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# Stormwater Management Decision Support System for Using Low Impact Development Best Management Practices in Industrial Areas

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This document is a field and desktop manual that is used to assist Naval personnel to develop strategies that can reduce or eliminate the concentration and mass of heavy metals in stormwater runoff at industrial areas with the use of Low Impact Development (LID). It guides personnel assigned to Environmental, Capital Improvements, Asset Management and Public Works businesses identifying, selecting, designing and maintaining LID technologies.

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Navy Environmental Sustainability Development to Integration Program

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NESDI Project Number 493

**Edwin Chiang P.E.**
**Naval Facilities Engineering and Expeditionary Warfare Center**

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# NESDI Program

## Technical Report

# *Stormwater Management Decision Support System for Using Low Impact Development Best Management Practices in Industrial Areas*

## ***Project # 493***

## ***May 2015***

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# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ASTM | American Society for Testing and Materials |
| BMP | Best Management Practice |
| CI | Capital Improvement Personnel |
| CGP | Concrete Grid Pavers |
| Cu | Copper |
| DoD | Department of Defense |
| DSS | Decision Support System |
| EISA | Energy Independence and Security Act |
| EMC | Event Mean Concentration |
| EXWC | Engineering and Expeditionary Warfare Center |
| EV | Environmental Personnel |
| HDG | Hot Dipped Galvanized |
| HVAC | Heating Ventilation Air Conditioning |
| LID | Low Impact Development |
| MS4 | Municipal Separate Storm Sewer System |
| NAVFAC | Naval Facilities Engineering Command |
| NESDI | Naval Environmental Sustainability Development to Integration |
| NPDES | National Pollution Discharge Elimination System |
| NRCS | Natural Resources Conservation Service |
| Pb | Lead |
| PFC | Permeable Friction Course |
| PICP | Permeable Interlocking Concrete Pavers |
| SWMM | Stormwater Management Model |
| SWPPP | Storm Water Pollution Prevention Plan |
| TKN | Total Kjeldahl Nitrogen |
| TMDL | Total Maximum Daily Load |
| TRM | Turf Reinforcement Mats |
| TSS | Total Suspended Solids |
| UFC | Unified Facilities Criteria |
| U.S. DOT | United States Department of Transportation |
| U.S. EPA | United States Environmental Protection Agency |
| USGS | United States Geological Services |
| WERF | Water Environment Research Foundation |
| WinSLAMM™ | Windows Source Loading and Management Model |
| WTR | Water Treatment Residuals |
| Zn | Zinc |

# EXECUTIVE SUMMARY

This document is a field and desktop manual used to assist Navy personnel in developing strategies to reduce or eliminate the concentration and mass of heavy metals in stormwater runoff at industrial areas with the use of Low Impact Development (LID). The LID stormwater management approach is used to replicate natural watershed functions (e.g., infiltration, evaporation, detention, etc.) in order to achieve pre-development or pre-project runoff conditions or achieve targeted stormwater management goals and objectives. The focus of this effort is on the reduction and elimination of the heavy metals zinc (Zn), copper (Cu), and lead (Pb) that are a result of the storage and/or processing of metals through the use of LID. The document will provide specific recommendations for the assessment and management of stormwater at scrap metal recycling facilities, motor pools, metal fabrication shops, and storage areas. This includes the reduction of pollution that is generated by the exterior of physical facilities (e.g., buildings, pavement, fences, etc.) or operation, such as the storage, handling, and processing of materials. This Decision Support System (DSS) is based on a literature review that was conducted by the Naval Facilities Engineering and Expeditionary Warfare Center (NAVFAC EXWC) as part of Naval Environmental Sustainability Development Integration (NESDI) Project 493 (EXWC, 2014).

The LID approach for best management practice implementation is an important component of the stormwater management program and infrastructure management for the Navy. LID is used to meet the Section 438 requirements of the Energy Independence and Security Act (EISA 438). The stormwater management requirements of EISA 438 require installations to reduce stormwater runoff volumes and meet pre-development watershed conditions. In addition, the Navy stormwater policy requires that new construction meets the pre-project conditions (US Navy, 1997).

**Use of this Decision Support System**

The focus of this DSS is to support Navy personnel responsible for compliance with the applicable provisions of the Clean Water Act through a stormwater National Pollutant Discharge Elimination System (NPDES) permit for stormwater discharges that is issued by the U.S. EPA or the state where the installation is located. This DSS can be used as a foundation and provide a general framework for decisions. The objective is to provide the user (Environmental, Asset Management, Capital Improvements and/or Public Works) with information and guidance on identifying and addressing potential heavy metals stormwater pollution. In many cases, the results of the DSS will require that the installation conduct further detailed investigations in order to determine the extent of the potential pollution and to develop long-term strategies for mitigating or eliminating the pollutant discharge for the stormwater at the installation. The DSS can be modified and be used to meet the mission of the activity as well as the permit requirements. The DSS has been developed to support the following missions and activities:

- **Environmental Personnel:** The first category is to help environmental personnel determine how to best meet regulatory compliance for existing facilities with the use of non-structural and structural stormwater BMPs. The DSS will help personnel identify potential problem areas, determine the most cost-effective and efficient compliance strategies and techniques, and develop or revise applicable SWPPPs and other materials that that demonstrate compliance.

- **Asset Management and Capital Improvement Personnel:** The second category is for Naval Facilities Engineering Command (NAVFAC) planners and engineers that are preparing designs for new or expanded facilities. This section of the DSS will aid in the location of facilities, development of storm drain and BMP systems, and selection of materials that can reduce or eliminate pollutant loads. The information and results of the DSS for operations can be used to develop the SWPPP BMPs for the facility.
- **Public Works Personnel (PW):** The third category is for facility operations personnel. It will aid in the identification of potential problem areas and can be used to inform compliance managers on potential problems and solutions to maintaining the BMP systems.

This document contains guidance on assessments that are based on typical layouts and operations of recycling facilities. Design templates that incorporate strategies to reduce or eliminate the pollutant loads are provided and include information on the location, size, and design of facilities and BMP mitigation techniques. Fact sheets on appropriate LID technologies are also included to help quickly identify solutions that are appropriate for Navy activities and operations in different climate areas and settings in coastal areas. Detailed information on calculating pollutant loads, design strategies, and BMP effectiveness are included in the supporting literature review (EXWC, 2014).

# 1.0 OVERVIEW AND BACKGROUND ON STORMWATER POLLUTION FROM METALS SOURCES AT INDUSTRIAL AREAS

This section presents an overview of the activities that can generate stormwater pollution from metals and potential compliance implications for operations at industrial areas. A general overview of typical facility layouts and operations at scrap metal recycling facilities, motor pools, storage areas, and metal fabrication facilities is presented.

The primary metals of concern for permit compliance are lead (Pb), copper (Cu), and zinc (Zn). The regulatory requirements are typically based on acute and/or chronic toxicity levels, or specific concentrations of the metals in the runoff. Acute toxicity occurs when the concentration can cause severe impacts or be toxic to one or more species, often referred to as indicator species, over a short period of time. Chronic toxicity results when prolonged exposure to the pollutant causes severe impacts or is toxic to an organism or species. Table 1-1 lists the metals of concern and the potential sources and activities that can generate runoff-containing metals.

**Table 1-1. Common Sources of Heavy Metals**

| METAL | COMMON SOURCES |
|---|---|
| Copper (Cu) | • Copper flashing<br>• Pressure-treated lumber<br>• Rainfall contact with copper stored outdoors<br>• Wear from vehicle brake pads<br>• Anti-fouling compounds applied to ship hulls<br>• Leaching from wooden pressure-treated structures<br>• Brass fixtures<br>• Roll off containers and dumpsters |
| Zinc (Zn) | • Vehicle traffic areas<br>• Exposed galvanized metal surfaces (e.g., roofs, fencing, storm drain grates, pipes, gutters, light poles, etc.)<br>• Outdoor storage of galvanized metals<br>• Tire wear<br>• Chain link fences<br>• Brass<br>• HVAC systems |
| Lead (Pb) | • Old paint mixtures<br>• Re-suspension of soils containing lead<br>• Old brick walls<br>• Solder |

The heavy metals of concern (Zn, Pb, Cu) can be found as individual elements, can be bonded to each other, or can be associated with each other in a given material. Brass is an example where zinc and copper are bonded or alloyed. Hot Dipped Galvanized (HDG) fences contain zinc, but not copper. Copper downspouts on older buildings are often joined with lead solder. These metals often have the same behavior or response to treatment processes because of their chemical properties. For example, many of the adsorption processes that are used to bind copper to a treatment surface in a BMP will also be applicable to zinc. This will allow for the selection of BMPs that can treat more than one pollutant of concern.

## 1.1 Sources and Processes for Copper Pollution in Stormwater Runoff

The physical and chemical characters and the environmental exposure of the surfaces will dictate the process for releasing copper and other heavy metals into stormwater. Some general observations about the forms and processes that are important in the consideration of the treatment approach are:

- Copper occurs in both particulate and dissolved forms in stormwater.
- As pH decreases, copper tends to dissolve into solution (the dissolved fraction increases).
- Dissolved copper is the most bioavailable and therefore the most toxic to aquatic biota (USEPA, 2007).
- Copper partitioning in stormwater has been evaluated in a number of studies (Sansalone and Buchberger, 1997; Sauvé et al., 2000; Li and Davis, 2009).
- Dissolved copper has a strong tendency to form complexes with dissolved hydroxides, carbonates, and dissolved organic matter. Studies have measured dissolved copper speciation in stormwater, finding that a majority of dissolved copper was present in a complexed form (Sauvé et al., 2000; Dean et al., 2005).

A study in Washington State (Golding, 2008) identified several environmental factors that influence the degradation and leaching of copper. Specific physical features (e.g., building surfaces, parking areas) can affect the release of copper into stormwater. Table 1-2 is a summary of those factors.

**Table 1-2. Environmental Factors Influencing Degradation and Leaching of Copper**

| FACTOR | PERTAINS TO | ANTICIPATED EFFECTS |
|---|---|---|
| Initial copper content | Algae resistant composition shingles | More granules → More Cu released<br>Larger granules → Cu released over longer time period |
| Age of feature | All features | Copper release higher in new features or in significantly older features |
| Weathered patina | Copper metal | Patina consists of copper sulfides, etc., that slow development of copper corrosion after 30+ years [24] |
| Physical orientation | Gutters & downspouts; Ornamentals | North facing or somewhat sheltered features may not dry, thereby increasing corrosion rate [18,19,37] |
| Galvanic action | All | Adjacent use of incompatible metals or presence of electrically induced currents will increase corrosion rates |
| Nearness to ocean | All | Salt content of air will increase corrosion rate [18] [20] |
| Rainfall chemistry | All | Low pH rain releases more copper |
| Rainfall frequency | Roof | More frequent and intense rainfall: more Cu removed |
| Rainfall frequency | Gutters | More frequent rainfall: less Cu removed from gutters where organic matter would otherwise accumulate and increase corrosion |
| Maintenance | All | Re-exposed/re-soldered copper features corrode faster than untouched features |
| Runoff or groundwater | Foundation wood | Higher flows → increased leaching of copper-containing wood preservative. However, this source releases much less copper than a roof made of that metal. |

## 1.2 Potential Pollution Sources at Scrap Metal Recycling Facilities

Outdoor storage areas that are not associated with industrial activities may generate significant heavy metals loads that have similar characteristics and impacts to industrial areas. The stormwater management for permanent and temporary storage of containers, materials, and loading and unloading of materials can potentially be addressed by using the same strategies that are recommended for industrial areas. Figure 1-1 is an illustration of typical physical features at storage and loading areas. Pallets, containers, stockpiles of materials, and the storage of equipment and materials can be significant sources. The leaching of metals from surfaces that are exposed or rusted can result in soluble or particulate metal loads. The abrasion of surfaces through handling in paved or unpaved areas can result in particulates. Brake dust from vehicles as well as physical features, such as gates, light poles, and utility boxes can also contribute to pollutant loads.

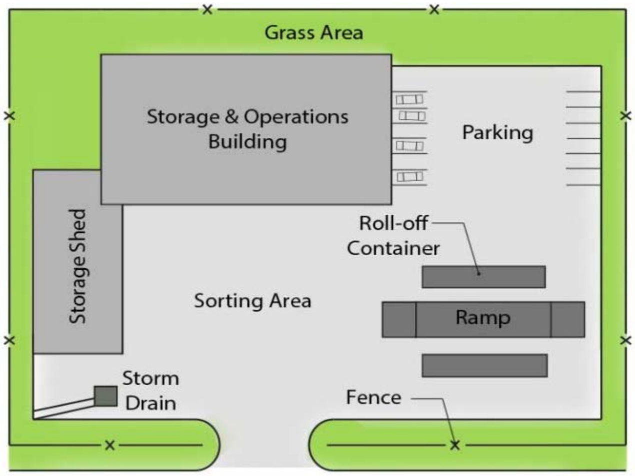

**Figure 1-1. Schematic of Navy Recycling Facility**

Many outdoor storage areas were constructed before post-construction BMPs were required as part of the building, site, and environmental permits. In these cases, the pollutants may be directly conveyed in the runoff to the storm drain inlet, and outfall directly to the receiving waters. Figure 1-2 is an example of storage areas that are unpaved and have direct connections through overland flow to a storm drain system.

**Figure 1-2. Drain for Untreated Runoff**
Source: U.S. Navy

## 1.3 Potential Sources of Pollution at Motor Pools

Motor pools and associated storage areas are places where vehicles are stored while awaiting mobilization or repair. Trailers, specialized equipment that is towed by vehicles and materials that will be loaded and hauled by the vehicles are often parked and stored at the facility while vehicles are being repaired or stored. Figure 1-3 is an illustration of typical physical features that are found at motor pools. Metal roofs, siding, light poles, fences, storm drain grates, and utility vault covers are all potential sources of metals. The cutting and storage of metals are the primary concern from repairs or modifications to vehicles. Operations such as loading and unloading of materials, frequent turning of trucks and other vehicles, and storage of vehicles can generate a significant amount of brake dust, which contains copper, zinc, and other contaminants, along with tire wear, oils, and other fluids, which will contain zinc. Some motor pool operation and storage areas might not be completely paved and vehicles will generate sediment loads from these areas. Figure 1-4 is a picture of activities at a motor pool.

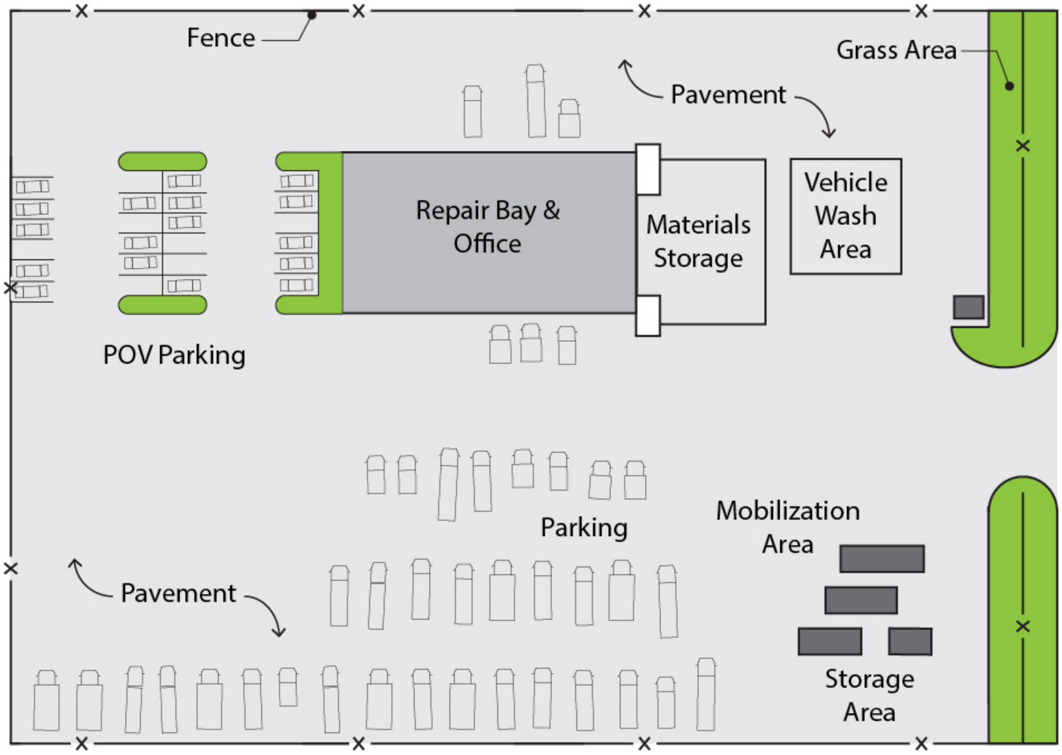

**Figure 1-3. Site Plan of Motor Pool**

**Figure 1-4. Historical Picture of Motor Pool**
Source: U.S. Navy

## 1.4 Potential Sources of Pollution at Metal Fabrication Shops

Metal fabrication typically occurs within warehouse-type buildings. These are often large metal structures with significant air handling and HVAC units on the exterior. Sheets and tubes of metal are often stored or handled outside. Some welding and cutting may occur outside of the building, as well as abrasion of the raw metal products from handling and storage. A significant amount of brake dust and tire wear may be present at truck or forklift loading and unloading areas. Figure 1-5 is a typical site plan layout. The mechanisms and processes that generate metal contamination in stormwater are similar to both motor pools and recycling centers. Figure 1-6 is a picture of outdoor metal storage at a fabrication shop.

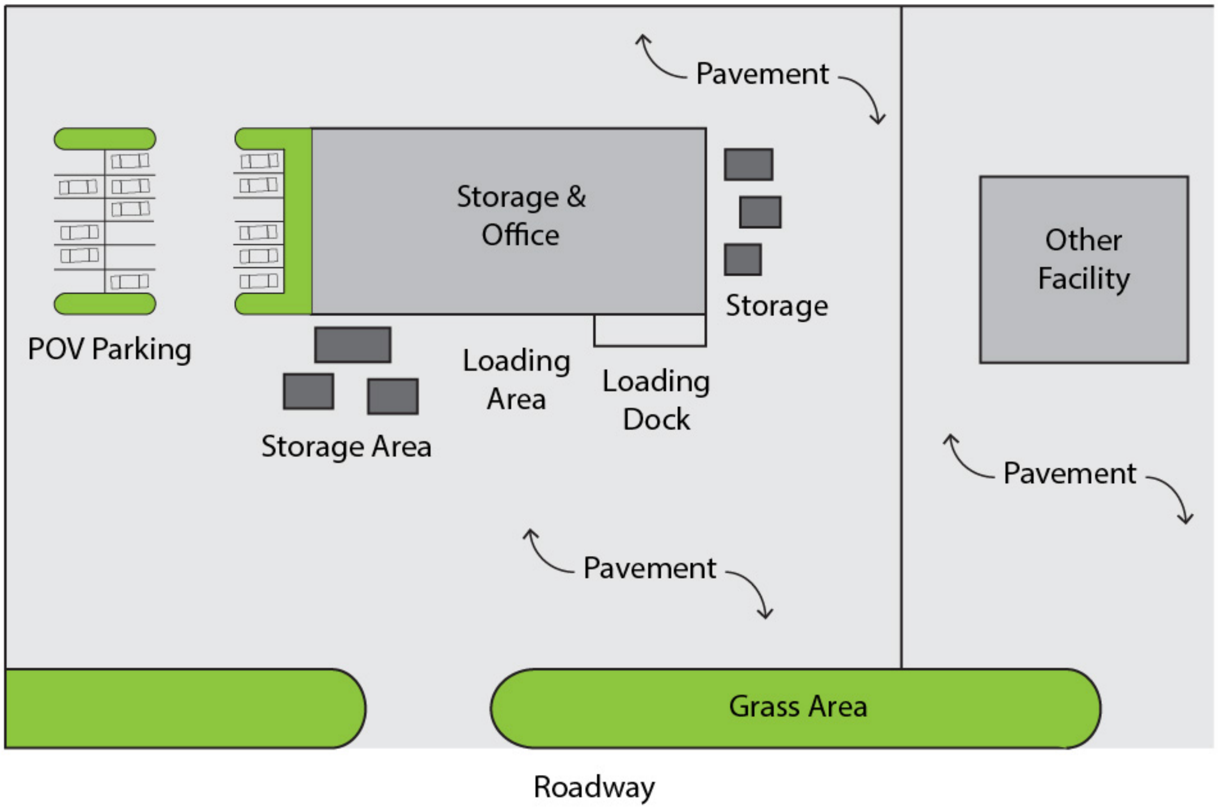

**Figure 1-5. Site Plan of Metal Fabrication Shop and Area**

**Figure 1-6. Metals Storage Area**
Source: U.S. Navy

## 1.5 Potential Pollution Sources at Outdoor Storage Areas

Outdoor storage areas that are not associated with industrial activities may generate significant heavy metal loads that have similar characteristics and impacts to industrial areas. The stormwater management for permanent and temporary storage of containers, materials, and loading and unloading of materials can be potentially addressed by using the same strategies that are recommended for industrial areas. Figure 1-7 is an illustration of typical physical features at storage and loading areas. Pallets, containers, stockpiles of materials, and the storage of equipment and materials can be significant sources. The leaching of metals from surfaces that are exposed or rusted can result in soluble or particulate metal loads. The abrasion of surfaces through handling in paved or unpaved areas can result in particulates. Brake dust/tire wear from vehicles can also contribute to loads. Physical features, such as gates, light poles, and utility boxes can also contribute to loads.

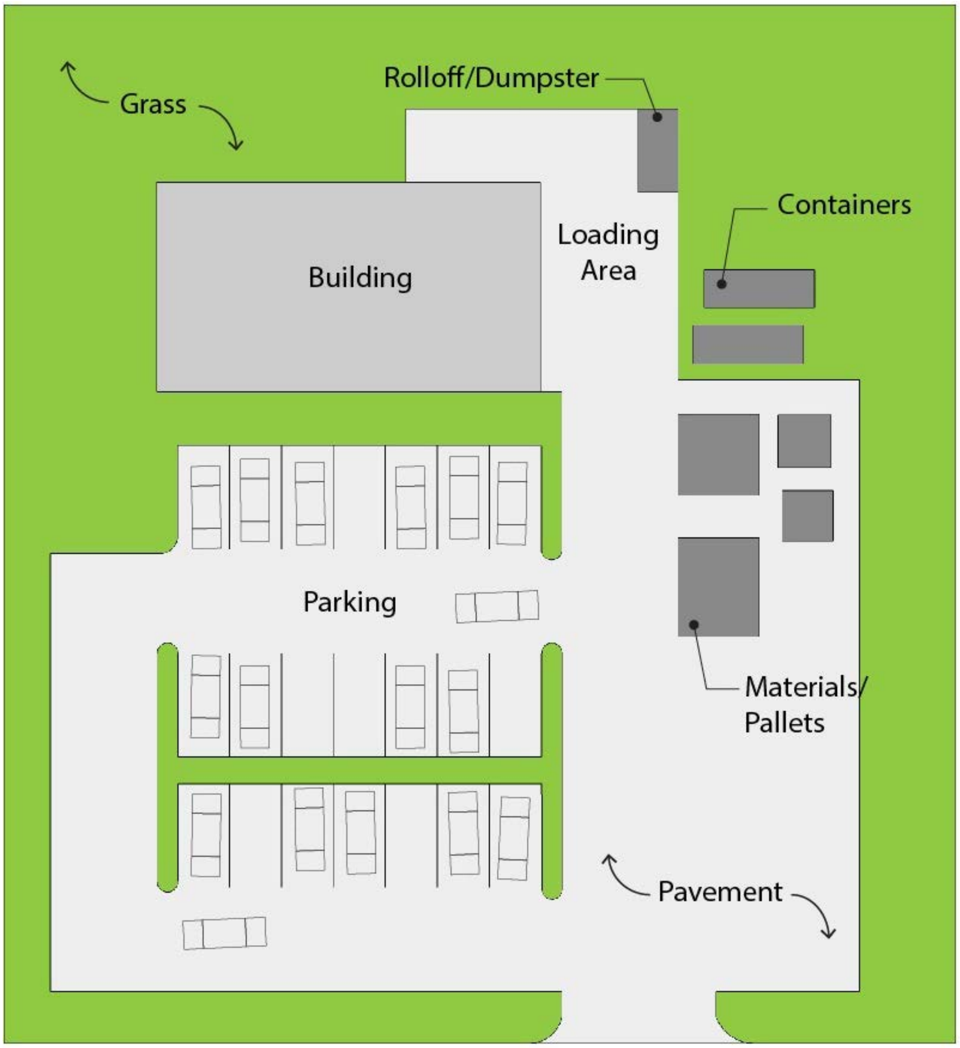

**Figure 1-7. Schematic of Storage Area**

Many outdoor storage areas were constructed before post-construction BMPs were required as part of the building, site, and environmental permits. In these cases, the pollutants may be directly conveyed in the runoff to the storm drain inlet, and outfall directly to the receiving waters. These areas can generate significant amounts of sediments and heavy metals. Figure 1-8 is an example of storage areas that are unpaved and have direct connections through overland flow to a storm drain system.

**Figure 1-8. Unpaved Storage Area**
Source: U.S. Navy

## 2.0 DEVELOPMENT AND USE OF THE DECISION SUPPORT SYSTEM

This section provides the background for the Decision Support System (DSS) and how it is used to select appropriate management and LID BMP techniques at the installation level. It is recognized that many organizations at the installation, region, and headquarters are involved in the development of compliance strategies and programs. This DSS is a synthesis of the considerations and metrics for Environmental, Capital Improvement, Public Works and Asset Management activities. The users for specific tasks are suggested and may be assigned to someone else deemed more appropriate. It is recognized that information on pollutant load determinations and the effectiveness of different BMPs is quite complex and much of the science is still emerging. A significant amount of this information is included in the literature review and research report that is a part of this research effort (EXWC 2014). This DSS presents generalized and “common sense” approaches for selection of practices that are cost-effective and will have positive results at reducing or eliminating heavy metals from stormwater. More detailed and complex compliance and monitoring projects and programs should utilize the information from the research report to develop compliance strategies and plans.

The DSS will require that the user (Environmental) calculate the annual runoff volume of stormwater from the site. This can be accomplished through many different modeling and assessment approaches. The DSS will use the Simple Method (Schueler, 1987). The Event Mean Concentration (EMC) of the expected pollutant load for the area is then multiplied by the result in order to determine the projected annual pollutant load. This information is used to determine the appropriate BMP technology, or suite of technologies, that can be used to reduce or eliminate the pollutant load.

The DSS is organized and presented through a series of flowcharts, templates of typical facilities and locations of potential sources runoff pollution, and templates of potential BMP solutions. The typical potential sources of stormwater pollution runoff identified on any of these facilities are:

- Building roofs and structures (this includes antennas, HVAC systems, flashing, and surfaces)
- Downspouts and gutters
- Fences
- Metal inlets and grates
- Storage and processing areas
- Parking and loading areas

The potential pollutant load in the DSS is calculated using one or more assessment methods that range from the use of simple look up tables for the type and extent of the land use to sophisticated and calibrated stormwater models. The selection of the methods is based on the user (Environmental) needs for the level of detail and accuracy that is required for the regulatory process. The user then determines if the potential amount of runoff is significant enough to warrant mitigation measures to reduce or eliminate the load. For example, a small copper roof may be a significant source or pollutant load per square foot, but because the roof area is small, the resultant load may be minimal when compared to larger land uses that generate lower concentrations of pollutants.

Two (2) approaches for reducing stormwater pollutant loads can be used, separately or in combination. The first approach is the reduction or elimination of the potential source or discharge of the polluted runoff to the receiving waters. This can be achieved through non-structural management practices such as, but not limited to, changes in operations, good housekeeping, or limiting the exposure of the surfaces to precipitation. The cost of covering or containing the surfaces and the potential effect on the efficiency and management of the facility are the key considerations for the first step. The second approach is the treatment of the pollutant through combinations of biological, chemical, and physical unit processes found in a structural BMP. A series of fact sheets is provided to the user (Environmental, Capital Improvements, Asset Management, Public Works) with detailed information on the sizing, design, construction, effectiveness, and maintenance of the LID BMPs. The fact sheets included in Appendix C of this document are:

- Bioswale
- Filter mat
- Sand/Media Filters
- Permeable Friction Course
- Permeable Pavement
- Vegetated Filter Strips
- Tree Box Filter

The DSS will present both of these approaches so that the user can determine the most cost-effective and efficient pathway to compliance that is acceptable for the operations of the facility and the overall installation.

The application and modification of conventional non-structural and structural BMP approaches may be required because of the unique physical and operational requirements of many Navy industrial activities. A series of templates have been developed to guide the user (Capital Improvements, Asset Management) for the proper location, configuration, and design of the practices. The document provides the following design templates in Appendix B:

- Sheet 1: Schematic of BMP Practices
- Sheet 2: Building Improvements
- Sheet 3: Downspout Disconnection
- Sheet 4: Filter Strip
- Sheet 5: Bioswale and Curb Cut
- Sheet 6: Tree Box Filter and Proprietary Devices
- Sheet 7: Metal Fence Treatment
- Sheet 8: Inlet Modification
- Sheet 9: Processing and Storage Area
- Sheet 10: Curb Cut

Figure 2-1 is a graphic representation of the potential BMP practices that are identified in Sheet 1: Schematic of BMP practices. The selection of the practices is based on the results of the DSS.

The process for the use of the DSS is illustrated in Figure 2-2 and is followed by a description of each of the key elements in the DSS.

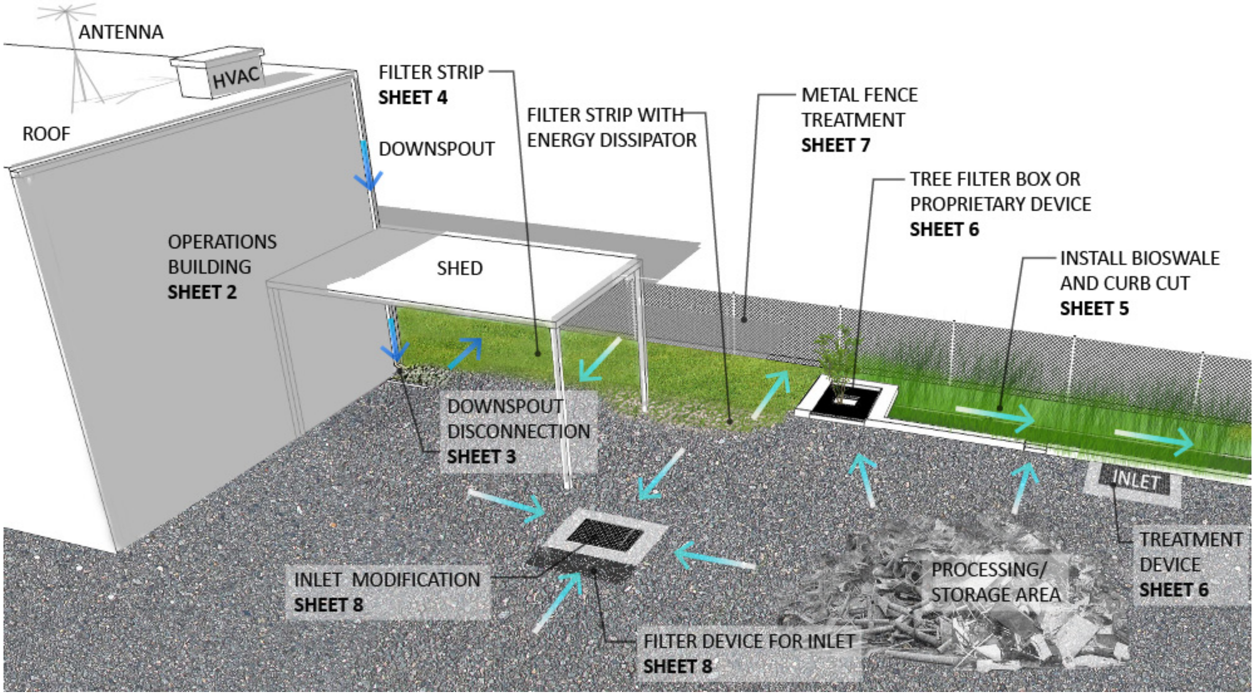

**Figure 2-1. Schematic of Potential LID Treatment Options**

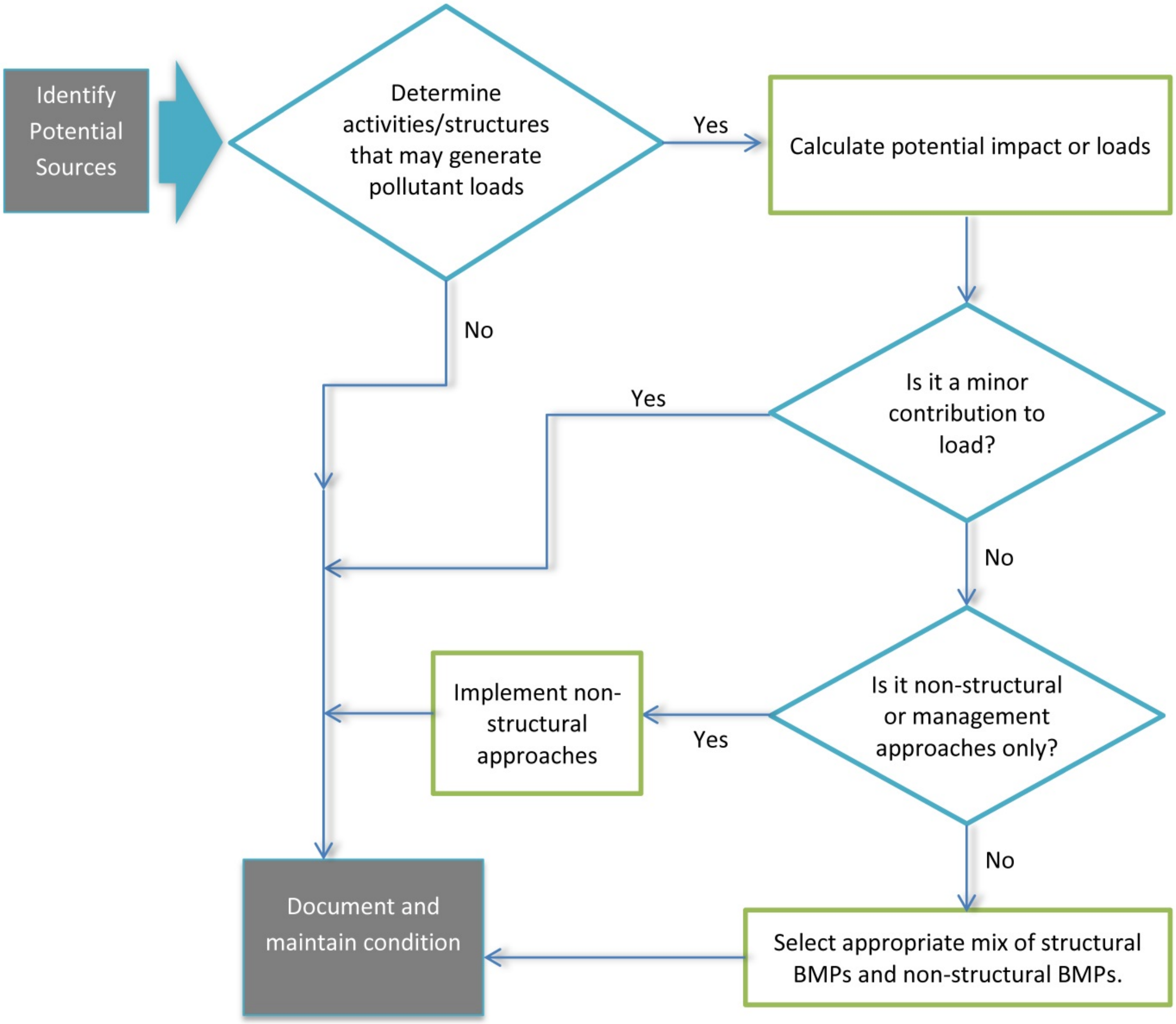

Figure 2-2. DSS Flowchart

**Identification of Sources:** The user (Environmental) identifies the potential activity or installation facility that may contain metal surfaces that can generate stormwater runoff, or are subject to metal pollution through the process of deposition. The installation should develop a list and location of these activities.

**Determine Activities and Structures That Can Generate Metals Pollution:** The user identifies the individual structures, physical features, and activities at the facility that can generate metal pollutant loads.

**Calculate Pollutant Loads:** Appropriate assessment methods and measurements are conducted in order to determine the potential pollutant load. The type and extent of investigation is a function of the regulatory compliance program.

**Is It a Minor Contribution to the Pollutant Load:** This step is used to determine if the source of the potential pollutant load is of concern or will have an impact on the permit requirements. If the load is minor and is considered to have no significant effect then the DSS process is essentially complete. This is based on analysis of the individual land use or operational source in relationship to the overall facility load and/or the pollutant load of the facility in relationship to the overall watershed load. The threshold for determining if a load is minor or not is based on the goals and objectives of the overall watershed master plan or compliance strategy and will be specific for each installation. For example, the pollutant loads from the exterior fencing may only be a small percentage of the sum of all the pollutant loads from the facility. As a guideline, loads that contribute to less than 10% of the pollutant load from the facility can be considered a minor load.

**Determine if Non-Structural BMPs are Adequate.** The pollutant load may be eliminated or reduced to the point where it has no significant effect by non-structural practices such as covering piles of metals, establishing vegetation, or good housekeeping. Non-structural practices can be employed at little or no cost and with minimal or no significant disruption to activities. Practices such as covering materials, coating materials, or substituting materials that have lower potential for generation of pollutants are effective strategies. If the reduction goals cannot be accomplished employing reasonable cost and operational requirements, the user (Environmental, Public Works, Capital Improvements, Asset Management) should investigate the use of structural BMPs. This may be done with an appropriate combination of non-structural practices or as stand-alone practices. This may be an iterative process where the cost, operational, and maintenance requirements are unique to the installation.

**Document and Maintain Improvements and Recommendations:** Proper documentation that includes regular inspection and maintenance requirements are essential to the success of non-structural and structural practices.

## 3.0 DETERMINATION OF STORMWATER POLLUTANT LOADS AND APPROPRIATE BMPS

The most suitable non-structural and structural BMP for a given drainage area is determined by balancing the degree of pollutant removal, or efficiency, needed against the physical constraints of the location, as well as the cost and maintenance requirements associated with the BMP. The speciation, concentration, and volume of the runoff/pollutant load must be determined in order to develop an effective BMP mitigation strategy. The effectiveness of the BMP is based on the biological, chemical, and physical processes within the facility to treat the specific or range of pollutant types. Three steps are employed to determine the effectiveness of BMPs:

- **Determine Stormwater Volume:** The first step in the process is to identify the amount of runoff volume that occurs at the facility. This may be for a discrete period of record, such as a year, for a series of storm events or for a single event. The period is identified by the permit requirements.
- **Identify Pollutants of Concern and Mass or Concentration of Pollutant:** The next step is to determine the type of pollutant and the mass of the pollutant that must be treated.
- **Determine Appropriate BMPs:** The final step is to determine the appropriate BMP technique or combination of techniques, along with non-structural control measures, that can reduce or eliminate the pollutant load to the required threshold.

Once this is accomplished, the user (Environmental, Public Works, Asset Management) can develop appropriate management and BMP locations, followed by development of a long-term inspection, maintenance, and reporting system. The specific location, configuration, and design of the BMPs may be an iterative process because of the unique conditions at every facility. A Case study that is used to demonstrate the process for developing these strategies is found in Appendix A.

### 3.1 Calculation of Stormwater Runoff Volumes

The amount of copper, lead, and zinc found in stormwater is a function of the concentrations of the heavy metals and the overall runoff volume originating from the site over a period of time. The volume can be determined for a single event, on an annual basis, or over another specified time period, such as a year or an average year. The volume of runoff on any site or watershed is a function of the hydrologic cycle, shown in Figure 3-1. The processes found in the hydrologic cycle (e.g., evaporation, transpiration, runoff, infiltration, etc.) can vary greatly throughout the country due to different climates, soils, groundwater tables, vegetation, land use, and many other factors.

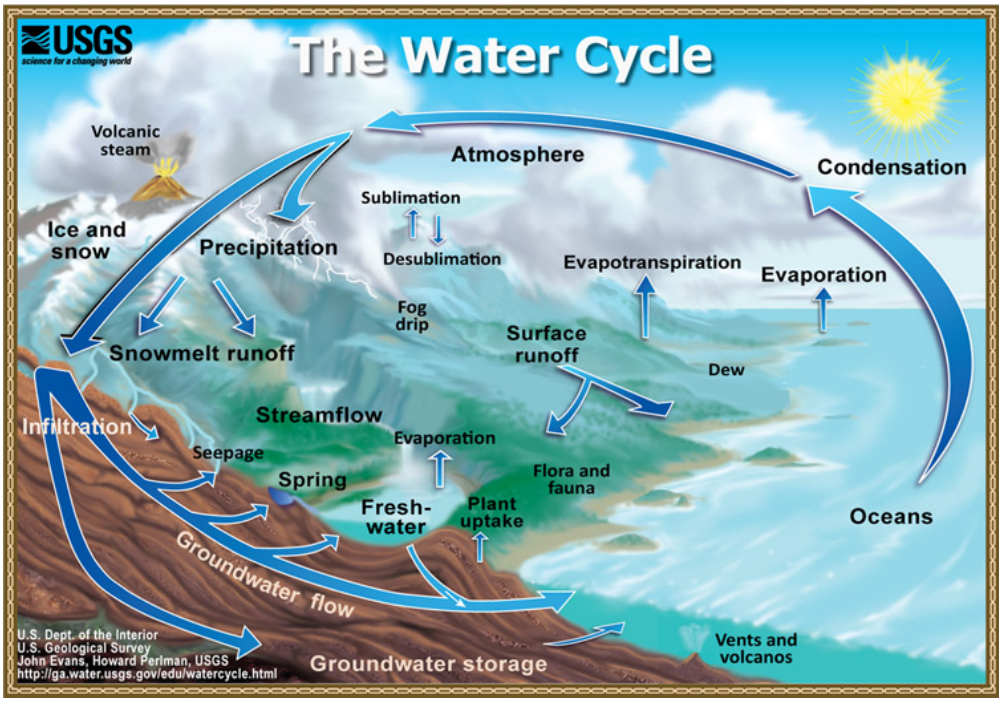

**Figure 3-1. Water Balance**
Source: USGS

Many regulatory programs, such as the National Pollutant Discharge Elimination System (NPDES) Total Maximum Daily Load (TMDL) program, require the calculation of the pollutant on an annual load basis. The determination of the annual rainfall volume or depth is often the first step that must be completed in the process. This information is readily available through the National Weather Service. Table 3-1 is a summary of annual rainfall at various coastal locations throughout the United States, which was included in the LID United Facilities Criteria (UFC) (US Navy, 2010). The table also includes the 95th percentile rainfall event, which is useful in developing compliance approaches for Section 438 of the Energy and Independence Security Act. Other methods and models may be used in the regulatory programs, including discrete events such as the 2-year 24-hour storm event.

**Table 3-1. Summary of Rainfall Data**

| DESCRIPTION | STATE | WEATHER STATION ID | APPLICABLE UNIT IDENTIFICATION CODE | ANNUAL RAINFAL DEPTH (inches) | 95th PERCENTILE (inches) | RAINY DAYS |
|---|---|---|---|---|---|---|
| San Diego WSO Airport | CA | 047740 | 62473 (1 mi.), 00681 (30 mi) | 11.69 | 1.28 | 23 |
| Jacksonville WSO Airport | FL | 084358 | 57061 (18.75 mi), 68248 (mi), 46134 (17.5 mi) | 52.35 | 2.12 | 74 |
| New Orleans WSMO Airport | LA | 166660 | 44218 (9 mi) | 65.10 | 2.48 | 77 |
| Portland WSFO Airport | MA | 176905 | 44214 (24 mi) | 42.49 | 1.55 | 71 |
| Norfolk WSO Airport | VA | 446139 | 62470 (5.7 mi) | 44.36 | 1.63 | 74 |
| Seattle Tacoma AP WBAS | WA | 457473 | 44255 (17 mi) | 37.11 | 1.03 | 87 |

Source: Unified Facilities Criteria (UFC), Low Impact Development, UFC 3-210-10, 2010.

Many methods are used to calculate the amount, or volume, of runoff and the resultant pollutant loads for regulatory compliance. These vary greatly in complexity, user requirements, required data, calibration, accuracy, and level of effort. More sophisticated or data intensive models can utilize the actual rainfall data, the project site soils types, vegetation, and land cover to calculate the runoff and pollutant loads. This includes the Windows Source Loading and Management Model (WinSLAMM™) and the Stormwater Management Model (SWMM). These models can be calibrated using monitoring data or user-specified data for individual pollutants. The functionality of these models is very site-specific and requires extensive knowledge of the site conditions for calibration and use. They are often used to demonstrate the effectiveness of BMPs in order to calibrate less complex models and methods that are used by regulatory and resource agencies in the permit process.

The DSS will utilize the Simple Method (Schuler, 1987) to calculate stormwater runoff volumes. It is widely accepted as both a screening and a regulatory compliance tool. The method can be easily modified for local conditions and calibrated to local information on pollution concentrations in runoff. In many instances, a more complex model and calibrated data will be required. In those cases, the Simple Method can be used to justify the investment for additional investigations. It should be noted that the loading calculations are a guide and that the stormwater permits or local research may dictate the actual load calculations. The calculations are presented in Equation 3-1. The equation accounts for minor losses of runoff volume due to evapotranspiration or surface storage by adjusting the Runoff Coefficient (Rv). The annual rainfall volume is also modified using an adjustment factor (Pj) for smaller rainfall events that do not produce runoff.

**Equation 3-1: Determination of Runoff Volume**

$$R = P * P_j * R_v$$

Where:
R = Annual runoff (inches or millimeters)
P = Annual rainfall (inches or millimeters)
$P_j$ = Fraction of annual rainfall events that produce runoff (usually 0.9)
$R_v$ = Runoff coefficient = 0.05+0.9Ia
Ia = Impervious fraction

An example calculation of annual runoff from a scrap metal recycling facility is presented in Equation 3-2. In this example, a one-acre scrap metal recycling facility is 100 percent impervious. The land cover is either building roof, shed, or pavement for parking and operations. The site is located in San Diego, California. For this example, the average annual rainfall is 11.69 inches. The resultant annual runoff depth for the site is 9.99 inches per year.

**Equation 3-2. Calculation of Runoff Example**

$$9.99 \frac{in}{yr} = 11.69 \frac{in}{yr} * 0.9 * (0.5 + 0.9 * 1)$$

Where:
R = Annual runoff (inches or millimeters)
P = Annual rainfall (inches or millimeters)
$P_j$ = Fraction of annual rainfall events that produce runoff (usually 0.9)
$R_v$ = Runoff coefficient = 0.05+0.9Ia
Ia = Impervious fraction

### 3.2 Determination of Pollutant Loads

The pollutant load is determined as a product of the annual depth of runoff, the contributing area, and the concentration of the pollutant (mass per volume). The concentration is based on the Event Mean Concentration (EMC) of the runoff event or events. The EMC is the total constituent mass (pollutant) divided by the total runoff volume. This is usually expressed as mg/L and then converted to pounds in the loading calculation. Equation 3-3 uses the EMC to determine the annual load and is provided below. The equation can also be modified to determine the load using SI units.

**Equation 3-3. Determination of Pollutant Load**

$$L = 0.226 * R * C * A$$

Where:
L = Annual load (lbs/yr)
R = Annual runoff (inches/yr)

C = Pollutant concentration (mg/L)
A = Area (acres)
0.226 = Unit conversion factor

An example of the determination of the annual pollutant load is presented in Equation 3-4. In this example the runoff depth that was determined in Equation 3-2 (9.99 inches/yr) is used along with an EMC of 3.0 mg/L, and a surface area of 3 acres. The result is an annual load of 135.5 lbs/year.

**Equation 3-4: Example Pollutant Load Calculation**

$$135.5\frac{lbs}{yr} = 0.226 * 9.99\ \frac{in}{yr} * 20\frac{mg}{l} * 3\ ac$$

Where:
L = 135.5 (lbs/yr)
R = 9.99 (inches/yr)
C = 20 (mg/L)
A = 3 (acres)
0.226 = Unit conversion factor

Stormwater pollutant concentrations can be estimated from local, state, or national data sources or from direct measurements. Many regulatory programs also use surrogate pollutants, such as loads of Total Suspended Solids (TSS) to determine the loads of metals in stormwater. This is because metals are often associated with a component of the sediment load. The mass, or concentration, of the heavy metals is based on a percentage of the overall TSS load. The removal or treatment of the runoff is then based on a capture or treatment of the overall percentage of stormwater or TSS loads. Table 3-2 presents an average concentration of a range of pollutants that can occur in stormwater, based on national averages. The median values at the local site or watershed level may vary greatly from these median concentrations.

**Table 3-2. National Median Concentrations for Chemical Constituents in Stormwater**

| CONSTITUENT | CONCENTRATION (mg/L) |
|---|---|
| TSS | 54.5 |
| TP | 0.26 |
| TN | 2.00 |
| Cu | 0.011 |
| Pb | 0.051 |
| Zn | 0.129 |

Adapted from Management, N. Y. S. S. (1987)

Stormwater loads can be calculated at various scales from site-specific to watershed wide. This is dependent on the compliance and management goals, available information, and the accuracy of data and computations that is required. The concentrations can vary over time as coatings on metals deteriorate or they begin to corrode. Localized conditions, such as acid rain, windblown dust and particulates, or periods of wet and dry may drastically affect the runoff concentrations. It should be noted that there is a great variation in the concentrations between different land covers or uses. Table 3-3 provides concentration data for a range of representative land uses in a specific watershed in New York. Residential roofs had a concentration for copper of 20 μg/L while industrial roofs had a concentration 62 μg/L.

**Table 3-3. Pollutant Concentrations from Source Areas**

| LAND USE | TSS (mg/L) | Cu (μg/l) | Pb (μg/l) | Zn (μg/l) |
|---|---|---|---|---|
| Residential Roof | 19 | 20 | 21 | 312 |
| Commercial Roof | 9 | 7 | 17 | 256 |
| Industrial Roof | 17 | 62 | 43 | 1,390 |
| Commercial and Residential Parking | 27 | 51 | 28 | 139 |
| Industrial Parking | 228 | 34 | 85 | 224 |
| Commercial Street | 468 | 73 | 170 | 450 |
| Landscaping | 37 | 94 | 29 | 263 |
| Auto Recycler | 335 | 103 | 182 | 520 |
| Heavy Industrial | 124 | 148 | 290 | 1600 |

Adapted from Management, N. Y. S. S. (1987)

The concentrations may also vary greatly from individual building, site, and infrastructure components. Table 3-4 shows some representative results for building components, infrastructure features, and stored materials that are exposed to the elements (Arias, 2014). The study tested different surface areas for their release of heavy metals into solution.

Table 3-4 are some representative results from a database that has been created to estimate metal fluxes from rainfall off of materials commonly found in Navy facilities (Arias, 2014). This database is based on a specific metals mass release from a surface during a washing event. The study shows that small areas with highly soluble or degradable surfaces can have a significant impact on the pollutant load. For example, a woodpile treated with copper azole as shown in Figure 3-2 has a zinc load of 50,000 μg/ft$^2$. It would take 100 times the same surface area of a galvanized staircase, as shown in Figure 3-3, to have an equivalent load of zinc. The surfaces were only tested one time in this study. The annual load from the surfaces may be quite different. Equation 3-1 is used to estimate annual metal loads from various surfaces and materials using this surface wash off information (Davis et al. 2001). Metals are being contributed with each rainfall event.

**Equation 3-1. Determination of Pollutant Load From Surface Wash Off**

$$L = 2.2x10^{-9} * N * S * A * F$$

Where:

L = Annual load (lbs/yr)
N = Average annual number of runoff-producing rainfalls (number/yr)
S = Surface pollutant wash off flux (μg/ft$^2$)
A = Area of object/surface (ft$^2$)
F = Factor to account for first flush (range from 0.2 to 1)
$2.2x10^{-9}$ = Unit conversion factor (μg/lb)

The surface wash off flux is an estimate based on a single evaluation. A similar study on washing lead-painted walls show that continued washing will dilute the metals concentrations as more water is used, suggestive of a first flush effect (Davis and Burns 1999). A steady state concentration of about 20% to 40% of the initial flush was noted. This is the reasoning behind the first flush factor, F, used in Equation 3-2. Without additional information, a default value of 0.5 may be assumed.

An example of the determination of the annual pollutant load, specifically copper, from surface wash off is presented in Equation 3-2. In this example, the number of runoff-producing rainfall events is estimated as 52 (one per week). The surface pollutant washout flux for wood, treated (copper azole) is 5,100 μg/ft$^2$ (for copper), with an exposed wood area of 48 ft$^2$ (4x12 ft). The result is an annual copper load of 0.014 lbs/year.

**Equation 3-2: Example Pollutant Load Calculation for Copper**

$$0.014\ \frac{lbs}{yr} = 2.2x10^{-9} * 52\ \frac{washes}{yr} * 5100 \frac{\mu g}{ft^2} * 48\ ft^2 * 0.5$$

Where:

L = 0.014 (lbs/yr) copper
N = 52 (washes/yr)
S = 5100 (μg/ft$^2$) copper
A = 48 (ft$^2$)
F = default = 0.5
$2.2x10^{-9}$ = Unit conversion factor

It should be emphasized that the methods presented above are very simplistic and should only be used for the screening of "hotspot" pollutant areas and situations. A more accurate accounting of metal loads would involve site-specific monitoring of areas.

**Table 3-4. Concentration of Copper Loads**

| TYPE OF USE | TYPE OF SURFACE | CONCENTRATION ($\mu g/ft^2$) |
|---|---|---|
| Building | Concrete wall | 80 |
| Building | Galvanized exterior stairs | 50 |
| Building | Copper flashing | 10 |
| Building | Metal siding | 5 |
| Infrastructure | Water Riser with brass fittings | 250 |
| Infrastructure | Fire hydrant | 100 |
| Infrastructure | Storm drain grate | 30 |
| Infrastructure | Galvanized fence | 30 |
| Operations/Storage | Pressure treated wood w/ copper | 5000 |
| Operations/Storage | Pressure treated deck material | 150 |
| Operations/Storage | Galvanized scaffolding | 90 |
| Operations/Storage | Dumpster | 15 |

**Figure 3-2. Wood Pile**
Source: U.S. Navy

**Figure 3-3. Galvanized Steps**
Source: U.S. Navy

## 3.3 Selection of Structural BMP Technology

Several types of BMPs are appropriate for use at a facility to mitigate the stormwater pollution. This section presents criteria that can be used to select the appropriate structural BMPs for the facility. A wide range of criteria and factors must be considered when selecting the BMP or suite of BMPs. The criteria can be based on qualitative and quantitative metrics. These include, but are not limited to, the efficiency of treatment, cost for construction, availability of materials, durability, maintenance requirements, and appearance. The user (Environmental, Public Works, Asset Management) must develop specific criteria for use at the installation or for the specific activity in order to meet the selection requirements. A series of matrices and tables that can be used to assist in the selection of BMPs and that can be customized for each installation is included in this section.

### 3.3.1 Unit Processes for Removal of Heavy Metals in Stormwater

Removal of pollutants from stormwater is achieved by applying a combination of physical, chemical and biological unit processes. Table 3-5 summarizes the unit processes that can be used to reduce the pollutant load of metals in the dissolved and particulate forms.

**Table 3-5. Treatment Processes**

| UNIT PROCESS | PARTICULATE METALS | DISSOLVED METALS |
|---|---|---|
| Sedimentation | X | |
| Filtration | X | |
| Sorption & Ion Exchange | | X |
| Precipitation | | X |
| Complexation | | X |
| Plant Uptake | | X |

Stormwater runoff will often contain metals in both the dissolved and particulate form. Therefore, it is important to have processes that can treat both forms present in the selected BMP. Some BMPs will be more effective at one or more of the unit processes, so an understanding of the pollutant load and source is critical to the selection of the BMP or BMPs in a series to effectively treat the runoff. In general, the more unit processes a BMP makes use of, the better it will be able to remove pollutants (Scholes et al., 2008). An ideal system would first employ settling to remove coarse solids. This step removes sand, grit, and metal filings, reducing particulate metals loads. Use of settling as a pre-treatment step provides the additional benefit of reducing the chances that BMPs employing filtration farther down the treatment train will clog. After coarse solids are removed through settling, a filtration step can provide removal of fine suspended solids. Once all particulate metals have been removed, dissolved metals can be removed through sorption. This is usually accomplished by passing the stormwater through a sorbent medium. A BMP or treatment train that employs these three unit processes in sequence is likely to provide effective removal of heavy metals, if each of the components is well designed. Table 3-6 lists some common standard LID BMPs that are effective at treating heavy metals and are appropriate for use in industrial areas and their associated unit processes. Table 3-6 lists the hydrologic functions of these BMPs.

**Table 3-6. Comparison of the Unit Processes Employed by LID Stormwater BMPs**

| UNIT PROCESS | BIORETENTION | BIOSWALE | BIOFILTER | PERMEABLE PAVEMENT | MEDIA FILTER | PERMEABLE FRICTION COURSE | COMPOST FILTER MAT | VEGETATED FILTER STRIP | INLET INSERT |
|---|---|---|---|---|---|---|---|---|---|
| Sedimentation | X | X | | | | X | | X | X |
| Filtration | X | X | X | X | X | X | X | X | X |
| Sorption & Ion Exchange | X | X | X | | X | X | X | | X |
| Precipitation | X | X | X | | X | X | X | | X |
| Complexation | X | X | X | | X | X | X | | X |
| Volatilization | X | X | X | | X | X | | X | X |
| Microbial Immobilization | X | X | X | | | X | X | X | X |
| Microbial Transformation: | | | | | | | | | |
| - Ammonification | X | X | X | | | | | X | X |
| - Nitrification | X | X | X | X | | | | X | X |
| - Denitrification | X | | X | | | | | | |
| Plant Uptake | X | X | | | | X | X | X | X |

**Table 3-7. Representative Effectiveness and Use of LID BMPs at Meeting Hydrologic Objectives**

| HYDROLOGIC FUNCTIONS | BIO-RETENTION/ BIOSWALE | PERMEABLE PAVEMENT | FILTER/ BUFFER STRIP | SWALES: GRASS, INFILTRATION, WET WELLS | PERMEABLE FRICTION COURSE | MEDIA FILTER | INLET INSERT |
|---|---|---|---|---|---|---|---|
| Interception | High | None | High | Moderate | None | None | None |
| Depression | High | None | High | High | None | None | Moderate |
| Infiltration | High | High | Moderate | Moderate | None | None | High |
| Ground Water Recharge | High | High | Moderate | Moderate | None | None | High |
| Runoff | High | High | Moderate | Moderate | Low | Moderate | High |
| Peak | Moderate | Low | Low | Moderate | Moderate | Moderate | Moderate |
| Base Flow | Moderate | High | High | Moderate | Moderate | None | Low |
| Transpiration | High | None | Moderate | Moderate | None | Low | None |

Source: Low-Impact Development Design Strategies, prepared by Prince George's County, Maryland

### 3.3.2 Facility Criteria for Selection of BMPs

When selecting the best BMP or set of BMPs for a site, consideration must be given to the particular physical and spatial requirements of the BMP, to the potential impact on operations of the facility, as well as to capital costs and ongoing maintenance requirements. These factors are discussed in the accompanying BMP factsheets in Appendix C. Table 3-8 is a summary of common sizes and drainage areas for LID BMPs. The size and drainage area considerations vary greatly due to regional climate conditions and regulatory requirements. State and local government stormwater design and construction manuals often dictate the type and sizing methods that are used for post-construction stormwater management practices. This prescriptive approach is developed to treat a wide range of pollutants. It may be necessary to modify the designs and sizing strategies to allow for more effective treatment of heavy metals. The user should consult the state and local stormwater design manuals for more detailed guidance on estimating the size of the facilities. Other stormwater objectives, besides the treatment of metals, must be considered when selecting BMPs. Table 3-8 is a summary of performance, maintenance and life cycle costs and other factors for BMP selection that can be used as a general guide for selection.

## Table 3-8. Site Considerations & Requirements

| PARAMETER | BIORETENTION | BIOSWALE | BIOFILTER | PERMEABLE PAVEMENT | MEDIA FILTER | PERMEABLE FRICTION COURSE | COMPOST FILTER MAT | VEGETATED FILTER STRIP | INLET INSERT |
|---|---|---|---|---|---|---|---|---|---|
| Space Required | Minimum surface area range:<br>50 to 200 ft$^2$<br>Minimum width:<br>5 to 10 ft<br>Minimum depth:<br>2 to 4 ft | Bottom width:<br>2 ft minimum,<br>6 ft maximum | | | | Minimum length of 15 to 20 ft | | | |
| Soils | Permeable soils with infiltration rates > 0.27 inches/hour are recommended. Soil limitations can be overcome with use of underdrains. | Permeable soils provide better hydrologic performance, but soils not a limitation. Selection of type of swale, grassed, infiltration or wet is influenced by soils. | | | | Permeable soils perform better, but soils not a limitation | | | |
| Slopes | Usually not a limitation, but a design | Swale side slopes: 3:1 or flatter | | | | Usually not a limitation, but a design | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | consideration | Longitudinal slope: 1.0% minimum; maximum based on permissible velocities | | | | consideration | | | |
| Water Table/ Bedrock | 2- to 4-ft clearance above water table/ bedrock recommended | Generally not a constraint | | | | Generally not a constraint | Generally not a constraint | | |
| Proximity to build foundations | Minimum distance of 10ft downgradient from buildings and foundations recommended | Minimum distance of 10 ft downgradient form buildings and foundations recommended | | | | Minimum distance of 10 ft downgradient from buildings and foundation recommended | | | |
| Max. Depth | 2- to 4-ft depth depending on soil type | Not applicable | | | | Not applicable | | | |
| Maintenance | Low requirement, property owner can include in normal site landscape maintenance | Low requirement, routine landscape maintenance | | | | Low requirement, routine landscape maintenance | | | |

Adapted from: DOD, 2010 and USACE, 2008

### Table 3-9. Relative Performance & Requirements of LID BMPs

| BMP | REMOVAL EFFECTIVENESS | | EFFICIENCY | | |
|---|---|---|---|---|---|
| | METALS | NITROGEN | SPACE | COST[1] | MAINTENANCE |
| Bioretention[3] | 🟢 | 🟢 | 🟢 | 🟢 | 🟡 |
| Bioswale | 🟢 | 🟢 | 🔴 | 🟢 | 🟡 |
| Biofilter | 🟢 | 🟢 | 🟢 | 🟢 | 🟡 |
| Media filter[2] | 🟢 | 🟡 | 🟢 | 🟡 | 🟡 |
| Permeable Friction Course | 🟢 | 🔴 | 🟢 | 🔴 | 🔴 |
| Compost filter mat | 🟢 | 🔴 | 🟢 | 🟢 | 🟡 |
| Vegetated filter strip | 🟢 | 🟡 | 🟡 | 🟢 | 🟡 |
| Inlet Insert | 🟢 | 🔴 | 🟢 | 🔴 | 🔴 |

[1]Pomeroy and Rowney, 2013; [2]Anguiano and Foreman, 2008; [3]Hunt et al, 2012

KEY: 🟢 Good 🟡 Moderate 🔴 Poor

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# GLOSSARY OF TERMS

| | |
|---|---|
| Ammonification | The microbially-mediated conversion of organic nitrogen to ammonium. |
| Complexation | A chemical process in which ions in solution bind with other dissolved substances. |
| Denitrification | The microbially-mediated conversion of nitrate to nitrogen gas. |
| Filtration | The process by which solid particles are removed from water by passing the water through a filtration medium with pores small enough to trap suspended particles, while allowing water to pass through. |
| Heavy metals | A loosely defined subset of elements, mainly transition metals, which can have toxic effects on organisms in the environment. This subset usually includes lead, copper, cadmium, mercury, zinc, chromium, and arsenic, among other elements. |
| Leaching | The process by which a metal or other chemical dissolves into rainwater or stormwater it comes into contact. |
| Load | The quantity of a metal or other chemical that is discharged to a receiving water. |
| Microbial immobilization | The removal of nutrients and pollutants from solution through their uptake and storage within microbial biomass. |
| Microbial transformation | The transformation of nutrients and pollutants from one form to another through their use in microbial respiration or metabolism. |
| Nitrification | The microbially-mediated conversion of ammonium to nitrate. |
| Plant uptake | The removal of nutrients and pollutants from solution through translocation into plant tissue. |
| Precipitation | The chemical process by which dissolved substances come out of solution and into solid form, after which they can be removed via settling or filtration. |
| Sedimentation | The process by which solid particles suspended in water are removed by holding the water for a sufficient amount of time to allow suspended particles to fall out of suspension through the influence of gravity. |

| | |
|---|---|
| Sorption & ion exchange | A set of physical and chemical processes by which dissolved ions are removed from water by adhering to media they come into contact with. |
| Volatilization | The process by which a dissolved substance is converted to a gaseous form, which then escapes into the atmosphere. |

# APPENDIX A: CASE STUDY

# A1.0 CASE STUDY: ASSESSMENT AND IMPLEMENTATION OF LID BMPS AT RECYCLING FACILITY

The following case study will demonstrate a representative approach for determining appropriate LID treatment options through the process identified in the DSS. The goal is to show potential ways that end users can incorporate the use of the calculations, checklists, design templates, and BMP fact sheets into their compliance programs.

## A1.1 Case Study Goals and Scenario

This scenario shows a representative approach to determine the location and type of appropriate LID BMPs for the retrofit of the site infrastructure that is being done in conjunction with the construction of a new processing building at a recycling facility in San Diego. In this scenario, the installation is required to reduce the copper loads at the storm drain outfall that is down gradient of the existing facility. For the purposes of this scenario, a stormwater management master plan has been prepared for the drainage basin. The rest of the basin is built out and there is limited space and opportunities for retrofits to the storm drain system or along the existing roadways infrastructure. This site has been identified as a priority site through modeling efforts as a large source of copper loads due to the activity and amount of materials stored at the facility. The site is approximately 4 acres in size and the watershed is approximately 200 acres. Figure A-1 is a schematic of the site plan. There is an existing building, storage shed, and processing and storage area on the site. The existing building has the roof drains tied into the storm drain system. The site drainage is divided into two areas. Drainage area one is about 1 acre and sheet flows off the property to the southwest corner. This drainage is collected in the street storm drain and is then conveyed to the outfall. Drainage area two is about 3 acres and is collected by an inlet in the northeast quadrant of the property that is conveyed downstream to where it joins with the water that is collected from drainage area one and then to the outfall point. A new 7,000 square foot processing building and the associated site and utility improvements are proposed to help process the volume of recyclable materials.

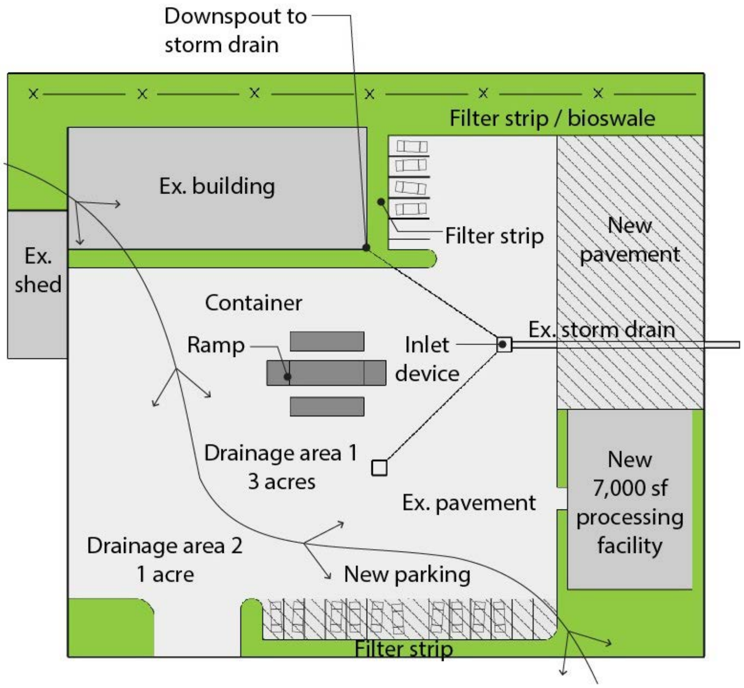


Figure A-1. Site Plan Schematic

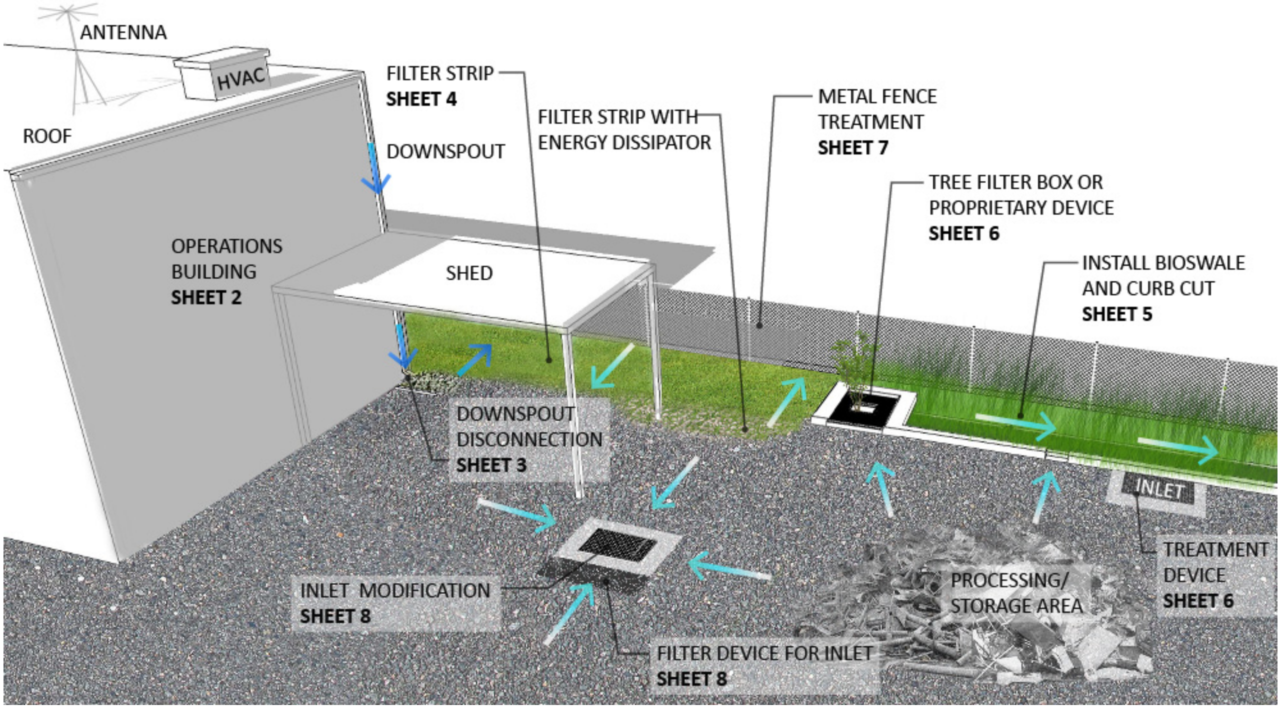


Figure A-2. Schematic of Potential LID Treatment Options

The flowchart shown in Figure A-3 will be followed to demonstrate the process for the DSS and the potential runoff treatment solutions.

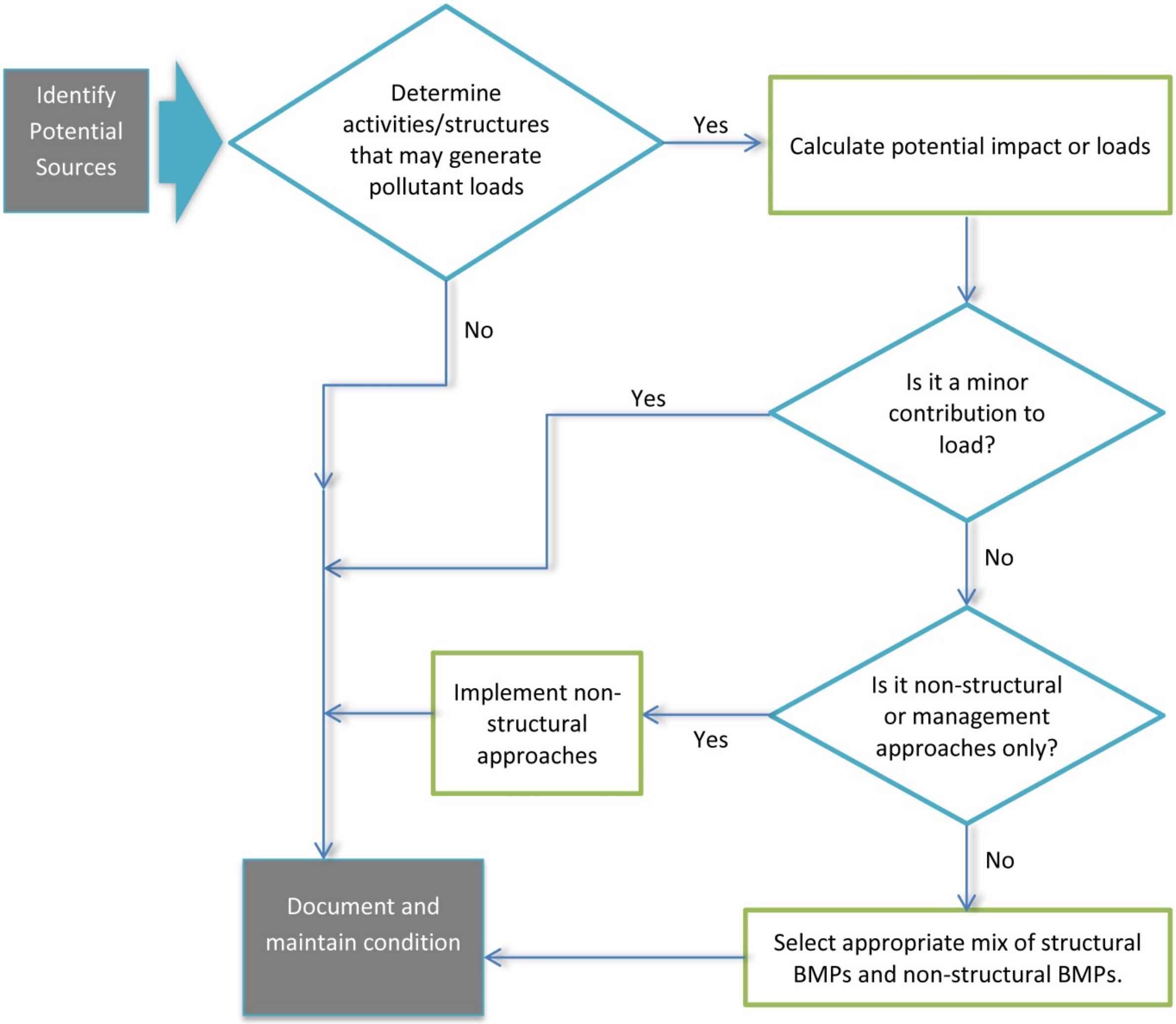


**Figure A-3. DSS Flowchart**

**Step One: Determine activities/structures that may generate pollutant loads.**
This step may require desktop and field evaluations. A desktop analysis using GIS can be used to identify drainage areas, building areas, and areas of parking and site improvements. Field evaluations can be used to determine the types and intensity of activities such as processing areas and storage of materials. For example, the area of scrap copper that is stored outside and waiting to be processed may be consistent throughout the year or it may be infrequent. The copper flashing on a roof may be deteriorating, as another example. It is important to have thorough knowledge of the operations and the field conditions to make effective BMP recommendations that will have predictable and positive results.

The desktop analysis showed that almost a ½ acre of metal roof areas exists on site and that almost 2 acres of pavement with no vegetated areas exist within the perimeter of the paved areas. The results of the site visit showed that several large stockpiles of scrap metal and copper tubing were left in the open until they were cut into smaller sheets, and then they were stored in the shed until they were loaded into trailers and shipped off site. The facilities manager indicated that the size of the stockpile area was consistent due to the amount of metal processed and that there were several pallets of wood and bundles of pressure treated wood that were stored for 3 or 4 months at a time at the facility. The roof leaders on the building are tied directly into the storm drain system. Also, an HVAC system is present on the roof. The metal siding on the building was in good condition and was painted. A significant amount of sediment and debris were collected around the storm drain inlet that is located within the pavement in the northeast drainage area. The existing inlet has a Hot Dipped Galvanized (HDG) grate and the invert is equal to the outfall pipe. The facility manager indicated that there was no sweeping or cleaning of the area around the inlet surface.

The large amount of impervious building and paved areas that contain metals or are exposed to metals and the intensity of uses on the site indicate that this facility has the potential to generate significant amounts of copper loads and the user should calculate the pollutant loads.

**Step Two: Calculate potential pollutant loads.**
The case study presented here will use the results of the study (Arias, 2014) that determined the concentration of copper in runoff from a one-time wash off event. The load will be determined by adjusting the concentration to account for the flux in weather conditions throughout the year (Davis, 2000). In this case study the number of runoff producing rainfall events was determined to be 50. This number can be determined from local rainfall tables. The default value of 0.5 was used to account for the first flush. The results are shown in Table A-1.

### Equation A-1. Determination of Pollutant Load From Surface Wash Off

$$L = 2.2x10^{-9} * N * S * A * F$$

Where:
L = Annual load (lbs/yr)
N = Average annual number of runoff-producing rainfalls (number/yr)
S = Surface pollutant wash off flux (µg/ft$^2$)
A = Area of object/surface (ft$^2$)
F = Factor to account for first flush (range from 0.2 to 1)
$2.2x10^{-9}$ = Unit conversion factor (µg/lb)

### Table A-1. Local Rainfall for Drainage Areas One and Two

| DRAINAGE AREAS | AREA (ac.) | AREA (µg/sq.ft) | Lbs. PER YEAR |
|---|---|---|---|
| **Drainage Area One** | | | |
| Pavement | 0.68 | 3.40 | 0.0055 |
| Roof Good Condition | 0.12 | 1.10 | 0.0003 |
| Building Exterior Walls | 0.01 | 3.00 | 0.0001 |
| HVAC | 0.02 | 1.70 | 0.0001 |
| Galvanized Fence (600 lf) | 0.17 | 4.50 | 0.0018 |
| **Subtotal Drainage Area One** | **1.00** | | **0.0078** |
| **Drainage Area Two** | | | |
| Pavement (Parking) | 1.79 | 3.40 | 0.0146 |
| Processing Area (Pavement) | 0.45 | 80.00 | 0.0862 |
| Copper stockpile | 0.15 | 1600.00 | 0.5750 |
| Pallet Storage | 0.02 | 16.00 | 0.0008 |
| Treated Wood Storage | 0.02 | 5125.00 | 0.2456 |
| Roof Good Condition | 0.08 | 1.10 | 0.0002 |
| New Building Roof | 0.16 | 3.40 | 0.0013 |
| New Building Exterior Walls | 0.07 | 2.80 | 0.0005 |
| New Building HVAC | 0.01 | 1.80 | 0.0000 |
| Galvanized Fence (1000 lf) | 0.25 | 4.50 | 0.0027 |
| **Subtotal Drainage Area Two** | **3.00** | | **0.9347** |
| **Total Drainage Areas 1 and 2** | **4.00** | | **0.9426** |

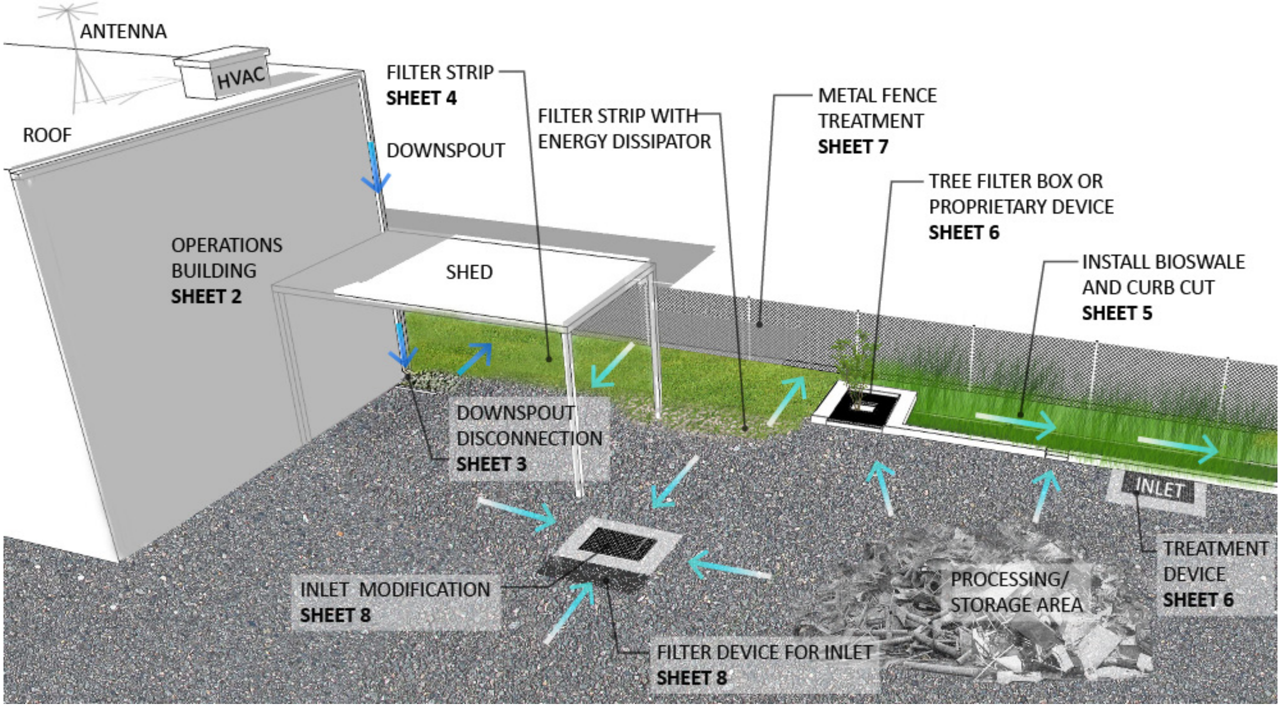
In this scenario the overall copper pollutant load per year is 0.94 lbs per year for the industrial activity and 5 lbs per year from the overall watershed at the discharge/monitoring point. Equation A-2 shows that this will generate approximately 18.8% of the pollutant load for the outfall.

**Equation A-2. Estimated Pollutant Load**

$$19\% = \frac{(0.94\ \frac{lbs}{yr})}{(\ 5.0\ \frac{lbs}{yr})}\ x\ 100\ (conversion\ to\ percentage)$$

**Step 3: Is the area a minor contribution to the load?**
This facility accounts for approximately 19 percent of the entire load for the watershed. This would be considered a significant source and the user (Environmental, Public Works, Asset Management) should proceed to the step for determining the best solution. There will be many instances where the decision is not so clear-cut and the planners may have to develop criteria to rank and prioritize the selection of one or more facilities or land uses in the watershed. The galvanized fencing and the metal building walls are in good condition and little surface rust is evident. Coating or replacing materials would not be effective. Another non-structural approach would be sweeping of the pavement surfaces with a vacuum sweeper. A contract could be solicited or a sweeper could be purchased and maintained by the installation for use throughout the base. The determination on the cost/benefit is more complex and outside the scope of this scenario.

**Step Four: Are only non-structural management approaches only available?**
Non-structural practices are often fairly inexpensive and simple to incorporate. The impact on operations is often the key consideration. When there are site constraints or limited opportunities to install BMPs, options such as coating surfaces, replacing materials, proper storage, and good housekeeping may be the only options. The comparison of the site elements to the schematics shown in the field sheets in Appendix A are useful tools to quickly make the determination on the feasibility of structural BMP practices. Figure A-4 is the overall summary of the Field Sheet Schematics. In this scenario, structural practices that are potentially available are shown on the field sheet. The user (Environmental, Asset Management, Capital Improvement) should proceed to Step 5 in order to determine the most cost effective and efficient mix of practices.



**A-4. Summary of Field Sheet Opportunities**

**Step Five: Select appropriate mix of structural and non-structural BMPs.**
This is often an iterative process where the user (Capital Improvement) must develop criteria for ranking and prioritizing options. Non-structural and management practices are often considered first because they may be relatively low-cost and non-obtrusive solutions. Providing temporary cover such as tarps or moving the stockpile of copper and the treated wood to a covered area to limit exposure to rainfall in this scenario would potentially eliminate approximately 87 percent of the annual load as shown in A-3.

**Equation A-3. Percent Reduction of Pollutant Load Using Non-Structural Practices**

87% = (0.8208 lbs copper from stockpile + 0.2456 lbs from wood storage) / 0.9426 lbs total load x 100 (percentage conversion)

The addition of the new processing building will allow scrap piles to be placed into containers that will be covered and then brought into the building for processing as necessary. This change in procedures should be incorporated into the facilities operations plans so that compliance staff can verify that the procedures are being followed as part of any Storm Water Pollution Prevention Plan (SWPPP) for industrial or related permits.

In this case, study almost 90% of the entire load can be reduced through non-structural practices. If this was not practicable or if additional load reductions are required than the structural BMP options can be determined. A suggested first activity in this step is to identify the most significant loads that can be targets for reduction. Table A-2 ranks the loads of the various sources at the activity. The table shows that the pavement areas are the highest sources, aside from the stockpiles and pallets.

**Table A-2. Significant Loads at Sources of Activity**

| DRAINAGE AREA ONE | AREA (ac.) | AREA µg/sq.ft. | Lbs. PER YEAR |
|---|---|---|---|
| New Building HVAC | 0.01 | 1.80 | 0.0000 |
| Building Exterior Walls | 0.01 | 3.00 | 0.0001 |
| HVAC | 0.02 | 1.70 | 0.0001 |
| Roof Good Condition | 0.08 | 1.10 | 0.0002 |
| Roof Good Condition | 0.12 | 1.10 | 0.0003 |
| New Building Exterior Walls | 0.07 | 2.80 | 0.0005 |
| Pallet Storage | 0.02 | 16.00 | 0.0008 |
| New Building Roof | 0.16 | 3.40 | 0.0013 |
| Galvanized Fence (600 lf) | 0.17 | 4.50 | 0.0018 |
| Galvanized Fence (1000 lf) | 0.25 | 4.50 | 0.0027 |
| Pavement | 0.68 | 3.40 | 0.0055 |
| Pavement (Parking) | 1.79 | 3.40 | 0.0146 |
| Processing Area (Pavement) | 0.45 | 80.00 | 0.0862 |
| Treated Wood Storage | 0.02 | 5125.00 | 0.2456 |
| Copper stockpile | 0.15 | 1600.00 | 0.5750 |

In this case, study the targeted areas for potential BMP implementation will be the pavement areas. The selection of BMPs begins with an understanding of the activities that are generating pollutant loads, the characteristics of the pollutants in the runoff, and the runoff characteristics (volume, frequency, rate). In this scenario there will be copper in the runoff in both soluble and particulate forms. The particulates are from the scrap metal operations from the handling and processing of materials. The soluble copper is generated from the roof runoff, metal fences, and other exposed metals at the site. Table A-3 lists appropriate BMPs for treatment of both forms through sedimentation, filtration, and other unit processes.

**Table A-3. BMPs and Treatment Processes**

| UNIT PROCESS | BIORETENTION | BIOSWALE | BIOFILTER | PERMEABLE PAVEMENT | MEDIA FILTER | PERMEABLE FRICTION COURS | COMPOST FILTER MAT | VEGETATED FILTER STRIP | INLET INSERT |
|---|---|---|---|---|---|---|---|---|---|
| Sedimentation | X | X | | | | X | | X | X |
| Filtration | X | X | X | X | X | X | X | X | X |
| Sorption & Ion Exchange | X | X | X | | X | X | X | X | X |
| Precipitation | X | | X | | X | X | | X | X |
| Complexation | X | X | X | | X | X | X | X | X |
| Volatilization | X | | X | | X | X | | X | X |
| Microbial Immobilization | X | X | X | | | X | X | X | X |
| Microbial Transformation: | | | | | | | | | |
| - Ammonification | X | X | X | | | X | | X | X |
| - Nitrification | X | X | X | | | X | | X | X |
| - Denitrification | X | | X | | | X | | | |
| Plant Uptake | X | X | | | | X | | X | X |

The use of simple matrices that are based on local conditions and regulations can be used to begin to determine the type, size and location of the candidate BMPs. Table A-4 is an example where the relative costs, effectiveness, and spatial constraints of BMPs are used to rank the type of practices. This selection can be further refined by determining the cost to construct and maintain the BMPs based on local data, related to the effectiveness and efficiency of treatment. Table A-4 is an example of a selection matrix that includes site constraint considerations. It can be modified to reflect local permit sizing and geometric requirements.

## Table A-4. BMP Effectiveness and Implementation Considerations

| BMP | REQUIREMENTS | | | |
|---|---|---|---|---|
| | METALS | SPACE | COST[1] | MAINTENANCE |
| Bioretention[3] | ● | ● | ◉ | ◉ |
| Bioswale | ● | ◉ | ◉ | ◉ |
| Biofilter | ● | ○ | ◉ | ◉ |
| Media filter[2] | ● | ○ | ◉ | ◉ |
| Permeable Friction Course | ● | ● | ○ | ◉ |
| Compost filter mat | ● | ◉ | ○ | ◉ |
| Vegetated filter strip | ● | ◉ | ○ | ◉ |
| Inlet Insert | ● | ● | ○ | ● |

## Table A-5: Site Considerations & Limitations*

| **SPACE REQUIRED** | **BIORETENTION** | **BIOSWALE** | **BIOFILTER** | **PERMEABLE PAVEMENT** | **MEDIA FILTER** | **PERMEABLE FRICTION COURSE** | **COMPOST FILTER MAT** | **VEGETATED FILTER STRIP** | **INLET INSERT** |
|---|---|---|---|---|---|---|---|---|---|
| Space Required | Minimum surface area range:<br>50 to 200 ft$^2$<br>Minimum width:<br>5 to 10 ft<br>Minimum depth:<br>2 to 4 ft | Bottom width:<br>2 ft minimum,<br>6 ft maximum | | | | Minimum length of 15 to 20 ft | | | |
| Soils | Permeable soils with infiltration rates > 0.27 inches/hour are recommended. Soil limitations can be overcome with use of underdrains. | Permeable soils provide better hydrologic performance, but soils not a limitation. Selection of type of swale, grassed, infiltration or wet is influenced by soils. | | | | Permeable soils perform better, but soils not a limitation | | | |
| Slopes | Usually not a limitation, but a design | Swale side slopes: 3:1 or | | | | Usually not a limitation, but a | | | |

|  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
|  | consideration | flatter Longitudinal slope: 1.0% minimum; maximum based on permissible velocities |  |  |  | design consideration |  |  |  |
| Water Table/ Bedrock | 2- to 4-ft clearance above water table/ bedrock recommended | Generally not a constraint |  |  |  | Generally not a constraint | Generally not a constraint |  |  |
| Proximity to build foundations | Minimum distance of 10ft down gradient from buildings and foundations recommended | Minimum distance of 10 ft down gradient form buildings and foundations recommended |  |  |  | Minimum distance of 10 ft down gradient from buildings and foundation recommended |  |  |  |
| Max. Depth | 2- to 4-ft depth depending on soil type | Not applicable |  |  |  | Not applicable |  |  |  |
| Maintenance | Low requirement, property owner can include in normal site landscape maintenance | Low requirement, routine landscape maintenance |  |  |  | Low requirement, routine landscape maintenance |  |  |  |

Adapted from: USACE, 2008

*Note: This table presents general design considerations. Always refer back to state regulations and site-specific requirements.

The next suggested activity in the selection process is to identify the opportunities and select the BMP options for treating each area or location. There may be several options for each location. In this example, a storm drain inlet receives approximately 1 acre of untreated drainage from the paved area. Field Sheet 8 presents several options for BMPs that can be placed adjacent to or inserted into the inlet. Preliminary sizing and cost calculations that are based on local requirements and efficiencies can be conducted for each candidate practice in order to determine the effectiveness. This analysis should also include the potential impact on operations. For example, a certain type of inlet insert may be extremely effective at trapping and filtering of metals and is relatively low cost to install. For the purposes of this case study, the slope of the pavement to the inlet is very flat, and there are high sediment and dust loads from the operations. The device would require frequent inspection and maintenance for the BMP to be effective and not clog. If the device clogged, the area could potentially be flooded and would impact operations. An alternative BMP for the inlet would be to install filter mats around the perimeter of the inlet. The mats could be easily inspected, and the sediment can be removed and properly disposed or the mats could be replaced with minimal costs and impacts to operations. There may be also several different types of BMPs that are available for treating a source. For example, filter strips described in Field Sheet 4 and shown if Figure A-5 or bioswales in Field Sheet 5 and shown in Figure A-6 could be applicable for perimeter parking and fenced areas.

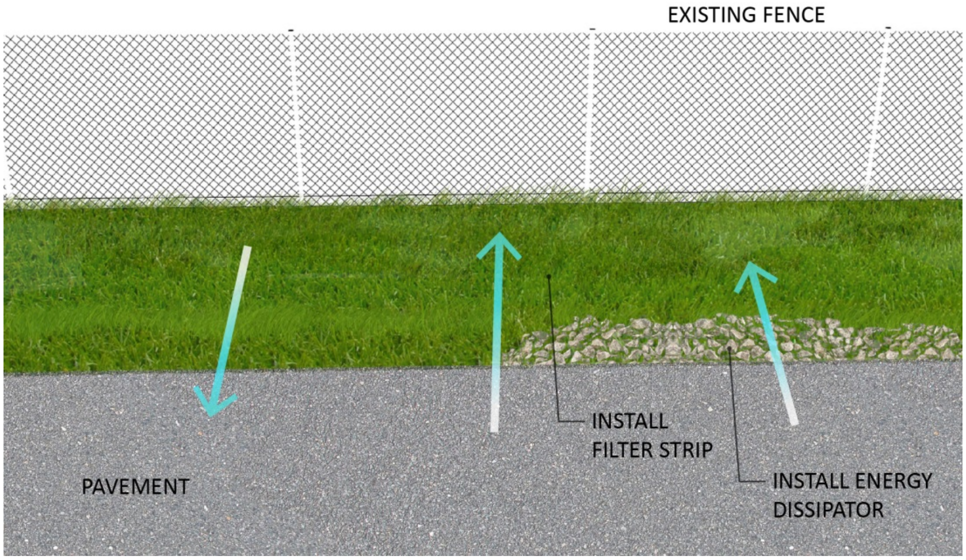


**Figure A-5. Vegetated Filter Strip Options**

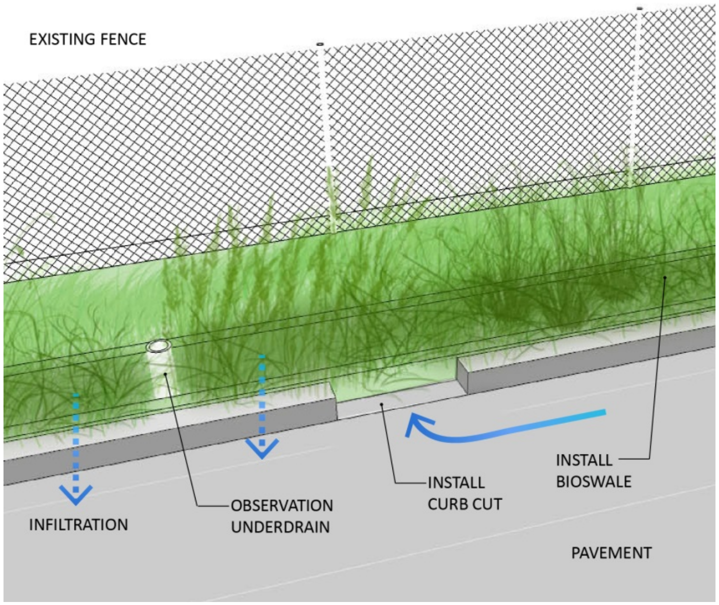


**Figure A-6. Perimeter Bioswale Schematic**

The procedures to determine the effectiveness of the candidate BMPs can be quite complex due to local regulatory requirements and the crediting systems that may be applied for the construction of facilities, as well as watershed-based permits. Some states, such as those in the mid-Atlantic Chesapeake Bay region, have specific design sizing procedures, standards, and efficiencies for post-construction BMPs that are different from the sizing and efficiencies that are used for TMDL compliance (MDE, 2011). The regulations may also have different sizing and efficiencies that are assigned for new and retrofit projects. In this case, there are new buildings and pavement areas that are subject to the local design manual for sizing and construction as part of the construction permit process. The BMPs for new construction require the capture and treatment of 1 inch of runoff for credit and there is not partial credit. The BMPs that are to be retrofit into the other areas are sized and given credit based on the volume of runoff that can be captured and treated. Some regulatory schemes may assign different removal/treatment efficiencies for each type of BMP (Virginia, 2013).

In this scenario, all of the BMPs will be assigned an 80 percent removal/treatment rate if they meet the local geometric sizing requirements. More detailed modeling and monitoring activities may be used to demonstrate different removal rates for specific BMPs. Table A-5 is a summary of the effectiveness of the BMPs when applied to each of the loads. This assumes that all of the BMPs are properly sized.

**Table A-6. Effectiveness of the BMPs for Each Pollutant Source**

| DRAINAGE AREAS | Area (ac.) | Area µg/sq.ft. | Lbs. Per Year | Lbs. Removed (80% effect) |
|---|---|---|---|---|
| **Drainage Area One** | | | | |
| Pavement | 0.68 | 3.40 | 0.0055 | 0.0044 |
| Roof Good Condition | 0.12 | 1.10 | 0.0003 | 0.0003 |
| Building Exterior Walls | 0.01 | 3.00 | 0.0001 | 0.0001 |
| HVAC | 0.02 | 1.70 | 0.0001 | 0.0001 |
| Galvanized Fence (600 lf) | 0.17 | 4.50 | 0.0018 | 0.0015 |
| **Subtotal Drainage Area One** | **1.00** | | **0.0078** | **0.0063** |
| **Drainage Area Two** | | | | |
| Pavement (Parking) | 1.79 | 3.40 | 0.0146 | 0.0117 |
| Processing Area (Pavement) | 0.45 | 80.00 | 0.0862 | 0.0690 |
| Copper stockpile | 0.15 | 1600.00 | 0.5750 | 0.4600 |
| Pallet Storage | 0.02 | 16.00 | 0.0008 | 0.0006 |
| Treated Wood Storage | 0.02 | 5125.00 | 0.2456 | 0.1965 |
| Roof Good Condition | 0.08 | 1.10 | 0.0002 | 0.0002 |
| New Building Roof | 0.16 | 3.40 | 0.0013 | 0.0010 |
| New Building Exterior Walls | 0.07 | 2.80 | 0.0005 | 0.0004 |
| New Building HVAC | 0.01 | 1.80 | 0.0000 | 0.0000 |
| Galvanized Fence (1000 lf) | 0.25 | 4.50 | 0.0027 | 0.0022 |
| **Subtotal Drainage Area Two** | **3.00** | | **0.9347** | **0.7415** |
| **Total Drainage Areas 1 and 2** | **4.00** | | **0.9426** | **0.7478** |

The results of the calculations in the table show that, aside from the copper stockpiles, treatment of the pavement areas would result in a significant load reduction. Some of the suggested BMPs are the use of filter strips and bioswales around the perimeter pavement areas and inlet inserts could be appropriate for existing storm drains. Additional low cost BMPs could be downspout disconnection and the use of filter strips around buildings.

This process can be applied to different combinations of practices until the user (Capital Improvement) determines the optimal types and sizes of the BMPs. In this scenario, almost all of the sources could be treated using these techniques. The selection is typically a function of the engineering feasibility of each practice and the available funding. Once these are determined, then the final funding, construction documents and operations manuals can be prepared for implementation.

**Step Six: Document and maintain conditions.**
The preparation of operations manuals that are available at the site and proper documentation for maintenance and inspection are critical to the effectiveness of the BMPs. Funding for maintenance and corrective actions are often limited so that the proper inspection, operations,

and reporting are essential for the systems to be effective. This process and the requirements are specific to each installation and facility.

# REFERENCES

Arias, E., C. Katz, and K.Sorensen. 2014. Storm Water Modeling Tool for Navy Facilities: Navy Materials Copper and Zinc Leachate Results. NESDI Project 455. Washington, D.C.

Davis, A. P., M. Shokouhian, and S.B. Ni. 2001. “Loading estimates of lead, copper, cadmium, and zinc in urban runoff from specific sources.” *Chemosphere*, 44(5), 997–1009.

Maryland Department of the Environment. 2011. *Accounting for Stormwater Wasteload Allocations and Impervious Acres Treated*. Baltimore, MD.

“Virginia Stormwater BMP Clearinghouse”. Last updated April 23, 2014. Accessed May 5, 2014. Virginia Department of Environmental Quality. Virginia Water Resources Center. http://vwrrc.vt.edu/SWC/index.html.

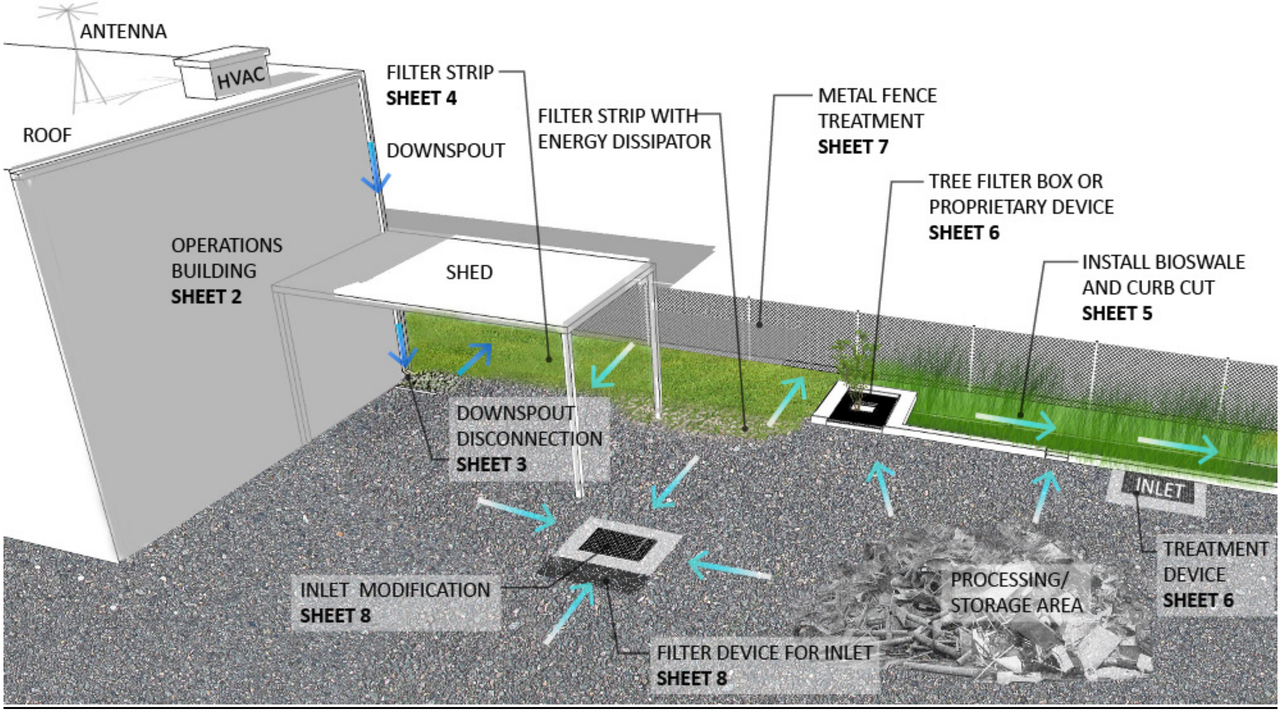
# APPENDIX B: ASSESSMENT AND DESIGN TEMPLATES

## Field Sheet 1: Overview

The following is a composite graphic representation of all of the BMP strategies that are found in the field sheets applied to a single industrial area. There may be multiple combinations of practices that can be installed at any facility.

Source: U.S. Navy

## Example



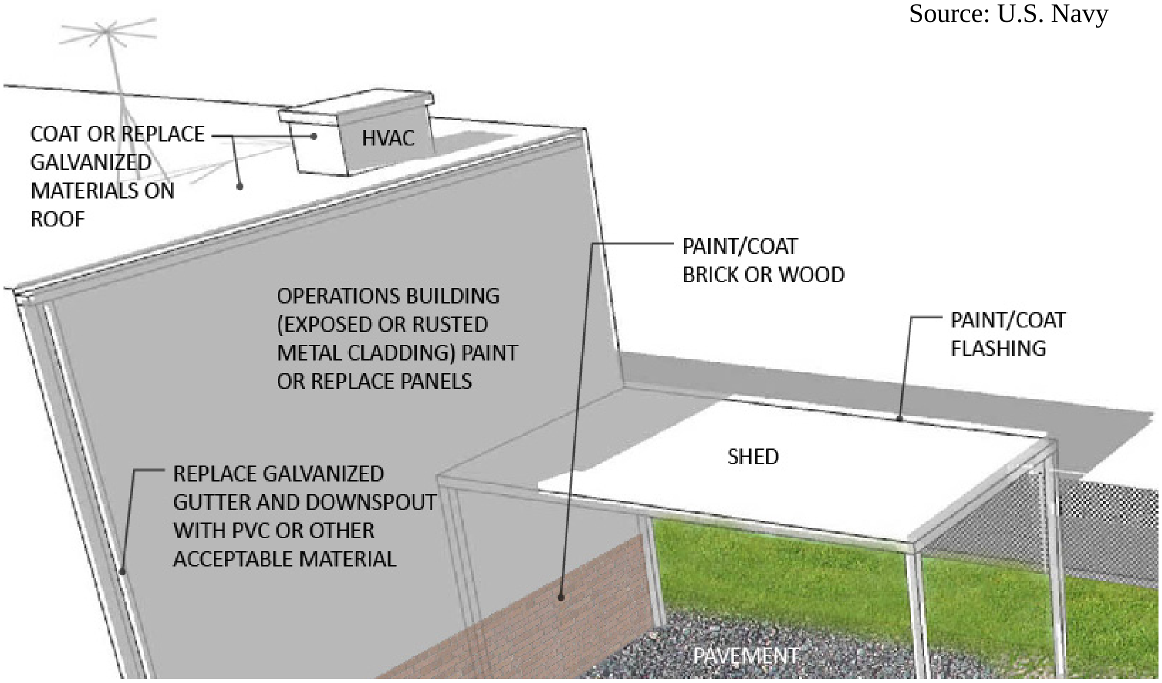
### Sheet List

- Sheet 1: Overview
- Sheet 2: Building Improvements
- Sheet 3: Downspout Disconnection
- Sheet 4: Filter Strip
- Sheet 5: Bioswale and Curb Cut
- Sheet 6: Tree Box Filter and Proprietary Devices
- Sheet 7: Metal Fence Treatment
- Sheet 8: Inlet Modification
- Sheet 9: Processing and Storage Area

## Field Sheet 2: Building Improvement

Exposed or deteriorated walls, roofs, downspouts, heating, ventilation, air conditioning (HVAC), antennas, water towers.

Source: U.S. Navy



**Building Improvements**

- Description and Approximate Size: ______________
  ________________________________________________
- Roof Material: ________________________________
- HVAC: ________________________________________
- Roof Area: ____________________________________
- Area Treated: __________________________________

Notes:
___________________________________________
___________________________________________
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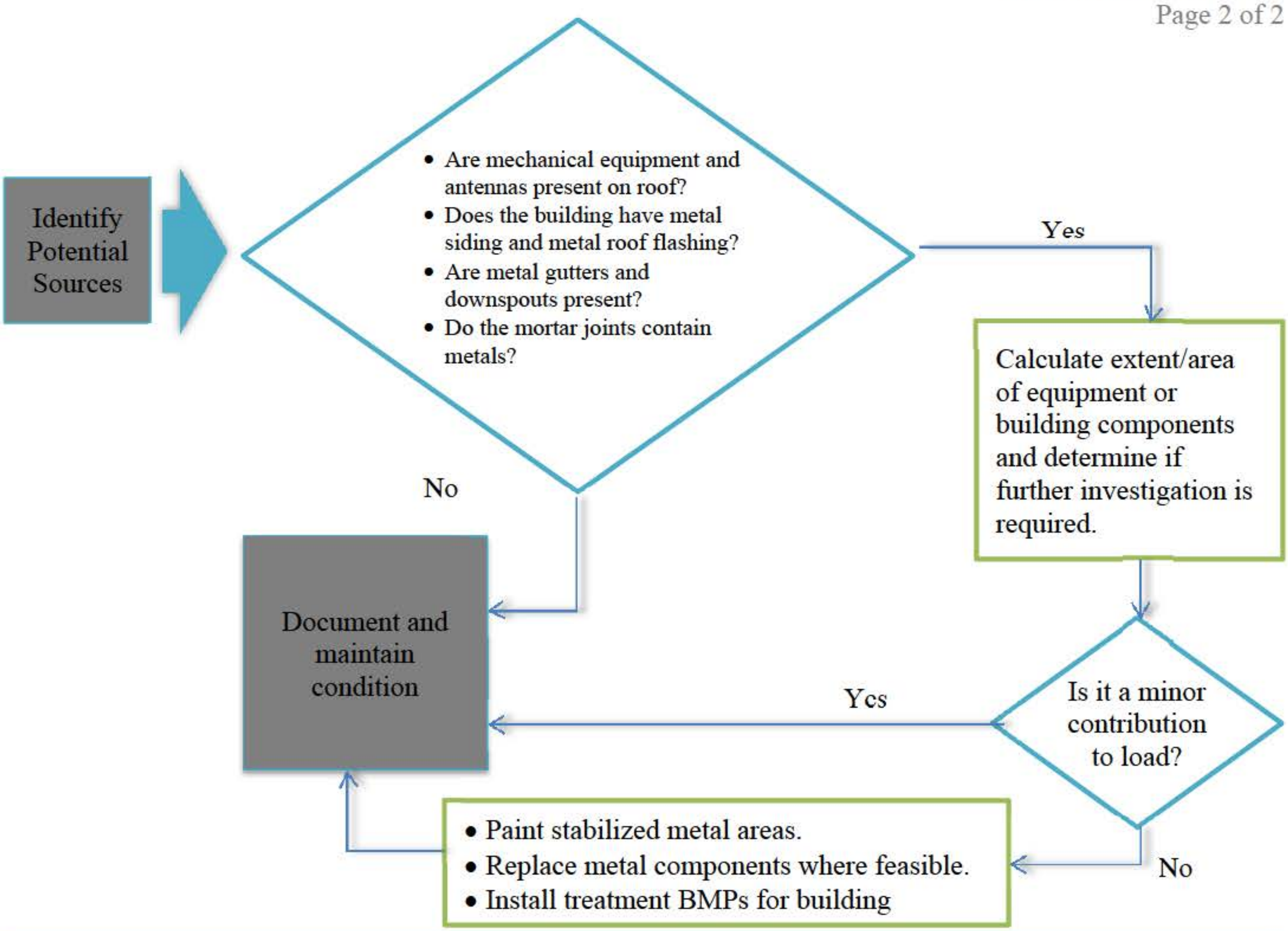


**Recommendations**

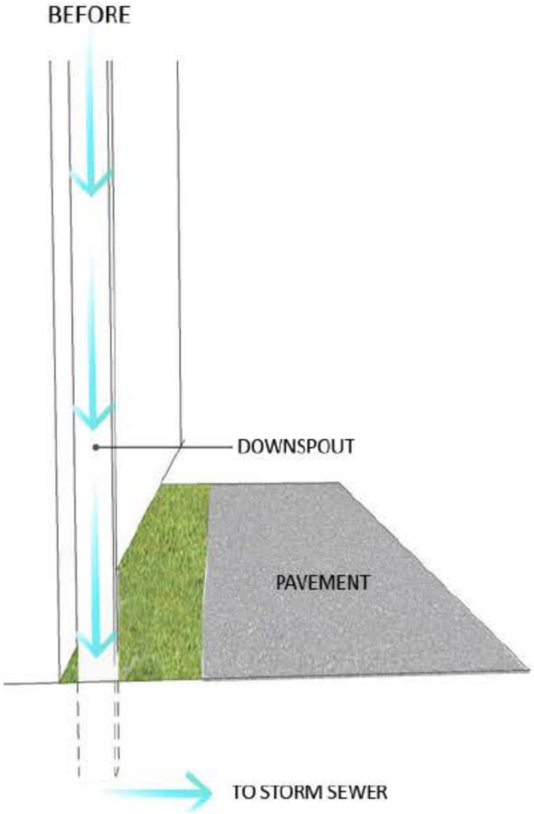
**Additional Information**

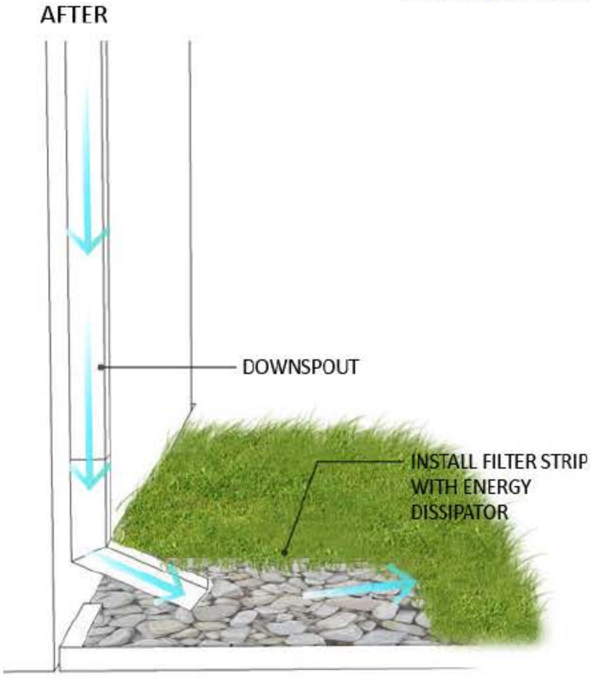
## Field Sheet 3: Downspout Disconnection

Disconnection of downspouts to direct flows away from the storm drain system to a filter strip, treatment device, or a cistern/rain barrel reduces the volumes of runoff and helps filter the pollutant loads.

Source: Low Impact Development Center

### Example





### Downspout Disconnect

- Location: ______________________________
- Material: ______________________________
- Length: ________________________________
- Area disconnected: _______________________

Notes:

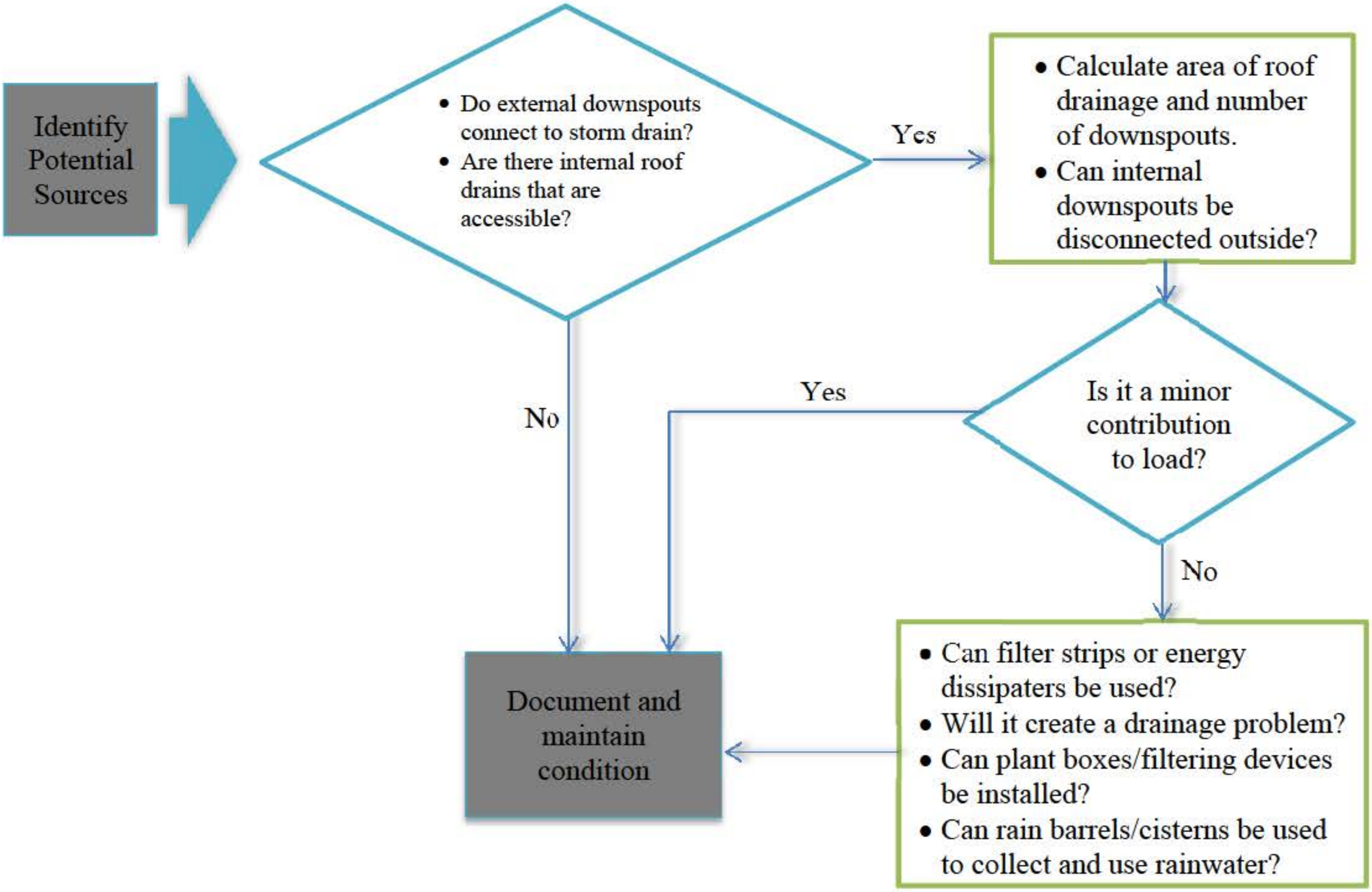
____________________________________

____________________________________

____________________________________

____________________________________

____________________________________



**Recommendations**

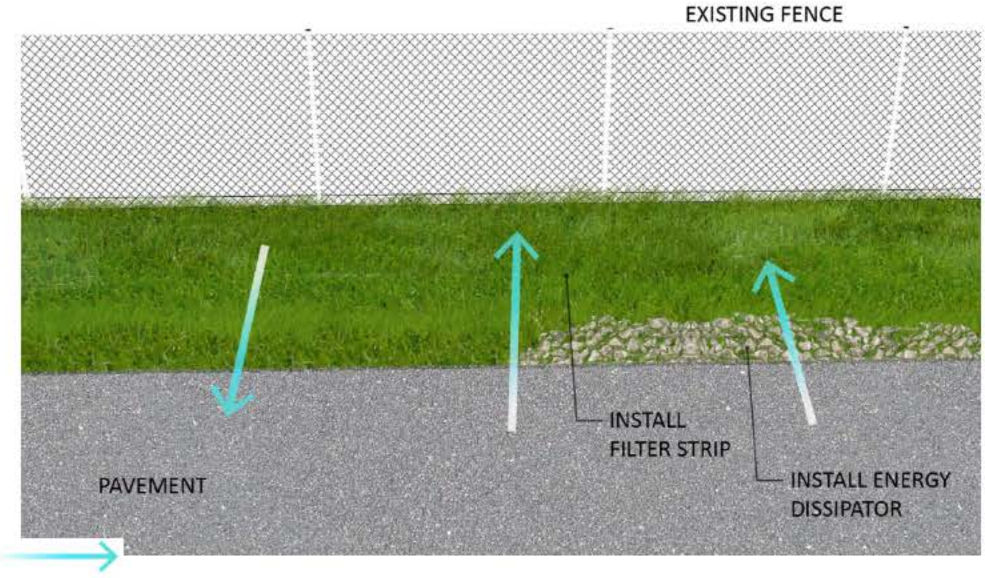
**Additional Information**

## Field Sheet 4: Filter Strip

Vegetated Filter Strips help filter pollutants and soluble metals. They are a low cost technology that is highly effective.

Source: Low Impact Development Center

**Example**



Stormwater Path

**Filter Strip**

- Location: ______________________________
- Source: ______________________________
- Material: ______________________________
- Area Treated: ___________________________
- Length & Width: _________________________

Notes:

______________________________________

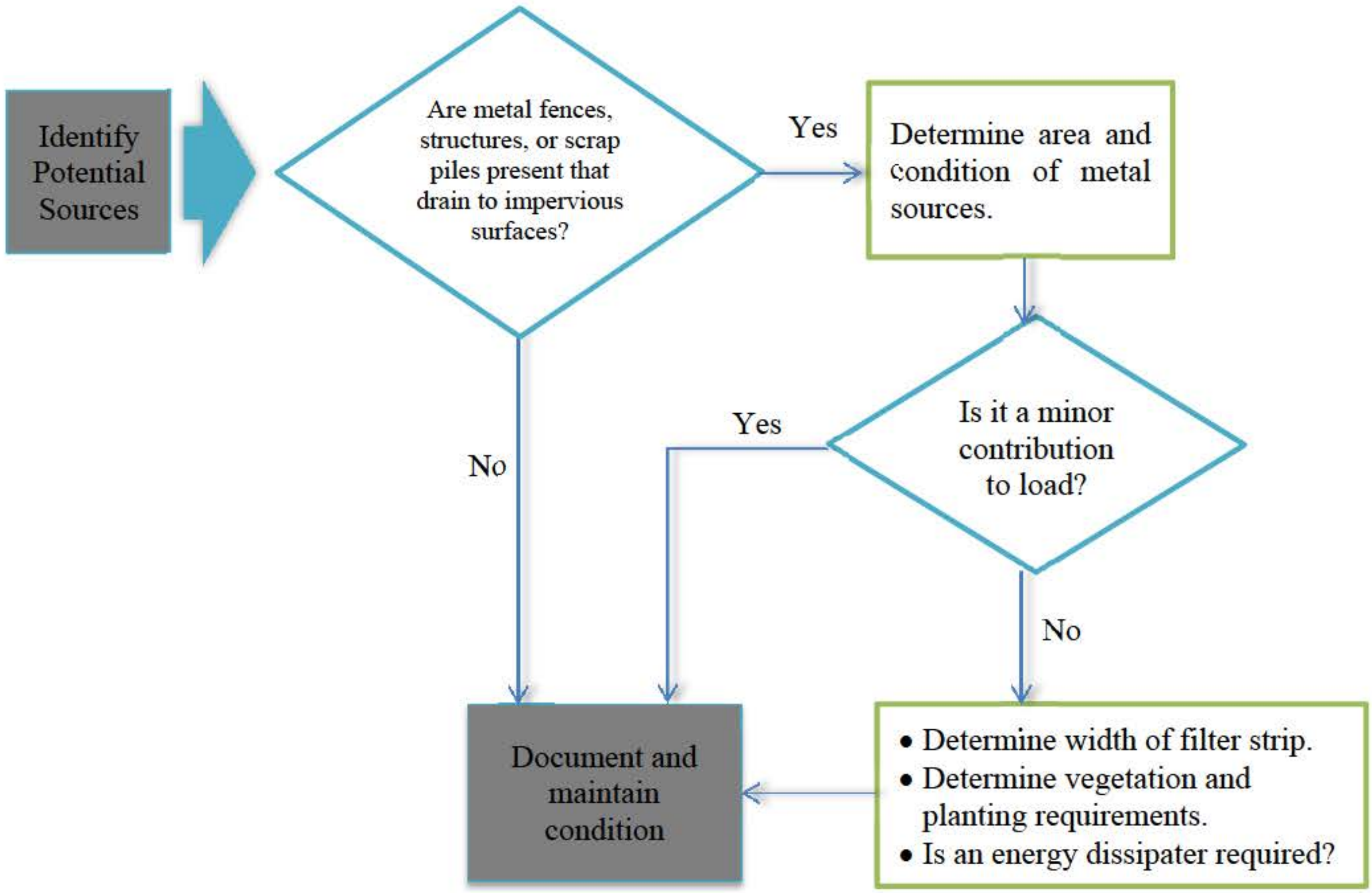
______________________________________

______________________________________

______________________________________

______________________________________

______________________________________



**Recommendations**

**Additional Information**

## Field Sheet 5: Bioswale and Curb Cut

Bioswales can be used to convey runoff and redirect flows away from inlets to reduce the volume of runoff, and filter pollutants, before it enters the storm drain system.

Source: Low Impact Development Center

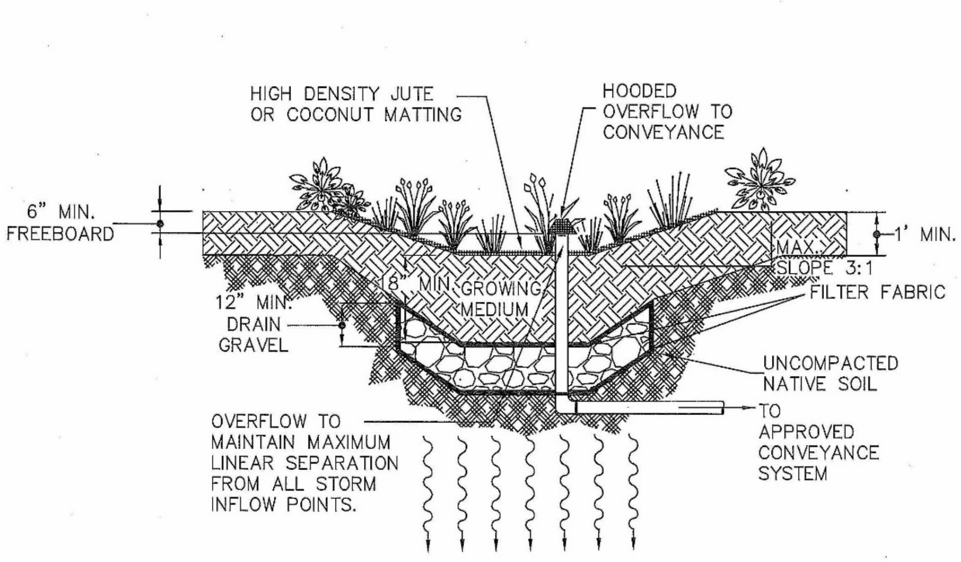
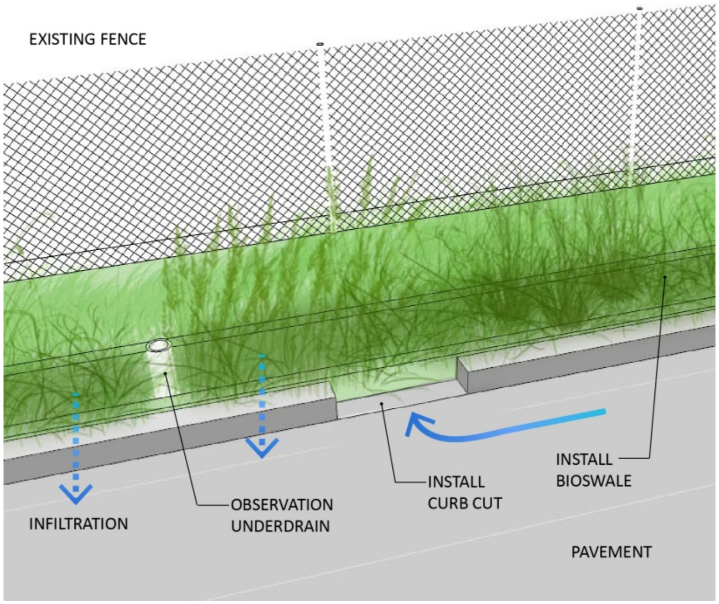


Diagram Source: CleanWater Services
LIDA Handbook

### Example



→ Stormwater Path

### Bioswale and Curb Cut

- Location: ______________________________
- Area Treated: ___________________________
- Swale Width & Depth: __________________

Notes:

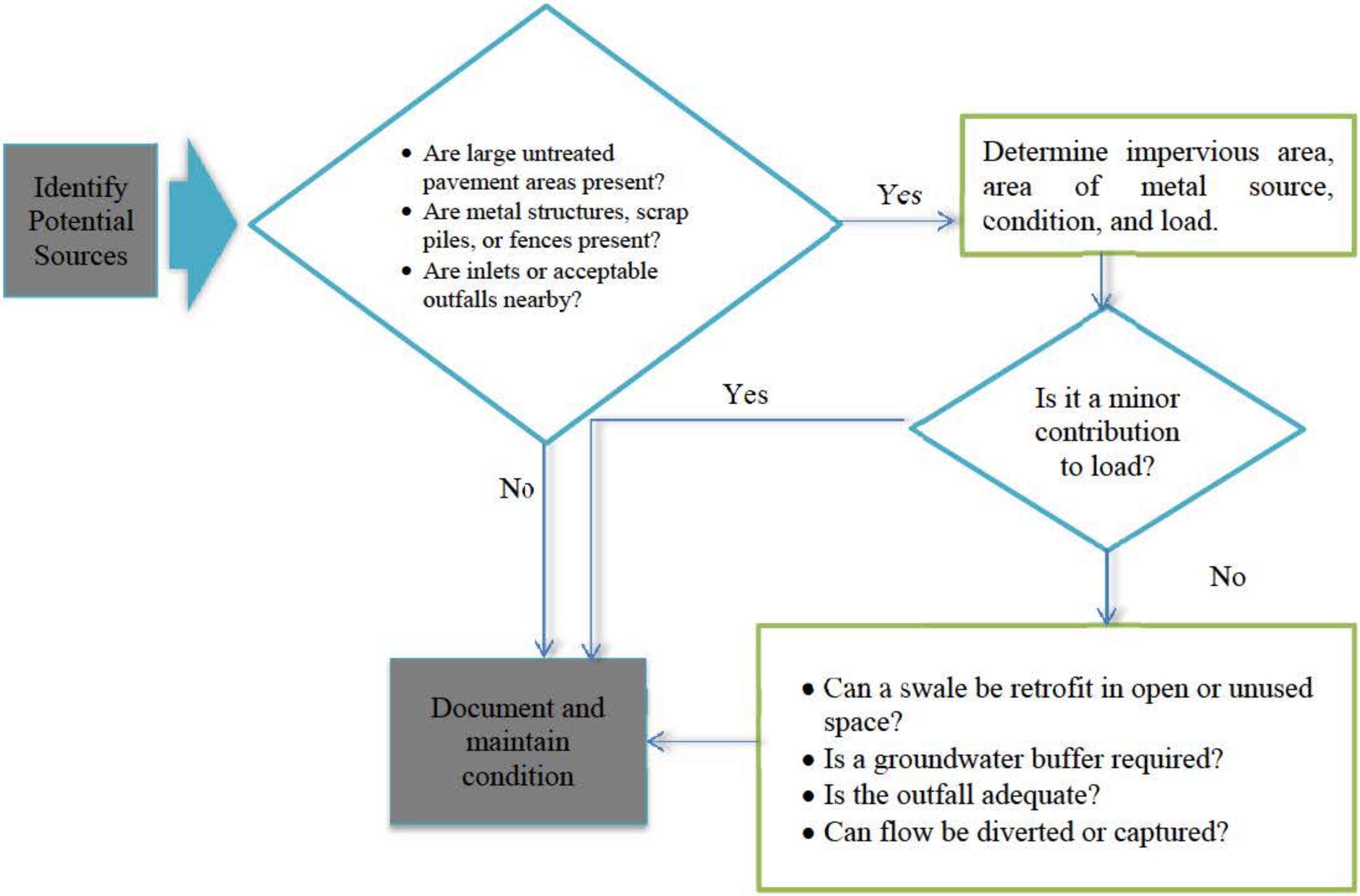
__________________________________________

__________________________________________

__________________________________________

__________________________________________

__________________________________________



**Recommendations**

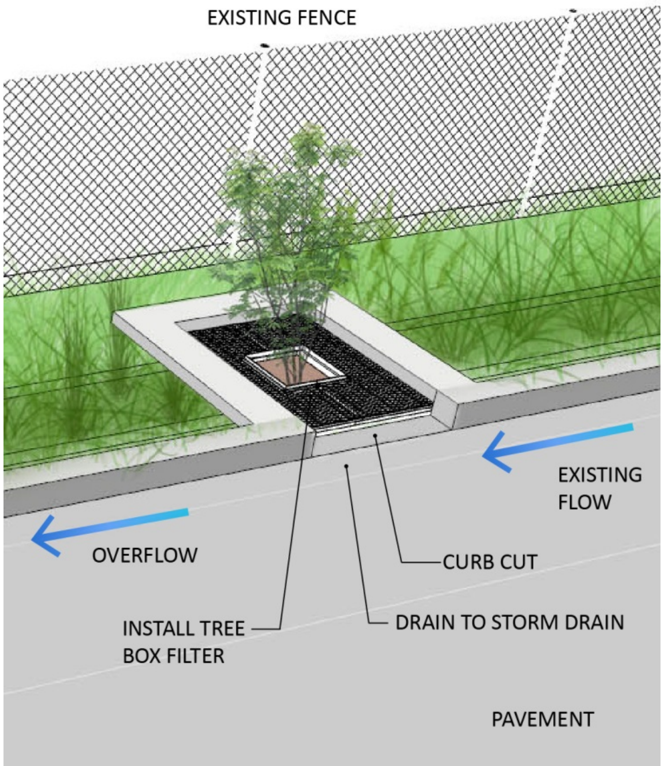
**Additional Information**

## Field Sheet 6: Tree Box Filter and Proprietary Devices

Propriety Devices are specially designed structures that are typically designed, constructed, warrantied, and maintained by vendors.

Source: Low Impact Development Center

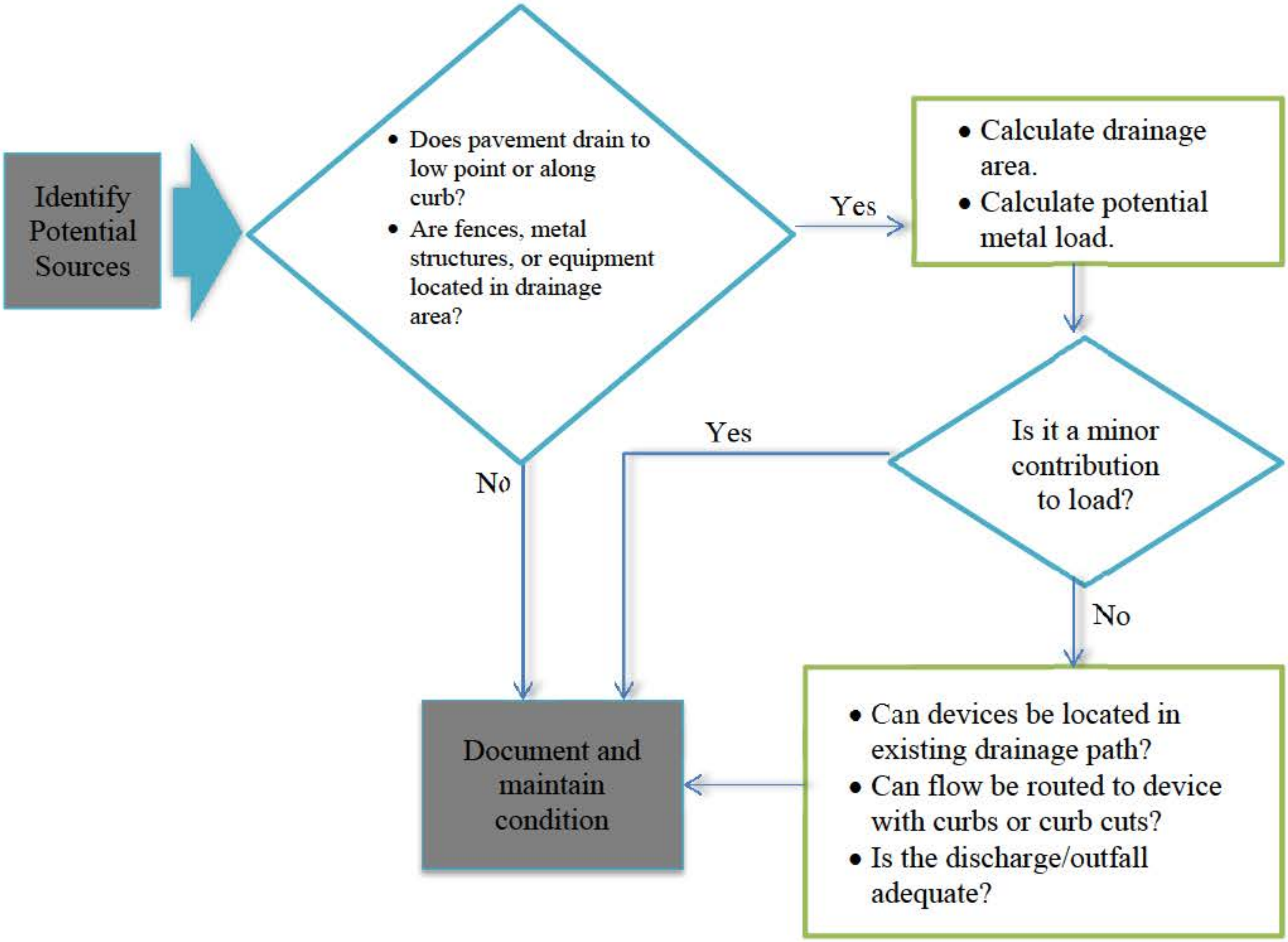
**Example**



**Tree Box Filter**

- Location: ________________________________
- Impervious Drainage Area: ________________
- Overall Drainage Area: ____________________

Notes:
___________________________________________
___________________________________________
___________________________________________
___________________________________________



**Recommendations**

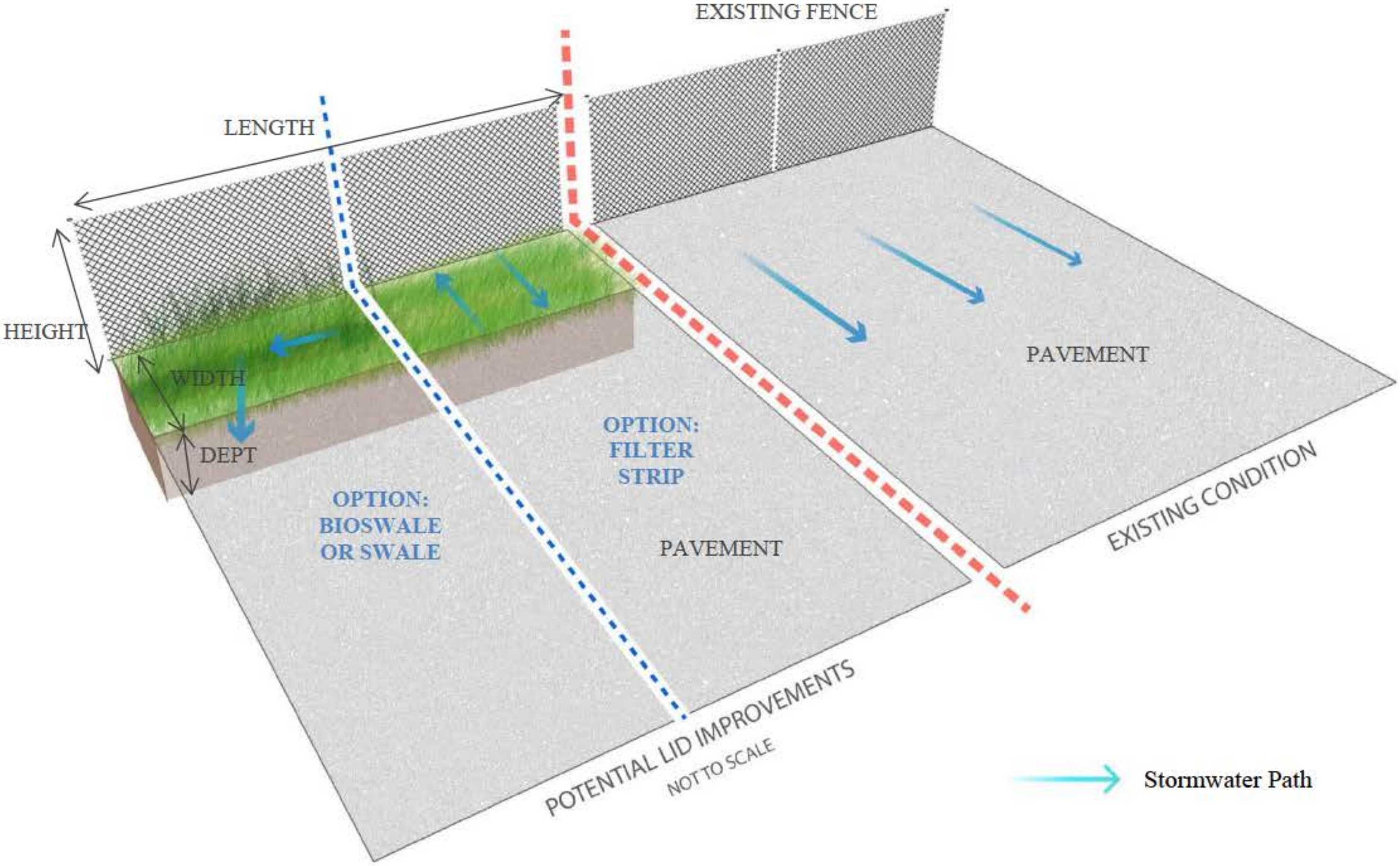
**Additional Information**

## Field Sheet 7: Metal Fence Treatment

Metal fence components that are uncoated, galvanized, or corroded can be a significant source of pollutants due to the extensive surface area.

Source: U.S. Navy

### Example



**Chain-link Fence**

- Facility Location: ______________________________
- Fence Location: ______________________________
- Material: ______________________________
- Area of Fence (Length & Width): ______________

Notes:

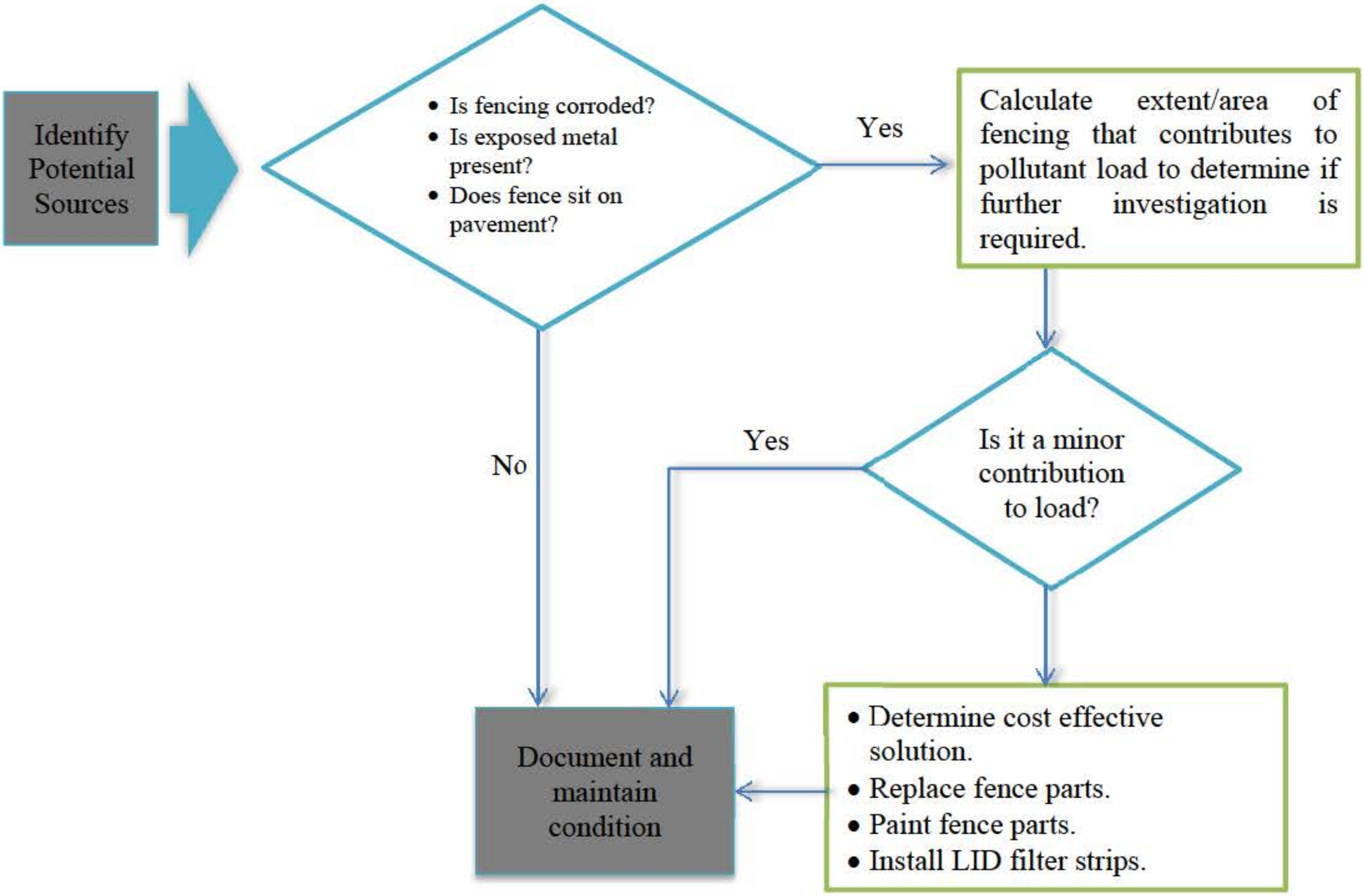
______________________________________________

______________________________________________

______________________________________________

______________________________________________

______________________________________________



**Recommendations**

**Additional Information**

## Field Sheet 8: Inlet Modification

Inlets are a direct connection to the storm drain system. The coatings on the inlets themselves can deteriorate and contribute to the pollutant load. Sediments and particulates can be trapped in the inlet then washed into the drainage system in a large storm event.

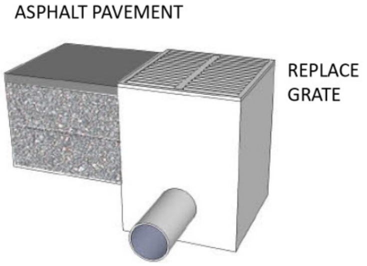
Source: U.S. Navy

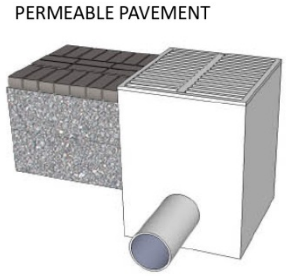
### Inlet Modification

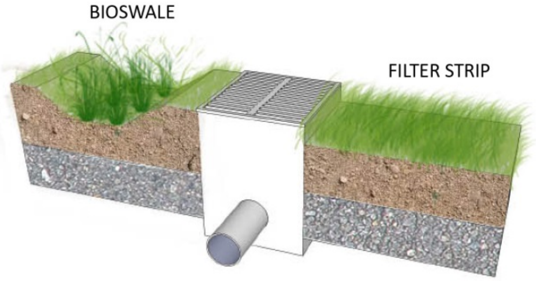
- Location: ___________________________________
- Source: ____________________________________
- Material: ___________________________________
- Drainage Area: ______________________________

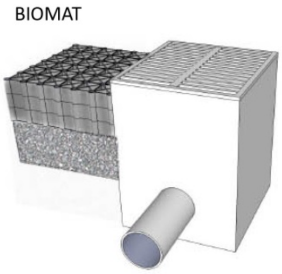
Notes:
_____________________________________________
_____________________________________________
_____________________________________________
_____________________________________________

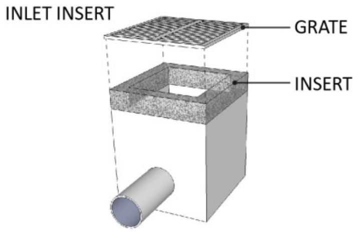
## Example

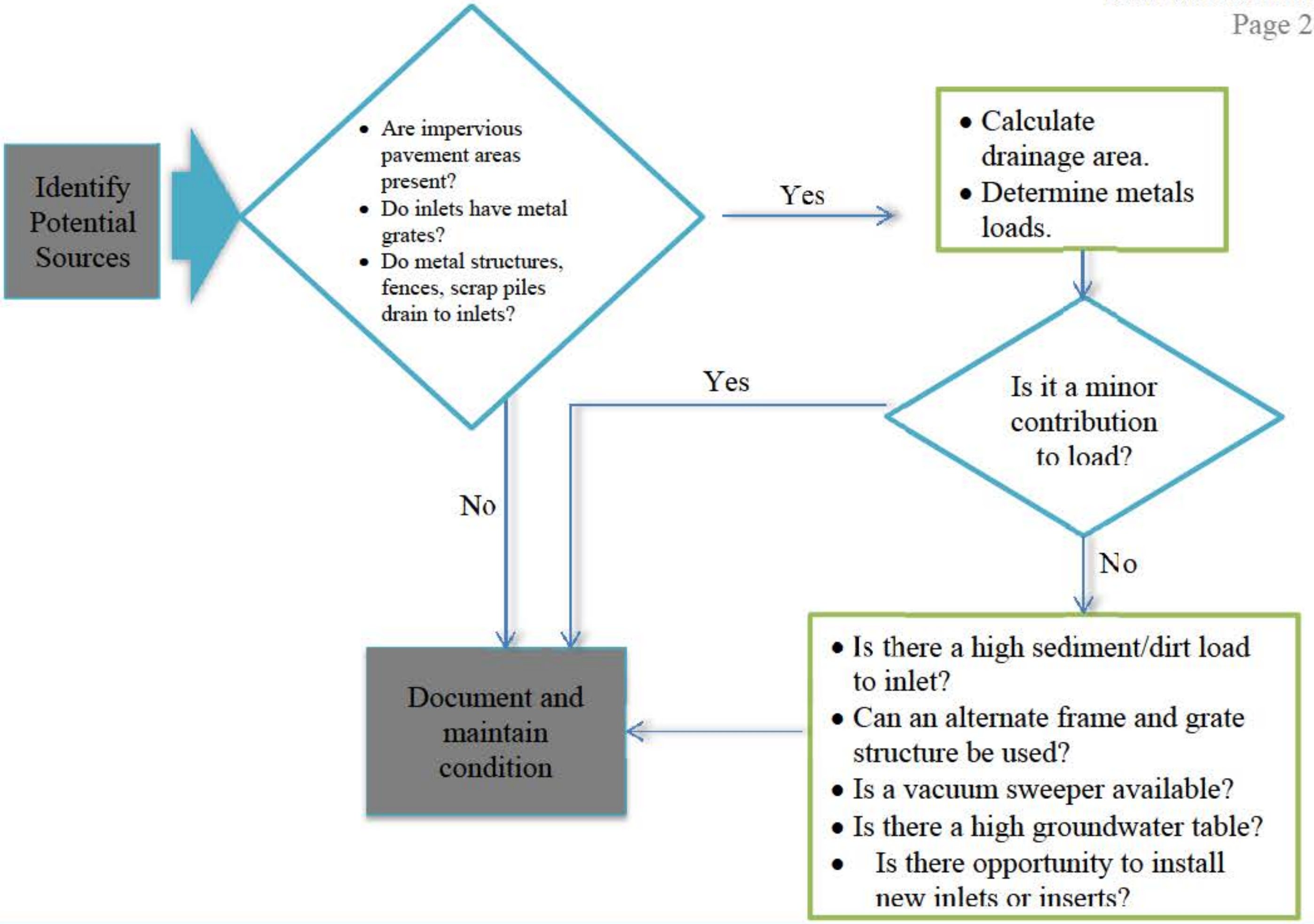












**Recommendations**

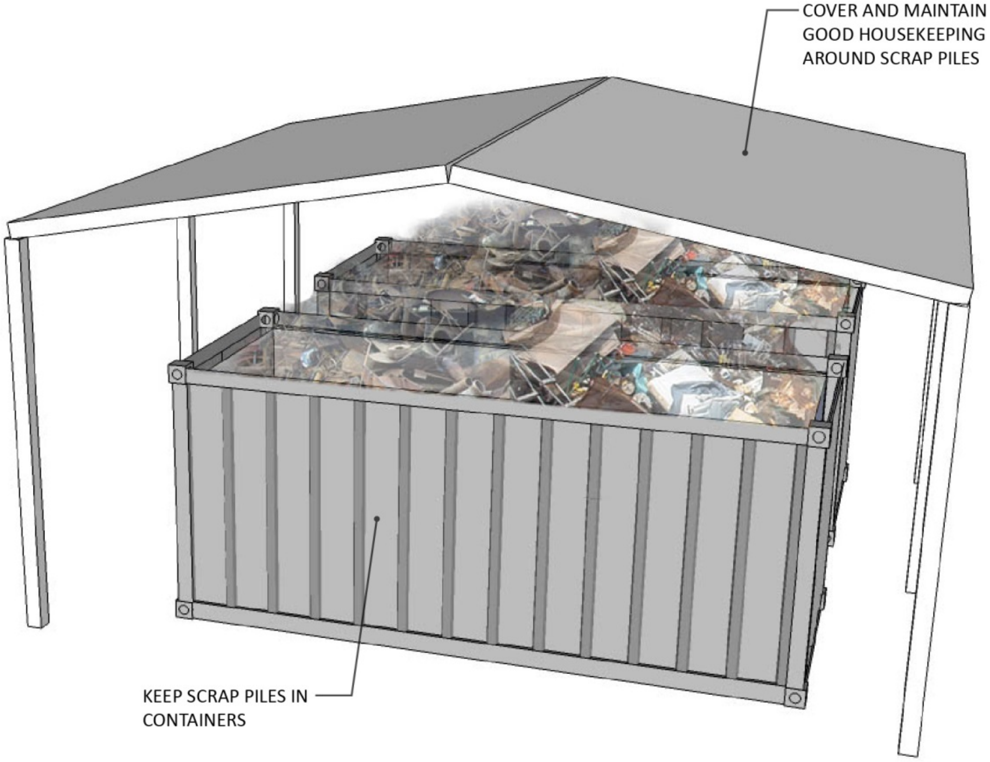
**Additional Information**

## Field Sheet 9: Processing, Mobilization and Storage Area

Exposed metals, crates, dumpsters, vehicle components, trailers, at processing areas contribute loads from exposed or deteriorated surfaces.

Source: U.S. Navy

### Example



**Processing and Storage Area**

- Location: ________________________________
- Area: ____________________________________
- Material: ________________________________

Notes:

____________________________________________

____________________________________________

____________________________________________

____________________________________________

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# APPENDIX C: LID BMP FACT SHEETS

# Bioretention/Bioswale Fact Sheet

**How Bioretention Works**

Bioretention areas consist of a shallow surface ponding area underlain by engineered soil media and an optional stone storage layer. Bioretention areas achieve pollutant removal through a combination of physical, chemical, and biological processes in plants and soils.

Source: Low Impact Development Center

Engineered soil media are designed to provide permeability, promote plant growth, and treatment using a mixture of sand, soils, and/or organic elements. Pollutant removal performance can be optimized by adjusting a number of design factors, including the composition of the filter media, plant selection, and drainage characteristics. Bioretention areas work best with vegetation such as grasses, sedges, and small woody plants and shrubs. Storage capacity is a function of the ponding depth, media/stone depth and porosity, and the footprint of the facility. Storage capacity can be increased by adding a stone storage layer or storage pipe beneath the soil medium. The shape of a bioretention area is not critical to its function, and it is common for facilities to be roundish, irregular, or linear. In the linear form, they are configured as linear channels and generally called bioswales. Bioswales are designed to collect sheet flow from small lengths of drainage and may have check dams to increase the travel time of runoff within the swale. Overall volume reduction potential relies on infiltration rates and storage capacity, with some losses to evapotranspiration. In areas where soil infiltration rates are low, an underdrain of stone and perforated drainage pipe is typically installed to convey the water that does not get absorbed in the plant and soil mix or does not infiltrate into the ground to an outfall.

**Effectiveness**

- When designs are optimized for metals removal, bioretention/bioswale have shown excellent removal of copper, zinc, and lead (>90%). It is important to keep in mind, however, that metal removal via chemical pathways is dependent upon a number of factors, including pH, the adsorption capacity of the media, the organic content of the media, and redox potential, which must be carefully managed in order to ensure optimal performance.

**Design Recommendations**

- Bioretention cells are typically 40 x 60 feet to treat an area of pavement or compacted soils of about ¼ to ½ acre.

- Both bioretention cells and bioswales work best when drainage areas are small. Areas should generally not exceed 1 acre.
- Metal removal takes place in the uppermost $^1/_3$ to $^2/_3$ feet of soil media, which would suggest the depth of the bioretention cells to be a minimum of $^2/_3$ feet, for optimal metal removal. However, soil media depth should provide a beneficial root zone for the chosen plants and it is generally recommended to be no less than 1½ feet.
- Bioretention media can be amended to enhance sorption capacity. Amendments that have been shown to improve metals removal include:
    - Bone char.
    - Biochar - Biochar is a low-cost material that can be made from a variety of organic wastes, including crop residues, wood, and even manures. Adding Biochar will increase the adsorption capacity equal to or greater than that of activated carbon.
    - Surface modified activated alumina.
    - Peat - Use of peat moss is discouraged as its production causes the loss of valuable wetlands.
    - Compost - Compost is not recommended where nutrient export is a concern.
    - A mixture of rhyolite sand (30% by volume), surface modified zeolite (30%), granular activated carbon (30%), and peat (10%) has been shown to achieve high levels of copper removal.
- Any media used in bioretention should have a low copper content.
- There is evidence that incorporating a submerged zone beneath the main bioretention media can improve retention of metals by maintaining even moisture in the upper bioretention layer. The submerged zone should be composed of a mixture of sand and organic matter in a form that is resistant to degradation, such as straw, wood chips, or shredded newspaper. Use of a submerged zone may have the additional benefit of improving nitrogen removal.
- Bioretention sizing and design requirements vary from one municipality to another. Check with state and local regulators for the most current stormwater design guidelines applicable to your site. A rough estimate of required bioretention size, performance, and expected cost can be generated using the BMP SELECT model produced by the Water Environment Research Foundation (WERF), which can be downloaded at: www.werf.org/SELECT.

**Nutrients**

- In regions where nutrient (nitrogen and phosphorus) discharges are a concern, bioretention design can be tailored to target nutrients in addition to metals.
    - Use a low-phosphorus medium.
    - The bioretention cell should be fully vegetated.
    - Use an upper aerobic zone depth of at least 2.5 feet, underlain by a submerged zone (described above).
    - Bioretention should employ organic matter with a low nitrogen content, such as shredded hardwood mulch.

    - Inoculation of bioretention with mycorrhizal fungi may improve nutrient uptake by plants.
    - Use of biochar may improve nutrient removal.
    - Use of Water Treatment Residuals (WTR) has been shown to improve phosphorus removal.

**Cost**

The WERF SELECT Model calculates the cost of bioretention based on the WERF Whole Life Cost Models, and uses the following values:

    - Capital costs are estimated at $53K per acre treated, which includes planning, engineering, and construction.
    - Operation and maintenance costs are estimated to be 3.5% of capital costs.
    - Replacement costs are estimated to be 80% of capital costs, with a design life of 25 years.

**Potential Limitations**

- Proper infiltration of captured stormwater from bioretention cells requires that the groundwater table be at least several feet below the bottom of the bioretention cell.
- Bioretention soils are highly porous and uncompacted; therefore, barriers should be used to prevent errant vehicles from entering the bioretention cell.
- In areas with high sediment loads, pretreatment is necessary to avoid clogging the bioretention cell. Grass buffer strips or settling basins should be used to remove sediment from runoff before it enters the bioretention cell.

**Typical Maintenance Schedule**

For the most part, bioretention maintenance is similar to general maintenance of landscaping.

- Inspection and Monitoring
    - Check periodically for evidence of erosion or excess sediment deposition.
- First Year
    - Water plants weekly when there has been no rain. Once plants have become established, watering is only necessary during drought conditions.
- Monthly
    - Remove accumulated trash, waste, and unwanted plants.
- Bi-Annually
    - Reapply mulch to a depth of 3 inches.
- Annually
    - If necessary, remove accumulated sediment from bioretention and pretreatment area.
    - Replace any dead plants.
    - Prune plants as appropriate for each plant species.
    - If underdrain becomes clogged, i.e. it takes longer than 6 hours to infiltrate the system, unclog the system.

**Regional Considerations**

- For best performance, select plantings that are adapted to the local climate.

- Irrigation is typically required for plant establishment in most climates in North America.
- During freezing conditions, bioretention cells will continue to remove metals, but may exhibit diminished nitrogen removal.

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# Filter Mats Fact Sheet

## How Filter Mats Work

Source: Low Impact Development Center

Filter mats are LID tools that are incorporated into slopes in vegetated areas, filter strips, or are placed around inlets or in swales as filtering devices. They may be vegetated or have exposed filter fabric surfaces.

They are used to trap the physical, chemical, and biological pollutants in stormwater. When seeded and successfully vegetated, they become part of a permanent slope erosion control solution. Filter mats are easy to install and particularly effective when used in situations requiring runoff volume reduction, vegetation establishment, and in conjunction with other erosion control and slope stabilization measures as a support practice. The drainage area to a swale should typically be less than 100 feet in length and no more than 1 acre of drainage. Filter mats may be usually used in conjunction with other, more technologically complex and permanent LID tools. Filter mats should not be used in areas where there is concentrated flow or where runoff velocities will undermine new vegetation.

Filter mats can be placed on any soil surface: flat, steep, rocky, or frozen. The mats are most effective when applied on slopes less than 4:1, such as construction sites, road embankments, and stream banks, where stormwater runoff can occur as sheet flow. There are two basic types of filter mats:

- *Turf Reinforcement Mats* – these are permanent structures intended to help establish vegetation and hold it in place. They are particularly useful on steep slopes or high-flow channels, where vegetation alone may be insufficient for stabilization.
- *Erosion Control Blanket or mats* – these are temporary structures incased in biodegradable materials, such as coconut fiber, or non-biodegradable materials. The non-biodegradable materials allow the mats to be rolled up and disposed of if they clog or the pollutant removal capacity is diminished.

**Effectiveness**

In 2007, the USEPA reported that filter mats effectively removed 30-70% sediment (TSS), reduced 93.5-99% of soil loss, reduced 20-76% of runoff volume for Erosion Control Blanket, and reduced 35-76% of runoff volume for Compost Stormwater Blanket. Metals removal efficiencies for non-biodegradable mats have been reported up to 95% for copper and zinc (Gleason, 2013).

**Design Recommendations**

**Required construction materials are:**

1. Blanket/mat
2. Hand tools: rakes, shovels
3. Hydroseeding machine
4. Hydroseed
5. Staples: 6-inch, 11-gauge sod staples
6. Staple gun
7. Water supply

**Installation Procedure**

Proper installation and good contact with the ground are essential to ensure proper performance for biodegradable and degradable configurations. If slopes are greater than 4:1, the slope should be vertically tracked to increase the soil roughness and increase soil contact with the mat. Aggregates may be added to increase the stability of the mats on paved areas and allow occasional vehicle loads to traverse the mat without compacting it. Select a locally adapted seed mix and plants in consultation with the landscape architect, Natural Resources Conservation Service (NRCS), or cooperative extension personnel associated with the project.

1. Prepare area so that soil is ready for seed; the surface should be free from large clods and debris and raked even to ensure even soil contact with the filter mat.
2. Seed and fertilize prior to applying the mat unless manufacturer’s specifications indicate otherwise (if hand seeded, roll the seeded area to ensure proper seed-soil contact).
3. Roll out mat, starting at the top of the slope and rolling downhill; overlap edges at least 4 inches.
4. Overlap ends shingle-style, with un-slope ends on top, at least 4 inches.
5. Staple in place.
6. Bury the top end of the mat in a 6 inch trench, and backfill (ensures that runoff is forced to run onto the mat, rather than under it).
7. Water.

**Cost**

Estimated costs for this technology:

- Capital costs are estimated at $2,000 per acre treated, which includes planning, engineering, and construction.
- Operation and maintenance costs are estimated to be 5% of capital costs.
- Replacement costs are estimated to be 100% of capital costs, with a design life of 4 years.

In general, the installed cost of Turf Reinforcement Mats (TRM) ranges from $5 to $15 per square yard. Other factors include the TRM material and site conditions like underlying soils and steepness of the slope, influencing the cost.

**Potential Limitations**

Certain site conditions may limit the appropriateness of filter mats. Filter mats work best in areas where vegetation can be established but have also been used in arid, semi-arid, and high-altitude regions. In these regions, the filter mat itself acts as the principal erosion control device. Filter mats should not be placed in locations that receive concentrated or channeled flows either as runoff or as a point source discharge. If filter mats are placed adjacent to areas that receive concentrated runoff, they should be protected by berms, or a similar structure that diffuses or diverts the concentrated runoff before it reaches the filter mat.

**Typical Maintenance Schedule**

Filter mats must be regularly and closely inspected to ensure that soil has not begun to erode beneath the mat.

**Regional Considerations**

Climate concerns will vary with each locality. Filter mats are more or less effective depending on a variety of climatic factors, primarily temperature and moisture regimes. *Factors to Consider:* Time of year for construction, availability of materials, volume of water and possible contaminants.

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# Sand/Media FiltersFact Sheet

**How Media Filters Work**

Source: Low Impact Development Center

Sand filters temporarily store stormwater runoff and pass it through a filter bed of sand or other filtering media. They are usually designed as two-chambered stormwater practices; the first is a settling chamber, and the second is a filter bed filled with the filtering media. As stormwater flows into the first chamber, large particles settle out, and then finer particles and other pollutants are removed as stormwater flows through the filtering medium. Sand filters could be constructed at the ground surface and be visible or may be constructed underground. Some of the more common types of sand filter designs include the surface sand filter, underground sand filter, perimeter sand filter, organic media filter, and three-chamber filter. All of these filtering practices operate on the same basic principle and include a settling chamber and a filtering chamber. Modifications to the traditional surface sand filter were made primarily to fit sand filters into more challenging design sites (e.g., underground and perimeter filters) or to improve pollutant removal (e.g., organic media filter).

The choice of which filter design to apply depends on available space, hydraulic head, and the level of pollutant removal desired. In ultra-urban situations where surface space is at a premium, underground sand filters are often the only design that can be used. The underground sand filter is modified to install the filtering components underground and is often designed with an internal flow splitter or overflow device that bypasses runoff from larger stormwater events around the filter. Underground sand filters are expensive to construct, but they consume very little space. Surface and perimeter filters are often a more economical choice when adequate surface area is available. The most common design variants are briefly described below.

<u>Non-Structural Sand Filter</u> – A surface filter is similar to a bioretention practice but has a filter media that is sand with a surface cover of sand, turf, or pea gravel. The filter surface is not planted with trees or plants and the bottom of the practice is lined with an

impermeable liner. Non-structural sand filters are the least expensive filter option for sites where bioretention facilities are not appropriate due to high pollutant loadings.

<u>Surface Sand Filter</u> - This is designed with both the filter bed and sediment chamber located at ground level. The most common filter media is sand; however, a peat/sand mixture may be used to increase the removal efficiency of the system. In most cases, the filter chambers are created using precast or cast-in-place concrete. Surface sand filters are normally designed to be off-line facilities, so that only the desired design volume is directed to the filter for treatment.

<u>Three Chamber Underground Sand Filter</u> - This is a gravity flow system that could be precast or cast-in-place. The first chamber acts as a pretreatment facility, removing any floating organic material such as oil, grease, and tree leaves. It has a submerged orifice leading to a second chamber containing the filter material consisting of gravel and sand. Along the bottom of the second chamber is a subsurface drainage system consisting of a parallel perforated PVC pipe system in a stone bed that connects to the third chamber, which is the discharge chamber. A dewatering valve is usually installed at the top of the filter layer for safety release in case of an emergency. The third chamber should also receive the overflow from the first chamber through a bypass pipe when the storage volume is exceeded.

<u>Perimeter Sand Filter</u> - In this design, flow enters the system through grates, usually at the edge of an impervious surface. The system typically consists of two parallel trenches connected by a series of overflow weir notches at the top of the partitioning wall that allows water to enter the second trench as sheet flow. The first trench is a pretreatment chamber that removes heavy sediment, particles, and debris. The second trench consists of the sand filter layer with a subsurface drainage pipe installed at the bottom to facilitate the filtering process and convey filter water into a receiving system.

**Effectiveness**

- Sand filters are effective stormwater treatment practices for pollutant removal.
- Sand filters typically remove over 80% of TSS and 50-85% of metals.
- Dual media filter systems using adsorbent material have been found to remove copper and zinc at efficiency levels between 89% and 99%. TSS removal efficiency rates for these units exceeded 90%.
- Available studies suggest that organic filters have similar efficiency rates to sand filters.

**Design Recommendations**

- Sedimentation chambers may be wet or dry but must be sized to accommodate at least 25% of the total design storm volume.
- Sediment chambers should be designed as level spreaders such that inflows to the filter bed have near zero velocity and spread runoff evenly across the bed.

- Non-structural and surface sand filters may use alternative pretreatment measures, such as a grass filter strip, fore-bay, gravel diaphragm, check dam, level spreader, or a combination of these.
- Filters are gravity flow systems that normally require 2 to 5 feet of driving head to push the water through the filter media through the entire maintenance cycle; therefore, sufficient vertical clearance between the inverts of the inflow and outflow pipes is required.
- The normal filter media consists of clean, washed AASHTO M-6/ASTM C-33 medium aggregate concrete sand with individual grains between 0.02 and 0.04 inches in diameter.
- Underground sand filters should have a pea gravel layer on top of the sand layer. The pea gravel helps to prevent bio-fouling or blinding of the sand surface.
- Sand media can be replaced by other suitable media to target specific pollutants such as using adsorbent material to increase the metal removal efficiency.
- Media filter sizing and design requirements vary from one municipality to another. Check with state and local regulators for the most current stormwater design guidelines applicable to your site. A rough estimate of required filter size, performance, and expected cost can be generated using the BMP SELECT model produced by the Water Environment Research Foundation (WERF), which can be downloaded at www.werf.org/SELECT.

**Nutrients**

- With the exception, of nitrate (NOx), sand filters perform reasonably well at removing nutrients.
- Studies have shown that nitrate is exported from filtering systems, which may be caused by mineralization of organic nitrogen in the filter bed.
- Sand filters typically have shown to have average efficiency rates of 59% for total phosphorus and 38% for total nitrogen.

**Cost**

- The average cost of a sand filter is about $5 per cubic foot of storm water treated and the estimated cost per system is estimated to be at $14,000 per impervious acre treated (USEPA, 2009).
- While underground systems are substantially more expensive than surface sand filter, they consume no surface space, thus making them a relatively cost-effective practice in ultra-urban areas where land is at a premium.

**Potential Limitations**

- Sand filters require frequent maintenance, and underground and perimeter versions of these practices are easily forgotten because they are out of sight.
- Sand filter cannot be used to treat large drainage areas and are best applied at treating areas less than 2 acres.

**Typical Maintenance Schedule**

- Frequent maintenance and inspection practices are needed to verify filtering systems are operating as intended.

- Monthly
    - Ensure that the drainage area and filtering practice are clear of debris and stabilized.
    - Check to ensure that the filter surface is not clogging. This should be done after moderate and major storms also.
    - If a permanent pool is maintained, ensure chamber does not leak.
- Yearly
    - Check to see that the filter bed is clean of sediments and the sediment chamber is not more than ½ full of sediment. Remove sediment if necessary.
    - Check structure, inspect grates, inlets, and outlets to ensure good condition and no evidence of erosion.
    - Ensure that flow is not bypassing the facility and that no noticeable odors are detected outside the facility.

**Regional Considerations**

- In cold climates, surface or perimeter filters will not be effective during the winter months, and may have unintended consequences from a frozen filter bed. Using alternative conveyance measures such as a weir system between the sediment chamber and filter bed may avoid freezing associated with the traditional standpipe.
- In such climates, where possible, the filter bed should be below the frost line.
- Some filters, such as the peat sand filter, should be shut down during the winter as these media will become impervious during freezing conditions.
- Sand filters have not been widely used in arid climates due to the high sediment loads in these regions. Designers should consider increasing the volume of the sediment chamber to up to 40% of the design runoff volume to account for the increased loading.

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# Permeable Friction Course Fact Sheet

## How Permeable Friction Course Works

A permeable friction course (PFC) is a layer of porous asphalt approximately 1.0 to 2.0 inches thick that is often applied as an overlay on top of conventional concrete and asphalt highways. Porous asphalt is an alternative to traditional hot mix asphalt and is produced by eliminating the fine aggregate from the asphalt mix. The void space in a PFC overlay layer generally is 18-22%. Rain that falls on the friction course drains through the porous layer to the original impervious road surface at which point the water drains along the boundary between the pavement types until the runoff emerges at the edge of the pavement.

Source: U.S. DOT

While originally used to enhance highway safety, recent research has shown that PFC may also provide water quantity and quality improvements to stormwater runoff. Porous asphalt overlays are used increasingly by state transportation agencies, including those in Georgia, Texas, California, and Utah, to improve drivability in wet weather conditions and to reduce noise from highway traffic. Acknowledged benefits include reduced splash and spray, better visibility, better traction, reduced hydroplaning, and less noise. These pavements also may reduce the runoff volume and peak runoff velocity, as well as increase the lag time between rainfall and runoff, especially for smaller storm events. The impact of PFC on stormwater runoff quality has been evaluated in few scientific studies and there are several reasons to think that improved water quality may result from the installation of this material. PFC might be expected to reduce the generation of pollutants, retain a portion of generated pollutants within the porous matrix, and impede the transport of pollutants to the edge of the pavement. The porous structure of PFC also may act as a filter of the stormwater. Runoff enters the pores in the overlay surface and is diverted towards the shoulder by the underlying conventional pavement. Pollutants in the runoff can be filtered out as the water flows through the pores, especially suspended solids and other pollutants associated with particles. Pollutants also may become attached to the PFC matrix by straining, collision, and other processes. Material that accumulates in the pore spaces of PFC is difficult to transport and may be trapped permanently. On the surface of a conventionally paved road, splashing created by tires moving through standing water easily can transport even larger particulate matter rapidly to the edge of pavement. However, water velocities within the pore spaces of the PFC are low and likely could only transport the smallest material.

Since research is still emerging on the benefits of PFC to stormwater runoff, specific pollutant reduction levels have not been established. State agencies do not consider PFC as a recognized stormwater Best Management Practice and therefore do not give stormwater credits for the installation of these practices. However, given the widespread interest in PFC, it can be expected that more information will be available to ascertain the benefits of PFC on stormwater runoff in the near future.

**Effectiveness**

Because PFCs reduce the amount of splash and spray, it is assumed that fewer contaminants are washed from vehicles. Studies suggest that the void structure within a PFC layer may act to filter pollutants, especially suspended soils and other pollutants associated with solid particles. A study in the Netherlands compared the concentrations of pollutants in runoff from porous and dense-graded surfaces where the porous layer was three years old and 55mm in thickness. This study found lower concentrations of pollutants in runoff sampled from the pavement having a porous wearing surface than the dense-graded surface. Based upon the test results, the following was observed: 91 percent reduction in total suspended solids (TSS); 84 percent reduction in total Kjeldahl nitrogen (TKN); 88 percent lower chemical oxygen demand; and 67 to 92 percent lower cooper, lead, and zinc. Consult the Literature Review for a detailed discussion of these factors.

**Design Recommendations**

- PFC has been primarily used on urban freeways and rural interstates. There are also cases in southeast U.S. where it has been used on urban arterial and collector type roads and rural primary highways.
- Design speeds specified on PFCs can exceed 55 mph.
- PFCs have been defined as specialty type open-graded friction courses that are specifically designed to have high air void contents, above 18 percent, for removing water from the pavement surface.
- The design of PFC mixes contains four primary steps: selection of appropriate materials, selection of a design gradation, selection of optimum asphalt binder content, and performance testing.
- Optimum asphalt binder content should be selected based upon balancing durability and drain down potential.
- Fibers or polymers are used as stabilizing additives and eliminates the issue of unravelling experienced with earlier Open Graded Friction Courses (OGFC). The percentage of fibers required ranges from 0.2% to 0.5%.

**Cost**

The construction cost of PFC surfaces is higher than conventional dense-graded surfaces, especially when polymers and fibers are used. In addition, the following factors add to the whole life cycle costs for PFCs being higher:

  - The expected service life for PFCs is typically 6-10 years; for conventional dense-graded surfaces it is 12-15 years.
  - Higher maintenance costs to keep the surface unclogged.
  - Higher winter maintenance costs to keep the surface operational.

**Potential Limitations**

- These mixes should not be utilized in areas with large amounts of dirt and debris. This will lead to the PFC layers clogging.
- PFCs should not be used in areas with high yearly snow fall rates. Winter maintenance can be expensive in these areas and snowplows have been shown to damage PFC layers.
- PFCs should not be used when long haul distances or haul times are needed. This will allow the PFC to cool during transportation and likely cause construction problems.
- As particles and particle associated pollutants accumulate within the pore structure it seems likely that more runoff will travel on the surface of the pavement, resulting in concentrations that might not be significantly different from those observed in runoff from conventional asphalt pavements, unless maintenance is performed to remove the accumulated material.

**Typical Maintenance Schedule**

- Maintenance of PFC mixtures is different from conventional dense-graded hot mix asphalt. Maintenance can be generally grouped into one of two categories: general maintenance and winter maintenance. General maintenance involves activities such as cleaning of clogged PFC, preventative surface treatments, and corrective surface treatments. Winter maintenance involves those activities required to maintain a safe driving surface during winter events.
- General Maintenance
  - Cleaning clogged PFC surfaces - usually done using a fire hose, a high water pressure cleaner, or with a specially designed manufactured cleaning vehicle. The frequency of cleaning needs to be determined through inspection of surface. It has been found that best cleaning results are obtained when PFC surfaces are cleaned prior to the surface becoming clogged.
  - Preventive and corrective surface treatment - conducted to repair delaminated areas or potholes and to repair minor surface distresses.
- Winter Maintenance
  - Currently, state agencies use different winter maintenance strategies that are adjusted for each location’s winter climate based on experience. However, it is widely expected that PFC layers require more winter maintenance chemicals than typical dense-graded layers during winter events.

**Regional Considerations**

- Winter maintenance on PFCs is a perceived problem worldwide since they are susceptible to freeze-thaw damage and black ice formation.

- In winter climates, PFCs require more intensive winter maintenance practices.

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# Permeable Pavement Fact Sheet

## How Permeable Pavement Works

Source: U.S. Navy

Permeable pavements, also called porous pavements, consist of a permeable surface course underlain by a uniformly graded gravel-bed laid on uncompacted soil. The surface course consists of porous asphalt, porous concrete, or various types of concrete paving block porous pavers. After water migrates through the surface, it temporarily collects in the gravel storage layer. Depending upon the rainfall intensity, rainfall volume, and existing soil infiltration rate, rainwater either exits the bottom of the permeable pavement (via soil infiltration or drain pipes beneath the pavement), or it builds up inside the pavement (gravel storage layer) until runoff occurs.

Very intense rainfalls can produce runoff from permeable pavement surfaces when the intensity exceeds the infiltration rate of water through the permeable surface. When water passes through a permeable pavement, many pollutants can be trapped inside of it or removed as the water passes out of the pavement into the surrounding soil. By temporally storing water with the gravel layer, permeable pavements provide peak flow reduction and promote infiltration to the underlying soils. The gravel layer functions to provide storage for stormwater and to provide structural support to bear vehicles or other weights on the surface. Typically, an underdrain connected to the storm sewer network will be located near the bottom of the gravel base to ensure stored water within the base is drained adequately. Permeable pavements provide water quantity and quality benefits by promoting infiltration, while still providing a stable load-bearing surface without increasing the project impervious area. Sometimes an impermeable liner will be needed to separate the gravel layer from the sub-base, if the underlying clay has a high shrink-swell potential or due to the presence of nearby structures. When infiltration rates are low or an impermeable layer is utilized around the practice, permeable pavements provide water quantity benefits by increasing the travel time of runoff and water quality benefits by filtering of pollutants as they travel within the permeable pavement section. Permeable pavements provide water quality treatment by removing sediments, nutrients, and some heavy metals.

Storage capacity is a function of the depth of the gravel bed and the footprint of the facility. The underdrain will convey stormwater from the storage layer in addition to any water that infiltrates into the sub-base. Two options could be utilized to reduce the amount of runoff via the underdrain and thereby increase the amount of water available to infiltrate when sufficient infiltration rates in the soil can be utilized to drain the gravel layer adequately. One option is to use an upturned underdrain that creates a permanent storage zone in the bottom of the gravel layer that can only be drained out via infiltration. The second option is to size the underdrain with a limited outflow rate (underdrains with a small diameter or restrictive orifice) and extend the amount of time water remains within the gravel layer.

**Types of Permeable Pavements**

Several types of permeable pavements are available, including pervious concrete, pervious asphalt, permeable interlocking concrete pavers (PICPs), and concrete grid pavers. The different types do not generally exhibit different levels of runoff and are treated the same way when assigning runoff reduction credits. Information on the different pavement types are provided below. Consult the Literature Review for a detailed discussion of the structural suitability of the different permeable pavements.

- Permeable Concrete - Permeable Concrete is a mixture of Portland cement, fly ash, washed gravel, and water. The water to cementitious material ratio is typically 0.35 – 0.45 to 1. Unlike traditional installations of concrete, permeable concrete usually contains a void content of 15 to 25 percent, which allows water to infiltrate directly through the pavement surface to the subsurface. A fine, washed gravel, less than 13mm in size (No. 8 or 89 stone), is added to the concrete mixture to increase the void space. An admixture improves the bonding and strength of the pavements. These pavements are typically laid with a 10 to 20 cm (4 – 8 in) thickness and may contain a gravel base course for additional storage or infiltration. Compressive strength can range from 2.8 to 28 MPa (400 to 4,000 psi).
- Permeable Asphalt - Permeable Asphalt consists of fine and course aggregate stone bound by a bituminous-based binder. The amount of fine aggregate is reduced to allow for a larger void space typically 15 to 20 percent. The thickness of the asphalt depends on the traffic load, but it usually ranges from 7.5 to 18 cm (3 – 7 in). A required underlying base course increases storage and adds strength.
- Permeable Interlocking Concrete Pavements (PICP) - PICP are available in many different shapes and sizes. When lain, the blocks form patterns that create openings through which rainfall can infiltrate. These openings, generally 8 to 20 percent of the surface area, are typically filled with pea gravel aggregate, but can also contain top soil and grass. ASTM C936 specifications state that the pavers be at least 60mm (2.36 in) thick with a compressive strength of 55 MPa (8,000 psi) or greater. Typical installations consist of the pavers and gravel fill, a 38 to 76 mm (1.5 – 3.0 in) fine gravel bedding layer, and a gravel base-course storage layer.
- Concrete Grid Pavers (CGP) - CGP conform to ASTM C 1319, *Standard Specification for Concrete Grid Paving Units* (2001a), which describes paver properties and specifications. CGP are typically 90mm (3.5 in) thick with a maximum 60 × 60 cm (24 × 24 in) dimension. The percentage of open area ranges from 20 to 50 percent and can contain topsoil and grass, sand, or aggregate in the void space. The minimum average

compressive strength of CGP can be no less than 35 MPa (5,000 psi). A typical installation consists of grid pavers with fill media, 25 to 38 mm (1 – 1.5 in) of bedding sand, gravel base course, and a compacted soil subgrade.

**Effectiveness**

- Research has investigated how well permeable pavements remove metals, sediment, motor oil, and nutrients and their impact on pH and temperature. As compared to asphalt runoff, permeable pavement drainage has been shown to decrease concentrations of several stormwater pollutants, including heavy metals, motor oil, sediment, and some nutrients. Consult the Literature Review written by NAVFAC EXWC and the LID Center Inc. for a detailed discussion of these factors. Studies have also found that installing permeable pavement over a crushed brick base increased the level of metals removal. Most heavy metals are captured in the top layers (1 to 2 in) of material in permeable pavement void space. For PICP and CGP that are filled with sand, this implies that *standard street sweeping will probably remove the majority of heavy metals* collected in the pavement fill material.

**Design Recommendations**

- The portion of the contributing drainage area to the permeable pavement should generally be kept at less than 5 times the surface area of the pavement. The contributing drainage must be completely stabilized to avoid clogging of the system from sediment. Permeable pavement must be designed so that the stormwater is detained in the gravel layer for as long as possible—36 to 48 hours—before completely discharging through an underdrain or infiltrating into the subsoil. A minimum orifice size of 1 inch is generally recommended.
- The thickness of the gravel layer is determined by both a structural and hydraulic design analysis. The gravel layer serves to retain stormwater and supports the design traffic loads for the pavement.
- If permeable pavement will be used in a parking lot or other setting that involves vehicles, the pavement surface must be able to support the maximum anticipated traffic load. The structural design process will vary according to the type of pavement selected, and the manufacturer’s specific recommendations should be consulted.
- To protect the bottom of the reservoir layer from intrusion by underlying soils, a filter layer can be used, such as a 2 to 4 inch layer of choker stone.
- An impermeable liner is not typically required, although it may be utilized in fill applications where deemed necessary by a geotechnical investigation, on sites with contaminated soils, or on the sides of the practice to protect adjacent structures from seepage.
- Permeable pavement sizing and design requirements vary from one municipality to another. Check with state and local regulators for the most current stormwater design guidelines applicable to your site. A rough estimate of required permeable pavement size, performance, and expected cost can be generated using the BMP SELECT model produced by the Water Environment Research Foundation (WERF), which can be downloaded at www.werf.org/SELECT.

**Nutrients**

- The nutrient removal capabilities of permeable pavements are less understood. Some permeable pavement studies have shown that removal of total phosphorus (TP) is often attributed to adsorption to the sand and gravel sub-base materials. It also appears that CGP and PG filled with sand are more able to reduce total nitrogen (TN). This occurs because CGP filled with sand closely resembles a low-head, limited-media sand filter.

**Cost**

The WERF SELECT Model calculates the cost of bioretention based on the WERF Whole Life Cost Models, and uses the following values:

  - Capital costs are estimated at $53K per acre treated, which includes planning, engineering, and construction.
  - Operation and maintenance costs are estimated to be 3.5% of capital costs.
  - Replacement costs are estimated to be 80% of capital costs, with a design life of 25 years.

**Potential Limitations**

- Proper infiltration of captured stormwater from permeable pavements requires that the groundwater table be at least several feet below the bottom of the pavement base.
- Permeable pavements should not be used on roads that have high speeds or heavy vehicle usage. Low speed roads, roadway shoulders, and parking lanes are optimal areas for permeable pavements within a roadway section.
- Permeable pavement is not intended to treat sites with high sediment or trash/debris loads, since such loads will cause the practice to clog and fail. If unavoidable, pretreatment measures such as a gravel or sod filter strip should be employed.
- The following activities should be avoided on permeable pavements to limit the potential for clogging: sanding, re-sealing, re-surfacing, power washing, storage of snow piles containing sand or mulch/ soil materials, and construction staging on unprotected pavement. In addition, it is critical that surrounding land areas remain stabilized.

**Typical Maintenance Schedule**

Maintenance is a required and crucial element to ensure the long-term performance of permeable pavement. The most frequently cited maintenance problem is surface clogging caused by organic matter and sediment. Many experts consider an annual, dry-weather sweeping in the spring months to be important. In addition, routine maintenance should be performed to remove soil or sediment deposited on pavement and to repair any surfaces that are degenerating or spalling.

- After installation
  - The practice and drainage area should be inspected regularly after significant rainfall events during the first 6 months. Repairs or stabilizations should be performed as needed.
- Biannually or more frequently
  - Mechanically sweep pavement with a standard street sweeper to prevent clogging.
- Annually

  - Conduct a maintenance inspection.
  - Spot weed for grass applications.

**Regional Considerations**

Winter maintenance for permeable pavements should take into consideration the following:

- Sand or cinders should never be applied for winter traction over permeable pavement or areas of standard (impervious) pavement that drain toward permeable pavement, since it will quickly clog the system.
- Chloride products should be used judiciously to deice above permeable pavement designed for infiltration, since the salt will be transmitted through the pavement. Salt can be applied but environmentally sensitive deicers are recommended. Permeable pavement applications will generally require less salt application than traditional pavements.
- Most permeable pavements can be plowed similar to traditional pavements. Refer to manufacturer's recommendations for specific guidelines.

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# Vegetated Filter StripsFact Sheet

**How Vegetated Filter Strips Work**

Source: Low Impact Development Center

Vegetated filter strips can be applied in many land use types, including residential, commercial, industrial, training areas, and road/highway transportation projects, as space and slopes are available. A vegetated filter strip is a densely vegetated strip of gently sloping area that receives runoff from an adjacent impervious area as sheet flow. The vegetated strip slows the velocity of runoff and allows for removal of sediments and other pollutants as the runoff flows through the filter strip. The runoff may flow from the vegetated filter strip to another structural LID BMP, a vegetated area, or a receiving water body. Vegetated filter strips are most effective in treating runoff from isolated impervious areas such as rooftops, parking lots, and smaller impervious areas. Usually, a vegetated filter strip is used as a pretreatment component to reduce sediments and particulate pollutant load before runoff reaches the primary stormwater BMP, such as bioretention, vegetated swale, or an infiltration trench. Frequently, vegetated filter strips are designed where runoff is directed from a parking lot into a stone trench, a grass strip, and a longer naturally vegetative strip. For ultra-urban areas and some redevelopment areas, they might not be appropriate due to lack of space. Because vegetated filter strips should be constructed as part of a larger stormwater treatment system, space requirements for additional BMPs should also be considered. Using vegetated filter strips as pretreatment practices to other BMPs is highly recommended. The stormwater runoff from the impervious area must sheet flow across the vegetated filter strip for the proper function and effectiveness of a vegetated swale.

**Effectiveness**

Vegetated buffer strips tend to provide somewhat better treatment of stormwater runoff than swales and have fewer tendencies for channelization or erosion. Table 1 documents the pollutant removal observed in a study by Caltrans (2002) based on three sites in southern California. The column labeled "Significance" is the probability that the mean influent and effluent EMCs are not significantly different based on an analysis of variance.

**Table 1: Pollutant Reduction in a Vegetated Filter Strip**[i]

| **Constituent** | **Mean EMC** | | **Removal %** | **Significance (P)** |
|---|---|---|---|---|
| | *Influent (mg/L)* | *Effluent (mg/L)* | | |
| TSS | 119 | 31 | 74 | <0.000 |
| Total Cu | 0.058 | 0.009 | 84 | <0.000 |
| Total Pb | 0.046 | 0.006 | 88 | <0.000 |
| Total Zn | 0.245 | 0.055 | 78 | <0.000 |
| Dissolved Cu | 0.029 | 0.007 | 77 | 0.004 |
| Dissolved Pb | 0.004 | 0.002 | 66 | 0.006 |
| Dissolved Zn | 0.099 | 0.035 | 65 | <0.000 |

**Design Recommendations**

- Maximum length (in the direction of flow towards the buffer) of the tributary area should be 60 feet.
- Slopes should not exceed 15%[ii].
- Minimum length (in direction of flow) is 15 feet.
- Width should be the same as the tributary area.
- Either grass or a diverse selection of other low growing, drought tolerant, native vegetation should be specified. Vegetation whose growing season corresponds to the wet season is preferred.
- Use energy dissipation devices and flow spreaders where there are high energy contributing flows such as sheet flow from pavements or from roof leaders.

**Cost**

Little data is available on the actual construction costs of filter strips because they are often incorporated into other site infrastructure systems. One rough estimate can be the cost of seed or sod, which is approximately \$0.30 per ft$^2$ for seed or \$0.70 per ft$^2$ for sod[iii]. This amounts to a cost of between \$13,000 and \$30,000 per acre for filter strips. This cost is relatively high compared with other treatment practices. However, the grassed area used as a filter strip may have been seeded or sodded even if it were not used for treatment.

**Potential Limitations**

- May not be appropriate for industrial sites or locations where spills may occur.
- Buffer strips cannot treat a very large drainage area.
- A thick vegetative filter length must be adequate and flow characteristics acceptable or water quality performance can be severely limited.
- Vegetative buffers may not provide treatment for dissolved constituents except to the extent that flows across the vegetated surface are infiltrated into the soil profile.

**Typical Maintenance Schedule**

Filter strips require mainly vegetation management, similar with standard landscaping demands; therefore, little special training is needed for maintenance crews. Typical maintenance activities and frequencies include:

- Inspect strips at least twice annually for erosion or damage to vegetation, preferably at the end of the wet season to schedule summer maintenance and before major fall runoff to be sure the strip is ready for winter. However, additional inspection after periods of heavy runoff is most desirable. The strip should be checked for debris, litter, and areas of sediment accumulation.
- Trash tends to accumulate in strip areas, particularly along highways. The need for litter removal should be determined through periodic inspection but litter should always be removed prior to mowing.
- Regularly inspect vegetated buffer strips for pools of standing water. Vegetated buffer strips can become a nuisance due to mosquito breeding in level spreaders, in pools of standing water if obstructions develop, and/or if proper drainage slopes are not implemented and maintained.

**Regional Considerations**

- Where seeds are used, erosion controls will be necessary to protect seeds for at least 75 days after the first rainfall of the season.
- Pedestrian and/or vehicular traffic on filter strips should be strictly discouraged. Since the function of filter strips can be easily overlooked or forgotten over time, a highly visible, physical "barrier" is suggested. This can be accomplished, at the discretion of the owner, by simple post and chain, signage, or even the level-spreading device itself.
- Filter strips often make convenient areas for snow storage. Thus, filter strip vegetation should be salt-tolerant and the maintenance schedule should involve removal of sand buildup at the toe of the slope.
- The bottom of the gravel trench (if used as the level spreader) should be placed below the frost line to prohibit water from freezing in the trench. The perforated pipe in the trench should be at least 8 inches in diameter to further discourage freezing.

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[i] Caltrans, 2002

[ii] California Stormwater Quality Association, 2003

[ii] Department of Defense, 2010

# Tree Box Filter Fact Sheet

**How Tree Box Filter Works**


Source: Low Impact Development Center

Tree box filters are essentially bioretention facilities utilizing the same techniques to improve storm water quality. They achieve pollutant removal through a combination of physical, chemical, and biological processes in plants and soils. The system consists of a container filled with a soil mixture, a mulch layer, under-drain system, and a shrub or tree. Runoff is directed to the tree box from impervious surfaces, where it is cleaned by vegetation and soil and is used to irrigate the trees. Remaining treated water flows out of the system through an under drain connected to a storm drainpipe / inlet or into the surrounding soil. The soil media is similar to media used in bioretention facilities and an optional stone storage layer can be provided beneath the soil to enhance storage.

Engineered tree boxes are installed in the sidewalk zone near the street where urban street trees are normally installed. The soil volume provided for the tree pit is larger than that provided for a normal street tree. Stormwater treatment can be increased by using a series of connected tree planting areas together in a row. The surface of the enlarged planting area may be mulch, grates, permeable pavers, or conventional pavement. The large and shared rooting space and a reliable water supply increase the growth and survival rates in what would otherwise be a harsh planting environment.

Engineered soil media are designed to provide permeability, promote plant growth, and treatment using a mixture of sand, soils, and/or organic elements. Pollutant removal performance can be optimized by adjusting a number of design factors, including the composition of the filter media, size of the practice, and drainage characteristics. Storage capacity is a function of the ponding depth, media/stone depth and porosity, and the footprint of the facility. Storage capacity can be increased by adding a stone storage layer beneath the soil medium. Overall volume reduction potential relies on infiltration rates and storage capacity, with some losses to evapotranspiration. In areas where soil infiltration rates are low, an underdrain of stone and perforated drainage pipe is typically installed to convey the water that does not get absorbed in the root and soil mix or does not infiltrate into the ground to an outfall.

### Effectiveness

- The effectiveness of tree box filters can be considered to be similar to bioretention practices given that the same processes occur in both to remove pollutants. Therefore, studies performed on bioretention cells can be considered applicable to tree box filters. Please refer to the bioretention fact sheet for information regarding effectiveness.

### Design Recommendations

- The bottom of the soil layer must be a minimum of 4 inches below the root ball of the plants to be installed.
- Engineered tree box designs sometimes cover portions of the filter media with pervious pavers or cantilevered sidewalks. In these situations, it is important that the filter media be connected beneath the surface so that stormwater and tree roots can share this space.
- The dug hole must be no deeper than the root ball or mass but two to three times wider than the spread of the root ball or mass. The majority of the roots on a newly planted tree will develop in the top 12 inches of soil and spread out laterally.
- One of the most important planting guidelines is to make sure the tree is not planted too deeply. The root collar, the lowest few inches of trunk just above its junction with the roots (often indicated by a flare), should be exposed.
- At least two cubic feet of useable soil per square foot of average mature tree canopy should be generally provided. (Useable soil must not be compacted and may not be covered by impervious material).
- Having at least a 6-foot wide planting strip or locating sidewalks between the trees and street allows more rooting space for trees in adjacent property.
- Similar to bioretention practices, tree box filters work best when drainage areas are small which generally should not exceed 1 acre.
- Installing an engineered tree pit grate over filter bed media is a possible solution to prevent pedestrian traffic and trash accumulation in highly walked areas.
- Select tree species that are drought tolerant, can grow in poor or compacted soils, and are tolerant to typical urban pollutants (oil and grease, metals, and chlorides).
- Mulch should never be more than 4 inches deep or applied right next to the tree trunk. A mulch-free area, 2- to 3-inches wide at the base of the tree, must be provided to avoid moist bark conditions and prevent decay.
- Refer to the bioretention fact sheet for other applicable design recommendations pertaining to enhancing media for metals removal.

### Nutrients

- Refer to the bioretention fact sheet for nutrient information.

Costs of tree box filters can be considered similar to bioretention practices. The WERF SELECT Model calculates the cost of bioretention based on the WERF Whole Life Cost Models, and uses the following values:

**Cost**

- Capital costs are estimated at $53K per acre treated, which includes planning, engineering, and construction.
- Operation and maintenance costs are estimated to be 3.5% of capital costs.
- Replacement costs are estimated to be 80% of capital costs, with a design life of 25 years.

**Potential Limitations**

- Proper infiltration of captured stormwater from tree box filters requires that the groundwater table be at least several feet below the bottom of the tree box.
- Tree box filter soils are highly porous and uncompacted; therefore, barriers should be used to prevent errant vehicles from entering the practice.

**Typical Maintenance Schedule**

For the most part, tree box filter maintenance is similar to general maintenance of landscaping.

- Post Planting Tree Protection
    - Once the tree has been properly planted, 2 to 4 inches of organic mulch must be spread over the soil surface out to the drip line of the tree. If planting a cluster of trees, mulch the entire planting area.
    - Slow-decomposing organic mulches, such as shredded bark, compost, leaf mulch, or wood chips provide many added benefits for trees.
- Watering Frequency
    - Water newly planted trees regularly (at least once a week) during the first growing season.
    - Water trees less frequently (about once a month) during the next two growing seasons.
    - After three growing seasons, water trees only during drought. The exact watering frequency will vary for each tree and site.
    - Water trees deeply and slowly near the roots. Light, frequent watering of the entire plant can actually encourage roots to grow at the surface. Soaker hoses and drip irrigation work best for deep watering of trees. Continue watering until mid-fall, tapering off during lower temperatures.

**Regional Considerations**

- For the best performance, select trees that are adapted to the local climate.
- Irrigation is typically required for plant establishment in most climates in North America.
- During freezing conditions, tree box filters will continue to remove metals, but may exhibit diminished nitrogen removal.

**References**

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Tree Box Filter. By the Low Impact Development Center, Inc. Photo not available online.