Chapter 4

Estimating the Level of Treatment Provided by a Site Design for Stormwater Management

What's in this Chapter?

Section 4.1 transitions from site assessment to quantitative analysis of runoff and introduces a stormwater runoff assessment tool that can be used to evaluate a proposed project.

Section 4.2 describes the mass balance of water as the foundation for assessing SCM performance.

Section 4.3 explains how hydrologic functions that affect the water balance are estimated.

Section 4.4 explains how pollutant removal is estimated.

Section 4.5 describes how SCMs for flood damage reduction and channel protection are related to site design for pollutant removal.

4.1 Moving from the Site Assessment to Runoff Assessment

In implementing the site assessment protocols and checklist from Chapter 3, the existing hydrologic functions are determined by soil properties, depth to water table, depth to bedrock, topography, and contributing drainage areas. In some cases, natural or man-made conditions might trigger the designation of a special management area by the local stormwater program.

Upon completion of the site assessment and conceptual design layout, design targets are set based on the proposed land cover and management characteristics of a project site. A stormwater runoff assessment tool was developed that uses a water balance approach to estimate the potential for infiltration and determine whether a project design meets the runoff reduction and pollutant removal requirements set forth in the 2010 MS4 general permit. The assessment tool provides a consistent method to evaluate projects, taking into account environmental and climatic variability across the state. Chapter 6 of this manual describes the usage of the stormwater runoff assessment tool in more detail. The assessment tool and related information can be accessed at:

http://tnpermanentstormwater.org/TNRRAT.asp

The Site Assessment and Inventory Checklist (Appendix E) should be used in conjunction with the assessment tool. Documented special management areas will provide input requirements and influence design targets that are built into the assessment tool. If an MS4 program has implemented an incentive program, "credits" within the assessment tool can be allocated for projects that include redevelopment, brownfield redevelopment, vertical density, or other types of development established by the local program, such as high density, mixed use, and transit-oriented development.

4.2 Mass Balance Within Site Design Units

Each permitted MS4 operator must develop a local program consistent their permit requirements. Within the stormwater runoff assessment tool, a step-wise mass balance of water is used to determine whether the SCMs for a proposed development project meet the program's requirements for pollutant removal (Figure 4.1, Table 4.1). This approach follows a water volume through a project site, starting with rainfall and including the various processes that transport, store, treat, and transform that water volume. The mass of water gained or lost from each design unit is calculated for each time step. The details of the assessment tool's development are available in a technical paper that accompanies it.

The assessment tool is not coefficient-based; rather, it calculates a mass balance of water for each time step within a simulation of a representative storm event. The time frame during precipitation when storage and transport processes are occurring is referred to as opportunity time, and the model estimates the potential for infiltration and retention within a system of connected design units. A unit is a user-defined area that has consistent properties (such as management and soil type), but not all units will have a surface area that is exposed to rainfall.

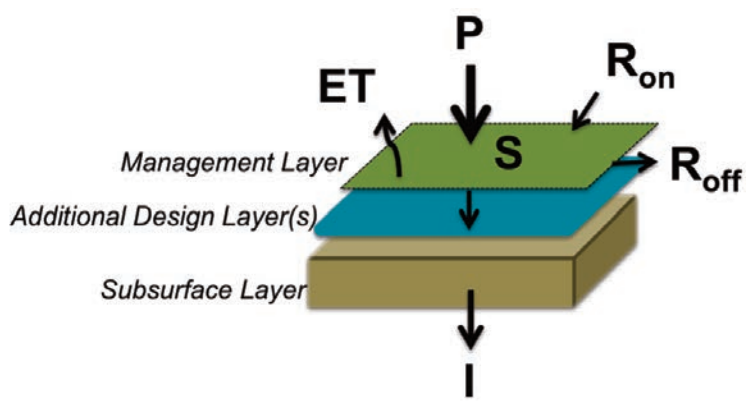

Figure 4.1: A conceptual diagram of the balance of water for a design unit.

Table 4.1: Description of the components in Figure 4.1.

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 representative storm with a specific depth and intensity for the selected geographic location
Run-on (R_{on})	Volume added from contributions coming from adjacent units	Direct model input
Runoff (R_{off})	Volume loss due to surface overflow	Mass balance
Infiltration (I)	Volume moving into and through the ground surface	Function of soil properties, management, and availability of water
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 assessment tool 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 and runoff. The target is to manage the representative storm event with no discharge of pollutants. Storage is a function of topography and soil/media properties. Infiltration is estimated using infiltration curves based on studies of farm-field irrigation, which represents the general spatial scale at which stormwater management is applied, a relatively large-scale as compared with plot-scale data. A factor is applied to represent the effects of land management (or cover) on soil-based infiltration. Storage within the surface layer only consists of interception and surface depression storage for units with surface area, or the specific storage volume for an SCM 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 field capacity of the layer based on its properties, as well as the degree of saturation.

A representative rainfall event was developed for different locations across the state in order to account for the spatial variability of those storms and to create a consistent evaluation target, given the presence of regional climatic variability. Representative rainfall events are available for Bristol, Knoxville, Chattanooga, Monterey/Crossville, Nashville, Jackson, and Memphis. These representative storms are each based on approximately 30 years of rainfall data to represent a relatively severe, real-world event with a specific amount, intensity, and duration. It may be assumed that areas within each region have the same representative rainfall event. The distribution of rainfall in 15-minute time-steps was then defined for each representative event. The details of rainfall simulation are also described in the previously mentioned technical paper.

4.3 Hydrologic Functions Within Site Design Units

The volume of runoff to be managed on-site is calculated within the stormwater runoff assessment tool 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 unit to the next until a user-defined outfall is reached.

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 down-gradient 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 stormwater runoff assessment tool requires the designer to take the following actions in order to assess a conceptual site layout:

- Selecting the project location from a pre-defined list of Tennessee cities, choosing a location most similar to the design location. This determines the regional representative rainfall event.
- Delineating the design units based on the project layout, with each unit representing a unique combination of soil, SCM/management, contributing unit(s), and down-gradient unit.
- Identifying for each unit its area, where it discharges (to a down-gradient unit or offsite), its SCM or management, the soil type (from a pre-defined list), and the depth to an impeding layer (such as a saturated zone, tight clay lens, man-made barrier, etc.) if applicable.

A pre-defined list of SCMs and management descriptions are also included in the assessment tool. 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 at the surface, whether it includes vegetation, and the type of vegetation.
- For infiltration-based SCMs, an estimate for the effect of land management at the soil surface.
- Estimation 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 Pollutant Removal Within Site Design Units

In the assessment tool, the treatment volume is any runoff generated by the first inch of rainfall onto site units that can potentially contribute pollutants. These areas include impervious surfaces (such as rooftops, pavements, dirt roads, etc.). For the performance criteria in the 2010 general permit, this is equivalent to the minimum treatment volume requiring 80% TSS removal. In order to be compliant with treatment requirements, this volume must run through an SCM that is approved for use in the local jurisdiction. (Note – the 2010 general permit requires one inch of runoff reduction and a minimum pollutant removal of 80% TSS, while the 2016 general permit requires 100% pollutant removal where conditions allow but without a required amount of runoff reduction. Local programs may base their requirements on either set of criteria.)

The assessment tool assumes 100% TSS removal for water that is infiltrated or harvested and reused, and it assumes a pollutant removal efficiency (based on TSS removal) for all other approved SCMs based on published data (Table 4.2). Any deviations from these values require validation by the designer with the local stormwater program.

Table 4.2: Summary of published data for 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 comprised of multiple SCMs in series. The assessment tool tracks flow routing through treatment train systems and the assigned pollutant removal efficiency of the individual measures. It also accounts for the runoff reduction with treatment train measures through mass balance. Total flow and treatment efficiency are accounted for volumetrically through the indicated flow routing paths. No additional inputs are needed to account for treatment train practices in the assessment tool.

4.5 Including SCMs for Stormwater Detention

While this manual and Tennessee's MS4 permits are focused on pollutant removal from small storms, SCMs that provide flood damage reduction and channel protection during larger storms are often required by local stormwater management programs. The design of these SCMs is based on a storm with a specific return frequency that is determined by the local program. Generally, a design storm with a 10-year or 25-year return period is used to size storm drainage infrastructure, and a 100-year return period is used to reduce flood damage. Channel protection is performed when outflow rates from SCMs are held at or below those for the 1-year or 2-year return period. This outflow rate protects the receiving channel from erosive flowrates that destabilize streambanks and channels. While SCMs that provide flood damage reduction and channel protection are encouraged, they are not mandated by MS4 permits. Check your local stormwater program for applicable regulations.

As seen in Table 4.2, SCMs that are designed primarily for larger storms, such as detention facilities, provide some pollutant removal for flows that pass through the SCM without infiltration, but it is less than the removal rate for infiltration-based SCMs. A treatment train or other combination of SCMs might be needed at sites with detention basins in order to meet design criteria for pollutant removal during small storms.

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.