Chapter 4

Smart Design for Stormwater Management

What's in this Chapter?

Section 4.1 transitions from site assessment to quantitative analysis of runoff reduction targets. We discuss the decisions and resultant pathways for setting design targets and showing they are met for a proposed project.

Section 4.2 describes mass-time approach as the foundation for implementing the Tennessee Runoff Reduction Assessment Tool (TNRRAT) for stormwater management compliance.

Section 4.3 explains runoff reduction volume calculations..

Section 4.4 explains runoff treatment volume calculations.

Section 4.5 describes how flood and channel protection are carried out after runoff reduction requirements are met.

4.1 Site Assessment for Runoff Reduction Requirements

In implementing the site assessment protocols and checklist (see Chapter 3), the existing hydrologic function was determined through documenting the effects of soil properties, depth to water table, depth to bedrock, topography, and contributing drainage areas. In extreme cases, natural conditions may be documented and trigger the designation of a special management area by the local stormwater program. Special management areas of karst (or other feature that leads to increased groundwater pollution potential), pollution hotspots, or brownfields were also identified.

Upon completion of site assessment and design layout, runoff reduction design targets are set based on the prevalence of special management areas and the final land cover and management characteristics of a project site. The **Tennessee Runoff Reduction Assessment Tool** (TNRRAT) is a time-mass approach to estimating the potential for infiltration and retention to determine whether a project design meets the runoff reduction and pollutant removal requirements set forth in the MS4 General Permit. The TNRRAT was developed to provide a consistent method to determine the success of a project for runoff reduction and treatment, which takes into account environmental and climactic variability across the state.

The Site Assessment and Inventory Checklist (Appendix E) should be used in conjunction with the TNRRAT. Documented special management areas will help complete the input requirements and identify design targets built into the model. When an MS4 program has implemented an incentive program, runoff reduction volume "credits" are allocated for projects that include redevelopment, brownfield redevelopment, high density, vertical density, mixed use, and transit-oriented development.

As delineated in Chapter 3, there exists a preference for runoff reduction and treatment approaches based on site characteristics and general project goals.

4.2 Site Water Balance

The overarching goal of runoff reduction with green infrastructure is to mimic the natural water cycle, or in other words create a design that preserves overall pre-development hydrology of the landscape by using control measures to mitigate for changes in land cover. A water balance approach is used to determine whether this goal is met. This approach follows a water volume through the hydrologic cycle of a project site, from rainfall through the hydrologic processes that transport, store, treat, and transform that water volume.

The TNRRAT is not coefficient-based, but rather calculates a water balance for each time step within a *representative storm* simulation for the duration that stormwater is required to be managed on site. This time frame during precipitation when storage and transport processes are occurring is referred to as *opportunity time.* This model emphasizes estimating potential for infiltration and retention within a system of connected units. A unit is a user-defined area that has consistent properties (such as management and soil type) and may or may not have a surface area.

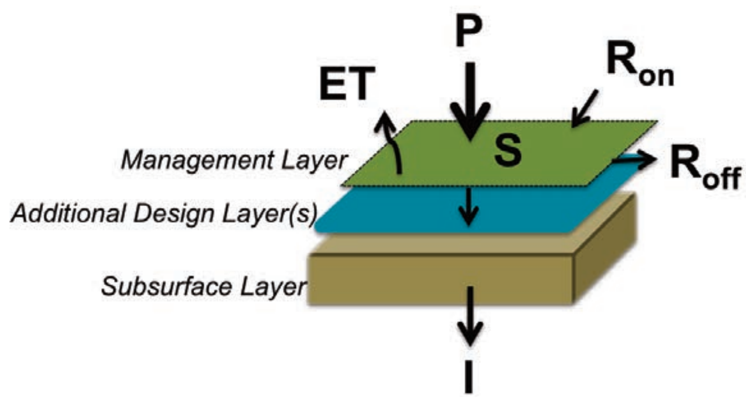

Figure 4.1: A conceptual diagram of the water balance of a unit.

$$S_2 = S_1 + P + R_{on} - R_{off} - I - ET$$
(Equation 1)

Table 4.1: Description of components in Equation 1.

Component (Abbrev.)	Description	Method of Estimation
Storage (S)	Volume captured above the surface	Direct model input of available volume and other pertinent soil properties
Precipitation (P)	Volume added from direct rainfall	A relatively-severe representative storm with a specific depth and intensity for a geographic location
Run-on (R_{on})	Volume added from contributions coming from adjacent units	Direct model input
Runoff (R_{off})	Volume loss due to gravity	Mass balance
Infiltration (I)	Volume moving through the ground surface; dependent on soil properties, management, and supply	Kostiakov-Lewis relationship with adjustments for land management
Evapotranspiration (ET)	Volume loss due to combined effects of evaporation and plant transpiration; only occurs after infiltration occurs	Function of management cover and soil properties

Using the TNRRAT allows the designer to estimate the needed amount of on-site storage based on a resultant water balance from the gains of rainfall and run-on and losses of soil-based infiltration. The target is to fully manage the representative storm event with no generated runoff. Storage is a function of topography and soil/media properties. Infiltration is estimated in the model using the Kostiakov-Lewis method, which was selected because it best represented the general spatial scale at which stormwater management is applied, a relatively large-scale as compared with plot-scale data. A coefficient-based adjustment factor (ie. curve number) may be applied in the model to represent the effects of land management (or cover) on soil-based infiltration. An assumption is made here that the landscape response to large storms is directly proportional to small storms for a given land management. Storage within the surface layer only consists of interception and surface depression storage for units with surface area, or the specific storage volume for a device within a specified surface area. Units with multiple layers route water from the surface layer downward through sequential subsurface layers. Water movement is controlled by the filed capacity of the layer based on its properties as well as saturation.

The representative rainfall event was identified for many different locations across the state in order to capture the spatial variability of those storm factors and create a consistent target in the presence of regional climactic variability. These storms were identified from approximately 30 years of rainfall data to represent a relatively severe, real world event with a specific amount, intensity, and duration. Rainfall records were analyzed, first defining rainfall events as being separated by at least 6 hours with no measureable rainfall in between. Data sets were not truncated in any way. Representative rainfall events are available for Bristol, Knoxville, Chattanooga, Monterey/Crossville, Nashville, Jackson, and Memphis. It may be assumed that proximate areas have the same representative rainfall event. The 95th percentile storm depth was selected, and the duration was set to the median event duration of the range from the 92.5 to 97.5 percentile storms. Finally, the event was then defined with Type II distribution.

4.3 Runoff Reduction Volume

The volume of runoff to be managed on-site is iteratively calculated within the TNRRAT on a 15-minute time step for the duration of the opportunity time during the representative rainfall event. The potential for infiltration rate changes over time, which is especially important because of how this timing coincides with water supply (or rainfall rate). Excess rainfall after losses of infiltration and available storage retention is accounted for as runoff. Based on user-input design element areas, steady-state runoff volume is routed from one area to the next until an outfall is indicated.

The logic for each user-defined unit for each time step is as follows:

1. If the unit has surface area, calculate the rainfall depth during the time step based on rainfall intensity (defined by event depth, Type II distribution, and 15-minute time step).
2. Add in the run-on additions coming from adjacent units and any water currently stored in this unit to determine total available water for this time step.
3. If this is an infiltration unit, then use the infiltration capacity (based on soil type, management, and current infiltration depth) to calculate potential infiltration during this time step.
4. Calculate the actual infiltration by adjusting the potential to account for available supply, and calculate a new total infiltration depth at the end of this time step.
5. If this is a reuse unit, remove the reused volume from the available storage.
6. Calculate the amount of water remaining in this subarea at the end of the time step as initial storage plus additions (rainfall and run-on) minus losses (infiltration and use).
7. Compare this remaining volume to the available unit storage. If the remaining volume is greater than the storage, then the difference is runoff and routed to the next downstream unit or offsite. If the remaining volume is less than or equal to the available unit storage, then the volume is stored in this unit until the next time step.

The TNRRAT requires the designer to take the following actions in order to obtain a final result:

- Selection of the project location from a pre-defined list of Tennessee cities, choosing a location most similar to the design location.
- Delineating units and routing information included in the project plan, each representing a unique combination of soil, SCM/management, contributing unit(s), and downstream unit.
- Identifying unit properties of area, unit to which it discharges (or offsite), SCM or management, soil type from a pre-defined list, and if there is soil, then depth to impending layer (such as a saturated zone, tight clay lens, man-made barrier, etc.).

A pre-defined list of SCMs and management descriptions are included in the TNRRAT. Each description includes a list of properties, including:

- The type of SCM, which indicates whether it collects rainfall, performs infiltration, or is simply a volume-based device.
- If the SCM is exposed to the surface, whether it includes vegetation, and the type of vegetation.
- For infiltration SCMs, the best estimates of curve number values for the land management at the soil/water contact surfaces based on hydrologic soil group.
- Definition of rainfall interception and depressional storage resulting from the SCM/management.
- Special characteristics of the SCM, including whether the practice contributes pollutants, the TSS removal efficiency, and any water removal (reuse) rate.
- If the SCM has multiple layers, then the characteristics of each layer, including fill media, normal layer thickness, presence of an underdrain, whether there is an impervious bottom, and rate of removal (or reuse).
- For each layer media, water content at saturation, field capacity, and wilting point.
- For each layer media, the analogous material that could be said to control infiltration into this material.

4.4 Runoff Treatment Volume

The treatment volume is any runoff generated from the first inch of rainfall from site elements that can potentially contribute pollutants. These areas include impervious surfaces (such as rooftops, pavements, dirt roads, etc.). This is equivalent to the minimum treatment volume for the performance-based criteria for 80% TSS removal. In order to be compliant with treatment requirements, this volume must run through an SCM that is approved for treatment.

The TNRRAT assumes 100% TSS removal for infiltrated water, 100% TSS removal for all harvested and reused water, and specifies a pollutant removal efficiency (based on TSS removal) for all other approved SCMs based on the best and most recent published data available. Any deviations from these values or efficiencies given to additional measures require validation by the designer with the local stormwater program. Table 4.2 shows a summary of literature findings on TSS removal by SCMs.

Table 4.2: Summary of literature findings on TSS removal by SCMs.

Stormwater Control Measure	Pollutant Removal Efficiency (%)			
	By Storage Infiltration	Drain Discharge	Surface Removal (Flowthrough)	Literature (Average)
Dry Detention	100	NA	40	40
Extended Detention	100	NA	60	80
Wet Ponds	100	NA	80	70
Vegetated Swales	100	NA	25	65 / 85
Managed Vegetated Areas	100	NA	NA	NA
Filter Strips	100	NA	30-35	70
Bioretention	100	85	10	85
Infiltration Areas	100	NA	25	65
Permeable Pavement	100	65	NA	80
Green Roofs	100	NA	NA	NA
Rainwater Harvesting	NA	100	100	NA
Stormwater Treatment Wetlands	80	NA	50-80	80
Manufactured Treatment Devices	NA	NA	50-80	50-100
Underground Infiltration Systems	100	40	NA	50

NA – Not Applicable. References: Chesapeake Bay Program (2006), Center for Watershed Protection (2007), New Hampshire Department of Environmental Services (2008)

Treatment train systems are systems comprised of multiple measures in series to meet design requirements. The TNRRAT accounts for the runoff reduction with treatment train measures through mass balance. The TNRRAT also tracks flow routing through treatment train systems and the assigned pollutant removal efficiency of the individual measures. Total flow and treatment efficiency is accounted for volumetrically through the indicated flow routing paths. No additional inputs are needed to account for treatment train practices in the tool.

4.5 Flood Control and Channel Protection

Flood control and channel protection remain primary goals of stormwater management while runoff reduction is a new standard for lower impact development. Flood protection controls are designed based on a design storm with a specific return frequency that is identified by local regulating jurisdictions. Generally, a 10-year or 25-year return design storm is used to size storm drainage infrastructure and a 100-year return design storm is used to protect from downstream flooding. Channel protection is performed when outflow rates from flood controls are held at or below the 1-year or 2-year return design storm. This outflow rate protects the receiving channel from erosive flowrates that destabilize streambanks and channels. While flood control and channel protection is greatly encouraged, it is not mandated by state standards. Check your local stormwater program for flood control and channel protection regulations.

REFERENCES

Center for Watershed Protection (CWP). 2007. National Pollutant Removal Performance Database, Version 3.

Chesapeake Bay Program. 2006. Best Management Practices for Sediment Control and Water Clarity Enhancement. CBP/TRS-282-06.

New Hampshire Department of Environmental Services. 2008. "Appendix B. BMP Pollutant Removal Efficiency." New Hampshire Stormwater Manual, Volume 2: Post-Construction Best Management Practices Selection & Design. Rev. 1.0.