Chapter 5

Permanent Stormwater Management Measures

What's in this Chapter?

Section 5.1 describes approaches to be taken in the concept and preliminary site design layout phases that will avoid and minimize the generation of stormwater runoff from new and redevelopment projects.

Section 5.2 provides an overview of the different stormwater control measures and management techniques.

Section 5.3 describes management techniques for establishing land use cover and protocol on how to apply specific techniques.

Section 5.4 provides engineering design specification and management protocol for individual stormwater control measures (SCMs) that can be used in stormwater management systems to achieve Smart Site Design goals for runoff reduction, pollutant removal, andpeak flow control.

Section 5.5 describes and provides design protocol for elements that are common to most SCMs such as pretreatment, inlets and outlets.

5.1 Stormwater Avoidance and Minimization Approaches

5.1.1 Protect Sensitive and Special Value Resources

This source control approach seeks to protect the innate characteristics of the landscape that absorb rainfall and provide other ecological services, such as wildlife habitat, runoff filtration, and nutrient cycling. Conservation of natural features and environmental resources help maintain the predevelopment hydrology of a site by reducing runoff, promoting infiltration, preventing soil erosion, and protecting areas that function as pockets of rainfall retention. Examples of these features include forests, wetlands, native grasslands, floodplains, riparian corridors, zero-order stream channel, springs and seeps, ridge tops, and shoreline buffers. In general, conservation of these areas should maximize contiguous area and avoid fragmentation.

Zero-order streams (or headwaters) provide important watershed functions, including groundwater recharge and discharge, nutrient storage and transformation processes, storage and retention of eroded hill slope sediments, and delivery of leaf and woody debris inputs. Compared to high-order streams, zero-order streams are disproportionately disturbed by mass grading, burying, or channelization.

The conservation approach should be implemented during the conception of the project plan. First, preserve the natural/native topography of a site as much as possible, then delineate drainage and conveyance patterns and protect these areas as much as possible, and finally, ensure that adequate buffers surround these areas including the largest buffer around the sensitive headwaters and wetland habitats. Continuing with the project-planning phase from this perspective will ensure that these sensitive hydrologic areas are preserved and remain linked to other habitat corridors from adjacent areas, minimize the need for grading, and maximize the land's natural retention processes.

Preserving natural areas may also provide secondary benefits of reducing noise pollution, providing valuable wildlife habitat, and creating scenic views and aesthetically-pleasing spaces. These benefits may equate to increased property value as well as quality of life components within the community.

5.1.2 Minimize Land Disturbance

This source control approach seeks to limit the degree of clearing and grading on a project site in order to prevent soil compaction, conserve native soil structure, prevent erosion, and protect zero-order streams. This approach is applied by setting grading limits to minimize the total site area that must be cleared and graded, and/or minimizing the disturbed site area at any one time by completing the project in phases, stabilizing one phase as the next phase is being cleared. This is accomplished by 1) identifying key soils, drainage features, and slopes in the initial site inventory, and then 2) establishing limits of disturbance beyond which construction equipment is excluded. Minimizing grading limits may reduce overall landscape costs as well as help preserve the natural character and aesthetic of a site, which may increase property value.

Specific landscape features on a site may also be more prone to contributing runoff and/or sediment erosion. Avoid disturbing long, steep sloped areas. If these areas are cleared, by essence of gravity and the propensity of water to concentrate and carry energy, then these areas may contribute more runoff and erosion relative to flatter areas. Furthermore, the footprint of impact for grading on a slope is greater than that on a flatter slope because of the efforts required to create a level building pad. General guidelines for slope development are listed in the Table 5.1. Development on slopes > 25% is strongly discouraged.

Table 5.1: Guidelines for slope development related to soil erosion risk exposure (Prince George's County, 2000).

Grade	Maximum Slope Length (ft)	Erosion Risk
0-7%	300	Low
7-15%	150	Moderate
Over 15%	75	High

5.1.3 Reduce and Disconnect Impervious Surfaces

A broad variety of actions can be taken to minimize the creation of new impervious surface and allow for disconnection of needed/existing impervious surface. Collectively, with the other avoidance and minimization approaches and stormwater control measures, these actions are key elements to the smart site design. The following is a list of common impervious surface reduction approaches in residential and commercial settings:

- Reduce residential street width, street right-of-way width, and cul-de-sac radius.
- Use swales and other linear control measures that can be located within the right-of-way.
- Install bioretention or vegetation on the island in the center of the cul-de-sac or other unused space.
- Use narrow sidewalks on one side of the street only, or move pedestrian pathways away from the street entirely.
- Provide greenspace for downspout disconnection of rooftops from storm drain systems.
- Minimize driveway length and width or use shared driveways.

- Allow for cluster or open-space designs (e.g. zero lot line) that reduces lot size or setbacks in exchange for conservation of open spaces.
- Use alternative permeable pavements instead of impervious surfaces.
- Design buildings and parking to have multiple levels.
- Store rooftop runoff in green roofs, foundation planters, bioretention areas, or cisterns.
- Reduce parking lot size by reducing parking demand ratios and stall dimensions.
- Use landscaping areas, tree pits, and planter boxes for stormwater runoff treatment.

Existing local development codes and ordinance may discourage or even prohibit the application of these elements of smart site design. Impervious surface reduction must be applied at the site layout phase of a project in order to be effective. Check with local jurisdictions to ensure that plans to incorporate these elements into a project design will not be contrary to any code or ordinance. If so, the local stormwater program should consider making changes to not only allow for these beneficial actions but, ideally, encourage their wide use.

Impervious surface disconnection is a stormwater control strategy that incorporates an infiltration zone into a site plan that is engineered to accept runoff from an adjacent rooftop, pavement, or other impervious surface (See Sec 5.4). While the detailed design of the infiltration zone is completed using a ratio of green area to impervious surface area, the disconnection approach needs to be implemented in the concept phase such that the site layout includes adequate areas for infiltration between impervious surfaces and stormwater drainage infrastructure or natural drainages.

5.2 Summary of Stormwater Management Techniques and Control Measures

Chapters 1-4 of this manual are a guide to integrating permanent stormwater management systems into development projects, including the conceptual, preliminary, final, and build-out phases. This approach improves upon traditional practices used across Tennessee, shifting from “end of pipe” and “single purpose solutions” to an integrated design, which includes systems of stormwater management techniques and control measures discussed later in this chapter.

The remainder of this chapter provides detailed guidance for the proper design and application of structural SCMs as well as management techniques that preserve and restore the intrinsic value and hydrological performance of the land. These landscape-based SCMs require a new approach to site design where landforms, soils, and vegetation are used together with structural SCMs to effectively achieve the required runoff reduction, pollutant removal and other site-specific goals. Developers and their designers are encouraged to integrate and combine management techniques and SCMs presented in here to achieve stormwater management goals and optimize preservation and restoration of natural features that play critical roles in hydrologic processes.

Each SCM is covered in this chapter, including an overview fact sheet and detailed review of function, design, construction requirements, and maintenance and management. Selecting the best SCM for a given development is heavily dependent on existing site characteristics (slopes, soil type, contributing area use, etc.) as well as the ultimate intended function, benefits and long-term operations of the SCM. Table 5.2 compares benefits of SCMs relative to each other on a categorical scale of low-moderate-high. Use this information along with additional pertinent considerations when selecting SCMs.

Table 5.2: Relative benefits comparison of SCMs on a categorical scale.

Stormwater Control Measures	Runoff Reduction[1]	Pollutant Removal[2]	Peak Rate Control	Land Consumption (per Impervious Area Managed for Runoff Reduction)	Maintenance Frequency[3]	Safety Concerns[4]	Land Cost[5]	Design and Build Cost[5]	Maintenance Cost[5]	Average Annual Costs[5,6]	Provide Water Source	Improves Community Livabillity	Provides Wildlife Habitat
Dry Detention	○	○	●	–	○	◐	●	◐	◐	◐	–	○	○
Wet Ponds	○	◐	●	–	◐	●	◐	◐	○	○	●	●	◐
Vegetated Swale	○	○	○	●	○	○	◐	○	○	○	–	◐	○
Water Quallity Swale	●	●	◐	○	◐	○	◐	◐	○	◐	–	◐	○
Managed Vegetated Areas	●	–	○	●	○	○	○	○	○	○	–	●	●
Filter Strips	○	●	○	–	◐	○	●	◐	◐	◐	–	◐	○
Rain Gardens	●	●	◐	◐	◐	○	◐	◐	◐	◐	–	●	◐
Bioretention	●	●	◐	◐	●	○	◐	◐	◐	◐	–	●	◐
Ultra-Urban Bioretention	●	●	◐	○	●	○	◐	●	●	●	–	●	◐
Infiltration Areas	●	◐	◐	●	◐	○	◐	◐	○	◐	–	●	●
Permeable Pavement	●	○	◐	◐	●	○	○	●	●	●	–	●	○
Subsurface Infiltration	●	○	●	◐	●	○	○	●	●	◐	◐	○	○
Green Roofs	◐	–	○	◐	●	○	○	●	●	◐	–	◐	○
Rainwater Harvesting	●	–	◐	○	●	○	○	◐	◐	◐	●	◐	○
Stormwater Treatment Wetlands	○	●	●	–	◐	◐	◐	○	○	○	●	●	●
Manufactured Treatment Devices	–	●	–	–	●	○	○	○	●	◐	–	○	○

– Not Applicable ○ Low ◐ Moderate ● High

1 Potential to store and retain runoff through infiltration
2 Potential pollutant removal from flowthrough water
3 Low: semi-annual to quarterly, Moderate: semi-seasonal, High: after rain events
4 Safety concerns related to deep ponded water
5 Cost data from King and Hagan, 2011
6 Average annual costs over 20 years

Chapter 5.3

Management Techniques

Installing SCMs prior to site preparation may result in failure of the measures due to sedimentation and/or compaction. Timing their installation (pre-planning) is important to protecting these SCMs and avoiding sometimes extensive post-construction rehabilitation or complete re-installation. Infiltration SCMs depend on quality of soils and their porosity. These SCMs depend on soil mixtures, types, and pH. For example, a standard functional bioretention facility should have sand, loam and compost mixture. No other materials or substance should be mixed in it that may be harmful to plant growth or prove a hindrance to planting or maintenance to operations. The planting soil must be free of plant or seed material of non-native invasive species or noxious weeds. Sediment run-on from disturbed areas can clog practices and change the soils composition and pH. Also, compaction due to construction disturbance can also impact their effectiveness and result in the necessity of spending more resources to restore their functionality.

This chapter will describe management techniques required to achieve the practice/management goal. The amount of required techniques depends on the initial condition and the management goal of each project (see Figure 5.1). As example, it takes more steps to get to good forest condition from compacted soil than from good turf.

Management is a clearly defined state of soil and vegetation that provides the desired degree of infiltration and pollutant removal under the optimal design condition. The design condition is assumed to be 15 years following stabilization, when the site has reached a reasonable level of maturity and is undergoing only gradual changes. Management is the defined desired endpoint and depends on a series of techniques to get from the current possibly highly disturbed condition to that endpoint. A management has clearly defined specifications including soil hydrologic characteristics and vegetation type and density. The term cover is sometimes used to describe a management that has minimal inputs.

A ***Technique*** as pertaining to permanent stormwater management is a method or operation that progresses or sustains progress from one state of management to a higher-functioning state of management. These can fall in two general categories:

1) Methods of getting from "here" to "there," from the presumed worst-case condition immediately following development to the desired management endpoint. The techniques used in a specific site design will vary greatly depending on the starting conditions. For example, if an area of "good forest" is left undisturbed, no technique is necessary to achieve a "good forest" management. On the other hand, if the post-construction condition is a bare highly-disturbed mixture of topsoil and subsoil that is heavily compacted, the required technique to achieve a "good forest" management in 15 years may include all or some of the following: soil ripping, soil amendments, temporary vegetative cover, slope erosion control, planting of trees, fertilization and irrigation.

2) The operations necessary to maintain the required trajectory towards the desired design condition, and to maintain that condition once it is achieved. In other words, the protocol for maintenance of a "good forest" management may include the techniques of tree thinning, fertilization, and invasive species removal. Note that the protocol for a "fair forest" management may include the same techniques, but with less intensive requirements.

Timing of SCM installation and protection of the SCM area are two critical techniques. Installing SCMs prior to adequate site preparation may result in failure due to sedimentation and/or soil compaction. Timing of their installation is important in protecting these SCMs and avoiding sometimes extensive post-construction rehabilitation or complete re-installation. Infiltration SCMs depend on the quality of soils and their characteristics of porosity, organic matter, pH, and texture. SCM performance is highly sensitive to compaction or deviation from good growing conditions. For example, a bioretention facility should have a mixture of sand, loam and compost. No other materials or substance should be mixed into these media because it may be harmful to plant growth or prove a hindrance to maintenance and operation. The planting soil should be free of plant or seed material of non-native invasive species or noxious weeds.

Sediment run-on from disturbed areas can clog practices and change soil composition or pH. Compaction due to construction disturbance can also impact their effectiveness and result in the necessity of spending more resources to restore their functionality.

Management may be thought of as a spectrum, and techniques are used to mitigate impacts expressed in a site's initial condition to achieve a goal of a managed vegetated area or other end management. Initial conditions are described in the left side of Figure 5.1, and a list of techniques used to move from the impacted end of the spectrum to the optimal soil condition are also listed. On the right side is the spectrum of managed vegetated, and below it is a list of techniques used to establish the desired vegetation.

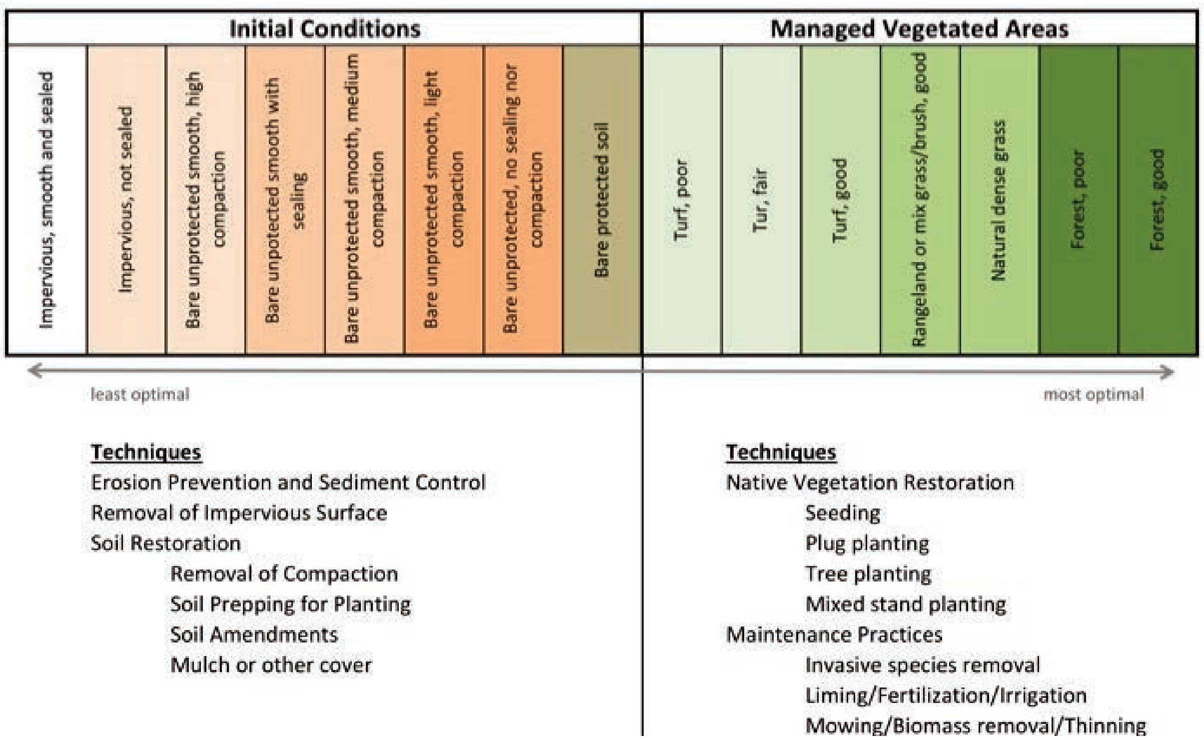

Figure 5.1: Spectrum of initial condition managements and permanent managements along with associated techniques used to improve from a least optimal state to a more optimal state.

Techniques are used to achieve a management goal. The amount and rigor of technique(s) applied depends on the initial condition and the management goal of each project element. For example, it takes the application of more techniques to establish a good forest condition from compacted bare soil than from a porous clay soil with established temporary cover. Soil ripping or removal of compaction is needed in the compacted clay scenario before fertilization techniques could be applied and a forest stand established.

Soil quality and vegetation are key factors in the effectiveness of an SCM at reducing runoff volume and removing pollutants. Soils must possess the structure and texture that allows water to infiltrate and plant roots to penetrate. Design of stormwater management systems is conducted through modeling that assumes disturbed soils are ameliorated back to a condition that resembles an undisturbed natural soil. A designer is responsible for documenting the initial condition and including in their plan the necessary technique(s) for soil amelioration and plant establishment to accomplish the projected target management for each element containing disturbed soils. This amelioration process should be included in the project application as part of the permanent stormwater management plan.

5.3.1 Erosion Prevention and Sediment Controls

To ensure the greatest potential of success of a LID facility, SCMs should not be installed until construction activity is completed and stabilized within the entire contributing drainage area; this means having all areas both fully landscaped and mulched or having well established grass or other ground cover. Construction drawings should clearly state the designer's intentions and an appropriate stage of construction should be shown on the plans. This staging should be covered in detail at the pre-construction meeting (including the on-site responsible construction personnel) and then enforced by an appropriate inspection program throughout the construction period. On-site education of contractor and/or subcontractors would also be advised. Storing and reestablishing top soil on site is important to reestablishing the overall infiltration of the site. Each site is unique, and this strict construction staging approach may not be necessary, such as in the case of bioretention in parking lot islands with little contributing pervious areas. It is critical that the designer understands these realities and plans accordingly. For more details, refer to TDEC E&S Handbook chapter 6 and 7 (TDEC E&S Handbook p:94).

5.3.2 Soil Restoration

Soil restoration is a technique used to enhance and restore soils by physical treatment and/or mixture with additives – such as compost – in areas where soil has been compacted. Soil media restoration increases the water retention capacity of soil, reduces erosion, improves soil structure, immobilizes and degrades pollutants (depending on soil media makeup), supplies nutrients to plants, and provides organic matter. Soil restoration is also used to reestablish the soil's long term capacity for infiltration and to enhance the vitality of the soil as it hosts all manner of microbes and plant root systems in complex, symbiotic relationships. .

Figure 5.2: Soil amended with compost (Source: USDA NRCS).

Restored soils result in increased infiltration and decreased volume of runoff. Designers can receive credit based on areas (acres) complying with the requirements of desired SCMs. For example, a bare soil can be assigned a management reflecting a "good" condition instead of "poor" condition.

A healthy soil (Figure 5.3) provides a number of vital functions including water storage and nutrient storage, regulate the flow of water, and immobilize and degrade pollutants. Healthy soil contains a diverse community of beneficial microorganisms, a sufficient amount of plant nutrients (nitrogen and phosphorous), some trace elements (e.g., calcium and magnesium), and organic matter (generally five to 10%).

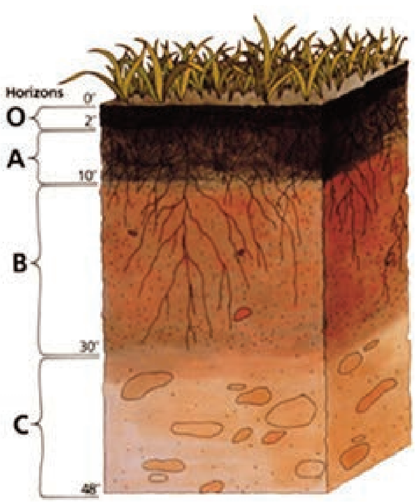

Figure 5.3: A healthy soil profile (Source: USDA NRCS).

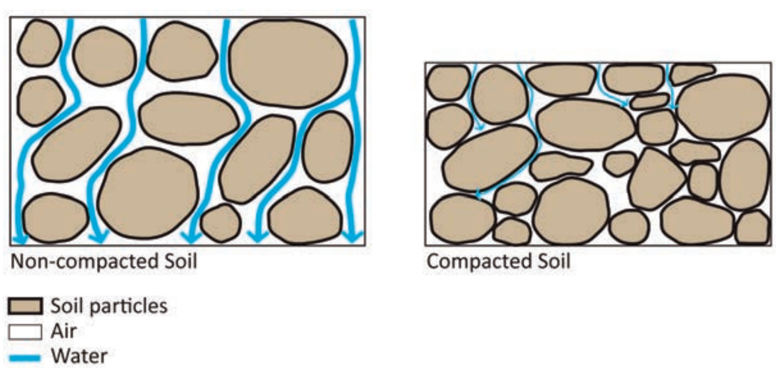

Figure 5.4: Compacted soil constraints movement of air and water (Source: USDA NRCS).

Healthy soil typically has a neutral or slightly acidic pH and good structure which includes various sizes of pores to support water movement, oxygenation, and a variety of other soil processes.

Caring for soil is also a critical component of water management, especially during development activities, such as construction grading, which often result in erosion, sedimentation, and soil compaction. Proper protection and restoration of soil are critical management techniques to combat these issues. Soil restoration prevents and controls erosion by enhancing the soil surface to prevent the initial detachment and transport of soil particles.

Soil compaction is the enemy of water quality protection. Soil compaction occurs when soil particles are pressed together, reducing the pore space necessary to allow for the movement of air and water throughout the soil (Figure 5.4). This decrease in porosity causes an increase in bulk density (weight of solids per unit volume of soil). The greater the bulk density of the soil means the lower the infiltration and the larger the volume of runoff (Table 5.3).

Compaction limits vegetative root growth, restricting the health of plants as well as the biological diversity of the soil. Compaction also affects the infiltrating and water quality capacity of soils. Soil compaction can lead to increased erosion and stormwater runoff, low infiltration rates, increased flooding, and decreased water quality from polluted runoff. After compaction, a typical soil has strength of about 6,000 kilopascals (kPa), while studies have shown that root growth is not possible beyond 3,000 kPa. . There are two types of compaction, minor and major, each of which requires a particular restoration technique(s) or method:

- **Minor compaction** – Surface compaction within 8-12 inches due to contact pressure and axle load <20 tons can compact through root zone up to one foot deep. Soil restoration activities can include: subsoiling, organic matter amendment, and native landscaping. Tilling/scarifying is an option as long as it is deep enough (i.e., 8-12 inches) and the right equipment is used (should not be performed with common tillage tools such as a disk or chisel plow because they are too shallow and can compact the soil just beneath the tillage depth).
- **Major compaction** – Deep compaction, contact pressure and axle load > 20 tons can compact up to two-feet deep (usually large areas are compacted to increase strength for paving and foundation with overlap to “lawn” areas). Soil restoration activities can include: deep tillage, organic matter amendment, and native landscaping.

To evaluate the level of compaction in soils, bulk density field tests are conducted. Table 5.3 shows the ideal bulk densities for various textures of soils.

Table 5.3: Bulk density for soil texture (Source: USDA NRCS).

Soil Texture	Ideal Bulk densities, g/cm^3	Bulk densities that may affect root growth, g/cm^3	Bulk densities that restrict root growth, g/cm^3
Sands, loamy sands	<1.60	1.69	1.8
Sandy loams, loams	<1.40	1.63	1.8
Sandy clay loams, loams, clay loams	<1.40	1.6	1.75
Silt, silt loams	<1.30	1.6	1.75
Silt loams, silty clay loams	<1.10	1.55	1.65
Sandy clays, silty clays, some clay loams (35-45% clay)	<1.10	1.49	1.58
Clays (>45% clay)	<1.10	1.39	1.47

5.3.2.1 Applications

Soil restoration can occur anywhere to alleviate soil compaction. It can be specifically addressed in the following examples:

- **new development (residential, commercial, industrial)** – Heavily compacted soils can be restored prior to lawn establishment and/or landscaping to increase the porosity of the soils and aid in plant establishment.
- **detention basin retrofits** – The inside face of detention basins is usually heavily compacted, and tilling the soil mantle will encourage infiltration to take place and aid in establishing vegetative cover.
- **golf courses** – Using compost as part of landscaping upkeep on the greens has been shown to alleviate soil compaction, erosion, and turf disease problems.

5.3.2.2 Removal of compaction

Table 5.4 describes various soil disturbance activities related to land development, soil types and the requirements for soil restoration for each activity. Soil Restoration or runoff reduction is a required practice. Restoration is applied across areas of a development site where soils have been compacted and will be vegetated according to the criteria defined in Table 3. Compacted soil can be amended by first tilling the soil, breaking apart the compaction, and then applying various soil media.

Table 5.4: Soil Restoration Recommendations [NY, 2010. P:99].

Type of Soil Disturbance	Soil Restoration Requirement	Comments/Examples
No soil disturbance	Restoration not permitted	Preservation of Natural Features
Minimal soil disturbance	Restoration not required	Clearing and grubbing
Minor soil compaction	Six inches of soil media (18.5 cubic yards per 1,000 square feet of soil) should be applied, and then tilled into the existing soil up to eight inches	Protect area from any ongoing construction activities.
Major soil compaction	10 inches of soil media (31 cubic yards per 1,000 square feet of soil) should be applied and then tilled into the existing soil up to 20 inches	
Areas where Runoff Reduction and/or Infiltration practices are applied	Restoration not required, but may be applied to enhance the reduction specified for appropriate practices.	Keep construction equipment from crossing these areas. To protect newly installed practice from any ongoing construction activities construct a single phase operation fence area
Redevelopment projects	Soil Restoration is required on redevelopment projects in areas where existing impervious area will be converted to pervious area.	

- **Tilling consideration:**

Tilling the soil (also referred to as aeration, scarification, ripping, or subsoiling):

a. Effective when performed on dry soils.

b. Should be performed where subsoil has become compacted by equipment operation, dried out, and crusted, or where necessary to obliterate erosion rills.

c. Should be performed using a solid-shank ripper and to a depth of 20 inches, (eight inches for minor compaction).

d. Should be performed before amending media is applied and after any excavation is completed.

e. Should not be performed within the drip line of any existing trees, over underground utility installations within 30 inches of the surface, where trenching/drainage lines are installed, where compaction is by design, and on inaccessible slopes.

f. The final pass should be parallel to slope contours to reduce runoff and erosion.

g. Tilled areas should be loosened to less than 1,400 kPa (200 psi) to a depth of 20 inches below final topsoil grade.

h. The subsoil should be in a loose, friable condition to a depth of 20 inches below final topsoil grade and there should be no erosion rills or washouts in the subsoil surface exceeding three inches in depth.

i. Tilling should form a two-directional grid. Channels should be created by a commercially available, multi-shanked, parallelogram implement (solid-shank ripper), capable of exerting a penetration force necessary for the site.

j. No disc cultivators, chisel plows, or spring-loaded equipment should be used for tilling. The grid channels should be spaced a minimum of 12 inches to a maximum of 36 inches apart, depending on equipment, site conditions, and the soil management plan.

k. The channel depth should be a minimum of 20 inches or as specified in the soil management plan. If soils are saturated, delay operations until the soil, except for clay, will not hold a ball when squeezed.

l. Only one pass should be performed on erodible slopes greater than one vertical to three horizontal.

5.3.2.3 Soil preparation for planting

5.3.2.3.2 Lime, fertilizer, and topsoil application

When conventional seeding is to be used, topsoil should be applied to any area where the disturbance results in subsoil at the final grade surface. Figure 3 provides guidance on the volume of topsoil required to provide specific topsoil depths. Soil pH should be above 5 – preferably between 6.0 and 6.5. Soil should be submitted to a soils specialist or County Agricultural Extension agent for testing and soil amendment recommendations. In the absence of soil test results, the following application rates can be used:

- **Ground agricultural limestone:**
  Light-textured, sandy soils: 1- 1 1/2 tons/acre.
  Heavy-textured, clayey soils: 2-3 tons/acre.
- **Fertilizer:**
  Grasses: 800-1200 lb/acre of 10-10-10 (or the equivalent).
  Grass-legume mixtures: 800-1200 lb/acre of 5-10-10 (or the equivalent) (TDEC E&S Handbook p:119).

- **Topsoil**

Table 5.5: Cubic Yards of Topsoil Required to Attain Various Soil Depths (TDEC E&S Handbook, P:120).

Depth (in)	Per 1,000 Square feet	Per acre
1	3.1	134
2	6.2	268
3	9.3	403
4	12.4	537
5	15.5	672
6	18.6	806

5.3.2.3.3 Herbicide application

Application of herbicides: This is a method of last resort, but necessary in some cases. Herbicide treatments should be applied only to a specific plant and never broadcast, especially near water bodies. Use a colored dye in the herbicide mix to identify areas that have been sprayed. Use the least persistent pesticide available to accomplish the job.

5.3.2.4 Soil amendment

Soil media used for amendment may be comprised of either organic or inorganic material (table 3). Organic media can increase soil organic matter content, which improves soil aeration, water infiltration, water and nutrient holding capacity, and is an important energy source for bacteria, fungi, and earthworms.

Table 5.6: Restoration Media (MI, 2011).

Organic Media	Inorganic Media
Compost*	Vermiculite
Aged manure*	Perlite
Biosolids* *(must be a Grade 1 biosolid)*	Pea gravel
Sawdust *(can tie up nitrogen and cause deficiency in plants)*	Sand
Wood ash *(can be high in pH or salt)*	
Wood chips *(can tie up nitrogen and cause deficiency in plants)*	
Grass clippings	
Straw	
Sphagnum peat *(low pH)*	

** Materials containing animal wastes can cause phosphorus*

- **Soil amendment considerations**

  Applying soil media for amendment:

  a. Soil media should not be used on slopes greater than 30 percent. In these areas, deep-rooted vegetation can be used to increase stability.

  b. Soil restoration should not take place within the critical root zone of a tree to avoid damaging the root system. To determine the critical root zone, measure the tree diameter four and half feet above grade. For every inch of diameter measured, the critical root zone will be one foot radius from the tree. (For example, a tree that measures 20 inches in diameter will have a critical root zone of 20 foot radius).

c. Onsite soils with an organic content of at least five percent can be stockpiled and reused to amend compacted soils, saving costs. Note: These soils must be properly stockpiled to maintain organic content.

d. Soils should generally be amended at about a 2:1 ratio of native soil to media. If a proprietary product is used, follow the manufacturer's instructions for the mixing and application rate.

e. Add six inches compost or other media and till up to eight inches for minor compaction. (Six inches of compost equates to 18.5 cubic yards per 1,000 square feet of soil.)

f. Add 10 inches compost or other amendment and till up to 20 inches for major compaction. 10 inches of compost equates to approx. 30.9 cubic yard per 1,000 square feet.

g. Compost can be amended with bulking agents, such as aged crumb rubber from used tires, or wood chips. This can be a cost-effective alternative that reuses waste materials while increasing permeability of the soil.

h. Compost shall be aged, from plan or dust produced when handling, pass through a half inch screen and have a pH suitable to grow desired plants.

5.3.2.5 Mulch and other cover applications (TDEC E&S Handbook, p:104)

Surface mulch is considered the most effective, practical means of controlling runoff and erosion on disturbed land prior to vegetative establishment. Mulch reduces soil moisture loss by evaporation, prevents crusting and sealing of the soil surface, moderates soil temperatures, provides a suitable microclimate for seed germination, and may increase the infiltration rate of soil.

Straw mulch is the most common type of mulch used in conjunction with seeding or providing a temporary groundcover. The straw should come from wheat or oats ("small grains"), and may be spread by hand or with a mulch blower. Note that straw may be lost to wind and must be tacked down. The recommended application rate for straw mulch is 2 tons per acre, dry unchopped, unweathered.

Mulch, as well as wood chip, bark chips, shredded bark, wood fiber, and other material are temporary stabilization practices. Those materials can only increase initial condition of unprotected bare soil to protected bare soil.

5.3.2.6 Winter considerations

Since soil restoration is performed in conjunction with plantings, this management technique should be undertaken in spring or autumn and during dry weather, so that plantings can establish.

5.3.2.7 Other considerations

- During periods of relatively low to moderate subsoil moisture, the disturbed subsoils are returned to rough grade and the following soil restoration steps applied:

  1. Apply 3 inches of compost over subsoil
  2. Till compost into subsoil to a depth of at least 20 inches using a cat-mounted ripper, tractor mounted disc, or tiller, mixing, and circulating air and compost into subsoils
  3. Rock-pick until uplifted stone/rock materials of four inches and larger size are cleaned off the site
  4. Apply topsoil to a depth of 6 inches
  5. Vegetate as required by approved plan.

Figure 5.5: Attachments used for soil decompaction.

At the end of the project an inspector should be able to push a 3/8" metal bar 12 inches into the soil just with body weight. Figure 5.5 shows two attachments used for soil decompaction (NY, 2010, p:100).

- Soil restoration may need to be repeated over time, due to compaction by use and/or settling. Taking soil core samples will help to determine the degree of soil compaction and if additional media application is necessary. Two points help ensure lasting results of decompaction:
  1. Planting the appropriate ground cover with deep roots to maintain the soil structure
  2. Keeping the site free of vehicular and foot traffic or other weight loads. Consider pedestrian footpaths. (Sometimes it may be necessary to de-thatch the turf every few years) [MI, P:298].

5.3.3 Native Vegetation Restoration

Native species are generally described as those existing in a given geographic area prior to European settlement. Over time, native vegetation does not typically require significant chemical maintenance by fertilizers and pesticides. This results in additional water quality benefits. Native species are typically more tolerant and resistant to pest, drought, and other local conditions than non-native species. In addition to chemical applications, minimum maintenance also means minimal mowing and irrigation in established areas. Native grasses and other herbaceous materials that do not require mowing or intensive maintenance are preferred.

"Restoration" implies returning a landscape to a former, more pristine state. In reality, historic conditions cannot be replicated. For most development and redevelopment projects, a realistic goal is to remove or mitigate destructive impacts and reintroduce significant missing processes and components, where possible. The intent of these actions is to allow natural processes to bring about gradual recovery.

While there are many benefits to improving existing native cover types, the primary purpose of this management technique is to increase the potential for effective stormwater management on a site and to provide the developer with another means of stormwater management. This management technique functions by reestablishing a healthy plant community with thick, spongy soil layers that:

- Generates less runoff.
- Absorbs a greater volume of water through infiltration, evaporation, and evapotranspiration.
- Improves soil conditions through the addition of organic material, which increases soil pore space.
- Reduces the need for maintenance by fertilizers, herbicides, and pesticides.
- Reduces the force of precipitation by leaf interception.

5.3.3.1 Variations

Species selection for any native landscape should be based on function, availability, and level of appropriateness for site conditions. Native species plantings can achieve variation in landscape across a variety of characteristics, such as texture, color, and habitat potential.

Properly selected mixes of flowering prairie species can provide seasonal color; native grasses offer seasonal variation in texture. Seed production is a food source for wildlife and reinforces habitat. In all cases, selection of native species should strive to achieve species variety and balance, avoiding creation of single-species or limited species "monocultures" which pose multiple problems. In sum, many different aspects of native species planting reinforce the value of native landscape restoration, typically increasing in their functional value as species grow and mature over time. Examples include:

- **Prairie** – Install Big Bluestem, Little Bluestem, Indian Grass, Switchgrass and others that resemble the Native Americans grassland [Shea, 1999]. Prairies have a tendency to establish and regain function rather quickly (3-10 years), and can provide lower-growing vegetation with highly attractive native grasses and wildflowers.
- **No-mow lawn area** – Install low-growing native grasses that are used as a substitute for lawn or cool-season grass plantings.
- **Woodland** – Install a balance of native trees, shrubs, forbs, grasses, and sedges. Woodlands will provide shade, vertical structure, and a high level of rainfall interception in the long term. It typically requires a significant amount of time to mature.
- **Constructed wetlands** – Historic drained wetlands or existing artificial low areas may be planted with wetland species that will thrive in standing water or saturated conditions.
- **Buffer areas** – Bands of re-established native vegetation occurring between impermeable surfaces, lawns, or other non-native land uses and existing natural areas.
- **Replacement lawn areas** – Existing turf lawns may be converted to native prairies, wetlands, or woodlands to minimize maintenance while increasing stormwater benefits and wildlife habitat.

Figure 5.6: Tennessee native no-mow lawn and woodland (Source: The SMART Center).

5.3.3.2 Calculation

Native revegetation and reforestation will increase infiltration capacity and reduce runoff volume. Designers can receive managed vegetated area credit based on the square feet of trees or shrubs being added. The credit is reflected through label "Good, fair, or poor", that is described below:

– **Good condition**
  - ≤ 200 ft^2 / tree, or expected full canopy cover
  - ≤ 25 ft^2 / shrub
  - > 90% turf cover, with no continuous bare areas
  - Trees or shrubs with lush undergrowth, with > 90% of surface under either canopy or ground cover

- **Fair condition**
  - 200 - 350 ft^2 / tree, or expected canopy cover > 75%
  - 25 - 40 ft^2 / shrub
  - > 75% turf cover, with no contiguous bare area > 50 ft^2
  - Trees or shrubs with fair undergrowth, with > 75% of surface under either canopy or ground cover
- **Poor condition**
  - 350 - 500 ft^2 / tree, or expected canopy cover > 50%
  - 40 - 60 ft^2 / shrub
  - > 50% turf cover, with no contiguous bare area > 75 ft^2
  - Trees or shrubs with some undergrowth, with > 50% of surface under either canopy or ground cover
- Below these targets, is not considered an adequate measure for which to claim credit, due to both very limited infiltration capacity and potential to serve as a source of TSS
- Minimum seeding/planting will receive "poor" credit, while optimize seeding/planting will receive "fair" credit. "Good" credit can only be achieved when optimized seeding/planting is followed by a maintenance practice (see Figure 5.1).

5.3.3.3 Materials

Whenever practical, native species should be from the same ecoregion as the project area. When necessary, species may be used from adjacent ecoregions for aesthetic or practical purposes. Information relating to Tennessee native species and their use in landscaping is available from on Appendix D.

Developments should use native trees for replacement in areas separate from residential lots, or storm drainage areas adjacent to roadway or parking lots. Species selection shall be based on the underlying soils and the historic, native indigenous plant community type for the site, if existing conditions can support the plant community.

Native plan restoration/reforestation is eligible under the following qualifying conditions:

- Avoid the use of a single species of tree. No more than 20% of the area composes of any single tree species. Reforestation should consider the composition of area forests, and two thirds of selected trees must be large canopy. Reforestation methods should achieve full canopy cover within ten to fifteen years.
- The minimum size requirement for reforestation is saplings 6-8 feet in height. The minimum size requirement for shrubs is 18-24 inches, or 3 gallon size. In addition, the entire reforestation should be covered with 2-4 inches of organic mulch or with a native seed mix in order to help retain moisture and provide a beneficial environment for the reforestation.
- The trees must be free from injury, pests, diseases, and nutritional disorders; and must be fully branched and have a healthy root
- A long-term vegetation management plan must be prepared and included in the site's maintenance agreement in order to demonstrate the ability to maintain the reforestation area in an appropriate forest canopy condition. The plan should include a scale drawing showing the area to be planted, along with a plant list which includes species, size, number, and packaging. In addition, the reforestation area shall be clearly identified on all construction drawings and EPSC plans during construction.
- The reforestation area must be protected in perpetuity such that no future development or disturbance may occur within the area.
- The planting plan must be approved by the local jurisdiction including any special site preparation needs.
- It is recommended that the construction contract contain a care and replacement warranty extending at least two growing seasons, to ensure adequate growth and survival of the plant community.

- The final size of the trees should be considered when designing the planting plan. Tennessee One-Call (811) must be contacted prior to the submission of the planting plan to ensure that no utilities will be impacted by the tree planting. The planting plan must also avoid placing trees under overhead utilities.

5.3.3.4 Restoration process

1. **Assess vegetation onsite and delineate areas to be preserved.** Note landscape cover type, size, condition, and age.
2. **Integrate areas selected for protection into site and stormwater plans** to meet multiple objectives and create environmental and social connections (trail systems, hedgerows, etc.).
3. **Identify glaring problems within the selected enhancement area**, e.g., fill and soil pushed over the slope into the valley, extreme cut, exposed subsoil or bedrock, bare and eroded soil, invasive exotic plants, trash, and toxic materials. Particularly note erosion and sedimentation problems such as gullies and bare soil. Also note influences beyond the site that may undermine enhancement efforts.
4. **Identify and address factors that suppress regeneration of native plants or contribute to overall plant community decline before replanting or amending the soil.** If these factors are not addressed, efforts spent on enhancement will be wasted.
5. **Where relevant, identify major cyclical processes that shape the site**, e.g., floods, fire, etc. These recurring natural events may help to sustain the native plant community and prevent colonization by invasive exotics.
6. **Search for a healthy model in the neighborhood to serve as a design reference:**
   - Plant community structure and pattern—Use the model to determine the arrangement, types, and density of plants.
   - Identify and protect desirable and sensitive species and any rare, threatened, or endangered plant (or animal) species. Particularly identify “keystone” species. If absent, replace these species where possible.
   - An unusual amount of dead or dying plants requires a determination of cause.
7. **General Recommendations**
   - In healthier systems with minimal disturbance, native seeds may be present in the soil. Areas adjacent to other healthy natural areas can benefit from seeds transported by wind, water, and animals. If time is not a factor, and rapid cover is not critical, these areas can be left to regenerate on their own.
   - Plant tough, vigorous, generalist species, which will create immediate cover and discourage invasive species.
   - Stabilize edges. Where a remnant natural area meets a manmade landscape, the design should create a graceful, smooth transition. Construction often leaves these transition areas highly disturbed. Repair of these newly exposed edges is critical.
   - Regrade where necessary, stabilize the soil, and replant with fast-growing, tough, native edge species. Repair of damaged edges will protect the health of the natural landscape and enhance its stormwater benefits.
   - Newly exposed, existing trees are often vulnerable to wind throw. Replant a strip along newly formed edges (where a portion of the natural landscape has been cut away) to buffer the remaining native landscape from increased wind, light, noise, and other impacts.

5.3.3.5 Tree planting guidelines

Figure 5.7: Tree planting guidelines.

For more guidance about planting tree, visit:

http://www.tn.gov/agriculture/publications/forestry/treeline_hbook.pdf

http://www.arborday.org/trees/planting/index.cfm

http://www.tn.gov/twra/pdfs/treeplanting.pdf

http://www.oregon.gov/odf/privateforests/docs/ReforestationGuide.pdf

5.3.4 Maintenance Practices

The requirements for the Maintenance Document are in Appendix F .They include the execution and recording of an Inspection and Maintenance Agreement or a Declaration of Restrictions and Covenants, and the development of a Long Term Maintenance Plan (LTMP) by the design engineer. The LTMP contains a description of the stormwater system components and information on the required inspection and maintenance activities. The property owner must submit annual inspection and maintenance reports to the local stormwater program.

First year maintenance operations includes

- Initial inspections for the first six months (once after each storm greater than half- inch).
- Reseeding to repair bare or eroding areas to assure grass stabilization.
- Water once every three days for first month, and then provide a half in year. Irrigation plan may be adjusted according to the rain event.
- Fertilization may be needed in the fall after the first growing season.

Ongoing maintenance

Two points help ensure lasting results of decompaction:

1. Planting the appropriate ground cover with deep roots to maintain the soil structure
2. Keeping the site free of vehicular and foot traffic or other weight loads. Consider pedestrian footpaths. (Sometimes it may be necessary to de-thatch the turf every few years)

- Soil restoration may need to be repeated over time, due to compaction by use and/or settling. Taking soil core samples will help to determine the degree of soil compaction and if additional media application is necessary.
- Mowing is permitted but not encouraged between the trees while they are being established. Eventually, the canopy should shade out the grass and forest undergrowth will be established removing the need to mow. Vegetation management plans should consider if residents would prefer the site mowed in perpetuity.
- Additional maintenance activities include:
  - Watering the trees as needed.
  - Repairing areas of erosion or reseeding areas that are bare.
  - Removing trash and debris from area.
  - Replanting any trees that die throughout the year (the construction contract should contain a care and replacement warranty extending at least two growing seasons, to ensure adequate growth and survival of the plant community).
  - Addressing areas of standing water which might breed mosquitoes.
  - Picking up branches that have fallen.
  - Grooming trees or shrubs as needed.
  - Removing any trees or limbs damaged in storms that might pose a danger.

Removing invasive species

- **Where necessary, remove masses of aggressive, invasive exotic species to expose the potential of the area.**
  - Invasive exotic species often occur as dense shrub thickets or extensive, heaping vine cover. Vines in trees and climbing over shrubs suppress reproduction on the ground and shade older trees and shrubs, eliminating seed sources. Privet, Japanese honeysuckle, kudzu, mimosa trees, and tree of heaven are the most prevalent invasive exotics.
  - Remove large tangles of aggressive exotic species to allow an accurate evaluation of the site and suggest appropriate repair strategies.

General considerations:

- Effective control treatments vary by species. In some cases, non-chemical options exist.
  - o Emphasize techniques that minimize soil disturbance and that remove the exotic plants by the roots where possible, while leaving adjacent, desirable plants undamaged. When removing existing invasive plants, either pull up by the roots or eliminate re-sprouts later.
- Some invasive exotics are more troublesome than others. For example, highly aggressive species such as kudzu and privet are particularly difficult to eradicate and should be removed as early as possible, before they are well established.
- Phase removal of exotic canopy trees to keep a shady forest cover.

Specific removal methods

- Hand pulling: Suggested for restricted areas of herbaceous weeds or small seedlings of woody plants.
- Tools: A weed wrench allows the user to pull up young tree seedlings (too large to pull by hand) by the roots. This tool disturbs the adjacent areas only minimally.
- Mowing: In general, broadleaved herbaceous plants will diminish with regular mowing. Broadleaved herbaceous plants include both weeds and wildflowers, and a meadow mown more than three times a year will become predominantly grasses.
- Controlled burning: This technique can be used to manage any landscape cover type. However, in meadow management, fire is used to reduce the number of trees and increase the amount of grasses and wildflowers.
  - o Burning can be used in two major ways: 1) If the remnant natural area is small, or only a small portion of it requires treatment, a single person, with a backpack propane torch, can burn small areas (approximately 10 feet by 10 feet). Generally, small-scale burns are done as a patchwork of squares, with unburned vegetation between burned patches. Extreme caution must be used to prevent wildfire; 2) Where a relatively large-scale burn is considered (approximately 1 acre or more), property managers should coordinate with the local fire department and state conservation agencies. Permits are required from the local government.
  - o Caution: Some undesirable species, such as black locust, are "fire increasers." If these species are already present, burning may encourage them. Conversely, successful regeneration of oak forests in the eastern United States has historically required fire.
- Tilling: For large areas of infestation, tilling can uproot and kill undesirable species. However, tilling can also kill native species and encourage invasive plants that spread by underground rhizomes or stolons, such as kudzu *(Pueraria lobata)*.

REFERENCES

Center for Watershed Protection. 2010. New York State Stormwater Management Design Manual. Tech. Albany, NY: Department of Environmental Conservation. P:97-102.

Chattanooga Hamilton County Regional Planning Commission (CHCRPC). 2012. Rainwater Management Guide. Chattanooga, TN.

King, D., P. Hagan, 2011. Costs of Stormwater Management in Maryland Counties. University of Maryland, Solomons, MD.

Metropolitan Government of Nashville and Davidson County. 2012. Low Impact Development: Stormwater Management Manual. Nashville, TN: Metro Water Services. P:213.

North Carolina Division of Water Quality. 2012. "Chapter 4: Selecting the Right BMP." NCDENR Stormwater BMP Manual.

Prince George's County, Maryland, Department of Environmental Resources. 2000. Low Impact Development Design Strategies: An Integrated Design Approach. Prince George's County, Maryland, Department of Environmental Resources, Programs and Planning Division, Largo, MD.

SEMCOG. 2008. A Design Guide for Implementers and Reviewers Low Impact Development Manual for Michigan. Rep. Detroit, MI. P:122-123; 293-288.

Tennessee Department of Environment and Conservation (TDEC). 2012. Tennessee Erosion & Sediment Control Handbook: A Stormwater Planning and Design Manual for Construction Activities. Fourth Edition. August 2012.

USDA Natural Resources Conservation Service (NRCS). A Soil Profile. 5 Dec. 2014.

USDA NRCS. St. Croix Watershed Restoration Project: Hope & Carton Hill Rain Garden. 5 Dec. 2014.