STATE OF FLORIDA

BEST MAINTENANCE PRACTICES FOR STORMWATER RUNOFF

DESIGNER AND REVIEW MANUAL

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1. Introduction

1.1. Purpose of the Handbook

This handbook has been developed to strive toward a consistent level of expertise in the field of Best Maintenance Practices (BMPs) for stormwater treatment. The manual provides information pertaining to implementation of maintenance practices to achieve reduction of pollutants in stormwater. Included are discussions on types and sources of stormwater pollutants, detrimental effects these pollutants may have on receiving water bodies, and how to reduce pollutant loading thorough use of sound BMP design, operation, and maintenance. Finally cost considerations and maintenance guidelines are presented for each BMP. Ultimately, the guidance of this handbook should give the reader knowledge in construction and maintenance of BMPs for successfully meeting stormwater management criteria.

1.2. Chapter Contents

1.3. Acronyms

BAT – Best Available Technology
BMP – Best Maintenance/Management Practice
BOD – Biological Oxygen Demand
BOD_5 – 5-day Biological Oxygen Demand
COD – Chemical Oxygen Demand
CBOD – Carbonaceous Biochemical Oxygen Demand
CWA – Clean Water Act
DMI – Distance Measuring Instrument
DO – Dissolved Oxygen
ED – Extended Detention
EMC – Event Mean Concentration
EPA – Environmental Protection Agency
FDEP – Florida Department of Environmental Protection
FEMA – Federal Emergency Management Agency
FDOT – Florida Department of Transportation
GIS – Geographic Information Systems
I/I – Infiltration and Inflow
MCL – Maximum Contaminant Level
MMS – Maintenance Management System
MPN – Most Probable Number
MRP – Maintenance Rating Program
MUTCD – Manual on Traffic Control Devices
N/A – Not Applicable
NH_3 – Ammonia
NH_4 – Ammonium
NO_2 – Nitrite
NO_3 – Nitrate
NOAA – National Oceanic and Atmospheric Administration
NPDES – National Pollutant Discharge Elimination System
NPS – Nonpoint Source

O&M – Operation and Maintenance
OP – Ortho-phosphate
OSHA – Occupational Safety and Health Administration
PAH – Poly-aromatic Hydrocarbon
PS – Point Source
PSI – Pounds per Square Inch
PVC – Polyvinyl Chloride
PW – Present Worth
QA/QC – Quality Assurance/Quality Control
QAPP – Quality Assurance Project Plan
RPD – Relative Percent Difference
SABS – Suspended and Bedded Sediments
SDWA – Safe Drinking Water Act
SCS – Sediment Control Structure
SOD – Sediment Oxygen Demand
SS – Suspended Solids
SWMM – Storm Water Management Model
SSWMP – Statewide Stormwater Management Plan
TDS – Total Dissolved Solids
TKN – Total Kjeldahl Nitrogen
TN – Total Nitrogen
TP – Total Phosphorus
TOC – Total Organic Carbon
TSS – Total Suspended Solids
USGS – United States Geological Survey
VOC – Volatile Organic Compound
WQ – Water Quality

1.4. Definitions

Alkalinity – A measure of the capacity of water to neutralize acids because of the presence of one or more of the following bases in the water: carbonates, bicarbonates, hydroxides, borates, silicates, or phosphates.

Ammonia nitrogen (NH_4-N) – A reduced form of nitrogen produced by the decomposition of organic matter and synthesized by biological and physical processes.

Best Available Technology – The best available technology that is economically achievable for an industry or entity to meet regulatory requirements.

Best Management Practice - a control technique used for a given set of conditions to achieve water quality and quantity at a reasonable? price.

Biochemical Oxygen Demand – A measure of the concentration of aerobically degradable compounds in water. Measured as the oxygen consumed during degradation of organic and inorganic materials in water.

5-day Biochemical Oxygen Demand – The biochemical oxygen demand which occurs after 5 days.

Chemical Oxygen Demand – A measure of the concentration of substances which can be oxidized in water. Expressed as the oxygen equivalent consumed when the organic matter in an aqueous sample is reacted with a strong chemical oxidant.

Clean Water Act – The primary federal law in the United States which governs water pollution.

Dissolved Oxygen - A measure of the total amount of oxygen which is dissolved in water.

Extended Detention – A function provided by BMPs which incorporates a water quality storage volume. BMPs with extended detentions capture and slowly release runoff, thereby extending the amount of travel time of the stormwater.

Filter Strip – A vegetated boundary characterized by the uniform slopes that contain vegetation. Filter strips serve to treat stormwater by creating uniform sheet flow conditions of stormwater.

Forebay – Stormwater structure that uses a small basin to settle out incoming sediment prior to discharge into a stormwater BMP.

Heavy Metal – Metallic elements which contain an atomic number greater than 21 on the periodic table.

Littoral Zone – A shallow area near to the edge of a pond which emergent vegetation may grow.

Maximum Contaminant Level – A maximum amount of a contaminant to be deemed acceptable.

Maintenance Rating Program – A uniform evaluation system for maintenance features on the State Highway System. It is defined as a method of conducting a visual and mechanical evaluation of routine highway maintenance conditions.

Method Detection Limit - The lowest concentration of a substance that can be measured and reported with a 99% confidence.

Nitrite – A polyatomic ion with the molecular formula NO_2^-. Nitrites are typically quickly oxidized into the nitrate form and rarely found in excessive concentrations in aquatic environments.

Nitrate – A polyatomic ion with the molecular formula NO_3^-. Nitrates are essential nutrients for vegetation and may also contribute to excessive algae blooms.

Non-Structural BMP - Preemptive actions taken to reduce the need or size of a structural BMP, such as educational measures, fertilizer control and street cleaning.

National Pollutant Discharge Elimination System (NPDES) – Authorized by the Clean Water Act, the NPDES permit program controls water pollution by regulating point sources that discharge pollutants into waters of the United States.

Nonpoint Source – Discharges due to intermittent, rain-fall driven, sources associated with everyday human activities, such as runoff from urban lands, which do not travel through a pipe.

Peak Attenuation Storage – A storage volume used to attenuate the peak flow in stormwater and reduce the peak flow rate.

Point Source – Discharges which occur through a continuous flow conveyance system, such as a pipe.

Precision – The degree of mutual agreement relative to individual measurements of a particular sample.

Seasonally High Water Table – The highest elevation a water table reaches during seasonally fluctuations.

Sediment Control Structure (SCS) – A BMP structure which is designed to settle and reduce the amount of sediments in the water column. Often times SCSs will encourage the pooling of stormwater to enhance the settling of solids.

Sediment Oxygen Demand – A measure of the biological and chemical oxygen demand that occurs in a sample of sediment.

Sheet Flow – Water flow characteristic of relatively thin and uniformly spread out across a given area.

Suspended and Bedded Sediments - Particulate organic and inorganic matter that suspend or are carried by water, and/or accumulate in a loose, unconsolidated form on the bottom of natural water bodies.

Structural BMP - An engineered stormwater management solution possessing a physical structure.

Total Dissolved Solids – A measure of the combined content of all inorganic and organic substances contained in a molecular form in water.

Total Kjeldahl Nitrogen – The sum of organic nitrogen, ammonia and ammonium in the chemical analysis of water.

Total Nitrogen – A measure of all organic and inorganic nitrogen forms in a water sample. The sum of TKN and NO_x equals the total nitrogen.

Total Organic Carbon – A measure of the total reduced carbon in a water sample.

Total Suspended Solids – A measure of the filterable solids in a water sample.

Treatment Train – Terminology used to refer to a combination of BMPs in series.

Volatile Organic Compound – Organic chemicals that have a high vapor pressure at ordinary room temperature.

1.5. Impacts of Urbanization

1.5.1. Stormwater Quantity and Quality in an Urban Setting

The hydrologic cycle is a continuous process that constantly cycles water from the atmosphere to the ground and back. Movement of water is made through many different phenomena including precipitation, runoff, evapotranspiration, infiltration, groundwater recharge, and stream base flow, all of which contain important properties of both water quantity as well as water quality. The development of urban settings may alter this water cycle in several ways, which if not adjusted by stormwater management practices, could lead to increases in flooding, eutrophication of lakes and other detrimental pollutant impacts to water bodies such as rivers, lakes, streams and oceans.

Firstly, the quantitative properties of stormwater may be changed with alterations in land characteristics due to urbanization. With the inclusion of impervious areas such as roads, parking lots, roofs, etc, quantities of water which previously percolated into the groundwater will be re-directed as surface runoff, thereby decreasing groundwater recharge volumes and increasing surface runoff volumes. These changes may have two major impacts on the surrounding areas. Increases in the *volume* of runoff can cause flooding within and downstream of the urban setting, especially during heavy rainfall events. While increases in the *peak* flow from the urban setting may increase water velocities in downstream water bodies such as rivers which in-turn may increase the erosion of banks and structures. To avoid such events, management of the stormwater is required to control the post-development volumes of runoff to match pre-developed conditions.

Secondly, chemical and biological water quality characteristics may be altered with the urbanization of land. As land is transformed from pervious to impervious areas, the retention time of stormwater remaining on the site will be decreased, resulting in a more rapid transport of runoff from the site. With a decrease in retention time, less time is allowed for the natural settling processes of suspended solids and other pollutants. Without proper management to attenuate the runoff leaving the site, the increased pollutant loading may lead to detrimental environmental and economic impacts downstream. Additionally, pollutant loading to water bodies is also likely to increase with urbanization as pollutants and nutrients are added to the land and transported in runoff during storm events. Nutrient loading has become a big issue due to fertilizer application to lawns and agricultural areas, which may lead to eutrophic conditions in downstream and surrounding water bodies. Other sources of pollutant sources are added such as vehicle exhaust and wear and tear. Management of the stormwater through BMPs may help to reduce such pollutant loadings, as will be discussed further in this manual.

1.5.2. First-Flush Phenomenon

The first-flush phenomenon in stormwater relates to the increased concentrations of pollutants commonly found during the initial “flush” of runoff from a storm event. During inter-event dry periods, a dry deposition build-up of pollutants from sources such as atmospheric deposition, fertilizer applications, vehicle wear and exhaust, spills, etc, will accumulate on the land within a watershed. During the first storm following this dry period, many of these pollutants are transported in the runoff to ponds, rivers and lakes. As a result, the first-flush of runoff will likely contain higher pollutant concentrations of heavy metals, suspended solids and nutrients as compared to the remaining runoff from the storm. By using

BMPs designed specifically to capture and treat the first-flush of storms, much of the pollutant loading may be reduced without needing to treat the entire volume of runoff. Additionally BMPs should typically be designed to provide treatment control for smaller rainfall events. In Florida, nearly 90 percent of the storm events in a given year produce one inch or less of rainfall and contribute to 75 percent of the total volume of rain fall (Wanielista, 1977). Therefore by designing BMPs to treat one inch storms or less, a cost-effective sizing of the BMP may be obtained.

1.6. Target Pollutants in Stormwater Runoff

In an urban environment, the roadways, parking lots, rooftops, sidewalks, and surfaces of low permeability contribute to the total imperviousness of an area. Impervious landscapes are known to affect an aquatic area's habitat, biodiversity, water quality, and hydrology (Schueler, 1994). The reason for this is twofold. Since the volume of the stormwater runoff is not reduced through infiltration, receiving water bodies will receive increased amounts of runoff, which causes erosion and flooding—leading to habitat destruction. Furthermore, as the runoff flows across the impervious surfaces, it acquires and transports nutrients, heavy metals, hydrocarbons, pathogenic bacteria, suspended solids, and trash. The significant influx of these pollutants into a domestic water body will disrupt the ecological balance, as evidenced by symptoms such as hypoxia, fish kills, eutrophication, and the accumulation of heavy metals and toxicants.

In order to better understand the maintenance problems caused by the pollutants in stormwater runoff, it is important to know the source of pollutants. In a natural watershed, the ecosystem operates in such a manner that the low concentrations of pollutants are utilized as resources; thereby moderating the amount that will be discharged downstream (NRC, 2008). However, anthropogenic activities have reshaped these natural waterways through the addition of impervious surfaces, disturbance of soils during construction and agriculture, and other forms of urbanization. As a result, the watersheds are exposed to elevated pollutant levels that cannot be remediated through natural processes. Pollutant sources are split into two main categories: point sources (PS) and nonpoint sources (NPS). As per section 502(14) of the Clean Water Act (CWA), point sources can be linked to a discernible and discrete point of supply, such as an industry or water treatment plant. Conversely, NPS are pollutant sources that cannot be labeled as a point source; their source is more widespread and diffuse such as runoff from an agricultural field. As stormwater runoff moves across the earth's surface, it collects deposited natural and anthropogenic pollutants, which are then transported to receiving water bodies. Common pollutants and pollutant sources in stormwater runoff are detailed in Table 1:

Table 1: Sources of Pollution in Highway and Residential Runoff (EPA, 1993)

Type	Pollutant	Common Sources
Sedimentation	Particulates	Pavement wear, vehicles, atmospheric deposition, maintenance activities, septic tank leakage
Nutrients	Nitrogen and Phosphorus	Atmospheric deposition, fertilizer application, septic tank leakage, roadway runoff, and decaying plant matter
Heavy Metals	Lead	Leaded gasoline from automotive exhaust and tire wear
	Zinc	Tire wear, motor oil, and grease
	Iron	Auto body rust, steel highway structures, and moving engine parts
	Copper	Metal plating, bearing and brushing wear, moving engine parts, brake lining wear, fungicides, and insecticides
	Cadmium	Tire wear and insecticide application
	Chromium	Metal plating, moving engine parts, and break lining wear
	Nickel	Diesel fuel and gasoline, lubricating oil, metal plating, brushing wear, break lining wear, and asphalt paving
	Manganese	Moving engine parts
Hydrocarbons	Petroleum	Spills, leaks, antifreeze and hydraulic fluid, and asphalt surface leachate
Coliforms	Fecal Coliform	Domestic animals, birds, and septic leakage

Care should be taken to manage runoff in a manner that has the least impact on the ecosystem within a watershed through the use of best management practices. A best management practice (BMP) is defined as “a control technique used for a given set of conditions to achieve water quality and quantity at a minimum price” (MRI, 2003). This is usually achieved through the reduction of the pollutant quantity, peak flow rate, and volume of the stormwater runoff. BMPs are separated into two main categories, structural and nonstructural. Structural BMPs are engineered stormwater management solutions possessing a physical structure. Nonstructural BMPs are not physical structures; instead, they are preemptive actions taken to reduce the need or size of structural BMPs. Nonstructural BMPs improve stormwater quality by managing both stormwater and pollutant accumulation and generation at or near the source. This can pertain to educational measures, as well as management and development exercises such as wetland and forest protection, fertilizer control, and street cleaning. Lastly, it should be noted that BMPs can be used together in series in order to meet flow attenuation and treatment criteria. A “treatment train” is the typical terminology used to refer to a combination of BMPs. As more BMPs are added to the system design, the effluent quality will increase.

1.6.1. Nutrients

As detailed in Section 303(d) of the 1998 *List Fact Sheet for Florida*, the EPA found that high concentrations of nutrients were the primary cause of surface water impairment in Florida. Nitrogen and phosphorus are the most common nutrients found in stormwater runoff, especially in agricultural and residential areas. Stormwater ponds require nutrients to maintain a healthy aquatic ecosystem, yet unmanaged excess nutrient loadings will cause the prolific development and growth of algae, shoreline plants, and submerged aquatic plants. Vegetation along the pond bank and littoral zone will populate and expand into the pond if left unchecked. This reduces the storage volume and visual aesthetics of the pond. For stormwater ponds with public access, this growth will interfere with recreational activities, such as boating and swimming.

Excessive nutrient loads to stormwater ponds may cause aesthetic and biological problems. Algal growth stimulated by excess nutrients can lead to large, unsightly blooms, which deprive submerged aquatic vegetation of sunlight and evoke hypoxic conditions. The destruction of submerged aquatic vegetation exposes juvenile fish to predation and combined with low oxygen levels in the water column can have drastic repercussions throughout the food chain. As the algal bloom dies and sinks to the bottom of the pond, bacteria begin to decompose the algal matter. The sudden increase in decay will spur the oxygen consumption rate of bacteria causing a rapid decrease in oxygen levels in a process called eutrophication. The depressed oxygen levels in the pond will have detrimental impacts on the pond ecosystem, sometimes leading to massive fish kills. Specific species of blue-green algae produce hepatotoxins and neurotoxins that impair or kill organisms within the water, as well as wildlife or humans using the pond as a water source (Zhang *et al.*, 1991).

Additional problematic forms of nitrogen identified by the EPA are ammonia, nitrate, and nitrite (EPA, 1993). Un-ionized ammonia is toxic to fish at concentrations higher than 0.2 $mg{\cdot}L^{-1}$ (EPA, 1986; EPA, 1993). Acute doses are known to cause a loss of equilibrium, increased cardiac output, comas, or death, while lower concentrations decrease hatching success and impair proper development (EPA, 1986). Humans are primarily exposed to nitrate through ingesting water contaminated with nitrogen-based fertilizers (Ward, 2008). Nitrates are known to cause organ cancers and nervous system disorders for both humans and animals through the formation of N-nitroso compounds (Lijinsky, 1986). Due to the increase in nitrogen fertilizers and fertilizer application, the presence of nitrate in stormwater runoff will remain a problem that must be dealt with (Reuben, 2010). At high levels of nitrate the reaction of nitrite with hemoglobin in infant warm blooded animals has the potential to prove fatal (EPA, 1986) although these levels are not commonly found in surface waters. Safe levels of nitrate and nitrite for warm water fish are 90 $mg{\cdot}L^{-1}$ and 5 $mg{\cdot}L^{-1}$ respectively (McCoy, 1972; Knepp and Arkin, 1973).

Phosphorus is rarely found in its elemental form, which is exceptionally toxic; instead, the more common form is as a phosphate (EPA, 1986). Phosphates are utilized by plants, algae, and bacteria for growth. An excess of phosphates leads to eutrophication of waters, which in turn leads to the proliferation of nuisance plants and increased biological activities in the pond. While this may not present a direct threat to human health or significantly compromise the ecology of the water body, the source of phosphorus could introduce dangerous pollutants into the water body. Phosphate fertilizers typically contain cadmium. In fact, areas using phosphate fertilizers exhibit up to six times the level of cadmium in the soil (IARC, 1973). Cadmium is known to accumulate within the tissues of grains and fish, which exposes predators to high concentrations of cadmium. Links have been established between pancreatic cancer in humans and high doses of cadmium (Mason *et al.*, 1975). Lastly, phosphate induces the leaching of arsenic from soil into the groundwater (Tao *et al.,* 2006).

1.6.2. Heavy Metals

Vehicles are the main source of heavy metals in stormwater ponds (EPA, 1993). Lead is discharged from leaded gas exhaust as well as during tire wear. Zinc is also a product of tire wear and is found in motor oil and grease. Iron, chromium, manganese, and copper are all generated from moving engine parts. Although living organisms require metals in small amounts, significant concentrations can produce lethal and sub-lethal impacts. Dissolved metals are more problematic and may be mobile enough to contaminate groundwater supplies. The high solids content present in the first-flush of stormwater runoff provides bonding sites for the metals, but there is the possibility that the metals will de-sorb at a later point and enter the water column.

Barium is commonly used in manufacturing applications for metals, glass, paint, and electronics (EPA, 1993). It has the potential to induce vomiting, diarrhea, spasms, and paralysis (Browning, 1961; Patty, 1962). Barium salts are water soluble, and the main method of exposure is through ingestion and respiration (NAS, 1974). However, these threats are minimized by the fact that barium ions adsorb and settle out from the water column quickly (NAS, 1974). For human safety, it is recommended that barium concentrations are limited to 1,000 $\mu g \cdot L^{-1}$ (EPA, 1986). Experiments conducted in marine environments have shown that barium levels would need to exceed a concentration of 50 $mg \cdot L^{-1}$before it poses a threat to aquatic species (EPA, 1986). The propensity for barium to react with sulfate and carbonate dictates that such concentrations of barium would rarely be achieved, and it would be unwarranted to consider barium a threat to aquatic life.

The application of phosphate fertilizers may facilitate the release of arsenic from contaminated soils. This substance is a valid concern in stormwater runoff due to its carcinogenic effects. Arsenic is subject to bioaccumulation within small aquatic species, but the short half-life ensures that significant amounts will not build up in the tissues of predatory fish (EPA, 1986). The level of acute toxicity for freshwater aquatic life is 48 $\mu g \cdot L^{-1}$ (EPA, 1986). For humans, regularly consuming arsenic-tainted water, the acceptable risk level is limited to 0.12 $ng \cdot L^{-1}$ and 1.76 $ng \cdot L^{-1}$ when consuming aquatic organisms.

Leaded gasoline is no longer permitted as an energy source for on-road vehicles, yet off-road vehicles, such as boats, airplanes, and farming equipment, are permitted to use it. Other sources of lead include tire and engine wear (EPA, 1993). Lead is toxic in aquatic life starting at concentrations of 142.5 $\mu g \cdot L^{-1}$. The human ingestion limit is 50 $\mu g \cdot L^{-1}$ (EPA, 1986; Reuben, 2010). Nickel is exposed to the environment from a variety of sources including: diesel fuel and gasoline, lubricating oil, metal plating, brushing wear, break lining wear, and asphalt paving (EPA, 1993; Reuben, 2010). The most sensitive aquatic organisms find nickel concentrations toxic at 56 $\mu g \cdot L^{-1}$, while humans should limit nickel levels in drinking water to 632 $\mu g \cdot L^{-1}$ in order to reduce the risk of pancreas, larynx, and stomach cancer (EPA, 1986; Reuben, 2010). Selenium is one of the metals commonly removed in drinking water treatment. Human health concerns cause by selenium occur in excess of 10 $\mu g \cdot L^{-1}$ when ingested, and concentrations should be limited to 35 $\mu g \cdot L^{-1}$ for the protection of aquatic wildlife (EPA, 1986). Tire wear, motor oil, and grease are the main sources of zinc in stormwater runoff (EPA, 1993). While zinc does not present any health concerns to humans, concentrations are toxic to aquatic organisms when in excess of 680 $\mu g \cdot L^{-1}$ (EPA, 1986). In addition to health risks to the environment, zinc will give water an unfavorable color and odor.

Sources of cadmium include fertilizers, tire wear, and insecticide application (EPA, 1993; Reuben, 2010). Cadmium presents a danger to both aquatic life and humans. Trout and similar fish species are sensitive to cadmium at concentrations of 1 $\mu g \cdot L^{-1}$ to 20 $\mu g \cdot L^{-1}$ (EPA, 1993). Contaminated water and the bioaccumulation of cadmium in fish and other wildlife exposes higher level members of the food chain to the pollutant. In humans, quantities of cadmium as low as 10 $\mu g \cdot L^{-1}$ acquired through ingestion may induce the formation of cancerous tumors (Mason *et al.*, 1975; Reuben, 2010). Silver concentrations in freshwater begin effecting the most sensitive species when present at 0.12 $\mu g \cdot L^{-1}$; however, the presence of hardness in the water can increase this to a range of 1.2 to 13 $\mu g \cdot L^{-1}$ (EPA, 1986). Significant concentrations of silver may discolor skin in humans and create ulcers. Chromium is applied over metals as a protective coating, and engine wear will introduce it into the environment. Chromium (III & IV) are toxic to freshwater aquatic life between concentrations of 23 $\mu g \cdot L^{-1}$ up to 2,221 $\mu g \cdot L^{-1}$. In humans, ulceration may occur after prolonged ingestion of contaminated water (EPA, 1993).

Brake wear and building siding are the leading contributors of copper collected by stormwater runoff (Davis *et al.*, 2001). Copper serves as an all-around treatment, capable of controlling algae, bacteria, external protozoa, and various parasites (Mackenthus, 1952; Watson, 2011). Copper sulfate, also known as bluestone and blue powder, is one of the more commonly used forms of copper for pond treatment due to copper sulfate's soluble nature which readily permeates through the water column (Watson, 2011). While cost effective, there are drawbacks to copper sulfate. "If your water is low in alkalinity, or you have a heavy algae bloom and no aeration, copper treatments are not recommended" (Watson 2011). Copper sulfate is toxic to fish when the pond alkalinity is below 50 ppm or a pH of 4 (Watson, 2011; Wurts, 2011). This is because the copper separates from the sulfate and can be toxic as a free ion to organisms that are sensitive to copper. However, too high of a pH will induce conditions that cause the copper ion to remain bound to the sulfate; thus, decreasing the effectiveness of the treatment method. In the event of adding copper sulfate to treat a large algae bloom, certain precautions should be taken. Algae serves as a major producer of oxygen in the pond, however when it dies, additional oxygen is required to decompose the algal matter (Watson, 2011). One solution to prevent an instantaneous drop in dissolved oxygen levels is to gradually treat the pond, or use an aerator to saturate the water column with dissolved oxygen. Lastly, copper sulfate is markedly toxic to invertebrates, such as snails and zooplankton (Watson, 2011).

1.6.3. Hydrocarbons

Poly Aromatic Hydrocarbons (PAHs) are a group of over 100 different organic compounds, composed of fused aromatic rings. PAHs are a pollutant of concern because of their carcinogenic, mutagenic, and teratogenic characteristics along with their slow half-lives in geological media. PAH concentrations in bottom sediments tend to be greater than water column concentrations due to their hydrophobic nature and high affinity for suspended particles (Neff, 1984). Because of their lipophilic chemical nature, dependent on chemical characteristics, PAHs may be absorbed through the skin, respiratory tract, and gastrointestinal tract then transported through the circulatory system and metabolized in the liver (Busbee, 1990). Several PAHs are considered probable or possible human carcinogens by the U.S. Department of Health and Human Services (HHS), International Agency for Research on Cancer (IARC) and the EPA. The US EPA has listed 16 PAHs as priority pollutants, and of these 16 priority PAHs, at least seven of the following PAHs are commonly found in stormwater runoff:

Benzo(a)anthracene, Chrysene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(a)pyrene (BaP), Dibenzo(a,h)anthracene, and Indeno(1,2,3-cd)pyrene (Prabhukumar *et al.*, 2011).

1.6.4. Pesticides

Pesticides picked up by stormwater runoff contribute as a non-point source of pollutant, which may cause serious environmental issues. Pesticides are normally referred as biopesticides, antimicrobials and chemical pesticides, which is a common source of pesticides used in urban watersheds. Pesticides are used to maintain lawn, garden, roadside greening, etc. Nonagricultural use of pesticides often causes a peak concentration due to the first-flush effect in highly impervious urban watersheds. Main examples of chemically-related pesticides include Organophosphate pesticides, Carbamate pesticides, Organochlorine insecticides and Pyrethroid pesticides.

The organophosphate (OP) pesticides, diazinon and chlorpyrifos are commonly used to control termites, ants, and lawn and garden pests. More than 100,000 pounds of active ingredient diazinon and chlorpyrifos are used each year on residential properties in some counties in the United States (Lee and Taylor, 1997). Pyrethroid pesticides are the most common class of insecticide used in urban environments today with over 700,000 lbs being used every year for residential use in California (Lee, 2009).

OP pesticides are toxic to a wide variety of non-target aquatic organisms including fish and invertebrates (Menconi *et al.* 1994). Diazinon and chlorpyrifos have been found in wet weather runoff from urban watersheds, resulting in discharge and ambient water column toxicity. Surface water with high organochlorine insecticides concentration alters the metabolic processes of the aquatic species. The well-known pesticide dichlorodiphenyltrichloroethane (DDT) has been shown to transform male fish into female (Savy, 2000). Exposure to pesticides in air may result in eyes, nose, or mouth irritations while direct contact of pesticides on human body through skin may cause skin allergies and skill diseases. Ingesting large amount of pesticides in drinking water or through food routes may result in vomiting, diarrhea, stomach flu, headache, nervous system problems, etc.

1.6.5. Coliforms

Coliforms and fecal streptococci are two bacterial groups commonly found in human and animal species and used as indicators of possible sewage contamination. Although the bacteria are generally not harmful themselves, their presence indicates the possible presence of pathogenic bacteria, viruses, and protozoans that typically live in the digestive systems of mammals. Coliforms are commonly found widespread in the environment and may not be an indication of contamination, however a subset of coliforms, known as fecal coliforms which are fecal-specific in origin, are more commonly used as an indicator of contamination. A specific species of fecal coliforms, known as *Escherichia coli*, or more commonly known as *E. coli*, is specific to the fecal material from humans and other warm-blooded animals and therefore recommended as the best indicator of health risk from water contact in recreational waters by the EPA (EPA, 1986).

Potential contamination of water bodies by coliforms and *E. coli* may come from a variety of both "point" (discharges through a continuous flow conveyance system, such as a pipe) and "non-point" sources (intermittent, rain-fall driven, sources from associated with everyday human activities, such as runoff from urban lands). Examples of point sources may include wastewater or industrial treatment plant pipe discharges, whereas examples of non-point sources may include leaking underground septic tanks, run-off from pasture lands containing mammals such as cows and sheep and run-off from natural and urban areas.

Criteria for assessing water quality in terms of fecal coliform bacteria are given numerically. For Florida, the water quality criteria for the protection of Class III waters, as established by Rule 62-302, F.A.C., states the following:

Fecal Coliform Bacteria:

> *The most probable number (MPN) or membrane filter (MF) counts per 100 mL of fecal coliform bacteria shall not exceed a monthly average of 200, nor exceed 400 in 10 percent of the samples, nor exceed 800 on any one day.*

1.6.6. Sedimentation

Sediments, as defined by the EPA, are fragmented materials that originate from weathering and erosion of rocks or unconsolidated deposits which are transported by, suspended in, or deposited by water. Excessive build-up of sediments within wet detention basins may become an issue by reducing the permanent pool volume of the basin, thereby decreasing the effective treatment volume and efficiency of the basin. Excessive sedimentation may also cause clogging issues for BMP structures such as swales and check dams, and in the case of filters and porous pavement may render them useless. A thorough understanding of the sediment loading characteristics of site runoff should be understood prior to proper design of BMPs. Some BMPs, such as baffle boxes, may be used to reduce the loading of sedimentation for downstream waters.

Sediments may also come in the form of suspended and bedded sediments (SABS), which defined by the EPA include particulate organic and inorganic matter that suspend in or are carried by the water, and/or accumulate in a loose, unconsolidated form on the bottom of natural water bodies. SABS can be a source of phosphorus and nitrogen loading due to its organic and inorganic nature.

1.7. Stormwater Pollutant Sources

1.7.1. Nutrient Sources

Common sources of nitrogen and phosphorus in stormwater runoff are residential fertilizer application, vehicular exhaust, animal waste, septic leakage, and atmospheric deposition. Suspended solids in stormwater often contain considerable amounts of adsorbed nutrients (Lin, 1972; Middlebroks, 1974; Carlile *et al.*, 1974). Nutrients attached to settling solids contribute to bacterial growth and ammonia production (Burton *et al.*, 2001). A primary example of a nutrient that is transported by sediment erosion is ammonia and phosphorus (EPA, 1993). Target nutrients along with their health concerns and sources are summarized in Table 2:

Table 2: Health and Environmental Concerns of Target Nutrients (EPA, 1986; Lijinsky, 1986; EPA, 1993; Reuben, 2010)

Nutrient	Health Concerns	Environmental Concerns	Primary Sources
Total Nitrogen (TN)	-	Eutrophic conditions encouraging the growth of algae and nuisance vegetation. Severe cases lead to hypoxia, fish kills, the destruction of sub-aquatic vegetation, odors, unsightliness, and the reduction of pond storage volume	Fertilizers, animal waste, vehicular exhaust, atmospheric deposition, septic leakage
Nitrate + Nitrite	Prolonged exposure may cause cancer, and may cause death in infant warm-blooded animals		
Ammonia	Disorientation, comas, and death in fish		
Total Phosphorus (TP) + Orthophosphate	Fertilizer sources often contain cadmium (cancer risk), and phosphates leach arsenic from the soil		

1.7.2. Heavy Metals

Common sources of heavy metals include vehicle exhaust and wear and tear, manufacturing operations, building siding, diesel fuel, gasoline, fertilizers, metal coatings, soil leaching and coal combustion operations. Metals have a tendency to adsorb to organic matter and although may be low in soluble concentrations may be higher in sediment concentrations. Table 3 summarizes the toxic effects and potential sources of a number of common heavy metals found in stormwater runoff.

Table 3: Toxic effects and sources of heavy metals

Heavy Metal	Health and Environmental Concern	Source	Reference
Arsenic	Carcinogenic effects	Soil leaching due to phosphate fertilizer application	Tau *et al.*, 2006
Barium	Vomiting, diarrhea, spasms, and paralysis in humans. It is rarely found in significant quantities to threaten aquatic life	Manufacturing operations involving metals, glass, paint, and electronics	EPA, 1993
Cadmium	Toxic to fish species, and exposure is linked with cancer formation in humans	Fertilizers, tire wear, insecticide application	EPA, 1993 Reuben, 2010
Chromium	Ulceration if ingested in significant quantities	Engine wear, protective coatings on metal, wood preservation, dye manufacture	EPA, 1986 EPA, 1993 Reuben, 2010
Copper	Acute toxicity to fish in water at a low pH, and it is generally toxic to aquatic invertebrates	Brake wear, building siding, engine wear	EPA, 1993 Davis, 2001 Watson, 2011
Lead	Cancer in the brain, nervous system, lungs, kidneys, and stomach	Leaded gas exhaust, tire wear, engine wear	EPA, 1993 Reuben, 2010

Nickel	Cancer in the larynx, stomach, and pancreas	Diesel fuel and gasoline, lubricating oil, metal plating, brushing wear, break lining wear, and asphalt paving	EPA, 1993 Reuben, 2010
Selenium	Toxic to aquatic species	Glass, electronic, and pigment manufacture. Agricultural and coal combustion operations	Weston, 2007
Silver	Discoloration of the skin and kidney damage	-	EPA, 1986
Zinc	Minor threat to aquatic organisms. Excess levels lead to unfavorable odor and color in water	Tire wear, motor oil, grease	EPA, 1993

1.7.3. Hydrocarbons

Hydrocarbons are known carcinogens (NTP *et al.*, 2002) and threaten aquatic wildlife (Long *et al.*, 1990). Typically found in developing urban areas, they are the result of incomplete combustion (Van Metre *et al.*, 2000). Specific sources of hydrocarbons include but are not limited to: vehicle exhaust, asphalt deterioration, engine oil, and gasoline (Van Metre *et al.*, 2000; Mahler *et al.* 2005). A more recently discovered source of polycyclic aromatic hydrocarbons (PAHs) are the coal-tar emulsion sealcoats used on parking lots (Mahler *et al.*, 2005). The purpose of these sealants is to protect the parking lot surface and enhance its appearance. By weight, PAHs make up at least 50% of coal-tar (NTP *et al.*, 2002), and the coal-tar emulsion "sealcoats" need replacement every two to three years as a result of rapid wear (Dubey, 1999). In a study by Mahler *et al.*, it was found that the PAH load from sealed parking lots is 50 times greater than unsealed parking lots, and it is suggested that sealed parking lots are the main sources of PAHs in watersheds. Infiltration trenches, oil and grit separators, and sorption media can be used to remove hydrocarbons from stormwater runoff.

1.8. Stormwater Regulations

1.8.1. Administrative Codes and Statues

Florida Administrative Codes, Rules, Guidelines, and Statues are subject to change, and to assure proper compliance, the most current version of the Florida Administrative Code and Florida Statues should be checked. The Florida Administrative Codes for regulating stormwater are given in Table 4:

Table 4: Florida Administrative Codes for Regulating Stormwater Management (FDOT, 2012)

Stormwater Management Topic	Florida Administrative Code Chapter
Drainage Connections	14-86
Permits	62-4
Water Resource Implementation Rule	62-40
Surface Water Improvement and Management	62-43

Surface Water Quality Standards	62-302
Dredge and Fill	62-312
Wastewater Facility and Activities Permitting	62-620
Generic Permits	62-621
Municipal Separate Storm Sewer Systems	62-624
Underground Storage Tank Systems	62-761
Environmental Resource Permits: Surface Water management Systems	40*-4
Standard Environmental Resource Permits	40*-4

Next, the Florida Statues involving stormwater management are detailed in Table 5:

Table 5: Florida Statutes for Regulating Stormwater Management (FDOT, 2012)

Stormwater Management Topic	Florida Statues Chapter
Laws of Florida	89-279
County and Municipal Planning and Land Development Regulations	163
Transportation Administration	334
State Highway System	335
Water Resources	373
Pollution of Waters	387
Environmental Control	403

2. Identifying Target Pollutants

2.1. Conducting a Sampling Campaign

Because of the intermittent nature of stormwater and urban runoff, testing of characteristics is often difficult. Nevertheless, sampling and quantification of pollutant loads, sources and fate are essential in developing a control plan. The data collected should be site specific, focus on potential pollution sources, compliance with local, state and federal regulations and take into consideration potential future changes in development to the site. The information presented in Section 1 should help to establish which sampling criteria and which potential sources to look for while preparing a sampling campaign.

The goals and priorities of a sampling campaign should be laid out prior to commencement and may differ from site to site. For example, if a site is discharging to a sensitive water body with historical eutrophication problems, then the analyses of phosphorus and nitrogen species may weigh more heavily than that of heavy metals. Conversely the source of runoff may play more importance in the sampling campaign, such as analyses of hydrocarbons for an area receiving runoff from a layer of asphalt. Wet-weather sampling may be used to determine the characteristics of stormwater runoff for parameters such as nutrient concentration, total suspended solids and flow rate. This data may assist in the decision process of which BMP may be most applicable to the site. The analysis may also give insights into the effects of runoff on ambient water quality, whether runoff is meeting water quality standards and whether the stormwater could be used for other purposes such recycle.

Sampling of water and sediments should be carried out according to methods prescribed by manufacture guidelines. In addition laboratory testing of samples should be carried out in methods prescribed by the manufacturer. For clarity, a list of commonly used symbols and units of the pollutants described in Section 1 is presented in Table 6.

Table 6: Commonly Reported Symbols and Units for Pollutants

Type	Pollutant	Common Symbol	Commonly Reported Units
Sediments	Total Suspended Solids	TSS	mg/L
Nutrients	Total Phosphorus	TP	mg/L
	Soluble Reactive Phosphorus or Orthophosphate	SRP or Ortho-P	mg/L
	Total Nitrogen	TN	mg/L
	Nitrate + Nitrite	$NO_3 + NO_2 = NO_x$	mg/L
	Ammonia	NH_3	mg/L
Heavy Metals	Arsenic	As	µg/L
	Barium	Ba	µg/L
	Cadmium	Cd	µg/L
	Chromium	Cr	µg/L
	Copper	Cu	µg/L
	Lead	Pb	µg/L
	Nickel	Ni	µg/L
	Selenium	Se	µg/L
	Silver	Ag	µg/L
	Zinc	Zn	µg/L

2.2. Quality Assurance and Quality Control for Sample Analysis

2.2.1. Intended Uses of Acquired Data

The intended uses of the data acquired under this protocol are to determine the degree of treatment a pollutant reduction technology achieves during a site-specific testing period by measuring influent and effluent concentrations of selected parameters.

2.2.2. Analytical Quality Levels and Quality Control Levels

Whether the quality assurance (QA) objectives for the project, as outlined in the Quality Assurance Project Plan (QAPP), are met will be determined through the use of quality control (QC) elements assessing precision, accuracy, representativeness, completeness and comparability. Each of the QC elements is discussed in the following section.

2.2.3. Quality Control Indicators

2.2.3.1. Precision

Precision is defined as the degree of mutual agreement relative to individual measurements of a particular sample. As such, Precision provides an estimate of random error. Precision is evaluated using analysis of field or matrix spiked duplicates. Method precision is demonstrated through the reproducibility of the analytical results. Relative percent difference (RPD) may be used to evaluate precision by the following formula:

$$\mathrm{RPD} = \frac{\left|C1 - C2\right|}{0.5 \cdot \left(C1 + C2\right)} \times 100$$

Where:

C1 = Concentration of the compound or element in the sample
C2 = Concentration of the compound or element in the duplicate

The relative standard deviation between replicates will be calculated as follows:

$$\%RSD = \left(\frac{S}{y'}\right) \times 100$$

Where:

S = Standard deviation
y’ = Mean of the replicates

2.2.3.2. Accuracy

For water quality analyses, accuracy is defined as the difference between the measured or calculated sample result and the true value for the sample. The closer the numerical value of the measurement comes to the true value or actual concentration, the more accurate the measurement. Loss of accuracy can be caused by errors in standards preparation, equipment calibrations, interferences, and systematic or carryover contamination from one sample to the next.

Analytical accuracy may be expressed as the percent recovery of a compound or element that has been added to laboratory reagent water at known concentrations prior to analysis. The following equation is used to calculate percent recovery:

$$\text{Percent Recovery (\%R)} = \frac{(Cs - Cu)}{Ca} \times 100$$

Where:

Cs = Total amount detected in spiked laboratory reagent water
Cu = Amount detected in unspiked laboratory reagent water
Ca = Spike amount added to laboratory reagent water.

For parameters which are not routinely spiked during analysis (e.g., BOD, CBOD, TSS, pH, and alkalinity), performance evaluation samples shall be obtained and used to develop control limits for the laboratory. Where appropriate and stable, the same performance evaluation sample may be analyzed over a period of time.

Accuracy will be ensured in technology evaluation by maintaining consistent sample collection procedures, including sample locations, sample timing, sample handling, and by executing random spiking procedures for specific target constituent(s). The Test Plan shall discuss methods to determine the accuracy of sampling and analyses.

For equipment operating parameters, accuracy refers to the difference between the reported operating condition and the actual operating condition. For operating data, accuracy entails collecting a sufficient quantity of data during operation to be able to detect a change in system operations. As an example, accuracy of flow rate may be the difference between the flow indicated by a flow meter and the flow measured on the basis of volume over time (with a container of known volume and a stopwatch). Meters and gauges shall be checked at least monthly for accuracy. The Test Plan shall discuss means for determining the accuracy of equipment operating parameters.

2.2.3.3. Method of detection limit

The lowest concentration that can be measured and is different from zero with a 99% confidence is determined as the MDL. The lowest standard concentration used for the calibration will be analyzed a number of times and the MDL will be calculated using the following equation:

$$MDL = t_{(n-1, 1-\alpha=0.99)} \times S$$

Where:

n = number of replicates
S = Standard deviation of the replicates

2.2.4. Type of QC samples

2.2.4.1. Method blank

A method blank is a generated sample prepared from a clean matrix, generally deionized water. It is treated exactly as a sample. This blank is prepared to check for contamination of container and equipment.

2.2.4.2. Calibration blank

A calibration blank is a volume of reagent water without the analyte. The concentration of the analyte should be less than three times the instrument detection limit.

2.2.4.3. Matrix spike

This is a sample with a known concentration of the analyte added to original sample and is used to assure that the recovery of the target compounds is acceptable for the matrix involved.

2.2.4.4. Field duplicate samples

A field duplicate sample is a second sample collected at the same location as the original sample. Duplicate sample results are used to assess precision, including variability associated with both the laboratory analysis and the sample collection process. Duplicate samples are collected simultaneously or in immediate succession, using identical recovery techniques, and treated in an identical manner during storage, transportation, and analysis. One of every ten samples will be collected as a duplicate for each sampling interval. The sample point which will be duplicated will be randomly selected.

3. Stormwater Pond Maintenance Issues

3.1. Maintenance Requirements Stemming from Excess Nutrient Loading

Common nutrients in stormwater are nitrogen and phosphorus. Algae, shoreline plants, and sub-aquatic plants use these nutrients for growth, which facilitates nutrient removal from stormwater. However, as these plants decay, stored nutrients are released and consumed by bacteria which may depress dissolved oxygen levels within the water column. Furthermore, excess nutrient loadings stimulate the growth of algae, which can lead to algal blooms and the eutrophication of the stormwater pond. Another consequence is that the littoral zone and nuisance vegetation can rapidly populate and expand into the water body; thus reducing the storage volume and visual appeal. From Table 1, typical sources of nitrogen and phosphorus include the atmosphere and fertilizer application. Methods for removing high nutrient concentrations from stormwater include baffle boxes where the nutrients are able to settle out, sorption media, and grass swales in addition to the biological uptake within the ponds.

3.2. Maintenance Requirements Stemming from Hydrocarbons

Hydrocarbons are known carcinogens (NTP *et al.*, 2002) and threaten aquatic wildlife (Long *et al.*, 1990). Typically found in developing urban areas, they are the result of incomplete combustion (Van Metre *et al.*, 2000). Excessive hydrocarbons concentrations may not be as visually apparent as excessive nutrients or sediment loading. However as hydrocarbons may affect aquatic life, changes in ecosystem dynamics of the pond, due to their detrimental effects, may lead to shifts in favoring conditions for one species. This could lead to an overgrowth of a single species rather than a mixture of many. However such cause and effects are complex and difficult to prove.

3.3. Maintenance Requirements Stemming from Heavy Metals

Vehicles are the main source of heavy metals that are washed into stormwater ponds (EPA, 1993). Lead is discharged from leaded gas exhaust as well as during tire wear. Zinc is also a product of tire wear, and it is also found in motor oil and grease. Iron, chromium, manganese, and copper are all generated from moving engine parts. Although living organisms require metals in small amounts, significant concentrations can produce lethal and sub-lethal impacts. Dissolved metals are the most toxic as they are suspended in the water column. The high solids content present in the first-flush of stormwater runoff provides bonding sites for the metals, but there is the possibility that the metals will desorb at a later point and enter the water column. Similarly to hydrocarbons the specific causes of excessive metal loading is complex and difficult to test. However due to the lethal nature of metals in high concentrations, it can be deduced that excessive loading may cause shifts in the ecosystem of ponds and result in changes in growth characteristics, which in turn could cause maintenance issue.

3.4. Maintenance Requirements Stemming from Floatable Debris

Types of floatable debris range from human made metal containers, plastic bags, tires, and glass bottles all the way to natural forms of debris such as leaves, branches, and other organic material. Floating debris has the potential to clog outlet structures, ruin the aesthetic look of the pond, and impact vegetation growth. Baffle boxes with screens can be used to capture debris at the pond inlet, while debris already present in the water body needs to be manually collected.

3.5. Maintenance Requirements Stemming from Sediment

Sediment sources can be local, such as bank erosion, or it can be carried overland or through stormwater pipes all the way from construction sites, pavement wear, and agricultural operations. Sediment that has been suspended in the water column will reduce the ability of light to penetrate into the water, which interferes with photosynthetic organisms. As previously mentioned, metals sometimes bond to solids and desorb within water bodies. Over time, the accumulation of heavy metals can prove toxic to the environment. Sediments will build-up in the pond and reduce the storage volume; however ponds may be designed deeper with this in mind. However, excess sediment loads will require the pond to be dredged more often. Sediment entry into the pond through overland stormwater flow can be controlled by seeding the pond banks to ensure stability. At the inlet of the pond, a baffle box or forebay may be put in place to allow for sediments to settle out before penetrating deeper into the pond.

4. Selection of Best Management Practices

4.1. Overview

Section 4 outlines the objectives, design criteria and details several types of structural BMP options for stormwater management. This section is intended as a guideline for understanding structural BMP background, design, treatment efficiencies, cost and maintenance concerns. Further detailed information on particular maintenance activities which may relate to each BMP is given in Section 5.

4.2. Determine Project Objectives

Determining the project objectives is the first step in selection of the best fit BMP. Oftentimes meeting regulations and budget may drive the decision process in selection of BMP. Attention should be made to the receiving bodies of water downstream of the project site, and whether discharged water is entering water bodies sensitive to suspended solids or prone to eutrophication, erosion or flooding. A table listing the water body classifications, as defined by the Florida Department of Environmental Protection (FDEP), is presented in Table 7 below.

Table 7: Florida Surface Water Quality Standards (FDEP, 2014)

CLASS I - Potable Water Supplies	Includes fourteen general areas throughout the state with tributaries, certain lakes, rivers.
CLASS II - Shellfish Propagation or Harvesting	Generally coastal waters where shellfish harvesting occurs.
CLASS III - Fish Consumption, Recreation, Propagation and Maintenance of a Healthy, Well Balanced Population of Fish and Wildlife	The surface waters of the state are Class III unless described in rule 62-302.400, F.A.C.
CLASS III - Limited - Fish Consumption, Recreation or Limited Recreation; and/or Propagation and Maintenance of a Limited Population of Fish and Wildlife	This classification is restricted to waters with human-induced physical or habitat conditions that, because of those conditions, have limited aquatic life support and habitat that prevent attainment of Class III uses.
CLASS IV - Agricultural Water Supplies	Generally located in agricultural areas around Lake Okeechobee.
CLASS V - Navigation, Utility and Industrial Use	Currently there are no designated Class V bodies of water.

Three primary mitigation strategies and control guidelines should be considered for project sites and discussed further in the following sub sections. These include:

- Volume Control
- Peak Rate Control
- Nutrient and Pollutant Loading Control

Volume Control Guidelines

Volume control is inherent in most land development. Due to the addition of impervious area, grading and/or compaction of underlying soils, run-off volume is usually expected to increase from a developed site without the installation of volume control structure. As discussed in Section 1 this may be attributed to decreased permeability of underlying soils in post-developed conditions, leading to more surface runoff. Pre-developed site permeability can help predict to what degree runoff rates will increase. For example a pre-developed site with existing low permeability soils will experience less additional post-developed runoff than a pre-developed site originally containing high permeability soils. Knowledge of pre-developed soils can therefore give insights into the degree of volume control required.

Criteria for volume control should take into account several factors to create post-developed conditions which are similar to pre-developed. These include protection of downstream channel morphology, maintaining groundwater recharge and prevention of flooding. With increases in volume, runoff channels and streams downstream of the site are more prone to bank full or near bank full conditions. Such increases in high flow conditions will increase the frequency and rate of natural erosional processes, which in turn could lead to higher suspended solids concentrations and loss of property near the banks. Volume control may be accomplished by either retention/detention facilities or BMPs capable of increased groundwater recharge through infiltration.

Peak Rate Control Guidelines

Peak rate control is imperative to mitigate against flooding and excessive erosion. Typically, detention systems are incorporated into the stormwater design to reduce post-developed peak flow rates to equal or below pre-developed flow rates. Both non-structural and structural BMPs may be used to decrease or delay the flow of water from a site. Often existing characteristics of the pre-developed site, such as shallow depressions or existing vegetation may be used in BMP design. By allowing pooling of water in the depressions or the sheet flow through existing vegetation, run-off peak flows may be reduced and delayed. Additionally, reducing the amount of compaction to a site will result in more ground water recharge, which will both decrease the volume and peak flow from the site. This may be especially useful in areas with existing high permeable soils.

Nutrient and Pollutant Loading Control

Reducing nutrient pollutant loading is an important consideration in keeping water bodies clean and healthy. Focus on nutrient loading has become more prominent in recent years with studies examining eutrophication in Florida water bodies. With the implementation of impervious areas in urban environments, runoff may quickly accumulate phosphorus, nitrogen, heavy metals, hydrocarbons and pesticides and transport them to receiving water bodies. With increases in traffic and fertilized areas, pollutant loading from cars and fertilized area runoff only increases pollutant loading rates. Without proper installation of BMPs to remove the pollutants and retain/slow the movement of the runoff, pollutant loads will increase in post-developed conditions. Both structural and non-structural BMPs may be utilized to help reduce the nutrient and pollutant loading for stormwater systems.

4.3. Identify BMPs that Meet Project Objectives

Several different options may exist when selecting a proper BMP to meet the project objectives. Each BMP will have unique advantages and disadvantages in regards to performance, cost and maintenance. In some cases one BMP may be more justified than another due to the particular characteristics of the project site such as slopes, infiltration rates, existing vegetation, etc. In other cases a BMP may make sense if included in the preliminary site development, yet be too costly or unfeasible as a retrofit option. An important first step in meeting project goals is developing an overall BMP plan during the preliminary stages of the project covering a wide spectrum of project criteria including:

- Required volume runoff criteria
- Peak flow attenuation requirements
- Effluent water quality levels
- Infiltration rates of the surrounding project site
- Existing natural features may be used as or in conjunction with a BMP
- Determining if a non-structural or structural BMP (or combination) is best suited for the project

- Analyzing costs associated with BMP implementation and maintenance
- Determining what degree of inspection and maintenance will be required of a proposed BMP

During the preliminary design stages of the project, it is key to determine which of these project objectives are most important. Often times the project area site may impact BMP selection. For instance if a narrow right-of-way is the only space available for implementation then a BMP such as an infiltration trench may be more feasible than a detention pond.

4.4. Selection and Design Considerations

4.4.1. Performance

The performance of a BMP will vary from one to another due to project site characteristics and construction methods. Generally each BMP performance may be characterized by the following:

- Run-off Volume Reduction
- Groundwater Recharge
- Peak Flow Attenuation
- Pollutant Reduction

Performance of a BMP should take all of these parameters into consideration. However depending on the project site, one BMP may have a more weighted advantage compared to another. Considerations in receiving water bodies may affect the selection of a BMP. For instance, for a project site discharging to a eutrophic lake, a BMP capable of reducing nutrient loading may be more advantageous; whereas for a project site discharging to a stream with high bank erosion a volume reduction may be more advantageous.

Often times utilizing existing site characteristics may be a viable option for implementation of a BMP. If a project site is situated around soils with high infiltration rates a BMP which utilizes stormwater infiltration may be more justified and cost effective. Conversely if a project site contains native vegetation a BMP may utilize the existing vegetation for water quality improvement. In these cases the performance of the BMP will largely rely on the site characteristics and may only be determined after site analysis.

Long-term performance of BMPs is also of great importance. Maintenance considerations must be accounted for in BMP selection. Some BMPs may perform well initially, however without proper maintenance may quickly deteriorate and may cause more harm than good. Additional the frequency of inspections and repair may justify one BMP over another due to cost considerations.

4.4.2. Cost

When conducting cost analysis for BMPs all associated costs should be taken into account. Costs for BMP installation at a minimum should account for material, labor, engineering, operation and inspection. In some cases the maintenance and inspection costs may be more than the material costs. The long-term availability of products and materials for constructing and maintaining the BMPs should also be considered. By not including maintenance costs a BMP may be unmaintained, potentially making the BMP inefficient. Cost prices per BMP is discussed further in section 4.6.

4.4.3. Maintenance

Maintenance requirements will vary from one BMP to another with maintenance frequencies varying from monthly to yearly. The proper maintenance of BMPs is crucial for effective performance and treatment efficiencies. Without placing the proper time in accounting for future maintenance activities, a BMP may not operate to its potential. In some instances, the simple logistics of maintenance may favor one BMP selection over another, while in others maintenance costs may play a more important role. Additionally, the maintenance frequency of BMPs may have an impact in selection. In some instances, such as check dams, excessive solids concentrations may cause the upstream pooling areas to fill up with sediments, thus decreasing the settling performance of the check dam and requiring increased maintenance for proper functionality. Understanding the runoff characteristics, such as total suspended solids, total dissolved solids, and nitrogen and phosphorus concentrations, is crucial in predicting how the BMP will perform. Further detailed maintenance per structural BMP may be found in section 4.6.

4.4.4. Safety

Safety should always be incorporated into the planning and design of BMPs. Understanding the site characteristics, equipment and environmental conditions all are important factors to consider. Further safety guidelines are presented in Section 5.4.

4.5. BMP Selection based on Maintenance Issues

In order to handle stormwater pond maintenance issues in the most effective manner possible, Table 8 has been developed to link maintenance issues to their causes. With the cause of the problem known, BMP solutions can be put in place to manage the problem.

Table 8: An Overview of O&M Problems, Causes, and Solutions

O&M Problem	Causes	Symptoms	BMP Solutions	References
Excess Littoral Zone Growth	• High N & P loading from agricultural runoff • Residential fertilizer usage	• Reduced flood storage capacity • Clogged discharge facilities • Enhanced internal nutrient circulation	• Vegetation removal • Baffle box • Sorption media • Vegetated/Grass swale • Infiltration Trench	• Grier, 2008 • Morris *et al.*, 2006
Sediment Accumulation	• Bank erosion • Pavement wear • Agricultural runoff • Construction sites	• Reduced water quality • High turbidity • Choked waterways	• Vegetated/Grass swale • Infiltration trench • Check dam • Forebay • Periodic removal	• Livingston *et al.*, 1997

O&M Problem	Causes	Symptoms	BMP Solutions	References
Hydrocarbons	• Oil and greases from vehicles • Release of PAHs from sealed parking lot surfaces	• Oil sheens • Death of sensitive aquatic wildlife • Bioaccumulation	• Oil and grit separator • Hydrocarbon absorbent materials • Infiltration trench	• WWEGC, 2010
Bacterial Contamination	• Birds • Domesticated pets • Exotic invasive animals (iguanas)	• Human health risks	• Infiltration trench • Sand Filters • Sorption Media	• Clary *et al.*, 2008
Algal Blooms	• High N & P loading from agricultural runoff • Residential fertilizer usage	• Eutrophication • Hypoxia	• Source control • Grass swale • Baffle box • Sorption media	• Grier, 2008
Heavy Metal Accumulation	• Vehicular engine wear, braking, and exhaust • Roof runoff	• Human and environmental health concerns • Loss of biodiversity	• Baffle box • Sorption media • Infiltration trench	• WWEGC, 2010
Excessive Runoff	• Lack of infiltration due to a impervious surfaces	• Downstream BMP facilities become overwhelmed • Flooding	• Outflow control structure	• Livingston *et al.*, 1997
Floatable Debris	• Human activity • Trees/brush	• Unsightly • Clogs inlets and outlets • Shelter mosquito larvae	• Manual removal • Baffle box with floatable collection screen	• NRC, 2008

BMPs that work in series with stormwater ponds are presented in **Table 9**:

Table 9: BMP Effectiveness Summary (Yes = effective, Partial = partially effective, No = not effective) (MRI, 2003; Wanielista *et al.*, 2008; WWEGC, 2010; Pazwash, 2011)

BMP	Nitrogen	Phosphorus	Suspended Solids	Hydrocarbons	Heavy Metals	Pathogens
Infiltration Basin	Yes	Yes	Yes	Partial	Yes	Partial
Infiltration Trench	Yes	Yes	Yes	Partial	Yes	Partial
Grass Swale	Yes	Yes	Yes	Partial	Yes	No
Filter Strip	Partial	Partial	Partial	Partial	Partial	No

Sand Filter	Partial	Partial	Yes	Partial	Yes	Partial
Bio-Retention Basin	Yes	Yes	Yes	Yes	Yes	Partial
Sorption Media	Yes	Yes	Yes	Yes	Yes	Yes

4.6. Structural BMPs

4.6.1. Introduction

Structural BMPs are BMPs which include a structural component to the design and include a variety of options for managing stormwater runoff. This section presents eleven (11) structural BMPs including a description or their function, design, performance, costs and maintenance considerations. These include:

- **Wet Detention Basin / Wet Pond**
- **Retention Basin / Infiltration Basin**
- **Exfiltration Trenches**
- **Vegetative Swales / Grass Swales**
- **Vegetated Filter Strips**
- **Constructed Filters**
- **Bioretention Basins / Landscape Retention**
- **Check Dams**
- **Baffle Boxes**
- **Floating Treatment Wetlands**
- **Turf Reinforcement Mats**

Structural BMPs operate by a number of mechanisms to reduce stormwater total volume flow and peak flows, increase groundwater recharge and reduce pollutant loading in runoff. Such mechanisms include: settling, physical filtration, attenuation, evapotranspiration, chemical processes, and biological transformation and uptake. Oftentimes the use of existing conditions and “natural” processes are incorporated into structural BMPs such as use of the soil mantle or existing vegetation. A structural BMP may be as simple as a vegetated swale or as complex as a sand filter with a holding basin and underdrain system. It is important to note that in many cases non-structural BMPs may be used in place or in combination with structural BMPs, and sometimes may offer a more affordable option with reduced maintenance concerns.

4.6.2. Wet Detention Basin / Wet Pond

Description: Wet detention basins / wet ponds are water basins that collect and store stormwater for peak runoff attenuation and water quality improvement. The basins maintain a permanent wet pool volume and allow space for an additional variable volume used for the attenuation of storm runoff. They mainly serve as means to reduce stormwater runoff peak loads and reduce pollutant loads through natural and biological processes.

Photo Source: Florida Department of Environmental Protection, (1991)

Design Considerations	Functions
• Natural high groundwater table • Maintenance of control structures • Short circuiting of run-off from influent to outlet control structures • Forebay or baffle box for sediment collection and removal • Adequate drainage area • Relatively impervious underlying soils • Relatively large areas required	Volume Reduction: Low Groundwater Recharge: Low Peak Rate Control: High Water Quality: Medium
	Removal Efficiency Sediments: 70% Total Phosphorus: 45% – 70% Total Nitrogen 30% – 50% COD/BOD: 30% Heavy Metals: 40% - 80%
Maintenance Considerations • Periodic removal of excess vegetation • Removal of invasive plant species • Restoring eroded bank slopes • Mowing of slopes	**Capital Costs** *High*
	O&M Costs *Medium*
	Maintenance *Medium*

Function: Wet basins / wet ponds function to attenuate the volumetric loading of stormwater runoff to receiving downstream water bodies "mimic" pre-development run-off characteristics, thereby minimizing the flooding potential downstream. By retaining stormwater runoff for extended periods of time the ponds also serve to reduce nutrient and pollutant loads by mechanisms including sedimentation, plant growth and bacterial processes. In addition the ponds serve as a habitat for aquatic wildlife and provide visual appeal to the public. These functions have been detailed in Table 10:

Table 10: Functionality of a Wet Detention Basin (WWEGC, 2010)

Water Quantity	**Benefit**
Flow Attenuation	Yes
Runoff Volume Reduction	No
Pollutant Removal	
Nitrogen	Partial
Phosphorus	Partial
Suspended Solids	Yes
Hydrocarbons	Partial
Heavy Metals	Partial
Pathogens	Partial

Design: Wet basins / wet ponds are designed to maintain a normal wet pool elevation throughout the year, as displayed in Figure 2. In order to maintain a wet pool elevation, wet basins / wet ponds are typically installed in areas with soils of low infiltration rates. As a result, only a minimal amount of groundwater infiltration will occur with wet basins / wet ponds.

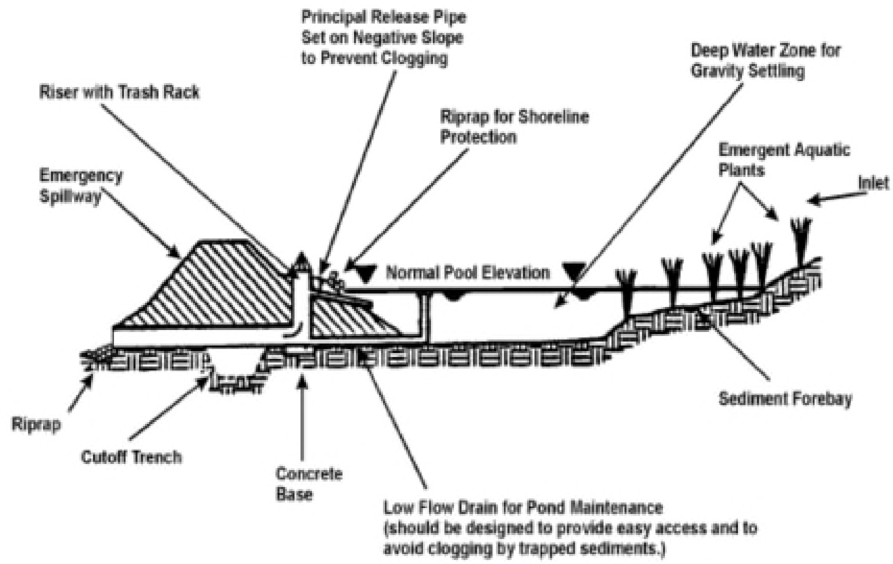

Figure 2: Wet Detention Basin Design (Maryland Department of the Environment, 1986)

The runoff that is trapped in the pool will experience an improvement in water quality as it is slowly released. The degree of water quality improvement is dependent upon the detention time, or the amount of time that water is detained before being released. With time, gravity will settle sediments to the bottom of the basin, and the inclusion of a littoral zone can provide nutrient and heavy metal reduction.

Several design considerations should be made when building wet detention basins / wet ponds. These include:

- Wet basins / wet ponds should be designed so as to receive and retain a sufficient amount of flow from run-off, rain and groundwater to maintain a permanent water surface.
- Soil testing should be conducted to determine if suitable soils with low infiltration rates currently exist or if modification by compaction or addition of new soils is required.
- Wet basins / wet ponds should be designed to treat the water quality volume required depending on specifications. If necessary the ponds should also mitigate against peak rate run-off and potential flooding.
- Wet basins / wet ponds should be designed to allow easy access for maintenance purposes.
- Short-circuiting of runoff flowing through the pond should be avoided. This may be achieved by pond configuration, placement of the influent and outlet control structures or by installation of baffle barriers to route the pond water throughout the pond prior to exiting through the outlet control structure. These design considerations may also reduce the chance of certain areas of the pond becoming stagnant.
- Influent and outlet control structures should be designed so as to reduce clogging frequency.
- Littoral zones, comprised of shallow water areas near the shore, may encourage the growth of certain emergent aquatic vegetative species. These zones may increase the nutrient removal of

the pond by enhancing the plant up-take of nitrogen and phosphorus species. Littoral zones should be designed to allow access for future maintenance and take into account the seasonal fluctuations of the water level in the pond and what impact this may have on the plants.

Maintenance Requirements: When calculating the size of the basin, a specific "water quality" volume is set aside for sediment capture. As this area fills to capacity, it will need to be dredged; otherwise, the design capacity of the pond will be diminished, which could lead to a decrease in water quality volume attenuation and possible flooding downstream. Other tasks include mowing the grass surrounding the pond, controlling weeds on the shoreline and in the littoral zone, and restoring portions of the bank lost to erosion. "This can be made easier with slopes of 3:1 or less for easy access, trash racks at principal intakes, and construction of the principal spillway to resist failure from erosion or deterioration for its design life" (Midwest Research Institute, 2003). Detailed maintenance tasks found in Section 5 which may relate to wet detention basins include:

- Activity No. 461: Cleaning Drainage Structures
- Activity No. 471: Large Machine Mowing
- Activity No. 482: Slope Mowing
- Activity No. 484: Intermediate Machine Mowing
- Activity No. 485: Small Machine Mowing
- Activity No. 494: Chemical Weed and Grass Control
- Activity No. 541: Litter Removal

Capital and Maintenance Costs: Capital costs for the installation of a wet detention basin may vary greatly depending on the size, depth, configuration, control structures, etc. Consideration also needs to be taken if property needs to be purchased, which depending on location could add a considerable amount to the capital cost. A majority of the capital costs will go to earthwork and planting. EPA estimates put capital costs for wet detention ponds in the range of $25,000 to $50,000 per acre-foot (USEPA, 1999). Annual maintenance costs may include mowing, fertilizer application, inspections, and upkeep of control structures. Studies have suggested that preliminary cost estimates may be made using the following equation (adapted from Wiegand et al., 1986)

$$\mathbf{C = 168.39 \times V*0.69}$$

Where:
C = construction cost estimate (based on 1995 dollars in the literature)
V = volume of storage of the pond (cubic meters) up to the crest of the emergency spillway

4.6.3. Retention Basin, Infiltration Basin

Description: Retention basins / infiltration basins capture stormwater runoff in a pond like structure and infiltrate the stored water directly to the groundwater. Unlike wet detention basins, the water level in retention basins will drop below ground level and become completely dry. The rate of infiltration depends on the volume captured, the infiltration characteristics of the underlying soil and degree of compaction.

Photo Source: Department of Environmental Protection, (2014)

Design Considerations • High infiltration rates of underlying soil • Keep compaction of subgrade to a minimum • Size to effectively attenuate peak volumetric loadings to receiving water bodies. • Preserve existing surrounding vegetation if possible • Design for applicable overflow conditions to prevent downstream flooding. • May require relatively large area to construct	**Functions** Volume Reduction: High Groundwater Recharge: High Peak Rate Control: Med/High Water Quality: High **Removal Efficiency** Sediments: 75% - 99% Total Phosphorus: 50% – 70% Total Nitrogen 45% - 70% COD/BOD: 70% - 90% Heavy Metals: 50% - 90%
Maintenance Considerations • Periodic removal of excess vegetation • Mowing and weed control • Inspection of inlet and outlet control Structures	**Capital Costs** *Medium* **O&M Costs** *Medium* **Maintenance** *Medium*

Function: Retention basins capture overland flow and store it; unlike a wet detention pond, this will not retain a permanent water level. The runoff is held indefinitely, allowing it to infiltrate into the soil, thus recharging the groundwater, or evaporate. This serves to reduce the peak stormwater flow rate and volume, as well as foster pollutant removal. Table 11 details the attributes of a retention basin.

Table 11: Functionality of an Infiltration Basin (MRI, 2003; WWEGC, 2010)

Water Quantity	**Benefit**
Flow Attenuation	Partial
Runoff Volume Reduction	Yes
Pollutant Removal	
Nitrogen	Yes
Phosphorus	Yes
Suspended Solids	Yes
Hydrocarbons	Partial
Heavy Metals	Yes
Pathogens	Partial

Design: Retention basins are partially effective at reducing the peak flow of stormwater runoff, since they are typically an off-line BMP and only the first-flush is received. There are a number of concerns when sizing the basin to adequately reduce the runoff volume. The area of the basin must be large enough to store an adequate amount of storm water, whilet allowing it to percolate into the ground at a rate of three to five inches an hour (Midwest Research Institute, 2003). If the water level in the basin is too high or the runoff does not percolate into the ground quickly enough, the vegetation in the basin can die off. Thus, the soil permeability and water table height in the area should be analyzed prior to design. There are also human health concerns associated with using retention basins. As these systems are designed to facilitate the movement of runoff into the ground, soluble contaminants and pollutant concentrations that cannot be completely filtered out by the basin can be carried into the groundwater.

Vegetation should be used to line the floor of the basin. This protects against erosion, and the plant root systems enhance the infiltration capacity of the basin by creating channels in the soil. Additionally, the vegetation serves as a source for nutrient uptake. One last consideration in designing infiltration basins is to remove coarse sedimentation from the influent through the use of another BMP. Heavy sedimentation will reduce the basin volume and reduce the infiltration rate of water into the soil.

Maintenance Considerations: Sedimentation buildup in the basin will need to be periodically removed. Vegetation should be maintained and replaced as necessary. The basin will need to be mowed and steps should be taken to control weeds. Control structures should periodically be inspected clogging or excessive debris or sediment buildup which may compromise the performance of the basin. Mowing and trimming of vegetation may be necessary to maintain the performance of the basin, all detritus should be removed of properly. Detailed maintenance tasks found in Section 5 which may relate to retention basins include:

- Activity No. 461: Cleaning Drainage Structures
- Activity No. 471: Large Machine Mowing
- Activity No. 482: Slope Mowing
- Activity No. 484: Intermediate Machine Mowing
- Activity No. 485: Small Machine Mowing
- Activity No. 494: Chemical Weed and Grass Control
- Activity No. 541: Litter Removal

Capital and Maintenance Costs: Capital costs for the installation of a wet detention basin may vary greatly depending on the size, depth, configuration, control structures, etc. Consideration also needs to be taken if property needs to be purchased, which depending on location could add a considerable amount to the capital cost. Adding rip rap for bank stabilization will increase the cost of the basin significantly. A majority of the capital costs will go to earthwork and planting. One method of evaluated proposed the following equation before adjusting for inflation from 1997 (Brown and Schueler, 1997)

$$\mathbf{C = 12.4V^{0.760}}$$

Where:
C = Construction, Design and Permitting Cost
V = Volume needed to control the 10-year storm (cubic feet)

Exfiltration Trench

Description: An exfiltration trench is a trench filled with highly permeable material (typically gravel) and/or a stormwater sewer pipe with perforated holes to allow infiltration of stormwater to the groundwater. Exfiltration trenches both increase infiltration to groundwater as well temporarily capture and store a certain volume of stormwater.

Photo Source: Village of Palmetto Bay, (2014)

Design Considerations

- Good for capturing the "first-flush" of storm-water runoff
- Trench may be wrapped in geotextile material to hold in place
- Typically placed over soils with good infiltration characteristics
- Best use over un-compacted soils
- Layer of top soil added above the trench

Maintenance Considerations

- Removal of accumulated debris

Functions

Volume Reduction:	Medium
Groundwater Recharge:	High
Peak Rate Control:	Medium
Water Quality:	High

Removal Efficiency

Sediments:	75% - 99%
Total Phosphorus:	50% – 75%
Total Nitrogen	45% - 70%
COD/BOD:	70% - 90%
Heavy Metals:	45% - 70%

Capital Costs

Medium

O&M Costs

Medium

Maintenance

Medium

Function: Infiltration trenches capture the first-flush during a storm event and facilitate the infiltration of the runoff into the ground through the sides and bottom of the trench. In comparison to an infiltration basin, the trenches are long, narrow, and filled with a coarse aggregate. The trenches reduce the peak flow and volume of runoff, and aid in the abatement of pollutant concentrations. This is summarized in Table 12:

Table 12: Functionality of an Infiltration Trench (WWEGC, 2010)

Water Quantity	**Benefit**
Flow Attenuation	Partial
Runoff Volume Reduction	Yes
Pollutant Removal	
Nitrogen	Yes
Phosphorus	Yes
Suspended Solids	Yes
Hydrocarbons	Partial
Heavy Metals	Yes
Pathogens	Partial

Design: Can be used in areas without space for infiltration basins. The trenches can be used at ground level to intercept overland flow, or depressions can be used to direct runoff into the trench. An example infiltration trench with surrounding pretreatment BMPs is shown in Figure 3:

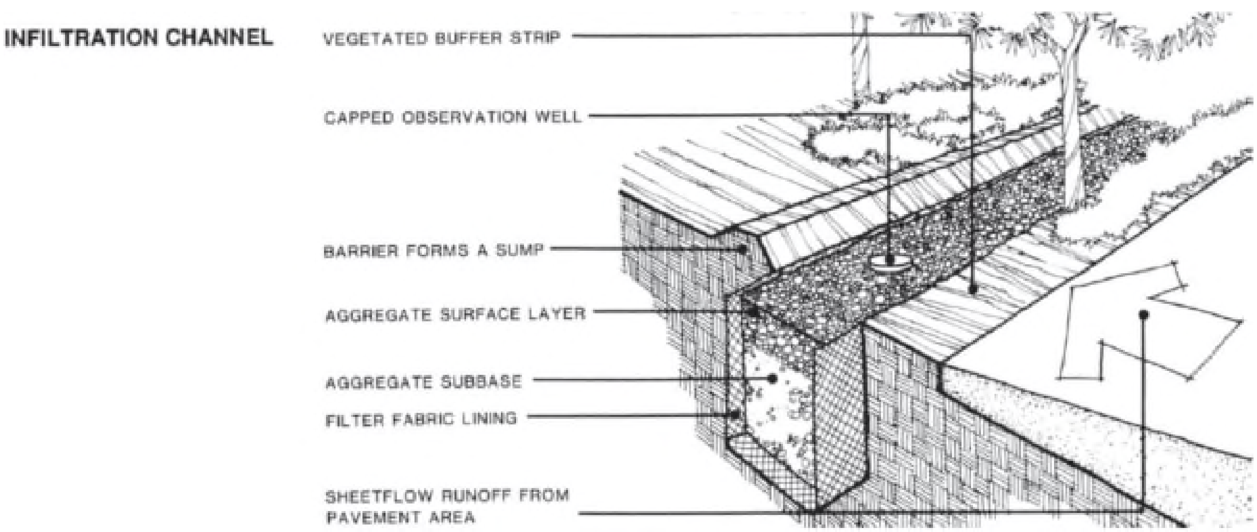

Figure 3: Example Infiltration Trench with Pretreatment BMPs

The trenches typically range from three to twelve feet in depth, as determined from a 1-year storm event and the permeability of the surrounding soil. The surrounding soils should be permeable, yet in the case of a less permeable medium, the trench should be deeper to increase the drainage surface area. The walls of the trench are lined with a filter fabric, while the bottom can be lined with fabric or a fine sand layer. The stormwater flowing into the trench will temporarily reside between the stone aggregate gaps, where microbial action and adhesion to the soil will reduce pollutant levels.

As with infiltration basins, the influent will need to be pretreated with an upstream BMP, such a grass filter strips, to reduce the quantity of course sediments and debris, which would clog pores and reduce the infiltration rate over time. Groundwater contamination can be inhibited by ensuring the trench bottom is at least four feet above the water table during the wet season (Livingston, 1991).

Maintenance Considerations: The removal of sediment from the trench and upstream BMPs is the most important aspect of infiltration trench maintenance. Once the upstream basins and grass filters have lost 10% of the design storage volume, the debris should be vacuumed out (Midwest Research Institute, 2003). Complete trench rehabilitation can be expensive, yet one way to minimize the amount of trench that needs to be reconstructed is to place a fabric liner six to twelve inches below the trench surface in order to capture inbound sediments. Detailed maintenance tasks found in Section 5 which may relate to exfiltration trenches include:

- Activity No. 482: Slope Mowing
- Activity No. 484: Intermediate Machine Mowing
- Activity No. 485: Small Machine Mowing
- Activity No. 494: Chemical Weed and Grass Control
- Activity No. 541: Litter Removal

Capital and Maintenance Costs: Capital costs for exfiltration trenches may vary greatly depending on the site configuration, dimensions of the trench and site-specific conditions. An analysis of the soil type beneath the trench may be necessary to determine infiltration rates. Typical construction costs have been reported as $4 - $9 per cubic foot of storage, in 2003 dollars (SWRPC, 1991; Brown and Schueler, 1997). Annual maintenance costs may be in the range of approximately 5% – 10% of capital costs (Schueler, 1987).

4.6.4. Vegetative Swales / Grass Swales

Description: Vegetative swales are narrow grass filled furrows used to channel stormwater, while increasing infiltration to the groundwater, sedimentation of suspended solids, and removal of pollutants.

Photo Source: US Environmental Protection Agency, (2014)

Design Considerations	Functions
• Should be planted with low growing native vegetation suitable for dry season weather • Properly slope side to prevent bank erosion • Should aesthetically be designed for the project site • Incorporation of check dams will increase the retention time of stormwater by creating small detention pool storage • Should percolate 80% of runoff from a 3-inch storm in 72 hours. **Maintenance Considerations** • Periodic removal of excess vegetation • Accumulated debris removal	Volume Reduction: Low/Med Groundwater Recharge: Low/Med Peak Rate Control: Med/High Water Quality: Med/High **Removal Efficiency** Sediments: 70% - 80% Total Phosphorus: 30% – 50% Total Nitrogen 25% - 40% COD/BOD: 25% - 40% Heavy Metals: 50% - 90% **Capital Costs** *Medium* **O&M Costs** *Medium* **Maintenance** *Medium*

Function: Vegetative swales are shallow, grass-lined furrows that are designed to settle pollutants and allow for the infiltration of stormwater runoff. Given their propensity to quickly settle coarse sediments, the swales can be used as the first step in a BMP treatment train. This allows for the pretreatment of runoff before it is discharged to BMPs that are prone to clogging from coarse sediments. A secondary function of grass swales is to provide minor to moderate attenuation of the runoff flow rate and volume. Refer to Table 13 for a summary of vegetative swale attributes:

Table 13: Functionality of Vegetative Swales (WWEGC, 2010)

Water Quantity	**Benefit**
Flow Attenuation	Partial
Runoff Volume Reduction	Partial
Pollutant Removal	
Nitrogen	Yes
Phosphorus	Yes
Suspended Solids	Yes
Hydrocarbons	Partial
Heavy Metals	Yes
Pathogens	No

Design: Grassed swales are commonly seen on the sides of highways and are one of the oldest BMPs for stormwater management. "Used alone, swales must percolate 80% of the runoff from a three-inch rainfall within 72 hours to provide proper water quality benefits" (Livingston, 1991). The shallow swales use low velocities and vegetation to facilitate the settling of pollutants. On a similar note, vegetative swales should not be installed in parallel with a steep slope because the increased flow rates will disrupt settling and cause erosion. In order to retard the flow, small check dams can be constructed, resulting in an increased detention time and torpid flows. Grass swales near highways must be designed with driver safety in mind. In order to accommodate this, the depth of the swales should be no greater than 1.5 feet and the facing slope of a check dam should be limited to 2.75 degrees (Livingston, 1991).

The swale is vegetated in order to prevent erosion, enhance nutrient uptake, and allow for quicker infiltration rates. Native grasses can be used as covering for the swale, and if the climate is not arid, the watering may not be required. When designing grass swales, care should be taken to ensure that water levels during storms will not rise above the grass level. High water levels can force the grass down flat; thus, reducing the treatment effectiveness.

Maintenance Considerations: Much like a residential lawn, the maintenance for grass swales is relatively simple. The grass swales will need to be mowed,, although the grass can be grown higher than normal lawns while be getting nutrient inflows from surrounding areas. Debris should be cleared from the swale, and vehicular usage on the swale should be prohibited. Detailed maintenance tasks found in Section 5 which may relate to vegetated swales may include:

- Activity No. 461: Cleaning Drainage Structures
- Activity No. 482: Slope Mowing
- Activity No. 484: Intermediate Machine Mowing
- Activity No. 485: Small Machine Mowing
- Activity No. 494: Chemical Weed and Grass Control
- Activity No. 541: Litter Removal

Capital and Maintenance Costs: Vegetated swales require a minimal amount of materials, and as such may be attractive options when compared to concrete guttering and piping. Capital costs will vary per design and site specifications. Generally speaking, costs will likely include earthwork, sodding, real estate value and installation fees. Total costs, including construction and material costs have been estimated as ranging from as little as $8.50 to as high as $50 per linear foot depending on swale depth and bottom width (SEWRPC, 1991). Annual operation costs have been estimated as $0.75 per linear foot (PDEP, 2006).

4.6.5. Vegetated Filter Strips

Description: Vegetated filter strips are comprised of indigenous vegetation located between nonpoint pollution sources and receiving water bodies. They serve to intercept runoff and remove pollutants, nutrients, sediments and pesticides.

Photo Source: VA Department of Environmental Quality, (2014)

Design Considerations	Functions
• Slope of vegetated strip effects sheet flow characteristics of runoff and retention • Slopes less than 5% are generally preferred • Level ground is preferable for uniform sheet flow across strip • Degree of slope should consider the type of soil and vegetation to minimize erosion • Length and width of filter strip will affect the percent reduction of pollutants	Volume Reduction: Low/Med Groundwater Recharge: Low/Med Peak Rate Control: Low Water Quality: High
	Removal Efficiency Sediments: 70% - 90% Total Phosphorus: 40% - 70% Total Nitrogen 20% - 40% COD/BOD: 40% - 80% Heavy Metals: 0% - 20%
Maintenance Considerations • Periodic mowing and fertilization • Inspection for sediment build-up	**Capital Costs** *Medium*
	O&M Costs *Medium*
	Maintenance *Medium*

Function: Filter strips are similar to grass swales in that they are vegetated surfaces designed to slow the flow rate of stormwater runoff discharged from impervious surfaces, and provide nutrient and sediment removal. Infiltration can occur, but this is not a primary application. These parameters are shown in Table 14:

Table 14: Functionality of Filter Strips (Pazwash, 2011)

Water Quantity	**Benefit**
Flow Attenuation	Partial
Runoff Volume Reduction	Partial
Pollutant Removal	
Nitrogen	Partial
Phosphorus	Partial
Suspended Solids	Partial
Hydrocarbons	Partial
Heavy Metals	Partial
Pathogens	No

Design: Filter strips are flat land surfaces with a gentle slope. They do not function properly in areas with a 10% gradient or limited space (Pazwash, 2011). In order for the filter strip to function properly, the filter strip should receive runoff as sheet flow and stretch along the length of the impervious surface, which makes it ideal for use alongside parking lots and road ways. Sheet flow ensures that the runoff is evenly distributed amongst the strip's surface area, which optimizes pollutant removal, infiltration, and flow attenuation. Figure 3 displays a typical design profile of a vegetated filter strip.

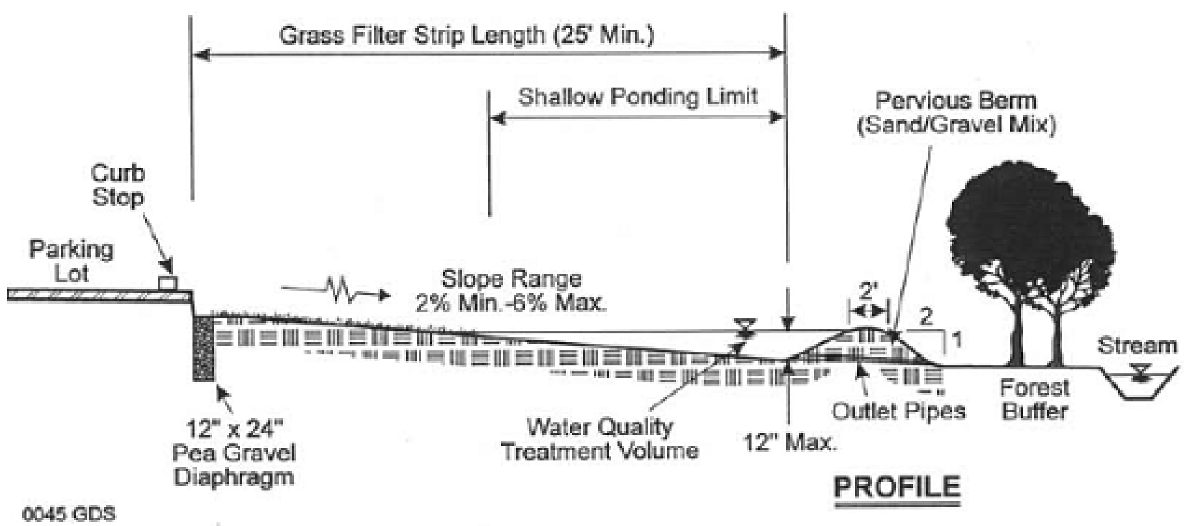

Figure 4: Example Filter Strip (FDOT, 2007)

Filter strips can be populated with a variety of vegetative covers. The vegetative cover serves to slow the runoff flow rate, trap sediments, and remove pollutants. The root systems from the vegetation protect against erosion and increases infiltration by creating channels in the soil. Selected vegetation can range from turf and meadow grasses to indigenous woods, which remove between 60-80% of the maximum suspended solids in the runoff (New Jersey Department of Environmental Projection, 2010).

Maintenance Considerations: Vegetated filter strips, as with all BMPs require a certain degree of maintenance. Of importance is ensuring that sheet flow conditions persist throughout the filter strip. If the filter strip is not inspected and maintained, preferential flow pathways may form which increase erosion rates and lead to the deterioration of the filter strip. The filter strips should be regularly mowed, only when the ground is dry to prevent compaction and tracking damage. Erosion gullies should be repaired and replaced where lost vegetative cover may occur. Depending on the sediments incorporated in the stormwater runoff, filter strips may need to be checked for buildup of sediments. If check dams are incorporated with the filter strip they should be routinely inspected for structural integrity and cracks. Detailed maintenance tasks found in Section 5 which may relate to vegetated filter strips include:

- Activity No. 461: Cleaning Drainage Structures
- Activity No. 471: Large Machine Mowing
- Activity No. 482: Slope Mowing
- Activity No. 484: Intermediate Machine Mowing
- Activity No. 485: Small Machine Mowing
- Activity No. 494: Chemical Weed and Grass Control
- Activity No. 541: Litter Removal

Capital and Maintenance Costs: Vegetated filter strips are minimal in material and construction costs. However, when compared with other BMPs they will likely require larger land area, as compared on a flow basis. As such vegetated filter strips may be an attractive option if land is cheap and readily available. Costs will include earthwork, sodding, installation of vegetation and installation of berms (if added). Annual maintenance costs will vary depending on maintenance frequency and site location but may include mowing, weeding, inspection, liter removal, etc. Annual maintenance costs have been estimated at $100 - $1,400 per acre (PDEP, 2006).

4.6.6. Constructed Filters

Description: Constructed filters are structures designed for the physical filtration of stormwater through a filtration media such as sand or sorption media. Filters may be built as large in-place structures or prefabricated and installed on location. Incorporation of groundwater infiltration may be used in filters to reduce runoff volumes.

Photo Source: City of Sandy, (2014)

Design Considerations	Functions
• Underlay perforated pipes may be used for conveyance of post-filter water • Pretreatment for debris and floatable solids may be necessary to prolong run times • Infiltration rates of media should be considered for effective design • Can be down-flow or up-flow design	Volume Reduction: Low-High Groundwater Recharge: Low-High Peak Rate Control: Low-High Water Quality: High
	Removal Efficiency Sediments: 70% - 90% Total Phosphorus: 50% - 70% Total Nitrogen 30% - 50% COD/BOD: 50% - 80% Heavy Metals: 50% - 90%
Maintenance Considerations	**Capital Costs** *High*
• Regular inspection and maintenance required for functionality of the filter • Replacement of filter media if excessive clogging occurs	**O&M Costs** *Medium* **Maintenance** *High*

Function: The primary purpose of sand filters is to provide water quality improvement. These devices are off-line systems and do not reduce the runoff flow rate. The concentrated first-flush from a storm event is channeled to the sand filter, where pollutants, mainly suspended solids and heavy metals, are removed. This is summarized in Table 15:

Table 15: Functionality of Sand Filters (Pazwash, 2011)

Water Quantity	**Benefit**
Flow Attenuation	No
Runoff Volume Reduction	No
Pollutant Removal	
Nitrogen	Partial
Phosphorus	Partial
Suspended Solids	Yes
Hydrocarbons	Partial
Heavy Metals	Yes
Pathogens	Partial

Design: Filters require frequent maintenance to maintain functional efficiency. Consequently, these systems are implemented when space is at a premium. Sand filter systems can have from two to three chambers as displayed in Figure 5:

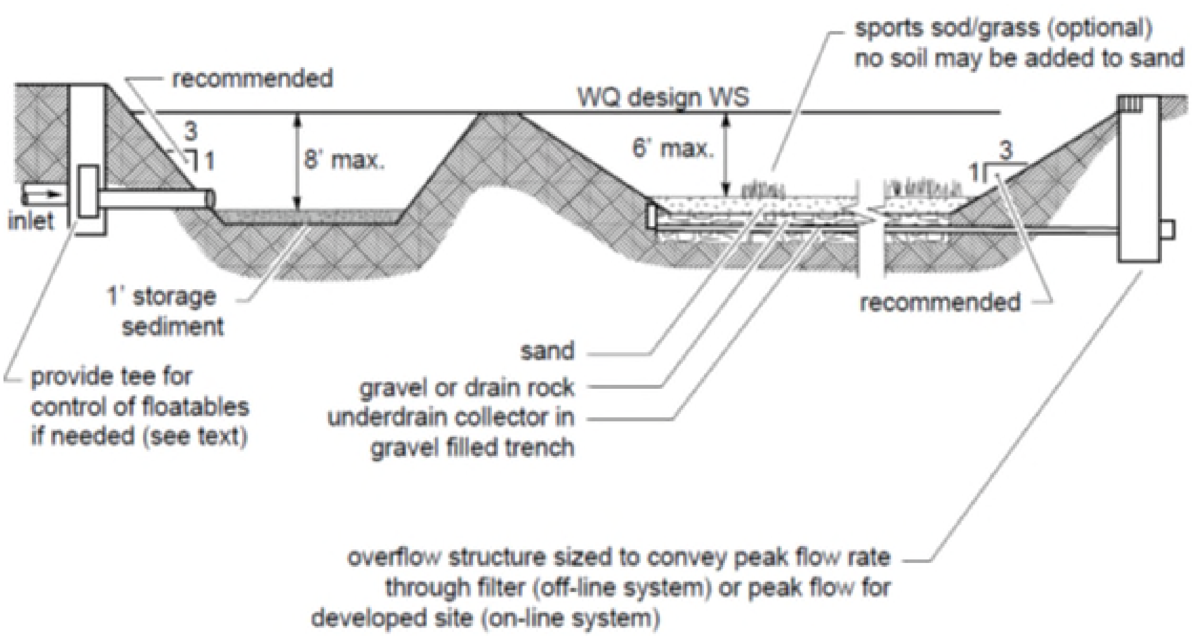

Figure 5: Example Sand Filter Configuration. Not to Scale. (Washington State Department of Ecology, 2000)

The first chamber serves to remove floatables and clarify the influent by removing solids, which would otherwise clog the pores of the sand filter. As treated water flows of the weir into the second chamber, percolation through the sand filters out additional suspended solids, while also removing nitrogen, biological oxygen demand, suspended solids, and pathogens. The third chamber is termed the discharge chamber and it is often combined with the second chamber. The effluent is then discharged through an outflow pipe.

Another configuration for filter designs for inter-event treatment of wet detention pond water are Media Bed Reactors (MBRs). MBRs may be designed in a sloped configuration or designed for horizontal placement. MBRs incorporate solar power and DC pumps to cycle pond water through the filter during dry inter-event periods, thereby creating a direct treatment method for the pond which may run under continual operation. MBRs are usually filled with a sorption media rather than sand due to low infiltration rates of sand. They may also be filled with “roughing” media or specialized media to remove metals in the primary chambers.

There are a number of pollutant removal mechanisms in a sand filter. Solids are removed through gravity settling in the sedimentation chamber. In the filtration chamber, particles that are too large to fit through the poor spaces will be trapped and can also block smaller particles. However, the straining of particles and subsequent clogging of pore spaces will increase the drawdown time. Adsorption is the chemical bonding of pollutants to the surface of the sand particles. This is the main mechanism for soluble nutrients, metals, and organic pollutant removal (FDOT, 2007). With regards to microbial action, if the sand layer is kept moist, a biological layer will develop which breaks down organic pollutants and consumes nutrients and coliforms. Lastly, wetland plants, algae, and grasses growing in the sand will serve as a source of nutrient uptake.

Maintenance Considerations: Twice a year, sediment buildup should be removed from the sedimentation chamber to ensure suitable detention times. Inspection of the filters is recommended four times per year (depending on site specifics). The top layer of sediment and discolored sand (if a second chamber is being used) should be removed and replaced when the sand filter is visibly clogged. Removal of any trash and debris should occur as necessary. Replacement of the filter media may eventually be necessary, however this will depend on the characteristic of the runoff and maintenance frequency. Detailed maintenance tasks found in Section 5 which may relate to filters include:

- Activity No. 461: Cleaning Drainage Structures
- Activity No. 541: Litter Removal

Capital and Maintenance Costs: Capital costs for constructed filters vary greatly depending on the configuration of the filter, piping, filtration media used as well as its availability and whether a concrete holding structure is required for the filter. Maintenance costs will include inspections, media replacement and labor for filter upkeep.

4.6.7. Bioretention Basin / Landscape Retention

Description: A bioretention basin is a shallow surface depression, either natural or constructed, with planted vegetation designed for the capture and treatment of stormwater through pooling, settling, filtration and plant up-take mechanisms. The bioretention basins may also add to the aesthetics in urban settings by the inclusion of vegetated areas.

Photo Source: Australian Department of the Environment, (2014)

<table>
<tr>
<td rowspan="4">
<u>Design Considerations</u>

Typically used for aesthetic quality
Vegetation should be adapted for submerged and dry environments
May incorporate trees
Deep rooted vegetation may increase infiltration rates by creation of flow pathways
Infiltration rates increased if placed on high permeable soils
Perforated underdrains may be incorporated for post-basin stormwater conveyance

<u>Maintenance Considerations</u>

Regular landscaping maintenance
Removal of trash and debris
Mowing
Erosion repair (if present)

</td>
<td>
<u>Functions</u>
Volume Reduction: Medium
Groundwater Recharge: Med/High
Peak Rate Control: Low/Med
Water Quality: Med/High
</td>
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<tr>
<td>
<u>Removal Efficiency</u>
Sediments: 85%
Total Phosphorus: 85%
Total Nitrogen *Limited data
COD/BOD: *Limited data
Heavy Metals: *Limited data
</td>
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<tr>
<td><u>Capital Costs</u>
Med</td>
</tr>
<tr>
<td><u>O&M Costs</u>
Med

<u>Maintenance</u>
Med</td>
</tr>
</table>

**Limited data available.*

Function: Bio-retention basins are commonly used in parking lots and residences to reduce the flow rate and volume of stormwater runoff. Furthermore, plants, microbes, and the soil improve the water quality through a number of pathways common to forested areas in nature. This is achieved by diverting runoff into the basin, where it is able to pool up. As the runoff percolates through the soil matrix, it is filtered by the soil and plants. The water is then discharged into the water table or transported away through a perforated pipe. Stormwater quantity and pollutant removal characteristics are shown in Table 16:

Table 16: Functionality of a Bioretention Basin (Pazwash, 2011)

Water Quantity	**Benefit**
Flow Attenuation	Partial
Runoff Volume Reduction	Partial
Pollutant Removal	
Nitrogen	Yes
Phosphorus	Yes
Suspended Solids	Yes
Hydrocarbons	Yes
Heavy Metals	Yes
Pathogens	Partial

Design: Bioretention systems are shallow depressions, composed of a plant and soil matrix which receives runoff from impervious surfaces and treats it onsite. Refer to Figure 5 for an example:

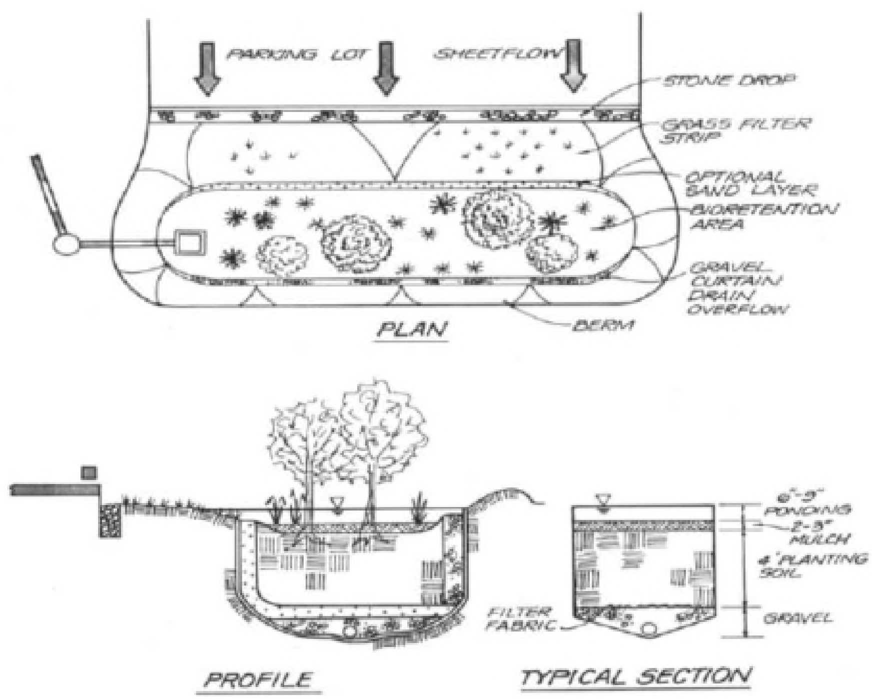

Figure 6: Exemplary Bioretention System (FDOT, 2007)

As the water pools in the depression, it is gradually filtered throughout the soil bed. In order to prevent flooding the vegetation, water levels above the water quality volume are diverted out of the basin. In regards to the soil matrix, it should be thick enough to properly treat the runoff, yet it should also be permeable to ensure drainage of the basin within two days after the storm event (Pazwash, 2011). Plants, trees, and grasses used within the basins should be native and able to withstand periods of partial immersion. The specific pollutant removal mechanisms used in bioretention basins are adsorption, filtration, volatilization, ion exchange, and decomposition (Prince George's Count Department of Environmental Protection, 1993).

Maintenance Activities: Typical maintenance in a bioretention system is relegated to landscaping. The system requires the most maintenance in the initial implementation phase. After the landscaping has taken root, the maintenance demands are less intense. The maintenance activities are presented in Table 17:

Table 17: Bioretention system maintenance activities and schedule (ETA and Biohabitats, 1993)

Maintenance Activity	Frequency
Mulch bare spots	As required
Treat diseased vegetation	As required
Mow turf	As required
Clear litter and debris	Monthly
Repair soil erosion	Monthly
Weeding	Monthly
Replace diseased and dead vegetation	Biannually
Prune shrubs	Biannually
Add fresh mulch	Yearly
Sediment removal	Once during the system’s lifetime

Detailed maintenance tasks found in Section 5 which may relate to bioretention basins include:

- Activity No. 461: Cleaning Drainage Structures
- Activity No. 482: Slope Mowing
- Activity No. 484: Intermediate Machine Mowing
- Activity No. 485: Small Machine Mowing
- Activity No. 494: Chemical Weed and Grass Control
- Activity No. 541: Litter Removal

Capital and Maintenance Costs: Capital costs for a bioretention can be estimated using the following equation relating treatment volume to cost (Brown and Schueler, 1997):

$$C = 7.30V^{0.99}$$

Where

C = cost of construction, design, and permitting (in 1997 dollars)
V = volume of water treated by the bioretention system (ft^3)

Inflation should be taken into account when using this equation. The maintenance costs for the system range from $2,000-$3,000 per year for mowing, debris removal, vegetation upkeep, and mulching. The facility rarely requires repair unless erosion is an issue.

Check Dams

Description: Check dams are small rock or concrete filled structures constructed across drainage channels such as swales or ditches. The goal of implementing check dams is to lower the speed of run-off, thereby decreasing erosion and encouraging sedimentation. They may be used as temporary installments for construction periods, or permanently.

Photo Source: Delaware Department of Transportation, (2014)

Design Considerations

- May be constructed using permeable material such as gravel and sorption media or non-permeable material such as concrete or wood
- May be incorporated into existing structures
- Top of check dam should be below the top bank elevation of the drainage channel
- Should be designed with sufficient size to withstand the hydraulic forces of the runoff

Maintenance Considerations

- Periodic inspection of check dam integrity and leaks

Functions

Volume Reduction:
Groundwater Recharge:
Peak Rate Control:
Water Quality:

Removal Efficiency

Sediments:	60% - 80%
Total Phosphorus:	*Limited Data**
Total Nitrogen	*Limited Data**
COD/BOD:	*Limited Data**
Heavy Metals:	*Limited Data**

Capital Costs

Low

O&M Costs

Low/Med

Maintenance

Low/Med

**Limited data available.*

Function: Check dams function to slow down and dissipate the energy of stormwater run-off in narrow channels such as swales or drainage ditches and create a sediment containment system (SCS). During run-off flows stormwater will pool upstream of the check dams, allowing solids and pollutants to settle. The pooling of the stormwater also decreases peak runoff volumes for the drainage system. During inter-event and low flow periods, runoff volumes may be decreased by allowing the pooled water to infiltrate into the ground or evaporate to the atmosphere. During high flow events water flows over or through the structure and continues through the drainage system. By slowing the run-off, check dams also serve to reduce erosion and incision of drainage channels.

Design: Check dams may be constructed using a variety of materials including porous material such as rock and gravel as well as non-porous material such as concrete. The check structure must be designed so as to be capable of withstanding the large hydraulic force of the channel runoff during peak flow events. It is important check dams be placed to cause a suitable reduction in flow velocity to allow pooling to occur. As pooling occurs upstream of the check dam, energy dissipates within the water column, thereby allowing the settling of suspended sediments to the channel bed.

As displayed in Figure 6 the configuration of the check dam must be high enough to allow the pooling of water upstream of the structure. If somewhat porous material is used for the check dam, such as rock, the infiltration rates through the check dam should be slow enough to allow pooling and settling to occur. The center of the check dam should typically be slightly lower than the edges so as to prevent side erosion pathways around the structure. For long channels check dams are commonly installed in series.

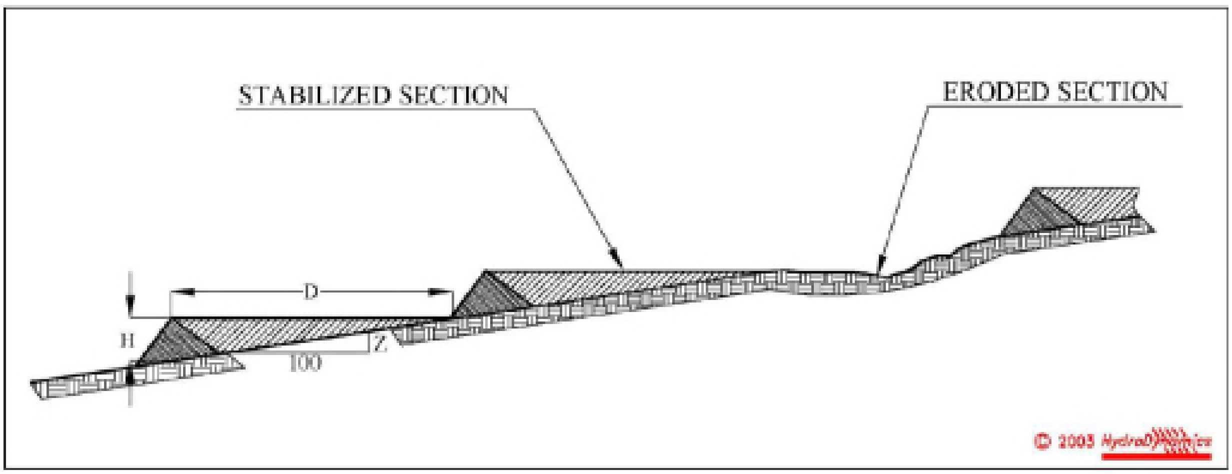

Figure 7: Check structure spacing diagram (FDOT, 2007)

Maintenance Activities: Routine clearing of accumulated sediment or trash may be required depending on the characteristics of the site runoff. Once accumulated sediment has reached half the height of the check dam it should be removed (EPA, 1992). Detailed maintenance tasks found in Section 5 which may relate to check dams include:

- Activity No. 471: Large Machine Mowing

- Activity No. 482: Slope Mowing
- Activity No. 484: Intermediate Machine Mowing
- Activity No. 485: Small Machine Mowing
- Activity No. 541: Litter Removal

Capital and Maintenance Costs: Check dams are relatively cheap and easy to install. Costs will largely depend on the material used and size of the check structure. For rock check structures EPA (1992) estimated installation of the check dam to cost approximately $100 per structure. Precast concrete check dams are more expensive, with an approximate cost of $200 or more per structure, however they provide more structural integrity and generally have a longer operating lifecycle when compared to rock structures. Periodic inspection of check dams should be conducted to check the structural integrity and if erosion may be occurring around the edges of the structure.

4.6.8. Baffle Boxes

Description: Baffle boxes are typically concrete or fiberglass constructed structures comprised of several small sedimentation chambers capable of trash collection and sedimentation of debris and suspended solids. Accumulated solids are periodically removed from the baffle box.

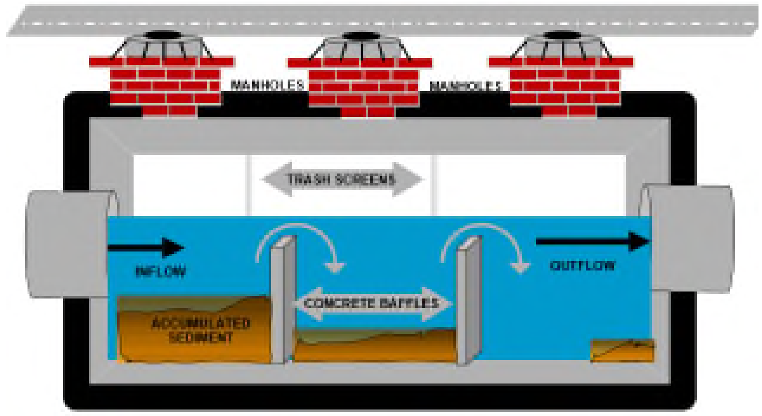

Figure 8 : US Environmental Protection Agency, (2001)

<table>
<tr>
<td rowspan="5">

<u>**Design Considerations**</u>

- Size will depend on the volume and velocity of incoming stormwater
- Design for variable volume
- Directional vanes may be incorporated to add further control of flow way patterns within the baffle box
- Screens incorporated in Type 2 baffle boxes to capture floating materials
- An upflow filter may be incorporated at the end of the baffle box for added filtration

<u>**Maintenance Considerations**</u>

- Baffle boxes require periodic removal of trash, debris and settled solids

</td>
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<u>**Functions**</u>
Volume Reduction: Low
Groundwater Recharge: Low
Peak Rate Control: None
Water Quality: Med

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<u>**Removal Efficiency**</u>
Sediments: 70%
Total Phosphorus: *Limited Data**
Total Nitrogen: *Limited Data**
COD/BOD: *Limited Data**
Heavy Metals: *Limited Data**

</td>
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<td>

<u>**Capital Costs**</u>
Med/High

</td>
</tr>
<tr>
<td>

<u>**O&M Costs**</u>
Med/High

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<td>

<u>**Maintenance**</u>
Med/High

</td>
</tr>
</table>

**Limited data available.*

Function: The primary function of baffle boxes is to capture and remove excess suspended solids and trash from stormwater runoff, although recent studies are also looking into the pollutant removal efficiencies of baffle boxes. Baffle boxes operate by slowing down flow velocity in stormwater runoff by the use of baffle walls and settling chambers. As stormwater enters the larger volume of the baffle box, as compared to the stormwater pipe, the hydraulic retention time is increased and the flow velocity decreases. The decrease velocity allows heavier suspended solids to settle. Typically heavier solids will settle in the first chamber while lighter solids will settle in the last chamber. Incorporation of a trash collector enables the screened capture of floatable debris such as trash and vegetation. Baffle boxes are usually installed just prior to discharge to receiving water bodies which are sensitive to suspended solids concentrations, such as lakes and rivers.

Design: Typically baffle boxes are approximately 3 to 5 meters (10 to 15 feet) long, 0.6 meters (2 feet) wider than the pipe, and 2 to 2.7 meters (6 to 8 feet) high, with a weir height of 1 meter (3 feet) (EPA, 2001). Weir elevations are typically set to match the influent pipe elevation so as to prevent excess headloss from occurring. Access covers may be designed as manhole covers or hatches. Maintenance activities should be incorporated into the access size and location to ensure ease of access during cleaning activities. Flow deflectors may also be incorporated into the chambers to prevent suspended solids overflowing into the next chamber, thereby increasing the capture rate of solids. Deflection plates may also be used to direct trash into the trash collector. A profile view of a baffle bax with a trash separator is displayed in Figure 8.

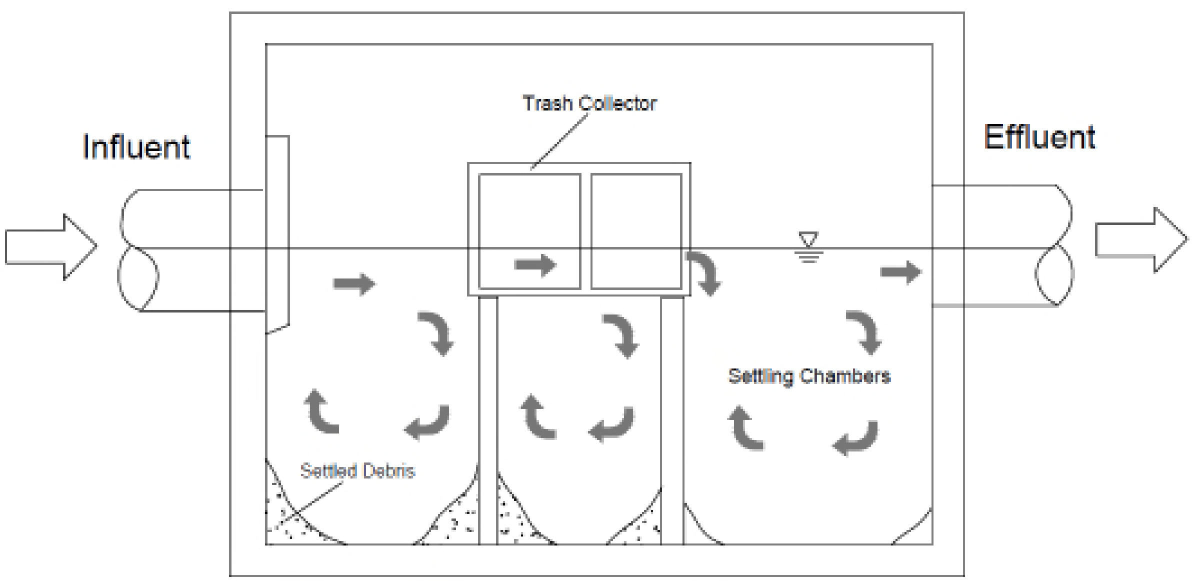

Figure 9: **Side view of typical baffle box with trash collector.**

Maintenance Activities: Baffle boxes must be regularly maintained in order for proper function. As the chambers fill with settled debris the effective volume of the chamber is decreased resulting in a gradual decrease in efficiency. Baffle boxes may accumulate from 225 to 22,500 kilograms (500 to 50,000 pounds) of material per month (England, 1998). Cleaning frequency is highly determined by the characteristics of the contributing watershed, however baffle boxes installed in Florida have been found to require monthly cleaning during the wet season and once every two months during the dry season (EPA, 2001), although cleaning frequency may be extended by constructing deeper chambers capable of a higher holding capacity of solids. Settled solids may be removed by use of a vacuum truck accessed through the access manhole or hatches. One vacuum truck can typically clean out two baffle boxes per day. During cleanout, flows should not be present within the baffle box and plugging of the influent and effluent pipes may be required. Detailed maintenance tasks found in Section 5 which may relate to baffle boxes include:

- Activity No. 461: Cleaning Drainage Structures
- Activity No. 541: Litter Removal

Capital and Maintenance Costs:

Costs for baffle boxes will largely depend on the volume, materials, location and what size storms sewer pipe is being connecting. Average costs for the installation of a cast-in-place baffle box have been reported as equaling $22,000 (Bateman, et. al, 1998), while one project including the retrofit of a cast-in-place baffle box to a 48-inch stormwater system was reported as equaling $250,000 (EPA, 2001). Operation costs have been reported as equaling $450 per cleaning.

4.6.9. Floating Treatment Wetlands

Description: Floating treatment wetlands (FTWs) are floating mats containing aquatic vegetation that provide pollutant removal directly from the water column. This is accomplished through direct uptake into the plants' biomass through a variety of biological and biochemical processes.

Photo Source: Beemats, LLC, (2014)

<table>
<tr>
<td rowspan="4">
<u>Design Considerations</u>

Amount of surface area coverage by FTW per Surface area of pond
Selection of floating mat construction and material
Location and arrangement of FTWs within the pond

<u>Maintenance Considerations</u>

Removal of invasive vegetation on the FTWs
Plant replacement frequency
Inspection and maintenance of anchoring System

</td>
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<u>Functions</u>
Volume Reduction: None
Groundwater Recharge: None
Peak Rate Control: None
Water Quality: Medium
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<tr>
<td>
<u>Removal Efficiency</u>
Sediments: 30% - 40%
Total Phosphorus: 15% - 25%
Total Nitrogen: 15% - 25%
COD/BOD: Limited data*
Heavy Metals: 10% - 20%
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<tr>
<td>
<u>Capital Costs</u>
Medium
</td>
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<tr>
<td>
<u>O&M Costs</u>
Medium
<u>Maintenance</u>
Medium
</td>
</tr>
</table>

** Limited data available*

Function: Floating treatment wetlands function as a water quality treatment BMP by providing on-line treatment of runoff within wet detention ponds. As the runoff moves through the pond from inlet to outlet, it comes into contact with the root system of the FTW. The aquatic plants on the floating mats form a hydroponic system in which the roots of the plants provide pollutant removal through plant uptake, and allow the formation of a biofilm to occur. The presence of a biofilm allows further pollutant removal mechanisms, including adsorption, nitrification, and denitrification (Tanner and Headley, 2011). Table 18 summarizes the functionality of FTWs.

Table 18: Functionality of Floating Treatment Wetlands (Pazwash, 2011)

Water Quantity	**Benefit**
Flow Attenuation	No
Runoff Volume Reduction	No
Pollutant Removal	
Nitrogen	Partial
Phosphorus	Partial
Suspended Solids	Partial
Hydrocarbons	Unknown
Heavy Metals	Partial
Pathogens	Unknown

Design: FTWs can be primarily used in wet detention ponds as a supplement or alternative to littoral zone vegetation for water quality improvement. However, FTWs present advantages over littoral zones in that they do not experience inundation or dry conditions during water level fluctuations. They can be implemented in most any wet detention pond in that they do not require any structural modifications to the pond and by floating on the surface, they do not decrease the detention capacity of the pond.

In FTW systems, water surface area coverage, and plant species selection, and floating mat material are the key design elements. Research involving both lab and field-scale applications of 5% up to 18% of water surface area coverage has found that increase in surface area coverage increase the pollutant removal rate (Chang et al, 2011; Winston et al, 2013). However, too much surface area coverage can decrease the necessary amount of sunlight reaching the pond bottom, so it is suggested that for normal ponds, percent coverage should not exceed 5%, while for impaired ponds, a surface area coverage of 10-15% is recommended. Selection of plant species should include consideration of local climate, frost-resistance, and aesthetics. Plant species should be of indigenous variety and a mixture of species should be employed to provide weather resistance, biodiversity, and aesthetic value. Floating mat material should be selected based on cost and ease of maintenance for the particular site. The most commonly used materials are interlocking foam mats, and fibrous polyester islands injected with buoyant foam, as see in Figure 9.

Figure 10: Examples of FTWs with different floating mat materials, from left to right: interlocking foam mats, fibrous polyester islands (Clemson University, 2013).

Maintenance Considerations: The FTWs will need to be inspected periodically to ensure that invasive plant species do not take over the mats and outcompete the design aquatic vegetation. If invasive species are observed, they should be removed by hand, or by application of herbicide if hand-removal is not practical. The plants should be removed and replaced with the same species to ensure that they do not die off and contribute to nutrient recycling in the pond. The period between plant removal maintenance depends on the local weather patterns and seasonality, occurrence of extreme events such as hard freezes or extreme heat, and the hardiness of the plant species selected for design. Anchoring systems should be inspected periodically to ensure that all ropes and cables are not frayed and that anchors have remained in their intended location, to prevent migration of the floating mats within the pond. Detailed maintenance tasks found in Section 5 which may relate to FTWs include:

- Activity No. 494: Chemical Weed and Grass Control
- Activity No. 541: Litter Removal

Capital and Maintenance Costs: Capital costs for FTWs depend on the size of the wet detention/retention pond, the amount of water surface area coverage desired, and the material used for the floating mats. Typical costs for installation of new FTWs are approximately \$6.50 to \$8 per ft^2. Maintenance costs consist of material costs for FTW plant replacement, which typically costs about \$2 per ft^2, and labor costs associated with inspection, nuisance vegetation removal, and plant replacement.

4.6.10. Turf Reinforced Mats

Description: Turf Reinforced Mats (TRMs) are composed of high strength synthetic materials, specially designed to reduce stormwater erosion by stabilizing slopes and enhancing vegetative growth. TRMs serve to reduce suspended solids in runoff by preventing soil erosion, as well as reduce nutrients by allowing for vegetative uptake.

Photo Source: Tensar Intl. Corp., (2014)

<table>
<tr>
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<u>Design Considerations</u>

- Amount of surface area being used for installation.
- Selection of TRM material per site hydraulic characteristics.
- Underlying soil conditions with selection of appropriate seed to field conditions.

<u>Maintenance Considerations</u>

- Inspection of structural integrity and anchoring of the TRM.
- Fertilization of the vegetation.

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<u>Functions</u>

Volume Reduction: Low/Med
Groundwater Recharge: Low/Med
Peak Rate Control: Low
Water Quality: High

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<u>Removal Efficiency</u>

Sediments: 30% - 70%
Total Phosphorus: *Limited Data**
Total Nitrogen: *Limited Data**
COD/BOD: *Limited data**
Heavy Metals: *Limited Data**

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<u>Capital Costs</u>

Medium

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<u>O&M Costs</u>

Medium

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<u>Maintenance</u>

Medium

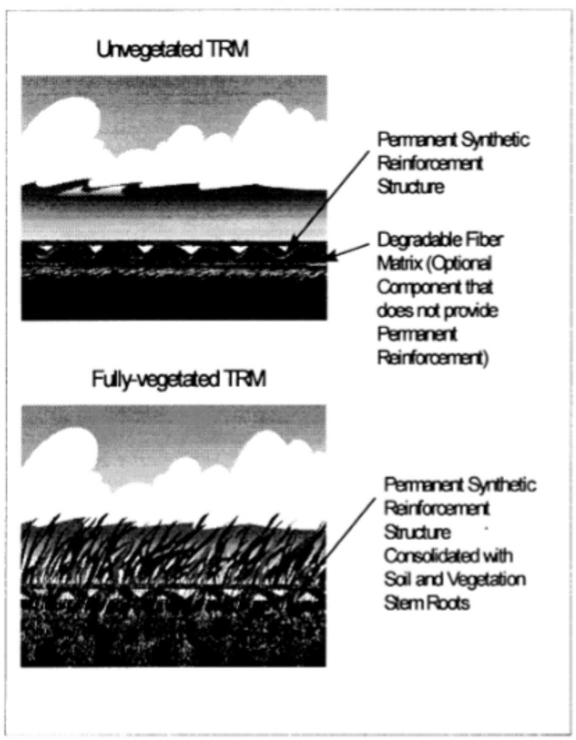
</td>
</tr>
</table>

** Limited data available*

Function: TRMs function to add reinforcement to stormwater open channels, drainage ditches, swales, steep slopes, thereby decreasing erosion rates and reducing suspended solids in the runoff. TRMs may be used in place of traditional "hard armor" techniques such as rip rap and concrete blocks. The advantage in TRMs over hard armor applications is the ability to promote the rooting and growth of vegetation which may enhance pollutant reductions. Incorporation of vegetation is beneficial as it may increase the settling capabilities as well as uptake nutrients from stormwater runoff.

Design: TRMs are composed of interwoven layers of non-degradable geosynthetic materials such as polypropylene, nylon and polyvinyl chloride (PVC) netting, stitched together to form a three-dimensional matrix (EPA, 1999). TRMs are designed to operate in high shear stress environments and should be resistant to ultraviolet (UV) degradation and chemicals commonly found in soil. As opposed to temporary erosion control products, TRMs are designed for long operational lives (5 to 30 years) and act to strengthen the soil even after vegetation has fully grown. The interwoven design reduces scouring forces which would normally occur at the vegetation base, which would ordinarily erode the soil, by doing so the vegetation's threshold to resist hydraulic forces is increased.

Vegetative seed should be selected based on the geographic region of the project and site specifics. Sources of information for seed selection include: the U.S. Natural Resource Conservation Service (NRCS); various universities and extension services; and state transportation departments (EPA, 1999). Seeding may occur before or after the mat has been paced depending on the manufactures guidelines. Comparison of an un-vegetative and fully-vegetative TRM is presented in Figure 10.



Source: Modified from North American Green, Inc., 1998.

Figure 10: Structure of a typical Turf Reinforcement Mat (Source: EPA, 1999)

Maintenance Considerations: TRMs require a relatively low amount of maintenance. Of importance is ensuring that sheet flow conditions persist throughout the TRM. The TRM should be regularly mowed after vegetation has fully developed and only when the ground is dry to prevent compaction and tracking damage. Depending on the sediments incorporated in the stormwater runoff, TRMs may need to be checked for buildup of sediments. Inspections should check to see if any part of the TRM has become unanchored and loose. In addition the integrity of the vegetation will be a factor in the effective performance of the TRM. Detailed maintenance tasks found in Section 5 which may relate to TRMs include:

- Activity No. 461: Cleaning Drainage Structures
- Activity No. 471: Large Machine Mowing
- Activity No. 482: Slope Mowing
- Activity No. 484: Intermediate Machine Mowing
- Activity No. 485: Small Machine Mowing
- Activity No. 494: Chemical Weed and Grass Control
- Activity No. 541: Litter Removal

Capital and Maintenance Costs: Generally, the installed cost of TRMs ranges from $6 to $18 per square meter ($5 to $15 per square yard) (EPA, 1999). Costs will vary based on several factors including; the type of TRM material used, site conditions such as steepness, grading logistics, soil type, etc,; and local construction costs. TRMs can be significantly cheaper options than hard armor applications such as riprap and concrete blocks (EPA, 1999).

4.7. Nonstructural BMPs

4.7.1. Harvesting

Harvesting of existing vegetation may serve as a non-structural BMP. Vegetation growing in areas such as vegetative swales and wet retention basins remove some degree of nutrients from runoff by incorporation of nitrogen and phosphorus species in the plant tissue. Upon death of the plant the plant matter will settle as detritus or flush downstream with runoff. As the plant matter decomposes, nutrients (including phosphorus and nitrogen) will be released back into the water column which in turn may be assimilated into algae fueling algae blooms. By periodically harvesting the vegetation, some of the nutrient loading may be directly removed from the watershed. In addition invasive plant species may be removed.

However care must be taken in the harvesting of vegetation. Littoral and riparian zone vegetation filter sediments and nutrients from runoff as well as provide a source of bank stabilization which may help reduce erosion (Randall et al. 1996). These plants also serve as habitats for fish, invertebrates and terrestrial mammals and provide food for waterfowl, crayfish, and many other aquatic and terrestrial species (Jones, 2004). Excessive harvesting may disrupt ecological balances and alter the dynamics of the basin?.

4.7.2. Fertilizer Management

Fertilizer means any substance that contains one or more recognized plant nutrients and promotes plant growth, or controls soil acidity or alkalinity, or provides other soil enrichment, or provides other corrective measures to the soil (FDEP, 2008). Several different forms of fertilizer exist and can contain different release rates of nitrogen species. Rapidly available nutrient fertilizer such as ammonium nitrate or urea, ammonium phosphate, potassium chloride will not retain nutrient sources as long as slow- or controlled-release fertilizers which, through a variety of mechanisms, will retain nutrients longer and last for a longer duration (FDEP, 2008). All fertilizers are a nutrient loading source for stormwater systems and if properly managed can help reduce nutrient loading to water bodies.

A Florida fertilizer label, by law, requires that information on the fertilizer be included on the bag. Information found on the label include the following: the brand and grade, manufacturer’s name and address, guaranteed analysis, sources from where the nutrients are derived, breakdown of total nitrogen as either nitrate-N, ammonia-N, water soluble or urea-N and water insoluble-N. The nitrogen breakdown enables the user to determine the availability of the nitrogen species of the fertilizer.

Plant species may have different growth rates during the year, as such, it is important to match the fertilizer application rate with the growth phase of the vegetation being fertilized (FDEP, 2008). Application during slow growth phases such as the fall will not require as much fertilizer application as those in the spring.

Proper application methods should be followed for water soluble, quick release fertilizers such as the commonly used urea. Urea within fertilizers will transform to ammonium and eventually nitrate. Urea is subject to volatilization, and if incorporated directly to grass as either a liquid or as granules may be significantly lost to the atmosphere. It is imperative that water (approximately 1/4 inch application) be applied following application of the fertilizer unless rainfall is anticipated within 8 to 12 hours (FDEP, 2008). Care should be taken in water application rates, if more than an inch of water is applied the urea may travel below the root zone and leach into groundwater sources, rendering it unusable for the plants being fertilized (FDEP, 2008). Some new types of fertilizers contain urease inhibitors which delay the transformation of urea to ammonium, which in turn decreases the volatilization rate and slows the release of nitrogen from the fertilizer, which may extend the nitrogen availability to turfgrass for 10 to 14 days (FDEP, 2008). Care however should be taken that heavy rainfall events during this period do not leach the fertilizer past the root zone.

Application of fertilizer should be done according to the guidelines in FDOT's *Turf Management Handbook*, the manufacturer's recommendations, or to site specific soil testing. Additional information regarding fertilizer application may be found in *A Guide for Roadside Vegetation Management* (2012). Table 19 lists recommended fertilizer application rates for various turfgrass species in Florida regions.

Table 19: Recommended Fertilizer Rates for Various Turfgrass Species (Ferrell, J. 2012)

Species/Location	Interim N Recommendations (lbs / 1000ft^2 / yr)	Interim N Recommendations (lbs / acre / yr)
North Florida		
Bahiagrass	1	43
Bermudagrass	2	87
Centipedegrass	1	43
St. Augustinegrass	2	87
Central Florida		
Bahiagrass	1	43
Bermudagrass	3	130
Centipedegrass	1	43
St. Augustinegrass	2	87
South Florida		
Bahiagrass	2	87
Bermudagrass	4	175
Centipedegrass	2	87
St. Augustinegrass	3	130

Application times will depend on the species of turfgrass and the time of the year. It is important to apply proper amounts of fertilizer in order to develop and maintain a proper turfgrass. If properly fertilized, turfgrass will use water more efficiently and develop a thick root system (Ferrell, J. 2012). A generalized application schedule is outlined in Table 20 below.

Table 20: Generalized Fertilizer Application Schedule (Ferrell, J. 2012)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
North Florida												
Bahiagrass				X								
Bermudagrass				X					X			
Centipedegrass				X								
St. Augustinegrass				X					X			
Central Florida												
Bahiagrass			X						X			
Bermudagrass			X		X				X			
Centipedegrass			X									
St. Augustinegrass			X						X			
South Florida												
Bahiagrass		X								X		
Bermudagrass		X		X			X			X		
Centipedegrass		X								X		
St. Augustinegrass			X			X				X		

Further information regarding fertilizer application may be found in The Florida Department of Environmental Protection's manual on lawn service best management practices, entitled *Florida Friendly Best Management Practices for Protection of Water Resources by the Green Industries*.

5. Best Maintenance Practices

5.1. Importance of Maintenance for Functionality

BMPs provide an effective means of reducing pollutant loading in stormwater systems only if maintained appropriately. For example, a wet retention basin may attenuate and treat a set water quantity volume, however if buildup of vegetation or sedimentation decreases the volume of the pond, the treatment volume will essentially be reduced, leading to a decrease in treatment effectiveness. It is also important to note that the improper maintenance of one BMP could lead to the failure of a separate BMP downstream, for BMPs installed in series. For example, if a vegetated filter strip or a check dam were to no longer properly function, leading to an increased rate of bank erosion, a downstream retention basin or filter may become rapidly clogged leading to a decrease in volume treatment. As such, it is important to keep in mind what vulnerabilities each BMP has and how to avoid potential problems in the future.

5.2. Maintenance Practices and Costs

The FDOT Maintenance Rating Program (MRP) Handbook (2013) details procedures for assessing the status of routine highway maintenance conditions. The following subsections are excerpts from the FDOT MRP Handbook (FDOT, 2013) and the FDOT SSWMP (FDOT, 2012) that cover MRP standards and

MMS related to stormwater management. Periodic maintenance is required to keep BMPs functioning at their design performance for stormwater attenuation, storage, and treatment, as well as accommodate safety, economic, environmental, and aesthetic standards.

5.2.1. Drainage MRP Standards

Drainage MRP standards are summarized in Table 21:

Table 21: FDOT MMS/MRP Standards for Drainage (FDOT, 2012; FDOT, 2013)

<table>
<tr><th>Activity Number</th><th colspan="2">Activity Label</th><th>Operational Standard</th></tr>
<tr><td rowspan="3">451</td><td rowspan="3">Clean Drainage Structures</td><td>Inlet</td><td>85% of opening is not obstructed.</td></tr>
<tr><td>Side/Cross Drain</td><td>60% of the cross-section of each pipe is free of obstructions and functions as intended.</td></tr>
<tr><td>Misc. Drain Structures</td><td>90% of each structure functions as intended.</td></tr>
<tr><td>452</td><td colspan="2">Roadway Sweeping: Manual</td><td rowspan="2">Material accumulation is not greater than 3/4 inch deep for more than 1 continuous foot in the traveled way or shall not exceed 2-1/4 inches in depth for more than 1 continuous foot in any gutter.</td></tr>
<tr><td>453</td><td colspan="2">Roadway Sweeping: Mechanical</td></tr>
<tr><td>461</td><td colspan="2">Roadside/Median Ditch: Clean and Repair</td><td>The ditch bottom elevation shall not vary from the ditch design elevation more than 1/4 of the difference between the edge of pavement elevation and the ditch design elevation.</td></tr>
<tr><td>464</td><td colspan="2">Outfall Ditch: Clean and Repair</td><td>The ditch bottom elevation shall not vary from the ditch design elevation more than 1/3 of the difference between natural ground and the ditch design flow line.</td></tr>
</table>

5.2.1.1. Drainage MMS/MRP Standards [Activity No. 451]

Description: Manual or mechanical cleaning of storm drains, french drains, manholes, side drains, ditches, cross drains, inlets, piped outlets, box culverts, and other miscellaneous drain structures. Not to include bridge drains.

Purpose: To maintain proper drainage system for protection of roadway.

Scheduling Frequency: As needed per inspection.

Recommended Work Sequence:

1. Place work zone traffic control devices in accordance with the MUTCD and Series 600 of the FDOT Roadway and Traffic Design Standards.
2. Remove debris such as lumber, tree branches, or material that might create an obstruction to proper drainage. Load into truck and haul away to appropriate disposal site.

3. Check the outfall end of the drainage system to be sure it is not plugged by sediment and vegetation and that there is no serious scour damage (See Activity No. 464 for cleaning outfall ditches).
4. Control soil run-off and other soil erosion in accordance with publications listed below.
5. Cleanup work site.
6. Complete crew report before moving to new site.
7. Pick up work signs and other safety equipment.

MRP Criteria by Structure Classification:

1. **Inlet**

   Description: This characteristic includes all inlets and enclosed junction boxes (manholes). Inlets may be found in curbs, ditches with or without ditch paving, in valley gutters and at other locations that are designed to collect water runoff.

   MRP Criteria: 85% of the opening area is not obstructed.

   Evaluation: Measure the opening to determine the area. When any inlet structure is unslotted then the grate is the collection area to be measured. Grates and manhole covers must be the correct size and in place to meet maintenance conditions. Grates and manhole covers that are broken will not meet conditions. In place is defined as properly seated in design cradle and cannot be unseated by normal pedestrian or vehicular traffic.

   Inlets with exposed steel, or surface damage 1/2 square foot or more, or any deformation of the inlet that creates a hazard, will also cause this characteristic not to meet desired conditions.

   The concrete ditch pavement, if present, around ditch bottom inlets should be in good condition. Concrete ditch pavement around inlets that has three (3) or more cracks greater than 1/2 inch in width and 1 foot in length or more than 33% of the concrete ditch pavement is crushed or broken does not meet desired conditions.

   Gutter grates or gutter cover plates on slotted curb inlets are installed as cleaning or maintenance access and are not to be considered as part of the opening area.

   Refer to the Design Standards to determine if the area around the inlet was designed as part of the inlet. If it was, then include it with the inlet evaluation, not as miscellaneous drainage.

   Inlets do not meet MRP standards when any of the following exist:

   1. More than 15% of the opening area is obstructed.
   2. The grate is broken.
   3. Grates and manhole covers are not the correct size and are not in place.
   4. Exposed steel or any deformation of the inlet that creates a hazard.
   5. Surface damage 1/2 square foot or more.

6. Concrete ditch pavement with three or more cracks greater than 1/2 inch in width and 1 foot in length.
7. If more than 33% of the concrete ditch pavement is crushed or broken around inlets.

2. **Side/Cross Drain**

Description: *Side Drain* – Side drains normally occur under turnouts.

Cross Drain – Cross drains will normally run under a roadway(s) at a perpendicular angle and begin or end in an open roadside ditch. Drains crossing under a roadway that connect to an inlet at both ends shall not be rated. If a box culvert of any length or width falls within a sample, evaluate as normal and rate the culvert as a cross drain.

MRP Criteria: 60% of the cross section of each pipe is free of obstructions and functions as intended.

Evaluation: Determine the diameter of each pipe. A table is provided listing most diameters of pipe used on the FDOT's roadways and includes a measurement to assist in determining whether a pipe is obstructed more than the desired maintenance condition. The measurement will be taken at the deepest point of obstruction within the limits of the pipe including mitered ends. The percent of open area desired for SIDE/CROSS DRAIN is listed at the top of the table. Determine the pipe diameter, select the diameter in the table and move to the right along that line until under the desired percent open area and read that figure. EXAMPLE: Given an 18 inch diameter SIDE DRAIN pipe, move to the right under 60% open area and read 11 inches. Measure the open area of the pipe being surveyed. If the measurement is less than the table value 11 inches, then less than 60% of this pipe area is open and does not meet the desired maintenance condition.

Grates on pipe end sections must be the correct size and in place to meet maintenance conditions. Grates that are broken will not meet maintenance conditions. In place is defined as properly seated in design cradle and cannot be unseated by normal pedestrian or vehicular traffic. For MRP evaluation purposes, a cross drain must have at least one end open within the sample point.

The reinforced concrete slab around mitered end pipes should be in good condition. Three or more cracks in the concrete slab greater than 1/2 inch in width and 1 foot in length and/or more than 33% of the concrete structure/slab is crushed or broken does not meet maintenance conditions.

NOTE: Elliptical pipe must be unobstructed more than 40% for both rise and span.

Side/Cross Drain does not meet MRP standards when the following exist:

1. More than 40% of the cross section of the pipe is obstructed.
2. The grates are not the correct type.
3. The grates are not the correct size.
4. The grates are broken.
5. The grates are not in place.
6. The concrete structure around a MES has three or more cracks greater than 1/2 inch in width and 1 foot in length.
7. If more than 33% of the concrete structure/slab is crushed or broken around a Mitered End Section.

3. **Miscellaneous Drainage Structure**

Description: This characteristic includes ditch paving, shoulder gutter, flumes, spillways, trench drains, French drains, edge drains, piped slope drains and other miscellaneous drainage structures that are used to enhance or control the flow of runoff or storm drain water, but does not include curb and gutter, retention/detention ponds or siltation devices. Any grates encountered on miscellaneous drainage structures or manhole covers will be rated under the inlet characteristic. A piped slope drain that is connected to a side/cross drain is evaluated as side/cross drain. U-type end walls are not to be evaluated as miscellaneous drainage unless they have baffles or some installed method of slowing the water velocity.

MRP Criteria: 90% of each structure functions as intended.

Evaluation: Determine the diameter of each pipe. A table is provided listing most diameters of pipe used on the FDOT's roadways and includes a measurement to assist in determining whether a pipe is obstructed more than the desired maintenance condition. The measurement will be taken at the deepest point of obstruction within the limits of the pipe including mitered ends. The percent of open area desired for SIDE/CROSS DRAIN is listed at the top of the table. Determine the pipe diameter, select the diameter in the table and move to the right along that line until under the desired percent open area and read that figure. EXAMPLE: Given an 18 inch diameter SIDE DRAIN pipe, move to the right under 60% open area and read 11 inches. Measure the open area of the pipe being surveyed. If the measurement is less than the table value 11 inches, then less than 60% of this pipe area is open and does not meet the desired maintenance condition.

Grates on pipe end sections must be the correct size and in place to meet maintenance conditions. Grates that are broken will not meet maintenance conditions. In place is defined as properly seated in design cradle and cannot be unseated by normal pedestrian or vehicular traffic. For MRP evaluation purposes, a cross drain must have at least one end open within the sample point.

The reinforced concrete slab around mitered end pipes should be in good condition. Three or more cracks in the concrete slab greater than 1/2 inch in width and 1 foot in length and/or more than 33% of the concrete structure/slab is crushed or broken does not meet maintenance conditions.

NOTE: Elliptical pipe must be unobstructed more than 40% for both rise and span.

Side/Cross Drain does not meet MRP standards when the following exist:

1. More than 40% of the cross section of the pipe is obstructed.
2. The grates are not the correct type.
3. The grates are not the correct size.
4. The grates are broken.
5. The grates are not in place.
6. The concrete structure around a MES has three or more cracks greater than 1/2 inch in width and 1 foot in length.
7. If more than 33% of the concrete structure/slab is crushed or broken around a Mitered End Section.

Method of Reporting:

1. Use a tape or measuring wheel and report the length cleaned to the nearest hundredth.
2. Each inlet cleaned equals 6 linear feet. If only inlet top cleaned, report 3 feet.

Unit of Measure: linear feet

5.2.1.2. Roadway Sweeping Manual [Activity No. 452]

Description: Hand sweeping of the roadway to protect the facility from excessive accumulation of debris.

Purpose: To remove debris from the roadway when mechanical means are not feasible before a drainage or safety problem is created or before it becomes unsightly.

Scheduling Frequency: As needed per inspection.

Recommended Work Sequence:

1. Place work zone traffic control devices in accordance with the MUTCD and Series 600 of the FDOT Roadway and Traffic Design Standards.
2. Sweep area with road brooms to convenient pickup points.
3. Load and haul accumulated material to nearest approved disposal site.
4. Complete crew report before moving to new site.
5. Pickup work signs and other safety equipment.

MRP Criteria: Material accumulation is not greater than 3/4 inch deep for more than 1 continuous foot in the traveled way or shall not exceed 2-1/4 inches in depth for more than 1 continuous foot in any gutter.

Evaluation: Review urban limited access roadways, and paved shoulders on urban limited access roadways, all curb and gutter, all valley gutter, all barrier wall and all intersections of State Roads to determine the debris buildup. Measure the depth and length of any buildup. If the debris buildup is more than allowed by the standard, it does not meet desired maintenance conditions.

Roadway Sweeping does not meet MRP standards when any of the following exist:

1. The accumulation of material is greater than 3/4 inch deep for more than 1 continuous foot in the travel way.
2. The material accumulation exceeds 2-1/4 inches in depth for more than 1 continuous foot in any gutter.
3. Material accumulation exceeds 3/4 inch deep at marked pedestrian crossings and curb ramps.

Method of Reporting:

1. Report the total length of curb or edges cleaned.
2. Report to the nearest hundredth.
3. Refer to conversion chart no. 5 – m (4)

Reporting Units: mile

5.2.1.3. Roadway Sweeping Mechanical [Activity No. 453]

Description: Mechanical sweeping of the roadway to protect the facility from excessive accumulation of debris.

Purpose: To remove debris from the roadway when mechanical means are not feasible before a drainage or safety problem is created or before it becomes unsightly.

Scheduling Frequency: As needed per inspection.

Recommended Work Sequence:

1. Place work zone traffic control devices in accordance with the MUTCD and Series 600 of the FDOT Roadway and Traffic Design Standards.
2. Operate machine so as to pick up debris from roadway.
3. Haul accumulated material to nearest approved disposal site.
4. Complete crew report before moving to new site.
5. Pickup work signs and other safety equipment.

MRP Criteria: Material accumulation is not greater than 3/4 inch deep for more than 1 continuous foot in the traveled way or shall not exceed 2-1/4 inches in depth for more than 1 continuous foot in any gutter.

Evaluation: Review urban limited access roadways, and paved shoulders on urban limited access roadways, all curb and gutter, all valley gutter, all barrier wall and all intersections of State Roads to determine the debris buildup. Measure the depth and length of any buildup. If the debris buildup is more than allowed by the standard, it does not meet desired maintenance conditions.

Roadway Sweeping does not meet MRP standards when any of the following exist:

1. The accumulation of material is greater than 3/4 inch deep for more than 1 continuous foot in the travel way.
2. The material accumulation exceeds 2-1/4 inches in depth for more than 1 continuous foot in any gutter.
3. Material accumulation exceeds 3/4 inch deep at marked pedestrian crossings and curb ramps.

Method of Reporting:

1. Report the total length of curb or edge miles cleaned.
2. Report to the nearest hundredth.
3. Refer to conversion chart no. 5 – m (4)

Reporting Units: mile

5.2.1.4. Roadside/Median Ditches: Clean and Reshape [Activity No. 461]

Description: Cleaning and reshaping of ditches other than outfalls.

Purpose: To maintain proper roadway drainage by restoring ditches to line, grade, and slope.

Scheduling Frequency: As needed per inspection.

Recommended Work Sequence:

1. Place work zone traffic control devices in accordance with the MUTCD and Series 600 of the FDOT Roadway and Traffic Design Standards.
2. Grade ditch to proper line and grade, loading excess material into truck.
3. Haul excess material to designated area.
4. Control runoff and other soil erosion in accordance with publications listed below.
5. Cleanup work site.
6. Complete crew report before moving to new site.
7. Pickup work signs and other safety equipment.

MRP Criteria: The ditch bottom elevation shall not vary from the ditch design elevation more than 1/4 of the difference between the edge of pavement elevation and the ditch design elevation.

Evaluation: Determine if the ditch has a front slope and at least a 6 inch back slope. If it does, then you would rate the sample for roadside/median ditch. Observation of the ditches throughout the section should provide insight as to the original design of the ditches. If all ditches are the same elevation and provide proper drainage, then they are probably functioning as intended. A check of construction plans will provide an answer when a field determination is not possible. The elevation of the outside edge of roadway (not paved shoulder) will be used to determine the depth of the ditch. A surveyor's handheld level and folding rule or string line level can be used to make measurements along the sample. The construction plans or structures in and adjacent to the ditch can be used to determine the design flow line.

Roadside/Median Ditch does not meet MRP standards when any of the following exist:

1. The ditch bottom elevation varies more than 1/4 of the difference between the edge of pavement elevation and the ditch design elevation.
2. There are erosions, washouts, or buildups that adversely affect the flow of water.

Method of Reporting:

1. Using a tape or measuring wheel to measure and report length of ditch cleaned or repaired to the nearest hundredth.
2. Report length in linear feet.

Reporting Units: linear feet

Specifications, Standards, Special Provisions, Procedures, and Training Resources (* All referenced publications shall be current edition with supplements ***):**

1. Manual on MUTCD.
2. FDOT Roadway and Traffic Design Standard Index No. 600.
3. FDOT Standard Design Specifications for Roadway and Bridge Construction.
4. M120-10, M577-70 & M575 Standard Maintenance Special Provisions.
5. BT 07-0022 – Work Zone Traffic Control for Maintenance and Utility Operations (Level 3).
6. Maintenance Rating Program Manual (Procedure No. 850-065-002).

5.2.1.5. Outfall Ditches: Clean and Repair [Activity No. 464]

Description: Cleaning of outfall ditches and restoration of slopes and bottom areas. Report to activity 487 when efforts are limited to brush and weed cutting only. Piped outfalls will be reported to activity 451. Repair of paved outfall ditch will report to activity 457.

Purpose: To provide adequate drainage and remove unsightly vegetation that cannot be controlled by more cost effective means.

Scheduling Frequency: As needed per inspection.

Recommended Work Sequence:

1. Place work zone traffic control devices in accordance with the MUTCD and Series 600 of the FDOT Roadway and Traffic Design Standards.
2. Clean and level access area for excavating equipment as required.
3. Proceed with cleaning operations by removing vegetation, debris, and silted material to desired grade. Restore slopes and bottoms to proper shape.
4. Control runoff and other soil erosion in accordance with publications listed below.
5. Dispose of excess as appropriate.
6. Cleanup work site.
7. Complete crew report before moving to new site.
8. Pick up work signs and other safety equipment.

MRP Criteria: The ditch bottom elevation shall not vary from the ditch design elevation more than 1/3 of the difference between natural ground and the ditch design flow line.

Evaluation: Piped outfall ditches will be evaluated using the SIDE/CROSS DRAIN characteristic. The “60% of the cross sectional area shall be unobstructed” criteria will apply. Paved outfall ditches will be evaluated using the criteria from “miscellaneous drainage structure” (rate as outfall only).

Outfall Ditch does not meet MRP standards when any of the following exist:

1. The ditch bottom elevation varies more than 1/3 of the difference between natural ground and the design flow line.

Method of Reporting:

1. Using a tape or measuring wheel to measure and report length of ditch cleaned or repaired.
2. Report to nearest hundredth.

Reporting Units: linear feet

Specifications, Standards, Special Provisions, Procedures, and Training Resources (* All referenced publications shall be current edition with supplements ***):**

1. Manual on MUTCD.
2. FDOT Roadway and Traffic Design Standard Index No. 600 and 200 series.
3. FDOT Standard Design Specifications for Roadway and Bridge Construction.
4. M577-70 Standard Maintenance Special Provisions.
5. BT 07-0022 – Work Zone Traffic Control for Maintenance and Utility Operations (Level 3).
6. Maintenance Rating Program Manual (Procedure No. 850-065-002).

5.2.2. Vegetation and Aesthetics MRP Standards

Drainage MRP standards are summarized in Table 22:

Table 22: FDOT MRP Standards Vegetation and Aesthetics (FDOT, 2012; FDOT, 2013)

Activity Number	Activity Label	Operational Standard
471	Large Machine Mowing	No more than 2% of vegetation exceeds 24 inches on rural interstate, 18 inches on urban interstate, and rural primary or 12 inches on urban primary roadways. Bahia seed stalks and decorative wild flowers excepted.
482	Slope Mowing	No more than 2% of vegetation exceeds 24 inches high. This excludes allowable seed stalks and decorative flowers allowed to remain for aesthetics. The area shall be evaluated in accordance with the mowing guide as a minimum.
484	Intermediate Machine Mowing	No more than 2% of vegetation exceeds 24 inches on rural interstate, 18 inches on urban interstate, and rural primary or 12 inches on urban primary roadways. Bahia seed stalks and decorative wild flowers excepted.
485	Small Machine Mowing	No more than 2% of vegetation exceeds 24 inches on rural interstate, 18 inches on urban interstate, and rural primary or 12 inches on urban primary roadways. Bahia seed stalks and decorative wild flowers excepted.
494	Chemical Weed and Grass Control	Chemically control the encroachment of grass and/or weeds more than 6 inches onto the sidewalk or curb for more than 10 feet. Turf in the mowing area is 75% free of the following undesired vegetation alone or in combination: 1. Cogon Grass, 2. Vasey Grass, 3. Johnson Grass, 4. Brooms Edge, 5. Dog Fennel, 6. Ragweed, 7. Castor Bean, 8. Maidencane, 9. Rhodes Grass, 10. Goose Grass, 11. Unstable bare ground, 12. Spanish Needle. [see expanded section for additional requirements]
541	Litter Removal	The volume of litter does not exceed 3 cubic feet per acre excluding all travel way pavement. No unauthorized graffiti/stickers within the state right-of-way on state owned property. No litter hazards are present.

Activity Number	Activity Label	Operational Standard
545	Edging and Sweeping	*Curb/Sidewalk Edging:* No encroachment of vegetation or debris onto the curb or sidewalk for more than 6 inches for more than 10 continuous feet. No deviation of soil of more than 4 inches above or 2 inches below the top of curb or sidewalk for more than 10 continuous feet. *Traffic Services Stardard for Edge Stripping:* 70% of each line must function as intended. Grass growing over edge of lines will cause stripping to fail MRP standards.

5.2.2.1. Large Machine Mowing [Activity No. 471]

Description: Mowing of the roadside with large mowers where conditions accommodate the most efficient use of 7 foot or larger mowers, alone or in combination.

Purpose: To maintain the safety, appearance, and drainage of the highway facility.

Scheduling Frequency: As needed per inspection.

Recommended Work Sequence:

1. Place work zone traffic control devices in accordance with the MUTCD and Series 600 of the FDOT Roadway and Traffic Design Standards.
2. Service equipment before mowing operation.
3. Pick up liter prior to mowing.
4. Perform mowing operations in accordance with established procedures and appropriate publications listed below.
5. Complete crew report before moving to new site.
6. Pick up work signs and other safety equipment.

MRP Criteria: No more than 2% of vegetation exceeds 24 inches on rural interstate, 18 inches on urban interstate, and rural primary or 12 inches on urban primary roadways. Bahia seed stalks and decorative wild flowers excepted.

Method of Reporting:

1. Report acres mowed to nearest hundredth.
2. Do not report overlapping or dead heading.
3. Use the following equation to convert square feet to acres:

$$\frac{\text{Length (ft.)} * \text{ Width (ft.)}}{\text{43,5760 sq. ft.}} = \text{acres}$$

4. If litter removal operations exceed 0.5 crew hours, report time to Activity 541.

Reporting Units: acres

Specifications, Standards, Special Provisions, Procedures, and Training Resources (* All referenced publications shall be current edition with supplements ***):**

1. Manual on MUTCD.
2. FDOT Roadway and Traffic Design Standard Index No. 600 Series.
3. FDOT "Guide to Roadside Mowing" Handbook
4. M 104-4 Standard Maintenance Special Provisions
5. BT 07-0022 – Work Zone Traffic Control for Maintenance and Utility Operations (Level 3).
6. Roadside Mowing Guide Self-Study BT 07-0010.
7. Turf Management, Self-Study, No. BT 07-0013.
8. Guide to Turf Management (Procedure No. 850-060-004).
9. Maintenance Rating Program Manual (Procedure No. 850-065-002).

5.2.2.2. Slope Mowing [Activity No. 482]

Description: Grass, brush, and weed cutting along slopes too steep to safely mow or are inaccessible for conventional mowing tractors. All mowing and brush cutting with mechanical slope mowers are to be reported to this activity. Boom Mower cutting heads shall not be operated higher than 1 foot above ground level.

Purpose: To maintain the safety, appearance, and drainage in areas that cannot be controlled by more economical means.

Scheduling Frequency: As needed per inspection.

Recommended Work Sequence:

1. Place work zone traffic control devices in accordance with the MUTCD and Series 600 of the FDOT Roadway and Traffic Design Standards.
2. Service equipment for slope mowing operations and brush cutting.
3. Pick up liter prior to mowing.
4. Perform mowing operations in accordance with established procedures and appropriate publications listed below.
5. Load and haul cut vegetation to an approved disposal site.
6. Complete crew report before moving to new site.
7. Pick up work signs and other safety equipment.

MRP Criteria: No more than 2% of vegetation exceeds 24 inches for slope mowing areas defined in the FDOT mowing guide. Bahia seed stalks and decorative wild flowers excepted.

Method of Reporting:

1. Report acres mowed to nearest hundredth.
2. Use the following equation to convert square feet to acres:

$$\frac{\text{Length (ft.)} * \text{ Width (ft.)}}{43{,}5760 \text{ sq. ft.}} = \text{acres}$$

Reporting Units: acres

Specifications, Standards, Special Provisions, Procedures, and Training Resources (* All referenced publications shall be current edition with supplements ***):**

1. Manual on MUTCD.
2. FDOT Roadway and Traffic Design Standard Index No. 600 Series.
3. FDOT "Guide to Roadside Mowing" Handbook
4. M 104-4 Standard Maintenance Special Provisions
5. BT 07-0022 – Work Zone Traffic Control for Maintenance and Utility Operations (Level 3).
6. Roadside Mowing Guide Self-Study BT 07-0010.
7. Turf Management, Self-Study, No. BT 07-0013.
8. Guide to Turf Management (Procedure No. 850-060-004).
9. Maintenance Rating Program Manual (Procedure No. 850-065-002).

5.2.2.3. Intermediate Machine Mowing [Activity No. 484]

Description: The intermediate mowing of areas (using mowers greater than 40 inches and less than 7 feet) too difficult to mow with larger mowers and not practical for small mowers.

Purpose: To maintain the safety, appearance, and drainage of the highway facility.

Scheduling Frequency: As needed per inspection.

Recommended Work Sequence:

1. Place work zone traffic control devices in accordance with the MUTCD and Series 600 of the FDOT Roadway and Traffic Design Standards.
2. Service equipment before mowing operation.
3. Pick up liter prior to mowing.
4. Perform cutting operations in accordance with established procedures and appropriate publications listed below.
5. Complete crew report before moving to new site.

6. Pick up work signs and other safety equipment.

MRP Criteria: No more than 2% of vegetation exceeds 24 inches on rural interstate, 18 inches on urban interstate, and rural primary or 12 inches on urban primary roadways. Bahia seed stalks and decorative wild flowers excepted.

Method of Reporting:

1. Report acres mowed to nearest hundredth.
2. Do not report overlapping or dead heading.
3. Use the following equation to convert square feet to acres:

$$\frac{\text{Length (ft.)} * \text{ Width (ft.)}}{\text{43,5760 sq. ft.}} = \text{acres}$$

4. If litter removal operations exceed 0.5 crew hours, report time to Activity 541.

Reporting Units: acres

Specifications, Standards, Special Provisions, Procedures, and Training Resources (* All referenced publications shall be current edition with supplements ***):**

1. Manual on MUTCD.
2. FDOT Roadway and Traffic Design Standard Index No. 600 Series.
3. FDOT "Guide to Roadside Mowing" Handbook.
4. M 104-4 Standard Maintenance Special Provisions.
5. BT 07-0022 – Work Zone Traffic Control for Maintenance and Utility Operations (Level 3).
6. Roadside Mowing Guide Self-Study BT 07-0010.
7. Turf Management, Self-Study, No. BT 07-0013.
8. Guide to Turf Management (Procedure No. 850-060-004).
9. Training for Small/Intermediate Mowing Equipment (BT 07-0026).
10. Maintenance Rating Program Manual (Procedure No. 850-065-002).

5.2.2.4. Small Machine Mowing [Activity No. 485]

Description: Mowing the roadside with small hand or riding mowers having a cutting width of 40 inches or less.

Purpose: To maintain the safety, appearance, and drainage of the highway facility.

Scheduling Frequency: As needed per inspection.

Recommended Work Sequence:

1. Place work zone traffic control devices in accordance with the MUTCD and Series 600 of the FDOT Roadway and Traffic Design Standards.
2. Service equipment for small machine mowing.
3. Pick up liter prior to mowing.
4. Perform cutting operations in accordance with established procedures and appropriate publications listed below.
5. Complete crew report before moving to new site.
6. Pick up work signs and other safety equipment.

MRP Criteria: No more than 2% of vegetation exceeds 24 inches on rural interstate, 18 inches on urban interstate, and rural primary or 12 inches on urban primary roadways. Bahia seed stalks and decorative wild flowers excepted.

Method of Reporting:

1. Report acres mowed to nearest hundredth.
2. Do not report overlapping or dead heading.
3. Use the following equation to convert square feet to acres:

$$\frac{\text{Length (ft.)} * \text{ Width (ft.)}}{43{,}5760\text{ sq. ft.}} = \text{acres}$$

4. If litter removal operations exceed 0.5 crew hours, report time to Activity 541.

Reporting Units: acres

Specifications, Standards, Special Provisions, Procedures, and Training Resources (* All referenced publications shall be current edition with supplements ***):**

1. Manual on MUTCD.
2. FDOT Roadway and Traffic Design Standard Index No. 600 Series.
3. FDOT "Guide to Roadside Mowing" Handbook.
4. M 104-4 Standard Maintenance Special Provisions.
5. BT 07-0022 – Work Zone Traffic Control for Maintenance and Utility Operations (Level 3).
6. Roadside Mowing Guide Self-Study BT 07-0010.
7. Turf Management, Self-Study, No. BT 07-0013.
8. Guide to Turf Management (Procedure No. 850-065-002).
9. Training for Small/Intermediate Mowing Equipment (BT 07-0026).
10. Maintenance Rating Program Manual (Procedure No. 850-065-002).

5.2.2.5. Chemical Weed and Grass Control [Activity No. 494]

Description: The application of herbicides to slopes, ditches, fences, guardrail, barrier walls, bridges, curb and gutter, obstructions, shoulders, and other areas within the highway rights of way. Do not include herbicide efforts within mitigation or landscape areas.

Purpose: To control undesirable vegetation when mechanical or manual methods are not practical.

Scheduling Frequency: As needed per inspection.

Recommended Work Sequence:

1. Place work zone traffic control devices in accordance with the MUTCD and Series 600 of the FDOT Roadway and Traffic Design Standards.
2. Spray prepared mix according to publications listed below.
3. Complete crew report before moving to new site.
4. Pick up work signs and other safety equipment.

MRP Criteria: Chemically control the encroachment of grass and/or weeds more than 6 inches onto the sidewalk or curb for more than 10 feet.

Turf in the mowing area is 75% free of the following undesired vegetation alone or in combination: 1. Cogon Grass, 2. Vasey Grass, 3. Johnson Grass, 4. Brooms Edge, 5. Dog Fennel, 6. Ragweed, 7. Castor Bean, 8. Maidencane, 9. Rhodes Grass, 10. Goose Grass, 11. Unstable bare ground, 12. Spanish Needle.

No more than a cumulative 50 sq. ft. of bare ground should be present in the turf evaluation area or this characteristic does not meet desired maintenance conditions. Bare ground is defined as any single area 5 sq. ft. or more with no evidence of vegetation. Purposely stabilized areas (limestone, shell, etc.) shall not be considered as bare ground and not included in the turf evaluation.

Method of Reporting: Report gallons of mix applied.

Reporting Units: gallons

Specifications, Standards, Special Provisions, Procedures, and Training Resources (* All referenced publications shall be current edition with supplements ***):**

1. Manual on MUTCD.
2. FDOT Roadway and Traffic Design Standard Index No. 600 Series.
3. Florida Statues; Chapter 5E-2, 5E-9 FAC; Florida Statues 16C-20 Rules of F.D.E.P.; Florida Pesticide Law & Rules, Chapter 487; Aquatic Plant Control Permits, Chapter 369.2.
4. M 580-3 Standard Maintenance Special Provisions (Chemical Weeds and Grass).
5. BT 07-0022 – Work Zone Traffic Control for Maintenance and Utility Operations (Level 3).
6. BT 07-0004, Herbicide Program Update Workshop
7. “A Guide to Chemical Weed and Grass Control”
8. Maintenance Rating Program Manual (Procedure No. 850-065-002).

5.2.2.6. Litter Removal [Activity No. 541]

Description: Clearing roadways of debris, tires, appliances, furniture, trash, Adopt-A-Highway litter bags, etc. Does not include wayside parks, rest areas, and service plaza barrels.

Purpose: To maintain the roadways and roadsides in a clean and safe condition by removing unsightly and hazardous objects.

Scheduling Frequency: As needed per inspection.

Recommended Work Sequence:

1. Place work zone traffic control devices in accordance with the MUTCD and Series 600 of the FDOT Roadway and Traffic Design Standards.
2. Pick up litter and place into litter bags.
3. Place litter into truck.
4. Dispose of collected litter at authorized locations.
5. Complete crew report before moving to new site.
6. Pick up work signs and other safety equipment.

MRP Criteria: Area will be free of litter that creates a hazard to motorist or pedestrian traffic and does not exceed 6 cu. ft. per 1 acre within the roadway and roadside area.

The volume of litter does not exceed 3 cubic feet per acre excluding all travel way pavement. No unauthorized graffiti/stickers within the state right-of-way on state owned property. No litter hazards are present.

Evaluation: The evaluation area for litter includes the mowing areas, parking areas, paved shoulders, crossovers, all medians, sidewalks, bike paths, driveways, traffic separators, gutters, travel way, and drainage structures. The evaluation area for unauthorized graffiti and/or stickers is all surfaces on state owned property within the right-of-way.

Calculation: Determine the number of acres in the mowing area within the sample point. Calculate the number of cubic feet of litter within the right-of-way of the sample point. If the volume of litter exceeds 3 cubic feet per acre, then the sample point does not meet MRP standards for Litter Removal.

(The travel way pavement includes through lanes, turn lanes and bi-directional lanes).

Do not include the volume of litter in the portion of the right-of-way that is continually under water.

For MRP purposes; a hazard is defined as the following: In the travel way or on the paved shoulders any object greater than 1/2 square foot in area and exceeds 1/2 inch in height. On the un-paved shoulder any rigid object greater than 1/2 square foot in area, and 2 inches in height. Any rigid object in the clear zone and greater than 1 sq. ft. in area, 3 inches thick, or any rigid protrusions above the ground greater than 4 inches in height on facility types 1, 2, and 3 roads, or in excess of 2 inches in height on facility type 4 roads.

No metal objects greater than 6 inches in length, located in the travel way, on the paved shoulder, or anywhere within the limits of the clear recovery zone .

Note: If the hazard is in the roadway it should be called into the local maintaining maintenance unit, if it can be removed safely from the roadway by the rating team, the object should be placed in a safer location, and rate the characteristic "N" for not meeting.

Items (leaves, bagged trash, tree-trimming residue) that appear to be those which will be picked up during the normal waste collection process will not be considered as litter.

Litter Removal does not meet MRP standards when any of the following exist:

1. There is more than 3 cubic feet of litter per acre within the right-of-way of the sample point.
2. Any hazard in the roadway or paved shoulder greater than 1/2 sq. ft. in area, and exceeds 1/2 inch in height.
3. Any hazard on the un-paved shoulder greater than 1/2 sq. ft. in area, and exceeds 2 inches in height.
4. Any hazard in the clear zone and greater than 1 sq. ft. in area, 3 inches thick, or metal objects greater than 6 inches in length.
5. Any rigid protrusions above the ground greater than 4 inches in height on limited access and rural arterial roads.
6. Any rigid protrusions above the ground greater than 2 inches in height on urban arterial roads.
7. Any metal objects greater than 6 inches in length, located in the travel way, on the paved shoulder, or anywhere within the limits of the clear recovery zone.
8. Any form of unauthorized graffiti and/or stickers on any state owned surface within the right-of-way.

Method of Reporting:

1. Measure the area that litter was removed and report length to the nearest hundredth.
2. Use the following formula:

$$\frac{\text{Length (ft.)} * \text{ Width (ft.)}}{43{,}5760\text{ sq. ft.}} = \text{acres}$$

Reporting Units: acres

5.2.2.7. Edging and Sweeping [Activity No. 545]

Description: Removal of vegetation and debris from the curb, gutter, sidewalk, and paved edges.

Purpose: Provide pleasing appearance to roadway and to remove vegetation and debris before it becomes unsightly or creates a safety or drainage problem..

Scheduling Frequency: As needed per inspection.

Recommended Work Sequence:

1. Place work zone traffic control devices in accordance with the MUTCD and Series 600 of the FDOT Roadway and Traffic Design Standards.
2. Edge roadways, paved shoulders, curb, gutter, and sidewalk using a tractor mounted or power edger.
3. Remove material by manual and/or mechanical shoveling.
4. Load material and haul to approved site.
5. Pick up litter and place into litter bags and cleanup work site.
6. Complete crew report before moving to new site.
7. Pick up work signs and other safety equipment.

MRP Criteria: *Curb/Sidewalk Edging:* No encroachment of vegetation or debris onto the curb or sidewalk for more than 6 inches for more than 10 continuous feet. No deviation of soil of more than 4 inches above or 2 inches below the top of curb or sidewalk for more than 10 continuous feet.

Traffic Services Standard for Edge Stripping: 70% of each line must function as intended. Grass growing over edge of lines will cause stripping to fail MRP standards.

Method of Reporting:

1. Report the total length of edging for roadway, paved shoulders, curb, gutter, and/or sidewalk actually completed.
2. Report to nearest hundredth
3. Refer to conversion chart no. 5 –m, (4)

Reporting Units: miles

5.3. Maintenance and Inspection Equipment

Proper maintenance and inspection of equipment may extend the life of the equipment by many years. In addition, ensuring the equipment is in proper working order may reduce accidents due to mechanical failures. Always exercise care when operating or maintaining all FDOT equipment.

The following adapted from the *FDOT Turf Management Guidelines* (2012) provides operator checklists for servicing equipment commonly used in mowing operations. An operator checklist is presented below:

Automotive and Trucking Equipment through One Ton

Daily:

- Fuel, oil, and water (check fluid levels, leaks).
- Tires (check condition).
- Damage (check after an accident; check for missing components, rust).
- Instruments and controls (check gauges, warning lights, knobs, wipers, washers, and switches).
- Lights and horn (check operation, condition).

- Steering (check for free play).
- Brakes (check pedal free travel, stopping action).
- Clutch (check pedal free travel).
- Interior (check cleanliness).

Weekly:
- Tires (check air pressure, visual check).
- Belts (check tension, condition).
- Battery (check fluid level, corrosion).
- Exterior of vehicle (wash/polish as required)

Mowing Tractors
Daily:
- Fuel, oil, water, and hydraulic fluids (check fluid levels, leaks).
- Belts (check tension, condition).
- Tires, wheels, and lugs (check condition, tightness).Damage (check after accident, for missing components).
- Hitch (check for bent or broken frame, arms; damaged hoses and lines).
- All pivot points and pins (lubricate as necessary).
- Instruments and controls (check gauges, knobs, levers, pedals and switches). Lights and warning devices (check operation, condition).
- Brakes (check pedal free travel, stopping action).
- Clutch (check pedal free travel).Steering (check for looseness).

Weekly:
- Tires (check air pressure).
- Filters, sediment bowls (drain water, sediment).
- Air cleaner (clean dirt and trash).
- Battery (check fluid level, corrosion).
- Cleanliness of equipment (wash or steam clean as required).
- Lubrication (per lubrication chart).

Mowers
Daily:
- Gear boxes (check oil level; clean vents and breathers).
- Drive belts (check tension, condition).
- Drive shafts, slip joints and U-joints (check condition).
- Hydraulic cylinders (check leaks, ram condition, mounts, hoses, and lines).
- Cutting edges (check condition of blades, bed knife, cutter blade knife, and flail knife).
- Pulleys and idlers (check condition, mountings).
- Slip clutches (check condition, operation).
- Shielding (check condition, mounting).
- Wings (check hinge condition).
- Height crank (check condition, operation).
- Wheels and tires (check condition, bearing adjustment).
- Reels, rotors and cutter bars (check condition, operation).

- All fittings, slip joints and hinges (lubricate).

Trailers
Daily:
- Landing gear (check pads or wheels, operation).
- Lunette and hitches (check for cracks, loose mountings).
- King pin (check for cracks in mounting).
- Wheels, tires and lugs (check condition, tightness).
- Lights and reflectors (check operation, condition).
- Brakes (check stopping action; drainair tanks).

Weekly:
- Tires (check air pressure).

5.4. Safety during Maintenance and Inspection

Safety guidelines should be followed at all times during maintenance and inspection of BMPs. In general it is very important that the operator be familiar with any equipment prior to using it by reading and understanding the manufacturer's operating manual. Knowing the equipment's capabilities, gauges, operating characteristics and control are all vital in ensuring the equipment is properly used. Equipment should be used in good operating condition, have all warning labels visible and employees should be fully clothed for the task. By following sound safety procedures, not only will it protect the operator, but also those around. A full guideline of safety procedures may be found in the FDOT's *Turf Management Guide (2012)*.

Works Cited

Australian Government Department of the Environment. Internet site *(accessed March 29th, 2014)*. http://www.environment.gov.au/topics/water/water-cities-and-towns/green-precincts-fund/blue-mountains-city-council/gallery-blue

Bateman, M., E. Livingston, and J. Cox, (1998). *Overview of Urban Retrofit Opportunities in Florida*. Proceedings of the National Conference on Retrofit Opportunites for Water Resources Protection in Urban Environments.

Beemats, LLC. Retrieved on Marh 29th, 2014, from *http://beemats.com/cgi-bin/p/awtp-pa.cgi?d=beemats&type=2036*

Brown, W., & Schueler, T. (1997). *The Economics of Stormwater BMPs in the Mid-Atlantic Region*. Prepared for: Chesapeke Research Consortium. Edgewater, MD. Center for Watershed Protection. Elliot City, MD.

Brown, W., & Schueler, T. (1997). *Stormwater Management Fact Sheet: Infiltration Trench*.

City of Sandy. Retrieved on Marh 29th, 2014, from http://www.ci.sandy.or.us/index.asp?Type=B_BASIC&SEC={A9D3CDDE-3BA0-42DE-BE30-4E321A155AA8}&DE={40CA8091-277E-4F97-81D4-671A67CD701F}

Claytor, R., & Schueler, T. (1996). *Design of Stormwater Filtering Systems.* Ellicott City, MD.: Center for Watershed Protection.

Clary, J., Jones, J., Urbonas, B., Quigley, M., Strecker, E., and Wagner, T., (2008). "Can Stormwater BMPs Remove Bacteria?" *Stormwater Magazine*.

Dubey, G., (1999). Selling sealcoating. *Pavement.* March/April, 42.

England, G. (2012). *Maintenace of Stormwater Retrofit Projects.* Retrieved on Marh 29th, 2014, from http://www.stormwater-resources.com/library.htm#BMP's.

Ferrell, J., Unruh, B., and Kruse, J. (2012). *A Guide to Roadside Vegetation Management*.

Florida Department of Environmental Protection (FDEP), (1991). *Stormwater Management: A Guide for Floridians*.

Florida Department of Environmental Protection. Retrieved on Marh 29th, 2014, from http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=67

Florida Department of Transportation (FDOT), (2012). *Florida Department of Transportation Statewide Management Plan*.

Florida Department of Transportation (FDOT), (2013). *Florida Department of Transportation Maintenance Rating Program Handbook*.

Gensemer, R. and Playle, R., (1999). The bioavailability and toxicity of aluminum in aquatic environments. *Critical Reviews of Environmental Science and Technology*, 29, 315-450.

Grier, A. (2008). *Management of Vegetation in Public Lakes and Reservoirs*. Indiana Division of Fish and Wildlife.

Harper, H. and Herr, J., (1996). Alum treatment of stormwater runoff – an innovative bmp for urban runoff problems. Environmental Research and Design, Inc., Orlando Florida.

Harris, G., Batley, G., Fox, D., Hall, D., Jernakoff, P., Molloy, R., *et al.*, (1996). Port Phillip Bay Environmental Study-Final Report. CSIRO Australia, Canberra, Australia.

Lewis, G., (1998). Using chemicals in pond management. The University of Georgia College of Agricultural and Environmental Sciences. Athens, Georgia.

Livingston, E. (1991). *Stormwater Management A Guide for Floridians.* Florida Department of Environmental Regulation.

Livingston, E., Shaver, E., and Skupien, J., (1997). *Operation, Maintenance, and Management of Stormwater Management Systems*. Watershed Management Institute, Inc.

Long, ER, and LG Morgan., (1990). The Potential for Biological Effects of Sediment-Sorbed Contaminants Tested in the National Status and Trends Program. National Oceanic and Atmospheric Administration (NOAA) Publication. Technical Memorandum NOS OMA 52.

Mackenthun, K. and Cooley, H., (1952). The biological effect of copper sulfate treatment on lake ecology. *Wisconsin Academy of Sciences, Arts and Letters*, Vol. 41, 177-187.

Mahler, B., Van Metre, P., Bashara, T., Wilson, J., and Johns, D., (2005). Parking lot sealcoat: an unrecognized source of Urban Polycyclic Aromatic Hydrocarbons. *Environmental Science & Technology*, Vol. 39, No. 15, 5560-5566.

Maryland Department of the Environment. (1986). *Feasibility and Design of Wet Ponds to Achieve Water Control Quality.* Sediment and Stormwater Administration.

Midwest Research Institute, F. C. (MRI), (2003). *Stormwater Best Management Practices (BMP) Implementation and Selection.*

Morris, J., and Clayton, R., (2006). *Best Management Practices for Aquatic Vegetation Management in Lakes*. Department of Natural Resource Ecology and Management, Iowa State University, Ames, Iowa.

National Research Council (NRC), (2008). *Urban Stormwater Management in the United States*. The National Academies Press. Washington, DC.

National Toxicology Program, Public Health Service, U.S. Department of Health and Human Services, (2002). *Report on Carcinogens*, 10th ed.; Washington, DC.

New Jersey Department of Environmental Projection, (2010). *New Jersey Stormwater Best Management Practices Manual.* Trenton.

North Carolina State University (NCSU), (2006). "Maintenance of Stormwater Wetlands and Wet Ponds." *Urban Waterways*, North Carolina Cooperative Extension Service.

Novotny, V., and Chester, G., (1981). *Handbook of nonpoint pollution: Sources and management*. Van Nostrand Reinhold Company, New York.

Pazwash, H. (2011). *Urban Storm Water Management.* Baco Raton, Florida: CRC Press.

Pennsylvania Department of Environmental Protection, (2006). *Stormwater BMP Manual*, Bureau of Watershed Management, Vol 34, Tab 20.

Prince George's Count Department of Environmental Protection. (1993). *Design Manual for Use of Bioretention in Stormwater Management.* Landover, MD.

Schueler, T., (1987). *Controlling Urban Runoff: A Pratical Manual for Planning and Designing Uban BMPs,* Metropolitan Washington Council of Governments, Washington DC

Schueler, T., (1994). The Importance of Imperviousness. *Watershed Protection Techniques, 3*, 100-111.

Schueler, T., (1997). "Comparative Pollutant Removal Capability of Urban BMPs: A Reanalysis." *Watershed Protection Techniques 2*.

Seitzinger, S.P., Sanders, R.W., Styles, R., (2002). Bioavailability of DON from natural and anthropogenic sources to estuarine plankton. *Limnol. Oceanogr*. 47 (2), 353–366.

Smelter, E., Kirn, R., and Fiske, S., (1999). Long-term water quality and biological effects of alum treatment of Lake Morey, Vermont. *Lake and Reservoir Management*, 15:3, 173-184.

State of Delaware Department of Transportation. Retrieved on Marh 29th, 2014, from http://www.deldot.gov/stormwater/bmp.shtml

SWRPC, (1991), *The Use of Best Management Practicces (BMPs) in Urban Watersheds*, US Environmental Protection Agency

Tensar International Corp. Retrieved on Marh 29th, 2014, from http://www.estormwater.com/tensar-international-corporation

USEPA (U.S. Environmental Protection Agency). 1992. *Stormwater Management for Construction Activities: Developing Pollution Prevention Plans and Best Management Practices*. EPA 832-R-92-005. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

USEPA (U.S. Environmental Protection Agency). 2001. *Storm Water Technology Fact Sheet*. EPA 832-F-01-0054. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

United States Environmental Protection Agency (EPA). Retrieved on Marh 29th, 2014, from http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=75

United States Environmental Protection Agency (EPA), (1986). *Ambient Water Quality Criteria for Bacteria - 1986*, EPA-440-5-84-002. Washington, D.C.

United States Environmental Protection Agency (EPA), (1993). *Guidelines Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters*, EPA-840-B-92-002. Washington, D.C.

United States Environmental Protection Agency (EPA), (1999). *Storm Water Technology Fact Sheet: Turf Reinforcement Mats*, EPA-832-F-99-002.

United States Environmental Protection Agency (EPA), (1999). *Storm Water Technology Fact Sheet: Wet Detention Ponds*, EPA-832-F-99-048.

United States Environmental Protection Agency (EPA), (2001). *Storm Water Technology Fact Sheet: Baffle Boxes*, EPA-832-F-99-002.

United States Environmental Protection Agency (EPA), (2002). National recommended water quality criteria: 2002. EPA-822-RT-02-047.

Van Metre, P., Mahler, B., Furlong, E., (2000). Urban sprawl leaves its PAH signature. *Environmental Science & Technology*, Vol. 34, 464.

Village of Palmetto Bay. Retrieved on Marh 29th, 2014, from http://www.palmettobay-fl.gov/content/village-wide-drainage-improvements-phase-v

Virginia Department of Environmental Quality. Retrieved on Marh 29th, 2014, from http://vwrrc.vt.edu/swc/NonPBMPSpecsMarch11/VASWMBMPSpec2SHEETFLOW.html

Wanielista, M.P., (1977). Quality Considerations in the Design of Holding Ponds. *Stormwater Retention/Detention Basins Seminar*, University of Central Florida, Orlando, Florida.

Wanielista, M. and Chang, N., (2008). *Alternative Sorption Media for the Control of Nutrients*. Stormwater Management Academy, University of Central Florida, Orlando, Florida.

Watson, C. and Yanong, P., (2011). *Use of copper in freshwater aquaculture and farm ponds*. University of Florida, Gainsville, Florida.

Washington State Department of Ecology. (2000). *Stormwater Management Manual For Western Washington, Volume V: Runoff Treatment BMPs Final Draft.* Olympia.

Wiegand, C., T. Schueler, W. Chittenden, and D. Jellick,. (1986). *Cost of Urban Runoff Quality Controls. In Urban Runoff Quality - Impact and Quality Enhancement Technology*, ed. B. Urbonas and L.A. Roesner, p.366-382. American Society of Civil Engineers, New York, NY.

Wright Water Engineers, I., & Geosyntec Consultants, I. (WWEGC), (2010). *BMP Performance Data Summary Table.* International Stormwater BMP Database.

Wurts, B., (2011). Algae, copper sulfate, and alkalinity. Kentucky State University, Princeton, Kentucky.

Appendix A

FDOT Guidelines, Handbooks, Procedures, and Policies Mentioned and Referenced in the Maintenance Practices for Stormwater Runoff Handbook

Drainage Manual
 http://www.dot.state.fl.us/rddesign/Hydraulics/files/2013Jan-DrainageManual.pdf
Drainage Handbook Stormwater Management Facility
 http://www.dot.state.fl.us/rddesign/hydraulics/files/StrmWtrMgmtFacHB.pdf
Maintenance Rating Program Handbook
 http://www.dot.state.fl.us/statemaintenanceoffice/MRPHandbook2013FinalA.pdf
Manual on Uniform Traffic Control Devices
 http://mutcd.fhwa.dot.gov/pdfs/2009/pdf_index.htm
Statewide Stormwater Management Plan (2012)
 http://www.dot.state.fl.us/emo/pubs/stormwater/FDOT%202005%20SSWMP%206-9-05.pdf