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Acknowledgement

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Chapter 1
INTRODUCTION

1.1 How to Use This Manual

This Volume presents an introduction to Low Impact Development (LID) design and specifically Green Infrastructure Practices (GIPs) which are characterized by their ability to reduce stormwater runoff volume through the use of infiltration, evapotranspiration, and/or rainwater reuse. It describes how LID designs should be selected, and contains a series of focused and concise fact sheets for each type of design. It is an addition to the Metropolitan Government of Nashville and Davidson County's (Metro's) Stormwater Management Manual (SWMM), which contains the following volumes:

Volume 1 – Regulations

Volume 2 – Procedures

Volume 3 – Theory

Volume 4 – Best Management Practices (BMP)

Volume 5 – Low Impact Development (LID) Design

Please see Volume 1 for information about site development, permitting procedures, and post-construction Stormwater Control Measure (SCM) requirements. SWMM Volume 5 contains the following four chapters:

Chapter 1 explains how to use this Manual, how it relates to the other volumes and why Metro is requiring LID.

Chapter 2 discusses principles of site layout, current incentives to promote the use of LID and an Operations and Maintenance overview.

Chapter 3 explains the methodology surrounding runoff reduction and how it shall be applied, including detailed guidance on design sizing and criteria.

Chapter 4 contains detailed specifications for each GIP.

When planning a site, this Manual may be best used in the order shown in **Figure 1**, below.

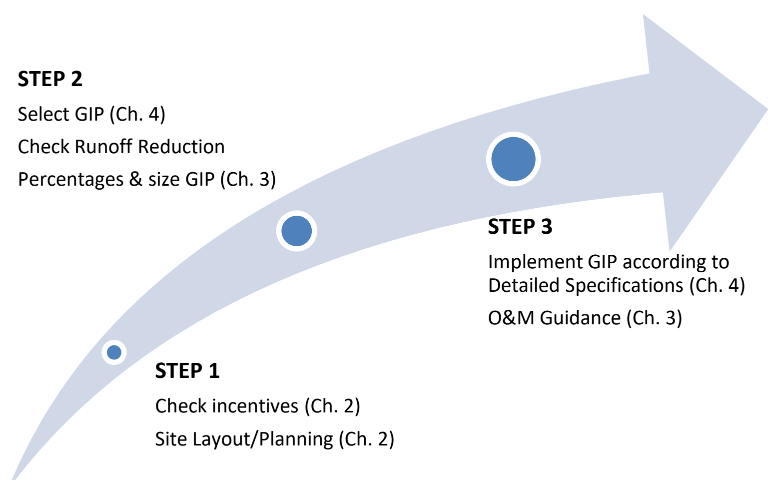


Figure 1 Site Planning Process

1.2 Why Green / Low Impact Development?

Current development patterns and traditional stormwater management techniques have resulted in large amounts of impervious surfaces in cities across the country – including Metro. Conventional development approaches to stormwater management often use practices to quickly and efficiently convey water away from developed areas. This results in larger volumes of runoff flowing directly to streams, rivers and combined sewer systems as well as any pollutants contained in the runoff.

In contrast, LID utilizes a system of source controls and small-scale, decentralized treatment practices to help maintain the hydrologic function of the landscape by allowing water to infiltrate, evapotranspirate or be reused onsite. The conservation of open space, the reduction of impervious surfaces, and the use of small-scale stormwater controls, such as green roofs, are just a few of the LID practices that can help maintain predevelopment conditions and keep greater volumes of runoff from routing to the stormwater system. Green Infrastructure Practices (GIP), as used in this Manual, is a term that refers to a subset of LID structural systems and practices that support the principles of LID and make use of volume-reducing designs and calculations.

LID techniques can offer many benefits:

<u>Municipalities</u>

- Protect flora and fauna
- Balance growth needs with environmental protection
- Installation of GIPs by private sector participation at residential, commercial, and industrial facilities
- Decrease flooding risks for small storms
- Create attractive natural and multifunctional public spaces

<u>Developers</u>

- Reduce land clearing and grading costs
- Potentially reduce infrastructure costs (streets, curbs, gutters, sidewalks)
- Reduce storm water management costs
- Increase lot and community marketability

<u>Environment</u>

- Preserve integrity of ecological and biological systems
- Protect site and regional water quality by reducing sediment, nutrient, and pollutant loads to water bodies
- Reduce impacts to terrestrial and aquatic plants and animals
- Preserve trees and natural vegetation
- Mitigate the heat island effect and reduce energy use

1.3 Brief Regulatory Background

As of 2016, Metro's National Pollutant Discharge Elimination System (NPDES) Phase I Municipal Separate Storm Sewer System (MS4) Permit requires that new development and significant redevelopment sites utilize GIPs for post development stormwater control where possible. The design requirement is to infiltrate, evapotranspire, or capture and reuse the first inch of rain preceded by 72 hours of no measureable rainfall. Metro Water Services (MWS) commissioned this Manual to encourage and incentivize LID design in Metro before its use became a requirement. The LID Manual was originally released in 2012, with minor revisions adopted in 2013. MWS has used the period since the Manual's release to test the methodology while the compliance path was voluntary. Where in its judgment strict application in a particular situation would conflict with sound engineering practice, Metro Water Services reserves the right to make exceptions to these regulations.

1.4 Stormwater Management Goals

GIPs are a set of land use and structural practices designed to reduce the volume of stormwater runoff from development through the use of the Runoff Reduction Method (RRM) employing runoff volume reducing approaches[1]. The overall goal of GIPs is to reduce stormwater runoff volume and to treat pollutant loads close to the source where they are generated. In doing so, GIPs provide many stormwater management benefits; such as improved water quality, flow management, groundwater recharge, and channel protection. GIPs minimize the hydrological impacts of urban development on the surrounding environment by intrinsically linking stormwater management to urban design and landscape architecture. This is accomplished with appropriate site planning and through the direction of stormwater towards small-scale systems dispersed throughout the site. These systems should be carefully selected based on the site's topographic and climatic conditions.

GIPs have numerous benefits and advantages over conventional stormwater management. The following benefits can be achieved by applying GIPs to new development, redevelopment, and capital improvement projects:

- **Provide volume control and pollutant removal**

  Under traditional flood-focused stormwater management, the importance of volume control from smaller storms and from the first flush of larger storms is overlooked. Reducing the amount of stormwater runoff, however, is one of the most effective stormwater pollution controls possible. GIPs help reduce runoff volume and decrease the amount of stormwater directly entering streams and sewer systems. In addition to reducing runoff volumes, individual GIPs can help address specific pollutant removal efficiencies through settling, filtration, adsorption, and biological uptake. By doing so, GIPs can help improve the receiving water's aquatic and terrestrial wildlife habitat and enhance recreational uses.

- **Recharge groundwater and stream base flows**

  Development tends to increase imperviousness, leading to increased direct runoff and reduced rainfall infiltration. Groundwater helps feed lakes and streams, and significant reductions or loss of groundwater recharge can reduce base flow in receiving waters, negatively impacting biological habitat and recreational opportunities. Many GIPs in Volume 5 infiltrate runoff, thus promoting ground water recharge.

- **Restore and protect stream channels**

  Channel erosion, on average, is estimated to account for most of the sediment load in urban watersheds and is a significant contributor to Total Suspended Solids (TSS) issues in middle Tennessee. GIPs can help protect or reduce stream channel degradation from accelerated erosion and sedimentation during and immediately after storm events by capturing stormwater volume and lowering stormwater peaks. By protecting stream channels, stream and riparian ecosystems have the potential to be improved and restored.

- **Address Combined Sewer Overflows**

  GIPs can be used to reduce stormwater inflows to combined sewer systems (CSS) that lead to overflows. Metro has approximately twelve square miles in the CSS area. Details of using green infrastructure in the CSS area are featured in Metro's Green Infrastructure Master Plan (MWS, 2009).

- **Provide ancillary environmental benefits**

  GIPs provide additional benefits, such as improved aesthetics through the use of attractive landscaping features (trees, shrubs, and flowering plants) which can increase property values. Other benefits include increased public awareness of stormwater management and water quality issues since practices are dispersed throughout a site and are typically more visible. GIPs such as green roofs, bioretention, and urban trees can help to mitigate the urban heat island effect and green roofs can also decrease the energy required to heat and cool buildings.

Chapter 2

PLANNING, DESIGN, INCENTIVES, AND OPERATIONS AND MAINTENANCE

2.1. Design Goals / Principles

Correctly pairing land uses with GIPs is an important first step in site planning. GIPs should be matched with land use and setting based on the criteria found in Chapter 4. For example, low density residential development lacks large parking areas conducive to pervious pavement with storage. However, bioretention may be especially good for residential use.

There are several important design goals and principals involved in incorporating GIPs:

- **Achieve multiple objectives**

  Stormwater management should be comprehensive and designed to achieve multiple stormwater objectives such as: managing peak flow and total volume; improving water quality; maintaining or improving the pre-development hydrologic characteristics; and maintaining water temperature. In some cases this requires multiple structural techniques; however, the objective of GIPs is to allow for less complex management systems to achieve multiple objectives.

- **Conserve natural features and resources**

  The conservation of natural features such as floodplains, soils, and vegetation helps to retain predevelopment hydrology functions, thus reducing runoff volumes. Impacts to natural features should be minimized by reducing the extent of construction and development practices that adversely impact predevelopment hydrology functions. This includes:
  - Avoiding mass clearing and grading, and limiting the clearing and grading of land to the minimum needed to construct the development and associated infrastructure
  - Leaving undisturbed stream buffers along both sides of natural streams, which is currently a Metro requirement
  - Preserving sensitive environmental areas, historically undisturbed vegetation, and native trees
  - Conforming to watershed, conservation, and open space plans
  - Designing development to fit the site terrain, and building roadways parallel to contour lines wherever possible
  - Clustering development and building upon the least porous soils or limiting construction activities to previously disturbed areas to preserve porous soils and natural slopes

- **Minimize soil compaction**

  Soil compaction disturbs native soil structure, reduces infiltration rates, and limits root growth and plant survivability. When protected, local soils can have a significant infiltration capacity, and can help meet design requirements. While soil compaction is necessary to provide structurally sound foundations, areas away from foundations are often excessively compacted by vehicle and foot traffic during construction. Minimizing soil compaction can be achieved by:
  - Reducing disturbance through design and construction practices
  - Limiting areas of access for heavy equipment
  - Avoiding extensive and unnecessary clearing and stockpiling of topsoil
  - Maintaining existing topsoil and/or using quality topsoil during construction

- **Manage stormwater close to the source**

  Redirecting runoff back into the ground, close to the point of origin, provides both environmental and economic benefits. Traditional stormwater systems, which collect and convey stormwater, generally increase flows and can suffer failures over time. GIPs are used to infiltrate stormwater into the ground instead of concentrating the flow and routing it offsite.

- **Reduce and disconnect impervious surfaces**

  Reducing and disconnecting impervious surfaces increases the rainfall that infiltrates into the ground. Impervious areas should be reduced by maximizing landscaping and using pervious pavements. In addition, the amount of impervious areas hydraulically connected to impervious conveyances (e.g., driveways, walkways, culverts, streets, or storm drains) should be reduced as much as possible. Examples include:
  - Installing green roofs
  - Directing roof downspouts to vegetated areas and GIPs
  - Using permeable pavements where permitted
  - Installing shared driveways that connect two or more homes or installing residential driveways with center vegetated strips
  - Allowing for shared parking in commercial areas
  - Encouraging building developers to increase their number of floors instead of their building's footprint

2.2. Incentives

Currently offered incentives for LID offered in Metro are shown in **Table 1**. Please visit MWS' Low Impact Development webpage to check for additional incentives.

Table 1. Green Infrastructure Incentives

Incentive	Requirement/Benefit
Stormwater User Fee Credit	Sites designed in accordance with the LID Manual can receive a downward adjustment in their Stormwater User Fees.
Redevelopment Credit	Certain previously developed sites can meet a Runoff Reduction goal of 60% instead of 80%. A site must have a current, pre-development runoff coefficient (Rv) greater than 0.4 to qualify.
Quantity Analysis (see Chapter 3.2.5.)	Volumetric GIPs can be utilized for water quantity in lieu of or in addition to traditional detention structures.

Certain GIPs will also help sites earn credits under the LEED certification system. Please consult the LEED Reference Guides for more information.

Chapter 3
THE RUNOFF REDUCTION METHOD

3.1 Introduction

The Runoff Reduction Method (RRM) serves as the basis for Metro's approach to GIP design. The basic RRM derivation can be found in original references.[1] Runoff volume reduction is the focus of this approach; and runoff reduction equals pollution reduction. Thus, understanding and calculating every aspect of a site's land condition in relation to runoff reduction is important. Using the RRM, every land surface can now have an assigned rating in terms of rainfall capture. For example, if open space can infiltrate a significant rainfall event, and it can be credited with 100% TSS removal for all the rainfall it infiltrates, then the open space itself becomes an effective control. Even impervious surfaces capture a small amount of water and therefore do not generate 100% runoff. An LID Site Design Tool has been created to aid engineers in designing the water quality treatment for a project in accordance with the methodology in the LID Manual. Please see MWS website for more information.

Site drainage areas that cannot meet the runoff reduction requirement due to site limitations must be designed for pollutant removal. Please see Section 7.2 of Volume 1 for more information on site limitations. This approach focuses mainly on engineered controls to reduce stormwater pollution as runoff flows through structural controls, and requires that they meet an 80% removal efficiency of Total Suspended Solids (TSS). Open space land use is of only minor importance.

3.1.1 Objectives

The basis for the RRM is a rainfall volume capture goal. In Metro the method was designed to fulfill several complimentary objectives:

- Meet the one-inch capture requirement under the NPDES MS4 Permit;
- Reflect local hydrologic and land conditions;
- Incentivize the use of natural solutions;
- Provide an approach that is simple and effective for the range of development projects occurring in Metro.

It was found that these objectives could be largely met through the use of a single overarching design standard, backed by specific volume-capture standards for structural controls and rainfall intensity scaled runoff coefficients for other land uses. To be eligible for approval of a site design under this approach the designer must lay out the site such that the total rainfall for a one-inch event of moderate intensity is captured and treated on site through a combination of infiltration, evapotranspiration, harvest and/or use. This objective is accomplished through site layout and GIP design.

The first step in determining if the standard is met is to determine the volumetric runoff coefficient, Rv, which is the percentage of fallen precipitation that runs off of a specific land use area (See Equation 3.1). Rv within this method reflects a site's post-development runoff volume for storms in the one-inch or larger range. Based on national studies and standards, and supported by local rainfall-runoff analysis for Nashville soils, it was found that an Rv value of 0.20 generally indicates the capture of the first one-inch of rainfall. Storms larger than one inch may cause runoff.

Each land use is assigned an Rv value. Once Rv values have been developed, they must be weighted for the respective areas. If the weighted Rv for the whole site is 0.20 or less, the standard has been met. If the Rv standard has not been met, GIPs consisting of intrinsic designs and structural controls devised to capture the remaining required volume are added to the design. These effectively modify the Rv value for contributing drainage areas to that intrinsic design or control. These are shown in **Tables 2 and 3** in **Section 3.2**.

[1] Chesapeake Stormwater Network, CSN Tech. Bull. No. 4, "Technical Support for the Bay-Wide Runoff Reduction Method, Ver. 2.0", (undated). and Center for Watershed Protection, "Technical Memorandum: The Runoff Reduction Method" April 18th, 2008

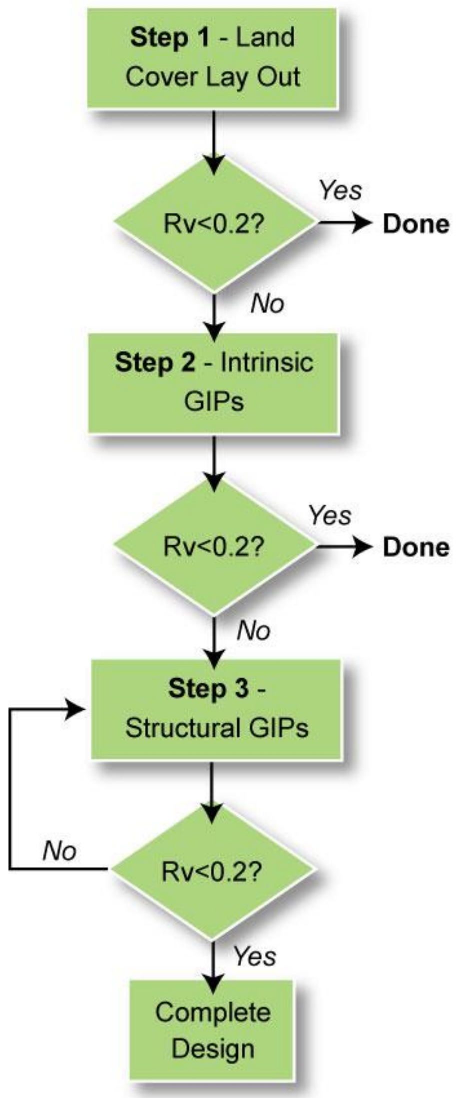
3.1.2 Conceptual Steps in the Runoff Reduction Method

The RRM follows the steps shown below:

Step 1: Reduce Runoff Through Land Use and Ground Cover Decisions.

This step focuses on the "background" land cover and how much rainfall it removes from runoff. Design activities in Step 1 focus on impervious area minimization, reduced soil disturbance, forest preservation, etc. The goal is to minimize impervious cover and mass site grading and to maximize the retention of forest and vegetative cover, natural areas and undisturbed soils, especially those most conducive to landscape-scale infiltration.

Calculations for the RRM for Step 1 include the computation of volumetric runoff coefficients (Rv) for land use and Hydrologic Soil Group (HSG) combinations (including impervious cover). Site cover runoff coefficients are shown in **Table 2**.



Step 2: Apply Environmental Site Design Practices (Non-Structural GIPs).

If the target volume capture (Rv ≤ 0.20) has not been attained in Step 1 then Step 2 is required. This step focuses on implementing the more intrinsic GIPs during the early phases of site layout. In this step the designer enhances the ability of the background land cover to reduce runoff volume through the planned and engineered use of such practices as sheet flow, grass channel, and reforestation. Each of these practices is assigned an ability to reduce one-inch of rainfall in a storm of moderate intensity; and this assignment is conveniently captured in the Runoff Removal Credit or the RR Credit. RR Credit values for non-structural GIPs are shown in **Table 3**.

Step 3: Apply Structural GIPs.

If the target one-inch capture volume (Rv ≤ 0.20) has not been attained, Step 3 is required. In this step, the designer experiments with combinations of more structural GIPs on the site. In each case, the designer estimates the area to be treated by each GIP to incrementally meet the overall runoff reduction goal. Such engineered practices as infiltration trenches, bioretention, green roofs, permeable pavement, cisterns, etc. are envisioned. Design and sizing standards have been created for each of these GIPs to ensure their ability to meet the one-inch volume capture still required after Steps 1 and 2 have been analyzed. RR Credit values for structural GIPs are also shown in **Table 3**.

The guidance for the effectiveness of the various GIPs is expressed in terms of percent volume reduction (Runoff Reduction Credit).

At the end of Step 3, the designer must have achieved the required one-inch volume capture – which is accomplished by attaining an area weighted Rv value of 0.20 or less. The following sections describe how to calculate Rv and associated variables.

3.2 Technical Details

3.2.1 STEP 1: Land Use Rv Values

The volumetric runoff coefficient (Rv) is the ratio of the runoff divided by the target rainfall. If 45% of the rainfall for a range of storms in the one-inch range and larger is discharged from the site, the Rv value equals 0.45. Unlike a Rational Method C Factor, for example, Rv is not a constant individual storm-based value but is rainfall intensity and total depth dependent. Rv values could be developed for individual storms, seasons, or even on an annual basis. **Table 2** shows the Rv values derived for Metro to estimate runoff from larger storms of moderate intensity meeting the one-inch and greater standard.

Table 2. Site Cover Runoff Coefficients

Soil Condition	Volumetric Runoff Coefficient (Rv)			
Impervious Cover	0.95			
Hydrologic Soil Group	**A**	**B**	**C**	**D**
Forest Cover	0.02	0.03	0.04	0.05
Turf	0.15	0.18	0.20	0.23
Gravel	0.6	0.6	0.6	0.6

These values serve as the basis for Step 1 in application of the RRM. The development of an area-weighted estimate of the total site Rv value using site land uses.

$$\text{Weighted } R_V = [(R_{V1} * A_1) + (R_{v2} * A_2) + \cdots]/(A_1 + A_2 + \cdots) \qquad \textbf{Equation 3.1}$$

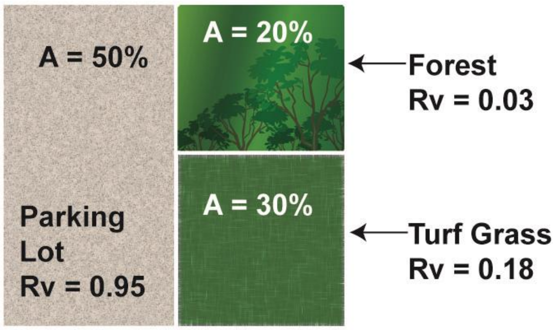


Figure 2 Site Example with Land Uses

Previously preserved areas or areas that cannot be developed should be excluded from the site Rv calculation. These areas may include, but are not limited to, water quality buffers, parkland, playgrounds, sport fields, floodway, preserved floodplain, and slopes $\geq$ 33%.

STEP 1 EXAMPLE

As shown in Figure 2, if we have a 10-acre site and 50% of the site was impervious, 20% forest, and 30% turf grass all over B Soils the Rv value would be:

Site Weighted Rv = [(5.0*0.95) + (2.0* 0.03) + (3.0*0.18)]/10 = 0.54

That is, 54% of the rainfall for the larger design storms on the site runs off. This step does not consider the flow path of the runoff but simply the land use. The standard is the capture of the first inch and an Rv of 0.20 or less so additional GIPs must be planned and implemented.

3.2.2 STEPS 2 AND 3: Green Infrastructure Practice Rv Values

Steps 2 and 3 of the RRM involve the planning and design of Green Infrastructure Practices (both intrinsic and structural) to reduce the total site Rv to 0.20 or less. For impervious areas draining directly to the MS4 without passing through water quality or quantity controls, **MWS reserves the right to require treatment if a negative impact is perceived.** **Table 3** lists the acceptable GIPs and the assigned RR Credits for each, which corresponds with the values listed in each GIP specification. The two levels refer to specific design requirements contained in the specific GIP General Application sheets.

Table 3. Green Infrastructure Practices Runoff Reduction Credit Percentages								
Green Infrastructure Practice	**% Rainfall Volume Removed/Captured – RR Credit**							
	Level 1				**Level 2**			
1. Bioretention	60				80			
2. Urban Bioretention	40				N/A			
3. Permeable Pavement	40				80			
4. Infiltration Trench	50				90			
5. Water Quality Swale	40				60			
6. Extended Detention	25				N/A			
7. Grass Channel	10/20*				20/30*			
8. Sheet Flow	Design dependent: 50-75*							
9. Reforestation (A, B, C, D soils)	96	94	92	90	98	97	96	95
10. Rain Tanks/Cisterns	Design dependent: 0-90*							
11. Green Roof	Design dependent: 40-90*							

* See GIP for additional information.

Note that the first six GIPs themselves occupy site land area. Because of their ability to absorb the rain that falls on them they are assigned the corresponding <u>Forest Cover</u> Rv values from **Table 2**. Other GIPs, where applicable, are assigned the <u>Turf</u> land cover Rv values from **Table 2**. The exception to this is Permeable Pavement (GIP-03), which is assigned the Rv values of 0.60 and 0.20 for Levels 1 and 2, respectively. Use of these values is <u>optional</u> and can be ignored for the first six GIPs if their area is less than ten percent of the total site area.

To calculate the Rv value for a Contributing Drainage Area (CDA) flowing through a GIP use Equation 3.2, below.

$$\text{GIP Rv} = \text{CDA } R_V(1 - \text{RR Credit})$$ **Equation 3.2**

GIP Rv equals the Contributing Drainage Area volumetric runoff coefficient as treated by the GIPs. CDA Rv is the weighted Rv value for the drainage area flowing to the GIPs. It should be weighted, using Equation 3.1, if the drainage area has multiple land uses. If the drainage area contains only one land use the CDA Rv value is the Rv for that single land use.

EXAMPLES

If part of the current site is impervious and has an Rv value of 0.95, it can be sent through a bioretention structure with Level 2 design (80% RR Credit) and the following reduction calculation would result:

GIP Rv = 0.95 *(1-0.80) = 0.19

Thus, the bioretention facility meeting the Level 2 design criteria would cause that impervious area to meet the standard of an Rv of 0.20 or less.

Level 1 Reforestation of a C soil would result in that land area changing from an Rv of 0.2 (See Table 2) to:

GIP Rv = 0.20 *(1-0.92) = 0.02

3.2.3 SPECIAL CASE: Rv Values for Controls in Series

The calculation of the volume removal rate for controls in series can be complex and specific GIP dependent. The upstream control has the benefit of initially handling runoff from the many small storms while the second control in series must handle the overflow from the first – a set of fewer and larger storms. Therefore, the ability to capture instantaneous volumes and store them for later removal is key for the downstream controls. In addition to cisterns, only the first six controls in **Table 3** can be used as the second GIP in a series volume removal calculation: bioretention, urban bioretention, permeable pavement, infiltration trench, water quality swale, and extended detention.

The following equation shall be used for calculation of the total Rv factor for GIPs in series:

$$\text{GIP } R_{V\,\text{SERIES}} = \text{CDA } R_V(1 - RR_1 \text{ Credit})(1 - RR_2 \text{ Credit})$$ **Equation 3.3**

Where CDA Rv is the volumetric runoff coefficient of the land cover flowing into the first GIP in the series (e.g. CDA Rv = 0.95 for impervious area). RR_1 Credit is the percent volume reduction credit for the first GIP in the series from **Table 3** and RR_2 is the percent volume reduction credit for the second (e.g. downstream) GIP in the series from **Table 3**. Credit will be granted for no more than two controls used in series.

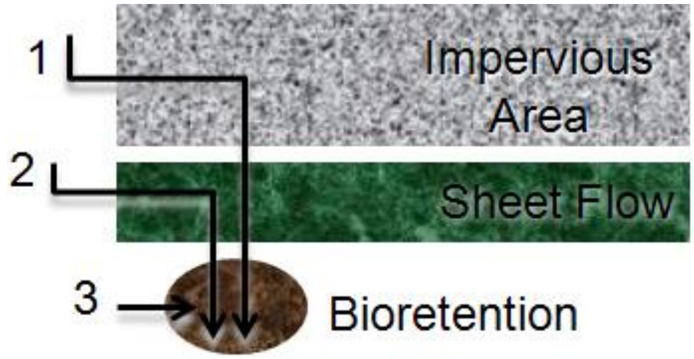


Figure 3 Series Credit Example

EXAMPLE

A 0.5-acre impervious area (IA) (Rv=0.95) is disconnected through a 0.25-acre C soil sheet flow area (Rv=0.20) and then enters a 0.06-acre Level 2 bioretention facility (Rv=0.04). See Figure 3 for schematic. The following calculation gives the Rv for that impervious area (note that the grassy area also has its own Rv value, and calculation (1) is only for the impervious area). Sheet flow is Level 1 (RR Credit 50%) while bioretention design is Level 2 (RR Credit 80%). Calculate the Rv for each of the three parts of the site – only the impervious area is demonstrating GIPs in series:

(1) IA through GIP $Rv_{SERIES} = 0.95*(1-0.50)(1-0.80) = 0.10$

(2) Sheet Flow GIP $Rv = 0.20*(1-0.80) = 0.04$

(3) Bioretention Rv (optional - Forest in C Soil) = 0.04

Site Rv for criteria attainment using Equation 3.1 is:

$$Rv_{FINAL} = (0.50*0.10 + 0.25*0.04 + 0.06*0.04)/(0.50+0.25+0.06) = 0.08$$

This equation says that 95% of the rainfall runs off the impervious area and enters the sheet flow area. 50% of that flow is captured in the sheet flow area. The remainder enters the bioretention facility (the largest storms) and 80% of that is captured by that GIP designed as a Level 2 facility allowing about 10% to overflow the facility in the design situation.

The Rv value for the whole site is 0.08, well ahead of the design requirement. Use of the bioretention area in the calculation is optional since its surface area is less than ten percent of the total site area.

3.2.4 Sizing of Media-Based GIPs

Standard practice in the sizing of media-based GIPs (bioretention, urban bioretention, permeable pavement, infiltration trenches and water quality swales) has been to assume that the runoff from a one-inch storm is instantaneously contained within the control, and that the control is completely dry prior to this. Through hourly rainfall simulation modeling using Metro rainfall, these offsetting assumptions, one conservative and one non-conservative, have been found to result in a design that approximates an 80% removal of runoff volume (Rv = 0.20) for all native soil infiltration rates. Underdrains are required for parent material infiltration rates less than or equal to 0.5 in/hr. As such the following guidance is provided for sizing these types of facilities. Details for each type are provided in the respective specification sections. Details for sizing cisterns are also located in the specific specifications.

Table 4 provides basic volume-based specifications for the standard recommended soil-based media and gravel. Soil-based media is used for GIPs: bioretention, water quality swales and urban bioretention. Gravel is used for design alternatives for the above listed GIPs, as well as, the storage layers for permeable pavement and infiltration trenches.

Field capacity of the soil is the amount of moisture typically held in the soil/gravel after any excess water from rain events has drained and varies greatly between soil-based media and gravel.

Table 4. Media Volume-Based Specifications		
Parameter	Value	
	Porosity	Field Capacity
Soil-Based Media[1]	0.25	0.25
Gravel[2]	0.40	0.04
Ponding	1.0	NA

1. Soil-Based Media GIPs - bioretention, water quality swales and tree planter boxes
2. Gravel GIPs - design alternatives for GIPs in 1, storage layers for permeable pavement and infiltration trenches

All media-based GIPs shall be sized to provide storage volume for the complete runoff from one inch of rain over the contributing drainage area (CDA). Thus, all media storage GIPs shall be sized using the following equations:

$$T_V = M(P)(CDA)(R_V)\left(\frac{43{,}560\ ft^2}{1\ ac}\right)\left(\frac{1\ ft}{12\ in}\right) = n(D)(SA)$$ **Equation 3.4**

Where:
Tv = GIP treatment volume in cubic feet; pretreatment volume is excluded from required treatment volume
CDA = the contributing drainage area in acres
M = Multiplier based on treatment level (included in the LID spreadsheet tool)
P = 1 inch
Rv = runoff coefficient for the CDA
SA = surface area in square feet of the GIP
D = media depth of GIP in feet.
n = Porosity
(D)(n) = D_E if more than one media type is required

To find the equivalent storage depth for media-based GIPs with multiple layers of media the equivalent storage depth must be calculated using the following equation:

$$\text{Equivalent Storage Depth} = D_E = n_1(D_1) + n_2(D_2) + \cdots$$ **Equation 3.5**

Where n_1 and D_1 are for the first layer, etc.

Note that the Rv value is for the total area draining to the control. So, if a filter strip is included in the area then a weighted Rv should be calculated but not a credit reduced Rv.

EXAMPLE

Using the previous example 0.5 acres of impervious area and 0.25 acres of grass enter the bioretention area. First calculate the volume design Rv for the CDA:

CDA Rv = (Rv1*A1 + Rv2*A2)/(A1+A2)= (0.95*0.50+0.20*0.25)/(0.50+0.25) = 0.70

The bioretention pond is Level 2 and thus will have 1.25*Tv for the volume, media depth of 36 inches and a maximum of 6 inches of ponding. The Equivalent Depth = (3 ft)(0.25) + (0.5 ft)(1.0) = 1.25 ft. Then by application of Equations 3.4 and 3.5, solving for SA:

Tv = 1.25*1"*0.75*0.70*43,560/12 = 2,382 cubic feet = SA*D_E = (SA)(1.25 ft)
SA of GIP = 1,906 Square Feet

3.2.5 Calculation of Curve Numbers with Volume Removed

The removal of volume by GIPs changes the runoff depth entering downstream stormwater quantity structures. An approximate approach to accounting for this in reducing the size of peak flow detention facilities is to calculate an "effective SCS curve number" (CNadj) which is less than the actual curve number (CN). CNadj can then be used in hydrologic calculations and in routing. The method can also be used for other hydrologic methods in which a reduction in runoff volume is possible.

Equation 3.6 provides a way to calculate a total runoff if the rainfall and curve number are known.

$$Q = \frac{(P-0.2\times S)^2}{(P+0.8\times S)} \quad \text{and} \quad S = \frac{1000}{CN} - 10$$ **Equation 3.6**

Equation 3.6 is the standard SCS rainfall-runoff equation where P is the inches of rainfall for the 24-hour design storm (See **Stormwater Management Manual, Volume 2**), and Q is the total runoff in depth for that storm in inches.

The adjusted total runoff in depth entering the flood control facility downstream of a GIP is calculated by taking the difference in the original total runoff in depth and the depth captured by the GIP (Tv from equation 3.4) expressed in watershed inches using equation 3.7 where CDA is the drainage area in acres for the subarea in question.

$$Q_{adj} = Q - \frac{12 * T_v}{43560 * CDA}$$ **Equation 3.7**

Equation 3.8 provides a method to calculate the modified curve number once the Qadj is found.

$$CN_{adj} = \frac{1000}{10 + 5P + 10Q_{adj} - 10\left(Q_{adj}{}^2 + 1.25Q_{adj}P\right)^{1/2}}$$ **Equation 3.8**

The steps in calculating an adjusted Curve Number (CNadj) are:

Step 1. **Calculate Total Runoff for Storm (Q)** Chose the design return period, and using that rainfall as P, calculate an initial Q using Equation 3.6 and the calculated site curve number.

Step 2. **Calculate GIP Capture Volume (Tv)** Compute the captured volume in the GIP control using Equation 3.4 or proven cistern volume assuming a 72-hour inter-event dry period since the last cistern filling event.

Step 3. **Calculate Adjusted Total Runoff (Qadj)** As shown in Equation 3.7, subtract Tv expressed in watershed inches from Q computed in Step 1.

Step 4. **Calculate Adjusted Curve Number (CNadj)** Using Qadj and the P corresponding to the return period in question (the P from step 1), calculate the adjusted CN from Equation 3.8.

Step 5. Use CNadj in routing calculations for the specific return period in question.

The LID spreadsheet tool can be used to calculate the CNadj. The example on the next page illustrates this procedure using manual calculations.

EXAMPLE

A 1.5-acre parking lot is to drain into a larger site detention pond for the 2-year through 100-year storm. We wish to determine the curve number taking into account a bioretention basin at the downstream end of the parking lot and therefore need to calculate a modified curve number for the parking lot. The developed curve number is 98 for the parking lot.

Step 1. Using Equation 3.6 for a P = 7.53, the calculated Q = 7.30 inches.

$$Q = 7.30 = \frac{(7.53 - 0.2 * 0.20)^2}{(7.53 + 0.8 * 0.20)} \quad \text{and} \quad S = 0.20 = \frac{1000}{98} - 10$$

Step 2. We find Tv through sizing a Level 1 bioretention facility:

$$T_v = 1.5 * 0.95 * \frac{43{,}560}{12} = 5{,}173\text{ft}^3$$

Step 3. Over 1.5 acres the depth, in inches, removed is:

$$Q_{removed} = 0.95\text{ in} = \frac{(5173\text{ft}^3)(12)}{43{,}560(1.5\text{ac})}$$

Step 3 cont. Qadj is:

$$Q_{adj} = 6.35\text{ in} = 7.30 - 0.95$$

Step 4. Using Qadj and the 100-year P in Equation 3.8 we obtain the adjusted curve number of 90. We can check our work by substituting this CN back into Equation 3.6 to obtain the Q of Step 3.

$$CN_{adj} = 90 = \frac{1000}{10 + 5(7.53\text{in}) + 10(6.35\text{in}) - 10[(6.35\text{in})^2 + 1.25(6.35\text{in})(7.53\text{in})]^{1/2}}$$

Chapter 4

GREEN INFRASTRUCTURE PRACTICES

4.1 Overview

Communities are increasingly moving towards green infrastructure practices – or a combination of green and conventional stormwater management practices – to manage stormwater. Green infrastructure systems are an innovative approach to urban stormwater management that do not rely on the conventional end-of-pipe structural methods. Rather, they are an ecosystem-based approach that strategically integrates stormwater controls throughout an urban landscape to attempt to maintain a site's pre-development conditions. Targeted community or watershed goals and objectives are addressed through the use of structural and non-structural techniques such as permeable pavement, bioretention, cisterns, and public outreach.

Green Infrastructure Practices (GIPs) are intended to mimic the natural hydrologic condition and allow stormwater to infiltrate into the ground, evapotranspirate into the air, or be captured for reuse. Typical GIPs include: sheet flow, infiltration practices, permeable pavement, cisterns, bioretention, reforestation, green roofs, etc.

These GIPs are designed to meet multiple stormwater management objectives, including reductions in runoff volume, peak flow rate reductions, and water quality protection. Multiple small, localized controls may be combined into a "treatment train" to provide comprehensive stormwater management. The GIPs in this section have been designed to be integrated into many common urban land uses on both public and private property, and may be constructed individually, or as part of larger construction projects. Decentralized management strategies are encouraged to be tailored to individual sites; which can eliminate the need for large-scale, capital-intensive centralized controls; and may improve the water quality in Metro's streams and reduce the number of combined sewer overflows.

Table 5 and **Table 6** are included to facilitate selection of the most appropriate GIPs for a given situation. The following chapters provide a brief introduction to each practice, details on performance, suitability, limitations, and maintenance requirements.

Table 5. Effectiveness of SCMs in Meeting Stormwater Management Objectives

Practices	Volume	Peak Discharge	Water Quality
Bioretention	●	●	●
Urban Bioretention	⦿	⦿	●
Permeable Pavement	●	●	⦿
Infiltration Trench	●	●	●
Water Quality Swales (Dry)	⦿	⦿	●
Extended Detention	○	●	○
Grass Channels	○	○	○
Sheet Flow	●	●	⦿
Reforestation	●	●	●
Cisterns*	⦿	○	○
Green Roofs	⦿	●	●

* A single cistern typically provides greater volume reduction than a single rain tank.

Key: ● High effectiveness ⦿Medium effectiveness ○Low effectiveness

Rankings are qualitative. "High effectiveness" means that one of the GIP's primary functions is to meet the objective. "Medium effectiveness" means that a GIP can partially meet the objective but should be used in conjunction with other SCMs. "Low effectiveness" means that the GIP's contribution to the objective is a byproduct of its other functions, and another decentralized control should be used if that objective is important.

Table 6. Green Stormwater Infrastructure Land Use and Land Area Selection Matrix								
Practices	**Criteria**							
	Land Use							**Land Area Required**
	Schools	**Com.**	**Indust.**	**SF Res.**	**MF Res.**	**Parks/Open Space**	**Roads/ Roadside**	
Bioretention	●	●		●	●	●	●	⦿
Urban Bioretention	⦿	●			●	●	●	○
Permeable Pavement	●	●	⦿	●	●	●	●	○
Infiltration Trench	●	●		●	●	●	⦿	○
Water Quality Swales (Dry)	●	●			●		●	⦿
Extended Detention	●	●	●		●		●	○
Grass Channels	●	●		●	●	⦿	●	⦿
Sheet Flow	●	●		●	●	⦿	●	⦿
Reforestation	⦿		⦿	⦿	⦿	●	●	○/●
Cisterns	●	⦿	⦿	●	●			○
Green Roofs	●	●	●		●			○

● - Well suited for land use applications or high relative dedicated land area required.
⦿ - Average suitability for land use applications or moderate relative dedicated land area required.
○ - Low relative dedicated land area required.
Blank – Not applicable for land use.

References

Chesapeake Stormwater Network, CSN Tech. Bull. No. 4, "Technical Support for the Bay-Wide Runoff Reduction Method, Ver. 2.0", (undated). and Center for Watershed Protection, "Technical Memorandum: The Runoff Reduction Method" April 18th, 2008

National Association of Homebuilders Research Center. (No date).Municipal Guide to Low Impact Development.

Metro Water Services. 2009. The Metropolitan Government of Nashville and Davidson County Green Infrastructure Master Plan.

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