Chapter 6

Using the Tennessee Runoff Reduction Assessment Tool (TNRRAT)

6.1 Overview – Terminology and Inputs

6.2 Design Examples

What's in this Chapter?

Section 6.1 provides general instruction on the use of the TNRRAT, mainly focusing on terminology used within the tool as well as preparing a user to execute the tool. This section does not provide substantial detail, relying for that instead on available video tutorials, which provide not only background but also step-by-step instructions.

Section 6.2 steps through two basic design examples from data input to running the tool.

The Tennessee Stormwater Management website is the clearinghouse for all state-stormwater management resources in Tennessee. Here, you will find a digital copy of this manual, a zip file that contains the TNRRAT files, and the tutorial videos described above. These videos walk users through the process of using the TNRRAT from loading the program to interpreting tool outputs.

www.tnpermanentstormwater.org

6.1 Overview – Terminology and Inputs

The Tennessee Runoff Reduction Assessment Tool, or TNRRAT, was created to help engineers, landscape architects, and other planners create development designs that meet Tennessee's runoff reduction requirements for permanent stormwater control performance. The tool was developed specifically to help designers and plan reviewers determine if projects meet requirements and to facilitate transparency throughout the process.

The TNRRAT models hydrologic processes on a time-mass basis using fundamental relationships to describe infiltration and storage phenomena under unique user-input conditions. Table 6.1 shows the equations used to characterize each pertinent hydrologic cycle component.

Table 6.1: Equations used to characterize each pertinent hydrologic cycle component.

Component	Equation	Justification
Storage	$= S_1 + P + RO_{on} - RO_{off} - 1 - ET$	A time-mass approach that accounts for runoff volume using a mass balance calculation of every 15 minutes of the representative storm event.
Precipitation	Representative Storm Event	95th-percentile rainfall depth over the median duration of storm event in a Type II storm intensity distribution.
Infiltration	Kostiakov-Lewis method (Walker and Skogerboe, 1987) $I = k * t^a + f_0 * t$	USDA-NRCS method developed from a range of large-scale supporting data in flooded systems across a wide range of soils and geographic locations. Where I = cumulative infiltration capacity, and *k, a,* and f_0 are empirical fit coefficients.
Management Adjustment	SCS Curve Number Approach (Hann et al., 1994) $MIR = \frac{S_{management}}{S_{bare}}$	Using a Management Infiltration Ratio (MIR) to adjust infiltration to account for the effects of vegetation and cover management. Curve Numbers were consistent with common values.

The fundamental approach of the TNRRAT design process is to divide the entire site into a number of design elements, which are units of land area or devices that affect the flow of water through the site. A design is created by defining and linking these elements in such a way to account for the entire site surface area that intercepts rain and then follow the path of any runoff until it goes offsite. The tool allows for treatment train routing configurations and multiple outfalls from the site. Each design element is a unique combination of factors including management or cover (including impervious), soil type, and routing information describing the flow patterns through contributing and receiving elements. Ultimately, performing a design analysis in the TNRRAT involves defining the elements and flow paths and then sizing and placing those elements such that permit requirements are met. User inputs and tool outputs are described in detail below.

User Inputs:

Location – the geographic location that best represents the project, which determines the representative rainfall information. Select the most proximate location to the proposed project site.

Target requirements – optional credits for special site land uses, as determined by the local jurisdiction. Credits may be applied towards meeting target requirements for the following types of projects: high density, vertical, brownfield/redevelopment, mixed use, and transit oriented projects.

Design elements – units of surface area or stormwater control measures (SCMs) that affect stormwater runoff and are spatially linked together to describe the entire project site. Design elements are delineated as having common characteristics of management (cover), soil type, and drainage point. There is no limit to the number of design elements within a project. Design elements are described, linked together, and routed to an outfall through the following element characteristics:

a. **Design element #** – a number given to the design element and used in describing flow routing. Design elements are automatically numbered sequentially starting with 1. Design element "0" is defined as being off-site.

b. **Discharges to design element #** – the design element to which discharge is routed, where "0" indicates routing off-site.

c. **Area, ft^2** – design element area. The only types of design elements not requiring specified areas are rainwater harvesting systems and manufactured treatment devices.

d. **Special condition** – indication that the element is a special management area that may place limits on allowable flow paths during the design process. Special conditions currently include hotspots, karst features, contaminated soil allowing infiltration, and contaminated soil without infiltration.

e. **Soil** – soil texture of the surface or otherwise "receiving" surface (i.e., the infiltration surface). If the design results in no or very little infiltration in this area (as for imperious surfaces or designs with and impermeable liner), this information is still shown, but has little impact on the result. Soils information may be gathered from the NRCS web soil survey for undisturbed areas. For highly disturbed area or areas without a true soil designation (such soils are often classified as "urban soils", a soil texture analysis or infiltration test is needed to classify soils (See Appendix A).

f. **Depth surf to restrictive, in** – depth from the final grade down to a restrictive layer. Restrictive layers include any material that impedes the infiltration of water into soil beneath and include bedrock, tight clay lenses, water table, etc. Most soils, whether undisturbed or disturbed, have a restrictive layer that will reduce infiltration. If the soil survey or expert opinion indicates that this location has no such restriction, entering a very large depth (e.g., 10 ft) will remove this impact.

g. **Base SCM/management** – the type of stormwater control measure and/or management of a design element. The menu includes impervious surface, unmanaged vegetated areas, and SCMs. Impervious surface characterizes all hard surfaces that contribute runoff, which is considered "dirty" and associated with target treatment volumes. Unmanaged vegetated areas are areas that do not meet management requirements of managed vegetated areas (see Chapter 5) and do not contribute pollutants. Variants of the SCMs are differentiated within the directory folders.

h. **Element SCM values** – information table of all pertinent design parameters associated with selected SCM/management. Some of these will be for informational purposes, and some will be eligible to be modified by the user as part of their design.

i. **Design element description** – optional description and notes.

TNRRAT Outputs:

Total surface area (ft^2) – the total project surface area, which includes all of the land area considered as part of the project. This is a summation of all the surface areas of the design elements and automatically calculated by the tool.

Impervious: Treatment ratio – calculated ratio of total impervious area to total treatment measure area used to evaluate spatial efficiency and optimization. TNRRAT result indicators – a set of three indicators that express the results of calculations for contaminant removal and runoff volume reduction requirements. These indicators are updated every time the user changes an input, and are as follows:

a. **"Pollutant removal OK?"** – indicates design status in meeting the minimum treatment requirement, defined in the permit as 80% pollutant removal from the first inch of rainfall through runoff reduction SCMs (infiltration or reuse). Green indicates a successful project design, yellow indicates that the pollutant removal requirement was nominally met, but not through volume reduction. Red indicates failure to meet requirements.

b. **"Volume reduction OK?"** – indicates whether the design meets the runoff volume reduction requirement, defined as one inch of the reduction sometime during the representative storm event. Green indicates a successful project design, yellow indicates that the designer indicated special management areas or other circumstances which lowered runoff reduction requirements and that these lower targets are met (but should be verified by a plans reviewer), and red indicates failure to meet requirements.

c. **"Flow paths OK?"** – indicates that routing between elements and saturation duration is acceptable.

Runoff requirements – tool outputs that show volume calculation results. "Net volume reduction depth (in)" is the total runoff depth that is reduced on the project elements. This number must be equal to or greater than the "Required volume reduction depth (1 inch)". "Net runoff volume (ft^3)" is the overall runoff leaving the site during the representative rainfall event. "Net runoff depth (in)" is the depth of runoff coming from the project site.

Treatment requirements – tool outputs that show pollutant calculation results. "Portion pollutant removed (%)" is the percent of the calculated contributed contaminated water that has been removed by the design. This number must be equal to or greater than the "Required pollutant portion removed (%)". "Portion pollutant removed by reduction (%)" is the percent of total flow volume treated through the preferred runoff reduction methods. "Net pollutant volume released (ft^3)" is the volume of runoff from pollutant potential areas released offsite. "Net hotspot volume released (ft^3)" is the volume of runoff from hotspot areas released offsite.

Using the Tool

The TNRRAT should be used early in the design process to help identify realistic design options and to optimize a project plan for meeting use targets (i.e., lot size, road size, impervious footprints) as well as runoff reduction targets. To complete a TNRRAT analysis, a designer must provide the following user inputs: 1) geographic location, 2) target requirements, 3) total project size, 4) exact locations of special conditions, 5) pertinent landscape capacity conditions, 6) locations of soil types, and 7) depth to any restrictive layers on the site.

A project concept plan should be developed to the extent that impervious surfaces and preferred SCMs are identified for the site given the intended landuse, keeping in mind long-term maintenance and operation. The areas of roadways, rooftops and all other impervious surfaces, as well as the pervious areas, should be determined with a known level of flexibility. For example, a target roadway and rooftop area per unit may be identified. Given the available pervious areas (i.e., lawns, landscaping, and common greenspace), the number of units and driveway dimensions may be optimized depending on runoff reduction capacity of that pervious area. Similarly, in a tight footprint commercial project, the area for parking may be limited by the selection and design of SCMs. Note too that flow patterns through the site are as important as the relative areas. This is the case since the net runoff from impervious areas must meet the pollutant removal requirements before leaving the site.

Suburban residential projects are often composed of repetitive units of roofs, driveways, roads, and lawn that may have consistent relative areas, as in Figure 6.1. Such repeated units comprise sub-basins that are delineated by a change in discharge element, soil, or other special site condition (i.e., hotspot, karst, depth to restrictive layer, etc.). If applicable, a representative unit may be created to determine the necessary size of lot-scale or sub-basin scale SCMs. The results can then be scaled up by multiplying the representative unit by the number of units in a particular plan. This will be successful for sub-basins that have relatively consistent management configurations. If the discharge element changes, then a new sub-basin is needed. Complex topography and natural drainages necessitate the use of routing and should be considered when creating representative units.

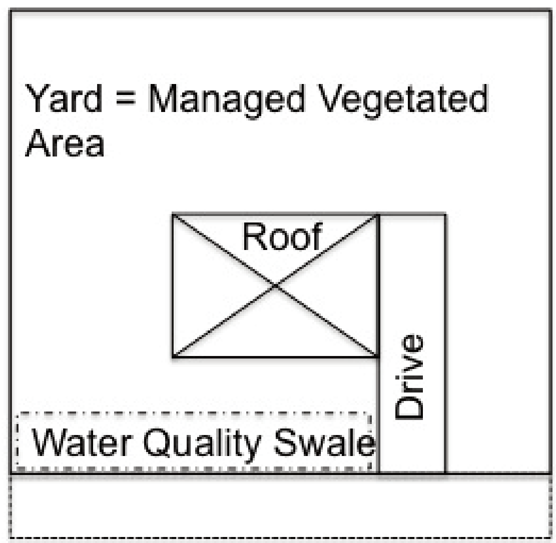


Figure 6.1: A representative single-family residential unit used to determine lot-scale SCM dimensions and scaled up by a factor equal to the number of units in a sub-basin.

The flowchart (Figure 6.2) provides a list of steps for general TNRRAT operation to help a designer integrate the tool into their design process. Information from the initial site inventory (see Chapter 3) will guide the concept plan stage. It is then advantageous to use the TNRRAT as a high-level check to ensure the envisioned land use needs can be accomplished within the available space, while taking into account any unique site conditions. Iterative use of the design worksheet and selecting appropriate SCMs is then required until routing flow paths from impervious surfaces and between sub-basins all connect to offsite discharge locations. From here, this plan may be tested using the TNRRAT to optimize placement and sizing of SCMs and other flexible elements.

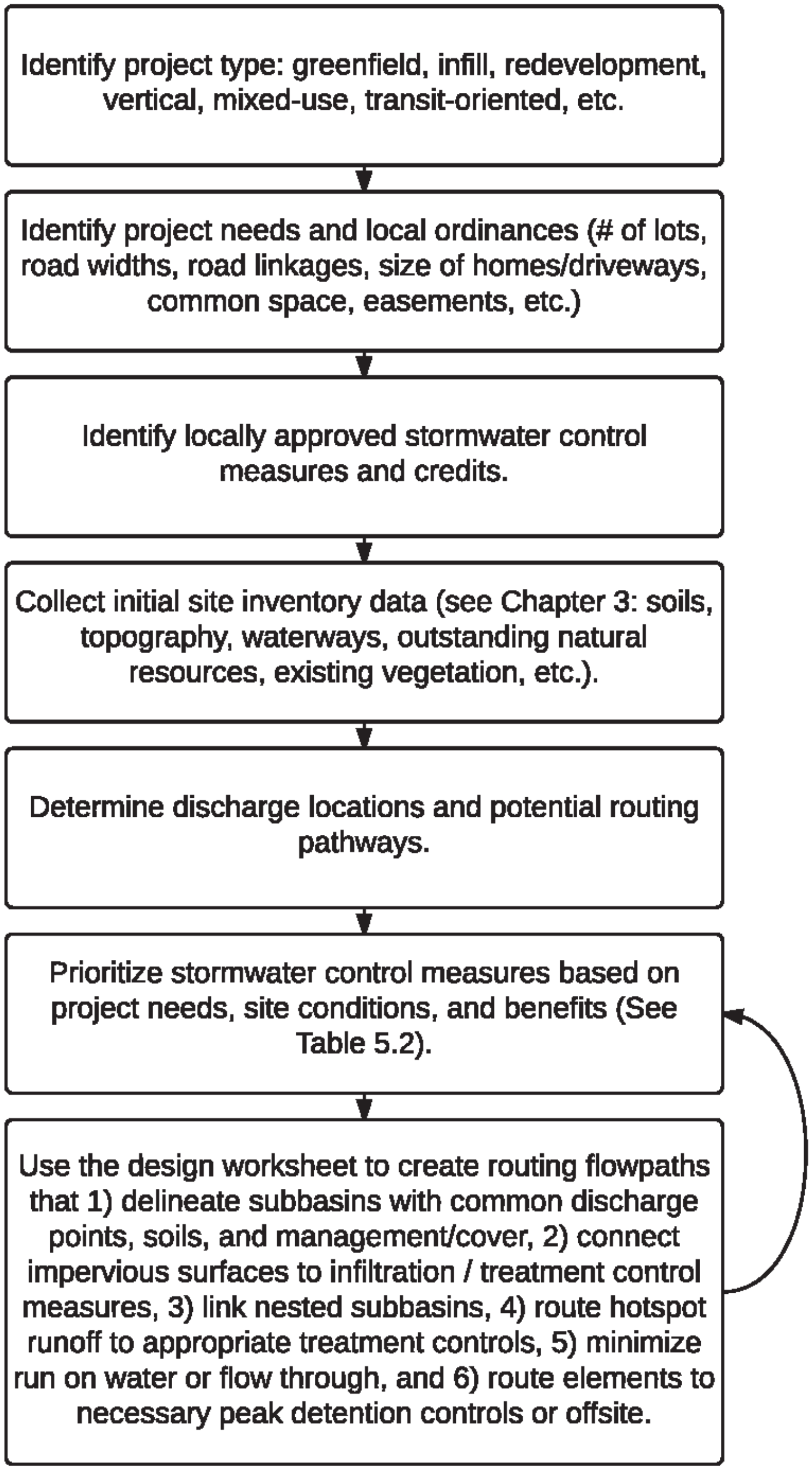


Figure 6.2: General design steps from project conceptualization and site inventory, transitioning to TNRRAT use.

Finally, a designer must understand the site and project conditions that affect routing between design elements. To assist in conceptualizing a project in terms of routing, the following design worksheet was developed to accompany the TNRRAT. Use this worksheet to lay out design elements, create flow paths, and delineate sub-basin units that discharge off-site. Once the worksheet is complete, a TNRRAT run can be easily performed.

Design #/Name: ____________________ Designer: ____________________ Date: ___________

Remember to include:
- area elements
- "arealess" elements
- flow directions
- soil differences

Location: ______________________________________

Jurisdictional requirement name: ________________

design elements: __________

Total surface area: __________

Special land use/s:
- Redevelopment ______
- Brownfield ______
- High density development ______
- High vertical density ______
- Mixed use / transit ______

Elem. #	Disch. #	Area (ft^2)	Special condition	Soil	Adds TSS?	Management / SCM

Figure 6.3: Tennessee Runoff Reduction Assessment Tool design worksheet to assist with efficient model use.

Now that the project has been conceptualized and routing flow paths have been identified, use the TNRRAT to determine the precise size of all elements. Revisit the project goals to help prioritize which elements may be adjusted to reach a successful design and set reasonable bounds for SCMs and other flexible elements.

1. Use unit blocks to represent areas of a project plan that: 1) have consistent soil types; 2) are comprised of consistently sized lots with consistent ratios of impervious to pervious surfaces; 3) have a common discharge point; and 4) incorporate the same lot-scale runoff reduction measures. Some additional considerations include:
    a. Once targets have been met for a unit, these elements may be routed offsite if there is no treatment to be accounted for in downstream practices. For example, if swales in the associated right-of-way of each lot create a successful design and there are no other areas of impervious runoff to treat, then the unit elements may be routed offsite even if there is a peak flow detention measure in place at the end of the flow path (assuming this measure is not needed to meet treatment requirements).
    b. Elements of each unit must be entered individually if treatment is needed in additional elements off the lot.
    c. Volume results may be scaled up by multiplying by the number of units; however, area may not be linearly scaled up due to the manner in which deep infiltration is modeled. Lateral infiltration is accounted for when the potential for infiltration into an adjacent soil is greater than the soil at the base of the cell. Due to this, many small infiltration cells will have a different overall impact on retention than one large cell.
2. SCMs will typically occupy areas that would otherwise be a managed vegetated or impervious area. It would be advantageous to highlight on the design worksheet the elements that are flexible in size (eg. the ones that can shrink as SCM space is needed). Remember to subtract the SCM area from the design element area it has replaced. Frequently check the Total Surface Area box to ensure the target project size is correct.
3. To gain runoff reduction volume, increase the ratio of pervious to impervious area or incorporate infiltration SCMs. These measures are most effective when applied as diffusely as possible throughout the project plan (keeping in mind operation and maintenance activities).
4. To gain pollutant removal percentages, look for opportunities to first increase infiltration. Keep in mind that the smaller the contributing drainage area, the smaller the necessary SCM footprint. Once these options are exhausted, look for opportunities to incorporate treatment measures or add storage to infiltration practices as appropriate.
5. The "Impervious:Treatment ratio" can be used as a general scaling tool to evaluate the efficiency of the space used for treatment measures relative to the contributing area, assuming an underlying goal is to minimize their footprint within the plan. Some SCMs such as infiltration areas and swales that rely purely on surface infiltration with no storage will have a relatively low ratio (< 4) while other SCMs with large storage volumes, such as bioretention or underground infiltration systems, may have ratios above 15. However, this number is also sensitive to soil characteristics including texture and depth to restrictive layer, and to the quality of the management vegetation.
6. If flow from an element runs onto an impervious surface that does not route to a SCM, then those elements may all be routed to offsite (aka "0"), assuming none of these elements are hotspots. There is no need to route impervious surfaces together if they both ultimately flow offsite without flowing through another SCM. The maximum percentage of offsite routing of impervious surface runoff without treatment is 20%, which would require 100% treatment of the remaining 80% volume.
7. Run on flow should be included as "upslope areas." These management selections are located in the "miscellaneous management" folder and are classified as either "dirty" or "clean." Calculate the volume of run on coming from the off-site contributing area. Input an element size equal to the volume divided by the representative rainfall depth for your location.

Additional useful tips and design examples may be found at the Tennessee Stormwater Management website. This site will be constantly updated with answers to frequently asked questions.

6.2 Design Examples

Design Example 1 – Mixed Single-Family (SF) and Multi-Family (MF) Residential, 40-acre Greenfield project in Knox County, TN

Site Location: Knox County, TN

Watershed: Beaver Creek, Clinch River

Size: 40 acres

Target Requirement Credits: None

Special Management Areas: None

Soils: Silt Loam, Clay Loam, restrictive layer at least 40”

Project Use: 70 single-family residential units, 35 condominium units

Typical Units:

- Single-family (SF) unit: 1/3-acre lot, 3200 ft^2 rooftop, 1000 ft^2 driveway, 105 ft frontages
- Condominium unit: 0.15-acre lot, 2100 ft^2 rooftop, 350 ft^2 driveway, 80 ft frontages

Roadways: 27 ft-wide roadways, 5,115 total length

Local Municipal Program Ordinance on SCM Use: All acceptable

Site considerations: The general lay of the parcel is along an existing roadway, where the highest elevations lie at the north end and elevations fall at a relatively consistent slope to the lower end. A natural drainage exists at the lower end of the project site between the SF units and condominiums. Another drainage runs along the eastern perimeter of the condominiums. These two drainages converge at the bottom of the site and are routed through a culvert under an existing road. A soil type change from silt loam to clay loam at the upper most elevations delineates a line between two single-family unit sub-basins.

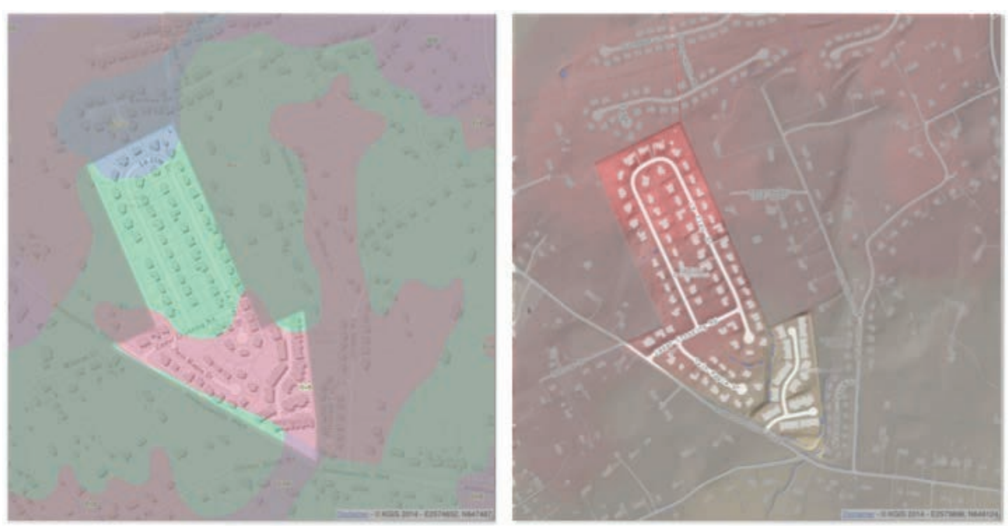


Figure 6.4: Project site maps with proposed plat overlay
***Left:* Soil classifications (blue show silt loam, green and pink show clay loams)**
***Right:* Topographic map showing higher elevations on the north of the property (red) and lower elevations in the south end (tan).**

Two approaches were used to model potential stormwater management systems. First, an approach using lot-scale SCMs was used to show how targets may be met through maximizing the use of small, diffuse pockets of storage on each individual lot. While this approach will require a larger inspection effort given the increased number of practices and their locations on private property, it most effectively uses a site’s vegetated areas as SCMs to capture stormwater runoff as close to its source as possible. The second approach recognizes that many communities will not have the capabilities to allow lot-scale practices. Here, subbasins of 2-3 acres are delineated throughout the project site and bioretention and swales capture flow from these subbasins. These SCMs are all located in either drainage easements along the rear property line or in common open spaces, which were already part of the neighborhood plan layout.

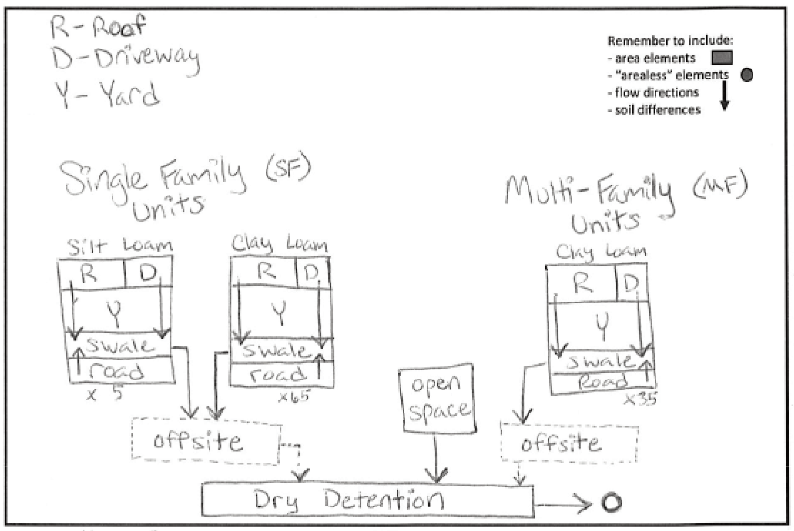
Approach 1: Lot-scale treatment of all “dirty” impervious areas (roads, roofs, driveways) with right-of-way, 8ft-wide vegetated swales with 3” storage.

The design worksheet below shows the compilation of design elements needed to test the overall plan in the tool. In this approach, there are two types of unit designs: single-family and multi-family units. Two single-family units are identified due to a change in soil type from silt loam to clay loam going down slope. Since there is a consistent density of impervious surface to lawn ratios among the units, lot-scale measures can be sized using a single individual unit comprised of a group of elements (roof, driveway, yard, road, and swale).

The only remaining management not treated in on-lot swales is open space, or managed vegetated area (turf, fair). Since there is no runoff volume coming from this open space that must be treated for pollutant removal requirements, the dry detention basin will be sized outside of the RRAT based on local detention requirements. The units are routed to “offsite” even though on the plan they will discharge to storm drains that carry flow to the detention basin. This type of routing to a false “offsite” location can only take place here because we have met runoff reduction and pollutant removal requirements at the lot scale for all the “dirty” areas in the entire plan.

TN Runoff Reduction Assessment Tool (RRAT) Design Worksheet

Design #/Name: Greenfield 1 Designer: A. Ludwig Date: 10/1/2014



Location: Knox County, TN
Jurisdictional requirement name: Knox County

Special land use/s: NA
Redevelopment ____
Brownfield ____
High density development ____
High vertical density ____
Mixed use / transit ____

design elements: 17
Total surface area: 1742,400 ft² → 40 acres

Elem. #	Disch. #	Area (ft²)	Special condition	Soil	Adds TSS?	Management / SCM
1	5	3200	NA	Silt Loam	Y	SF roof -unit
2	5	1000	NA	"	Y	SF drive -unit
3	5	9580	NA	"	N	SF yard -unit
4	5	1418	NA	"	Y	SF road -unit
5	0	740	NA	"	N	SF swale – 3" store-unit
6	10	3200	NA	Clay loam	Y	SF roof -unit
7	10	1000	NA	"	Y	SF drive -unit
8	10	9580	NA	"	N	SF yard -unit
9	10	1418	NA	"	Y	SF road - unit
10	0	740	NA	"	N	SF swale – 3" store-unit
11	15	2600	NA	"	Y	MF roof -unit
12	15	350	NA	"	Y	MF drive -unit
13	15	3084	NA	"	N	MF yard -unit
14	15	1080		"	Y	MF road -unit
15	0	525		"	N	MF swale -unit 3" store
16	17	359,170		"	N	open space - MVA
17	0	ND		"	N	Dry Detention

Figure 6.5: Design Worksheet from the lot-scale management approach of a greenfield development in Knox County, TN.

On-lot swales were sized to treat runoff from the roof, driveway, and road. From this result, the yard area was determined as the difference in element 1-3 area and the sum of the hard surfaces and the swale area. The final project plan uses vegetated swales on SF lots with an area of 740 ft2 and 3” storage capacity and on MF lots with an area of 525 ft2 and the same storage. The overall Impervious:Treatment ratio is approximately 6. A detention facility will be required at base of the project to meet local flood protection standards. This facility does not need to be in included in the model because the system does not rely on the treatment by this facility in order to meet targets (e.g. treatment from the detention facility will be above and beyond the minimum requirement).

Approach 2: Roof and driveways all connected to roads (no on-lot treatment), sub-basin SCMs in common areas and linked with vegetated swales.

Bioretention and swales were selected for use on this project due to the aesthetic benefits for the neighborhood and potential for flexible storage capacity. The design worksheet shows the compilation of design elements in this second approach. Fourteen sub-basins of 2-3 acres of SF and MF lots are delineated to drain to bioretention cells that are located either in drainage easements (running along the rear property line of SF lots) or in common green space areas. Larger bioretention cells are used in the common areas and smaller cells used in the easements. A network of swales connects bioretention cells and routes flow down through the site and ultimately to the inlet of a detention facility.

On the worksheet, a SF unit and an MF unit are described in the box to the left and represented in the flow network with an abbreviation. Because this approach necessitates careful tracking of routing flow paths, elements and units should be placed on the worksheet in a spatially-representative pattern to reflect the general overall topography of the site. A dashed dotted line delineates the soil transition from silt loam soils to clay loam soils and the associated design elements for each.

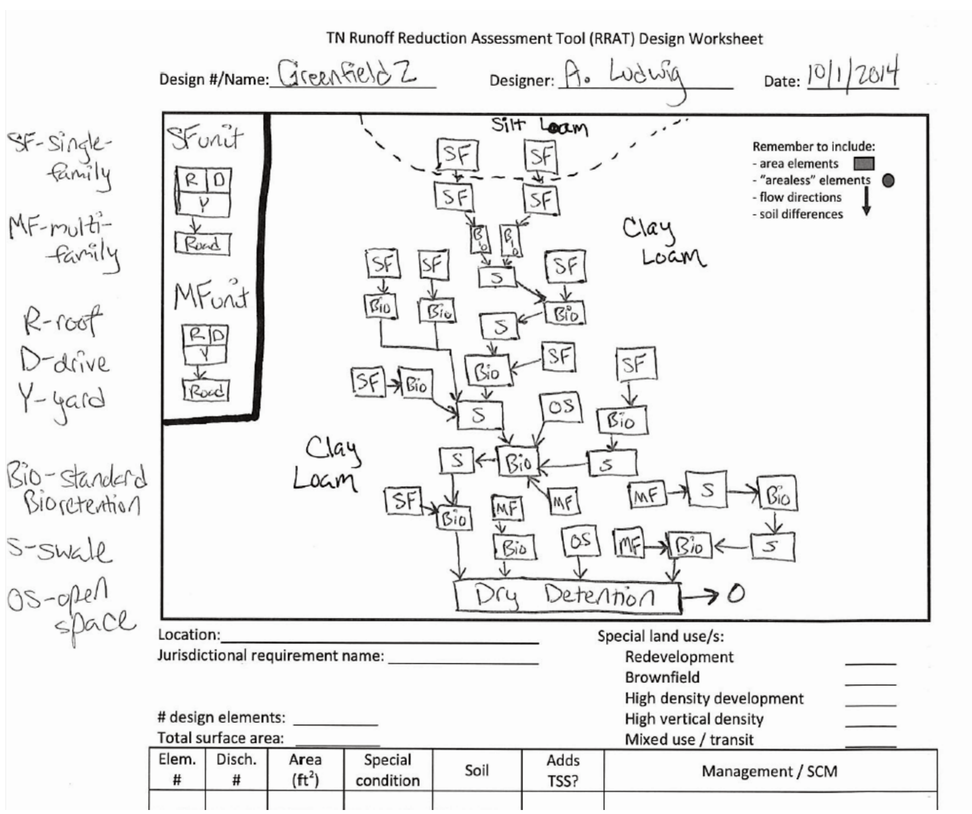


Figure 6.6: Design Worksheet from the common space management approach of a greenfield development in Knox County, TN.

The system of SCMs is completely located in common space and easement areas, with no on-lot practices.

The managed vegetated area in the design layout is large enough relative to the amount of impervious surface that the plan meets volume reduction requirements. However, structural SCMs need to be implemented to meet pollutant removal requirements. Water quality swales and bioretention were selected for the site due to the following characteristics: 1) provides adequate surface storage, 2) easily incorporated into landscaping aesthetics of the neighborhood, and 3) provides infiltration-based treatment since there is no restrictive layer influence. Water quality swales with 6 inches of surface storage with a width of 10-12 ft lie along major routing flowpaths. Standard bioretention cells receive water from 6-8 single family (SF) units, or approximately 2.5 acres. There are 14 bioretention cells that vary in size from 600-2000 ft^2, for a total cumulative area of 17,225 ft^2. There are approximately 3,360 linear feet of water quality swale, for a total cumulative area of 37,000 ft^2. Finally, MVA (open space, OS) size was determined by subtracting the needed bioretention area from the available managed vegetation area space. The Impervious:Treatment ratio is approximately 10. Again, the detention facility is outside of this system, as it is only needed to meet flood and channel protection requirements.

REFERENCES

Hann, C.T., B.J. Barfield, J.C. Hayes. 1994. Design Hydrology and Sedimentology for Small Catchments. Academic Press, New York.

Walker, W.R., G.V. Skogerboe. 1987. Surface irrigation: Theory and practice. Prentice-Hall, Englewood Cliffs.