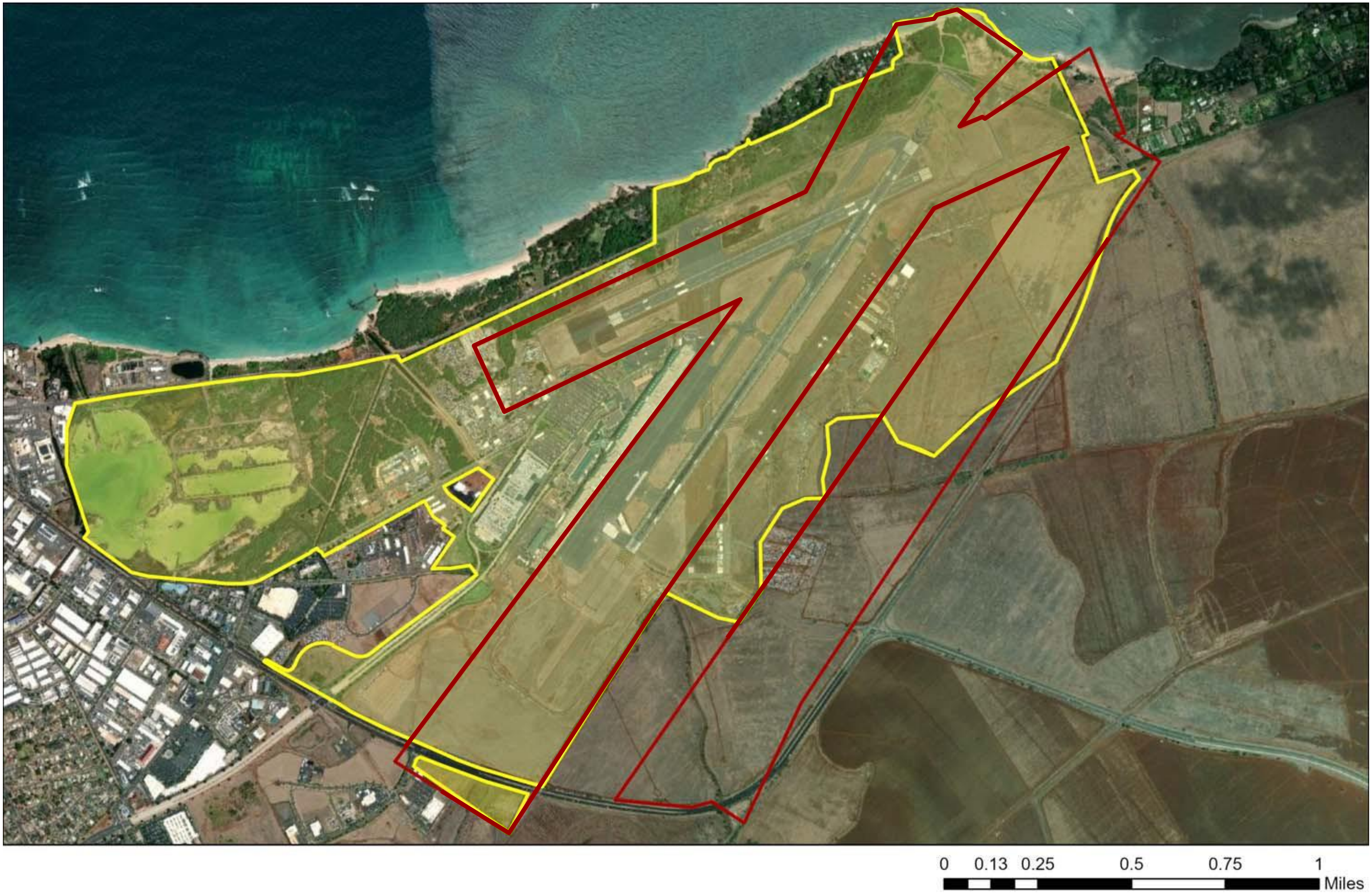
Legend

FAA PBMP Exemption Zone

Airport Property Line

0 0.05 0.1 0.2 0.3 0.4 Miles

N

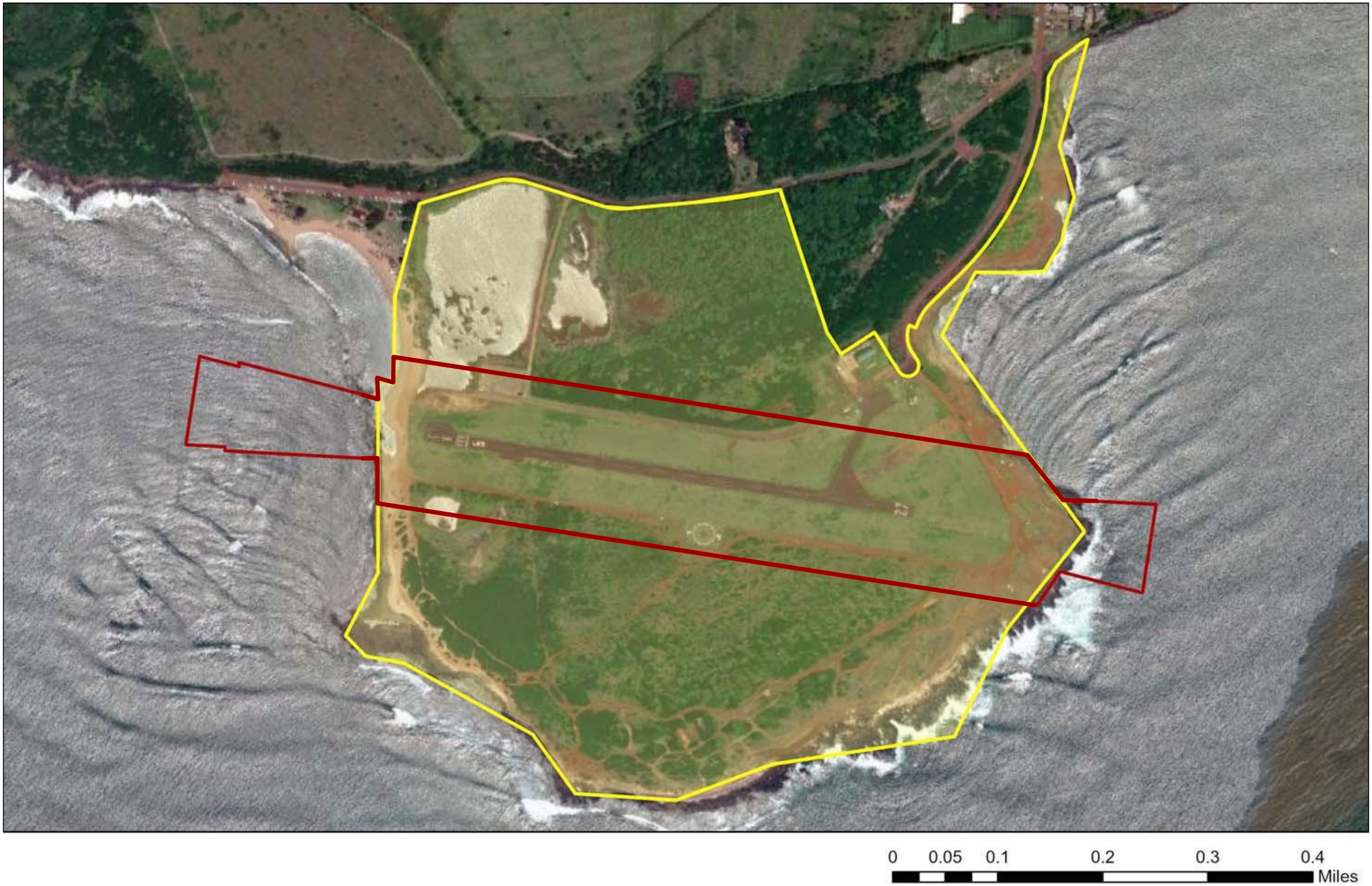


FAA Exemption Zone for PBMP Installation Kahului Airport (OGG)

Legend

FAA PBMP Exemption Zone

Airport Property Line

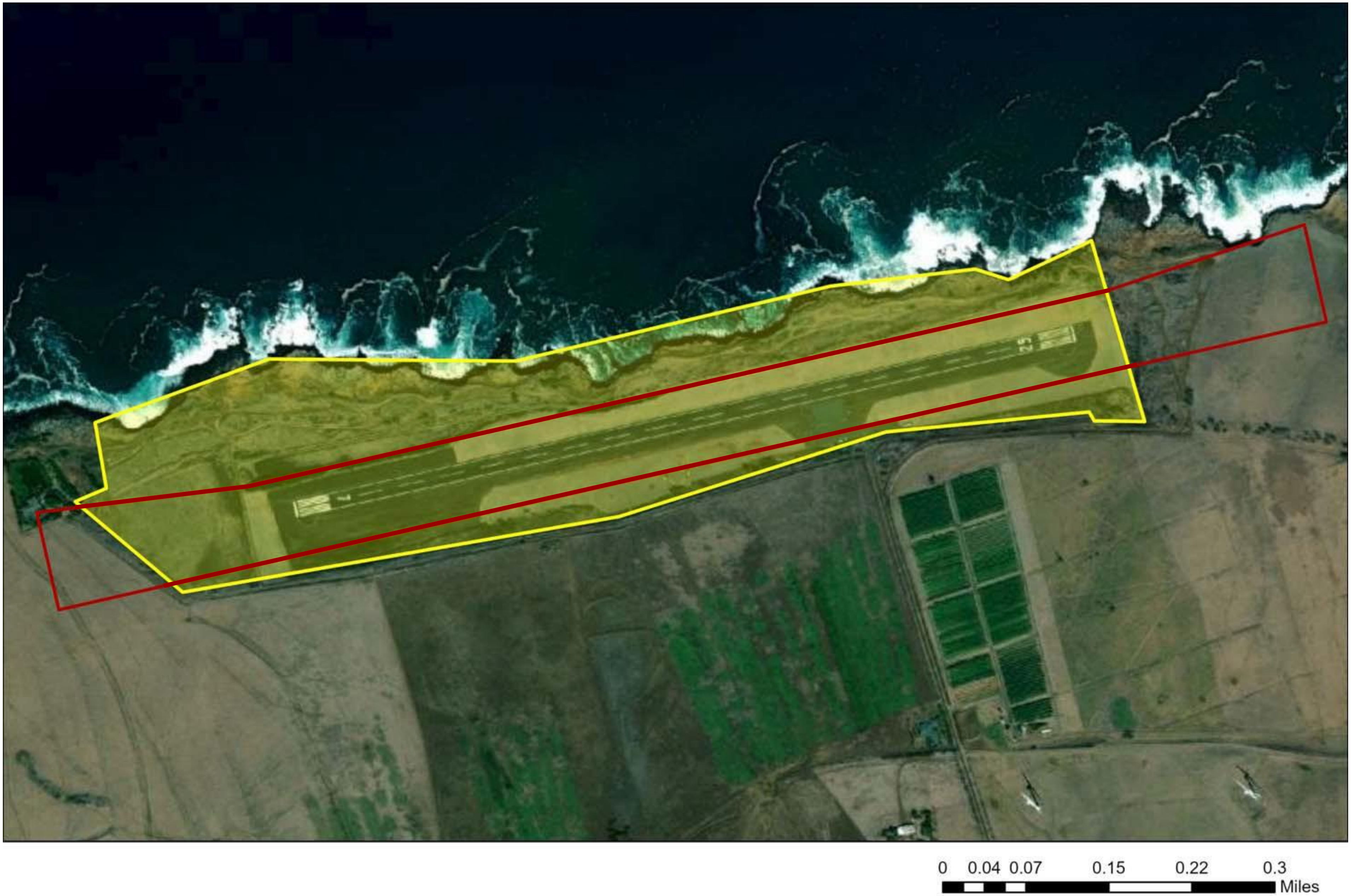


FAA Exemption Zone for PBMP Installation Port Allen Airport (PAK)

Legend

FAA PBMP Exemption Zone

Airport Property Line



FAA Exemption Zone for PBMP Installation Upolu Airport (UPP)

Legend

FAA PBMP Exemption Zone

Airport Property Line

APPENDIX II
EVAPORATION RATES AND RAINFALL DATA FOR AIRPORTS

Pan Evaporation Rate (E_{pan}) Data for DOT Airports

Island	OAHU	OAHU	MAUI	HAWAII	MAUI	OAHU	HAWAII	KAUAI	LANAI	MOLOKAI	MOLOKAI	HAWAII	MAUI	KAUAI	HAWAII
Airport Name	Dillingham Airfield	Daniel K. Inouye International Airport	Hana Airport	Hilo International Airport	Kapalua Airport	Kalaeloa Airport	Ellison Onizuka Kona International Airport at Keahole	Lihue Airport	Lanai Airport	Kalaupapa Airport	Molokai Airport	Waimea-Kohala Airport	Kahului Airport	Port Allen Airport	Upolu Airport
Airport Code	**HDH**	**HNL**	**HNM**	**ITO**	**JHM**	**JRF**	**KOA**	**LIH**	**LNY**	**LUP**	**MKK**	**MUE**	**OGG**	**PAK**	**UPP**
Units	**(in)**	**(in)**	**(in)**	**(in)**	**(in)**	**(in)**	**(in)**	**(in)**	**(in)**	**(in)**	**(in)**	**(in)**	**(in)**	**(in)**	**(in)**
January	4.36	5.10	[*1]	5.05	4.61	4.85	[*1]	5.36	2.16	7.78	5.73	4.21	5.10	5.84	5.72
February	4.36	5.34	[*1]	4.92	5.28	4.93	[*1]	5.66	1.83	7.70	6.43	4.12	5.44	5.38	0[*2]
March	4.80	6.70	[*1]	5.24	6.23	5.91	[*1]	6.46	2.55	9.63	7.36	5.32	6.80	6.56	0[*2]
April	5.36	7.36	[*1]	5.61	6.77	6.72	[*1]	7.19	2.64	9.91	7.84	5.38	7.59	7.64	0[*2]
May	6.48	8.13	[*1]	5.96	7.86	7.53	[*1]	7.76	2.06	10.70	10.63	5.78	8.90	8.35	0[*2]
June	7.20	8.73	[*1]	6.54	7.91	7.78	[*1]	8.09	2.07	11.56	10.75	6.22	9.86	8.90	0[*2]
July	7.47	9.44	[*1]	6.59	9.07	7.90	[*1]	8.72	3.91	11.87	11.01	6.13	10.67	9.87	0[*2]
August	7.09	9.24	[*1]	6.20	9.17	8.17	[*1]	8.56	2.35	11.79	12.38	7.08	10.39	8.88	0[*2]
September	6.26	7.96	[*1]	5.73	7.92	6.73	[*1]	7.52	2.11	10.67	10.29	6.41	9.44	8.18	9.36
October	5.54	7.03	[*1]	5.50	6.98	6.12	[*1]	6.83	2.67	9.73	9.98	5.63	8.07	7.63	5.92
November	4.45	5.94	[*1]	4.22	5.42	4.44	[*1]	5.56	1.00	8.62	7.74	4.25	6.46	6.39	6.09
December	3.64	5.12	[*1]	4.33	5.13	3.48	[*1]	5.12	1.50	8.14	6.32	3.88	5.31	5.49	6.33
Station #	*O-1 (841.00)*	*O-10 (751.20)*	*M-16 x*	*H-67 (87.00)*	*M-1 (458.10)*	*O-6 (702.00)*	*H-2 x*	*K-11 (1020.40)*	*687*	*Mo-2 (531.10) not super close*	*Mo-2 (528.30) white dot*	*H-25 (191.10)*	*M-7 (396.00)*	*K-5 (927.00) or 925.00 white dot*	*H-13 (160.30)*

Notes:

[*1] indicates data not available.

0[*2] indicates data reported as zero.

Source: *Pan Evaporation: State of Hawaii 1894-1983. State of Hawaii, Department of Land and Natural Resources, Division of Water and Land Development (Ekern, P.C. and Chang, J.H., 1985).*

Rainfall Data for DOT Airports

Island	OAHU	OAHU	MAUI	HAWAII	MAUI	OAHU	HAWAII	KAUAI	LANAI	MOLOKAI	MOLOKAI	HAWAII	MAUI	KAUAI	HAWAII
Airport Name	Dillingham Airfield	Daniel K. Inouye International Airport	Hana Airport	Hilo International Airport	Kapalua Airport	Kalaeloa Airport	Ellison Onizuka Kona International Airport at Keahole	Lihue Airport	Lanai Airport	Kalaupapa Airport	Molokai Airport	Waimea-Kohala Airport	Kahului Airport	Port Allen Airport	Upolu Airport
Airport Code	**HDH**	**HNL**	**HNM**	**ITO**	**JHM**	**JRF**	**KOA**	**LIH**	**LNY**	**LUP**	**MKK**	**MUE**	**OGG**	**PAK**	**UPP**
Units	**(in)**	**(in)**	**(in)**	**(in)**	**(in)**	**(in)**	**(in)**	**(in)**	**(in)**	**(in)**	**(in)**	**(in)**	**(in)**	**(in)**	**(in)**
January	5.23	2.89	8.98	9.64	4.94	3.63	1.89	4.44	3.05	6.08	4.02	5.98	3.40	3.80	5.05
February	4.13	2.53	6.56	9.73	3.59	2.15	1.13	3.49	2.69	4.26	2.94	4.24	2.38	2.61	3.23
March	3.50	2.36	11.36	14.02	4.14	1.87	1.38	4.26	1.66	5.80	2.97	5.80	2.13	3.35	5.84
April	2.34	0.98	8.43	12.45	2.72	1.26	0.73	2.34	1.10	4.49	2.00	5.51	1.16	1.46	3.44
May	1.93	0.79	7.11	8.74	2.07	0.90	1.16	2.46	1.05	3.28	1.27	4.02	0.71	1.29	2.22
June	0.89	0.66	4.62	7.81	1.28	0.29	0.72	1.74	0.87	1.80	0.67	2.95	0.35	0.81	2.77
July	1.90	0.80	6.76	10.97	1.49	0.31	0.71	1.88	0.70	2.22	0.40	4.13	0.35	0.89	3.12
August	2.05	1.42	6.15	10.09	1.39	1.27	0.86	1.96	0.41	2.24	0.46	3.19	0.42	0.88	2.86
September	2.44	1.35	6.70	10.20	1.17	1.36	0.85	2.42	1.19	1.60	0.29	2.06	0.29	1.13	2.13
October	3.04	2.17	7.85	10.13	1.88	2.44	0.75	4.26	1.52	3.33	1.47	4.43	0.82	2.72	2.39
November	4.09	2.97	8.78	15.62	4.04	2.98	1.13	5.18	2.62	4.78	2.88	4.08	2.34	3.28	4.11
December	4.51	3.27	7.51	10.65	5.04	2.99	1.66	4.81	3.05	5.50	3.35	5.11	3.22	3.70	3.95
Station #	*843.7*	*759*	*353*	*87*	*462*	*702.5*	*68.13*	*1020.1*	*656*	*563*	*524*	*192.7*	*398*	*926*	*160.3*
Additional Information on Station	*Dillingham - Other Stations*				*Field 32a No station at airport*	*702.5 Campbel Ind Pk*						*Kamuela Upper (Other Station)*	*Kahului Ap*		

Source: *http://rainfall.geography.hawaii.edu/interactivemap.html*

APPENDIX III
LID PBMP
DESIGN FACT SHEETS

LID PBMPs are required for all projects with site conditions where LID PBMPs are feasible. LID PBMPs should be considered first before implementing Treatment Control PBMPs.

The following lists the various LID PBMP types to be considered. More than one may be used depending on site-specific conditions:

- LC-1: Biofilter
- LC-2: Bioretention
- LC-3: Bioswale
- LC-4: Harvesting/Reuse
- LC-5: Dry Well/Drainage Well
- LC-6: Infiltration Basin
- LC-7: Infiltration Trench
- LC-8: Permeable Pavement
- LC-9: Subsurface Infiltration
- LC-10: Vegetated Buffer Strip
- LC-11: Vegetated Swale

The following information is provided for each of the above-listed LID PBMP Fact Sheets:

- Description
- Limitations
- Design Criteria and Guidelines
- Construction Considerations
- Cut Sheet Examples
- Sizing Guidelines

Please refer to Appendix VI for the corresponding O&M Fact Sheets.

LC-1 Biofilter

A biofilter is an engineered shallow depression or above ground facility that collects and filters stormwater runoff using specialized soil media and planting. Filtered runoff discharges to an underdrain and returns to the storm drainage system. Types of biofilters include vegetated biofilters, stormwater curb extensions, tree or planter box filters, or similar proprietary devices. Stormwater curb extensions are landscaped areas within the street parking zone that collect and filter stormwater runoff. Tree box filters and planter boxes are proprietary biotreatment devices designed to mimic natural systems by incorporating plants, soil, and microbes.

Vegetated Biofilter
Source: https://www.sfbetterstreets.org/find-project-types/greening-and-stormwater-management/stormwater-overview/bioretention-rain-gardens/

Design Criteria

Table 1: Minimum Design Criteria and Guidelines

Category	Guidelines
General	
Ponding Depth	12 in or less.
Overflow Device (e.g., riser, spillway) or Bypass	• Include an overflow device to convey peak flows. • Overflow for the 10-yr storm event directed to an outlet with energy dissipators to prevent erosion from the 10-yr storm velocity.
Flow Regulation	A flow regulator may be provided to divert runoff from large drainage areas, if needed.
Landscaping	• Avoid vegetation that could be hazardous to airport operations (i.e., provide food [seeds] or habitat for wildlife). • Select appropriate plantings considering local climate, water depth, native species, and pollutant tolerance. • Use small stature trees with non-invasive root systems, followed by ground cover. • Consider irrigation during dry periods, if necessary.
Vegetated Biofilter	
PBMP Footprint Area	3.3% to 3.8% of contributing impervious area.
Media Layer	• 2- to 4-ft deep media layer and a 2- to 4-in surface mulch layer. • May include a gravel layer at the bottom. • Place permeable filter fabric between media and gravel layers.
Drawdown (drain) Time	48 hrs or less.
Planting Media Coefficient of Permeability	1 ft/day
Observation Wells	Recommended for monitoring facility dewatering and functionality.
Underdrains (Optional)	DOTA prefers no underdrains; if site conditions warrant using underdrains: - Minimum 6-in perforated underdrain pipe in a gravel layer. - Include cleanout pipe tied into the end of all underdrain pipe runs.
Stormwater Curb Extension	
Area Requirements	Biofilter cell within curb extension should follow area requirements for vegetated biofilter above.
Design Criteria	Biofilter cell within curb extension should follow minimum design criteria for vegetated biofilter above.
Location	• Can be used at roadway intersections or midblock and can be combined with crosswalks to increase pedestrian safety. • Place at lowest point of the curb/flow line or immediately upstream of storm drains to maximize runoff interception.
Design	• Typically recessed 1 to 2 ft from the outside edge of the right-most travel lane. • Design to capture runoff from the gutter and not cause ponding. • Design to allow street sweepers along curb edge, typically angled between 30 and 60 degrees relative to the curb line. Steeper return angles will usually require hand-sweeping. • Design inlets and outlets to resist incursions by vehicles and bicycles.
Landscaping	• Plant height should be < 24 in above sidewalk grade to maintain sight clearance. • Irrigation may be needed during dry periods.
Tree Box Filter or Planter Box	
Design	• Design to enhance pollutant removal and hydraulic performance, allowing for a smaller footprint and ease of construction and maintenance. • Follow the manufacturer's instructions for the design guidelines. • Can be used as pretreatment for other LID and Treatment Control PBMPs.

Table 2: Pretreatment Considerations

Category	Considerations
General	Biofilters are susceptible to clogging and premature failure from sediment, trash, and other contaminants. Pretreatment should be provided where sediments, debris, or trash may cause clogging or impact the system functionality.
Vegetated Biofilter	Pretreatment can be provided by sedimentation basins, forebays, or manufactured treatment devices.
Stormwater Curb Extension	None
Tree Box Filter or Planter Box	Follow manufacturer's instructions for pretreatment considerations.

LIMITATIONS

May be considered infeasible or impractical if:
- Determined to be infeasible through the LID PBMP Infeasibility & Waiver Screening step in Veoci®.
- The invert of the underdrain layer is below the seasonally high groundwater table.
- The amount of sunlight received by the site is inadequate or irrigation is infeasible to support vegetation.
- The site lacks a sufficient hydraulic head to support operation by gravity.
- Unable to operate off-line with bypass, and unable to operate in-line with a safe overflow mechanism.

Vegetated Biofilter
- Unstable soil stratum or soils with > 25% clay content.
- Slopes > 20%.

Stormwater Curb Extension and Tree Planter Box Filters
- Too much on-street parking removed to accommodate BMP.
- Location conflicts with fire hydrants, utilities, catch basins that cannot be moved.
- Excessive sediment sources within drainage area (e.g., dirt roads, gravel shoulders and driveways).

Construction Considerations

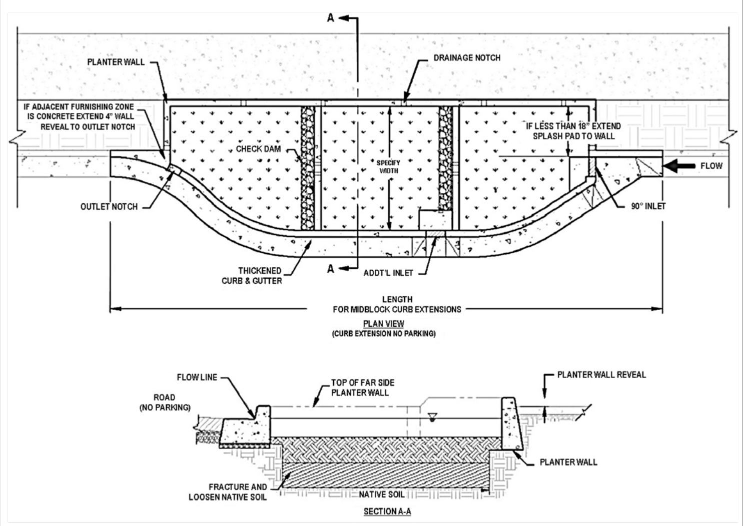
UNDERDRAINS
- Place underdrains on a 3-ft-wide section of permeable filter fabric. The pipe is placed next, followed by the gravel bedding. The ends of underdrain pipes not terminating in an observation well should be capped.
- The main collector pipe for underdrain systems should be constructed at a minimum slope of 0.5 %. Observation wells or cleanout pipes should be provided (1 minimum per every 1,000 ft² of surface area).

LANDSCAPING
- Plant as soon as possible after the area has been graded. Protect sod with tarps or other protective covers during delivery and do not allow to dry out between harvesting and placement.
- Keep rootstock moist during transport and on-site storage. Plant so 1/8 of rootball is above final grade and diameter of the hole is at least 6 in larger than the planting ball. Set and maintain straightness during planting. Thoroughly water ground around the plant after installation.
- Place a uniform thickness of 2 to 3 in of mulch or compost on the surface. Compost is preferred over mulch and wood chips as it is heavier and less likely to disperse to the perimeter of the facility during a storm event.
- Per FAA Regulations, do not scatter or apply seeds through hydroseeding or within hydromulch in areas that could attract wildlife and cause safety concerns for aircraft operations. Use alternative methods such as sprigs. For areas that do not create safety concerns for aircraft operations, seeds may be used with explicit approval from Airport Management.

MISCELLANEOUS
- Install at a time of the year when there is a reasonable chance of successfully establishing grass without irrigation; temporary irrigation may be required.
- Do not use as sediment control measures during construction.
- Do not establish until the contributing drainage area is stabilized.
- Removal of mature trees for the construction of the biofilter may be infeasible and requires additional review and approval by DOTA on a case-by-case basis.

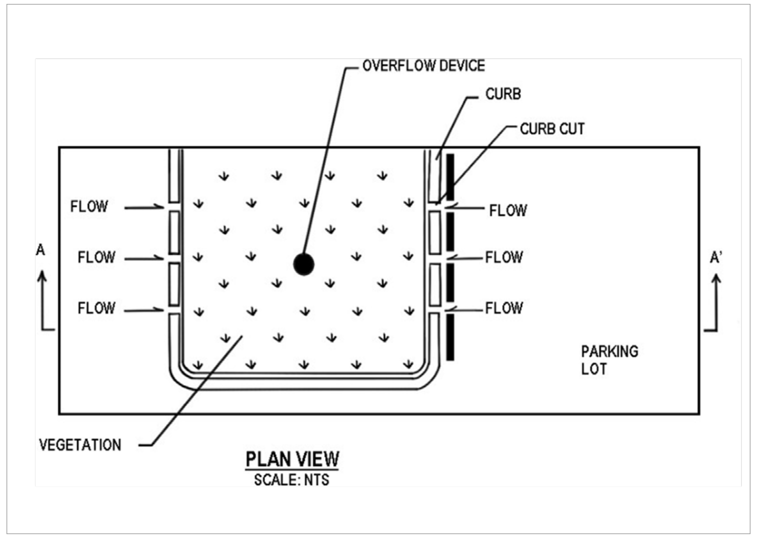
Cut Sheet Examples

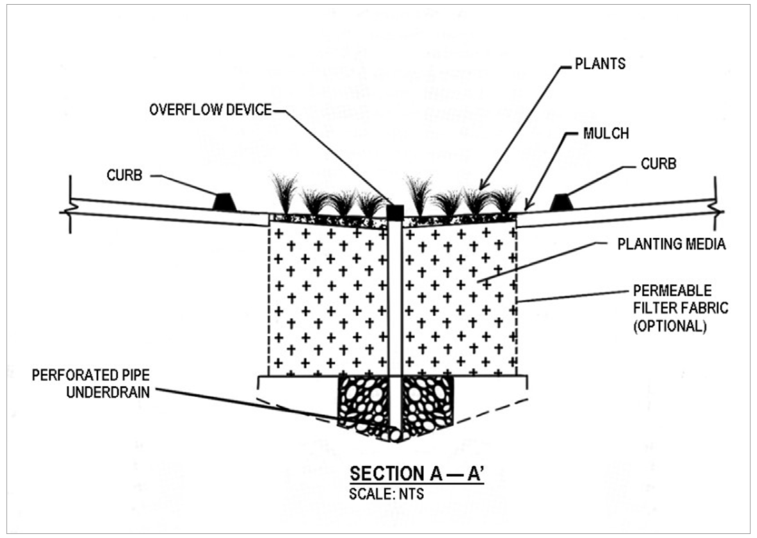
Disclaimer: The example schematics provided below are intended for visual aid purposes only and not for design purposes. The example schematics are not intended to be used as a design guide for the items, descriptions, and details (depths, etc.). The actual configuration will vary depending on specific site constraints and the design criteria of this fact sheet. Refer to the information provided above for details on the design.



Example Schematic of a Stormwater Curb Extension

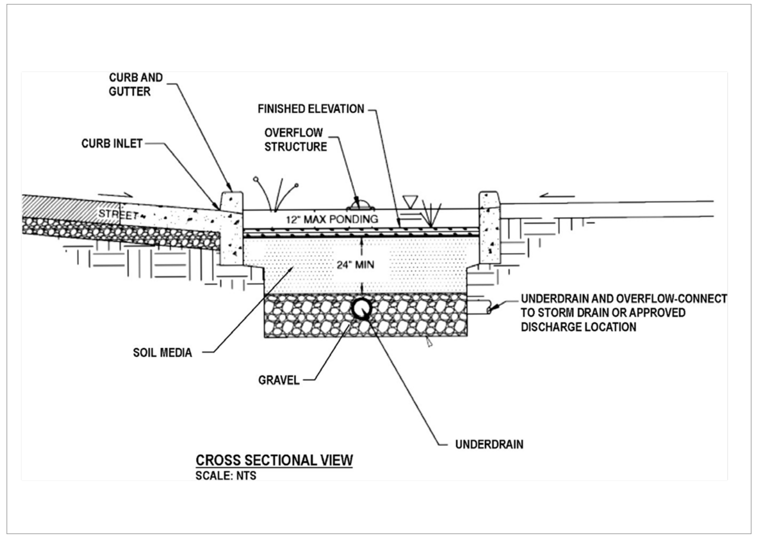
Source: *2020 Stormwater Management Manual, SWMM Details* (City of Portland, Oregon, Bureau of Environmental Services, December 2020). The source schematic was modified to remove design details that are not consistent with this Fact Sheet.





Example Schematic of a Vegetated Biofilter

Source: *Storm Water BMP Guide for New and Redevelopment* (CCH, 2017). The source schematic was modified to remove design details that are not consistent with this Fact Sheet.



Example Schematic of a Planter Box with Underdrain

Source: *Low Impact Development Initiative, Low Impact Development Stormwater Management Standard Details* (California Stormwater Quality Association (CASQA), August 2017). The source schematic was modified to remove design details that are not consistent with this Fact Sheet.

Sizing Guidelines

VEGETATED BIOFILTER/STORMWATER CURB EXTENSION

Step 1:
Use the procedure below to compute the volumetric runoff coefficient (C) and water quality design volume (WQV). The C should be calculated using the following equation:

$$C = 0.05 + 0.009I$$

where C = Volumetric Runoff Coefficient

I = Impervious Cover (%)

The WQV is calculated using the following equation:

$$WQV = PCA \times 3630$$

where WQV = Water Quality Design Volume (ft³)

P = Design Storm Runoff Depth (in) (refer to Section 4.5.3.1)

C = Volumetric Runoff Coefficient

A = Tributary Drainage Area (ac)

Step 2:
Select initial values for the planting media depth (l_m) and allowable maximum ponding depth (d_p).

Step 3:
Calculate the filter bed surface area (A_b):

$$A_b = (WQV \times l_m) / [k_m (l_m + d_p/24) (t/24)]$$

where A_b = Filter Bed Bottom Surface Area (ft²)

WQV = Water Quality Design Volume from Step 1 (ft³)

l_m = Planting Media Depth from Step 2 (ft)

k_m = Planting Media Permeability Coefficient (ft/day) (refer to Section 4.5.3.6)

d_p = Maximum Ponding Depth from Step 2 (ft)

t = Filter Bed Drain Time (hrs) (refer to Section 4.5.3.5)

Step 4:
Select a filter bed width (w_b), and calculate the filter bed length (l_b):

$$l_b = A_b / w_b$$

where l_b = Filter Bed Length (ft)

A_b = Filter Bed Bottom Surface Area from Step 3 (ft²)

w_b = Filter Bed Width (ft)

Step 5:
Calculate the total area occupied by the PBMP excluding pretreatment (A_{PBMP}) using the filter bed dimensions, embankment side slopes, and freeboard:

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

where A_{PBMP} = Area Occupied by PBMP Excluding Pretreatment (ft²)

w_b = Filter Bed Width from Step 4 (ft)

z = Filter Bed Interior Side Slope (length per unit height)

d_p = Maximum Ponding Depth from Step 2 (ft)

f = Freeboard (ft)

l_b = Filter Bed Length from Step 4 (ft)

If the calculated area does not fit in the available space, either reduce the drainage area, increase the planting media depth (if it is not already equal to the maximum depth), and repeat the calculations.

TREE BOX FILTER OR PLANTER BOX

Follow the manufacturer's instructions for sizing guidelines.

LC-2 Bioretention

Bioretention is an engineered excavated facility that collects and filters stormwater runoff using specialized soil media and planting. It captures the water quality volume; passes it through layers of sand, organic matter, soil, or other media; and infiltrates it into native soils.

Bioretention
Source: https://www.epa.gov/system/files/documents/2021-11/bmp-bioretention-rain-gardens.pdf

Design Criteria

Table 1: Minimum Design Criteria and Guidelines

Category	Guidelines
PBMP Footprint Area	4% to 13% of contributing impervious area.
Media Layer	• 2- to 4-ft layer depth. • May include a gravel layer at the bottom. • Place permeable filter fabric between media and gravel layers.
Mulch Layer (as appropriate)	• 2- to 4-in layer depth. • Consider dispersion during storm events if used on the surface.
Drawdown (drain) Time	48 hrs or less.
Ponding Depth	12 in or less.
Minimum Soil Infiltration Rate	0.5 in/hr
Maximum Interior Side Slope (length per unit height)	3:1
Minimum Depth from Basin Invert to Groundwater Table	3 ft
Overflow	• Include an overflow device (e.g., riser, spillway) for significant storm events. • Direct overflow for 10-yr storm event to outlet with energy dissipators to prevent erosion from 10-yr storm velocity.
Minimum Freeboard Above Overflow Device	1 ft
Flow Regulation	Divert runoff from large drainage area using flow regulator, if needed.
Observation Wells	Recommended for monitoring facility dewatering and functionality.
Landscaping	• Avoid vegetation that could be hazardous to airport operations (i.e., food [seeds] or habitat for wildlife). • Select appropriate plantings considering local climate, water depth, native species, and pollutant tolerance. • Use small stature trees with non-invasive root systems, followed by ground cover. • Irrigation may be needed during dry periods.

Table 2: Pretreatment Considerations

Category	Considerations	
General	Bioretention facilities are susceptible to clogging and premature failure.	
Pretreatment Requirments	**Soil Infiltration Rate**	**Pretreatment Requirement**
	< 3 in/hr	Pretreatment strongly recommended. Size pretreatment device for at least 25% of WQV.
	> 3 in/hr and < 5 in/hr	Pretreatment mandatory. Size pretreatment device for at least 50% of WQV.
	> 5 in/hr	Pretreatment mandatory. Size pretreatment device for 100% of WQV.
Pretreatment Options	• Vegetated swales, vegetated buffer strips, sedimentation basins, forebays, or manufactured treatment devices. • Forebay considerations: - 18- to 30-in depth. - Use where standing water is not a safety or vector concern. - Line to prevent water flow into underdrains without first passing through the treatment area. - Lining allows for sediment and debris removal with a shovel or vac truck.	

LIMITATIONS

May be considered infeasible or impractical if:
- Determined to be infeasible through the LID PBMP Infeasibility & Waiver Screening step in Veoci®.
- The amount of sunlight received by the site is inadequate or irrigation is infeasible to support vegetation.
- The site lacks sufficient hydraulic head to support operation by gravity.
- Unable to operate off-line with bypass, and unable to operate in-line with a safe overflow mechanism.
- Soils have a clay content >25%.
- Slopes are >20%.

Construction Considerations

COMPACTION

- Place backfill in 12- to 18-in lifts to minimize compaction; use a primary tiling operation such as chisel plow, ripper, or subsoiler to refracture the soil profile through the 12-in compaction zone. May use heavy equipment around but not inside the perimeter.
- Do not use as sediment control measures during construction.
- Use wide track or marsh track equipment or light equipment with turf-type tires. Equipment with narrow tracks or tires, rubber tires with large lugs, or high-pressure tires is unacceptable as it may cause excessive compaction and reduced infiltration rates.

LANDSCAPING

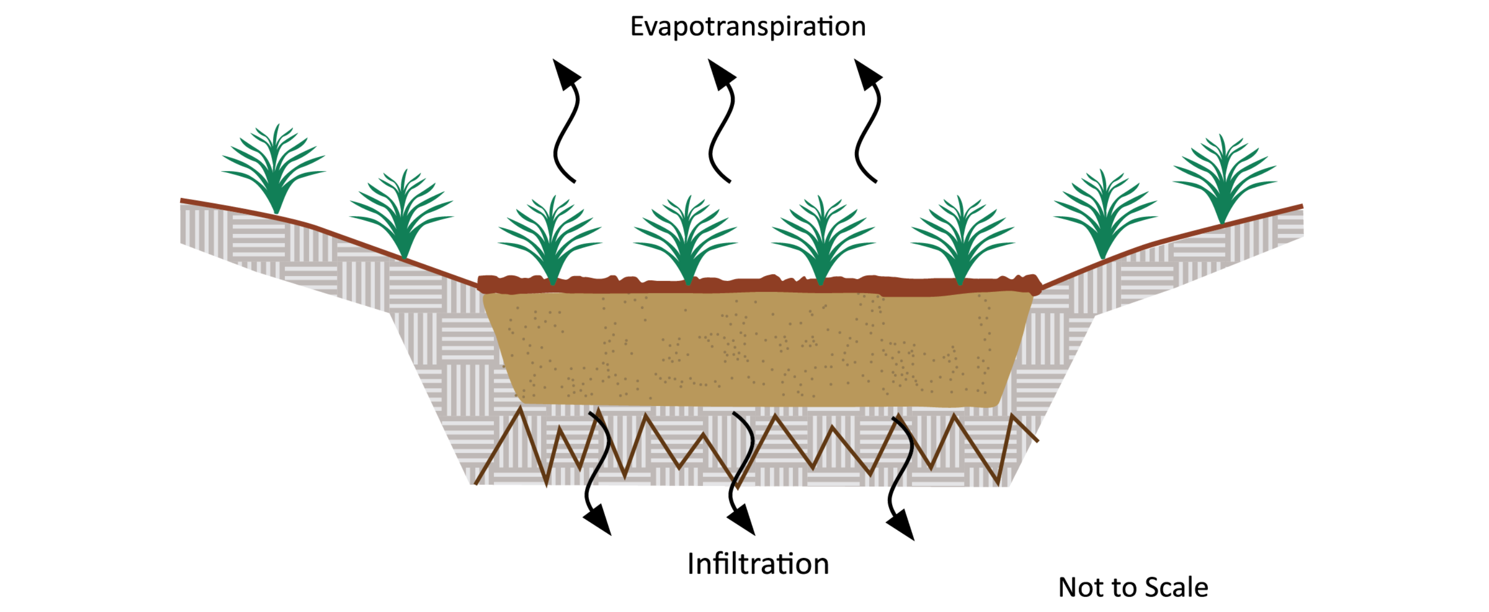
- Select plants that may survive without irrigation; native Hawaiian plants shall compose 35% of the total plant footprint for the landscaped areas of the site project per HRS § 103D-408.
- Plant as soon as possible after soil stabilization of the upgradient area is completed and the ground is ready for planting.
- Keep rootstock moist during transport and on-site storage. Plant so 1/8 of rootball is above final grade and diameter of the hole is at least 6 in larger than the planting ball. Maintain straightness during planting. Thoroughly water ground around the plant after installation.
- Place a uniform thickness of 2 to 3 in of mulch or compost on the surface. Compost is preferred over mulch and wood chips as it is heavier and less likely to disperse to the perimeter of the bioretention facility during a storm event.
- Per FAA Regulations, do not scatter or apply seeds through hydroseeding or within hydromulch in areas that could attract wildlife and cause safety concerns for aircraft operations. Use alternative methods such as sprigs. For areas that do not create safety concerns for aircraft operations, seeds may be used with explicit approval from Airport Management.
- Include directions in the specifications for appropriate fertilizer and soil amendments based on soil properties determined through testing and landscaping needs.

MISCELLANEOUS

- Install at a time of the year when there is a reasonable chance of successfully establishing vegetation without irrigation; temporary irrigation may be required.
- Do not establish until the contributing drainage area is stabilized.
- Removal of mature trees for the construction of the bioretention facility may be infeasible and requires additional review and approval by DOTA on a case-by-case basis.

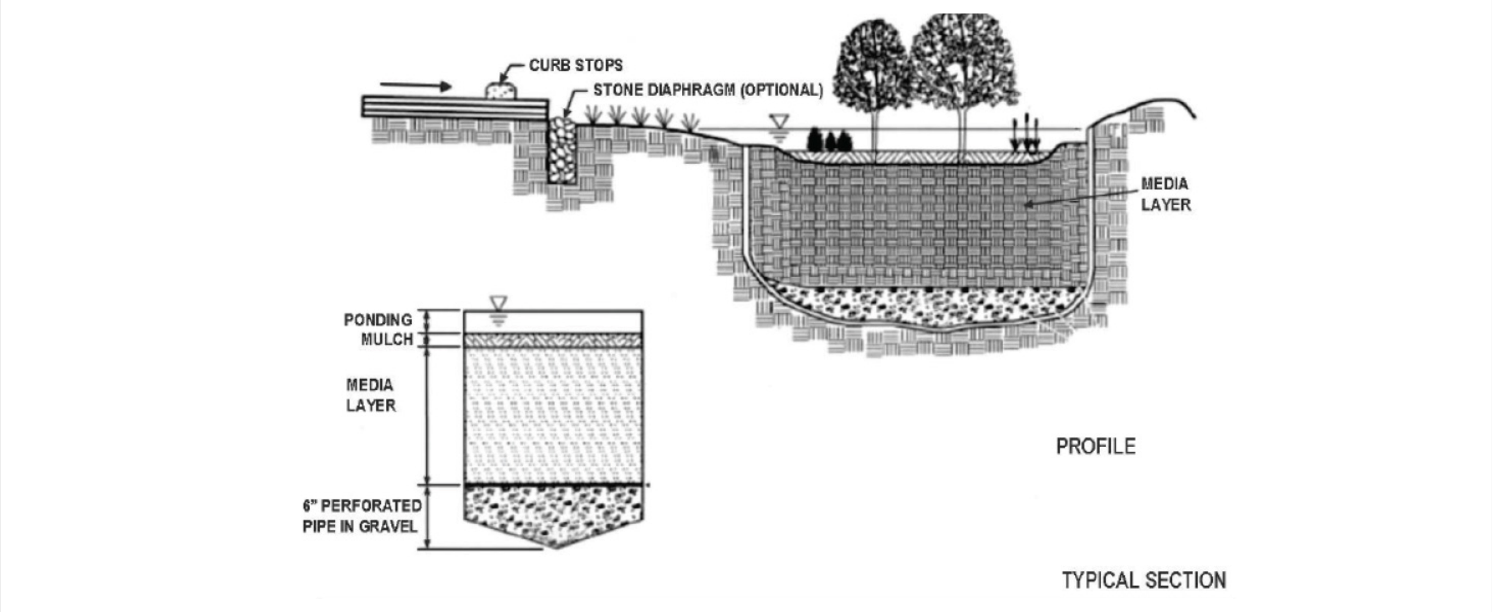
Cut Sheet Examples

Disclaimer: The example schematics provided below are intended for visual aid purposes only and not for design purposes. The example schematics are not intended to be used as a design guide for the items, descriptions, and details (depths, etc.). The actual configuration will vary depending on specific site constraints and the design criteria of this fact sheet. Refer to the information provided above for details on the design.



Example Schematic of a Bioretention Facility

Source: *Minnesota Stormwater Manual* (Minnesota Pollution Control Agency, February 17, 2021). The source schematic was modified to remove design details that are not consistent with this Fact Sheet.



Example Schematic of a Bioretention Facility

Source: *2000 Maryland Stormwater Design Manual Volumes I & II* (CWP and MDE, May 2009). The source schematic was modified to remove design details that are not consistent with this Fact Sheet. The sand filter layer and the gravel curtain drain shown above are not needed.

Sizing Guidelines

Step 1:
Use the procedure below to compute the volumetric runoff coefficient (C) and water quality volume (WQV). The C should be calculated using the following equation:

$C = 0.05 + 0.009I$

where ***C*** = Volumetric Runoff Coefficient

I = Impervious Cover (%)

The WQV is calculated using the following equation:

$WQV = PCA \times 3630$

where ***WQV*** = Water Quality Design Volume (ft³)

P = Design Storm Runoff Depth (in) (refer to Section 4.5.3.1)

C = Volumetric Runoff Coefficient

A = Tributary Drainage Area (ac)

Step 2:
Calculate the maximum water storage depth (d_{max}) using the underlying soil infiltration rate (k) and the required drawdown time (t):

$d_{max} = kt / (F_s \times 12)$

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

k = Soil Infiltration Rate (in/hr)

t = Drawdown (drain) Time (hrs) (refer to Section 4.5.3.5)

Fs = Infiltration Rate Factor of Safety (refer to Section 3.3.1)

Step 3:
Select a ponding depth (d_p), media layer thickness depth (l_m), and gravel layer thickness depth (l_g; this is optional) such that the total effective storage depth (d_t) is no greater than the maximum water storage depth (d_{max}) calculated in Step 2:

$d_t = d_p + l_m n_m + l_g n_g \leq d_{max}$

where d_t = Total Effective Water Storage Depth (ft)

d_p = Ponding Depth (ft)

l_m = Media Layer Depth (ft)

n_m = Media Layer Porosity (refer to Section 4.5.3.7)

l_g = Gravel Layer Depth (ft)

n_g = Gravel Layer Porosity (refer to Section 4.5.3.7)

d_{max} = Maximum Storage Depth from Step 2 (ft)

Step 4:
Calculate the bioretention facility bottom surface area (A_b):

$A_b = WQV / [d_t + (kT / 12F_s)]$

where A_b = Bottom Surface Area (ft²)

WQV = WQV from Step 1 (ft³)

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

k = Soil Infiltration Rate (in/hr)

T = Fill Time (time for the PBMP to fill with water [hrs]) (refer to Section 4.5.3.10)

F_s = Infiltration Rate Factor of Safety (refer to Section 3.3.1)

Step 5:
Select a bioretention facility bottom or invert width (w_b), and calculate the bioretention facility bottom or invert length (l_b) using the surface area (A_b) calculated from Step 4:

$l_b = A_b / w_b$

where l_b = Bottom or Invert Length (ft)

A_b = Bottom Surface Area from Step 4 (ft²)

w_b = Bottom or Invert Width (ft)

Step 6:
Calculate the total area occupied by the PBMP excluding pretreatment (A_{PBMP}) using the bioretention facility bottom dimensions, embankment side slopes, and freeboard:

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

where A_{PBMP} = Area Occupied by PBMP Excluding Pretreatment (ft²)

w_b = Bottom Width from Step 5 (ft)

z = Bioretention Facility Interior Side Slope (length per unit height)

d_p = Design Ponding Depth from Step 3 (ft)

f = Freeboard (ft)

l_b = Bottom Length from Step 5 (ft)

If A_{PBMP} is greater than the available space, reduce the drainage area or increase d_p, l_m, or l_g (if d_t is not already equal to d_{max}), and repeat the calculations. If A_{PBMP} is still greater than the available space, reduce F_s (if the minimum number of test pits and permeability tests have not been performed) and repeat the calculations.

LC-3 Bioswale

A bioswale, sometimes referred to as a bioretention swale or an enhanced swale, is a shallow channel with a media layer covered with turf or other surface material (other than mulch or plants). Runoff is captured in the cells formed by check dams, filters through a media layer, and discharges at the downstream end of the swale; the filtered runoff can also collect and return to the storm drainage system via underdrains.

Bioswale at Terminal 3 Parking Lot, Daniel K. Inouye International Airport
Source: Hawaii DOTA

Design Criteria

Table 1: Minimum Design Criteria and Guidelines

Category	Guidelines
PBMP Footprint Area	8% to 40% of contributing impervious area.
Contributing Drainage Area	5 ac or less.
Media Layer	• 18- to 36-in layer depth. • Include a gravel drainage layer at the bottom. • Place permeable filter fabric between media and drainage layers.
Bottom Width	2 to 8 ft wide.
Ponding Depth at Downstream End	18 in or less.
Minimum Freeboard	0.5 ft
Check Dams	• 12-in maximum height. • Install perpendicular to flow. • Provide a v-notch weir, weep hole, or similar drainage feature to direct low flow volume.
Inlet and Outlet Protection	Provide energy dissipators such as riprap to prevent erosion from 10-yr storm velocity and scour at inlets and outlets.
Maximum Longitudinal Slope	• 2% slope without check dams. • 5% slope with check dams.
Maximum Interior Side Slope (length per unit height)	3:1
Overflow	Include an overflow device (e.g., riser, spillway) for significant storm events.
Flow Regulation	Provide a flow regulator to divert runoff from large drainage area, if needed.
Observation Wells	Recommended for monitoring facility dewatering and functionality.
Underdrains	DOTA prefers no underdrains; if site conditions warrant using underdrains: - Minimum 6-in perforated underdrain pipe in a gravel layer. - Include cleanout pipe tied into the end of all underdrain pipe runs.
Landscaping	• Avoid vegetation that could be hazardous to airport operations (i.e., food [seeds] or habitat for wildlife). • Select appropriate plantings considering site-specific soils and hydraulic conditions. Design to facilitate regular mowing. • Select plants based on local climate, water depth, native species, and pollutant tolerance. • Use small stature trees with non-invasive root systems, followed by ground cover. • Irrigation may be needed during dry periods. • Vegetate with dense turf grasses to promote sediment capture, filtration, nutrient uptake, and lower flow velocity.

Table 2: Pretreatment Considerations

Category	Considerations
Pretreatment Options	• Vegetated swales, vegetated buffer strips, sedimentation basins, forebays, or manufactured treatment devices. • Pea gravel diaphragm used along top of channel for pretreatment of lateral sheet flow entering bioswale. • Forebay considerations: - Volume equal to at least 0.05 in per impervious ac of drainage area. - Use where standing water is not a safety or vector concern. - Line to prevent water flow into underdrains without first passing through the treatment area. - Lining allows for easy sediment and debris removal with a shovel or vector truck.

LIMITATIONS

May be considered infeasible or impractical if:

- Determined to be infeasible through the LID PBMP Infeasibility & Waiver Screening step in Veoci®.
- Unstable soil stratum or soils with > 25% clay content.
- Slopes > 5%.
- The invert of the underdrain layer is below the seasonally high groundwater table.
- The amount of sunlight received by the site is inadequate or irrigation is infeasible to support vegetation.
- The site lacks sufficient hydraulic head to support operation by gravity.
- Unable to operate off-line with bypass, and unable to operate in-line with a safe overflow mechanism.

Construction Considerations

COMPACTION

- Use excavation hoes to remove original soil. Place backfill in 12- to 18-in lifts to minimize compaction; use a primary tiling operation such as chisel plow, ripper, or subsoiler to refracture the soil profile through the 12-in compaction zone. Heavy equipment can be used around but not inside the perimeter of the bioswale facility to supply materials.
- Use wide track or marsh track equipment or light equipment with turf-type tires. Equipment with narrow tracks or tires, rubber tires with large lugs, or high-pressure tires is unacceptable as it may cause excessive compaction and reduced infiltration rates.

CHECK DAMS

Construct check dams using concrete, stone, or other non-erodible material and anchor appropriately into the bottom and side slopes.

UNDERDRAINS

- Place underdrains on a 3-ft-wide section of the permeable filter fabric. Place pipe next, followed by the gravel bedding. Cap ends of underdrain pipes not terminating in an observation well.
- Construct the main collector pipe for underdrain systems at a minimum slope of 0.5 %. Provide observation wells or cleanout pipes (1 minimum per every 1,000 ft^2 of surface area).

LANDSCAPING

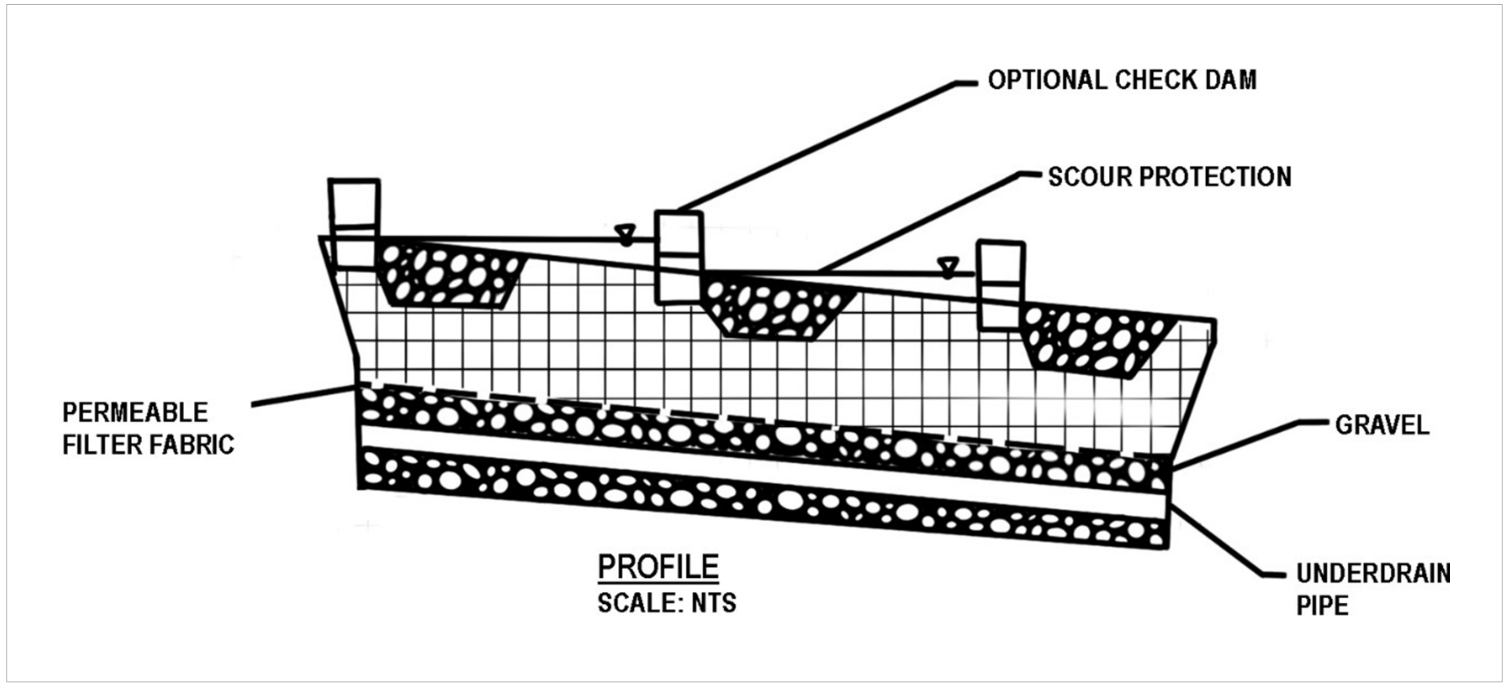
- Plant as soon as possible after soil stabilization of the upgradient area is completed and the ground is ready for planting.
- Keep rootstock moist during transport and on-site storage. Plant so 1/8 of rootball is above final grade and diameter of the hole is at least 6 in larger than the planting ball. Set and maintain straightness during planting. Thoroughly water ground around the plant after installation.
- Place a uniform thickness of 2 to 3 in of mulch or compost on the surface. Compost is preferred over mulch and wood chips as it is heavier and less likely to disperse to the perimeter of the facility during a storm event.
- Include directions in the specifications for appropriate fertilizer and soil amendments based on soil properties determined through testing and landscaping needs.
- Landscaping should be done as soon as possible after soil stabilization of the upgradient area is completed and the ground is ready for planting.
- If sod tiles are used, place so that there are no gaps between the tiles; stagger the ends of the tiles to prevent channels from forming along the bioswale.
- Use a roller on the sod to verify no air pockets form between the sod and the soil.
- Per FAA Regulations, do not scatter or apply seeds through hydroseeding or within hydromulch in areas that could attract wildlife and cause safety concerns for aircraft operations. Use alternative methods such as sprigs. For areas that do not create safety concerns for aircraft operations, seeds may be used with explicit approval from Airport Management.

MISCELLANEOUS

- Install at a time of the year when there is a reasonable chance of successfully establishing grass without irrigation; temporary irrigation may be required.
- Do not use as sediment control measures during construction.
- Removal of mature trees to construct a bioretention facility may be infeasible and requires additional review and approval by DOTA on a case-by-case basis.
- Do not establish until contributing drainage area is stabilized.

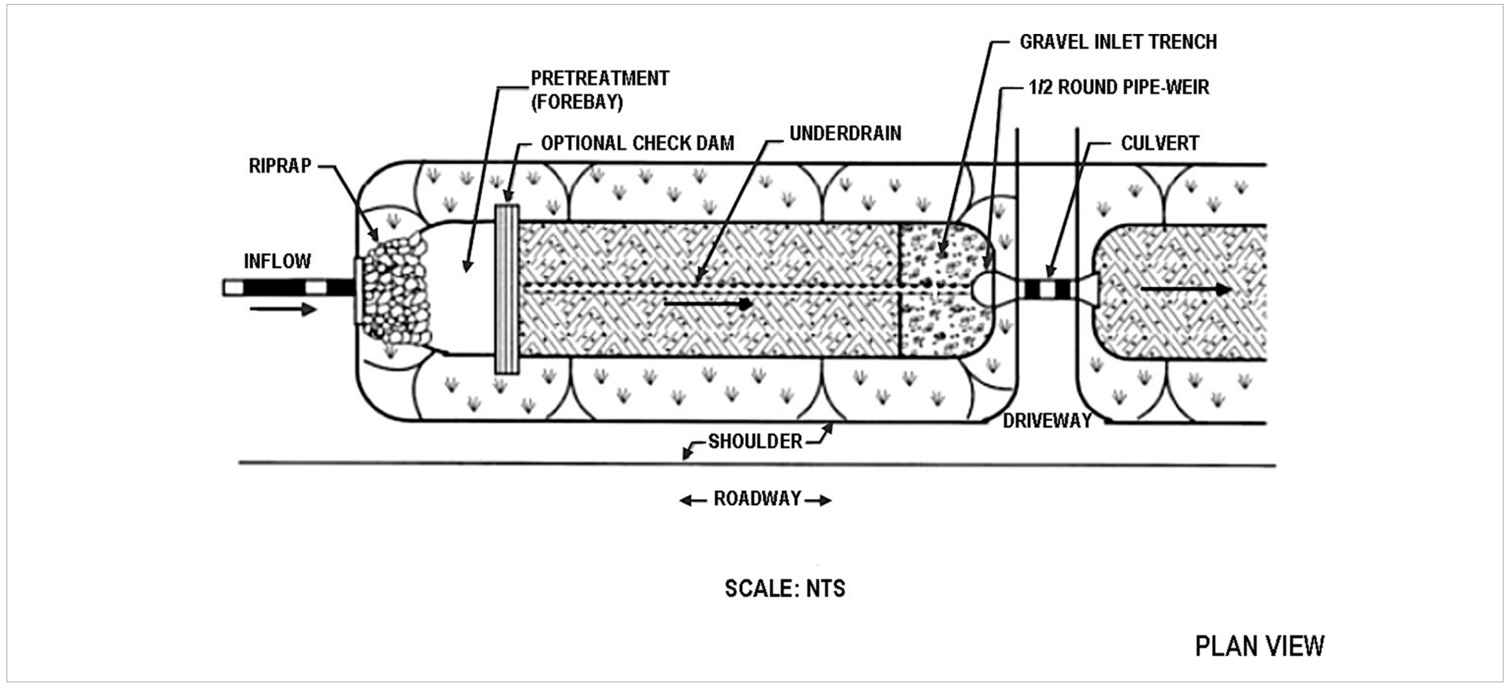
Cut Sheet Examples

Disclaimer: The example schematics provided below are intended for visual aid purposes only and not for design purposes. The example schematics are not intended to be used as a design guide for the items, descriptions, and details (depths, etc.). The actual configuration will vary depending on specific site constraints and the design criteria of this fact sheet. Refer to the information provided above for details on the design.



Example Schematic of a Bioswale

Source: *Storm Water BMP Guide for New and Redevelopment* (CCH, 2017). The source schematic was modified to remove design details that are not consistent with this Fact Sheet.



Example Schematic of a Bioswale

Source: *2000 Maryland Stormwater Design Manual Volumes I & II* (CWP and MDE, May 2009). The source schematic was modified to remove design details that are not consistent with this Fact Sheet.

Sizing Guidelines

Step 1:
Use the procedure below to compute the volumetric runoff coefficient (C) and water quality design volume (WQV). The C should be calculated using the following equation:

$C = 0.05 + 0.009I$

where C = Volumetric Runoff Coefficient

I = Impervious Cover (%)

The WQV is calculated using the following equation:

$WQV = PCA \times 3630$

where WQV = Water Quality Design Volume (ft³)

P = Design Storm Runoff Depth (in) (refer to Section 4.5.3.1)

C = Volumetric Runoff Coefficient

A = Tributary Drainage Area (ac)

Step 2:
Select values for the media layer depth (l_m), drainage layer depth (l_d), media layer porosity (n_m), drainage layer porosity (n_d), maximum surface ponding depth (d_p, if check dams are used), bottom width (w_b), and interior side slope (z, length per unit height).

Step 3:
Calculate the total effective storage depth (d_t) based on the instantaneous storage capacity using the average ponding depth (assumed to be one-half the maximum ponding depth) and the void space in the media layer and drainage layer:

$d_t = [(d_p/2) + l_m n_m + l_d n_d]/12$

where d_t = Total Effective Water Storage Depth (ft)

d_p = Maximum Ponding Depth from Step 2 (ft)

l_m = Media Depth from Step 2 (ft)

n_m = Media Layer Porosity (refer to Section 4.5.3.7)

l_d = Drainage Layer Depth from Step 2 (ft)

n_d = Drainage Layer Porosity (refer to Section 4.5.3.7)

Step 4:
Calculate the swale invert area required (A_b) based on the instantaneous storage capacity (neglecting the additional ponding capacity due to the shape of the swale sides):

$A_b = WQV / d_t$

where A_b = Swale Invert Surface Area (ft²)

WQV = WQV from Step 1 (ft³)

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

Step 5:
Calculate the total area required (A_{PBMP}) taking into account the side slopes along the length of the swale:

$A_{PBMP} = [w_b + 2z\,(f + d_p / 12)] \times (A_b / w_b)$

where A_{PBMP} = Total Surface Area (ft²)

W_b = Bioswale Bottom Width from Step 2 (ft)

z = Interior Bioswale Side Slope (length per unit height) from Step 2

d_p = Design Ponding Depth from Step 3 (ft)

f = Freeboard (ft)

A_b = Bottom Surface Area from Step 4 (ft)

If A_{PBMP} is greater than the available space, reduce the tributary drainage area or increase one or more design depths (media, drainage, ponding), and repeat the calculations.

LC-4 Harvesting/Reuse

Harvesting/Reuse is the collection and temporary storage of stormwater runoff from roofs in rain barrels or cisterns for subsequent non-potable use, including landscape irrigation or vehicle washing. Rain barrels are small containers with capacity ranging from 50 to 100 gal, whereas cisterns are larger containers with capacity of 100 gal and above.

Cistern, Maui
Source: Sea Grant, University of Hawaii

Design Criteria

Table 1: Minimum Design Criteria and Guidelines

Category	Guidelines
Cistern/Rain Barrel Sizing	• Dependent on project area, roof size, and irrigation area. • Can vary from < 1,000 gal to > 1,000 gal per 1,000 ft² of roof area.
Capacity Design	• Design to capture a minimum of 80% of the average annual runoff volume and meet 80% of the overall annual demand. • Use local rainfall data and/or local pan evaporation data if available.
Appropriate Usage	• Small drainage areas. • Runoff from roofs only.
Drawdown (drain) Time	48 hrs or less.
Spigot/ Hose Bibb Height	2 in from ground.
Non-Potable Requirements	• Label “Caution: Non-Potable Water, Do Not Drink” on all cisterns, rain barrels, and spigot/hose bibb locations. • Reused stormwater piping systems must be separate from other potable water piping.
Material Specifications	Plumbing must meet county codes and be appropriate to the use.
Construction Considerations	• Direct downspouts and storm drains to the cisterns and rain barrels. • Use tight-fitting covers to exclude contaminants and animals. • Block sunlight to limit algae growth. • If used in areas where located partially below the water table, use design features to prevent floating. • Provide observation risers.
Bypass	High flow bypass may be needed: locate so discharges do not impact downstream structures.

Table 2: Pretreatment Considerations

Category	Considerations
Pretreatment Options	Roof gutter guards or leaf gutter screens for roof runoff. Screens may be used to filter debris.

LIMITATIONS

May be considered infeasible or impractical if:

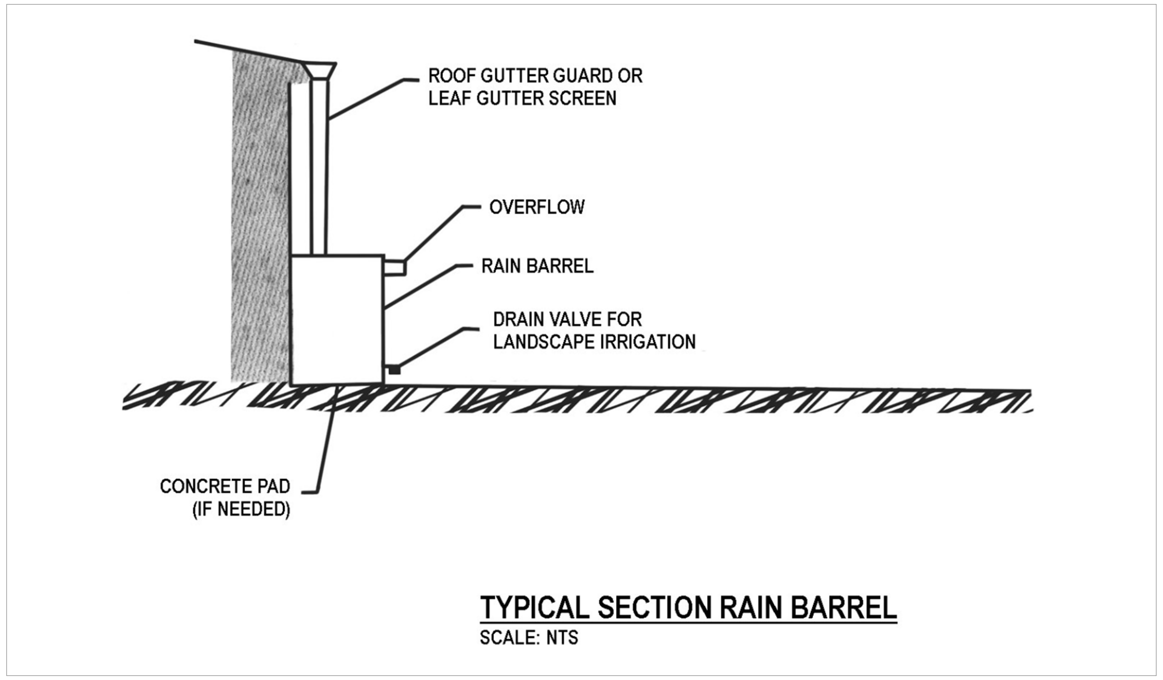
- Determined to be infeasible through the LID PBMP Infeasibility & Waiver Screening step in Veoci®.
- The site lacks a sufficient hydraulic head to support operation by gravity.
- Unable to operate off-line with bypass, and unable to operate in-line with a safe overflow mechanism.
- The space needed to support a collection system large enough for the design volume is not available on site.

Construction Considerations

- Do not connect the piping to a potable water system.
- Roofs that convey stormwater runoff to be harvested and reused should be cleaned regularly. Do not allow wash water to enter the collection system.

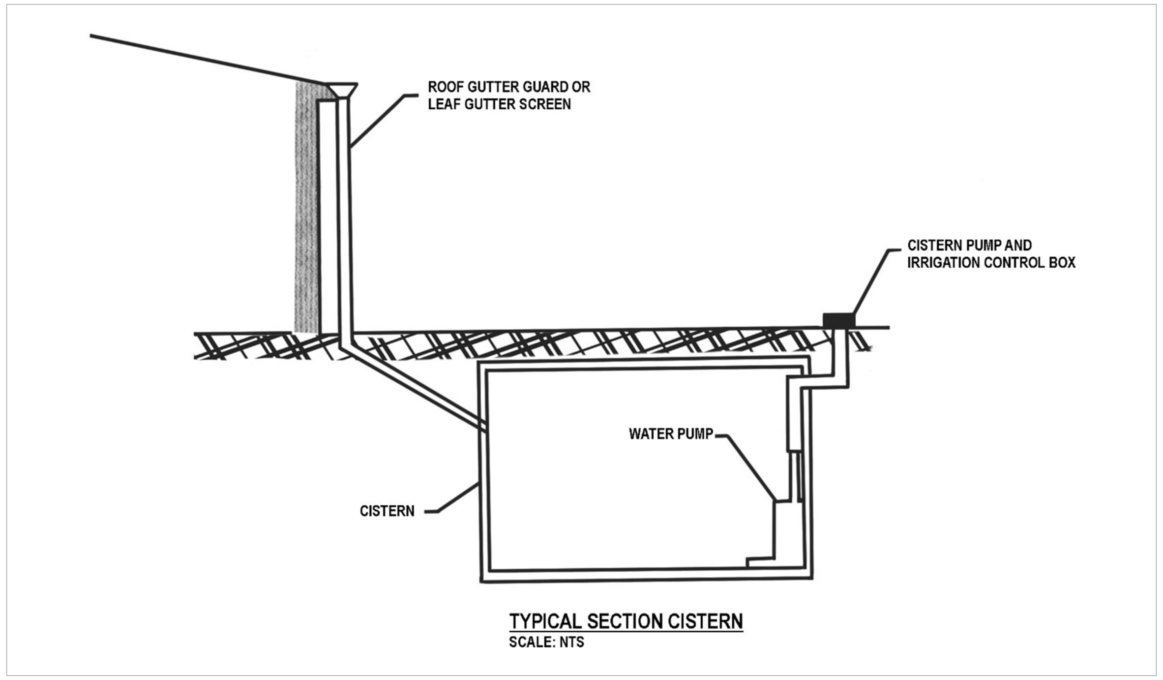
Cut Sheet Examples

Disclaimer: The example schematics provided below are intended for visual aid purposes only and not for design purposes. The example schematics are not intended to be used as a design guide for the items, descriptions, and details (depths, etc.). The actual configuration will vary depending on specific site constraints and the design criteria of this fact sheet. Refer to the information provided above for details on the design.



Example Schematic of a Harvesting/Reuse System

Source: *Storm Water BMP Guide for New and Redevelopment* (CCH, 2017). The source schematic was modified to remove design details that are not consistent with this Fact Sheet.



Example Schematic of a Harvesting/Reuse System

Source: *Storm Water BMP Guide for New and Redevelopment* (CCH, 2017). The source schematic was modified to remove design details that are not consistent with this Fact Sheet.

Sizing Guidelines

Step 1:
Define the reuse (irrigation) demand by selecting the values for the irrigation area (A_i), pan evaporation coefficient (K_p), landscape coefficient (K_l), and irrigation system efficiency (e). Use specific data if available; if specific data is unavailable, use values of 0.80 for K_p, 0.60 for K_l, and 0.90 for e (refer to Section 4.5.3).

Step 2:
Define the non-irrigation demand (D_o), which may include other non-potable uses.

Step 3:
Define the runoff available for reuse by selecting values for the drainage area (i.e., roof area) (A), % of impervious cover (I), and cistern capacity (C_v).

Step 4:
Identify the project's nearest reference point and use the corresponding monthly rainfall rates and monthly pan evaporation rates (E_{pan}).

Step 5:
Perform a month-to-month analysis, starting with January and ending with December. Set the beginning cistern volume in January to 0.

Step 5a:
Calculate the reference evapotranspiration rate for the month (ET_o) using the pan evaporation rate (E_{pan}) and the pan evaporation coefficient (K_p):

$$ET_o = E_{pan} \times K_p$$

where ET_o = Reference Evapotranspiration Rate for the month (in)

E_{pan} = Pan Evaporation Rate for the month (in) from Step 4

K_p = Pan Evaporation Coefficient from Step 1 (refer to Section 4.5.3.4)

Step 5b:
Calculate the actual evapotranspiration rate for the month (ET_a) using the reference evapotranspiration rate (ET_o) and the landscape coefficient (K_l):

$$ET_a = ET_o \times K_l$$

where ET_a = Actual Evapotranspiration Rate for the month (in)

ET_o = Reference Evaporation Rate for the month (in) from Step 5a

K_l = Landscape Coefficient from Step 1 (refer to Section 4.5.3.8)

Step 5c:
Calculate the total demand for the month (D_t) by multiplying the irrigation area (A_i) by the difference between the actual evapotranspiration rate (ET_a) and the rainfall (r), and adding the non-irrigation demand (D_o):

$$D_t = 7.48A_i \times (ET_a - r)/(12e) + D_o$$

where D_t = Total Demand for the month (gal)

A_i = Irrigation Area from Step 1 (ft²)

ET_a = Actual Evapotranspiration Rate from Step 5b

r = Total Rainfall for the month (in) from Step 4

e = Irrigation System Efficiency from Step 1 (refer to Section 4.5.3.9)

D_o = Other Non-Irrigation Demand for the month (gal) from Step 2

If the total demand for the month is negative (because the rainfall amount exceeds the evapotranspiration rate), set the total demand to 0.

Step 5d:
Calculate the amount of runoff generated for the month by multiplying the drainage area by the rainfall by the volumetric runoff coefficient:

$$R_g = 7.48Ar \times (0.05 + 0.009I)/12$$

where R_g = Runoff Generated for the month (gal)

A = Drainage Area from Step 3 (ft²)

r = Total Rainfall for the month (in) from Step 4

I = Impervious Cover (%) from Step 3

Step 5e:
Compare the total demand (D_t) to the cistern capacity (amount of runoff in the cistern) at the beginning of the month (C_b) plus the runoff generated during the month (R). If the monthly demand is greater, set the amount of runoff reused (R_u) to the sum of C_b and R. If the monthly demand is less, set the amount of runoff reused to D_t.

Step 5f:
Compare the Cistern capacity (C_v) to the cistern capacity at the beginning of the month (C_b) plus the runoff generated during the month (R_g) minus the amount of runoff used (R_u). Set the amount of runoff in the cistern at the end of the month (C_e) to the lower of the two values.

$$C_e = \min(C_b + R_g - R_u, C_v)$$

where C_e = Cistern Capacity at the End of the month (gal)

C_b = Cistern Capacity at the Beginning of the month (gal)

R_g = Runoff Generated for the month (gal)

R_u = Runoff Used for the month (gal)

C_v = Cistern Capacity (gal)

Step 5g:
Compare the sum of runoff generated during the month (R_g) and the amount in the cistern at the beginning of the month (C_b) to the total demand (D_t). Set the amount of runoff used (R_u) to the lower of the two values.

$$R_u = \min(R_g + C_b, D_t)$$

where R_u = Runoff Used for the month (gal)

R_g = Runoff Generated for the month (gal)

C_b = Amount of Runoff in Cistern at the beginning of the month (gal)

D_t = Total Demand for the month (gal)

Step 5h:
Calculate the amount of cistern overflow by the following:

$$O = C_b + R_g - D_t - C_e$$

where O = Total Cistern Overflow for the month (gal)

C_b = Cistern Capacity at the beginning of the month (gal)

R_g = Runoff Generated for the month (gal)

D_t = Total Demand for the month (gal)

C_e = Cistern Capacity at the end of the month (gal)

If the overflow is negative (because the amount of runoff in the cistern at the end of the month is less than the cistern capacity), set the overflow to 0.

Step 5i:
Calculate the amount of runoff captured in the cistern by subtracting the overflow from the amount of runoff generated:

$$R_c = R_g - O$$

where R_c = Runoff Capture in the cistern for the month (gal)

R_g = Runoff Generated for the month (gal)

O = Total Cistern Overflow for the month (gal)

Step 5j:
Set the beginning cistern amount for the next month equal to the ending cistern amount for the current month. Repeat Steps 5a through 5i for each subsequent month. Continue to Step 6 after Steps 5a through 5i have been performed for all 12 months.

Step 6:
Calculate the overall runoff capture efficiency by dividing the cumulative runoff captured by the cumulative runoff generated:

$$E_c = 100 \times \sum_{n=1}^{12} R_c \Big/ \sum_{n=1}^{12} R_g$$

where E_c = Overall Runoff Capture Efficiency (%)

R_c = Runoff Capture from each month (gal)

R_g = Runoff Generated from each month (gal)

If the calculated efficiency is below the minimum design criteria value, revise one or more of the following parameters and return to Step 1: drainage area (A), cistern size (C), irrigation area (A_i), and other non-irrigation demand (D_o).

Step 7:
Calculate the overall demand met efficiency by dividing the cumulative runoff used by the cumulative demand:

$$E_d = 100 \times \sum_{n=1}^{12} R_u \Big/ \sum_{n=1}^{12} D_t$$

where E_d = Overall Demand Met Efficiency (%)

R_u = Runoff Used from each month (gal)

D_t = Total Demand from each month (gal)

If the calculated efficiency is below the minimum design criteria value, revise one or more of the following parameters and return to Step 1: drainage area (A), cistern size (C), irrigation area (A_i), and other non-irrigation demand (D_o).

Step 8:
Calculate the WQV credit:

$$WQV = \frac{PCA}{12}$$

where WQV = Water Quality Volume (ft³)

P = Design Storm Runoff Depth (in) (refer to Section 4.5.3.1)

C = Volumetric Runoff Coefficient

A = Tributary Drainage Area (ft²)

LC-5 Dry Well/ Drainage Well

A drainage well (also known as a dry well) is a subsurface aggregate-filled or prefabricated, perforated storage facility, where stormwater runoff is stored and infiltrates. It is constructed by excavating a pit and filling it with aggregate. Stormwater drains to the drainage well, and runoff is stored in void space.

According to the State and Federal UIC Program regulations, a drainage well can be considered a Class V stormwater drainage well if it is deeper than wide. Drainage wells that fall under Class V injection well category shall apply for a UIC permit (refer to Federal UIC regulations, 40 CFR § 144 and State of Hawaii UIC regulations, HAR § 11-23).

Dry Well
Source: California Office of Environmental Health Hazard Assessment

Design Criteria

Table 1: Minimum Design Criteria and Guidelines

Category	Guidelines
PBMP Footprint Area	2% to 20% of contributing impervious area.
Appropriate Usage	• Small drainage areas. • Area with low pollutant loading such as rooftops.
Drawdown (drain) Time	48 hrs or less.
Minimum Soil Infiltration Rate	0.5 in/hr
Infiltration	Bottom should remain open to maximize infiltration.
Aggregate Specifications	• 1- to 3-in diameter. • Double-washed, locally available rock.
Minimum Depth from Basin Invert to Groundwater Table	3 ft

Table 2: Pretreatment Considerations

Category	Considerations
General	Susceptible to clogging from sediment, leaves, and organic materials.
Pretreatment Options	• Roof gutter guards or leaf gutter screens for roof runoff. • If non-roof runoff, provide pretreatment by vegetated swales, vegetated buffer strips, mesh screens, or manufactured treatment devices. • May use an intermediate box with an elevated outflow to allow for sediment to settle followed by a mesh screen prior to discharging to the drainage well. • For stormwater runoff from areas prone to oil leaks and spills, an OWS or similar treatment device with sufficient oil capacity to capture the volume of the largest leak or spill likely to occur.

LIMITATIONS

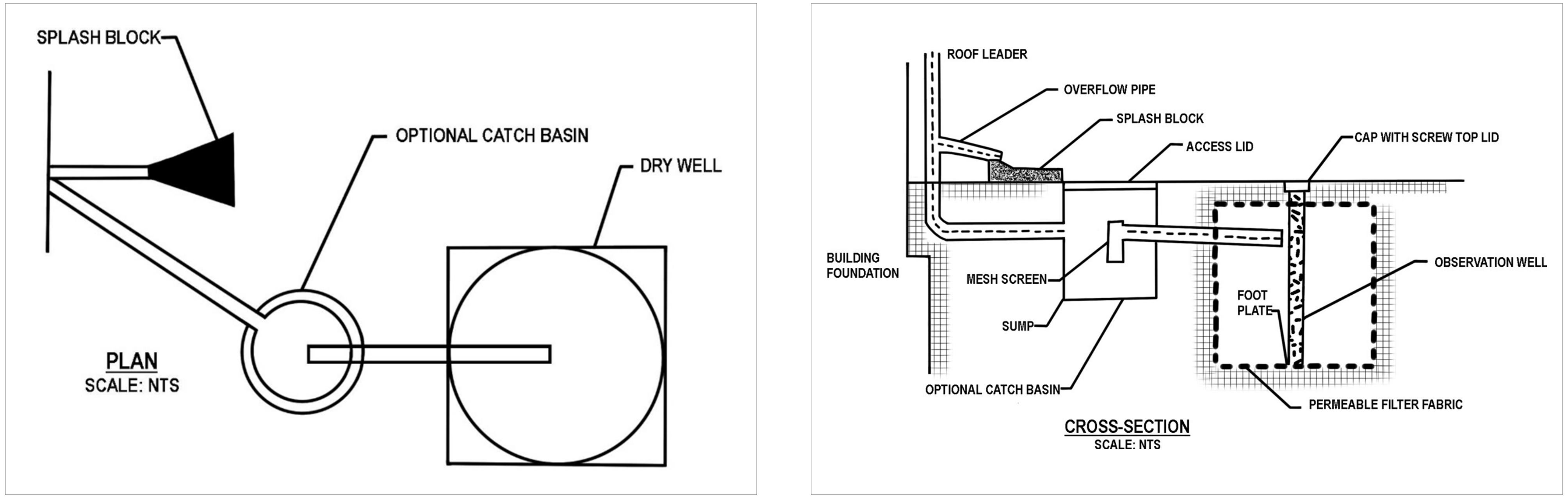
- Drainage Wells that are deeper than wide have a higher risk to groundwater. Therefore, there are additional permitting and reporting requirements associated with UIC permitted Drainage Wells.
- May be considered infeasible or impractical if:
  - Determined to be infeasible through the LID PBMP Infeasibility & Waiver Screening step in Veoci®.
  - Slopes > 20%.
  - Depth of drainage well is less than 2 ft.
  - Documented concern that there is potential on-site for soil pollutants, groundwater pollutants, or pollutants associated with industrial activities to be mobilized.

Construction Considerations

- Excavate in native soil matrix, uncompacted by heavy equipment.
- Refer to manufacturer guidelines if using any manufactured treatment devices.
- Plant trees and other large vegetation away from drainage wells so roots will not penetrate the well and drip lines do not overhang the wells.
- Provide access for well maintenance via a secured manhole or cleanout.
- Submit a General Application for a UIC Permit to Operate to DOH-SDWB at least 6 months before the anticipated date of UIC well construction. Refer to the DOTA UIC Permit Application Guidance on the DOTA Construction Site Runoff/PBMP Control Program webpage for more information.

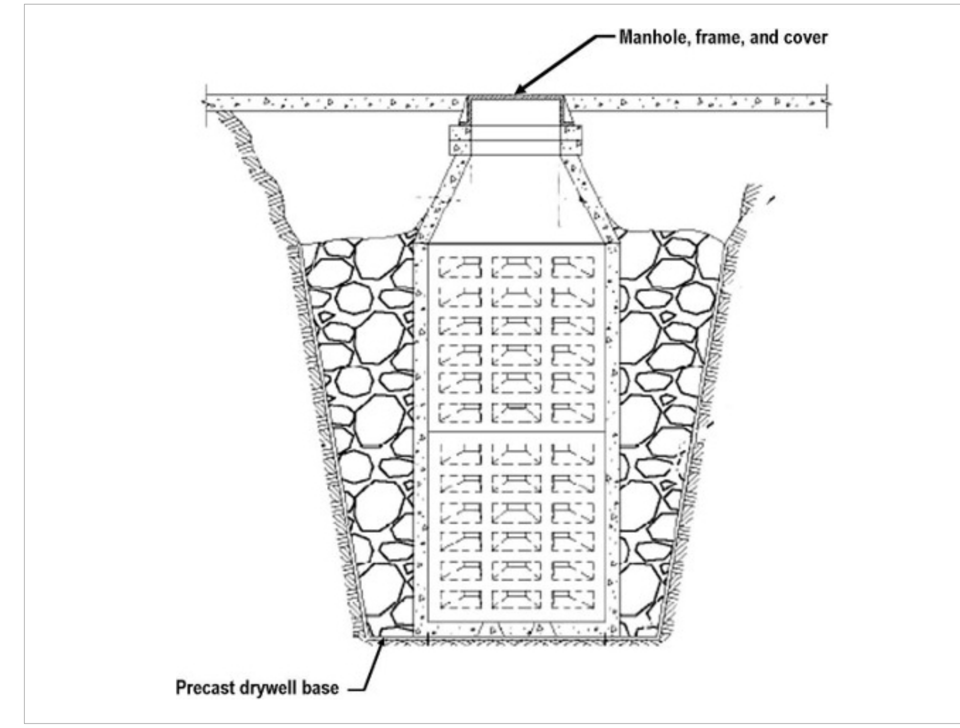
Cut Sheet Examples

Disclaimer: The example schematics provided below are intended for visual aid purposes only and not for design purposes. The example schematics are not intended to be used as a design guide for the items, descriptions, and details (depths, etc.). The actual configuration will vary depending on specific site constraints and the design criteria of this fact sheet. Refer to the information provided above for details on the design.



Example Schematic of a Dry Well/Drainage Well

Source: *Storm Water BMP Guide for New and Redevelopment* (CCH, 2017). The source schematic was modified to remove design details that are not consistent with this Fact Sheet.



Example Schematic of a Dry Well/Drainage Well

Source: *Stormwater Management Manual for Western Washington* (State of Washington, Department of Ecology, 2019). The source schematic was modified to remove design details that are not consistent with this Fact Sheet.

Sizing Guidelines

Step 1:
Use the procedure below to compute the volumetric runoff coefficient (C) and water quality design volume (WQV). The C should be calculated using the following equation:

$C = 0.05 + 0.009I$

where ***C*** = Volumetric Runoff Coefficient

I = Impervious Cover (%)

The WQV is calculated using the following equation:

$WQV = PCA \times 3630$

where ***WQV*** = Water Quality Design Volume (ft³)

P = Design Storm Runoff Depth (in) (refer to Section 4.5.3.1)

C = Volumetric Runoff Coefficient

A = Tributary Drainage Area (ac)

Step 2:
Calculate the maximum water storage depth (d_{max}) using the underlying soil infiltration rate (k) and the required drawdown time (t):

$d_{max} = kt / (Fs \times 12)$

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

k = Soil Infiltration Rate (in/hr)

t = Drawdown (drain) Time (hrs) (refer to Section 4.5.3.5)

F_s = Infiltration Rate Factor of Safety (refer to Section 3.3.1)

Step 3:
Select a ponding depth and drainage well backfill material depth (l_{bf}) such that the total effective storage depth is no greater than the maximum storage depth (d_{max}) calculated in Step 2:

$d_t = d_p + l_{bf} n_{bf} \leq d_{max}$

where d_t = Total Effective Water Storage Depth (ft)

d_p = Ponding Depth (ft)

l_{bf} = Backfill Material Depth (ft)

n_{bf} = Backfill Material Porosity (refer to Section 4.5.3.7)

d_{max} = Maximum Storage Depth from Step 2 (ft)

Step 4:
Calculate the PBMP surface area (A_{PBMP}):

$A_{PBMP} = WQV / (dt + (kT / 12Fs))$

where A_{PBMP} = PBMP Surface Area (ft²)

WQV = WQV from Step 1 (ft³)

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

k = Soil Infiltration Rate (in/hr)

T = Fill Time (time for the PBMP to fill with water [hrs]) (refer to Section 4.5.3.10)

F_s = Infiltration Rate Factor of Safety (refer to Section 3.3.1)

If A_{PBMP} is greater than the available space, reduce the drainage area or increase d_p or l_{bf} (if d_t is not already equal to d_{max}), and repeat the calculations. If A_{PBMP} is still greater than the available space, reduce F_s (if the minimum number of test pits and permeability tests have not been performed) and repeat the calculations.

LC-6
Infiltration Basin

An infiltration basin is an engineered shallow impoundment facility that collects and stores stormwater runoff, passes it through permeable soils, and infiltrates it through the basin bottom into native soils.

Infiltration Basin, Kahului Airport
Source: Hawaii DOTA

Design Criteria

Table 1: Minimum Design Criteria and Guidelines

Category	Guidelines
PBMP Footprint Area	7% to 20% of contributing impervious area.
Media Layer	6-in sand layer may be placed at bottom.
Drawdown (drain) Time	48 hrs or less.
Minimum Soil Infiltration Rate	0.5 in/hr
Maximum Interior Side Slope (length per unit height)	3:1
Minimum Depth from Basin Invert to Groundwater Table	3 ft
Minimum Freeboard Above Overflow Device	1 ft
Outlet	• Include an outlet structure and overflow spillway to convey peak flows. • Include energy dissipators at outlet to prevent erosion from the 10-yr storm velocity.
Basin Grading	Grade basin bottom as flat as possible for uniform ponding and infiltration.
Flow Regulation	Use a flow regulator to divert runoff from large drainage areas, if needed.
Embankment Design	If located in State of Hawaii, Department of Land and Natural Resources (DLNR), Engineering Division, Dam Safety Program jurisdiction, design to meet applicable requirements.
Access	Consider including vehicle access to basin invert for maintenance.
Observation Wells	Recommended for monitoring facility dewatering and functionality.
Underdrains (Optional)	DOTA prefers no underdrains; if site conditions warrant using underdrains: - Minimum 6-in perforated underdrain pipe in a gravel layer with permeable filter fabric between infiltration basin media and gravel layer. - Include cleanout pipe tied into the end of all underdrain pipe runs.
Landscaping	• Avoid vegetation that could be hazardous to airport operations (i.e., food [seeds] or habitat for wildlife). • Establish vegetation on side slopes and floor to naturally maintain higher infiltration rates. • Select appropriate plantings considering site-specific soils and hydraulic conditions. Design to facilitate regular mowing. • Select plants based on local climate, water depth, native species, and pollutant tolerance. • Consider irrigation during dry periods, if necessary.

Table 2: Pretreatment Considerations

Category	Considerations	
General	Infiltration basins are susceptible to clogging and premature failure from sediment, trash, and other contaminants.	
Pretreatment Requirements	**Soil Infiltration Rate**	**Pretreatment Requirement**
	< 3 in/hr	Pretreatment strongly recommended. Size pretreatment device for at least 25% of WQV.
	> 3 in/hr and < 5 in/hr	Pretreatment mandatory. Size pretreatment device for at least 50% of WQV.
	> 5 in/hr	Pretreatment mandatory. Size pretreatment device for 100% of WQV.
Pretreatment Options	• Vegetated swales, vegetated buffer strips, sedimentation basins, forebays, or manufactured treatment devices. • Forebay considerations: - 18- to 30-in depth. - Use where standing water is not a safety or vector concern. - Line to prevent water flow into underdrains without first passing through the treatment area. - Lining allows for sediment and debris removal with a shovel or vector truck.	

LIMITATIONS

May be considered infeasible or impractical if:

- Determined to be infeasible through the LID PBMP Infeasibility & Waiver Screening step in Veoci®.
- Unstable soil stratum or soils with > 25% clay content.
- Slopes > 5%.
- The invert of the underdrain layer is below the seasonally high groundwater table.
- The amount of sunlight received by the site is inadequate or irrigation is infeasible to support vegetation.
- The site lacks a sufficient hydraulic head to support operation by gravity.
- Unable to operate off-line with bypass, and unable to operate in-line with a safe overflow mechanism.
- Documented concern that there is a potential on the site for soil pollutants, groundwater pollutants, or pollutants associated with industrial activities to be mobilized.

Construction Considerations

COMPACTION

- Use excavation hoes to remove the original soil. Place backfill in 12- to 18-in lifts to minimize compaction; Use a primary tilling operation such as chisel plow, ripper, or subsoiler to refracture the soil profile through the 12-in compaction zone.
- Heavy equipment can be used around but not inside the perimeter of the infiltration basin facility to supply materials. Use wide track or marsh track equipment or light equipment with turf-type tires.
- Equipment with narrow tracks or tires, rubber tires with large lugs, or high-pressure tires is unacceptable as it may cause excessive compaction and reduced infiltration rates.

UNDERDRAINS

- Place underdrains on a 3-ft-wide section of the permeable filter fabric. Place pipe next, followed by the gravel bedding. Cap ends of underdrain pipes not terminating in an observation well.
- Construct the main collector pipe for underdrain systems with a minimum slope of 0.5 %. Provide observation wells or cleanout pipes (1 minimum per every 1,000 ft^2 of surface area).

LANDSCAPING

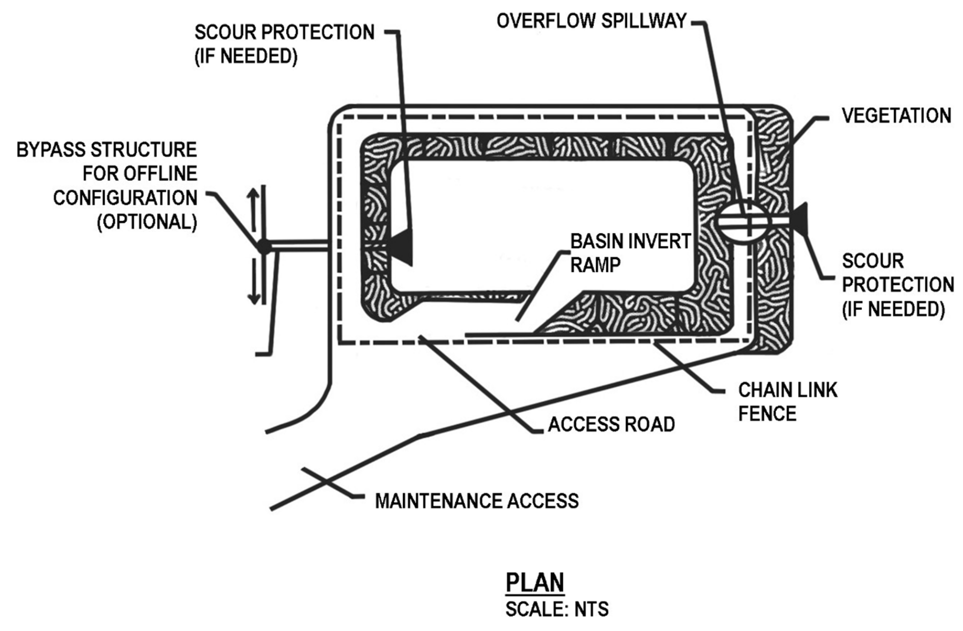
- Include directions in the specifications for appropriate fertilizer and soil amendments based on soil properties determined through testing and landscaping needs.
- Landscaping should be done as soon as possible after soil stabilization of the upgradient area is completed and the ground is ready for planting.
- If sod tiles are used, place them so that there are no gaps between the tiles; stagger the ends of the tiles to prevent the formation of channels along the bioswale.
- Use a roller on the sod to verify no air pockets form between the sod and the soil.
- Per FAA Regulations, do not scatter or apply seeds through hydroseeding or within hydromulch in areas that could attract wildlife and cause safety concerns for aircraft operations. Use alternative methods such as sprigs. For areas that do not create safety concerns for aircraft operations, seeds may be used with explicit approval from Airport Management.

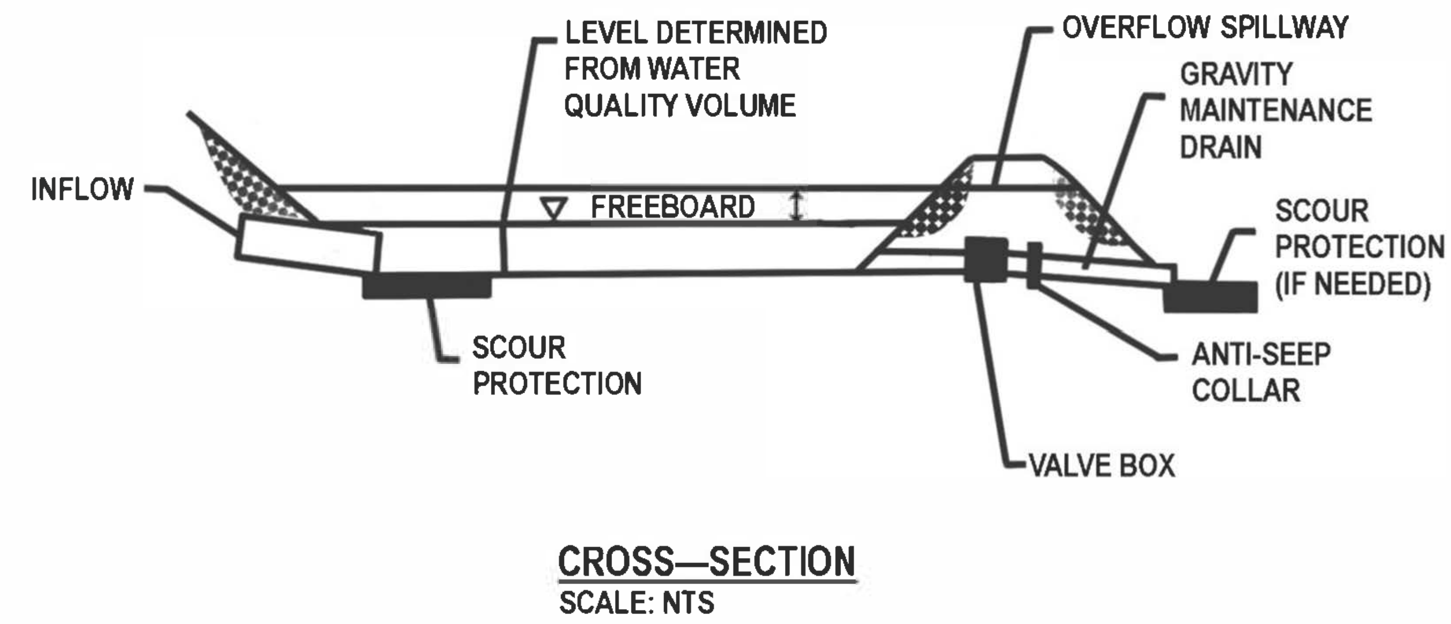
MISCELLANEOUS

- Install at the time of year when there is a reasonable chance of successfully establishing grass without irrigation; temporary irrigation may be required.
- Do not use as sediment control measures during construction.
- Removal of mature trees to construct a bioretention facility may be infeasible and requires additional review and approval by DOTA on a case-by-case basis.
- Prevent natural or fill soils from intermixing with the stone aggregate.
- Place excavated material so it cannot be washed back into the basin if a storm occurs during construction.
- Vertically excavated walls may be difficult to maintain in areas where soil moisture is high or where soft cohesive or cohesionless soils are dominant. These conditions may require laying back the side slopes to maintain stability.
- Do not establish until the contributing drainage area is stabilized.

Cut Sheet Examples

Disclaimer: The example schematics provided below are intended for visual aid purposes only and not for design purposes. The example schematics are not intended to be used as a design guide for the items, descriptions, and details (depths, etc.). The actual configuration will vary depending on specific site constraints and the design criteria of this fact sheet. Refer to the information provided above for details on the design.





Example Schematic of an Infiltration Basin with No Underdrain

Source: *Storm Water BMP Guide for New and Redevelopment* (CCH, 2017). The source schematic was modified to remove design details that are not consistent with this Fact Sheet.

Sizing Guidelines

Step 1:
Use the procedure below to compute the volumetric runoff coefficient (C) and water quality design volume (WQV). The C should be calculated using the following equation:

$C = 0.05 + 0.009I$

where C = Volumetric Runoff Coefficient

I = Impervious Cover (%)

The WQV is calculated using the following equation:

$WQV = PCA \times 3630$

where WQV = Water Quality Design Volume (ft³)

P = Design Storm Runoff Depth (in) (refer to Section 4.5.3.1)

C = Volumetric Runoff Coefficient

A = Tributary Drainage Area (ac)

Step 2:
Calculate the maximum water storage depth (d_{max}) using the underlying soil infiltration rate (k) and the required drawdown time (t):

$d_{max} = kt / (F_s \times 12)$

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

k = Soil Infiltration Rate (in/hr)

t = Drawdown (drain) Time (hrs) (refer to Section 4.5.3.5)

F_s = Infiltration Rate Factor of Safety (refer to Section 3.3.1)

Step 3:
Select a ponding depth (d_p) no greater than the maximum water storage depth (d_{max}) calculated in Step 2:

$d_p \leq d_{max}$

where d_p = Ponding Depth (ft)

d_{max} = Maximum Storage Depth from Step 2 (ft)

Step 4:
Calculate the bioretention facility bottom surface area (A_b):

$A_b = WQV / (d_t + (kT / 12F_s))$

where A_b = Bottom Surface Area (ft²)

WQV = WQV from Step 1 (ft³)

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

k = Soil Infiltration Rate (in/hr)

T= Fill Time (time for the PBMP to fill with water [hrs]) (refer to Section 4.5.3.10)

F_s = Infiltration Rate Factor of Safety (refer to Section 3.3.1)

Step 5:
Select a bioretention facility bottom or invert width (w_b), and calculate the bioretention facility bottom or invert length (l_b) using the surface area (A_b) calculated from Step 4:

$l_b = A_b / w_b$

where l_b = Bottom or Invert Length (ft)

A_b = Bottom Surface Area from Step 4 (ft²)

w_b = Bottom or Invert Width (ft)

Step 6:
Calculate the total area occupied by the PBMP excluding pretreatment (A_{PBMP}) using the bioretention facility bottom dimensions, embankment side slopes, and freeboard:

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

where A_{PBMP} = Area Occupied by PBMP Excluding Pretreatment (ft²)

w_b = Bottom Width from Step 5 (ft)

z = Bioretention facility Interior Side Slope (length per unit height)

d_p = Design Ponding Depth from Step 3 (ft)

f = Freeboard (ft)

l_b = Bottom Length from Step 5 (ft)

If A_{PBMP} is greater than the available space, reduce the drainage area or increase d_p (if it is not already equal to d_{max}), and repeat the calculations. If A_{PBMP} is still greater than the available space, reduce F_s (if the minimum number of test pits and permeability tests have not been performed) and repeat the calculations.

LC-7 Infiltration Trench

An infiltration trench is a long, narrow rock-filled trench with no outlet, where stormwater runoff is stored in the void space between the rocks and infiltrates through the trench bottom and into soil.

Infiltration Trench at Kakoi Baseyard, Oahu
Source: HDOT Highways Division

Design Criteria

Table 1: Minimum Design Criteria and Guidelines

Category	Guidelines
PBMP Footprint Area	2% to 20% of contributing impervious area.
Layer Depths	• Minimum 2 ft of trench rock or similar backfill layer. • Optional 6-in sand layer at bottom to sustain design permeability rate over time. • Optional 2-in pea gravel or similar filter material layer on surface to prevent clogging.
Filter Fabric	• Line sides with permeable filter fabric that prevents soil piping but has greater permeability than parent soil. • Place permeable filter fabric between backfill (trench rock or similar) and sand layers.
Drawdown (drain) Time	48 hrs or less.
Minimum Soil Infiltration Rate	0.5 in/hr
Depth	2 to 8 ft.
Width	2 to 25 ft.
Minimum Depth from Basin Invert to Groundwater Table	3 ft
Outlet	• Outlet structure to convey peak flows exceeding design capacity and bypass to convey peak flows that exceed combined infiltration and outlet structure capacity. • Include energy dissipators at outlet to prevent erosion from the 10-yr storm velocity.
Bottom Grading	Grade trench bottom as flat as possible for uniform ponding and infiltration.
Flow Regulation	Provide a flow regulator for diverting runoff from large drainage area, if needed.
Access	Consider including vehicle access to basin invert for maintenance.
Observation Wells	Recommended at 50-ft intervals over length of the trench for monitoring dewatering and functionality.
Underdrains (Optional)	DOTA prefers no underdrains; if site conditions warrant using underdrains: - Minimum 6-in perforated underdrain pipe in a gravel layer. - Include cleanout pipe tied into the end of all underdrain pipe runs.

Table 2: Pretreatment Considerations

Category	Considerations	
General	Infiltration trenches are susceptible to clogging and premature failure.	
Pretreatment Requirments	**Soil Infiltration Rate**	**Pretreatment Requirement**
	< 3 in/hr	Pretreatment strongly recommended. Size pretreatment device for at least 25% of WQV.
	> 3 in/hr and < 5 in/hr	Pretreatment mandatory. Size pretreatment device for at least 50% of WQV.
	> 5 in/hr	Pretreatment mandatory. Size pretreatment device for 100% of WQV.
Pretreatment Options	• Vegetated swales, vegetated buffer strips, sedimentation basins, forebays, or manufactured treatment devices. • Forebay considerations: - 18- to 30-in depth. - Use where standing water is not a safety or vector concern. - Line to prevent water flow into underdrains without first passing through the treatment area. - Lining allows for sediment and debris removal with a shovel or vac truck.	

LIMITATIONS

May be considered infeasible or impractical if:

- Determined to be infeasible through the LID PBMP Infeasibility & Waiver Screening step in Veoci®.
- Unstable soil stratum or soils with > 25% clay content.
- Slopes > 20%.
- The invert of the underdrain layer is below the seasonally high groundwater table.
- The site lacks a sufficient hydraulic head to support operation by gravity.
- Unable to operate off-line with bypass, and unable to operate in-line with a safe overflow mechanism.
- Documented concern that there is potential on-site for soil pollutants, groundwater pollutants, or pollutants associated with industrial activities to be mobilized.
- Subsurface infiltration systems must be designed to be wider than they are deep or follow the LC-5 Dry Well/Drainage Well design fact sheet.

Construction Considerations

COMPACTION

- Use excavation hoes to remove the original soil. Place backfill in 8-in lifts to minimize compaction; use a primary tilling operation such as chisel plow, ripper, or subsoiler to refracture the soil profile through the compaction zone. Heavy equipment can be used around but not within the infiltration trench.
- Use wide track or marsh track equipment or light equipment with turf-type tires. Equipment with narrow tracks or tires, rubber tires with large lugs, or high-pressure tires is unacceptable as it may cause excessive compaction and reduced infiltration rates.

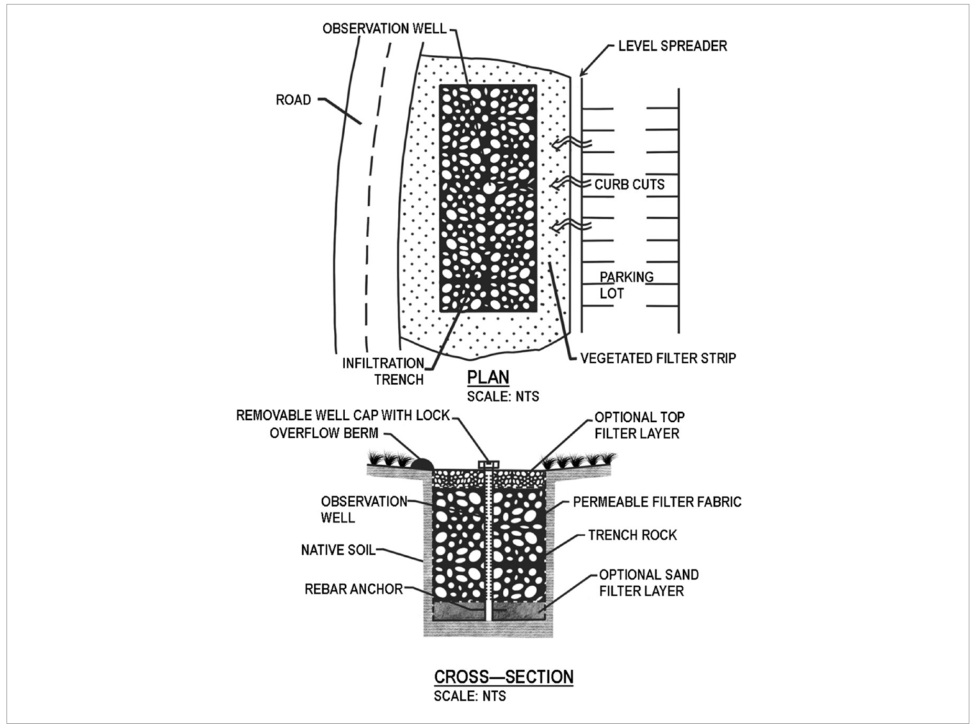
UNDERDRAINS

- Place underdrains on a 3-ft-wide section of the permeable filter fabric. Place pipe next, followed by the gravel bedding. Cap ends of underdrain pipes not terminating in an observation well.
- Construct the main collector pipe for underdrain systems with a minimum slope of 0.5 %. Provide observation wells or cleanout pipes (1 minimum per every 1,000 ft^2 of surface area).

MISCELLANEOUS

- Do not use as sediment control measures during construction.
- Removal of mature trees to construct an infiltration trench facility may be infeasible and requires additional review and approval by DOTA on a case-by-case basis.
- Prevent natural or fill soils from intermixing with the stone aggregate.
- Place excavated material so it cannot be washed back into the basin if a storm occurs during construction.
- Vertically excavated walls may be difficult to maintain in areas where soil moisture is high or where soft cohesive or cohesionless soils are dominant. These conditions may require laying back the side slopes to maintain stability.
- Do not establish until the contributing drainage area is stabilized.

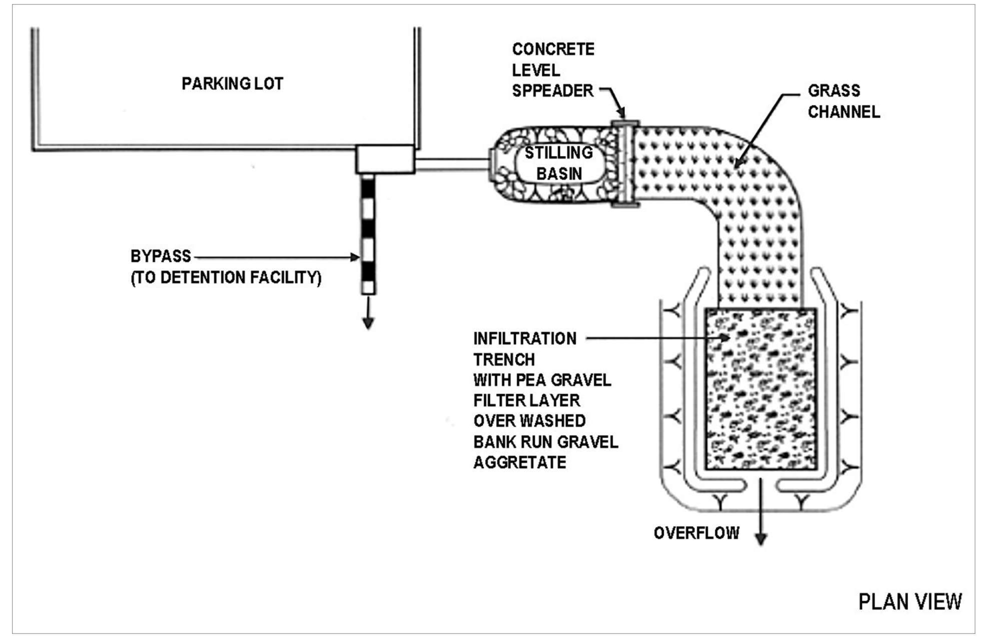
Cut Sheet Examples

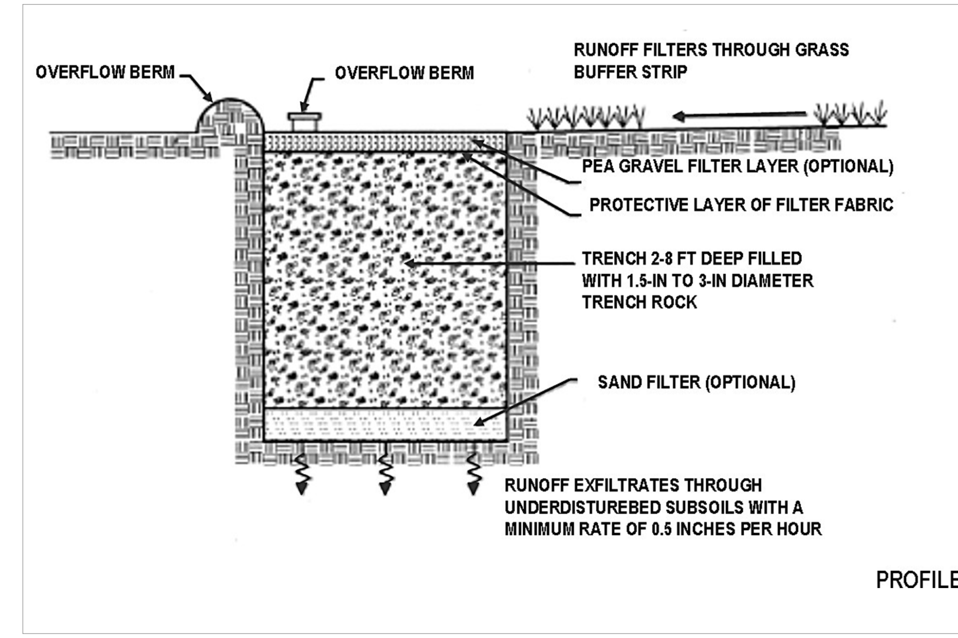


Example Schematic of an Infiltration Trench

Source: *Storm Water BMP Guide for New and Redevelopment* (CCH, 2017). The source schematic was modified to remove design details that are not consistent with this Fact Sheet.

Disclaimer: The example schematics provided below are intended for visual aid purposes only and not for design purposes. The example schematics are not intended to be used as a design guide for the items, descriptions, and details (depths, etc.). The actual configuration will vary depending on specific site constraints and the design criteria of this fact sheet. Refer to the information provided above for details on the design.





Example Schematic of an Infiltration Trench

Source: *2000 Maryland Stormwater Design Manual Volumes I & II* (CWP and MDE, May 2009). The source schematic was modified to remove design details that are not consistent with this Fact Sheet.

Sizing Guidelines

Step 1:
Use the procedure below to compute the volumetric runoff coefficient (C) and water quality design volume (WQV). The C should be calculated using the following equation:

$C = 0.05 + 0.009I$

where ***C*** = Volumetric Runoff Coefficient

I = Impervious Cover (%)

The WQV is calculated using the following equation:

$WQV = PCA \times 3630$

where ***WQV*** = Water Quality Design Volume (ft³)

P = Design Storm Runoff Depth (in) (refer to Section 4.5.3.1)

C = Volumetric Runoff Coefficient

A = Tributary Drainage Area (ac)

Step 2:
Calculate the maximum water storage depth (d_{max}) using the underlying soil infiltration rate (k) and the required drawdown time (t):

$d_{max} = kt / (F_s \times 12)$

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

k = Soil Infiltration Rate (in/hr)

t = Drawdown (drain) Time (hrs) (refer to Section 4.5.3.5)

F_s = Infiltration Rate Factor of Safety (refer to Section 3.3.1)

Step 3:
Select a design ponding depth (d_p)(optional), trench rock or alternative backfill layer depth (l_{bf}), and sand layer depth (l_s) (optional) such that the total effective storage depth (d_t) is no greater than the maximum allowable depth (d_{max}) calculated in Step 2:

$d_t = d_p + l_{bf}n_{bf} + l_s n_s \le d_{max}$

where d_t = Total Effective Water Storage Depth (ft)

d_p = Ponding Depth (ft)

l_{bf} = Backfill Layer Depth (ft)

n_{bf} = Backfill Material Porosity (refer to Section 4.5.3.7)

l_s = Sand Layer Depth (ft)

n_s = Sand Porosity (refer to Section 4.5.3.7)

d_{max} = Maximum Storage Depth (ft) from Step 2

Step 4:
Calculate the infiltration trench surface area (A_{PBMP}):

$A_{PBMP} = WQV / (d_t + (kT / 12F_s))$

where A_{PBMP} = Surface Area Excluding Pretreatment (ft²)

WQV = WQV from Step 1 (ft³)

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

k = Soil Infiltration Rate (in/hr)

T = Fill Time (time for the PBMP to fill with water [hrs])

(refer to Section 4.5.3.10)

F_s = Infiltration Rate Factor of Safety (refer to Section 3.3.1)

If A_{PBMP} is greater than the available space, reduce the drainage area or increase d_p, l_{bf}, or l_s (if d_t is not already equal to d_{max}), and repeat the calculations. If A_{PBMP} is still greater than the available space, reduce F_s (if the minimum number of test pits and permeability tests have not been performed) and repeat the calculations.

LC-8 Permeable Pavement

Permeable pavement, also known as pervious or porous pavement, is a load-bearing surface that allows for the temporary storage of runoff in an underlying aggregate reservoir layer until it infiltrates into native soils. Permeable pavement includes pervious concrete, porous asphalt, interlocking pavers, and reinforced and gravel-filled grids.

Elliott Street Parking Lot Permeable Pavement, Daniel K. Inouye International Airport
Source: Hawaii DOTA

Design Criteria

Table 1: Minimum Design Criteria and Guidelines

Category	Guidelines
PBMP Footprint Area	5% to 18% of contributing impervious area.
Appropriate Usage	Use in areas with light to medium duty loads such as parking areas, driveways, sidewalks, and bike paths.
Material Layer Order (Generally)	1) Permeable pavement surface material. 2) Filter layer or choker coarse (optional). 3) Reservoir layer (can be combined with base coarse and sub-base reservoir layer): - Maximum depth of reservoir layer = 3 ft. - Install permeable fabric between reservoir layer and underlying subgrade. 4) Subgrade (native soil matrix).
Drawdown (drain) Time of Subgrade	48 hrs or less.
Minimum Soil Infiltration Rate	0.5 in/hr
Maximum Depth of Reservoir Layer	3 ft
Minimum Depth from Reservoir Invert to Groundwater Table	3 ft
Overflow	Connect a downstream conveyance or other PBMP for flows exceeding design capacity.
Vertical Bypass	Install measures to allow runoff to enter reservoir layer if surface course becomes clogged.
Flow Distribution	Perforated pipes laid flat along bottom of reservoir layer may be used to uniformly distribute runoff. These may also provide additional storage volume depending on size.
Underdrains (Optional)	DOTA prefers no underdrains; if site conditions warrant using underdrains: - Minimum 6-in perforated underdrain pipe in a gravel layer. - Include cleanout pipe tied into the end of all underdrain pipe runs.
Design Specifications	Additional design details on specific permeable pavement systems are provided by 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.

Table 2: Pretreatment Considerations

Category	Considerations
Pretreatment Options	• Provide if run-on from non-impervious surface is present that can lead to sediment clogging. • If needed, options include gravel filter strips, vegetated swales, or vegetated buffer strips.

LIMITATIONS

May be considered infeasible or impractical if:
- Determined to be infeasible through the LID PBMP Infeasibility & Waiver Screening step in Veoci®.
- Unstable soil stratum or soils with > 25% clay content.
- Slopes > 20%.
- The site lacks a sufficient hydraulic head to support operation by gravity.
- Unable to operate off-line with bypass, and unable to operate in-line with a safe overflow mechanism.
- Documented concern that there is potential on-site for soil pollutants, groundwater pollutants, or pollutants associated with industrial activities to be mobilized.
- Maintenance may be excessive in areas with high or frequent traffic.

Construction Considerations

COMPACTION

- Prior to installation, schedule a pre-construction meeting with the superintendent, foremen, permeable pavement manufacturer representative, testing lab representative, and the engineer or owner's representative to discuss logistical considerations. Logistical considerations may include:
  - Scope and schedule.
  - Test locations.
  - Site access plans including staging and construction areas.
  - Quality control plans (prevention of sedimentation and compaction, material testing protocols and frequency, site inspection procedures and frequency).
  - Documentation protocols and procedures.
- Do not use heavy equipment within the permeable pavement. Heavy equipment can be used around the perimeter of the permeable pavement to supply media materials.
  - When possible, use excavation hoes to remove original soil.
  - If permeable pavements are excavated using a loader, use wide track or marsh track equipment or light equipment with turf-type tires. Use of equipment with narrow tracks or narrow tires, rubber tires with large lugs, or high-pressure tires is unacceptable. Compaction could contribute to design failure.
  - Use a primary tilling operation such as a chisel plow, ripper, or subsoiler to refracture the soil profile through the 12-in compaction zone.
  - Grade permeable pavement backfill with light equipment such as a compact loader or a dozer/loader with marsh tracks.
- Permeable pavement surfaces can be laid without cross-falls or longitudinal gradients.
- Do not store site materials on permeable pavement surfaces unless it is well protected from the deposition of silt and other spillages.

SCHEDULING

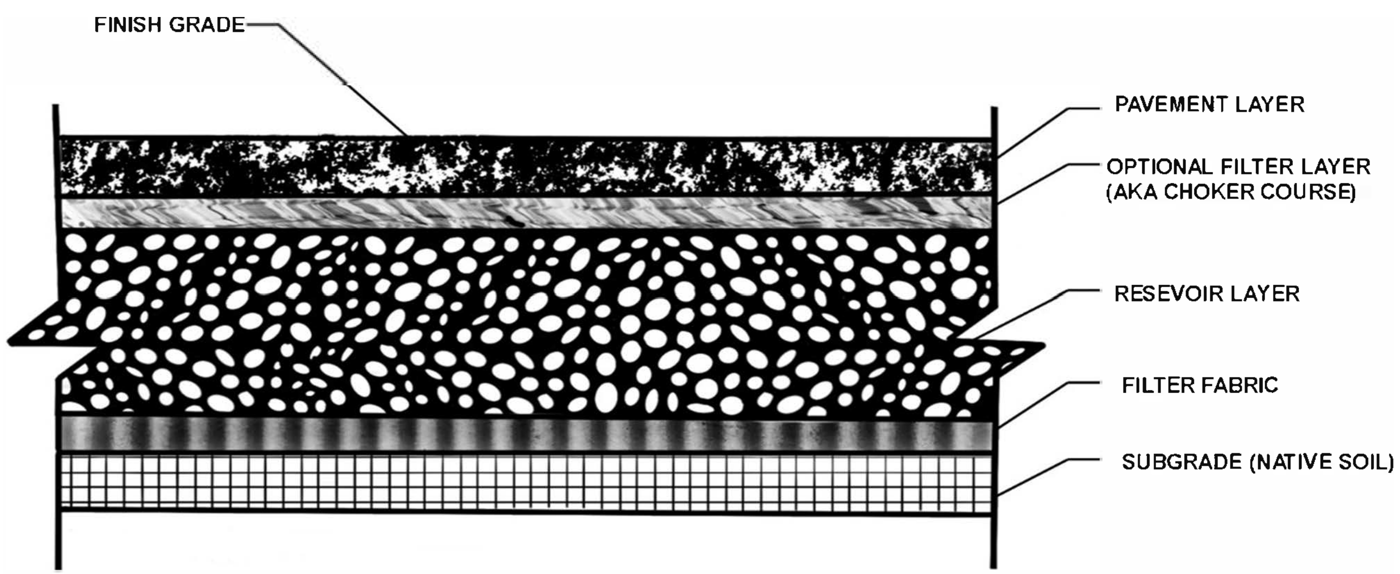
- Construct pavement in a single operation, as one of the last items to be built.
- Complete landscaping before pavement construction to avoid contamination by silt or soil.
- Stabilize surfaces draining to the permeable pavement before pavement construction.

MAINTENANCE

- Include signage on-site to educate airport users, visitors, and maintenance crews about the permeable pavement system. Signage can also help readers understand system functions and the consequences of different activities. Construct signage that is resilient to environmental conditions to prevent frequent replacement.
- Provide access to maintain the permeable pavement.

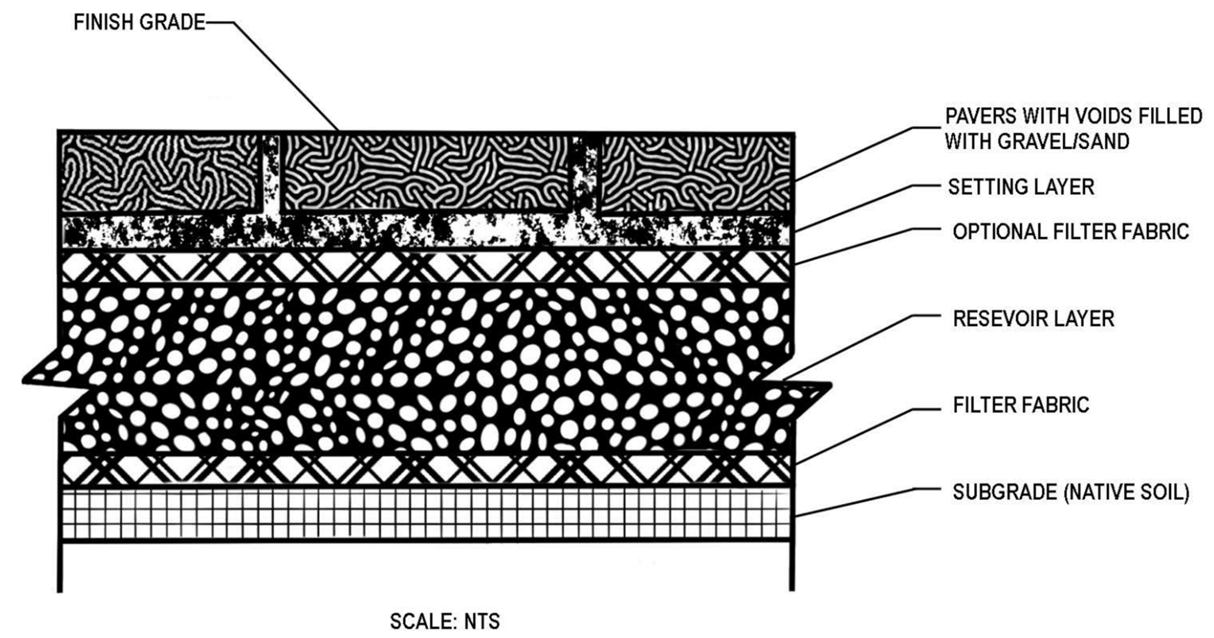
Cut Sheet Examples

Disclaimer: The example schematics provided below are intended for visual aid purposes only and not for design purposes. The example schematics are not intended to be used as a design guide for the items, descriptions, and details (depths, etc.). The actual configuration will vary depending on specific site constraints and the design criteria of this fact sheet. Refer to the information provided above for details on the design.



Example Schematic Showing Typical Section of Pervious Concrete or Porous Asphalt

Source: *Storm Water BMP Guide for New and Redevelopment* (CCH, 2017). The source schematic was modified to remove design details that are not consistent with this Fact Sheet.



Example Schematic Showing Typical Section of Permeable Pavers

Source: *Storm Water BMP Guide for New and Redevelopment* (CCH, 2017). The source schematic was modified to remove design details that are not consistent with this Fact Sheet.

Sizing Guidelines

Step 1:
Use the procedure below to compute the volumetric runoff coefficient (C) and water quality volume (WQV). The C should be calculated using the following equation:

$C = 0.05 + 0.009I$

where ***C*** = Volumetric Runoff Coefficient

I = Impervious Cover (%)

The WQV is calculated using the following equation:

$WQV = PCA \times 3630$

where ***WQV*** = Water Quality Design Volume (ft³)

P = Design Storm Runoff Depth (in) (refer to Section 4.5.3.1)

C = Volumetric Runoff Coefficient

A = Tributary Drainage Area (ac)

Step 2:
Calculate the maximum allowable water storage depth (d_{max}) using the underlying soil infiltration rate (k) and the required drawdown time (t):

$d_{max} = kt / (F_s \times 12)$

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

k = Soil Infiltration Rate (in/hr)

t = Drawdown (drain) Time (hrs) (refer to Section 4.5.3.5)

F_s = Infiltration Rate Factor of Safety (refer to Section 3.3.1)

Step 3:
Select a pavement course depth (l_p) and reservoir depth (l_r), such that the total effective storage depth (d_t) is no greater than the maximum allowable depth (d_{max}) calculated in Step 2:

$d_t = l_p n_p + l_r n_r \leq d_{max}$

where d_t = Total Effective Water Storage Depth (ft)

l_p = Pavement Course Depth (ft)

n_p = Pavement Course Porosity (refer to Section 4.5.3.7)

l_r = Reservoir Layer Depth (ft)

n_r = Reservoir Layer Porosity (refer to Section 4.5.3.7)

d_{max} = Maximum Storage Depth from Step 2 (ft)

Step 4:
Calculate the permeable pavement surface area (A_{PBMP}):

$A_{PBMP} = WQV / (d_t + (kT / 12F_s))$

where A_{PBMP} = Bottom Surface Area (ft²)

WQV = WQV from Step 1 (ft³)

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

k = Soil Infiltration Rate (in/hr)

T = Fill Time (time for the PBMP to fill with water [hrs])

(refer to Section 4.5.3.10)

F_s = Infiltration Rate Factor of Safety (refer to Section 3.3.1)

If A_{PBMP} is greater than the available space, reduce the drainage area or increase d_p, l_m, or l_g (if d_t is not already equal to d_{max}), and repeat the calculations. If A_{PBMP} is still greater than the available space, reduce F_s (if the minimum number of test pits and permeability tests have not been performed) and repeat the calculations.

LC-9 Subsurface Infiltration

A subsurface infiltration system is a stone storage (or alternative pre-manufactured material) bed below surfaces such as parking lots and landscaped areas for temporary storage and infiltration of runoff. Subsurface infiltration systems, including pre-manufactured pipes, vaults, modular structures, etc., are alternatives to infiltration basins and trenches for space-limited sites and stormwater retrofit applications.

Subsurface Infiltration
Source: Philadelphia Stormwater Management Guidance Manual, Version 3.2

Design Criteria

Table 1: Minimum Design Criteria and Guidelines

Category	Guidelines
Area Requirements	• Follow manufacturer's guidelines for configuration and area requirements. • Sizing calculations based on detailed infiltration hydraulic analysis. • Generally applicable to small sites (< 10 ac).
System Selection	Consider systems certified by Washington State Department of Ecology Technology Assessment Protocol (TAPE) or the New Jersey Department of Environmental Planning (NJDEP).
Drawdown (drain) Time	72 hrs or less.
Minimum Soil Infiltration Rate	0.5 in/hr
Minimum Depth from Basin Invert to Groundwater Table	3 ft
Media Layering	Add permeable filter fabric between rock or alternative material layer and subsurface infiltration system invert.
Overflow	An overflow or bypass must be incorporated to convey flows greater than the design storm to downstream drainage systems.
Basin Grading	Grade basin bottom as flat as possible for uniform ponding and infiltration.
Observation Wells	Recommended for monitoring facility dewatering and functionality.
Manholes	• Include for cleaning access. • Some designs include isolated row for inspection ports and manholes for maintenance.

Table 2: Pretreatment Considerations

Category	Considerations	
General	Infiltration basins are susceptible to clogging and premature failure.	
Pretreatment Requirements	**Soil Infiltration Rate**	**Pretreatment Requirement**
	< 3 in/hr	Pretreatment strongly recommended. Size pretreatment device for at least 25% of WQV.
	> 3 in/hr and < 5 in/hr	Pretreatment mandatory. Size pretreatment device for at least 50% of WQV.
	> 5 in/hr	Pretreatment mandatory. Size pretreatment device for 100% of WQV.
Pretreatment Options	• Vegetated swales, vegetated buffer strips, sedimentation basins, forebays, or manufactured treatment devices. • Forebay considerations: - 18- to 30-in depth. - Use where standing water is not a safety or vector concern. - Line to prevent water flow into underdrains without first passing through the treatment area. - Lining allows for sediment and debris removal with a shovel or vac truck.	

LIMITATIONS

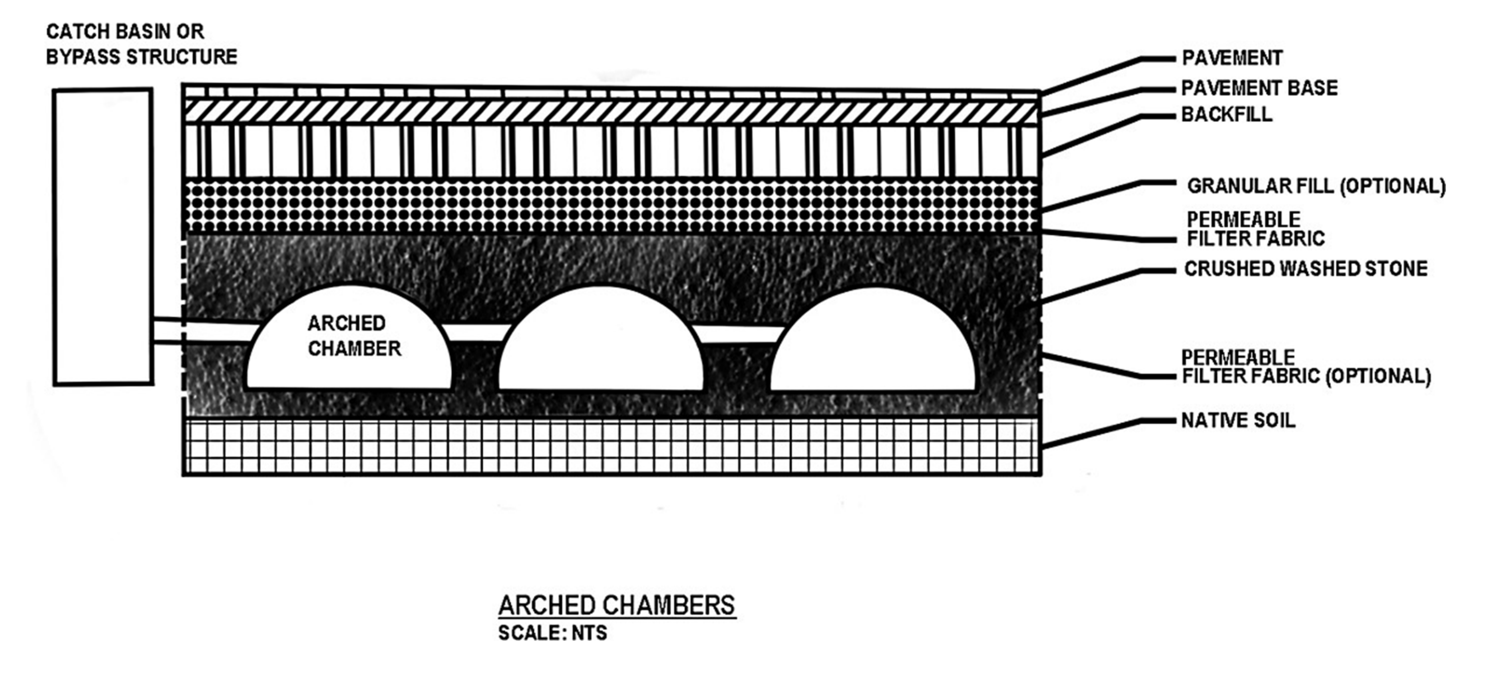
- Subsurface infiltration systems must be wider than they are deep or follow the LC-5 Dry Well/Drainage Well design fact sheet.
- May be considered infeasible or impractical if:
  - Determined to be infeasible through the LID PBMP Infeasibility & Waiver Screening step in Veoci®.
  - Unstable soil stratum or soils with > 25% clay content.
  - Slopes > 20%.
  - The site lacks a sufficient hydraulic head to support operation by gravity.
  - Unable to operate off-line with bypass, and unable to operate in-line with a safe overflow mechanism.
  - Documented concern that there is potential on-site for soil pollutants, groundwater pollutants, or pollutants associated with industrial activities to be mobilized.

Construction Considerations

Follow the manufacturer's recommendations.

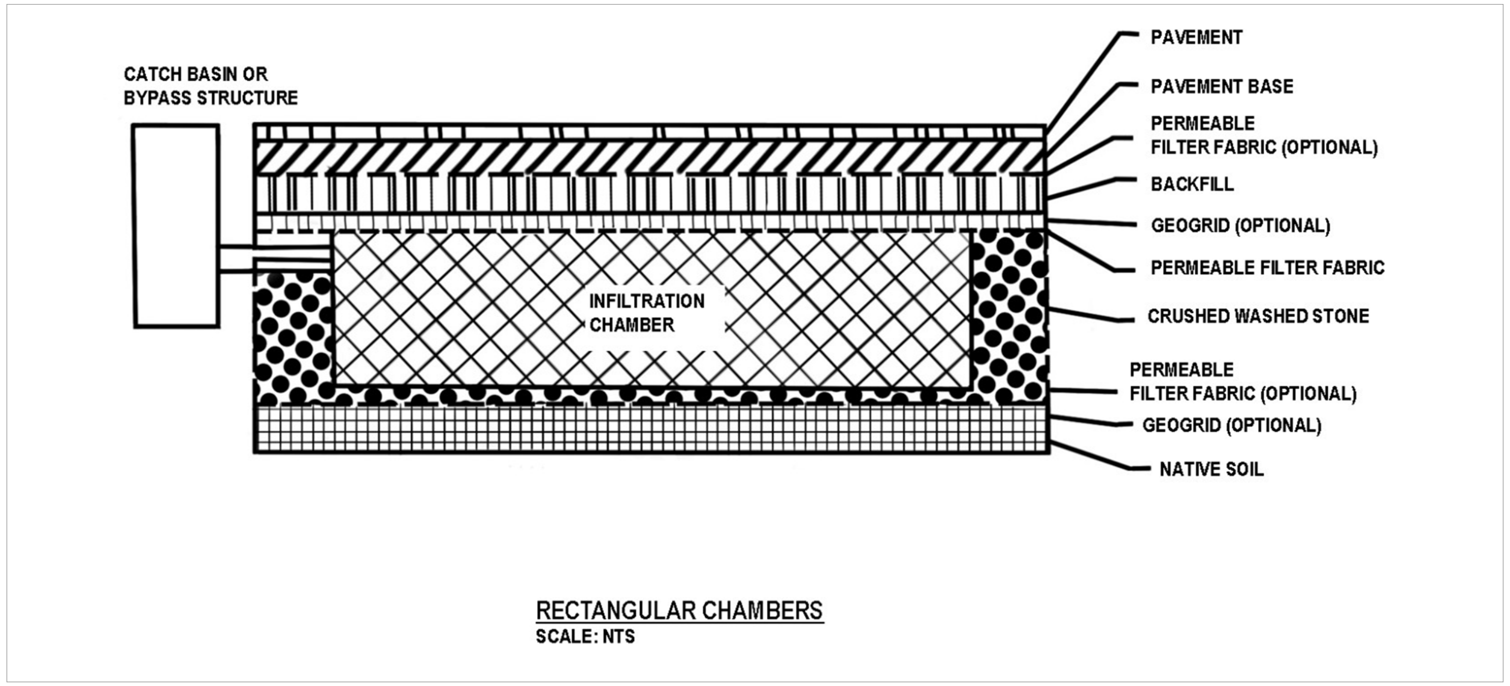
Cut Sheet Examples

Disclaimer: The example schematics provided below are intended for visual aid purposes only and not for design purposes. The example schematics are not intended to be used as a design guide for the items, descriptions, and details (depths, etc.). The actual configuration will vary depending on specific site constraints and the design criteria of this fact sheet. Refer to the information provided above for details on the design.



Example Schematic of a Subsurface Infiltration Systems

Source: *Storm Water BMP Guide for New and Redevelopment* (CCH, 2017). The source schematic was modified to remove design details that are not consistent with this Fact Sheet.



Example Schematic of a Subsurface Infiltration Systems

Source: *Storm Water BMP Guide for New and Redevelopment* (CCH, 2017). The source schematic was modified to remove design details that are not consistent with this Fact Sheet.

Sizing Guidelines

- DOTA sizing guidelines are not provided as sizing procedures will vary by manufacturer.
- Follow the manufacturer's guidelines for appropriate sizing calculations and selection of appropriate device/model.
- Every unit requires detailed hydraulic analysis before installation to verify optimum infiltration is achieved.

LC-10 Vegetated Buffer Strip

A vegetated buffer strip is a strip of land parallel to and adjacent to the edge of the contributing impervious surface and designed to accommodate sheet flow. A vegetated buffer strip is typically vegetated with turfgrass. Vegetated buffer strips provide filtration, reduce flow velocity, and prevent erosion.

Vegetated Buffer Strip, Oahu
Source: HDOT Highways Division

Design Criteria

Table 1: Minimum Design Criteria and Guidelines

Category	Guidelines
PBMP Footprint Area	At least 0.4% of contributing impervious area.
Maximum Flow Velocity	1 ft/s
Maximum Length of Tributary Flow	75 ft
Maximum Flow Depth	1 in
Minimum Length	15 ft
Width Dimensions	• Width should equal the length of the tributary area (perpendicular to the buffer strip). • Runoff should enter the vegetated buffer strip as sheet flow spread over the width of the strip. • If tributary area > buffer strip, use a pea gravel diaphragm or engineered level spreader to establish uniform sheet flow. • Level spreader options include: - Porous pavement strips. - Stabilized turf strips. - Slotted curbing. - Rock filled trenches. - Concrete sills.
Landscaping	• Avoid vegetation that could be hazardous to airport operations (i.e., food [seeds] or habitat for wildlife). • Most economical if existing vegetation can be retained or when a landscaped area serves as a buffer strip in design. • Select appropriate grasses considering site-specific soils and hydraulic conditions. Design to facilitate regular mowing. • Vegetate with dense turf grasses to promote sediment capture, filtration, nutrient uptake, and lower flow velocity. • Irrigation may be needed during dry periods.

LIMITATIONS

May be considered infeasible or impractical if:

- Determined to be infeasible through the LID PBMP Infeasibility & Waiver Screening step in Veoci®.
- Unstable soil stratum or soils with > 25% clay content.
- Slopes > 5%.
- The amount of sunlight received by the site is inadequate or irrigation is infeasible to support vegetation.

Construction Considerations

LANDSCAPING

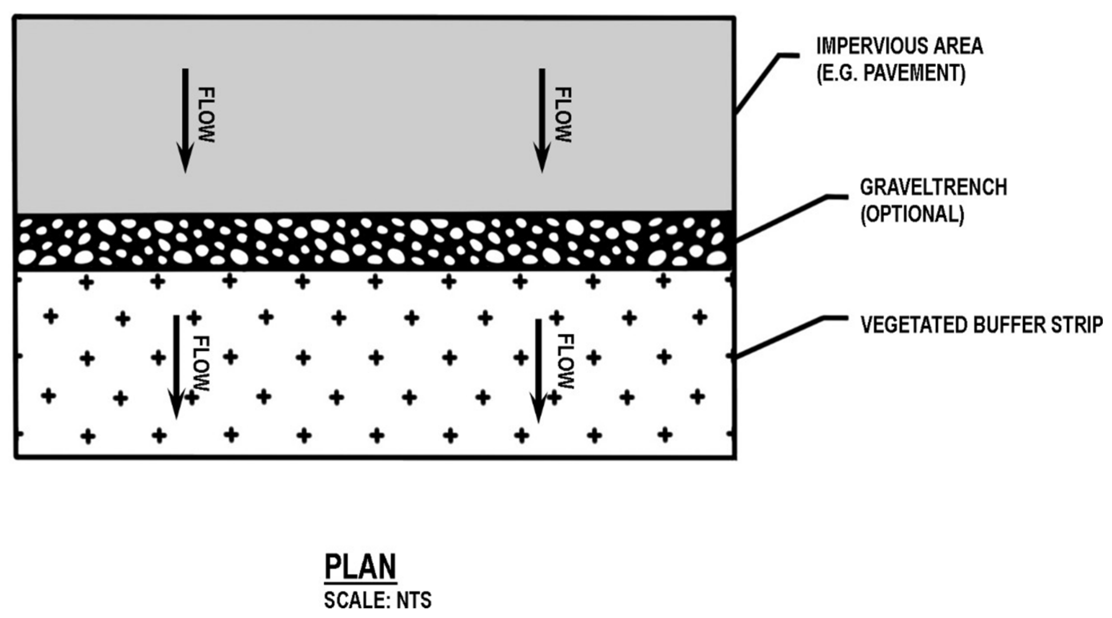
- Include directions in the specifications for appropriate fertilizer and soil amendments based on soil properties determined through testing and to the needs of the grass.
- Landscaping should be done as soon as possible after the area has been graded.
- If sod tiles are used, place so that there are no gaps between the tiles; stagger the ends of the tiles to prevent the formation of channels along the bioswale.
- Use a roller on the sod to verify no air pockets form between the sod and the soil.
- Per FAA Regulations, do not scatter or apply seeds through hydroseeding or within hydromulch in areas that could attract wildlife and cause safety concerns for aircraft operations. Use alternative methods such as sprigs. For areas that do not create safety concerns for aircraft operations, seeds may be used with explicit approval from Airport Management.

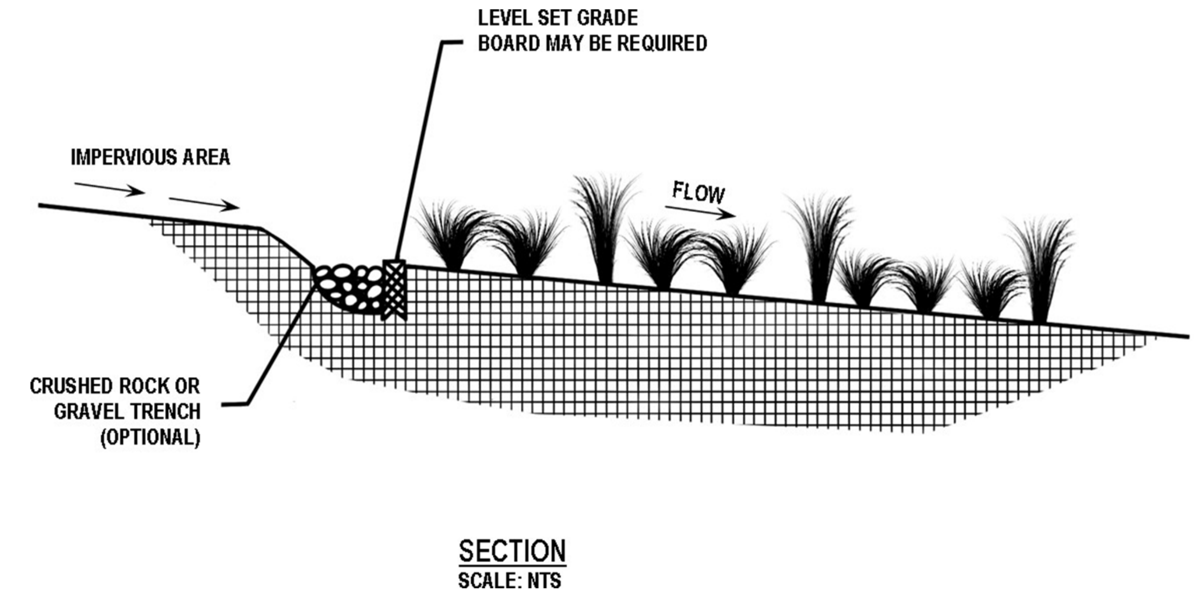
MISCELLANEOUS

- Install at a time of the year when there is a reasonable chance of successfully establishing grass without irrigation; temporary irrigation may be required.
- Strip and stockpile good topsoil during construction for use in surface preparation prior to planting.
- Do not use for vehicular traffic, this can be damaging to the vegetation and reduce its effectiveness.
- Do not establish vegetated buffer strips until the contributing drainage area is stabilized.

Cut Sheet Examples

Disclaimer: The example schematics provided below are intended for visual aid purposes only and not for design purposes. The example schematics are not intended to be used as a design guide for the items, descriptions, and details (depths, etc.). The actual configuration will vary depending on specific site constraints and the design criteria of this fact sheet. Refer to the information provided above for details on the design.





Example Schematic of a Vegetated Buffer Strip

Source: *Storm Water BMP Guide for New and Redevelopment* (CCH, 2017). The source schematic was modified to remove design details that are not consistent with this Fact Sheet.

Sizing Guidelines

Step 1:
Use the procedure presented below to compute a composite weighted runoff coefficient and the water quality design flow rate. For drainage areas containing multiple land uses, a composite runoff coefficient is calculated using the following equation:

$$C_c = \left[\frac{\sum_{i=1}^{n} C_i A_i}{A_t}\right]$$

where C_c = Composite Weighted Runoff Coefficient

$C_{1,2,..n}$ = Runoff Coefficient for each Land Use Cover Type

$A_{1,2,..n}$ = Drainage Area to each Land Use Cover Type (ac)

n = Number of Land Use Cover Types within the Drainage Area

A_t = Total Drainage Area (ac)

Compute the peak inflow rate using the Rational Method:

$Q = CiA$

where Q = Water Quality Design Flow Rate (cfs)

C = Runoff Coefficient

i = Peak Rainfall Intensity (in/hr) (refer to Section 4.5.3.2)

A = Tributary Drainage Area (ac)

Step 2:
Select initial values for the buffer strip width (w) and buffer longitudinal slope (s).

Step 3:
Compute the design flow depth for the water quality flow rate using a simplified form of Manning's Equation assuming a shallow flow depth:

$y = 12 \times [nQ/1.49\sqrt{(s/100)}]^{0.6}$

where y = Design Flow Depth for water quality flow rate (in)

n = Manning's n value (refer to Section 4.5.3.11)

Q = Water Quality Flow Rate (cfs) from Step 1

w = Design Width (ft) from Step 2

s = Longitudinal Slope (%) from Step 2

Step 4:
Calculate the design flow velocity using the flow continuity equation:

$V = 12Q/wy$

where V = Design Flow Velocity (fps)

Q = Water Quality Flow Rate (cfs) from Step 1

w = Design Width (ft) from Step 2

y = Design Flow Depth (ft) from Step 3

If the design flow velocity is greater than the maximum allowed velocity, revise one of the parameters and repeat the calculations.

Step 5:
Select a design buffer strip length (L) equal to or greater than the minimum length, and calculate the total PBMP area required (A_{PBMP}):

$A_{PBMP} = Lw$

where A_{PBMP} = Total Area (ft²)

L = Design Length (ft)

w = Design Width (ft) from Step 2

LC-11 Vegetated Swale

A vegetated swale is a broad, shallow earthen channel designed to treat the stormwater within dry or wet cells formed using check dams or other means. Vegetated swales are typically vegetated with flood-tolerant grasses that can provide filtration, reduce flow velocity, and prevent erosion. Stormwater runoff typically enters at one end of the vegetated swale and exits at the other end.

Vegetated Swale along H-3, Oahu
Source: HDOT Highways Division

Design Criteria

Table 1: Minimum Design Criteria and Guidelines

Category	Guidelines
PBMP Footprint Area	2% to 4% of contributing impervious area.
Contributing Drainage Area	5 ac or less.
Swale Geometry	Trapezoidal shape with flat bottom (in direction perpendicular to flow).
Bottom Width	2 to 10 ft.
Maximum Flow Depth	4 in
Maximum Flow Velocity	1 ft/s
Minimum Freeboard	6 in
Minimum Hydraulic Residence Time	7 min
Check Dams	• 12 in maximum height. • Install perpendicular to flow. • Provide a v-notch weir, weep hole, or similar drainage feature to direct low flow volume.
Maximum Longitudinal Slope	• 2% slope without check dams. • 5% slope with check dams.
Maximum Interior Side Slope (length per unit height)	3:1
Overflow / Bypass	• Include high flow bypass to convey flow velocities exceeding 1 ft/s. • Direct overflow to an outlet with energy dissipators to prevent erosion from the 10-yr storm velocity.
Landscaping	• Avoid vegetation that could be hazardous to airport operations (i.e., food [seeds] or habitat for wildlife). • Select appropriate grasses considering site-specific soils and hydraulic conditions. Design to facilitate regular mowing. • Use dense turf grasses to promote sediment capture, filtration, nutrient uptake, lower flow velocity to limit erosion. • Consider irrigation during periods dry periods, if necessary.
Underdrains (optional)	DOTA prefers no underdrains; if site conditions warrant using underdrains: - Minimum 6-in perforated underdrain pipe in a gravel layer. - Include cleanout pipe tied into the end of all underdrain pipe runs.

LIMITATIONS

May be considered infeasible or impractical if:

- Determined to be infeasible through the LID PBMP Infeasibility & Waiver Screening step in Veoci®.
- Unstable soil stratum or soils with > 25% clay content.
- Slopes > 5%.
- The amount of sunlight received by the site is inadequate or irrigation is infeasible to support vegetation.
- The site lacks sufficient hydraulic head to support operation by gravity.

Construction Considerations

CHECK DAMS

Construct check dams using concrete, stone, or other non-erodible material and anchored appropriately into the bottom and side slopes.

LANDSCAPING

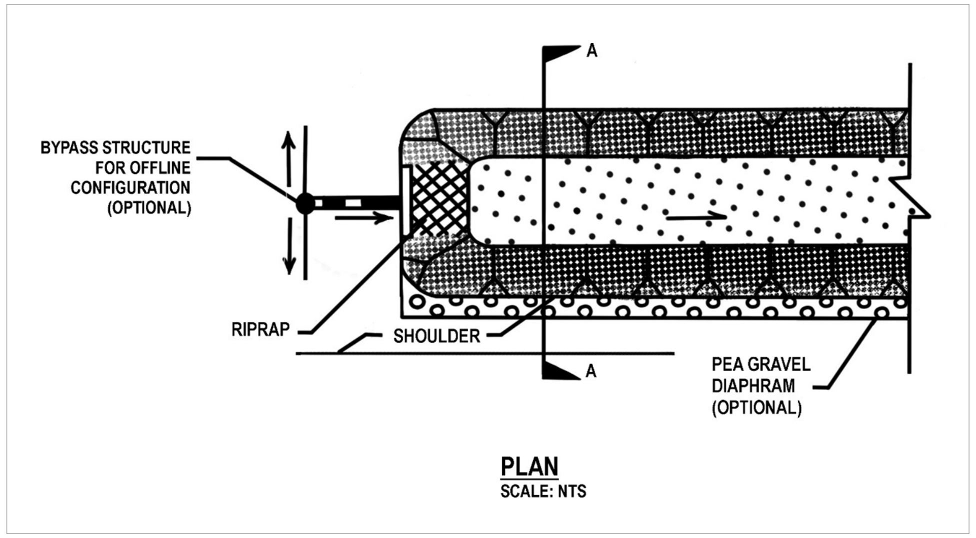
- Include directions in the specifications for appropriate fertilizer and soil amendments based on soil properties determined through testing and the needs of the grass.
- Landscaping should be done as soon as possible after the area has been graded.
- If sod tiles are used, place so that there are no gaps between the tiles; stagger the ends of the tiles to prevent the formation of channels along the bioswale.
- Use a roller on the sod to verify no air pockets form between the sod and the soil.
- Per FAA Regulations, seeds are not to be scattered or applied through hydroseeding or within hydromulch in areas that could attract wildlife and cause safety concerns for aircraft operations. Alternative methods such as sprigs shall be utilized, as approved in the project documents. If seeds are to be used in areas that do not create safety concerns for aircraft operations, consult with USDA prior to implementation.

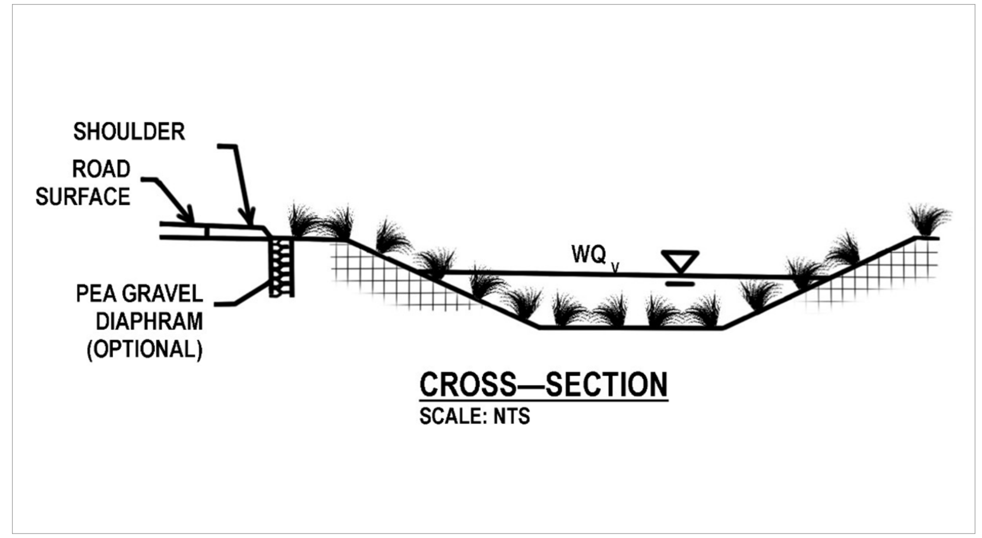
MISCELLANEOUS

- Install at a time of the year when there is a reasonable chance of successfully establishing grass without irrigation; temporary irrigation may be required.
- Direct inflow toward the upstream end of the swale.
- Do not use as sediment control measures during construction.
- Do not establish until the contributing drainage area is stabilized.

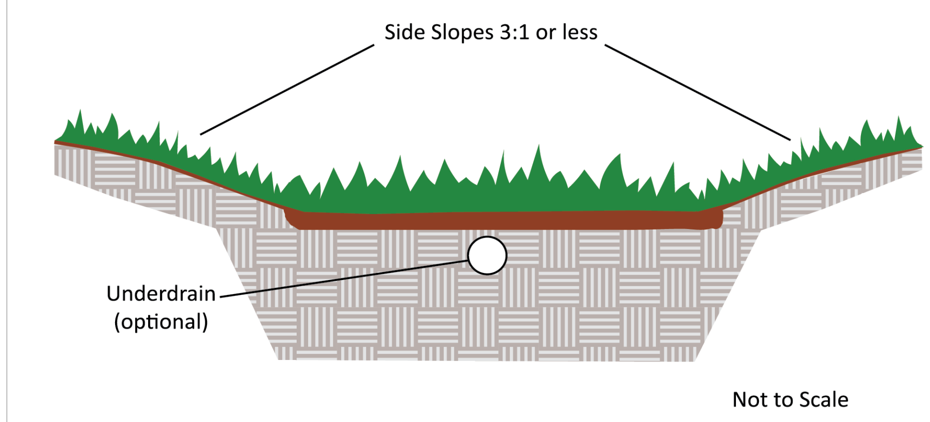
Cut Sheet Examples

Disclaimer: The example schematics provided below are intended for visual aid purposes only and not for design purposes. The example schematics are not intended to be used as a design guide for the items, descriptions, and details (depths, etc.). The actual configuration will vary depending on specific site constraints and the design criteria of this fact sheet. Refer to the information provided above for details on the design.





Example Schematic of a Vegetated Swale



Example Schematic of a Vegetated Swale

Source: *Storm Water BMP Guide for New and Redevelopment* (CCH, 2017). The source schematic was modified to remove design details that are not consistent with this Fact Sheet.

Sizing Guidelines

Step 1:
Use the procedure presented below to compute a composite weighted runoff coefficient and the water quality design flow rate. For drainage areas containing multiple land uses, a composite runoff coefficient is calculated using the following equation:

$$C_c = \left[\frac{\sum_{i=1}^{n} C_i A_i}{A_t}\right]$$

where C_c = Composite Weighted Runoff Coefficient

$C_{1,2,..n}$ = Runoff Coefficient for each Land Use Cover Type

$A_{1,2,..n}$ = Drainage Area to each Land Use Cover Type (ac)

n = Number of Land Use Cover Types within the Drainage Area

A_t = Total Drainage Area (ac)

Compute the peak inflow rate using the Rational Method:

$$Q = CiA$$

where Q = Water Quality Design Flow Rate (cfs)

C = Runoff Coefficient

i = Peak Rainfall Intensity (in/hr) (refer to Section 4.5.3.2)

A = Tributary Drainage Area (ac)

Step 2:
Select initial values for the swale bottom width (b), depth of flow (y), swale side slope (z), and swale longitudinal slope (s).

Step 3:
Calculate the cross-sectional area (A_c), wetted perimeter (WP), and hydraulic radius (R) using the dimensions established in Step 2:

$$A_c = (by/12) + (zy^2/144)$$

$$WP = b + (2y/12)\sqrt{(1+z^2)}$$

$$R = A_c/WP$$

where A_c = Cross-sectional Area (ft²)

WP = Wetted Perimeter (ft)

R = Hydraulic Radius (ft)

b = Swale Bottom Width (ft) from Step 2

y = Depth of Flow (in) from Step 2

z = Swale Side Slope (length per unit height) from Step 2

Step 4:
Compute the calculated flow rate in the swale using the selected dimensions and Manning's Equation:

$$Q = (1.49A_cR^{2/3}s^{1/2})/n$$

where Q = Calculated Flow Rate (cfs)

A_c = Cross-sectional Area (ft²) from Step 3

R = Hydraulic Radius (ft)

s = Longitudinal Slope (%) from Step 2

n = Manning's n value (refer to Section 4.5.3.11)

Step 5:
Once an appropriate design flow rate is achieved, calculate the design flow velocity using the flow continuity equation:

$$V = Q/A_c$$

where V = Design Flow Velocity (fps)

Q = Design Flow Rate (cfs) from Step 4

A_c = Cross Sectional Area (ft²) from Step 3

If the design flow velocity is greater than the maximum allowed velocity, either include check dams with vertical drops of no more than 12-in or revise one or more swale dimensions and repeat the calculations.

Step 6:
Select an initial value for the hydraulic residence time (T) to compute the swale length (L). Multiply the velocity by the hydraulic residence time to determine the length:

$$L = 60VT_h$$

where L = Swale Length (ft)

T_h = Hydraulic Resistance Time (min)

V = Design Flow Velocity from Step 5 (fps)

Step7:
Calculate the total area required (A_{PBMP}) taking into account the side slopes along the length of the swale and the freeboard:

$$A_{PBMP} = [b + 2z(f + y/12)] \times L$$

where A_{PBMP} = Total Surface Area (ft²)

b = Swale Bottom Width (ft) from Step 2

z = Swale Side Slope (length per unit height) from Step 2

f = Freeboard (ft)

y = Depth of Flow (in) from Step 2

L = Swale Length (ft) from Step 6

If A_{PBMP} is greater than the available space, either reduce the drainage area, reduce the T_h (if longer than the minimum), or revise one or more swale dimensions and repeat the calculations.

APPENDIX IV
SOURCE CONTROL PBMP DESIGN FACT SHEETS

Source Control PBMPs are required for all non-exempt projects for the following activities and areas:

- SC-1: Dispersion for landscaped areas and velocity dissipation
- SC-2: Fueling Area Design for aircraft, vehicle, and equipment fueling
- SC-3: Loading/Unloading Area Design for outdoor loading and unloading operations related to aircraft, vehicle, and equipment
- SC-4: Maintenance Area Design for aircraft, vehicle, and equipment maintenance and repair
- SC-5: Material Storage Area Design for material storage
- SC-6: Triturator Facility Design for triturator facilities
- SC-7: Washing Area Design for aircraft, vehicle, and equipment washing
- SC-8: Waste Management Area Design for outdoor waste storage

The following information is provided for each of the above-listed Source Control PBMP Fact Sheets:

- Description
- Suitable Applications
- Limitations
- Design Criteria and Guidelines

Please note that Operational O&M recommendations can be found in the Best Management Practice (BMP) Field Manual for Operations at State of Hawaii Airports.[11]

[11] https://hidot.hawaii.gov/airports/doing-business/engineering/environmental/tenant-bmp-field-manual/

SC-1 Dispersion

Dispersion PBMPs provide runoff reduction and attenuation by dispersing stormwater runoff through vegetation or other media. Dispersion slows runoff entering the storm or drainage system, impeding the velocity of stormwater runoff, allowing some infiltration, and providing some water quality benefits.

Splashblock located along HART, Daniel K. Inouye International Airport
Source: Hawaii DOTA

Design Criteria

Table 1: Minimum Design Criteria and Guidelines

Category	Guidelines
General	
Landscaping	• Select vegetation based on soil type, soil condition, site topography, climate, seasonal variation, maintenance concerns, aesthetic considerations, water, fertilizer, and pesticide usage. • Roughen planting area by plowing, disking, or raking to a depth of 6 in with furrows trending along contours. • Plant grass using sprigs, plugs, or sod, as appropriate. • If sod tiles used, place with no gaps between tiles, stagger ends to prevent formation of channels. • Roll or compact sod/tamp down plugs immediately after installation.
Flow Path	• Should consist of well-established lawn or pasture, landscaping with well-established groundcover, native vegetation with natural groundcover. • Groundcover should be dense enough to help disperse and infiltrate flow.
Level Spreader	
Underlying Soil	Construct level spreader on undisturbed soil, not fill.
Pretreatment	Pretreatment should be provided for runoff water with high sediment load.
Flow	The maximum flow into a level spreader should not exceed 30 ft^3/s.
Sizing	• Length dependent on inflow rate, pipe diameter, number and size of perforations, downhill cover type. • Long enough to discharge calculated peak flow rate from minimum 10-yr, 24-hr design storm. • A level spreader perforated pipe diameter may range in size from 4 in to 12 in.
Aggregate	• Lay pipe in an envelope of aggregate (AASHTO #57 or equivalent). • Thickness of aggregate based on desired volume reduction. • Non-woven geotextile should be placed below aggregate to discourage clogging.
Slopes	• Level spreader should be level. • Slope below level spreader should be relatively smooth in the direction of flow to discourage channelization. • Outlet area should be uniform and well vegetated with a slope of 10% or less. • Lip of level spreader should have zero slope for proper operation, allowing even flow of discharged water.
High Flow Conditions	Use rigid outlet lip design (concrete or metal) for high discharge flow conditions (flow greater than design flow).

Table 1: Minimum Design Criteria and Guidelines (Cont.)

Category	Guidelines
Splashblocks	
Minimum Length of Vegetated Discharge Flow Path	• 50 ft (measured from downspout to downstream property line, stream, wetland, or other impervious surface). • Sensitive buffer areas may count toward flow path length.
Flow Path	To maintain separation of flows from adjacent dispersion devices, do not overlap vegetated flow path with other flow paths except those associated with sheet flow from non-native pervious surface.
Max Contributing Area	700 ft^2 of roof area.
Placement	Place splashblock at each downspout discharge point. Downspout should empty onto splashblock and should carry water away from foundation to prevent erosion.
Perforated Stub-Out Connection	
Sizing	At least 10 ft of perforated pipe per 5,000 ft^2 of roof area laid in a level 2-ft-wide trench backfilled with washed drain rock with a diameter range of 3/4 in to 1.5 in.
Drain Rock	Extend to at least 8 in below bottom of pipe and cover pipe.
Pipe Layout	Lay pipe level and cover rock trench with filter fabric and 6 in of drain rock.

LIMITATIONS

General

If the site is susceptible to erosion, additional control measures may be necessary during landscaping.

Level Spreader

- A level spreader is not a sediment trapping or filtering device. Water flowing into the level spreader should be free of sediment.
- Not applicable in areas with erodible soils or little vegetation.

Splashblocks

Can not be placed on slopes > 20%.

Perforated Stub-Out Connections

- Can not be placed on slopes > 20%.
- Seasonal groundwater table < 1 ft below bottom.
- Little or no flow control in wet winter months, when ground is more likely to be saturated.

Construction Considerations

GENERAL

- Stabilize upstream areas before runoff is diverted to dispersion PBMPs.
- Install all contributing storm drainage system elements (inlets, outlets, pipes, storm drains, other PBMPs, etc.) before installing the dispersion PBMPs.

LANDSCAPED AREAS

- Inspect grassed areas frequently after the first installation, especially after large storm events, until permanent cover is established.
- Per FAA Regulations, seeds are not to be scattered or applied through hydroseeding or within hydromulch in areas that could attract wildlife and cause safety concerns for aircraft operations. Alternative methods such as sprigs shall be utilized, as approved in the project documents. If seeds are to be used in areas that do not create safety concerns for aircraft operations, consult with Airport Management prior to implementation.

LEVEL SPREADER

- When the level spreader is used as an erosion and sediment control measure, restore to original state (flush perforated pipe and clean out all sediment) before using it as a dispersion PBMP.
- Install perforated pipe along a contour, with care taken to construct a level bottom.
- Do not allow discharge flow to pond below the level spreader outlet.
- Do not operate vehicles and heavy equipment in the level spreader because they can create surface indentations that can impede flow.

SPLASHBLOCKS

Secure splashblocks and position to receive the downspout flow.

PERFORATED STUB-OUT CONNECTIONS

None.

SC-2 Fueling Area Design

Airfield fueling areas, jet fuel dispensing areas, gasoline outlets, car rental facilities, and other fueling areas can discharge jet fuel, aviation fuel, diesel, and gasoline to the drainage system or receiving waters. Spills or releases are a common occurrence at fueling areas due to the nature of the activity and the stored materials. Develop plans for containment, leak prevention, and cleaning near fuel dispensers.

Jet Fuel Loading Rack at Fueling Facility, Kahului Airport
Source: Hawaii DOTA

Design Criteria

Table 1: Minimum Design Criteria and Guidelines

Category	Guidelines
Covering	• Include overhanging roof structure. • At minimum, cover fuel dispensing area with minimum dimensions equal to or greater than area within grade break or fuel dispensing area. • Do not drain into fuel dispensing area; route downspouts to prevent drainage. • Direct stormwater runoff from fueling area to treatment control PBMP prior to discharging to storm drainage system.
Containment	• If covering fueling area is impracticable due to Fueling large equipment or vehicles, design island to accommodate and prevent stormwater runoff and run-on. • Consider providing a berm around the fueling area to contain spills. Include a discharge drain that may be locked until accumulated, uncontaminated stormwater is ready to be released.
Paving	• Pave with non-porous Portland cement concrete or equivalent smooth impervious surface. • Extend minimum of 6.5 ft from corner of each fuel dispenser or the length that the hose and nozzle may be operated plus 1 ft, whichever is greater. • Use of asphalt prohibited. • Use asphalt sealant to protect areas surrounding fuel area.
Drainage	• Provide appropriate slope to prevent ponding. • Provide a grade break that prevents stormwater run-on. • Drain toward dead end sump or vegetated landscaped area. • Do not locate storm drains near fueling area. • Direct downspout/roof runoff away from fueling area, and toward vegetated/landscaped areas, if possible. • Direct stormwater runoff from fueling areas to an OWS prior to discharge into the storm drainage system.
Spill Response	Provide storm drain seals such as isolation valves for emergency conditions, to prevent spills from discharging into the drainage system.
Signage	• Provide signage for tank operations and emergency shutoff, if applicable. • Provide signage warning vehicle operators against “topping off” at the fuel dispenser or fuel island. • Provide signage with information on how and to whom spills or releases are to be reported.
Fuel Containers	• Provide secondary containment to the fuel containers and piping. • Designate appropriate location for emergency shutoff that is accessible but a sufficient distance from pumps for safety and provide signage indicating the location.
O&M Plan	Develop an operations plan that describes procedures for fueling.

LIMITATIONS

Canopy must meet FAA setback regulations from AOA fence lines.

SC-3 Loading/Unloading Area Design

Several measures can be implemented at loading/unloading docks to prevent discharge of various pollutants such as oil and grease, heavy metals, nutrients, suspended solids, and trash to the drainage system or receiving waters. Develop plans for overflow containment structures, dead-end sumps, engineered infiltration or other treatment systems.

Loading Area at Cargo Facility, Daniel K. Inouye International Airport
Source: Hawaii DOTA

Design Criteria

Table 1: Minimum Design Criteria and Guidelines

Category	Guidelines
Standards and Specifications	• Design requirements governed by applicable standards of federal, state, and county agencies with jurisdiction. • Additional requirements by DOTA, FAA, Building Code, Fire Code, county agency ordinances, and county zoning may apply.
Covering	Cover all loading/unloading dock areas or design them to preclude stormwater run-on and runoff.
Containment	• Provide containment areas and sumps for accumulation of stormwater and non-stormwater as accumulated water can be contaminated. Dispose of contaminated stormwater following applicable laws and do not discharge directly to the drainage system or receiving waters. • Other features such as impermeable berms, overflow containment structures, etc., may be comparable and equally effective.
Paving	Pave loading/unloading areas with non-porous Portland cement concrete (or equivalent smooth impervious surface) instead of asphalt.
Drainage	• Do not allow runoff from depressed loading docks (truck wells) to discharge into drainage system, unless first filtered through an HDS unit or other approved PBMP. • Grade or berm the loading/unloading area to a drain that is connected to a dead-end sump, sewer system, septic system, HDS unit, or other approved PBMP. • Design loading/unloading area to prevent stormwater run-on. • Drain below grade loading docks from warehouse/distribution centers of fresh food items through water quality inlets, engineered infiltration system, or similar. • Direct downspouts so runoff does not flow through loading/unloading areas.
Signage	Provide signage with information on how and to whom spills or releases are to be reported.
O&M Plan	Develop an operations plan that describes procedures for loading and unloading.

LIMITATIONS

Implementation of covers may be limited depending on the size of the aircraft, vehicle, or equipment that could be loaded or unloaded.

SC-4 Maintenance Area Design

Aircraft, vehicle, and equipment maintenance/repair may contribute various pollutants such as petroleum products, solvents, paints, antifreeze, other vehicle fluids, oil and grease, heavy metals, suspended solids, and trash to the drainage system or receiving waters in the event of spills or leaks. Project plans should include overflow containment structures and dead-end sumps. Engineered infiltration or other treatment systems may also be considered.

Aircraft Maintenance Hangar, Daniel K. Inouye International Airport
Source: Hawaii DOTA

Design Criteria

Table 1: Minimum Design Criteria and Guidelines

Category	Guidelines
Covering	Locate maintenance/repair areas indoors or undercover, when possible.
Containment	• Provide impermeable berms, trench drains, or other containment systems around the maintenance/repair area to prevent spilled materials or wash waters from entering the drainage system or receiving waters. • Connect trench drains to sumps or the sanitary sewer through OWSs or other treatment control PBMPs. Direct collected spilled materials or wash waters from the maintenance/repair areas to OWSs or other treatment control PBMPs. • Provide containment areas and sumps with impervious surfaces for accumulation of stormwater and non-stormwater.
Paving	Pave maintenance area/bay floors with non-porous Portland cement or equivalent to prevent leaks and spills from seeping into the ground.
Drainage	• Direct connection from maintenance bays into the drainage system or receiving waters is prohibited. • Configure downspouts and stormwater conveyance systems to prevent run-on through the maintenance/repair area. • Grade or berm the maintenance/repair area to a drain that is connected to an OWS.
Spill Response	Provide storm drain seals such as isolation valves for emergency conditions, to prevent spills from discharging into the drainage system.
Material and Waste Storage	Designate locations for material and waste storage that follow the criteria outlined in SC 5: Material Storage Area Design and SC 8: Waste Management Area Design.
Signage	Provide signage with information on how and to whom spills or releases are to be reported.
O&M Plan	Develop an operations plan that describes procedures for conducting maintenance/repair activities.

LIMITATIONS

Implementation of covers may be limited depending on the size of the aircraft, vehicle, or equipment that could be maintained.

SC-5 Material Storage Area Design

Material storage areas may include materials stored in bulk piles, containers, shelving, stacking, or tanks. A properly designed material storage area can reduce the potential for pollutants to impact the drainage system or receiving waters. Since material spills may occur in these areas, measures such as enclosures, secondary containment structures, and impervious surfaces are encouraged. Control measures may also include minimizing the storage area. It is not recommended for runoff from outdoor material storage areas to discharge to infiltration or detention systems.

Material Storage Area with a Containment Berm at Hangar, Daniel K. Inouye International Airport
Source: Hawaii DOTA

Design Criteria

Table 1: Minimum Design Criteria and Guidelines

Category	Guidelines
Location	Whenever possible, outdoor storage areas should be situated away from areas prone to flooding and in a location where storage containers will not be accidentally damaged by equipment or vehicles.
Covering	• Design material storage areas to be indoors or under cover, if feasible. Cover all material storage areas, or design them to preclude stormwater run-on and runoff. • Extend roof or awning over storage area beyond the storage area to minimize stormwater collection within the secondary containment area. A manufactured storage shed may be used for small containers.
Containment	• Provide secondary containment for liquids if they are: - Stored outdoors or in an area where spills could potentially be exposed to stormwater, regardless of container size. - Stored in a container with a capacity of 25 gal or more, regardless of location. - Categorized as hazardous, regardless of location. - Mobile storage tanks (including tanks on trailers where approved) that meet the following conditions: ▪ 500-gal capacity or larger. ▪ Have fittings, valves, connectors, and/or fuel sumps situated on the bottom or sides of the tank. ▪ Have the potential to contain product when unattended or overnight. • Secondary containment must be large enough to capture 100% of the capacity of the single largest container. If stored outdoors and exposed to rainfall, additional freeboard must be included to account for the precipitation of a 25-yr, 24-hr storm event. • Secondary containment can include structures such as berms, dikes, curbs, etc., or enclosures that prevent contact with stormwater runoff and discharge into the drainage system or receiving waters. Secondary containment for liquids and batteries may include spill pallets, double-walled tanks, or other appropriate methods. • Provide containment areas and sumps with impervious surfaces for accumulation of stormwater and non-stormwater. Contaminated stormwater should be disposed of following applicable laws and cannot be discharged directly to the drainage system or receiving waters.
Paving	Pave the material storage area with non-porous Portland cement or equivalent to prevent leaks and spills from seeping into the ground and allow for easier cleanup of spills.
Drainage	• For areas that will be uncovered (e.g., material stockpile), contain the site with berms, trench drains, or other systems. • Connect drains to sumps or sanitary sewer through OWSs or other treatment devices. • Direct connection from material storage areas into drainage system or receiving waters is prohibited. • Configure downspouts and stormwater conveyance systems to prevent run-on through the material storage areas.
Spill Response	For emergency conditions, provide storm drain seals such as isolation valves, etc., to prevent spills from commingling with stormwater, as practical.
Pretreatment	If the material storage area cannot be situated indoors or under cover, pretreatment of runoff prior to discharge into a storm drainage system or receiving water is required. The PBMP selected for pretreatment must be designed to target pollutants with the most potential to become entrained in stormwater, dependent on the materials stored.
Signage	Provide signage with information on how and to whom spills or releases are to be reported.
O&M Plan	Develop an operations plan that describes procedures for material storage.

LIMITATIONS

Implementation of covers may be limited depending on the materials being stored and the timeframe for storage.

SC-6 Triturator Facility Design

The sanitary sewage and associated rinse waters produced during the servicing of aircraft lavatory facilities must pass through a special grinder known as a triturator, which grinds the contents into small enough pieces to enter the sanitary sewer system safely. The proper design of a triturator facility can prevent potential pollutants associated with servicing aircraft lavatory facilities from impacting drainage systems or receiving waters. Due to the potential of spills at the triturator facilities, PBMPs focus on containment and pollution prevention. The triturator facility is generally located airside, near airline operations and acts as pretreatment prior to discharge to the sanitary sewage system.

Triturator Facility at Kahului Airport
Source: Hawaii DOTA

Design Criteria

Table 1: Minimum Design Criteria and Guidelines

Category	Guidelines
Triturator Design	• Design triturator (grinder) to be a closed, self-contained, below-grade, automated station that allows for the simple, clean, and efficient disposal of sewage pumped from airplane lavatories. • Design triturator (grinder) and water flush system to start automatically when the lavatory vehicle enters the facility and turn off when the vehicle exits. • Design triturator facility with vehicle stops or signage to verify the lavatory service equipment parks directly over the floor drain leading to the triturator.
Covering	Include a cover and low, roll-over type berming.
Water Source	Include a water source at the triturator facility for cleanout and backflushing lavatory service equipment.
Sewer Connection	Design triturator facilities to provide the required volume disposal from aircraft bulk tanks into the sanitary sewer system.
Containment	Design triturator facilities with low, roll-over type berming.
Paving	Pave the triturator facility area with non-porous Portland cement or equivalent to prevent leaks and spills from seeping into the ground.
Drainage	• Design triturator facilities away from storm drains to preclude stormwater run-on and runoff. • Route downspouts and storm drains so that runoff does not flow through the triturator facility. • Slope the triturator facility toward the floor drain leading to the triturator to capture the lavatory wastes.
Spill Response	For emergency conditions, provide storm drain seals such as isolation valves, etc., to prevent spills from commingling with stormwater.
Signage	• Provide signage indicating how to conduct operations at the triturator facility. • Provide signage with information on how and to whom spills or releases are to be reported.
O&M Plan	Develop an operations plan that describes procedures for triturator operations.

LIMITATIONS

Implementation of berms at the triturator facilities may be limited depending on the size of the trucks or trailers equipped with bulk storage containers used to service lavatory facilities.

SC-7 Washing Area Design

Aircraft, vehicle, and equipment washing may result in various pollutants associated with washing activities such as surfactants, sediment, and petroleum products that may impact drainage systems or receiving waters. Depending on the size and other parameters of the facility, wash water may be conveyed to a sewer, an infiltration system, a recycling system, or another alternative. Pretreatment may be required for discharge to a sanitary sewer.

East Wash Rack, Daniel K. Inouye International Airport
Source: Hawaii DOTA

Design Criteria

Table 1: Minimum Design Criteria and Guidelines

Category	Guidelines
Wash Water Disposal	• Design washing area to discharge wash water to the sanitary sewer, a holding tank, process treatment system, or an enclosed recycling system. • Include wash water treatment device or pretreatment device such as OWS. • Consider recycling water after filtration or direct excess to sanitary sewer where county ordinances allow. • Install sumps or drain lines to collect wash water. Divert wash water to the sanitary sewer or an equally effective alternative. • Dispose of contaminated stormwater following applicable laws and do not discharge directly to drainage system or receiving waters.
Covering	The washing area should be self-contained and include a roof or an overhang, if feasible.
Containment	• Design washing area to be contained and to prevent drag out of wash water; include grading to a central drain, placing berms around the perimeter, and/or locating indoors or under cover (if feasible). • Slope washing area toward a dead-end sump to contain spills. • Provide containment areas and sumps with impervious surfaces for accumulation of stormwater and non-stormwater.
Drainage	• Direct and divert stormwater runoff away from the washing area and the exposed area around the washing area to alternatives other than the sanitary sewer. • Configure downspouts and stormwater conveyance systems to prevent run-on through the washing area.
Signage	• Provide identification for the wash area and signage about approved washing practices. • Provide signage stating that washing is only allowed in the wash area.
Sewer Connection	The washing area should have a proper connection to a sanitary sewer, where county regulations allow.
O&M Plan	Develop an operations plan that describes procedures for washing.

LIMITATIONS

Covering is not feasible for aircraft or GSE wash racks due to the size of equipment serviced.

SC-8
Waste Management Area Design

Improper waste management can result in various contaminants being discharged by stormwater runoff. Specifically, pollution may occur when loose trash and debris are dispersed by the wind or when waste containment devices leak. Additional contaminants may be discharged to stormwater depending on the type of waste. Project plans should include preventative measures such as enclosures, containment structures, and impervious pavements to mitigate spills and reduce the likelihood of contamination.

Waste Management Area, Daniel K. Inouye International Airport
Source: Hawaii DOTA

Design Criteria

Table 1: Minimum Design Criteria and Guidelines

Category	Guidelines
Waste Hauler	Design criteria is not intended to conflict with the needs of waste haulers. Waste haulers should be contacted prior to the design of trash collection areas and any conflicts should be discussed with DOTA.
Covering	• Design waste management areas to be indoors or under cover, if feasible. Cover all waste management areas or design them to preclude stormwater run-on and runoff. • Extend roof or awning over waste management area beyond the storage area to minimize stormwater collection within the secondary containment area. A manufactured storage shed may be used for small containers.
Containment	• Berm outdoor waste management areas to prevent run-on from adjoining roofs and pavement or grade areas toward vegetated/landscaped areas, if feasible. • Provide secondary containment for liquid wastes if they are: - Stored outdoors or in an area where spills could potentially be exposed to stormwater, regardless of container size. - Stored in a container with a capacity of 25 gal or more, regardless of location. - Categorized as hazardous, regardless of location. • Secondary containment must be large enough to capture 100% of the capacity of the single largest container. If stored outdoors and exposed to rainfall, additional freeboard must be included to account for the precipitation of a 25-yr, 24-hr storm event. • Secondary containment can include structures such as berms, dikes, curbs, etc., or enclosures that prevent contact with stormwater runoff and discharge into the drainage system or receiving waters. Secondary containment for liquids and batteries may include spill pallets, double walled tanks, or other appropriate methods. • Provide containment areas and sumps with impervious surfaces for accumulation of stormwater and non-stormwater. Contaminated stormwater should be disposed of following applicable laws and cannot be discharged directly to the drainage system or receiving waters.
Paving	Pave waste storage areas with non-porous Portland cement or equivalent to prevent leaks and spills from seeping into the ground and allow for easier cleanup of spills.
Drainage	• Do not locate waste storage areas near storm drains. • Configure downspouts and stormwater conveyance systems to prevent run-on through the waste management areas. • Connect drains to sumps or sanitary sewer through OWSs or other treatment devices. • Direct connection from waste management areas into drainage system or receiving waters is prohibited.
Wind Protection	Screen or wall waste container areas to prevent off-site transport of trash by wind dispersion, as practical.
Spill Response	For emergency conditions, provide storm drain seals such as isolation valves, etc., to prevent spills from commingling with stormwater, as practical.
Signage	• Provide signage to indicate the types of wastes that can be disposed of within the area. • Provide signage with information on how and to whom spills or releases are to be reported.
O&M Plan	Develop an operations plan that describes procedures for waste management.

LIMITATIONS
Berms may not be practical in areas where access for trash collection is needed.

APPENDIX V
TREATMENT CONTROL PBMP
DESIGN FACT SHEETS

Treatment Control PBMPs are required for all non-exempt projects that do not qualify for a PBMP Variance with site conditions where LID PBMPs are infeasible. LID PBMPs should be considered first before implementing Treatment Control PBMPs.

The following lists the various Treatment Control PBMP types to be considered, and may include the use of more than one depending on site specific conditions:

- TC-1: Alternative Wetland
- TC-2: Dry Detention Basin
- TC-3: Evaporation Pond
- TC-4: Hydrodynamic Separator Unit
- TC-5: Drain Inlet Insert
- TC-6: Oil Water Separator
- TC-7: Sand Filter
- TC-8: Subsurface Detention

The following information is provided for each of the above-listed Treatment Control PBMP Fact Sheets:

- Description
- Limitations
- Design Criteria and Guidelines
- Construction Considerations
- Cut Sheet Examples
- Sizing Guidelines

Please refer to Appendix VI for the corresponding O&M Fact Sheets.

TC-1 Alternative Wetland

Alternative wetlands considered at airports may include floating wetlands (also known as floating treatment wetlands or FTW) or modular wetlands.

FTWs consist of a floating raft and suspended matrix with aquatic wetland plants, and are placed in a water body where the plants are able to draw pollutants out of the water. The floating treatment wetland technology is an emerging approach used to treat stormwater for nutrients.

Modular wetlands are proprietary biotreatment devices approved by the Washington State University TAPE, NJDEP, California State Water Resources Control Board, Virginia Department of Environmental Quality, etc. They can be installed adjacent to storm drains for basic stormwater treatment and enhanced treatment, including sediment, nutrients, and heavy metals uptake. The pollutant removal performance may vary depending on the type and model selected for the project.

Floating Wetland in Kaanapali Lagoon, Maui
Source: West Maui Ridge 3 Reef Initiative

Design Criteria

Table 1: Minimum Design Criteria and Guidelines

Category	Guidelines
General	
Vegetation	Choose hardy plants common to Hawaii.
Storm Drain	Design storm drain so water is directed through plant bed before entering drainage system or receiving waters.
Bypass	Provide bypass valve for flows exceeding the WQF or WQV to a downstream drainage system.
Drawdown	Perform water balance to demonstrate wetlands can withstand a 30-day drought at summer evaporation rates without completely drawing down.
Floating Treatment Wetland	
Area	10-50% of water body surface coverage.
Placement	• Place perpendicular to stormwater flow path. • At least 3.5 ft above the bottom of the waterway or pond. • Near shoreline for wave action attenuation and reduction of undercutting and bank/shoreline erosion.
Anchoring	• Anchor FTW to allow rise and fall with changes in water level. • Anchored adequately in the water body to protect its flood control function during major storms and enable retrieval for periodic maintenance, yet not be too taut to inundate the surface and flood the raft.
Planting	Pre-plant vegetation. Construct by pinning potted plants or using coir or other compatible substance for the base.
Modular Wetland	
Design Guidelines	Follow manufacturer's instructions.
Pretreatment	Some models may incorporate pretreatment chambers that include separation and prefilter cartridges.

LIMITATIONS

General

- FAA requires that wildlife attractants be limited within the airport due to the safety threat they pose to aircraft.
- Vegetation disposal may also need to be considered.

Floating Treatment Wetland

- Can only be installed as a retrofit of an existing water body.
- Anchoring can be challenging due to wind shock, hydraulic flow, and float material integrity.
- Can block access or available area for recreational use.
- For maximum nutrient removal efficiency, harvest or remove seasonally.

Modular Wetland

Refer to manufacturer's instructions.

Construction Considerations

FLOATING TREATMENT WETLANDS

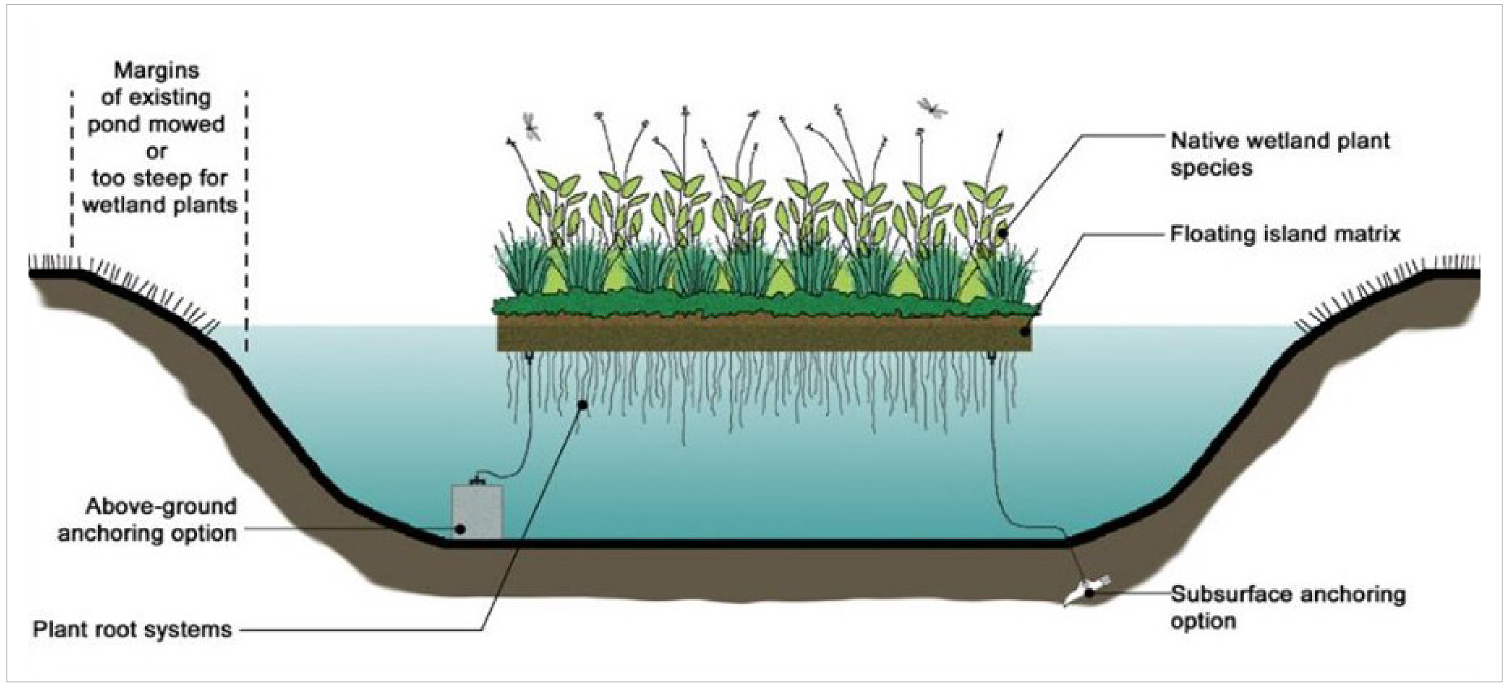
- The floating matrix is usually manufactured off site and assembled at the desired location.
- Plant establishment may require 6-12 months, depending on location and weather conditions.
- Follow the manufacturer's instructions for construction considerations.

MODULAR WETLANDS

Follow the manufacturer's instructions for construction considerations.

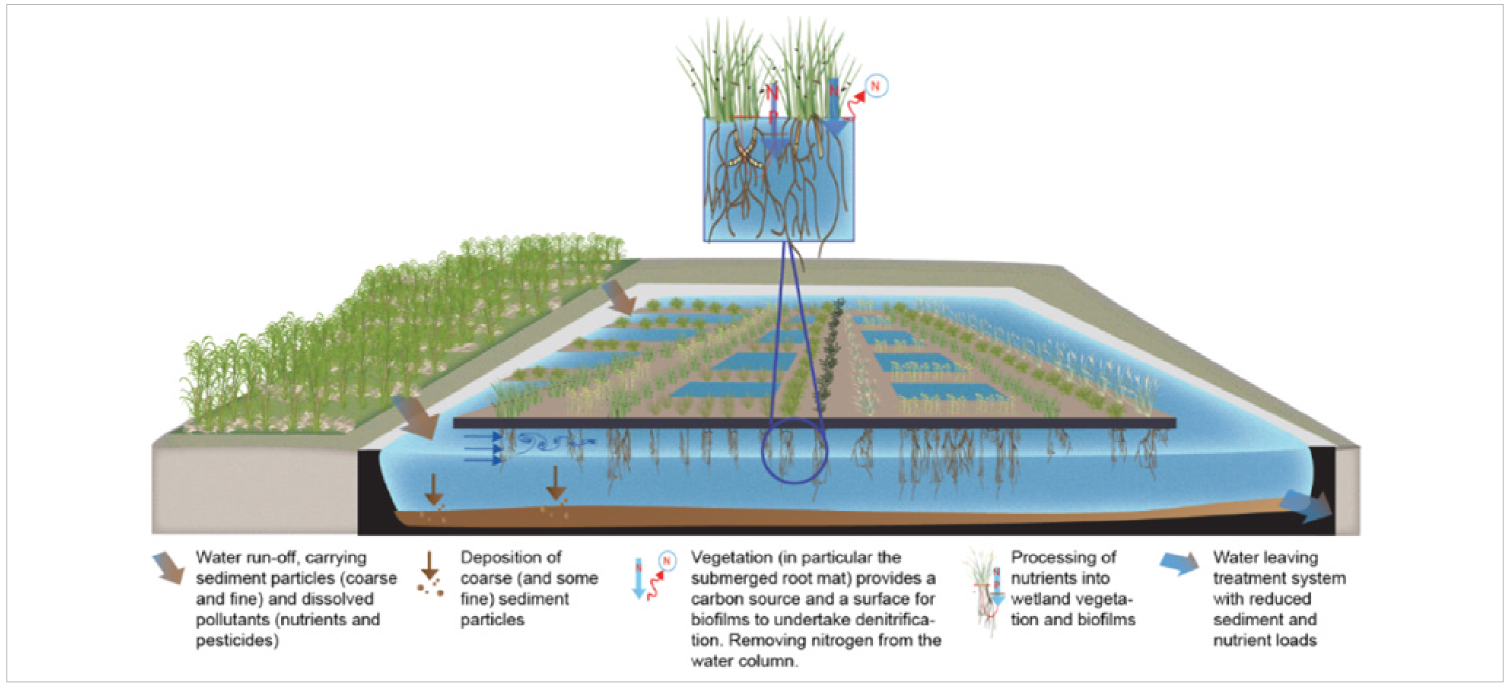
Cut Sheet Examples

Disclaimer: The example schematics provided below are intended for visual aid purposes only and not for design purposes. The example schematics are not intended to be used as a design guide for the items, descriptions, and details (depths, etc.). The actual configuration will vary depending on specific site constraints and the design criteria of this fact sheet. Refer to the information provided above for details on the design.



Schematic of a Floating Treatment Wetland

Source: Texas Community Watershed Partners



Schematic of a Floating Treatment Wetland Processes

Source: Texas Community Watershed Partners

Sizing Guidelines

FLOATING TREATMENT WETLANDS

- Most FTW are implemented as retrofits and can be expanded if results indicate more area is required to achieve the discharge criteria (based on the targeted pollutants of concern).
- Follow the manufacturer’s instructions for sizing guidelines.

MODULAR WETLANDS

- Follow the manufacturer’s instructions for sizing guidelines.

TC-2 Dry Detention Basin

Dry detention basins can provide stormwater quantity control and improve water quality using shallow, man-made impoundments that provide temporary stormwater storage to allow particles to settle. Dry detention basins retain stormwater until it can be released slowly over time. Dry detention basins can also be used to provide flood control by including flood detention storage. Dry detention basins are designed to drain completely between storm events

Detention Basin at Kahului Airport
Source: Hawaii DOTA

Design Criteria

Table 1: Minimum Design Criteria and Guidelines

Category	Guidelines
PBMP Footprint Area	1-9% of contributing impervious area.
Maximum Detention Period	48 hrs
Storage	Provide enough storage for multiple day rain events.
Maximum Interior Side Slope	2:1
Maximum Length to Width Ratio	3:1
Maximum Depth	8 ft
Maximum Drawdown (drain) Time for WQV	48 hrs
Drawdown (drain) Time for 50% of WQV	24 hrs
Basin Invert Slope	1-2%
Minimum Outlet Size	4 in
Minimum Freeboard	1 ft
Two-cell Design	• Two-cell designs are acceptable, where the upper cell remains dry and the lower cell detains water for an extended period following consecutive storm events. • Lower cell needs additional wildlife deterrent measures.

Category	Guidelines
Wildlife Control	• May use physical barriers, bird balls, wire grids, floating covers, vegetation barriers (bottom liners), pillows, or netting to prevent access to open water and prevent wildlife-aircraft interactions. • Evaluate physical barriers for effectiveness and maintenance requirements. They should not adversely affect water rescue. • Before installing physical barriers over detention basins, approval is needed from DOTA and the appropriate FAA Regional Airports Division Office (14 CFR § 139). • Incorporating steep sides, riprap or concrete lining, or narrow/linear geometry can help reduce wildlife attractants. • Eliminate vegetation that provide food or cover for wildlife.
Outlet	• Position outlet control structure at the lowest point and locate in the enclosed or covered downstream cell of the basin. • Outlet structures should be designed with a restrictor device to control the discharge flow rate from a detention basin (e.g., orifice, weir, outlet pipe, etc.). • Stage is the depth of water, as defined by the absolute distance from the water surface to the bottom of the water body when it has certain volume of water. Combinations of orifices, weirs, and pipes can provide multi-stage outlet control for different control volumes. • Provide a low-flow orifice capable of discharging the WQV over 48 hrs.
Erosion Control	Provide an energy dissipator (e.g., riprap, plunge pool, splash pad, etc.) at the outlet to prevent scouring and erosion.
Overflow/Bypass	• Include an overflow structure and/or high-flow bypass for significant rainfall, outlet structure blockage, or mechanical failure. • Provide weirs for overflow of the streambank protection volume and flood control volume. Overflow weirs can be of different heights and configurations, including sharp-crested weirs, broad-crested weirs, v-notch weirs, etc., to maintain control of multiple design flows. • Design overflow spillway to contain or bypass the 100-yr storm, depending on local requirements. • Locate so high-flow discharges will not adversely impact downstream structures.
Maintenance Access	• Provide maintenance access for inlets, outlets, and overflow structures. • Access openings can consist of standard frame, grate, and solid cover, or removable panel.
Dam Safety	If the embankment falls under the jurisdiction of the State of Hawaii, DLNR Engineering Division, Dam Safety Program, it shall be designed to meet the applicable requirements, or these requirements, whichever are more stringent.

Table 2: Pretreatment Considerations

Pretreatment Options	• Vegetated swales, vegetated buffer strips, sedimentation basins, forebays, or manufactured treatment devices. • Forebay considerations: - Volume equal to at least 5% of WQV. - Use where standing water is not a wildlife safety or vector concern. - Locate at each major inlet to provide pretreatment, preserve basin capacity, and reduce maintenance requirements. - Lining allows for sediment and debris removal with a shovel or vactor truck.

LIMITATIONS

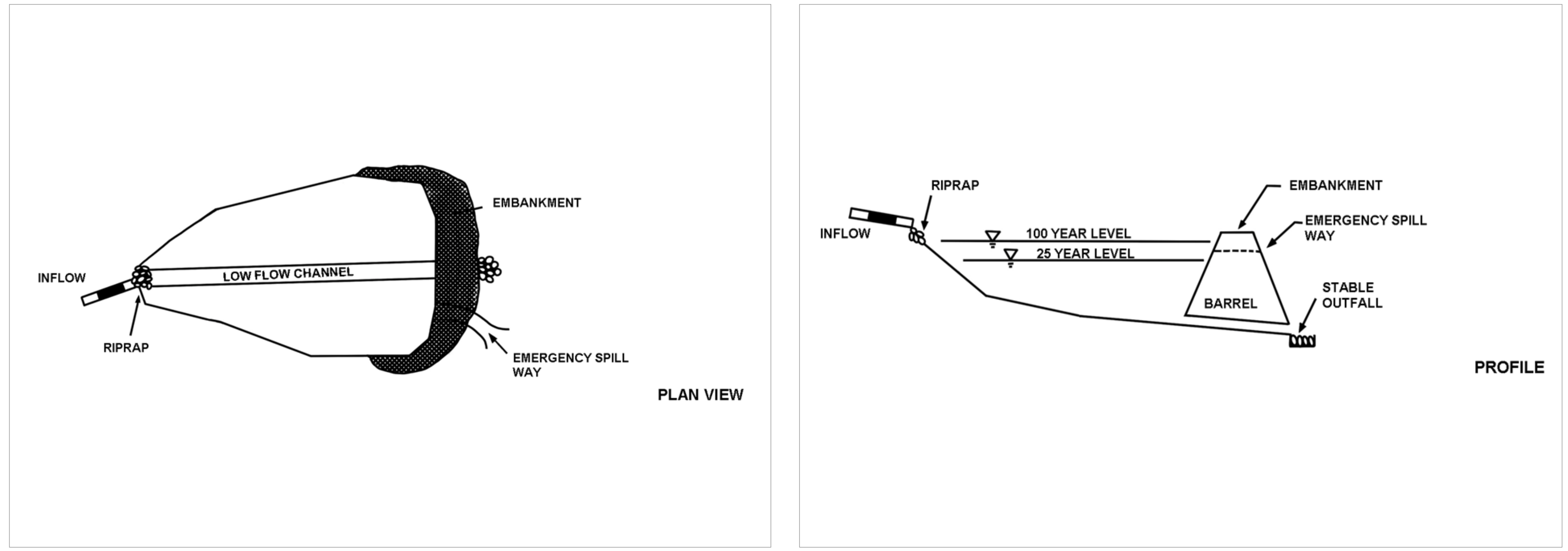
- Ineffective at removing soluble pollutants.
- May not be suitable near septic tanks, drain fields, fill sites, steep unstable slopes.
- Infeasible if any of the following conditions are met:
  - Standing water for duration longer than 48 hrs.
  - Invert below seasonal high groundwater.
  - Unable to operate with a safe overflow mechanism.
  - Sited within the required setback distance from the AOA.
  - Basin includes wildlife attractants.
  - Sited within 20 ft of any building foundation.
  - Located within 35 ft of drinking water well.

Construction Considerations

- Inspect the facility after the first large storm to determine whether the desired residence time has been achieved.
- When constructed with a small drainage area, orifice sizing is critical, and inspections should verify that flow through additional openings such as bolt holes does not occur.

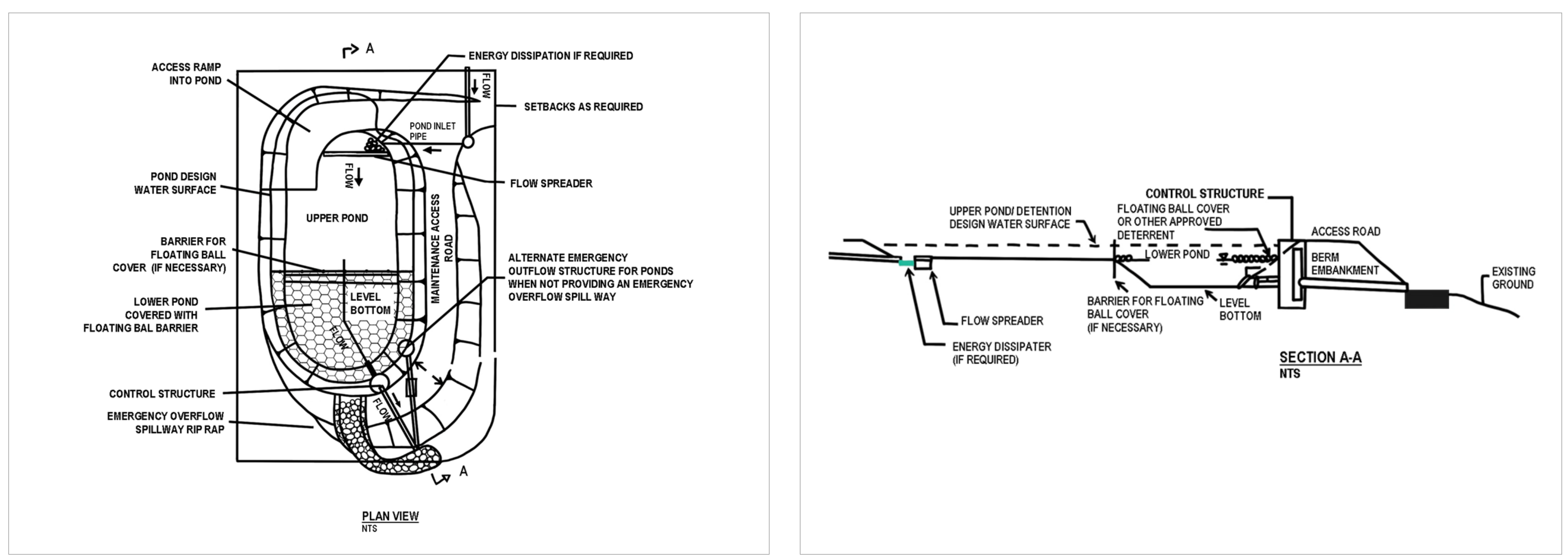
Cut Sheet Examples

Disclaimer: The example schematics provided below are intended for visual aid purposes only and not for design purposes. The example schematics are not intended to be used as a design guide for the items, descriptions, and details (depths, etc.). The actual configuration will vary depending on specific site constraints and the design criteria of this fact sheet. Refer to the information provided above for details on the design.



Example Schematic of a Detention Basin

Source: *Iowa Storm Water Management Manual* (Iowa Department of Natural Resources, 2009). The source schematic was modified to remove design details that are not consistent with this Fact Sheet.



Example Schematic of a Detention Basin with Two Cell Design

Source: *Aviation Stormwater Design Manual, Managing Wildlife Hazards Near Airports, M 3041.00* (Washington DOT, 2008). The source schematic was modified to remove design details that are not consistent with this Fact Sheet.

Sizing Guidelines

Dry detention basins must be sized to provide adequate capacity to capture the WQV and a complete drawdown within 48 hrs. The following is a simplified method for sizing a trapezoidal dry detention basin (assuming the same side and end slopes). Other design methods or modeling procedures may be used at the project proponent's discretion but are subject to approval by DOTA.

Step 1:
Use the procedure presented below to compute the pre-project (i.e., undeveloped) and post-project (i.e., developed) weighted runoff coefficients. For drainage areas containing multiple land uses, the following formula may be used to compute a composite weighted runoff coefficient (refer to Section 4.5.3.1):

$$C_c = \left[\frac{\sum_{i=1}^{n} C_i A_i}{A_t}\right]$$

where C_c = Composite Weighted Runoff Coefficient

$C_{1,2,..n}$ = Runoff Coefficient for each Land Use Cover Type

$A_{1,2,..n}$ = Drainage Area to each Land Use Cover Type (ac)

n = Number of Land Use Cover Types within the Drainage Area

A_t = Total Drainage Area (ac)

Compute the peak flow rate into the basin using the Rational method:

$$q_i = C_{post} iA$$

where q_i = Peak Flow Rate into the Basin (cfs)

C_{post} = Post-project Weighted Runoff Coefficient

i = Peak Rainfall Intensity (in/hr) (refer to Section 4.5.3.2)

A = Tributary Drainage Area (ac)

Step 2:
Compute the peak flow rate leaving the basin using the pre-project runoff coefficient, which effectively requires the detention basin to maintain the pre-project discharge rates:

$$q_o = C_{pre} iA$$

where q_o = Peak Flow Rate leaving Basin (cfs)

C_{pre} = Pre-project Weighted Runoff Coefficient

i = Peak Rainfall Intensity (in/hr)

A = Tributary Drainage Area (ac)

Step 3:
Calculate the basin storage volume required:

$$SV_{reqd} = 3630 \times PA[1- (q_o/q_i)]$$

where SV_{reqd} = Storage Volume Required (ft^3)

P = Design Storm Runoff Depth (in)

A = Tributary Drainage Area (ac)

q_o = Peak Flow Rate leaving the Basin (ft^3) from Step 2

q_i = Peak Flow Rate into the Basin (ft^3) from Step 1

Step 4:
Select initial values for the detention basin total width (w_t), total length (l_t), and depth (d) based on space availability, topography, and existing drainage facilities. Also select values for the interior side slope (z) and required freeboard (f). Calculate the basin invert width and invert length:

$$w_b = w_t - 2z(d+f)$$

$$l_b = l_t - 2z(d+f)$$

where w_b = Basin Bottom Width (ft)

l_b = Basin Bottom Length (ft)

w_t = Basin Total Width (ft)

l_t = Basin Total Length (ft)

z = Basin Interior Side Slope (ft/ft)

d = Depth of Flow for Storage Volume (ft)

f = Freeboard (ft)

Step 5:
Calculate the resulting storage volume using the prismoidal formula for trapezoidal basins:

$$SV_{calc} = (w_b l_b d + (w_b+l_b)zd^2 + 4z^2d^3/3$$

where SV_{calc} = Volume of Trapezoidal Basin (ft^3)

w_b = Basin Bottom Width (ft) from Step 4

l_b = Basin Bottom Length (ft) from Step 4

d = Depth of Flow for Storage Volume (ft) from Step 4

z = Basin Interior Side Slope from Step 4

If the dry detention basin is not trapezoidal, SV_{reqd} from Step 3 should be used instead of SV_{calc}.

If the calculated volume of the basin (SV_{calc}) from Step 5 is greater than or equal to the storage volume required (SV_{reqd}) from Step 3, the selected dimensions (w_t and l_t) and depth (d) are adequate for preliminary design. If the SV_{calc} is less than SV_{reqd}, increase the dimensions and/or depth (w_t, l_t, d) and repeat Steps 4 and 5. If the values cannot be increased based on site characteristics and the calculated volume of the basin is still less than the storage volume required, reduce the drainage area (A) and repeat Steps 1 through 5.

Alternatively, a stage-storage curve can be analyzed to check whether the basin has adequate storage. A stage-storage curve defines the relationship between the depth of water and storage volume in a basin. The estimated peak stage occurs for the estimated volume from Step 3 (depth of water for the storage volume required) or at the 100-yr storm event (depending on county requirements). Compare the depth of the basin to the peak stage. If the depth of the basin is less than the peak stage accommodating freeboard, set the depth to maximum allowable value or reduce the drainage area and repeat Steps 1 through 5.

Step 6:
Select the type and size of the outlet structure for both water quality and water quantity control. The outlet structure should be sized to convey the allowable discharge at the stage from Step 3 (depth of water for the storage volume required) and at the stage from 100-yr storm event depending on the project requirements. A stage-discharge curve can provide the discharge that the outlet structure should convey at the peak stages. The outlet structure can be designed as a multi-stage control.

Step 7:
Perform routing calculations using inflow hydrographs to check the preliminary design using a storage routing computer model. If the routed post-development peak discharges from the design storm exceed the pre-development (existing) peak discharges, revise the available storage volume, outlet structure, etc., and return to Step 6.

TC-3 Evaporation Pond

Evaporation ponds are shallow man-made ponds with large surface areas designed to hold a set volume of runoff and allow for evaporation by sunlight and exposure to ambient temperatures, wind, and humidity with no outlet structure. Evaporation ponds are constructed in relatively impervious soils or with a liner to retain stormwater and reduce the risk of contaminants being discharged to the drainage system or receiving waters during a significant storm event exceeding the design capacity. Evaporation ponds can significantly reduce total annual surface runoff volume, stream bank erosion, and other adverse impacts to the drainage system or receiving waters.

In general, DOTA discourages the use of evaporation ponds since the FAA recommends that airports avoid ponds with standing water, which can attract various waterfowl and increase the risk of bird strikes. DOTA should be consulted prior to the implementation of an evaporation pond in a project design.

Evaporation Pond at Kahului Airport
Source: Hawaii DOTA

Design Criteria

Table 1: Minimum Design Criteria and Guidelines

Category	Guidelines
Acceptable Use	• Only use where stormwater infiltration is not allowed due to risk of groundwater contamination, where discharge into the sanitary sewer is prohibited, or where there is potential for chemical spills. • Do not use outlet structure. Consideration should be given to surrounding drainage patterns or additional storage capacity to accommodate larger storm events that exceed design storm.
Discharge Restrictions	Design and maintain to prevent discharge into drainage system, receiving waters, or sanitary sewer.
Drawdown	Only effectively used where evaporation capacity is adequate to drawdown the required quantity of stormwater within 48 hrs. This time allows capacity to be reestablished and reduces potential for unsanitary conditions and vectors associated with stagnant water.
Maximum End Slope (length to unit height)	3:1
Maximum Side Slope (length to unit height)	3:1
Maximum Depth	8 ft
Maximum Drawdown (pond evaporation) Time	48 hrs or less.
Minimum Distance Basin Invert to Groundwater Table	3 ft
Minimum Freeboard	2 ft
Liner	• Typically include liner to prevent infiltration. • May be compacted till, clay, synthetic, or concrete. • If liner is exposed, use material resistant to ozone and UV deterioration. Otherwise, cover with at least 6 in of soil or other suitable material as a protective layer. • Synthetic liner should be polyethylene or rubber with min 40 mils thickness. • Consider geotextile installation under membrane liner. • Pond with membrane liner must include underdrain with leak detection. • Adjoining liner sheets required for larger sized evaporation ponds may be welded in the field. Test seams in accordance with applicable industry standards for quality control.
Anchor Trench	Provide top anchor trenches along liner edge in accordance with manufacturer's recommendations to prevent liner slippage.
Dam Safety	If the embankment falls under the jurisdiction of the State of Hawaii, DLNR Engineering Division, Dam Safety Program, it shall be designed to meet the applicable requirements, or these requirements, whichever are more stringent.

Table 2: Pretreatment Considerations

Pretreatment Options	If significant amounts of sediment or sand are anticipated at the site, design sediment forebays as follows: - Volume equal to at least 5% of WQV. - Provide a separate cell that drains into the main pond and is formed by an acceptable barrier such as earthen berm or gabion baskets. - Locate forebay at each major inlet to provide pretreatment, preserve basin capacity, and reduce maintenance requirements.

LIMITATIONS

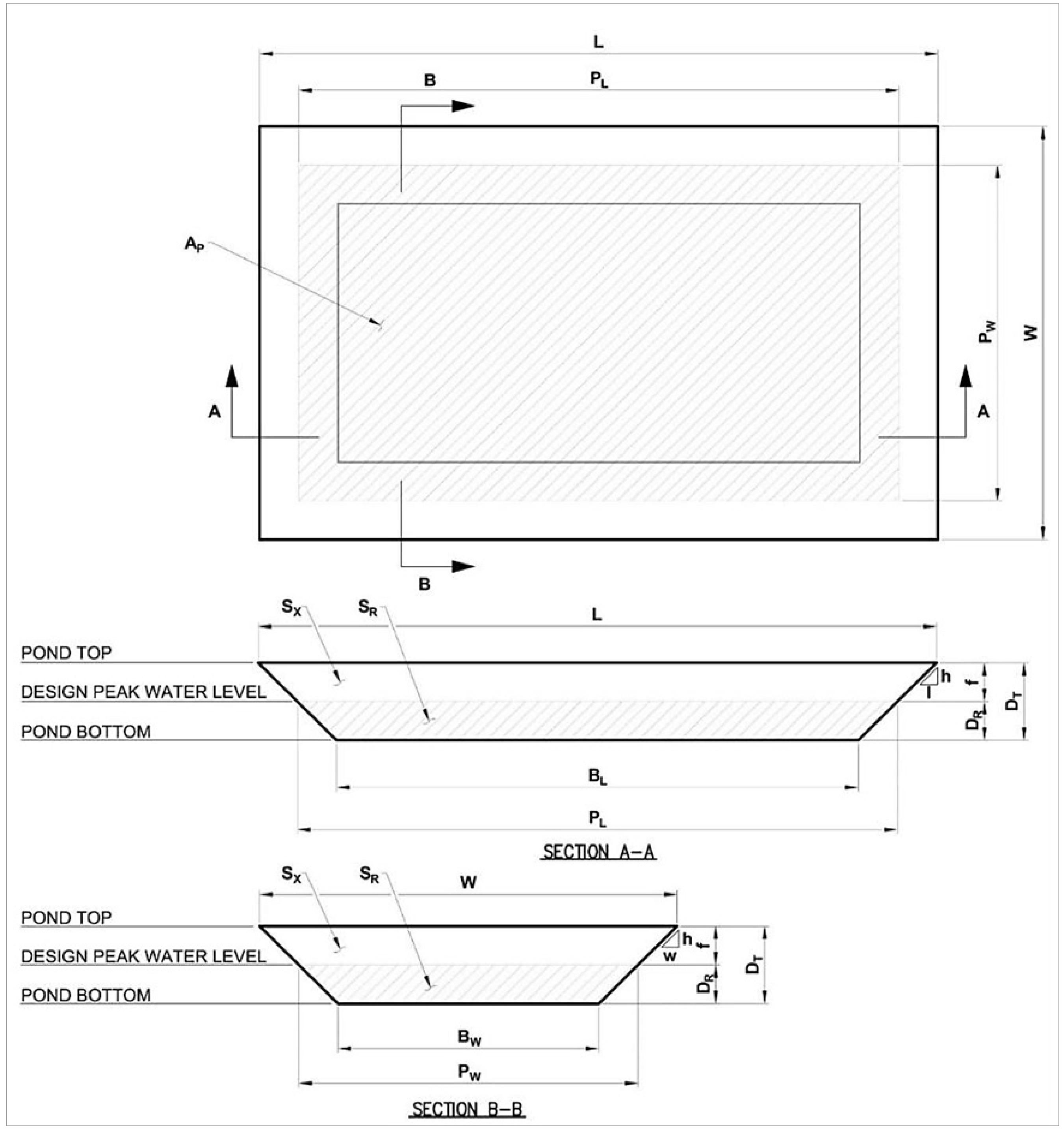
- Limited in areas of airport due to wildlife attraction.
- May be infeasible or impractical if:
  - Ponds with standing water for duration longer than 48 hrs.
  - Invert below seasonal high groundwater table.
  - Located within 20 ft of any building foundation.
  - Located near drinking water wells, septic tanks, drain fields, fill sites, or steep unstable slopes.

Construction Considerations

- Remove sharp objects (e.g., stones) below the liner to prevent punctures.
- Do not allow stormwater to enter the evaporation pond until construction is completed and the contributing drainage area to the basin is adequately stabilized. If this prohibition is not feasible, do not excavate the evaporation pond to the final grade until the contributing drainage area has been stabilized.

Cut Sheet Examples

Disclaimer: The example schematics provided below are intended for visual aid purposes only and not for design purposes. The example schematics are not intended to be used as a design guide for the items, descriptions, and details (depths, etc.). The actual configuration will vary depending on specific site constraints and the design criteria of this fact sheet. Refer to the information provided above for details on the design.



Example Schematic of an Evaporation Pond

Sizing Guidelines

Evaporation ponds must be sized to provide adequate capacity to capture the WQV and surface area to allow evaporation within 48 hrs. The following is a simplified method for determining the approximate size of a trapezoidal evaporation pond. Other design methods or modeling procedures may be used at project proponent's discretion but are subject to approval by DOTA.

Step 1:
Identify the project's nearest reference point and use the corresponding Monthly Rainfall (r) and Monthly Pan Evaporation Rates (E_{pan}) (refer to Section 4.5.3.4 and Appendix II).

Step 2:
Calculate the contributing Tributary Drainage Area (A) to the evaporation pond. Since evaporation ponds do not allow for infiltration, the WQV is based on the total rainfall depth compared to a design storm runoff depth typically used to size other treatment control BMPs.

Step 2a:
Calculate the Tributary Drainage Area (A) that generates runoff to the evaporation pond. The Tributary Drainage Area (A) should also include the pond area.

Step 2b:
Enter the design Freeboard (f).

Step 2c and 2d:
Enter assumed Top Length (L) and Top Width (W) for the Pond Structure based on available space at the site.

Step 2e and 2f:
Enter assumed End Slope (z_e) and Side Slope (z_s) values.

Step 2g:
Calculate the % impervious cover (I) of the Tributary Drainage Area (A). Please note: the evaporation pond surface area should be counted towards the % impervious cover.

Step 2h:
The Pan Evaporation Coefficient (K_p) is a regionally defined parameter (refer to Section 4.5.3.4).

Step 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 (%)

Step 4:
Calculate the dimensions of the pond at freeboard depth.

$$P_L = L - 2z_e f$$

$$P_W = W - 2z_s f$$

where P_L = Design Peak Evaporation Pond Surface Length (ft)

P_W = Design Peak Evaporation Pond Surface Width (ft)

L = Top Length (ft)

W = Top Width (ft)

z_e = End Slope (ft/ft)

z_s = Side Slope (ft/ft)

f = Freeboard (ft)

Step 5:
Perform a month-to-month analysis, starting with January and ending with December, and calculate the monthly WQV based on Monthly Rainfall (r) from Step 1 using the following equation:

$$WQV = 3630 \times rCA$$

where WQV = Monthly Water Quality Design Volume (ft³)

r = Monthly Rainfall (in)

C = Volumetric Runoff Coefficient

A = Tributary Drainage Area (ac)

Calculate the Monthly Evaporation Volume (E) using the Monthly Pan Evaporation Rates (E_{pan}), Evaporation Pan coefficient (K_p), and the Evaporation Pond Surface Area (A_p).

While the Evaporation Pond Surface Area (A_p) depends on the depth of water in the trapezoidal pond, the pond depth is not yet known; therefore, it is initially estimated to be the area of the pond at freeboard depth. Calculate the Evaporation Pond Surface Area (A_p) based on the values for P_L and P_W and then calculate the Monthly Evaporation Volume (E).

$$A_p = P_L P_W / 43{,}560$$

where A_p = Evaporation Pond Surface Area (ac)

P_L = Design Peak Evaporation Pond Surface Length (ft)

P_W = Design Peak Evaporation Pond Surface Width (ft)

$$E = 3630 \times E_{pan} K_p A_p$$

where E = Monthly Evaporation Volume (ft³)

E_{pan} = Monthly Pan Evaporation Rate (in) from Step 1

K_p = Pan Evaporation Coefficient (refer to Section 4.5.3.4)

A_p = Evaporation Pond Surface Area (ac)

After Step 5, repeat Steps 4 and 5 several times for each month to obtain a precise estimate of the Evaporation Pond Surface Area (A_p) through iteration. After the first estimate, subsequent iterations use the following calculation for A_p that involves solving for the Water Depth in the pond at the end of the month (D) and then calculating the Evaporation Pond Surface Area (A_p) at that depth.

$$S_e = \tfrac{1}{6} D \left(l_b w_b + (l_b+2z_e D)(w_b+2z_s D) + 4(l_b+z_e D)(w_b+z_s D)\right) \text{ – SOLVE FOR } D$$

$$A_p = (l_b+2z_e D)(w_b+2z_s D)/43{,}560$$

where S_e = Storage Capacity at the end of the month (ft³)

l_b = Bottom Length (ft)

w_b = Bottom Width (ft)

D = Water Depth in the pond at the end of each month (ft)

z_e = End Slope (ft/ft)

z_s = Side Slope (ft/ft)

A_p = Evaporation Pond Surface Area (ac)

Compare the monthly inflow (WQV) to the Monthly Evaporation Volume (E).

The storage capacity at the beginning of the month (S_b) is the same as the storage capacity at the end of the previous month (S_e). For the first month of the analysis (January), set S_b to 0.

If WQV exceeds E for a given month, add the difference to the storage capacity at the beginning of the month (S_b) and calculate the storage capacity at the end of the month (S_e).

$$S_e = S_b + WQV - E$$

where S_e = Storage Capacity at the end of the month (ft³)

S_b = Storage Capacity at the beginning of the month (ft³)

WQV = Monthly Water Quality Design Volume (ft³)

E = Monthly Evaporation Volume (ft³)

If E exceeds WQV for a given month, subtract the difference from the storage capacity at the beginning of the month (S_b) and calculate the storage capacity at the end of the month (S_e). Continue the for the remaining months until December. If the calculated storage capacity at the end of the month is negative, set S_e to 0.

Step 6:
Calculate the remaining required pond dimensions. Calculate the Required Storage Capacity (S_R) as the maximum computed Storage Capacity at the end of the month (S_e).

$$S_R = MAX(S_e) \text{ for } S_e \text{ from January through December}$$

where S_R = Required Storage Capacity (ft³)

S_e = Storage Capacity at the end of the month (ft³)

Calculate the Required Pond Depth (D_R) as the depth below the freeboard required to contain the Required Storage Capacity (S_R).

$$S_R = \tfrac{1}{6} D_R \left(P_L P_W + (P_L-2z_e D_R)(P_W-2z_s D_R) + 4(P_L-z_e D_R)(P_W-z_s D_R)\right) \text{ - SOLVE FOR } D_R$$

where S_R = Required Storage Capacity (ft³)

D_R = Required Pond Depth (ft)

P_L = Design Peak Evaporation Pond Surface Length (ft)

P_W = Design Peak Evaporation Pond Surface Width (ft)

z_e = End Slope (ft/ft)

z_s = Side Slope (ft/ft)

Calculate the Overall Pond Structure Depth (D_T) as the summation of the Required Depth (D_R) and the Freeboard Depth (f).

$$D_T = D_R + f$$

where D_T = Overall Pond Structure Depth (ft)

D_R = Required Pond Depth (ft)

f = Freeboard Depth (ft) (refer to Section 4.5.3)

Calculate the bottom Length (l_b) and Bottom Width (w_b) of the Pond Structure from the Overall Pond Structure Depth (D_T), Top Length (L), Top Width (W), Side Slope (z_s), and End Slope (z_e).

$$l_b = L - 2z_e D_T$$

$$w_b = W - 2z_s D_T$$

where l_b = Bottom Length (ft)

w_b = Bottom Width (ft)

D_T = Overall Pond Structure Depth (ft)

L = Top Length (ft)

W = Top Width (ft)

z_e = End Slope (ft/ft)

z_s = Side Slope (ft/ft)

Step 7:
Calculate the Maximum Pond Storage Capacity Available (S_A) as the total volume of the overall pond structure based on the Overall Pond Structure Depth (D_T) from Step 6 and the Top Length (L) and Width (W) of the pond structure from Step 2c and 2d.

$$S_A = \tfrac{1}{6} D_T \left(LW + l_b w_b + 4(L-z_e D_T)(W-z_s D_T)\right)$$

where S_A = Maximum Pond Storage Capacity Available (ft³)

D_T = Overall Pond Structure Depth (ft)

L = Top Length (ft)

W = Top Width (ft)

l_b = Bottom Length (ft)

w_b = Bottom Width (ft)

z_e = End Slope (ft/ft)

z_s = Side Slope (ft/ft)

The difference between the Maximum Pond Storage Capacity Available (S_A) and the Required Storage Capacity (S_R) is the amount of Excess Pond Storage Capacity (S_X). The excess capacity provides a factor of safety during larger storm events or periods of lower-than-expected evaporation rates.

$$S_X = S_A - S_R$$

where S_A = Maximum Pond Storage Capacity Available (ft³)

S_R = Required Storage Capacity (ft³)

S_X = Excess Pond Storage Capacity (ft³)

Step 8:
If the Required Depth (D_R) is greater than what is possible with the pond dimensions entered in Step 2, increase the size of the evaporation pond by increasing the Top Length (L) or Top Width (W) and recalculate.

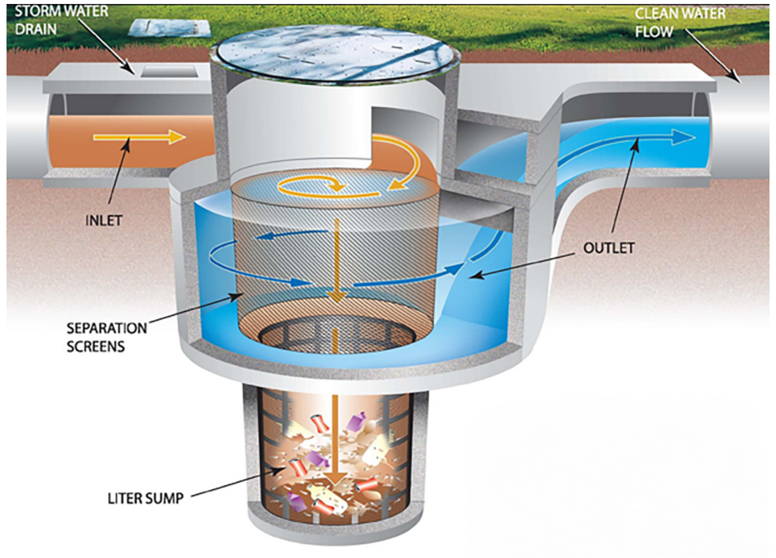
Use the lowest Monthly Pan Evaporation Rate (E_{pan}) to calculate the maximum allowable depth of water that can evaporate in 48 hrs. If the maximum allowable depth is not feasible to design, consider a different PBMP or contact DOTA to discuss modifications.

TC-4 Hydrodynamic Separator Unit

A hydrodynamic separator or HDS unit is also known as a vortex separator, a swirl separator, a swirl concentrator, or a continuous deflective separator unit. Vortex separators are gravity separators and essentially wet vaults. They use a vortex action to separate coarse sediment and floatables (trash, debris, etc.) from stormwater. They are flow-through structures with a settling or separation unit to remove sediments and other pollutants. No outside power source is required because the energy of the flowing water allows the sediments to separate efficiently. Depending on the type of unit, this separation may be achieved using swirl action or indirect filtration.

Continuous deflective hydrodynamic separators use swirl concentration and continuous deflective separation to screen, separate and trap trash, debris, sediment, and hydrocarbons from stormwater runoff. The continuous deflective separator technologies direct solids into the lower catchment chamber and floatables to the surface of the upper chamber using a non-mechanical, non-blocking screen technology.

A multi-stage hydrodynamic separator directs stormwater through a concrete structure that uses baffles to separate and retain sediment.



Vortex Separator
Source: https://lbpost.com/news/city/city-receives-grant-for-coastal-water-filtration-systems/

Design Criteria

Table 1: Minimum Design Criteria and Guidelines

Category	Guidelines
Selection	Select based on documented performance standards that include third party scientific verification of the ability of the HDS to meet the quality and quantity control objectives of the project.
PBMP Footprint Area	Footprint requirements for propriety manufactured treatment devices vary by manufacturer. Follow manufacturer's guidelines for appropriate sizing calculations and selection of appropriate device/model.
Certification	Consider using HDS unit models certified for general use by the Washington State Department of Ecology TAPE or certified by the NJDEP.
Sizing and Minimum Design Criteria	Follow manufacturer's guidelines for design criteria and considerations.
Overflow/Bypass	Incorporate an overflow or bypass for flows exceeding the WQF to a downstream drainage system.
Maintenance Access	Manholes should be included in each chamber for cleaning access.
Oil Separation	HDS units with oil separation may be required in areas with a high risk for spills.

Table 2: Pretreatment Considerations

Pretreatment Options	A treatment train in conjunction with OWS or manufactured treatment devices may be considered if targeting various pollutants.

LIMITATIONS

General

- Some HDS units have standing water that remains between storms and could be a mosquito breeding concern.
- Drainage area served is limited by model size.
- Not effective for removal of dissolved pollutants, fine sediments, and pollutants that adhere to fine sediments.
- Infeasible if bottom is below seasonal high groundwater.
- Unable to operate off-line with bypass and unable to operate in-line with a safe overflow mechanism.

Construction Considerations

Follow manufacturer's recommendations.

Cut Sheet Examples

Product dependent.

TC-5 Drain Inlet Insert

Drain Inlet Inserts are filters designed to remove the trash, sediment, and contaminants such as hydrocarbons and metals from stormwater runoff. A metal frame with a filter screen is the primary method for pollutant removal. A non-leaching absorbent material in a pouch can be placed with the insert to remove hydrocarbons or metals.

Drain Inlet Insert at Maintenance Baseyard (right) and Drain Inlet Insert at Elliott Street Parking Lot (left), Daniel K. Inouye International Airport
Source: Hawaii DOTA

Design Criteria

Table 1: Minimum Design Criteria and Guidelines

Category	Guidelines
Selection	Select based on documented performance standards. They should include third party scientific verification of the ability of the drain inlet insert to meet the quality and quantity control objectives of the project.
Area Requirements	Footprint requirements vary by manufacturer. Follow manufacturer's guidelines for appropriate sizing calculations and selection of appropriate device/model.
Certification	Consider using models certified for general use by the Washington State Department of Ecology TAPE or certified by the NJDEP.
Sizing and Minimum Design Criteria	Follow manufacturer's guidelines for design criteria and considerations.
Overflow/Bypass	Safely overflow or bypass flows exceeding the WQF or WQV to the drainage system.

Table 2: Pretreatment Considerations

Pretreatment Options	No pretreatment required.

LIMITATIONS

- Drainage area served is limited by model size.
- Not effective for removal of dissolved pollutants, fine sediments, and pollutants that adhere to fine sediments.
- Unable to operate off-line and unable to operate in-line with a safe overflow mechanism.
- Requires a flat site and hydraulic gradient to support gravity flow.
- Refer to manufacturer's instructions for specific design constraints and limitations for use.

Construction Considerations

Follow manufacturer's recommendations.

Cut Sheet Examples

Product dependent.

Sizing Guidelines

- Sizing procedures vary by manufacturer.
- Follow the manufacturer's guidelines for appropriate sizing calculations and selection of appropriate device/model.

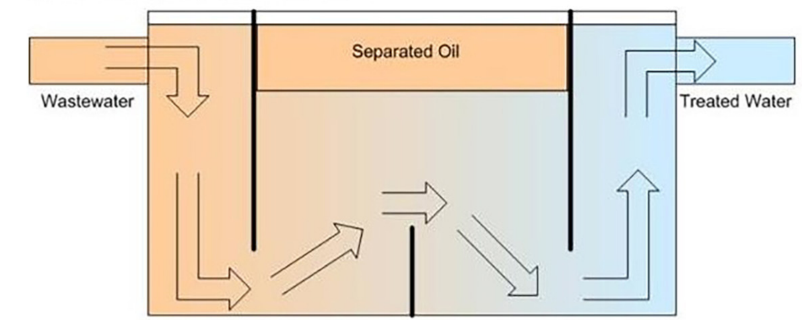
TC-6 Oil Water Separator

OWSs are treatment control devices designed to remove water-insoluble hydrocarbons and settleable solids from stormwater runoff. The primary function of OWSs is to remove oil, water-insoluble hydrocarbons (e.g., jet fuel, gasoline, diesel), floatable debris, and settleable solids. The two commonly used OWSs are the conventional American Petroleum Institute or API separator (also known as the baffle type) and the coalescing plate separator. Both use gravity to remove floating and dispersed oil.

Conventional API OWS have three bays separated by baffles. The efficiency of API OWS depends on detention time in the oil separator bay and on droplet size. These are typically designed to protect from spills.

Coalescing plate OWSs are composed of parallel plates in the separator bay, which improves efficiency by providing more surface area. Coalescing plate OWS need less space to separate oil due to shorter travel distances between the parallel plates. Coalescing plate OWS are typically used for small drainage areas such as fueling stations, maintenance shops, etc.

While OWSs connected to sanitary sewer are not considered PBMPs, they shall be considered for maintenance areas, material storage areas, and washing areas to meet the requirements of the county Pretreatment Programs.



Standard Gravity Oil/Water Separator
Source: https://www.epa.gov/sites/default/files/2014-04/documents/5_owseparators_2014.pdf

Design Criteria

Table 1: Minimum Design Criteria and Guidelines

Category	Guidelines
Selection	Select based on documented performance standards that include third party scientific verification of the ability of the OWS to meet the quality and quantity control objectives of the project.
OWS Components	Includes three compartments: 1. Forebay - designed to trap and collect sediment, support plug flow conditions, and reduce turbulence. 2. Oil Separator Bay - traps and holds oil as it rises from the water column and serves as a secondary sediment collection area. 3. Afterbay - relatively oil-free cell before the outlet and secondary oil separation area.
Installation	• DOTA recommends that OWS be installed off-line when used for stormwater treatment. • Install OWS upstream of any other stormwater treatment PBMPs and any pumps to prevent oil from emulsifying.
Area Requirements	Footprint requirements vary by manufacturer. Follow manufacturer's guidelines for appropriate sizing calculations and selection of appropriate device/model.
Sizing and Minimum Design Criteria	Follow manufacturer's guidelines for design criteria and considerations.
Overflow	Safely overflow or bypass OWS for flows exceeding the WQF or WQV to a downstream drainage system.
Shutoff	Include shutoff mechanism on the outlet pipe to prevent discharges during maintenance or after a spill event.
Piping	• Use storm drain pipes or impervious conveyances for routing oil-contaminated stormwater to the OWS. • Include a submerged inlet pipe with a turned down elbow in the forebay at least 2 ft from the bottom. • Design outlet pipe as a tee, sized to pass the WQF at least 12 in below water surface.
Absorbents or Skimmers	Use in afterbay as needed.
Maintenance Access	Provide maintenance access for each chamber.

Table 2: Pretreatment Considerations

Pretreatment Options	Should be considered if the level of sediment in the inflow would cause clogging or otherwise impair the long-term efficiency of the OWS.

LIMITATIONS

- Some have standing water that remains between storms and could be a mosquito breeding concern.
- Drainage area served is limited by model size.
- May not be effective for removal of dissolved pollutants, fine sediments, and pollutants that adhere to fine sediments.
- The design load rate for OWSs is low, only cost effective to treat nuisance and low flows.
- The low concentrations of oil in stormwater result in considerable performance uncertainty.
- Infeasible if bottom is below seasonal high groundwater.
- Unable to operate off-line and unable to operate in-line with a safe overflow mechanism.
- Requires a flat site and hydraulic gradient to support gravity flow.
- Cannot be used to remove dissolved or emulsified oils such as coolants, soluble lubricants, glycols, and alcohols.
- Refer to manufacturer's instructions for specific design constraints and limitations for use.

Construction Considerations

- Follow manufacturer's recommendations.
- OWS vaults should be watertight. Seal pipes entering and exiting a vault below the water surface using a non-porous, non-shrinking sealant or concrete mastic.

Cut Sheet Examples

Product dependent.

Sizing Guidelines

- Determine the size of separators based on the WQF, treatment flow rate, rise-rate velocity of the oil droplets, and settling rate of solids to be removed. OWS sizing should also consider spill capacity and applicable codes and regulations.

- The following forebay design criteria should be followed:
  - To collect floatables and settleable solids, design the surface area of the forebay (the first bay) at ≥ 20 ft^2 per 10,000 ft^2 of the area draining to the OWS.
  - The length of the forebay should be 1/3 to 1/2 of the length of all three bays combined. Include roughing screens for the forebay or upstream of the OWS to remove debris, if needed.
  - Screen openings should be approximately ¾ in.

- The following baffle design criteria should be followed:
  - Oil retaining baffles (top baffles) should be located at least at 1/4 of the length of all three bays from the outlet and should extend down at least 50% of the water depth and at least 1 ft from the OWS bottom.
  - The baffle height to water depth ratios should be 0.85 for top baffles and 0.15 for bottom baffles.

- General sizing guidelines for API OWSs include the following:
  - Horizontal velocity: 3 ft/min.
  - Depth of 3 to 8 ft.
  - Depth-to-width ratio of 0.30 to 0.50.
  - Width of 6 to 16 ft.
  - Baffle height-to-depth ratios of 0.85 for top baffles and 0.15 for bottom baffles.

- Coalescing plate OWSs sizing is more complex; sizing calculations require information such as packing plate surface areas and plate angles.

- Follow the 2019 Stormwater Management Manual for Western Washington sizing criteria for API and coalescing plate OWS sizing. Alternatively, follow manufacturer's guidelines for appropriate sizing calculations and selection of appropriate device/model.

TC-7
Sand Filter

A sand filter is a basin or chambered structure that captures, temporarily stores, and treats stormwater runoff by passing it through sand, organic matter, soil, or other media. Sand filter design can include a surface sand filter, perimeter sand filter, and underground sand filter. Wildlife deterrence should be a top priority to prevent sand filters from posing a safety hazard to aircraft.

A surface sand filter is a ground-level open-air structure that consists of a pretreatment sediment forebay and a filter bed chamber. Surface sand filters can treat the largest drainage area of all the sand filtering systems. A perimeter sand filter is an enclosed filter system typically constructed just below grade in a vault along the edge of an impervious area such as a parking lot. Perimeter sand filters are most practical for small sites with flat terrain. An underground sand filter is similar to a surface sand filter, but the sand layer and underdrains are installed below grade in a vault. An underground sand filter is an option when space is limited.

Oak Manor Surface Sand Filter, Maryland
Source: Montgomery County, Maryland

Design Criteria

Table 1: Minimum Design Criteria and Guidelines

Category	Guidelines
PBMP Footprint Area	1.5-3% of contributing impervious area.
Maximum Drainage Area	• 10 ac for surface sand filter. • 2 ac for perimeter sand filter.
Sand Coefficient of Permeability	3.5 ft/day
Filter Media Depth	18 in
Maximum Ponding Depth	12 in
Maximum Interior Side Slope if Earthen	3:1
Maximum Drawdown (drain) Time	48 hrs
Minimum Underdrain Diameter	6 in
Elevation Drop	Require elevation drop or head - approximately 5-8 ft.
Minimum Separation Between Bottom of Filter and Seasonal High Groundwater	2 ft
Two-chamber Design	Usually designed with two chambers: first for large particle settling, second as a filter bed with sand or other filter media for finer particles and pollutants.
Underdrain	• Perforated pipe system in gravel bed installed at bottom of filter to collect and remove filtered runoff. • Tie cleanout pipe into end of all underdrain pipe runs.
Filter Fabric	Place permeable filter fabric between the gravel bed and the filter media.
Flow Splitter	Use flow splitter, or structure that bypasses larger flows to a downstream drainage system or stabilized channel during larger storms.
Erosion Control	Install flow spreader at inlet along one side to distribute incoming runoff across filter evenly and prevent erosion.
Underground Sand Filters	• Construct underground sand filters with gate valve just above top of filter bed for dewatering if clogging occurs. • Protect from trash accumulation with wide mesh geotextile screen placed on surface of sand bed. Remove, clean, and reinstall screen during maintenance.
Pretreatment	Incorporate pretreatment to reduce sediment load entering the sand bed, prevent clogging, and provide filter longevity.

Table 2: Pretreatment Considerations

Pretreatment Options	• Vegetated swales, vegetated buffer strips, sedimentation basins, forebays, sedimentation manholes, manufactured treatment devices, or a sedimentation chamber that preceded the filter bed. • Provide at least 25% of WQV. • Typical method is sedimentation basin with l:w ratio of 2:1 sized using the Camp-Hazen equation.

LIMITATIONS

- Requires a flat site and hydraulic gradient to support gravity flow.
- Cannot be installed within the AOA.
- May be infeasible or impractical if:
  - Bottom is below seasonal high groundwater.
  - Unable to operate off-line and unable to operate in-line with a safe overflow mechanism.

Construction Considerations

GENERAL

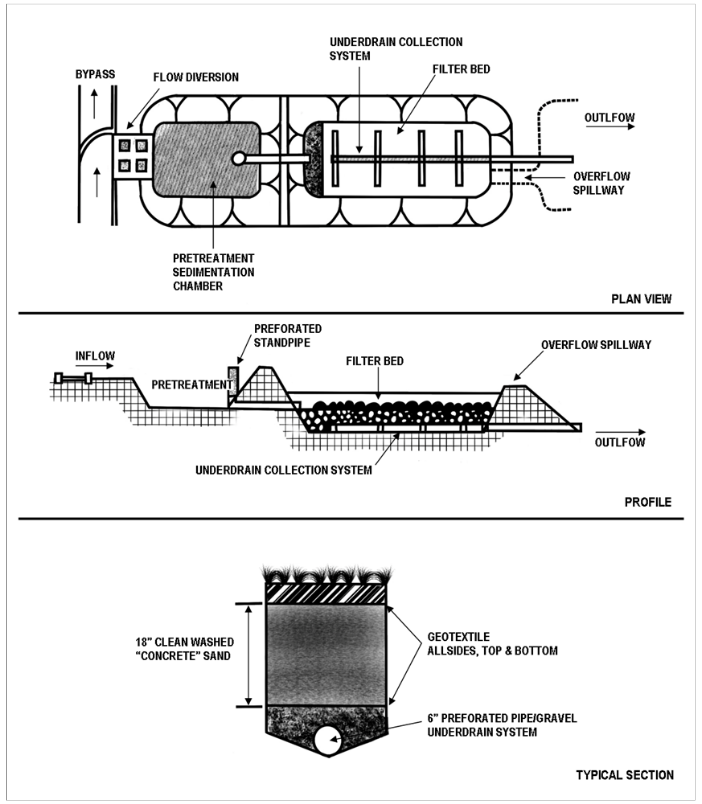
- The tributary area should be completely stabilized before media is installed to prevent premature clogging.
- Level placement of the sand is necessary to avoid the formation of voids within the sand filter that could lead to short-circuiting (particularly around penetrations for underdrain cleanouts) and prevent damage to the underlying geomembranes and underdrain system.
- Avoid over-compaction to provide adequate filtration capacity. Place sand with a low ground pressure bulldozer. After the sand layer is placed, flood the sand with 10-15 gal of water per ft^3 of sand, to provide water settling. Avoid driving heavy equipment on the sand filter to prevent compaction and rut formation.
- The surface of the filter bed is to be level.
- All underground sand filters should be delineated with signs to be located nearby that include when maintenance is due.

UNDERDRAINS

- Place underdrains on a 3-ft-wide section of permeable filter fabric and cover with gravel. The ends of underdrain pipes not terminating in an observation well should be capped.
- The main collector pipe for underdrain systems should be constructed at a minimum slope of 0.5 %.
- Observation wells or cleanout pipes should be provided (1 minimum per every 1,000 ft^2 of surface area).

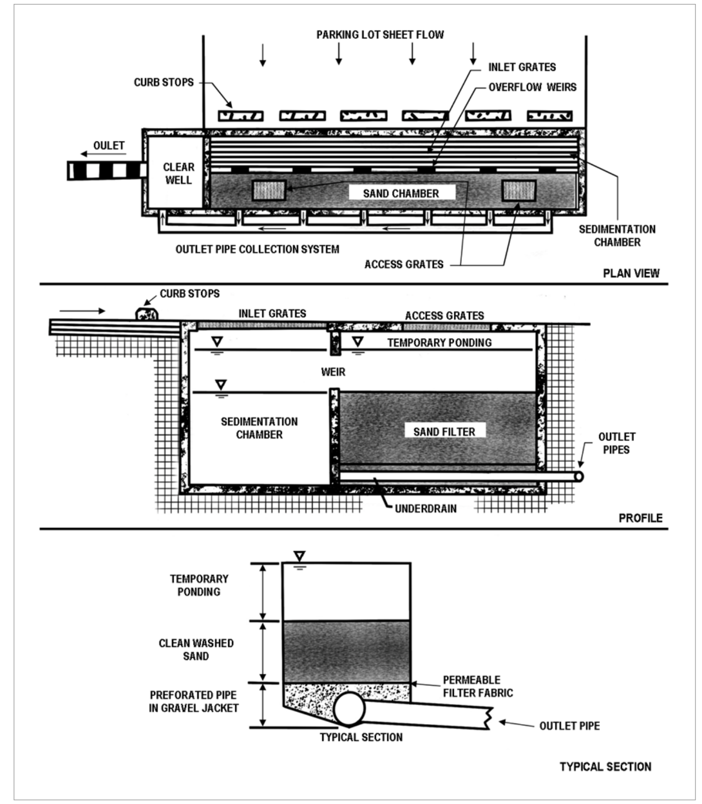
Cut Sheet Examples

Disclaimer: The example schematics provided below are intended for visual aid purposes only and not for design purposes. The example schematics are not intended to be used as a design guide for the items, descriptions, and details (depths, etc.). The actual configuration will vary depending on specific site constraints and the design criteria of this fact sheet. Refer to the information provided above for details on the design.



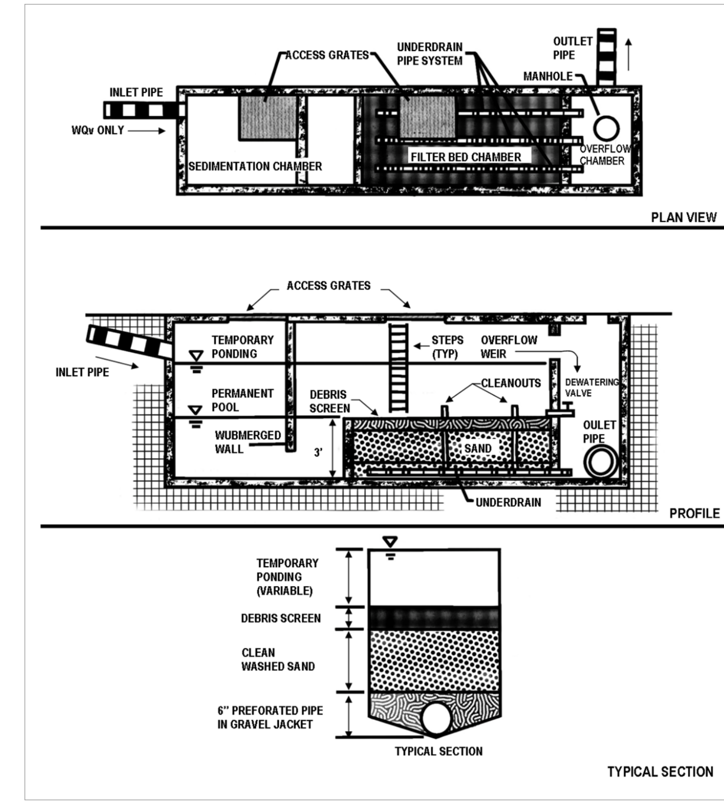
Example Schematic of a Surface Sand Filter

Source: Center for Watershed Protection and the Maryland Department of the Environment, 2000 Maryland Stormwater Design Manual Volumes I & II, revised May 2009. The source schematic was modified to remove design details that are not consistent with this Fact Sheet.



Example Schematic of a Perimeter Sand Filter

Source: Center for Watershed Protection and the Maryland Department of the Environment, 2000 Maryland Stormwater Design Manual Volumes I & II, revised May 2009. The source schematic was modified to remove design details that are not consistent with this Fact Sheet.



Example Schematic of an Underground Sand Filter

Source: Center for Watershed Protection and the Maryland Department of the Environment, 2000 Maryland Stormwater Design Manual Volumes I & II, revised May 2009. The source schematic was modified to remove design details that are not consistent with this Fact Sheet.

Sizing Guidelines

Step 1:
Use the procedure below to compute the volumetric runoff coefficient and WQV. The C should be calculated 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 (%)

The WQV is calculated using the following equation:

$WQV = PCA \times 3630$

where WQV = Water Quality Design Volume (ft³)

P = Design Storm Runoff Depth (in) (refer to Section 4.5.3.1)

C = Volumetric Runoff Coefficient

A = Tributary Drainage Area (ac)

Step 2:
Select sand filter depth (l_m) and maximum ponding depth (d_p). Use Darcy's Law to calculate the required sand filter bed surface area (A_{fb}):

$A_{fb} = (WQV \times l_s)/[k_s(l_s + d_p/24)(t/24)]$

where A_{fb} = Filter Bed Surface Area (ft²)

WQV = WQV from Step 1 (ft³)

l_s = Sand Filter Depth from Step 2 (ft)

k_s = Sand Coefficient of Permeability (ft/day) (refer to Section 4.5.3.6)

d_p = Maximum Ponding Depth from Step 2 (in)

t = Filter Bed Drain Time (hr) (refer to Section 4.5.3.5)

Step 3:
Select a filter bed width (w_b), and calculate the filter bed length (l_b):

$l_b = A_b / w_b$

where l_b = Filter Bed Length (ft)

A_b = Filter Bed Surface Area from Step 3 (ft²)

w_b = Filter Bed Width (ft)

Step 4:
Select the side slope (z) and freeboard (f). Calculate the total area occupied by the PBMP (A_{PBMP}) using the filter bed interior side slopes and assuming a rectangular basin:

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

where A_{PBMP} = Area Occupied by PBMP Excluding Pretreatment (ft²)

w_b = Filter Bed Width (ft)

z = Filter Bed Interior Side Slope (length per unit height)

d_p = Maximum Ponding Depth from Step 2 (ft)

f = Freeboard (ft)

l_b = Filter Bed Length from Step 3 (ft)

If the calculated area does not fit in the available space, either reduce the drainage area, increase the ponding depth, or increase the interior side slope (if it's not already set to the maximum) and repeat the calculations.

TC-8 Subsurface Detention

Subsurface detention PBMPs are underground structures that temporarily detain stormwater then release it to the drainage system. They are suitable on sites where infiltration is infeasible and space constraints prevent the use of surface-level PBMPs.

Subsurface detention storage is identified in the following categories:

- Underground storage vaults: buried concrete, fiberglass, or polyethylene chambers.
- Underground stone storage: buried stone beds wrapped in geotextile fabric.
- Underground pipe and chamber storage: perforated plastic or metal pipes or pipe-like linear chambers, placed in a stone bed to provide more storage per unit.
- Underground plastic grid storage: buried plastic structures stacked and inter-connected to form various shapes and sizes.

The pollutant removal performance may vary depending on the type and model of the proprietary subsurface detention PBMP selected for the project. Therefore, project proponents need to review the manufacturer's specifications to determine pollutants targeted for removal.

Subsurface Detention Installation, Philadelphia
Source: Philadelphia Stormwater Management Guidance Manual, Version 3.2

Design Criteria

Table 1: Minimum Design Criteria and Guidelines

Category	Guidelines
Selection	Select based on documented performance standards that include third party scientific verification of the ability of the PBMP to meet the quality and quantity control objectives of the project.
Maximum Drainage Area	25 ac per single underground detention vault.
Certification	Consider using models certified for general use by the Washington State Department of Ecology TAPE or certified by the NJDEP.
Sizing and Minimum Design Criteria	Follow manufacturer's guidelines for design criteria and considerations.
Location	Can be located beneath landscaped areas, parking lots, buildings, or other impervious area where space allows.
Structural Requirements	Must meet structural requirements for overburden support and traffic loading.
Storage	Routing calculations must be used to demonstrate that the storage volume is adequate.
Maximum Drawdown (drain) Time	72 hrs after 24-hr storm event.
Erosion Control	Provide an energy dissipator (e.g., riprap, plunge pool, splash pads, etc.) at the end of the outlet to prevent scouring and erosion.
Flood Protection Controls	Design as final controls for on-site stormwater for peak discharges.
Overflow/Bypass	• Include an overflow structure and/or high-flow bypass to address significant rainfall, outlet structure blockage, or mechanical failure. • Safely overflow or bypass flows exceeding the WQF or WQV to a downstream drainage system. • Locate so high-flow discharges will not adversely impact downstream structures.
Maintenance Access	• Provide adequate maintenance access over each chamber, inlet pipe, and outflow structure. • Access openings can consist of standard frame, grate, and solid cover, or removable panel.

Table 2: Pretreatment Considerations

Pretreatment Options	• Consider if level of sediment in inflow would cause clogging or impair long-term efficiency. • Provide a separate sediment sump or vault chamber sized to 0.10 in per impervious ac of contributing drainage area at inlet for underground detention systems that are in a treatment train with off-line water quality treatment structural controls.

LIMITATIONS

- Some models have standing water that remains between storms and could be a mosquito breeding concern.
- Requires a flat site and hydraulic gradient to support gravity flow.
- May infeasible or impractical if:
  - Bottom is below seasonal high groundwater.
  - Unable to operate off-line and unable to operate in-line with a safe overflow mechanism.
  - Located within 20 ft of any building foundation.
  - Located within 35 ft of a drinking water well.
  - Unstable surrounding soil stratum and solids with clay content > 25%.
  - Slopes > 20%.
- Bottom and sides must be impermeable on sites with a documented concern that there is a potential for soil pollutants, groundwater pollutants, or pollutants associated with industrial activities to be mobilized.

Construction Considerations

- Follow manufacturer's recommendations.
- Construct subsurface detention vaults and components to be watertight. Seal pipes entering and exiting a vault below the design water surface using a sealant or concrete mastic.
- All construction joints must be provided with water stops.
- Cast-in-place wall sections must be designed as retaining walls.

Sizing Guidelines

Follow the manufacturer's guidelines for appropriate sizing calculations and selection of appropriate device/model.

Cut Sheet Examples

Product dependent.

APPENDIX VI
PBMP O&M
FACT SHEETS

The following lists the O&M Fact Sheets for LID and Treatment Control PBMPs (named with corresponding design fact sheets):

- LC-1: Biofilter
- LC-2: Bioretention
- LC-3: Bioswale
- LC-4: Harvesting/Reuse
- LC-5: Dry Well/Drainage Well
- LC-6: Infiltration Basin
- LC-7: Infiltration Trench
- LC-8: Permeable Pavement
- LC-9: Subsurface Infiltration
- LC-10: Vegetated Buffer Strip
- LC-11: Vegetated Swale

- TC-1: Alternative Wetland
- TC-2: Dry Detention Basin
- TC-3: Evaporation Pond
- TC-4: Hydrodynamic Separator Unit
- TC-5: Drain Inlet Insert
- TC-6: Oil Water Separator
- TC-7: Sand Filter
- TC-8: Subsurface Detention

Note that Operational O&M recommendations for Source Control PBMPs can be found in the Best Management Practice (BMP) Field Manual for Operations at State of Hawaii Airports.[12]

The following information is provided for each of the above-listed O&M Fact Sheets:

- PBMP Name
- Inspection procedures
- Conditions that warrant maintenance
- Maintenance procedures

Refer to Appendices III and IV for the corresponding PBMP Design Fact Sheets.

[12] https://hidot.hawaii.gov/airports/doing-business/engineering/environmental/tenant-bmp-field-manual/

LC-1 Biofilter

Biofilters detain and filter runoff through internal media and return treated runoff to the storm drainage system (e.g., vegetated biofilter) or detain and treat runoff by infiltrating into the underlying soil (e.g., stormwater curb extension, tree box, planter box, etc.). Regular inspections and maintenance are needed to verify flow is unobstructed, vegetation is healthy, erosion is prevented, soils are biologically active, and the system is functioning properly.

Refer to the manufacturer's inspection and maintenance requirements for additional information on maintaining Tree Box Filters and Planter Boxes.

Vegetated Biofilter
Source: https://www.sfbetterstreets.org/find-project-types/greening-and-stormwater-management/stormwater-overview/bioretention-rain-gardens/

Operations & Maintenance

Category	Inspections	Conditions that Require Maintenance	Maintenance
Sediment and Debris	Inspect surface drainage systems, flow entrances, pretreatment measures, stormwater curb extensions for sediment, trash, debris, and leaf accumulation.	Accumulation of sediment, trash, debris, and leaves.	• Remove accumulated sediment, trash, debris, and leaves. • Remove vegetation clippings and leaves. • If excessive sediment is deposited, immediately determine the source, remove sediment deposits, and correct the problem. • Remove trash and debris from the drainage system leading to and within biofilters.
Standing Water/ Clogging	• Inspect for standing water after inflow has ceased. • Monitor observation wells, if present, to determine how quickly the system is draining after a storm and the condition of the filter media.	Standing water suggests blockages may be present, infiltration rate might be reduced by compaction, media layer may be clogged, or the underdrain/permeable filter fabric may be clogged.	• Clear the outlet of sediment or trash blockages, remove the top layer of material, and replace with fresh material. • If standing water persists, the media layer, underdrain, or permeable filter fabric may be clogged; unclog or replace components as necessary.
Erosion	• Inspect inlets, outlets, side slopes, and flow paths for evidence of undercutting or erosion. • Note erosion locations or drainage changes.	• Significant erosion observed. • Changes to the drainage pattern.	• Stabilize eroded areas, replace dead vegetation, repair erosion, and replenish mulch. • Re-grade to reshape the cross-section as sediment collects and form pools. • Remove and properly dispose of the sediment.
Landscaping	Note landscaping needs (grass cutting, vegetation pruning, etc.).	• Significantly overgrown areas that require landscape maintenance. • Dead or diseased vegetation (some vegetation can be dormant during dry seasons).	• Conduct regular plant maintenance including mowing, pruning, and weeding. • Replace dead and diseased vegetation. • Irrigation may be required during prolonged dry periods. • Avoid or minimize fertilizer and herbicide use.
Irrigation System	Inspect for proper operation and water distribution.	System not functioning correctly (overwatering, over spraying, underwatering) or not functioning at all.	• Turn water off and depressurize the irrigation system immediately upon identifying a waterline break. • Repair broken sprinkler heads and lines.
Water Quality	• Observe runoff entering the PBMP, if present, and identify its origin, if visible. • Observe outflow from the system, if present and visible. • Observe standing water, if present.	Water is significantly dirty/discolored, contains foul odors, or has an oily sheen.	Inspect areas upstream to identify the source and attempt to eliminate.
Damage/Repairs	Inspect surfaces and structures (e.g., curbs, tree box filters, planter boxes, etc.) for damage by rodents, vehicles, etc.	Structural or curb damage or obstructions are present.	• Repair curb damage or other structural damage. • Clear obstructions.
Scheduling	Inspect regularly and after significant rain events.	See above.	• Schedule long-term repairs before the rainy season. • Maintenance should be conducted during dry weather when no flow is entering the PBMP.

LC-2 Bioretention

Bioretention is an engineered excavated facility that collects and filters stormwater runoff using specialized soil media and planting. It captures the water quality volume; passes it through layers of sand, organic matter, soil, or other media; and infiltrates it into native soils. Regular inspections and maintenance are needed to verify flow is unobstructed, maintain healthy vegetation, prevent erosion, verify soils are biologically active, and verify the system is functioning properly.

Bioretention
Source: https://www.epa.gov/system/files/documents/2021-11/bmp-bioretention-rain-gardens.pdf

Operations & Maintenance

Category	Inspections	Conditions that Require Maintenance	Maintenance
Sediment and Debris	Inspect surface drainage systems, flow entrances, and pretreatment measures for sediment, trash, debris, and, leaf accumulation.	Accumulation of sediment, trash, debris, and leaves.	• Remove vegetation clippings and leaves. • Remove accumulated sediment, trash, debris, and leaves. • If excessive sediment is deposited in the biofilter, immediately determine the source, remove sediment deposits, and correct the problem. • Remove trash and debris from the drainage system leading to and within bioretention.
Standing Water/ Clogging	• Inspect for standing water that does not drain after 48 hrs of a storm event. • Monitor observation wells, if present, to determine how quickly the system is draining after a storm and the condition of the filter media.	If standing water remains for longer than 48 hrs, sediment or trash blockages may be present, soil infiltration rate may have been reduced due to compaction, media layer may be clogged, or the permeable filter fabric may be clogged.	• Clear the outlet and bioretention surface of sediment or trash blockages and remove the top layer of material to replace with fresh material. • If standing water persists, the media layer or permeable filter fabric may be clogged; unclog or replace components as necessary.
Erosion	• Inspect inlets, outlets, side slopes, and flow paths for evidence of undercutting or erosion. • Note erosion locations or drainage changes.	• Significant erosion observed. • Changes to the drainage pattern.	• Stabilize eroded areas, replace dead vegetation, repair erosion, and replenish mulch. • Re-grade to reshape the cross-section as sediment collects and form pools. • Remove and properly dispose of the sediment.
Landscaping	Note landscaping needs (grass cutting, vegetation pruning, etc.).	• Significantly overgrown areas that require landscape maintenance. • Dead or diseased vegetation (some vegetation can be dormant during dry seasons).	• Conduct regular plant maintenance including mowing, pruning, and weeding. • Replace dead and diseased vegetation. • Irrigation may be required during prolonged dry periods. • Avoid or minimize fertilizer and herbicide use.
Irrigation System	Inspect for proper operation and water distribution.	System not functioning correctly (overwatering, underwatering or not functioning at all).	• Turn water off and depressurize the irrigation system immediately upon identifying a waterline break. • Repair broken sprinkler heads and lines.
Water Quality	• Observe runoff entering the PBMP, if present, and identify its origin, if visible. • Observe outflow from the system, if present and visible. • Observe standing water, if present.	Water is significantly dirty/discolored, contains foul odors, or has an oily sheen.	Inspect areas upstream to identify the source and attempt to eliminate.
Damage/Repairs	Inspect surfaces for damage caused by rodents, vehicles, etc.	Structural damage or obstructions are present.	• Repair structural damage. • Clear obstructions.
Scheduling	Inspect regularly and 48 hours after significant rain events.	See above.	• Schedule long-term repairs before the rainy season. • Maintenance should be conducted during dry weather when no flow is entering the PBMP.

LC-3 Bioswale

Bioswales are vegetated open channels designed and constructed to capture and treat stormwater runoff within dry or wet cells formed by check dams or other means. Regular inspections and maintenance are needed to verify flow is unobstructed, vegetation is healthy, erosion is prevented, soils are biologically active, and the system is functioning properly.

Bioswale at Terminal 3 Parking Lot
Source: Hawaii DOTA

Operations & Maintenance

Category	Inspections	Conditions that Require Maintenance	Maintenance
Sediment and Debris	Inspect surface drainage systems, flow entrances, and pretreatment measures for sediment, trash, debris, and leaf accumulation.	Accumulation of sediment, trash, debris, and leaves.	• Remove accumulated sediment, trash, debris, and leaves. • If excessive sediment is deposited, immediately determine the source, remove sediment deposits, and correct the problem. • Remove trash and debris from the drainage system leading to and within bioswale.
Standing Water/ Clogging	• Inspect for standing water after inflow has ceased. • Monitor observation wells, if present, to determine how quickly the system is draining after a storm.	Standing water suggests sediment or trash blockages may be present, soil infiltration rate may have been reduced due to compaction, media layer may be clogged, the underdrain/permeable filter fabric may be clogged, or the bottom needs regrading.	• Clear the outlet and surface of sediment or trash blockages and remove the top layer of material to replace with fresh material. • If standing water persists, the media layer, underdrain, or permeable filter fabric may be clogged or the bottom may need to be regraded; unclog/ replace components or regrade to surface match the design geometry and revegetate, as necessary.
Erosion	• Inspect inlets, outlets, side slopes, and flow paths for evidence of undercutting or erosion. • Note erosion locations or drainage changes.	• Significant erosion observed. • Changes to the drainage pattern.	• Stabilize undercuts and eroded areas at the inflow, outflow, and check dam structures. • Re-grade to reshape the cross-section as sediment collects and form pools. • Remove and properly dispose of the sediment.
Landscaping	Note landscaping needs (e.g., grass cutting).	• Significantly overgrown areas that require landscape maintenance. • Grass coverage is less than 90%. • Dead or diseased vegetation (some vegetation can be dormant during dry seasons).	• Conduct regular plant maintenance including mowing and weeding; grass should maintain a height of at least 3 in. • Replace dead and diseased vegetation. • Irrigation may be required during prolonged dry periods. • Avoid or minimize fertilizer and herbicide use.
Irrigation System	Inspect for proper operation and water distribution.	System not functioning correctly (overwatering, underwatering or not functioning at all).	• Turn water off and depressurize the irrigation system immediately upon identifying a waterline break. • Repair broken sprinkler heads and lines.
Water Quality	• Observe runoff entering the PBMP, if present, and identify its origin, if visible. • Observe outflow from the system, if present and visible. • Observe standing water, if present.	Water is significantly dirty/discolored, contains foul odors, or has an oily sheen.	Inspect areas upstream to identify the source and attempt to eliminate.
Damage/Repairs	Inspect surfaces for damage caused by rodents, vehicles, etc.	Structural damage or obstructions are present.	• Repair structural damage. • Clear obstructions.
Scheduling	Inspect regularly and after significant rain events.	See above.	• Schedule long-term repairs before the rainy season. • Maintenance should be conducted during dry weather when no flow is entering the PBMP.

LC-4 Harvesting/Reuse

Harvesting/reuse is the collection and temporary storage of roof runoff in rain barrels or cisterns for subsequent non-potable use, including landscape irrigation or vehicle washing. Regular inspections and maintenance are needed to prevent sediment build-up and clogging, which reduces the capacity of the system.

Cistern, Maui
Source: Sea Grant, University of Hawaii

Operations & Maintenance

Category	Inspections	Conditions that Require Maintenance	Maintenance
Sediment and Debris	Inspect filters, screens, gutters, downspouts, first flush devices, roof washers, cisterns, rain barrels, and flow entrances for sediment, trash, debris, and leaf accumulation.	Accumulation of sediment, trash, debris, and leaves.	Remove accumulated sediment, trash, debris, and leaves.
Clogging	• Inspect first flush devices, diverter valves, inlets, and outlets for clogging. • Monitor observation wells, if present, to determine how quickly the system is draining after a storm.	• First flush devices are clogged, or diverter valves need cleaning. • Outlet is clogged. • Inlet or conveyance to cistern/rain barrel is clogged.	• If the cisterns/rain barrels are not draining completely within 48 hrs of a rain event, unclog the outlet. • If after unclogging the system continues to drain slowly or not at all, flush the system, clean inside surfaces thoroughly, and disinfect. • Clear obstructions at the first flush devices and diverter valves.
Water Quality	• Observe runoff entering the PBMP, if present, and identify its origin, if visible. • Observe outflow from the system, if present and visible. • Observe water in rain barrel or cistern, if present.	Water is significantly dirty/discolored or contains foul odors.	Inspect areas upstream to identify the source and attempt to eliminate.
Irrigation System	Inspect irrigation system, if connected to the rain barrel or cistern.	System not functioning correctly (overwatering, underwatering or not functioning at all).	• Turn water off and depressurize the irrigation system immediately upon identifying a waterline break. • Repair broken sprinkler heads and lines.
Damage/Repairs	• Inspect for water leaking from the system outlet, allowing excessive flows. • Verify collection systems are functioning and operational.	• Cistern/rain barrel has structural damage. • Cistern/rain barrel leaks or outlets are allowing excessive flows. • Collection system not working as intended.	Repair leaks and structural damage.
Scheduling	Inspect regularly and after significant rain events.	See above.	• Schedule long-term repairs before the rainy season. • Maintenance should be conducted during dry weather when no flow is entering the PBMP.

LC-5 Dry Well/ Drainage Well

A drainage well, also known as a dry well, is a subsurface aggregate-filled or prefabricated perforated storage facility, where stormwater runoff is stored and infiltrates into the ground. Strict adherence to regular inspections and maintenance are needed to prevent sediment buildup and clogging, which reduces the capacity of the system.

Dry Well
Source: California Office of Environmental Health Hazard Assessment

Operations & Maintenance

Category	Inspections	Conditions that Require Maintenance	Maintenance
Sediment and Debris	Inspect surface drainage systems, flow entrances, and pretreatment measures for sediment, trash, debris, and leaf accumulation.	Accumulation of sediment, trash, debris, and leaves.	• Remove accumulated sediment, trash, debris, and leaves from the drainage system leading to and within dry wells/drainage wells. • Sediment removal may need to be accomplished with a vacuum truck or a similar process. • If excessive sediment is deposited, immediately determine the source, remove sediment deposits, and correct the problem.
Standing Water/ Clogging	Inspect for standing water in the drainage well that does not drain after 48 hrs.	Standing water remaining for longer than 48 hrs suggests the sediment or trash blockages may be present or soil infiltration rate may have been reduced.	• Clear flow entrances, pretreatment measures, and the bottom of the system of sediment or trash blockages. • If standing water persists, replace the system and surrounding gravel.
Erosion	• Inspect flow paths for evidence of undercutting or erosion. • Note erosion locations or drainage changes.	• Significant erosion observed. • Changes to the drainage pattern.	Stabilize eroded surrounding areas and repair erosion.
Water Quality	• Observe runoff entering the PBMP, if present, and identify its origin, if visible. • Observe water in the well, if visible.	• Water is significantly dirty/discolored, contains foul odors, or has an oily sheen. • Significant or foul odors emanating from the well.	Inspect areas upstream to identify the source and attempt to eliminate.
Damage/Repairs	• Inspect for structural damage and obstructions. • Inspect surrounding area for waterlogged solids.	• Structural damage or obstructions are observed. • Surrounding areas are waterlogged, indicating well failure.	• Repair structural damage. • Clear obstructions.
Scheduling	Inspect regularly and 48 hours after significant rain events.	See above.	• Schedule long-term repairs before the rainy season. • Maintenance should be conducted during dry weather when no flow is entering the PBMP. • Strict adherence to a regularly scheduled maintenance frequency may be needed to reduce the risk of clogging.

LC-6 Infiltration Basin

An infiltration basin is an engineered shallow impoundment facility that collects and stores stormwater runoff, passes it through permeable soils, and infiltrates it through the basin bottom into native soils. Regular inspections and maintenance are needed to prevent sediment buildup and clogging, which reduces the capacity of the system.

Infiltration Basin, Kahului Airport
Source: Hawaii DOTA

Operations & Maintenance

Category	Inspections	Conditions that Require Maintenance	Maintenance
Sediment and Debris	Inspect surface drainage systems, flow entrances, and pretreatment measures for sediment, trash, debris, and leaf accumulation.	Accumulation of sediment, trash, debris, and leaves.	• Remove vegetation clippings and leaves. • Remove accumulated sediment, trash, debris, and leaves. • If excessive sediment is deposited in the infiltration basin, immediately determine the source, remove sediment deposits, and correct the problem. • Remove trash and debris from the drainage system leading to and within the infiltration basin.
Standing Water/ Clogging	• Inspect for standing water that does not drain after 48 hrs. • Monitor observation wells, if present, to determine how quickly the system is draining after a storm.	Standing water remaining for longer than 48 hrs suggests sediment or trash blockages may be present, soil infiltration rate may have been reduced due to compaction, or media layer may be clogged.	• Clear the outlet of sediment or trash blockages and remove the top layer of material to replace it with fresh material. • If standing water persists, the media or permeable filter fabric may be clogged; unclog or replace components as necessary.
Erosion	• Inspect inlets, outlets, side slopes, for evidence of undercutting or erosion. • Note erosion locations or drainage changes.	• Significant erosion observed. • Changes to the drainage pattern.	• Stabilize undercuts and eroded areas at the inflow, outflow, overflow structures and embankments. • Re-grade to reshape the cross-section as sediment collects and form pools. Remove and properly dispose of the sediment.
Landscaping	Note landscaping needs (e.g., grass cutting).	• Significantly overgrown areas that require landscape maintenance. • Grass coverage is less than 90%. • Dead or diseased vegetation (some vegetation can be dormant during dry seasons).	• Conduct regular plant maintenance including mowing and weeding; grass should maintain a height of at least 3 in. • Replace dead and diseased vegetation. • Irrigation may be required during prolonged dry periods. • Avoid or minimize fertilizer and herbicide use.
Irrigation System	Inspect for proper operation and water distribution.	System not functioning correctly (overwatering, underwatering or not functioning at all).	• Turn water off and depressurize the irrigation system immediately upon identifying a waterline break. • Repair broken sprinkler heads and lines.
Water Quality	• Observe runoff entering the PBMP, if present, and identify its origin, if visible. • Observe outflow from the system, if present and visible.	Water is significantly dirty/discolored, contains foul odors, or has an oily sheen.	Inspect areas upstream to identify the source and attempt to eliminate.
Damage/Repairs	Inspect surfaces and embankments for damage caused by rodents, vehicles, etc.	Structural damage or obstructions are present.	• Repair structural damage. • Clear obstructions.
Scheduling	Inspect regularly and 48 hours after significant rain events.	See above.	• Schedule long-term repairs before the rainy season. • Maintenance should be conducted during dry weather when no flow is entering the PBMP.

LC-7 Infiltration Trench

An infiltration trench is a long, narrow, rock-filled trench with no outlet, where stormwater runoff is stored in the void space between the rocks and infiltrates through the trench bottom and into the soil matrix. Regular inspections and maintenance are needed to prevent sediment buildup and clogging, which reduces the capacity of the system.

Infiltration Trench at Kakoi Baseyard, Oahu
Source: HDOT Highways Division

Operations & Maintenance

Category	Inspections	Conditions that Require Maintenance	Maintenance
Sediment and Debris	Inspect surface drainage systems, flow entrances, and pretreatment measures for sediment, trash, debris, and leaf accumulation.	Accumulation of sediment, trash, debris, and leaves.	• Remove accumulated sediment, trash, debris, and leaves. • If excessive sediment is deposited, immediately determine the source, remove sediment deposits, and correct the problem. • Remove trash and debris from the drainage system leading to and within the infiltration trench.
Standing Water/ Clogging	• Inspect for standing water that does not drain after 48 hrs. • Monitor observation wells to determine how quickly the system is draining after a storm.	Standing water remaining for longer than 48 hrs suggests sediment or trash blockages may be present, soil infiltration rate may have been reduced due to compaction, media/gravel layer may be clogged, or permeable filter fabric may be clogged.	• Clear the outlet of sediment or trash blockages and remove the top layer of trench rock to replace it with fresh material. • If standing water persists, the trench rock or permeable filter fabric may be clogged; unclog or replace components as necessary.
Erosion	• Inspect inlets and outlets for evidence of undercutting or erosion. • Note erosion locations or drainage changes.	• Significant erosion observed. • Changes to the drainage pattern.	• Stabilize undercuts and eroded areas at the inflow, outflow, overflow structures and embankments. • Re-grade to reshape the cross-section as sediment collects and form pools. Remove and properly dispose of the sediment.
Water Quality	• Observe runoff entering the PBMP, if present, and identify its origin, if visible. • Observe outflow from the system, if present and visible.	Water is significantly dirty/discolored, contains foul odors, or has an oily sheen.	Inspect areas upstream to identify the source and attempt to eliminate.
Damage/Repairs	Inspect surfaces and embankments for damage caused by rodents, vehicles, etc.	Structural damage or obstructions are present.	• Repair structural damage. • Clear obstructions.
Scheduling	Inspect regularly and 48 hours after significant rain events.	See above.	• Schedule long-term repairs before the rainy season. • Maintenance should be conducted during dry weather when no flow is entering the PBMP.

LC-8 Permeable Pavement

Permeable pavement is a permeable surface that allows stormwater runoff to move through surface voids into an underlying aggregate reservoir for temporary storage and infiltration. Regular inspections and maintenance are needed to prevent sediment buildup and clogging, which reduces the capacity of the system.

Elliott Street Parking Lot Permeable Pavement, Daniel K. Inouye International Airport
Source: Hawaii DOTA

Operations & Maintenance

Category	Inspections	Conditions that Require Maintenance	Maintenance
Sediment and Debris	Inspect surface drainage systems, flow entrances, and pretreatment measures for sediment, trash, debris, and leaf accumulation.	Accumulation of sediment, trash, debris, and leaves.	• Remove accumulated sediment, trash, debris, and leaves. • If excessive sediment is deposited, immediately determine the source, remove sediment deposits, and correct the problem.
Clogging	Inspect for water present in the underlying soil matrix for longer than 48 hrs after of a storm event or standing water on the pavement.	• Water present in the underlying soil matrix for longer than 48 hrs of a storm event. • Standing water on the pavement.	• Annually and conditions suggest sediment blockages may be present, use a regenerative air or vacuum sweeper to remove sediment and debris from the surface. • If conditions persist, the pavement may need replacement.
Spills/Stains	Inspect surface for any oil staining or sheen.	• Recent oil or fuel spill. • Oil staining on pavement.	• Promptly clean up any fresh petroleum spills using dry methods (e.g., absorbent pads) and properly dispose of spent absorbent materials. Do not use clay absorbents as they may clog permeable pavement. • Treat stains with an environmentally friendly degreaser.
Runoff	• Observe standing water and runoff entering the PBMP, if present, and identify its origin, if visible. • Note characteristics (e.g., color, smell, sheen) and if drainage patterns have changed.	Runoff is significantly dirty/discolored, contains foul odors, or has an oily sheen.	Inspect areas upstream to identify the source and attempt to eliminate.
Water Quality	Observe standing water, if present.	Water is significantly dirty/discolored, contains foul odors, or has an oily sheen.	Inspect areas upstream to identify the source and attempt to eliminate.
Damage/Repairs	Inspect for signs of pavement structural damage such as deformations, cracked pavers, etc.	Structural damage is present.	Repair structural damage.
Scheduling	Inspect regularly and after significant rain events.	See above.	• Schedule long-term repairs before the rainy season. • Maintenance should be conducted during dry weather when no flow is entering the PBMP. • Strict adherence to a regularly scheduled maintenance frequency may be needed to reduce the risk of clogging.

LC-9 Subsurface Infiltration

A subsurface infiltration system is a stone storage (or alternative pre-manufactured material) bed below surfaces such as parking lots, lawns, and playfields for temporary storage and infiltration of runoff. Regular inspections and maintenance are needed to prevent clogging and accumulation of sediment/debris, which reduces the capacity of the system.

Refer to the manufacturer's inspection and maintenance requirements for additional information.

Subsurface Infiltration
Source: *Philadelphia Stormwater Management Guidance Manual, Version 3.2*

Operations & Maintenance

Category	Inspections	Conditions that Require Maintenance	Maintenance
Sediment and Debris	Inspect surface drainage systems, flow entrances, and pretreatment measures for sediment, trash, debris, and leaf accumulation.	Accumulation of sediment, trash, debris, and leaves.	• Remove accumulated sediment, trash, debris, and leaves. • If excessive sediment is deposited, immediately determine the source, remove sediment deposits, and correct the problem. • Remove trash and debris from the drainage system leading to and within the subsurface infiltration system.
Standing Water/ Clogging	• Inspect for standing water that does not drain after 72 hrs. • Monitor observation wells to determine how quickly the system is draining after a storm.	Standing water remaining for longer than 72 hrs suggests sediment or trash blockages may be present, soil infiltration rate may have been reduced, or clogging of native soil or permeable filter fabric.	• Annually and if standing water remains for more than 72 hrs, clear the outlet and use a vacuum truck to remove sediment and debris from the surface and subsurface infiltration system invert. • If standing water persists, additional efforts may be needed to unclog or replace components, per the manufacturer's specifications.
Erosion	• Inspect inlets for evidence of undercutting or erosion. • Note erosion locations or drainage changes.	• Significant erosion observed near the inlet. • Changes to the drainage pattern.	Stabilize surrounding eroded areas and regrade so water drains toward PBMP, as necessary.
Water Quality	• Observe runoff entering the PBMP, if present, and identify its origin, if visible. • Observe standing water in the subsurface collection system, if present.	Water is significantly dirty/discolored, contains foul odors, or has an oily sheen.	If runoff is significantly dirty/discolored, contains foul odors, or has an oily sheen, inspect areas upstream to identify the source and attempt to eliminate.
Damage/Repairs	Inspect storage system and inlet structure for signs of damage or obstructions.	Structural damage or obstructions are present.	• Repair structural damage. • Clear obstructions.
Scheduling	Inspect regularly and 72 hours after significant rain events.	See above.	• Schedule long-term repairs before the rainy season. • Maintenance should be conducted during dry weather when no flow is entering the PBMP.

LC-10 Vegetated Buffer Strip

Vegetated buffer strips are strips of land parallel to and adjacent to the edge of the contributing impervious surface and designed to accommodate sheet flow. Regular inspections and maintenance are needed to verify flow is unobstructed, vegetation is healthy, erosion is prevented, and the system is functioning properly.

Vegetated Buffer Strip, Oahu
Source: HDOT Highways Division

Operations & Maintenance

Category	Inspections	Conditions that Require Maintenance	Maintenance
Sediment and Debris	Inspect inlets and sheet flow areas for sediment, trash, debris, and leaf accumulation.	Accumulation of sediment, trash, debris, and leaves.	• Remove accumulated sediment, trash, debris, and leaves. • If excessive sediment is deposited, immediately determine the source, remove sediment deposits, and correct the problem. • Remove trash and debris from the drainage system leading to and within vegetated buffer strip.
Standing Water	Inspect for standing water after inflow has ceased.	Standing water suggests blockages may be present, soil infiltration rate may have been reduced due to compaction, or the bottom needs regrading.	• Clear the outlet and vegetated buffer strip surface of sediment or trash blockages. • If standing water persists, remove the top layer, regrade to match the design geometry, and revegetate.
Erosion	• Inspect inlets, outlets, side slopes, and flow paths for evidence of undercutting or erosion. • Note erosion locations or drainage changes.	• Significant erosion observed. • Changes to the drainage pattern.	• Stabilize undercuts and eroded areas at the buffer strip inflow and outflow structures. • Re-grade to reshape cross-section as sediment collects and forms pools. • Remove and properly dispose of the sediment.
Landscaping	Note landscaping needs (e.g., grass cutting).	• Significantly overgrown areas that require landscape maintenance. • Grass coverage is less than 90%. • Dead or diseased vegetation (some vegetation can be dormant during dry seasons).	• Conduct regular plant maintenance including mowing and weeding; grass should maintain a height of at least 3 in. • Replace dead and diseased vegetation. • Irrigation may be required during prolonged dry periods. • Avoid or minimize fertilizer and herbicide use.
Irrigation System	Inspect for proper operation and water distribution.	System not functioning correctly (overwatering, underwatering or not functioning at all).	• Turn water off and depressurize the irrigation system immediately upon identifying a waterline break. • Repair broken sprinkler heads and lines.
Water Quality	• Observe runoff entering the PBMP, if present, and identify its origin, if visible. • Observe outflow from the system, if present and visible. • Observe standing water, if present.	Water is significantly dirty/discolored, contains foul odors, or has an oily sheen.	Inspect areas upstream to identify the source and attempt to eliminate.
Damage/Repairs	Inspect surfaces for damage caused by rodents, vehicles, etc.	Structural damage or obstructions are present.	• Repair structural damage. • Clear obstructions.
Scheduling	Inspect regularly and after significant rain events.	See above.	• Schedule long-term repairs before the rainy season. • Maintenance should be conducted during dry weather when no flow is entering the PBMP.

LC-11 Vegetated Swale

Vegetated swales are designed to remove pollutants by physically straining and filtering water through vegetation. Maintenance is primarily focused on maintaining healthy vegetation and avoiding clogging.

Vegetated Swale along H-3, Oahu
Source: HDOT Highways Division

Operations & Maintenance

Category	Inspections	Conditions that Require Maintenance	Maintenance
Sediment and Debris	Inspect inlets and sheet flow areas for impoundments for sediment, trash, debris, and leaf accumulation.	Accumulation of sediment, trash, debris, and leaves.	• Remove accumulated sediment, trash, debris, and leaves. • If excessive sediment is deposited, immediately determine the source, remove sediment deposits, and correct the problem. • Remove trash and debris from the drainage system leading to and within the vegetated swale.
Standing Water	Inspect for standing water after inflow has ceased.	Standing water suggests blockages may be present, soil infiltration rate may have been reduced due to compaction, or the bottom needs regrading.	• Clear the outlet and surface of sediment or trash blockages. • If standing water persists, remove the top layer, regrade to match the design geometry, and revegetate.
Erosion	• Inspect inlets, outlets, side slopes, flow path, and check dam structures for evidence of undercutting and erosion. • Note erosion locations or drainage changes.	• Significant erosion observed. • Changes to the drainage pattern.	• Stabilize undercuts and eroded areas at the inflow and outflow structures. • Re-grade to reshape cross-section as sediment collects and forms pools. • Remove and properly dispose of the sediment.
Landscaping	Note landscaping needs (e.g., grass cutting).	• Significantly overgrown areas that require landscape maintenance. • Grass coverage is less than 90%. • Dead or diseased vegetation (some vegetation can be dormant during dry seasons).	• Conduct regular plant maintenance including mowing and weeding; grass should maintain a height of at least 3 in. • Replace dead and diseased vegetation. • Irrigation may be required during prolonged dry periods. • Avoid or minimize fertilizer and herbicide use.
Irrigation System	Inspect for proper operation and water distribution.	System not functioning correctly (overwatering, underwatering or not functioning at all).	• Turn water off and depressurize the irrigation system immediately upon identifying a waterline break. • Repair broken sprinkler heads and lines.
Water Quality	• Observe runoff entering the PBMP, if present, and identify its origin, if visible. • Observe outflow from the system, if present and visible. • Observe standing water, if present.	Water is significantly dirty/discolored, contains foul odors, or has an oily sheen.	Inspect areas upstream to identify the source and attempt to eliminate.
Damage/Repairs	Inspect surfaces for damage caused by rodents, vehicles, etc.	Structural damage or obstructions are present.	• Repair structural damage. • Clear obstructions.
Scheduling	Inspect regularly and after significant rain events.	See above.	• Schedule long-term repairs before the rainy season. • Maintenance should be conducted during dry weather when no flow is entering the PBMP.

TC-1 Alternative Wetlands

Alternative wetlands considered at airports may include floating wetlands (also known as floating treatment wetlands or FTW) or modular wetlands. FTWs consist of a floating raft and suspended matrix with aquatic wetland plants, and are placed in a water body where the plants are able to draw pollutants out of the water. Modular wetlands are proprietary biotreatment devices. Regular inspections and maintenance are needed to maintain healthy vegetation, prevent clogging and accumulation of sediment/debris, prevent erosion, control mosquito breeding, verify soils are biologically active, and verify the system is functioning properly. Refer to the manufacturer's inspection and maintenance requirements for additional information.

Floating Wetland in Kaanapali Lagoon, Maui
Source: West Maui Ridge 3 Reef Initiative

Operations & Maintenance

Category	Inspections	Conditions that Require Maintenance	Maintenance
Sediment and Debris	Inspect surface drainage systems, flow entrances, and pretreatment measures for sediment, trash, debris, and leaf accumulation.	Accumulation of sediment, trash, debris, and leaves.	• Remove accumulated sediment, trash, debris, vegetation clippings, and leaves. • Remove trash and debris from the drainage system leading to and within wetlands. • For modular wetlands, replace media or filter cartridges periodically, if applicable.
Erosion	• Inspect inlets and outlets for evidence of undercutting and erosion. • Note erosion locations or drainage changes.	• Significant erosion observed. • Changes to the drainage pattern.	• Stabilize undercuts and eroded areas at the inflow and outflow structures. • Remove and properly dispose of the sediment.
Wildlife/Pests	Inspect for wildlife issues and evidence of mosquitoes or mosquito larvae in the wetlands.	• Evidence of mosquitoes or mosquito larvae. • Evidence of wildlife frequenting the area.	• Conduct mosquito abatement using a bubbler or other means. • Remove vegetation that appears to be attracting wildlife. • Incorporate fencing or other barriers to keep wildlife from entering.
Landscaping	• Note landscaping needs (e.g., grass cutting, vegetation pruning, etc.). • Inspect to check that the vegetation is viable and that water is flowing through the wetland system.	• Significantly overgrown areas that require landscape maintenance. • Dead or diseased vegetation (some vegetation can be dormant during dry seasons).	• Conduct regular plant maintenance including mowing, pruning, and weeding. • Replace dead and diseased vegetation. • Irrigation may be required during prolonged dry periods. • Avoid or minimize fertilizer and herbicide use.
Irrigation System	Inspect for proper operation and water distribution.	System not functioning correctly (overwatering, over spraying, underwatering) or not functioning at all.	• Turn water off and depressurize the irrigation system immediately upon identifying a waterline break. • Repair broken sprinkler heads and lines.
Water Quality	• Observe runoff entering the PBMP, if present, and identify its origin, if visible. • Observe outflow from the system, if present and visible.	Water is significantly dirty/discolored, contains foul odors, or has an oily sheen.	Inspect areas upstream to identify the source and attempt to eliminate.
Damage/Repairs	• Inspect for FTW raft and matrix damage or other structural damage. • Inspect for structural damage to the prefabricated modular wetland box. • Inspect surfaces for damage caused by rodents, vehicles, etc. • Inspect anchors or tethers to verify FTW rises and falls with stormwater fluctuations and is protected from flooding (no inundation of the FTW matrix). Additionally, the anchors or tethers should be functional to retrieve the FTW for maintenance.	Structural damage or obstructions are present.	• Repair structural damage. • Clear obstructions. • For FTW, repair anchors or tethers as needed.
Scheduling	Inspect regularly and after significant rain events.	See above.	• Schedule long-term repairs before the rainy season. • Maintenance should be conducted during dry weather when no flow is entering the PBMP.

TC-2 Dry Detention Basin

Dry detention basins can provide stormwater quantity control and improve water quality using shallow man-made impoundments that provide temporary stormwater storage to allow particles to settle. Dry detention basins do not have a permanent pool and are designed to drain completely between storm events. Regular inspections and maintenance are needed to maintain healthy vegetation, prevent clogging and accumulation of sediment/debris, and prevent erosion.

Detention Basin at Kahului Airport
Source: Hawaii DOTA

Operations & Maintenance

Category	Inspections	Conditions that Require Maintenance	Maintenance
Sediment and Debris	Inspect surface drainage systems, flow entrances, control structures, overflow structures, piping, and pretreatment measures for sediment, trash, debris, and leaf accumulation.	Accumulation of sediment, trash, debris, and leaves.	• Remove vegetation clippings and leaves. • Remove accumulated sediment, trash, debris, and leaves. • Remove trash and debris from the drainage system.
Erosion	• Inspect inlets, outlets, side slopes, and flow paths for evidence of undercutting and erosion. • Inspect embankment, dikes, and berms for signs of erosion. • Note erosion locations or drainage changes.	• Significant erosion observed. • Changes to the drainage pattern.	• Stabilize undercuts and eroded areas at the inflow and outflow structures. • Re-grade to reshape the bottom as sediments collect and form pools. • Remove and properly dispose of the sediment.
Wildlife/Pests	Inspect for wildlife issues and evidence of mosquitoes or mosquito larvae.	• Evidence of mosquitoes or mosquito larvae. • Evidence of wildlife frequenting the area.	• Conduct mosquito abatement using a bubbler or other means. • Remove vegetation that appears to be attracting wildlife. • Incorporate fencing or other barriers to keep wildlife from entering.
Standing Water	Inspect for standing water that does not drain within 48 hrs.	Standing water remaining for longer than 48 hrs suggests that sediment or trash blockages may be present, the outflow structure may be clogged, or the low flow orifice may be clogged.	• Clear the control structure of sediment or trash blockages. • If standing water persists, unclog or replace the low flow orifice.
Landscaping	Note landscaping needs (e.g., grass cutting, vegetation pruning, etc.).	• Significantly overgrown areas that require landscape maintenance. • Dead or diseased vegetation (some vegetation can be dormant during dry seasons).	• Conduct regular plant maintenance including mowing, pruning, and weeding. • Replace dead and diseased vegetation. • Irrigation may be required during prolonged dry periods. • Avoid or minimize fertilizer and herbicide use.
Irrigation System	Inspect for proper operation and water distribution.	System not functioning correctly (overwatering, underwatering or not functioning at all).	• Turn water off and depressurize the irrigation system immediately upon identifying a waterline break. • Repair broken sprinkler heads and lines.
Water Quality	• Observe runoff entering the PBMP, if present, and identify its origin, if visible. • Observe outflow from the system, if present and visible. • Observe standing water, if present.	Water is significantly dirty/discolored, contains foul odors, or has an oily sheen.	Inspect areas upstream to identify the source and attempt to eliminate.
Damage/Repairs	Inspect the outlet, embankment, dikes, berms, and side slopes for structural integrity and signs of erosion and rodent burrow.	Structural damage or obstructions are present.	• Repair structural damage. • Clear obstructions.
Scheduling	Inspect regularly and 48 hours after significant rain events.	See above.	• Schedule long-term repairs before the rainy season. • Maintenance should be conducted during dry weather when no flow is entering the PBMP.

TC-3
Evaporation Pond

Evaporation ponds are shallow man-made ponds with large surface areas designed to hold a set volume of stormwater runoff and allow for evaporation by sunlight and exposure to the ambient temperatures, wind, and humidity with no outlet structure. Regular inspections and maintenance are needed to prevent clogging and accumulation of sediment/debris, control mosquitoes, and verify the system is functioning properly.

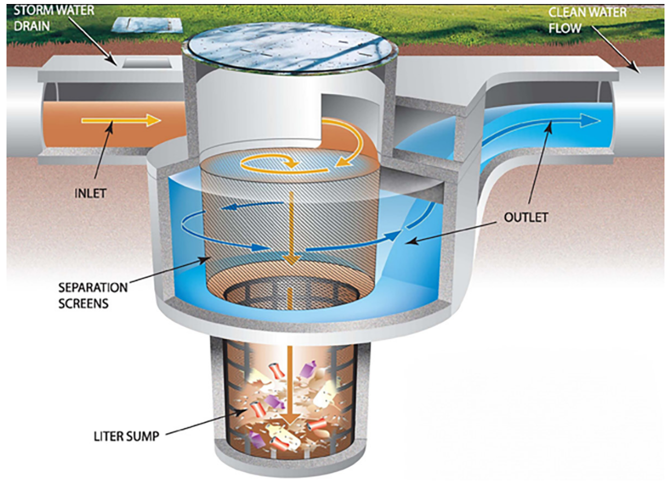
Evaporation Pond at Kahului Airport
Source: Hawaii DOTA

Operations & Maintenance

Category	Inspections	Conditions that Require Maintenance	Maintenance
Sediment and Debris	Inspect surface drainage systems, flow entrances, and pretreatment measures for sediment, trash, debris, and leaf accumulation.	Accumulation of sediment, trash, debris, and leaves.	• Remove accumulated sediment, trash, debris, and leaves. • Remove trash and debris from the drainage system leading to and within the evaporation pond.
Erosion	• Inspect inlets and flow paths for evidence of undercutting and erosion. • Note erosion locations or drainage changes.	• Significant erosion observed. • Changes to the drainage pattern.	Stabilize eroded areas and repair erosion.
Wildlife/Pests	Inspect for wildlife issues and evidence of mosquitoes or mosquito larvae.	• Evidence of mosquitoes or mosquito larvae. • Evidence of wildlife frequenting the area.	• Conduct mosquito abatement using a bubbler or other means. • Incorporate fencing or other barriers to keep wildlife from entering.
Standing Water	Inspect for standing water that does not evaporate within 48 hrs.	Standing water remaining for longer than 48 hrs suggests system may not be functioning properly.	Evaluate the system for design changes necessary to achieve a desirable evaporation rate or re-route excess flows to an alternative PBMP.
Water Quality	• Observe runoff entering the PBMP, if present, and identify its origin, if visible. • Observe standing water, if present.	Water is significantly dirty/discolored, contains foul odors, or has an oily sheen.	Inspect areas upstream to identify the source and attempt to eliminate.
Damage/Repairs	• Inspect the embankment, dikes, berms, and side slopes for structural integrity and signs of erosion and rodent burrow. • Inspect for structural damage of structures.	Structural damage or obstructions are present.	• Repair structural damage. • Clear obstructions.
Scheduling	Inspect regularly and 48 hours after significant rain events.	See above.	• Schedule long-term repairs before the rainy season. • Maintenance should be conducted during dry weather when no flow is entering the PBMP.

TC-4 Hydrodynamic Separator Unit

Hydrodynamic Separator (HDS) units are flow-through structures with a settling or separation unit to remove sediments and other pollutants. An HDS unit is also known as a vortex separator, a swirl separator, a swirl concentrator, or a continuous deflective separator unit. Refer to the manufacturer's inspection and maintenance requirements for additional information.



Vortex Separator
Source: https://lbpost.com/news/city/city-receives-grant-for-coastal-water-filtration-systems/

Operations & Maintenance

Category	Inspections	Conditions that Require Maintenance	Maintenance
Sediment and Debris	• Inspect surface drainage systems and flow entrances for sediment, trash, debris, and leaf accumulation. • Inspect sediment depth in the HDS unit with a calibrated dipstick, tape measure, or other measuring instrument to determine if cleaning is needed based on the specified unit cleaning depth. • Inspect HDS unit for accumulation of trash, floatables, and debris. • Inspect pretreatment measures for sediment, trash, debris, and leaf accumulation.	Accumulation of sediment, trash, debris, and leaves.	• Remove accumulated sediment and floating trash, and debris with a scoop net or an extension on the end of the boom hose of the vacuum truck. It is recommended to clean using a vacuum truck. • Remove sediment from the bottom of the sump with a vacuum truck. • Remove trash and debris from the drainage system leading to and within the HDS unit. • Some jetting may be required to loosen up sediment from the sump. • The jetting can be achieved by inserting a jet hose through the vortex tube opposite the tube used for vacuum hose access; follow manufacturer's O&M procedures. • Brush the screen clean and, if needed, follow up with a wash (if applicable).
Pests	Inspect for evidence of mosquitoes or mosquito larvae.	Evidence of mosquitoes or mosquito larvae.	Conduct mosquito abatement using a bubbler or other means.
Clogging	Inspect inlets, piping, and outlets for clogging.	Conditions suggesting clogging, per the manufacturer's O&M recommendations.	• Follow manufacturer's O&M recommendations to remove blockages from inlets, pipes, and outlets. • If the problem persists, consider a higher frequency of inspection and maintenance.
Water Quality	• Observe runoff entering the PBMP, if present, and identify its origin, if visible. • Open the separation chamber manhole cover or grate and observe water in vault, if present. • Observe outflow from the system, if present and visible.	Water is significantly dirty/discolored, contains foul odors, or has an oily sheen.	Inspect areas upstream to identify the source and attempt to eliminate.
Damage/Repairs	• Remove access covers and visually inspect the internal components for broken or missing parts. • Inspect for structural damage.	Structural damage or obstructions are present.	• Repair structural damage. • Clear obstructions.
Absorbent Materials (if present)	Inspect the color of absorbent material, if used in the HDS unit.	Significant discoloration of the absorbent material.	• Replace absorbent material if damage or discoloration is observed. • If absorbent pads are tethered to the unit, only OSHA confined space entry trained and certified personnel may enter the structure to remove and replace spent material.
Scheduling	Inspect regularly and after significant rain events.	See above.	• Schedule long-term repairs before the rainy season. • Maintenance should be conducted during dry weather when no flow is entering the PBMP.

TC-5
Drain Inlet Insert

Drain Inlet Inserts are filters designed to remove the trash, sediment, and contaminants such as hydrocarbons and metals from stormwater runoff. A metal frame with a filter screen is the primary method for pollutant removal. A non-leaching absorbent material in a pouch can be placed with the insert to remove hydrocarbons or metals. Regular inspections and maintenance are needed to replace filter media (including cartridges), prevent clogging and accumulation of sediment/debris, control mosquitoes, and verify the system is functioning properly. Refer to the manufacturer's inspection and maintenance requirements for additional information.

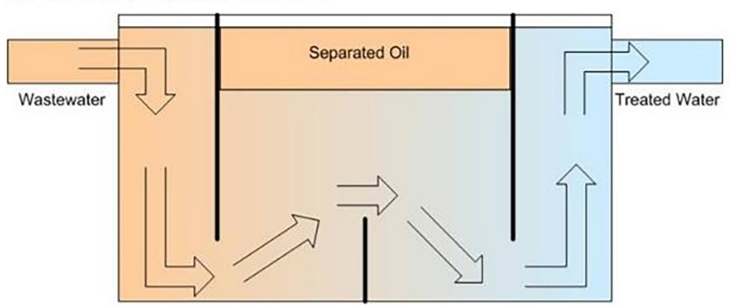
Drain Inlet Insert at Maintenance Baseyard (right) and Drain Inlet Insert at Elliott Street Parking Lot (left), Daniel K. Inouye International Airport
Source: Hawaii DOTA

Operations & Maintenance

Category	Inspections	Conditions that Require Maintenance	Maintenance
Sediment and Debris	• Inspect surface drainage systems and flow entrances for sediment, trash, debris, and leaf accumulation. • Inspect the insert and screens for accumulation of trash, floatables, and debris.	Accumulation of sediment, trash, debris, and leaves.	• Remove accumulated trash and debris from the interior of the insert and the upper portion of the filter/insert by removing the insert or an extension on the end of the boom hose of the vacuum truck. • Remove sediment, trash, debris, and leaves from the bottom of the sump with a vacuum truck. • Brush the screen clean if present and, if needed, follow up with a wash. • Remove trash and debris surrounding the inlet.
Pests	Inspect for evidence of mosquitoes or mosquito larvae.	Evidence of mosquitoes or mosquito larvae.	Conduct mosquito abatement using a bubbler or other means.
Standing Water/ Clogging	• Inspect for standing water after inflow has ceased. • Inspect inlets, piping, and outflow for clogging.	Standing water suggests filter media needs replacement, sediment/trash blockages may be present, or the overflow may be clogged.	• Clear the insert of sediment or trash blockages. • If standing water persists, replace the filter media or cartridges, whichever is applicable. • Consider a higher frequency of inspection and maintenance, as necessary.
Water Quality	• Observe runoff entering the PBMP, if present, and identify its origin, if visible. • Observe outflow from the system, if present and visible.	Water is significantly dirty/discolored, contains foul odors, or has an oily sheen.	Inspect areas upstream to identify the source and attempt to eliminate.
Damage/Repairs	• Inspect for structural damage. • Inspect for tears or gaps.	• Structural damage or obstructions are present. • Tears or gaps in the insert, screen, or fabric where sediment, trash, debris, or leaves can bypass the system.	• Repair structural damage. • Clear obstructions.
Absorbent Materials	Inspect the color of absorbent material, if used in the MTD.	• Significant discoloration of the absorbent material. • Frequency established by manufacture.	• Replace absorbent material if damage or discoloration is observed. • Routinely or when standing water is observed, remove and replace the filter media, including absorption media, filter pads, fabric, etc. • Remove the absorption media, if loose, with a vacuum truck.
Scheduling	Inspect regularly and after significant rain events.	See above.	• Schedule long-term repairs before the rainy season. • Maintenance should be conducted during dry weather when no flow is entering the PBMP.

TC-6 Oil Water Separator

OWSs are treatment control devices designed to remove water-insoluble hydrocarbons (e.g., jet fuel, gasoline, and diesel) and settleable solids (e.g., sediment, trash, debris, and leaves) from stormwater runoff. The primary function of OWSs is to remove oil, jet fuel, gasoline, diesel, other water-insoluble hydrocarbons, floatable debris, and settleable solids. Regular inspections and maintenance are needed to remove oil, sediment, and trash to prevent clogging and oil buildup. Refer to the manufacturer's inspection and maintenance requirements for additional information.



Standard Gravity Oil/Water Separator
Source: https://www.epa.gov/sites/default/files/2014-04/documents/5_owseparators_2014.pdf

Operations & Maintenance

Category	Inspections	Conditions that Require Maintenance	Maintenance
Sediment and Debris	• Inspect surface drainage systems and flow entrances for sediment, trash, debris, and leaf accumulation. • Inspect for accumulation of oil, grease, trash, floatables, and debris. • Inspect pretreatment measures for sediment, trash, debris, and leaf accumulation. • Inspect inlets, piping, and outlet for clogging.	Accumulation of sediment, trash, debris, and leaves.	• Remove accumulated sediment and floating trash, and debris with a scoop net or an extension on the end of the boom hose of the vacuum truck. • Remove the floatable trash and debris from the drainage system leading to and within the OWS.
Pests	Inspect for evidence of mosquitoes or mosquito larvae.	Evidence of mosquitoes or mosquito larvae.	Conduct mosquito abatement using a bubbler or other means.
Clogging	Inspect inlets, piping, and outlets for clogging.	Conditions suggesting clogging, per the manufacturer's O&M recommendations.	• Follow manufacturer's O&M recommendations to remove blockages from inlets, pipes, and outlets. • If the problem persists, consider a higher frequency of inspection and maintenance.
Water Quality	• Observe runoff entering the PBMP, if present, and identify its origin, if visible. • Open the separation chamber manhole cover or grate and observe water in vault, if present. • Observe outflow from the system, if present and visible.	Water is significantly dirty/discolored, contains foul odors, or has an oily sheen.	Inspect areas upstream to identify the source and attempt to eliminate.
Damage/Repairs	• Remove access covers and visually inspect the internal components for broken or missing parts. • Inspect for structural damage.	Structural damage or obstructions are present.	• Repair structural damage. • Clear obstructions.
Fuel	Note any fuel smell in the OWS.	Smell of fuel in OWS.	Stop work and arrange for immediate maintenance.
Absorbent Materials	Inspect the hydrocarbon boom used in the OWS.	Significant discoloration of the hydrocarbon boom.	Replace hydrocarbon boom if damage or discoloration is observed.
Disposal	Inspect accumulated oil and sediment levels.	Oil or sediment accumulation warranting removal per the manufacture's specifications.	• Transport and dispose of liquid removed from OWS following all applicable rules and regulations for waste oil disposal. • Test and properly dispose of sediment removed from OWS.
Scheduling	Inspect regularly and after significant rain events.	See above.	• Schedule long-term repairs before the rainy season. • Maintenance should be conducted during dry weather when no flow is entering the PBMP.

TC-7
Sand Filter

A sand filter is a basin or chambered structure that captures, temporarily stores, and treats stormwater runoff by passing it through sand, organic matter, soil, or other media. Regular inspections and maintenance are needed to prevent clogging and accumulation of sediment/debris and verify the system is functioning properly.

Oak Manor Surface Sand Filter, Maryland
Source: Montgomery County, Maryland

Operations & Maintenance

Category	Inspections	Conditions that Require Maintenance	Maintenance
Sediment and Debris	Inspect surface drainage systems, flow entrances, and pretreatment measures for sediment, trash, debris, and leaf accumulation.	Accumulation of sediment, trash, debris, and leaves.	• Remove accumulated sediment, trash, debris, and leaves. • If excessive sediment is deposited, immediately determine the source, remove sediment deposits, and correct the problem. • Remove trash and debris from the drainage system leading to and within sand filters.
Erosion	• Inspect inlets, outlets, side slopes, and flow paths for evidence of undercutting or erosion. • Note erosion locations or drainage changes.	• Significant erosion observed. • Changes to the drainage pattern.	• Stabilize eroded areas and repair erosion. • Re-grade to reshape cross-section as sediment collects and form pools. • Remove and properly dispose of the sediment.
Standing Water and Clogging	• Inspect for standing water that does not drain after 48 hrs. • Monitor observation wells, if present, to determine how quickly the system is draining after a storm.	Standing water suggests that sediment or trash blockages may be present, the media layer may be clogged, or the underdrain/permeable filter fabric may be clogged.	• Clear the outlet and surface of sediment or trash blockages and scarify the sand media surface. • If standing water persists, the sand media layer, underdrain, or permeable filter fabric may be clogged; unclog or replace components as necessary.
Water Quality	• Observe runoff entering the PBMP, if present, and identify its origin, if visible. • Observe standing water in the subsurface collection system, if present. • Observe outflow from the system, if present and visible.	Water is significantly dirty/discolored, contains foul odors, or has an oily sheen.	Inspect areas upstream to identify the source and attempt to eliminate.
Damage/Repairs	• Inspect surfaces for damage caused by rodents, vehicles, etc. • Inspect underground sand filter for structural damage to the subsurface collection system.	Structural damage or obstructions are present.	• Repair structural damage. • Clear obstructions.
Scheduling	Inspect regularly and 48 hours after significant rain events.	See above.	• Schedule long-term repairs before the rainy season. • Maintenance should be conducted during dry weather when no flow is entering the PBMP.

TC-8 Subsurface Detention

Subsurface detention PBMPs are underground structures that temporarily detain stormwater and release it to the drainage system or receiving waters. Regular inspections and maintenance are needed to prevent sediment build-up and clogging, which reduces the capacity of the system. Refer to the manufacturer's inspection and maintenance requirements for additional information.

Subsurface Detention Installation, Philadelphia
Source: Philadelphia Stormwater Management Guidance Manual, Version 3.2

Operations & Maintenance

Category	Inspections	Conditions that Require Maintenance	Maintenance
Sediment and Debris	Inspect surface drainage systems, flow entrances, and pretreatment measures for sediment, trash, debris, and leaf accumulation.	Accumulation of sediment, trash, debris, and leaves.	• Remove accumulated sediment, trash, debris, and leaves. • If excessive sediment is deposited, immediately determine the source, remove sediment deposit, and correct the problem. • Sediment removal may need to be accomplished with vacuum truck or a similar process. • Remove trash and debris from the drainage system leading to and within PBMP.
Erosion	• Inspect inlets, outlets, and flow paths for evidence of undercutting and erosion. • Note erosion locations or drainage changes.	• Significant erosion observed. • Changes to the drainage pattern.	• Stabilize eroded areas and repair erosion. • Remove and properly dispose of the sediment.
Standing Water and Clogging	• Inspect for standing water that does not drain within 72 hrs. • Monitor observation wells to determine how quickly the system is draining after a storm.	Standing water for longer than 72 hrs suggests that sediment or trash blockages may be present, the media layer may be clogged, or the underdrain/permeable filter fabric may be clogged.	• Annually and if conditions suggest sediment or trash blockages may be present, use a vacuum truck to remove sediment and debris from the subsurface detention system invert. • If standing water persists, additional efforts may be needed to unclog or replace components, per the manufacturer's specifications.
Water Quality	• Observe runoff entering the PBMP, if present, and identify its origin, if visible. • Observe standing water in the subsurface collection system, if present. • Observe outflow from the system, if present and visible.	Water is significantly dirty/discolored, contains foul odors, or has an oily sheen.	Inspect areas upstream to identify the source and attempt to eliminate.
Damage/Repairs	• Inspect surfaces for damage caused by rodents, vehicles, etc. • Inspect for structural damage or obstructions.	Structural damage or obstructions are present.	• Repair structural damage. • Clear obstructions.
Scheduling	Inspect regularly and 72 hours after significant rain events.	See above.	• Schedule long-term repairs before the rainy season. • Maintenance should be conducted during dry weather when no flow is entering the PBMP.