Appendix 3

Milwaukee Metropolitan Sewerage District (MMSD)
Quicksheet 1.2

LID QuickSheet 1.2

A Spreadsheet for Determining the Capacity of LID Features
to Meet MMSD Chapter 13 Requirements

USER MANUAL

May 6, 2005

The Milwaukee Metropolitan Sewerage District

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LID QuickSheet 1.2

A Spreadsheet for Determining the Capacity of LID Features
to Meet MMSD Chapter 13 Requirements

USER MANUAL

1. Introduction

MMSD Chapter 13 permits governmental units to require analyses of individual site developments to demonstrate that those developments meet one of two technical requirements for managing runoff. The requirements to be met for the site are:

1. Peak flow control that meets Unit Release Rate (URR) targets. Those targets are 0.15 cfs/acre for the 2-year return period storm and 0.50 cfs/acre for the 100-year return period storm.

2. Volume control that meets the Volumetric Design Procedure (VDP) target. The VDP requires that the amount of runoff that is discharged from the developed site during a critical time period does not exceed the amount generated under predevelopment conditions. The critical time period has been predetermined for different watersheds, as described in the MMSD Surface Water and Storm Water Rules (MMSD 2002).

This spreadsheet estimates the capacity of Low Impact Development (LID) design strategies to help meet the URR requirements and thereby reduce or eliminate the need for conventional detention storage to meet the Chapter 13 requirements. LID design involves:

1. Minimizing the capacity of the land surface to generate runoff.
2. Slowing down and dispersing the runoff.
3. Collecting and retaining the runoff in small, distributed storage volumes.
4. Infiltrating the runoff where possible.

To determine the collective effect of these strategies on the hydrology of a site, the spreadsheet incorporates a subset of the analytic methods described in Technical Release 55 (TR-55), *Urban Hydrology for Small Watersheds* (Soil Conservation Service, 1986)[1] and Technical Release 20 (TR-20), *Computer Program for Project Formulation Hydrology* (Soil Conservation Service, 1983). The spreadsheet is intended to be used in conjunction with these reference documents. Both of these methods are based on the procedures for hydrologic analysis that are presented in the *National Engineering Handbook,* Section 4 (Soil Conservation Service, 1985). Additionally, various LID design features are described in *Memorandum: Evaluation of Stormwater Reduction Practices* (MMSD 2003).

[1] Note: Since the publication of TR-55 and TR-20, the Soil Conservation Service (SCS) has been renamed the National Resources Conservation Service (NRCS). The abbreviations SCS and NRCS are used within this document interchangeably.

Through the use of curve number (*CN*) and time of concentration (*Tc*) parameters, the procedures found in TR-55 and TR-20 can already take into account the manner in which LID influences the rate of runoff generation and the rate at which the runoff is conveyed across a site. Relative to the *CN* value for conventional site design, for example, the *CN* value might be decreased for an LID design because of reductions in the amount of impervious area. Likewise, the *Tc* value for an LID design might be increased on account of the greater use of vegetated swales rather than channelized stormwater conveyance systems.

Beyond the *Tc* and *CN* effects, however, LID design will also take advantage of opportunities for providing distributed retention storage. Retention may be provided, for example, in bioretention cells, in the gravel beds underlying permeable pavements, or on vegetated roofs. To directly account for the effect of distributed retention storage in a manner not currently available in TR-55 or TR-20, this spreadsheet has incorporated an adaptation of the TR-20 unit hydrograph calculations in a manner that treats the site retention volume as a uniform depth of storage across the drainage area.

2. General Guidelines

This spreadsheet requires the input of standard NRCS unit hydrograph parameters and additional information about the runoff storage capacity of specific LID features. These guidelines assume that the user already has a familiarity with the NRCS runoff calculation procedures for developing a composite *CN* value as an area-weighted average and for determining *Tc* values. Please refer to TR-55 and TR-20 for a detailed description of those procedures.

2.1. Terminology

The term *retention* in this document refers to the capture of runoff during a storm event so that it is not discharged from the site as surface flow, but is retained on site and subsequently infiltrated, evaporated, absorbed by vegetation, or withdrawn for consumptive use. *Retention* is carefully distinguished here from *detention*, which refers to runoff that is only temporarily stored, as in a detention pond, before it is released from the site.

The term *rain garden* is here used synonymously with the term *bioretention cell*. A rain garden is a landscaped depression that is designed to capture and infiltrate runoff.

2.2. Technical Issues

The spreadsheet sums the total retention storage volume provided on site and then obtains an average storage depth by dividing the total volume by the drainage area. Only after the runoff depth exceeds the storage depth during a design storm is a component of the runoff hydrograph generated. The rationale for adapting the NRCS unit hydrograph calculations in this manner is presented in Appendix A.

Care should be taken in the design and analysis of a site to ensure that the retention volumes entered into the spreadsheet are actually filled during the storm event. It is conceivable that the amount of runoff going into a rain garden, for example, will not actually fill the storage volume available. In such a situation, the runoff volume, rather than the full capacity of the rain garden, will represent the amount of water that does not flow to the drainage area outlet.

The analysis of a site will require subdividing it into small drainage subareas and comparing the volume of runoff flowing into each retention feature with the capacity of that feature. The lesser of the runoff volume and the storage capacity should be aggregated with the rest of the on-site retention for input into the hydrograph calculations.

Because the effect of the storage depth is evaluated as if it is uniform across the site, it is left to the analyst and reviewer to determine whether this assumption is appropriate for a particular site design.   The more uniform the distribution of retention is, the more appropriate the assumption. Figure 1 is an example of a residential area that makes considerable use of on-lot space for retention storage (as indicated by the small irregular shapes on the site). Although the placement of retention is not perfectly uniform, the wide distribution suggests that treating the storage depth as uniform may not be unreasonable for this design.

While LID features such as rain gardens and permeable pavements may be designed with underdrains, the calculations provided in the Quicksheet assume that no LID feature has an underdrain flow rate that contributes significantly to the peak of the runoff hydrograph. If the rate does become significant, then an additional analysis may be advisable to count that rate as being added to the hydrograph peak, or to route the runoff hydrograph through the device.

As with conventional approaches to stormwater management, some engineering judgment will be required to ensure that the parameter values selected in practice represent actual site conditions. Responsible design and analysis using this tool will seek to fully account for the capacity of LID features to reduce runoff. It is equally important, however, to avoid overestimating their capacity in a manner that would pose an increased risk of flooding and erosion downstream of the modeled drainage area.

3. Comparison of Conventional and LID Curve Number Calculations

Figures 2 and 3 show conventional and LID site plans for a 6.5-acre residential townhouse development. Tables 1 and 2 show the weighted curve number calculations for each site. The reduction in the curve number was achieved primarily by increasing the amount of wooded area. Additionally, the impervious area was somewhat reduced in the LID design by decreasing the road width.

According to the standard NRCS runoff depth calculation, for a 2.57-inch storm the lower curve number will reduce the depth of runoff from 0.9 to 0.6 inches. When the bioretention areas that have an average ponding depth of 6 inches and a subsurface storage capacity of 3 inches, the LID spreadsheet indicates that only 2.2% of the site area is needed to reduce the peak flow to a target level of 0.15 cfs/acre. Without the reduction in curve number, approximately 5.0% of the area would be needed.

For sites with no more than 30% impervious area, additional reductions in the curve number can be gained by disconnecting the impervious coverage. This encourages infiltration by preventing runoff from flowing continuously across hard surfaces from the point of runoff generation to the drainage area outlet.

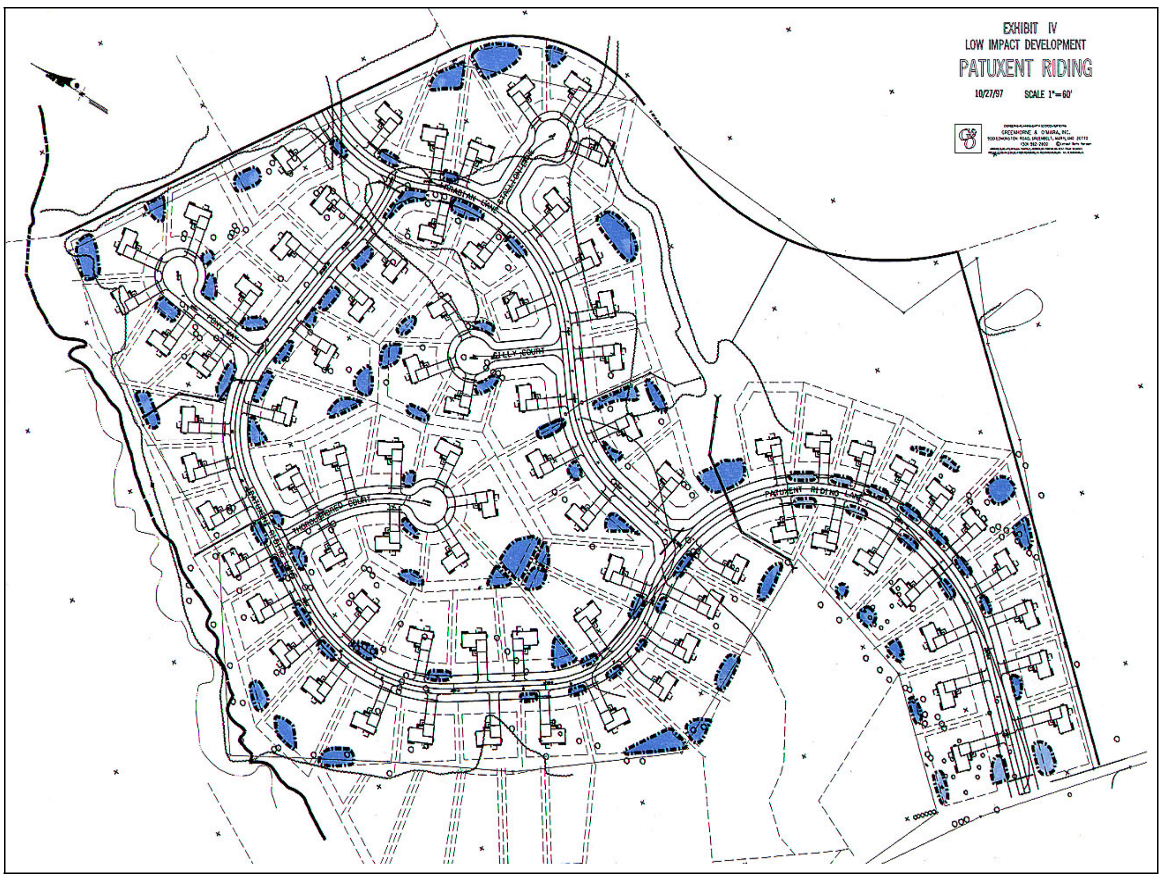


Figure 1. Residential LID Case Study Site Plan
Source: Prince George's County, MD, 1997

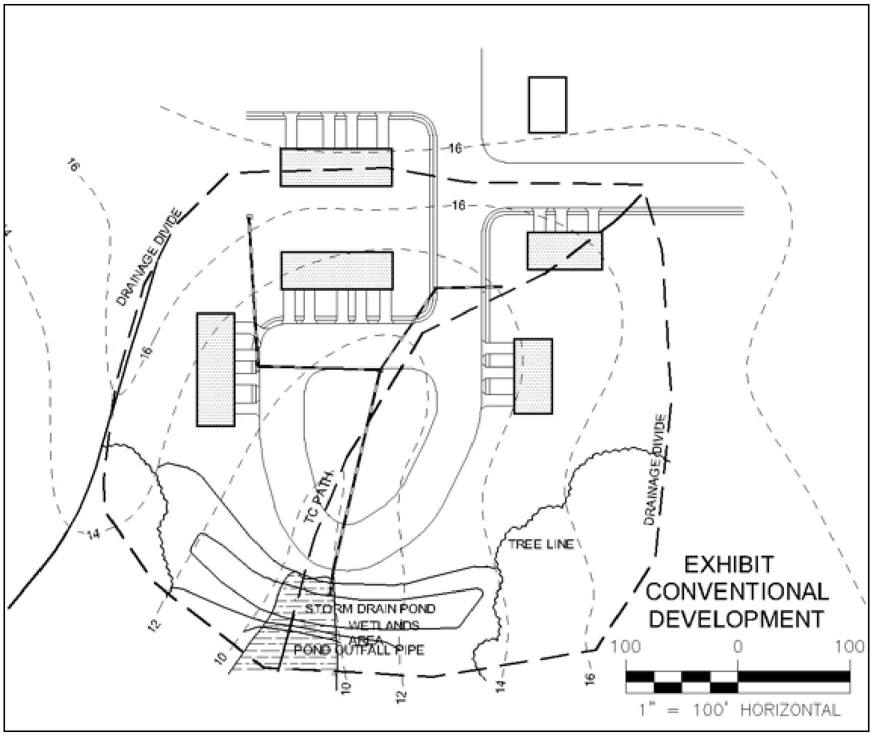


Figure 2. Conventional Site Example

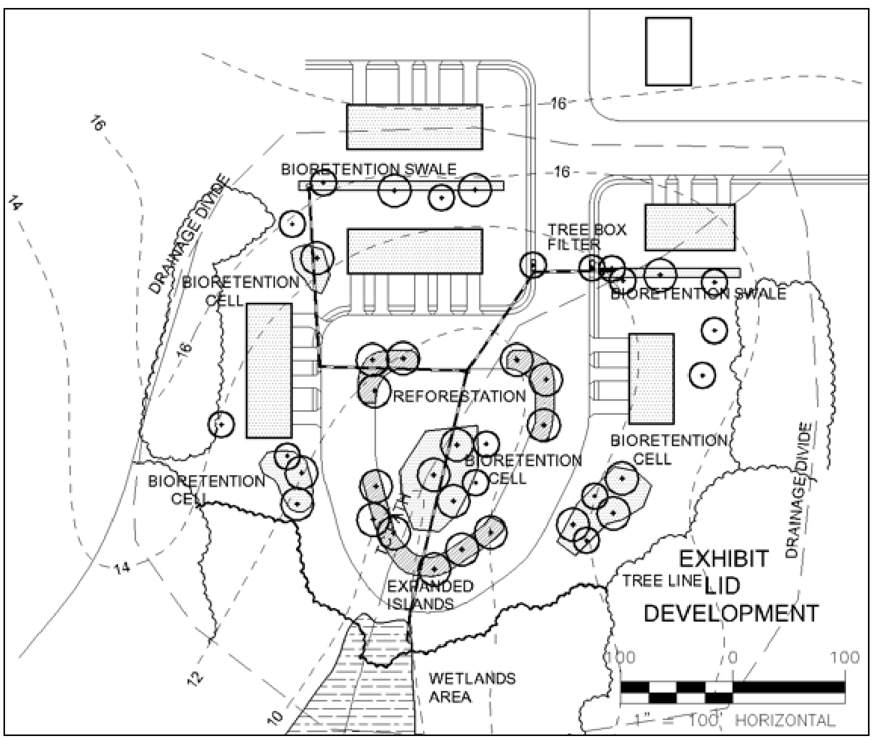


Figure 3. LID Site Example

Hydrologic Soils Group	Cover Description	CN (Table 2-2 TR-55)	Area (Acres)	Product of CN x Area
B	Lawn (fair condition)	69	3.2	220.8
B	Woods, Fair	60	0.7	42.0
B	Impervious	98	2.6	254.8
			Sum of Products	**517.6**
			÷ Drainage Area	6.5
			Weighted CN	**80**

Table 1. Area-Weighted CN Calculation for Conventional Design

Hydrologic Soils Group	Cover Description	CN (Table 2-2 TR-55)	Area (Acres)	Product of CN x Area
B	Lawn (good condition)	61	1.8	109.8
B	Woods, Fair	60	2.5	150.0
B	Impervious	98	2.2	215.6
			Sum of Products	**475.4**
			÷ Drainage Area	6.5
			Weighted CN	**73**

Table 2. Area-Weighted CN Calculation for LID Design

4. Designing with the Spreadsheet

4.a. How the Spreadsheet is Organized

Within the spreadsheet file, five different sheets are available to the user by clicking on tabs at the bottom of the page. The portions of the spreadsheet available for user input and output are as follows:

- *ReadMe* Basic information about the use and function of the spreadsheet.
- *MainPage* The main page used for the input and output (Figures 4a and 4b).
- *SubareaCheck* Justifies use of retention volumes entered into *MainPage*.
- *RainDistribution* Allows the use of different temporal rainfall distributions.
- *OutputHydrograph* Provides LID hydrograph values for export.

4.b. Stepwise Overview of LID Site Design

Here is a brief overview of how to proceed using information available about your site:

1. For the proposed site design, determine drainage area divides, land use, and flow paths.
2. For comparison purposes, estimate the *CN* and *Tc* values assuming that no LID features are used on the site.
3. Enter the *CN* and *Tc* values into the spreadsheet to estimate a detention pond volume when no LID features are used.
4. Minimize the overall *CN* and maximize the *Tc* values for your LID site design, and enter those values into the spreadsheet.
5. Select the LID features that are feasible for the proposed site, considering the options described in *Memorandum: Evaluation of Stormwater Reduction Practices.*
6. Enter into the spreadsheet realistic values for the amount of retention storage that could be provided on site using the selected LID features at identified locations, and observe the calculated reductions in the peak flow runoff rate and detention pond size.
7. Add no more storage when the desired level of reduction in the peak flow value or the detention pond size is achieved, or if no additional storage will be provided due to site constraints.
8. Compare the volume of runoff flowing into each feature with the actual retention volume of that feature, and check to ensure that the volume considered in the calculations is the lesser of the two. The comparisons can be summarized in the sheet *SubareaCheck*.
9. Check the final site plan against spreadsheet input and finalize the two pages of *MainPage* as part of the Chapter 13 submittal.
10. If a detention pond needs to be sized, use the LID hydrograph values provided in the sheet *OutputHydrograph*.

Screenshots of the main page of the user interface are shown on the next two pages. Following the screenshots are line-by-line instructions for providing the input and interpreting the output of the spreadsheet.

LID QuickSheet 1.1

SITE SUMMARY *Enter data into the shaded boxes only.*

Line						
	PRECIPITATION and DRAINAGE AREA					
1a		100	*years*	Return period for this storm event.		
1b		NRCS Type II		Rainfall distribution. *See RainDistribution sheet to change.*		
2a	**P**	5.88	*inches*	Total precipitation.		
2b	**A**	100.0	*acres*	Drainage area.		
2c	**CN minimum**	25		CNs must be greater than this value to generate runoff.		
	NoLID DESIGN					
3a	**CN**	85	Area-weighted average for the NoLID site design.			
3b	**Tc**	30	*minutes*	Cannot be less than 5 minutes.		
	LID DESIGN					
		Standard CN Determination				
4a	**CN**	78	Area-weighted average for the LID site.			
		Optional CN Determination	*If option not used, enter zeroes in Lines 4b-4d.*			
4b	**CN_p**	70	Composite CN_p for pervious areas alone.			
4c	**P_{imp}**	30%	Actual percent impervious.			
4d		0.2	Decimal <= 1.0. Ratio of unconnected impervious area to total impervious area. *(Enter "0" as the ratio if total impervious area is greater than 30% of site.)*			
4e	**CN result:**	77	(The "CN_c" in TR-55 Appendix F)			
4f	**Selected CN**	77	Enter the value from Line 4a or Line 4e.			
4g	**Tc**	45	*minutes*	Cannot be less than 5 minutes.		
	LID Retention Features		*For individual features, compare the contributing runoff with the capacity, and take the lesser of the two. Summarize on SubareaCheck sheet.*			
	Rain Garden Capacity					
5a		6.0	*inches*	Average ponding depth.		
5b		16.0	*inches*	Average soil mix depth available for retention (24 inches or less).		
5c		0.2	*(unitless)*	Average fillable porosity.	**Design**	**Volume**
5d		9.2	*inches*	Storage per unit area.	*acre-feet*	*gallons (thousand)*
5e	**Rain Garden**	4.0%	of drainage area used for rain gardens.		3.07	999
5f	**Coverage**	174240	*sq.ft.*	*(average of top and bottom areas)*		
6a	**Rain**	55.0	*gallons*	Capacity of each rain barrel.		
6b	**Barrels**	100		Number of rain barrels.	0.02	6
7a	**Green Roofs**	3.0	*inches*	Maximum Water Capacity (MWC).		
7b		0.50		Multiplier between 0.33 and 0.67.		
7c		10000	*sq.ft.*	Area.	0.03	9
8	**Cisterns**	1000	*cu.ft.*	Sum of all cistern volumes.	0.02	7
9a	**Permeable**	5.0	*inches*	Storage depth, or capacity per unit area.		
9b	**Pavement**	1600	*sq.ft.*	Paved area.	0.02	5
10	**Other**	80000	*cu.ft.*	Additional storage not listed above.	1.84	598
				Total	4.99	1625

Figure 4a. First page of the main spreadsheet interface (*MainPage* tab)

LID QuickSheet 1.1

URR SUMMARY *Enter data into the shaded boxes only.*

Line	***Unit Release Rate Target***		
20	0.50	*cfs/acre*	*See User Manual to select value.*

Site Runoff

Line			NoLID	LID	Reduction
21a	**Depth**	*inches*	4.19	2.78	34%
21b	**Volume**	*ac-ft*	34.91	23.13	
22a	**Peak**	*cfs*	352.5	184.1	48%
22b	**Peak/area**	*cfs/acre*	3.52	1.84	

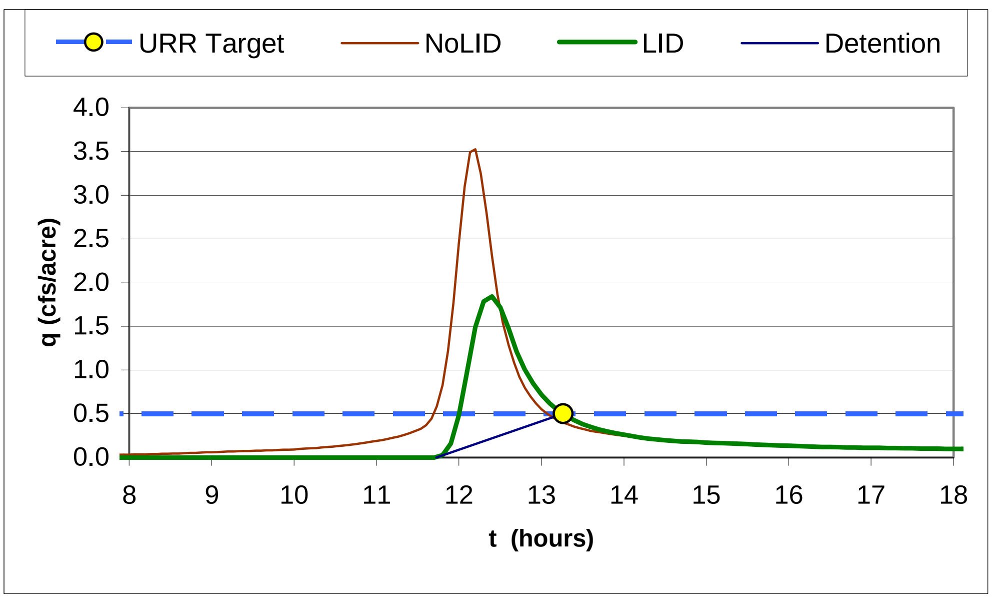
Conventional Detention Needed to Meet Peak Flow Target

Line			NoLID	LID	Reduction
23a	**Depth**	*inches*	1.98	1.10	44%
23b	**Volume**	*ac-ft*	16.49	9.18	

LID Split Flow Option. *If discharge above target rate is directed into retention at outlet, this retention volume can replace detention pond volume:*

Line				
24a	**Depth**	*inches*	0.79	(Compare to Line 23a, LID column)
24b	**Volume**	*ac-ft*	6.59	(Compare to Line 23b, LID column)

25 ***Runoff Hydrographs for URR Analysis***



Input by: ______________________ Date: ____________

Checked by: ______________________ Date: ____________

Figure 4b. Second page of main spreadsheet interface (*Mainpage* tab)

5. Site Summary

The Site Summary page (Figure 4a) is for the user to provide input values for the URR evaluation.

5.1. Precipitation and Drainage Area

1a. Enter the return period associated with the precipitation depth and peak target rate given. Both the 2-year and 100-year 24-hour storm events should be evaluated.

1b. This line shows the name of the design storm distribution that has been entered on the *RainDistribution* sheet.

2a. Input the rainfall depth designated by the Southeastern Wisconsin Regional Planning Commission (SEWRPC) for the 2-year and 100-year 24-hour storm events. For the 2-year event, the rainfall depth is 2.57 inches, and for the 100-year event, the rainfall depth is 5.88 inches.

2b. Input the drainage area. If the site as a whole does not have uniform land cover and soil types, consider dividing it into separate drainage areas and using the spreadsheet multiple times.

2c. This output is for user information as *CN* values are input in the cells below.

5.2. NoLID Design

These values are used to generate a runoff hydrograph and estimate the detention pond volume if no LID strategies are implemented on the site. In Figure 4a, for example, the “No LID” *CN* value of 83 was taken from Table 2-2a of TR-55 as the value associated with 1/4-acre lots on hydrologic soil group C.

Because the LID design does not depend on these numbers, for practical reasons a detailed evaluation of the NoLID design may not be necessary. The calculations for the NoLID design are provided simply for comparison with the LID design.

3a. Enter the curve number for the NoLID design.

3b. Enter the time of concentration for the NoLID design.

5.3. LID Design

Taking Into Account the Preservation of Natural Features

The preservation of natural features on a site often helps to control runoff. Well-established naturally wooded areas or prairie are often characterized by thick vegetation and high levels of organic matter in the soil. These conditions promote rainfall interception and runoff infiltration. Where these features are preserved, a *CN* value can be selected from Table 2-2 of TR-55 to reflect the continued influence of these natural features on the generation of runoff from a site.

Additionally, sheet flow and shallow concentrated flow that is conveyed through naturally vegetated areas flows more slowly than runoff that travels across grassed lawns (for example). Consequently, the preservation of natural features can be taken into account for both the *Tc* and *CN* values selected for the site.

5.3.1. Standard CN Determination

4a. Enter an area-weighted average *CN* value. This *CN* value should include the vegetative cover for bioretention areas assuming that bioretention soils are the same as the surrounding soils. The subsurface porosity of bioretention cells is accounted for in Line 5c.

Accounting for Permeable Pavements in the Standard *CN* Determination

Use one of the following sub-options, but not both.

Sub-Option A. Incorporate permeable pavement *CN* into the Line 4a value as part of the weighted average for the entire site. See Appendix C for a brief discussion of alternative values.

Sub-Option B. Treat the pavement as an *impervious* area when calculating the input for Line 4a but incorporate a determination of the total storage depth in Line 9a.

5.3.2. Optional CN Determination

For urban and residential districts, the *CN* values published in Table 2-2a of TR-55 are based on sites that have the following characteristics:

(a) The percentage of impervious area shown in the table.
(b) The connection of impervious areas directly to the drainage system.
(c) Grass as the primary pervious ground cover.

An LID strategy typically involves reducing and disconnecting impervious areas, and increasing the density of vegetative cover using trees or native plants, for example. Because these methods help to reduce runoff, it is highly desirable to recalculate a composite curve number to fully account for their effects. Lines 4b through 4e allow for a quick estimate of the effect of reducing and disconnecting the impervious area, assuming that the CN value for the pervious area does not change significantly. This approach is based on TR-55 p. 2-9 and TR-55 Appendix F.

In the example input shown in Figure 4a, the LID *CN* is based on a vegetative land cover of woods in good condition over hydrologic soil group C (*CN*=70). The impervious area has been reduced from an average of 38% for the No LID condition (TR-55 Table 2-2a) down to 30% here, and a portion of that is disconnected. This combination of factors results in a lower overall curve number of 77.

4b. The value entered should be the area-weighted average of the curve numbers associated with the different land covers (native plants, woods, grass, etc.) and should not include any impervious area or vegetated roof area. This *CN* value should include the vegetative cover for bioretention areas assuming that bioretention soils are the same as the surrounding soils. The subsurface porosity of bioretention cells is accounted for in Line 5c.

Accounting for Permeable Pavements in the Optional *CN* Determination

Use one of the following sub-options, but not both.

Sub-option C. Incorporate permeable pavement into the *pervious CN* value calculated in Line 4b and *do not* treat it as part of the impervious area in Line 3a. See Appendix C for a brief discussion of *CN* values for permeable pavement.

Sub-option D. Do not incorporate a permeable pavement *CN* into line 4b. Instead treat the pavement as an *impervious* area in Line 4b but incorporate a determination of the total storage depth in Line 9a.

4c. Use an actual impervious area. Vegetated roofs should be treated as impervious here. Vegetated roof retention is specifically accounted for in Lines 7a-7b.

4d. Treat as disconnected, for example: Roof downspouts that are not directly connected to the drain system, pavement area that conveys runoff into grassed swales rather than down a curb and gutter system. Conventional pavement or other impervious area that conveys runoff onto permeable pavement may be considered disconnected.

4e. This amount is computed automatically, and the letters “N/A” appear if zeroes are entered in Lines 4b and 4c.

4f. This input value must be entered manually and will be identical to the value shown in line 4a or 4e. It is the LID *CN* value used for the hydrograph calculations.

4g. This is the time of concentration for the LID design. All other conditions being equal, an increase in the *Tc* will result in a reduction in the peak runoff rate. A typical approach to LID site design will seek to maximize the *Tc* by using conveyances that slow down travel times without compromising the effectiveness of drainage away from buildings and off roadways. LID favors the use of shallow vegetated conveyances rather than sewer pipes, for example, open section road rather than curb and gutter, and the spreading of flows rather than the concentration of flows. A discussion of how to determine runoff travel times and to calculate *Tc* values is provided in Chapter 3 of TR-55.

5.3.3. LID Retention Features

The remaining input cells within the spreadsheet can be used for site components that retain runoff. The spreadsheet calculates the total retention volume as a depth across the drainage area, and for each time step checks to see whether that depth has been filled before generating runoff.

> The *SubareaCheck* sheet is provided to compare the capacity of each retention feature with the volume of runoff flowing into that feature. If the runoff volume is less than the capacity of the retention feature, then that runoff volume rather than the capacity should be counted in the *MainPage* input toward the reduction in runoff.
>
> Note that the volume check does not require a detailed analysis that generates an area-weighted *CN* value based for each subarea contributing runoff. It is sufficient only to show that the storage volume will be filled. Consequently, evaluating the runoff from only a portion of the subarea (such as the impervious area) or selecting an obviously low curve number for the subarea may produce a volume that exceeds the retention capacity.
>
> The *SubareaCheck* sheet also serves as a check on the underdrain flow for individual LID features, such as rain gardens and permeable pavements. The peak flow rate that occurs when the device is full may be controlled either by the size of the underdrain orifice or by the flow rate through the subsurface media. In either case, if the underdrain flow is substantial, it is conceivable that it may diminish the effectiveness of that feature in reducing the peak flow rate at the outlet.
>
> An acceptable approach to accounting for the hydrologic influence of underdrains is left here to the judgment of the engineer and the reviewing agency. In some cases, relative to the peak flow rate for the entire site, the underdrain rate may be insignificant. In other situations, as when underdrain rates are significant and retention features are not along the same flow path, it may be acceptable to require the LID hydrograph peak *plus* the sum of the underdrain flow rates to equal the Unit Release Rate (URR) (cfs/ac) target.

5a-5c. These input lines indicate the typical capacity of the rain garden design no matter how many rain gardens are used within the drainage area. The ponding depth should be considered as an approximate average. While the ponding volume available in rain gardens can be readily estimated based on surface contours, estimating the volume of subsurface storage will require consideration of the soil characteristics and behavior during a storm event.

The spreadsheet allows input of a value for *fillable porosity*. This is the amount of pore space assumed to be available within the soil prior to the design storm event.

The porosity of a soil is the measure of the void space in an oven-dried soil sample. A saturated soil has a water content equivalent to its porosity. As the soil drains by gravity to a moisture level known as the field capacity, more pore space becomes available to hold water. Over time, vegetation will extract moisture still further until the moisture level reaches the wilting point.

Figure 5 shows how soil properties will affect values of the field capacity and the wilting point. These values can be calculated using the software, Soil Water Properties from Texture (Saxton 2003), which is based on research by Saxton et al. (1996).

For the purpose of LID design and analysis, the value of the fillable porosity should be no greater than the difference between the porosity and the field capacity for soils in a rain garden.

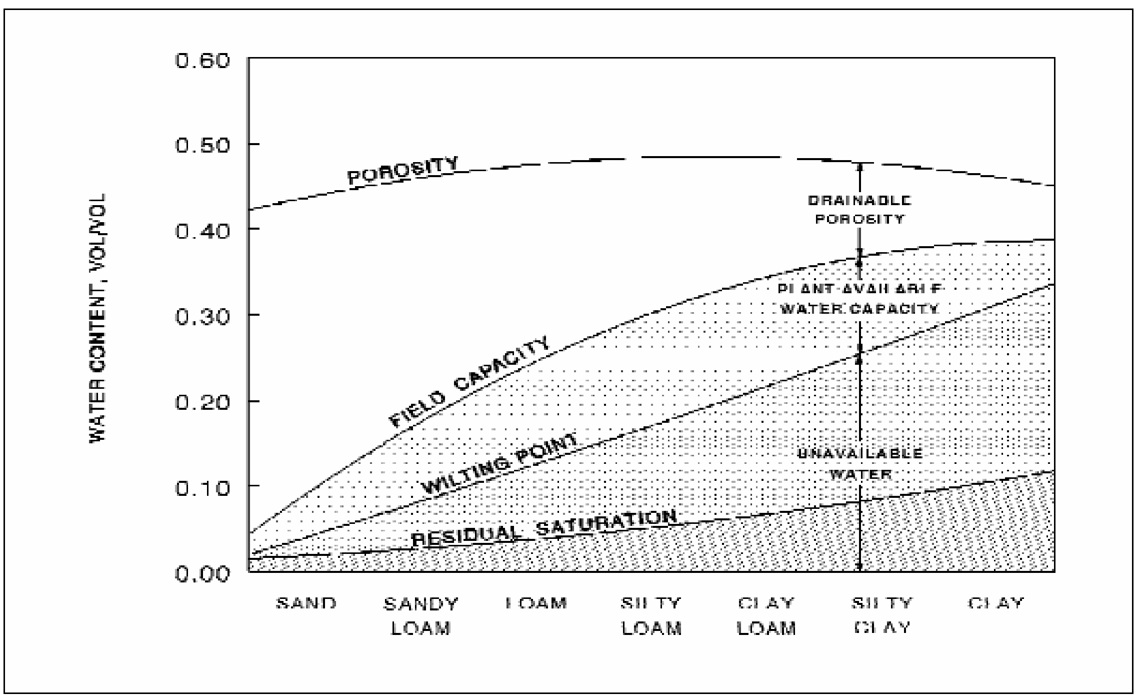


Figure 5. Moisture retention parameters associated with USDA soil texture classes (Source: http://msw.cecs.ucf.edu/AndFiles/hlp2.html)

A question may arise as to whether the overall storage capacity of rain garden soils will diminish significantly over time. It will be reasonable to assume a constant value for the fillable porosity as long as the conditions at or near the soil surface do not impede infiltration due to silting or surface crusting, and the vegetation is maintained. The use of a vegetated filter strip or grassed area around a rain garden can help reduce the conveyance of sediment into the rain garden.

In light of the various factors that can affect infiltration rates and subsurface storage volumes, some consideration may be given to whether the value selected for the input will more likely err on the side of overestimating or underestimating runoff rates at the outlet during an actual storm event under typical conditions. A conservative approach to the analysis will involve using smaller values for porosity.

Some consideration may also be given to the fact that some of the infiltration capacity in a bioretention cell has been accounted for in the overall *CN* value for the drainage area. Where surrounding soils are sandy with high rates of infiltration, a sandy bioretention soil may add little to the capacity of the bioretention area to reduce runoff and consequently a conservative value for the fillable porosity will be more desirable so that the infiltration capacity of the bioretention area is not double counted. When the surrounding areas have low rates of infiltration, however, larger values for the fillable porosity will be justified.

5d. This value is computed automatically.

5e. This is the area associated with the average design depth, roughly the average of the top and bottom of the ponding area.

5f. This value is computed automatically.

6a-6b. Rain barrels can be situated at roof downspouts to collect runoff.

7a-7c. The capacity of vegetated roofs to absorb rainfall is a function of vegetated roof design, and designs can vary considerably. The Maximum Water Capacity (MWC), is a benchmark number that is discussed in Appendix D. Reasonable values for the multiplier will generally lie between 0.33 and 0.67. The minimum value of the multiplier is the most conservative, because it represents only the initial abstraction, the amount of rainfall quickly absorbed by the roof at the beginning of the storm. Field capacity for a vegetated roof is typically about 0.50 of the MWC, which would leave the other 0.50 of the MWC available to absorb rainfall. Since evapotranspiration between storm events will reduce the moisture content from field capacity as far down as the wilting point, a value higher than 0.50 will tend to be more representative of the condition of the vegetated roof following a dry period. Because the antecedent moisture conditions for a vegetated roof will not generally be known, a median multiplier value of 0.50 is recommended.

8. This input value is the total volume of cistern storage provided on site.

9a-9b. The depth of storage entered here is the total depth of water storage provided in the permeable pavement system. This should take into account pore spaces in the pavement, as well as the aggregate base layers beneath the payment. A gravel layer 8 inches deep with a typical porosity of 0.40, for example, will provide a water storage depth of 3.2 inches for each unit of pavement area.

10. This cell allows for the input of a combination of other retention volumes not already listed above. This might include, for example, sand filters, infiltration trenches or infiltration swales. The number entered here should be supported by calculations that show how a surface component and subsurface component of storage have been taken into account. As with the other retention volumes, this input value is interpreted as an added depth of storage evenly distributed across the drainage area.

6. URR Summary

The URR Summary page (Figure 4b) shows how the use of LID features affects the runoff hydrograph relative to the URR target.

6.1. Input

To determine whether your site design meets the URR requirements, enter input data required.

20. The MMSD Chapter 13 Uniform Release Rate flow target is 0.15 cfs/acre for the 2-year storm and 0.50 cfs/acre for the 100-year storm.

6.2. Output

The Output Summary and Runoff Hydrographs will change instantaneously in response to user input. (To easily view the input and output at the same time, select menu item *View*, then *Zoom*, and lower the magnification.)

21a-21b. For the NoLID site condition, the runoff depth is calculated using standard NRCS curve number calculations, and is equivalent to the area under the runoff hydrograph shown. For the LID condition, the depth is also equivalent to the area under the corresponding runoff hydrograph. That depth reflects both the curve number calculations based on land surface conditions and the combination of retention volumes associated with the LID components that have been sized on the Input page.

22a-22b. These peak flow values are obtained from the runoff hydrographs.

23a-23b. As illustrated in the hydrograph below the output tables, the detention volume is estimated as the area above a straight diagonal line that starts at the runoff target and runs tangent to the ascending limb of the runoff hydrograph. Drawing a diagonal line to a point near the beginning of the runoff hydrograph is a common approach to estimating detention volume.

24a-24b. Due to site constraints, LID features might not fully achieve the URR target. Such is the case for the example illustrated in Figure 4b. Consequently, a detention pond at the drainage area outlet may still be seen as necessary. However, rather than routing the entire hydrograph through a detention pond, it may be more desirable to minimize the storage requirement at the outlet by splitting out the flow that exceeds the desired flow rate, placing only that excess flow into a retention area. Figure 6 illustrates the relationship between the split flow retention storage volume and the detention storage requirements at the outlet.

25. As indicated in the legend, the two runoff hydrographs represent the runoff pattern with and without an LID strategy applied. The beginning and ending time have been set at 8 and 18 hours, respectively so that the change in flow rate near the peak can be easily seen.

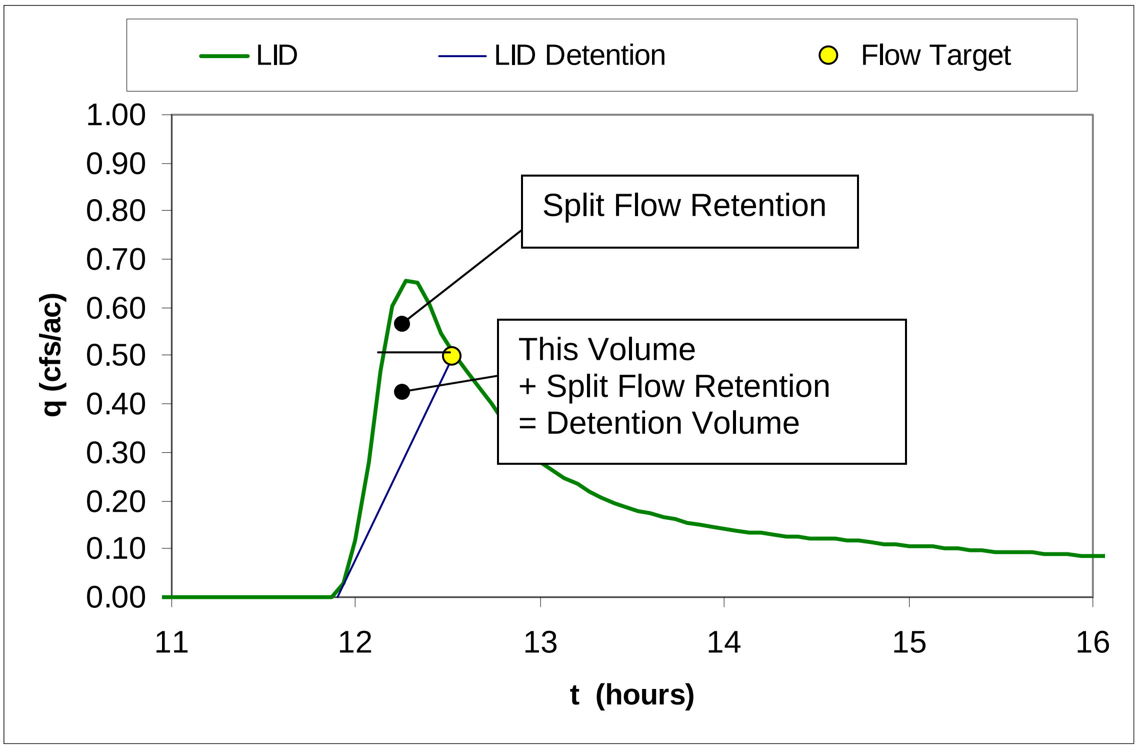


Figure 6. An example of how splitting flow at outlet can achieve a flow target for less than the volume required by detention

7. Exporting the LID Hydrograph

The LID hydrograph can be exported to other programs for subsequent routing calculations, such as those typically required in detention pond design and analysis. The *OuputHydrograph* sheet contains the hydrograph values presented in three different ways:

1. As originally calculated (Columns A and B).
2. Calculated on a user-selected time step (Columns H and I).
3. Arranged and formatted for export to TR-20 READHD records (Column J through N).

See the *OutputHydrograph* sheet itself for more information.

8. References

Milwaukee Metropolitan Sewerage District, 2002. *Surface Water and Stormwater Rules: Interim Guidance Manual.* Accessed on April 28, 2004 at http://www.mmsd.com/stormwaterweb/Startpg.htm.

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Saxton, K. E., Rawls, W. J., Romberger, J. S. and Papendick, R. I. 1986. Estimating generalized soil water characteristics from texture. *Soil Sci. Soc. Amer. J.* 50(4):1031-1036.

Saxton, K.E. 2003. Soil water characteristics from texture. United States Department of Agriculture.

Soil Conservation Service, 1983. *Computer Program for Project Formulation Hydrology, Technical Release 20 (TR-20).*

Soil Conservation Service, 1985. *National Engineering Handbook, Section 4 (NEH-4).*

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Appendix A.

Five Methods of Accounting for the
Effect of Distributed Retention on the Runoff Hydrograph

Paul Koch, Ph.D., P.E.

This Appendix describes five options that were considered to account for the retention volume provided within a drainage area. Each of these options is derived in some way from the NRCS unit hydrograph method. A comparison of the options provides a rationale for ultimately selecting the one option incorporated into the spreadsheet.

The first two of these options performs calculations directly on the runoff hydrograph generated without taking into account retention storage. The remaining three options employ calculations that adjust the NRCS runoff depth formula before hydrograph components are generated.

Option 1. Truncated hydrograph

One approach to evaluating the impact of retention on a drainage area is to treat the retention as if it is all provided in-line at the downstream end of the drainage area, just above the outlet. A family of curves illustrating the results of this approach is shown in Figure A1. In that figure, the influence of the retention is represented by a vertical line representing an assumed rising limb of the hydrograph that corresponds to the moment that the retention storage is filled.

Note that for the retention to be expected to have any influence on the peak at all, it must have the capacity to capture all the flow up to and past the peak—an approach which is likely to result in fairly conservative designs. Where storage is provided with some uniformity upstream of the outlet, however, it stands to reason that some of that retention will reduce the peak to some degree even when the retention is provided in relatively small amounts.

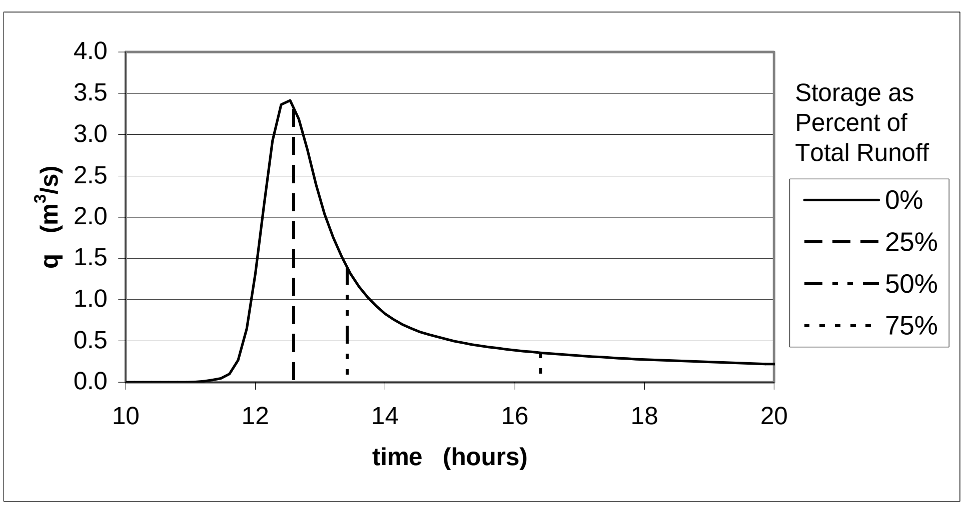

Figure A1. Retention volume evaluated as a truncation of the runoff hydrograph

Option 2. Scalar Multiplication

A second option involves taking the NoLID ordinates and simply multiplying them by the ratio of the LID runoff depth to the NoLID runoff depth. For each flow rate represented in the NoLID runoff hydrograph an adjusted flow rate was calculated as

$$q_{adjust} = q_{NoLID}\left(\frac{Q_{LID}}{Q_{NoLID}}\right) \tag{A1}$$

where q_{adjust} = ordinate of adjusted runoff hydrograph
q_{NoLID} = ordinate of runoff hydrograph for NoLID
Q_{LID} = total depth of runoff associated with LID
Q_{NoLID} = total depth of runoff associated with NoLID

A family of curves showing how the runoff hydrograph will be changed using this method with increasing amounts of retention is presented in Figure A2. This method requires only a direct adjustment in the magnitude of the runoff hydrograph. However, rather than reducing runoff by filling the retention capacity toward the beginning of the storm event, this method places the effect of much of the retention well after the hydrograph peak, significantly discounting the degree to which a uniform distribution of retention would actually reduce the peak.

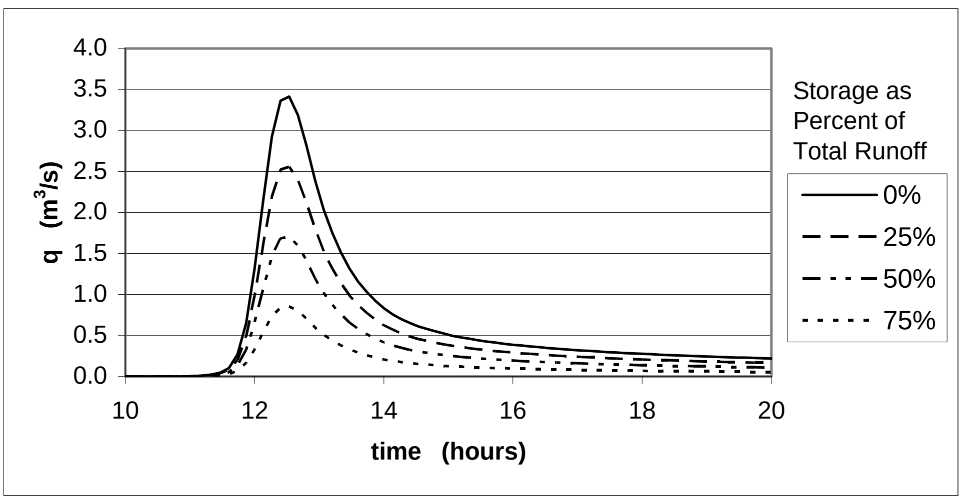

Figure A2. Changes in runoff hydrograph when original hydrograph is multiplied by a scalar to account for retention storage

A Closer Look at Runoff Hydrograph Calculations

The standard method for generating a runoff hydrograph using the SCS unit hydrograph with convolution calculations offers several options for taking into account distributed retention volumes within a drainage area. The calculations involve these steps for each time increment:

1. Within the storm event, calculate the total rainfall up to that point in time.

2. Check the total rainfall against the capacity that needs to be filled on the land surface (the initial abstraction) before runoff can occur.
3. If the total rainfall exceeds the initial abstraction, construct a hydrograph that shows the effect of that single increment of excess rainfall on the runoff pattern at the outlet.
4. Repeat for the next time step within the storm, offsetting the resulting hydrograph by the time increment.
5. Add the components hydrographs to establish a total storm hydrograph for runoff at the outlet.

TR-55 provides this formula for calculating the depth of runoff:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad \text{(A2)}$$

where Q = runoff depth (in.)
P = precipitation depth (in.)
S = potential maximum retention after runoff begins
I_a = initial abstraction, volume that must be filled before runoff begins. $I_a = 0.2\,S$

Additionally, S is related to the *CN* as

$$S = \frac{1000}{CN} - 10\,. \qquad \text{(A3)}$$

Current software implementations of TR-55 and TR-20 calculate Equations A2 and A3.

Option 3. Subtract retention from rainfall

If the retention distributed in a watershed is sufficiently uniform, it might be convenient simply to divide the total retention volume by the drainage area and subtract the result from the rainfall along with I_a.

Letting R represent the total retention volume divided by total drainage area, the calculation of runoff using this approach can be formulated as follows:

$$Q = \frac{(P - I_a - R)^2}{(P - I_a - R) + S} \qquad \text{(A4)}$$

Subsequently, the analyst can perform the usual unit hydrograph calculations. However, the approach is problematic because the volume of retention provided will never be fully accounted for. Just as runoff is always less than rainfall when the standard formula is used, the change in runoff volume will always be less than the volume of retention actually provided when the retention volume is first subtracted from the rainfall before the runoff depth is calculated.

For example, if the depth of precipitation is 2.57 inches over a drainage area having a CN of 80, then the depth of runoff is 0.94 inches. If the distributed retention depth is 0.39 inches, then subtracting the retention from the rainfall leads to a runoff of 0.67 inches. But since 0.94 - 0.67 = 0.27 rather than 0.39, it is clear that not all the retention depth has been accounted for using this approach. If it were, the final runoff value would be approximately 19% less.

A family of curves showing how the runoff hydrograph will be changed using this method with different amounts of retention is shown in Figure 3. It is worth noting that when the retention storage capacity is equated to the total runoff volume without retention, there is still some runoff. At the extreme, Equation 5 indicates that reducing the amount of runoff to zero requires that the amount of excess rainfall (P – Ia – R) be reduced to zero. Because this ignores the infiltration potential of the ground upstream of the retention area, the technical inadequacy of this approach is apparent.

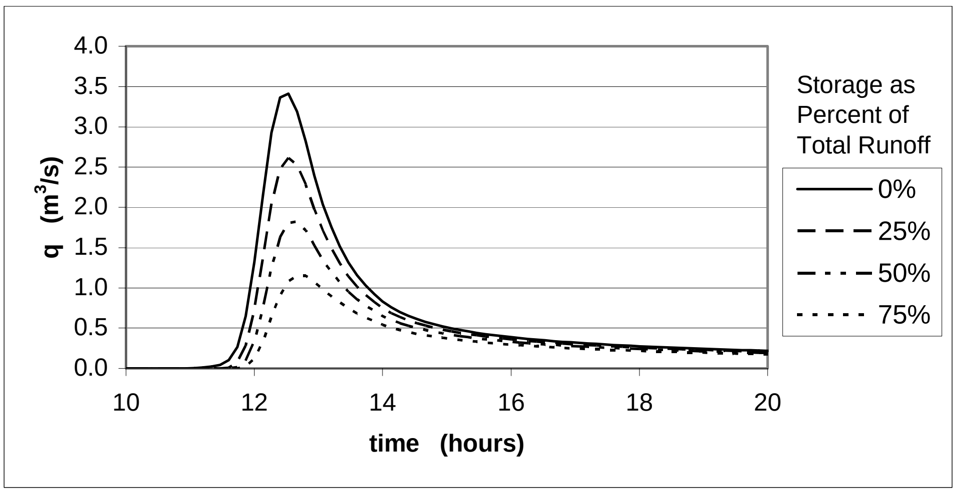

Figure A3. Changes in runoff hydrograph when storage is subtracted from rainfall

Option 4. Subtract retention from runoff

Subtracting retention from the runoff generated by the land surface will account for the retention explicitly, as in this formula:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} - R \qquad \text{(A5)}$$

Within the NRCS convolution calculations, the formula can be applied as follows: First the standard runoff volume is calculated, and then it is checked against the available retention volume to determine whether that volume has been filled. After the total runoff exceeds the total retention volume, a component of the runoff hydrograph is developed to represent the incremental amount of runoff generated in each succeeding time increment.

If the retention is constrained to a small percentage of the total drainage area, it seems reasonable to assume that the S value for the drainage area as a whole will not change. An upward or downward revision of S may be warranted depending on the effect of the retention facility on the local infiltration capacity. For rain gardens, which are typically designed with highly pervious soil mixtures, keeping the S representative of the surrounding land cover will constitute a conservative assumption, more likely leading to an overestimation rather than underestimation of runoff.

A family of curves showing how the runoff hydrograph will be changed using this method with different amounts of retention is shown in Figure A4. While this option is straightforward, current software implementations of TR-55 and TR-20 cannot calculate Equation A5. Adaptation of NRCS methods using the formulation for this option requires other software.

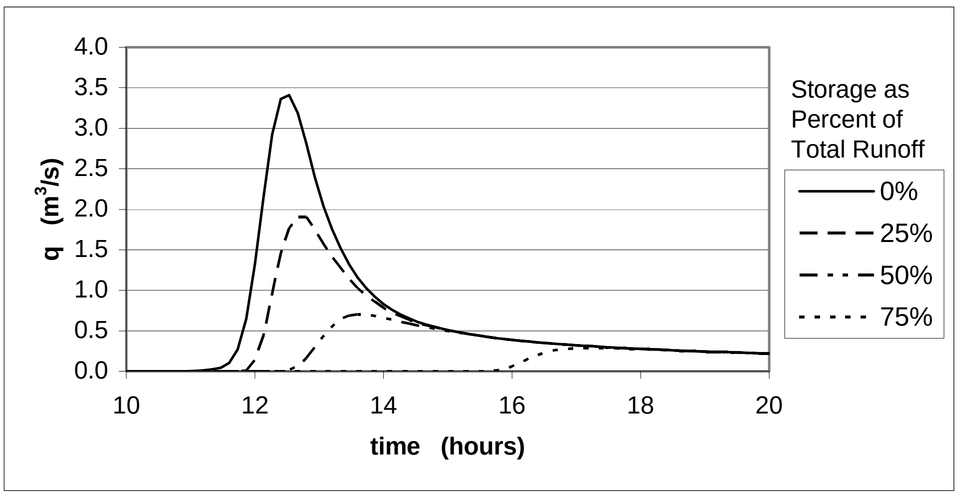

Figure A4. Changes in runoff hydrograph when storage is subtracted from runoff

Option 5. Adjust CN for 24-hour Storm Depth

A standard assumption given in TR-55 is that $I_a = 0.2S$. Consequently, the NRCS standard runoff equation is sometimes expressed as

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{A5}$$

Subtracting the total retention from the total runoff at the end of a storm event gives a runoff value that a different S value can be based on. The equation

$$Q - R = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{A6}$$

can be solved for a revised value of *S*, which will increase with increases in retention, and then a revised *CN* value can be calculated from the revised *S*. That revised *CN* can subsequently be used to generate a new runoff hydrograph.

This approach does properly account for the effect of the retention volume on the runoff volume for the storm as a whole. That is, the total area under the runoff hydrograph will be equivalent to *Q* minus *R*. The remaining difficulty is that the effect of the retention volume is not fully accounted for until the end of the storm. By design, the placement of retention should typically result in the retention cells being filled well before the end of the storm, so that retention will actually have greater value in reducing the peak flow than a simple *CN* adjustment would indicate.

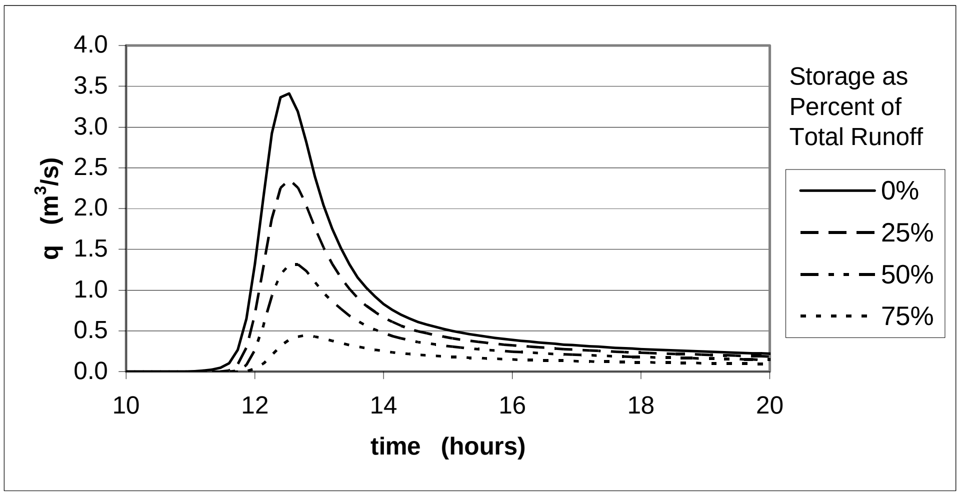

Figure A5. Changes in runoff hydrograph when CN adjustment is made to account for retention storage

Runoff Depth Comparisons

There are significant differences in the depth of runoff calculated for these three different approaches. Figure A6 shows a comparison of depth calculations for Options 3, 4 and 5. Relative to the standard runoff curve, Option 3 moves the runoff curve to the right, and Option 4 moves it downward. Option 5 starts somewhat to the right of the standard curve, and ends where the difference in runoff is equal to the total depth of retention.

It is worth noting that the *CN* adjustment method will produce a different *CN* value for different depths of rainfall, even if the land cover, soil characteristics and amount of added retention remains the same. If, as Figure A6 shows, a *CN* is determined using Equation A6 for a rainfall depth of 80 mm and retention depth of 10 mm, the amount of runoff generated for 60 mm of rainfall is approximately 13 mm. However, if a *CN* is recalculated using Equation A6 for a rainfall depth of 60 mm, the amount of runoff is approximately 10 mm.

This presents a logical difficulty. Since the accumulation of precipitation from 0 to 80 mm passes through the value of 60 mm, it seems reasonable to expect that the runoff depth associated with 60 mm should be the same for the same land use and soil type, regardless of whether the storm lasts longer.

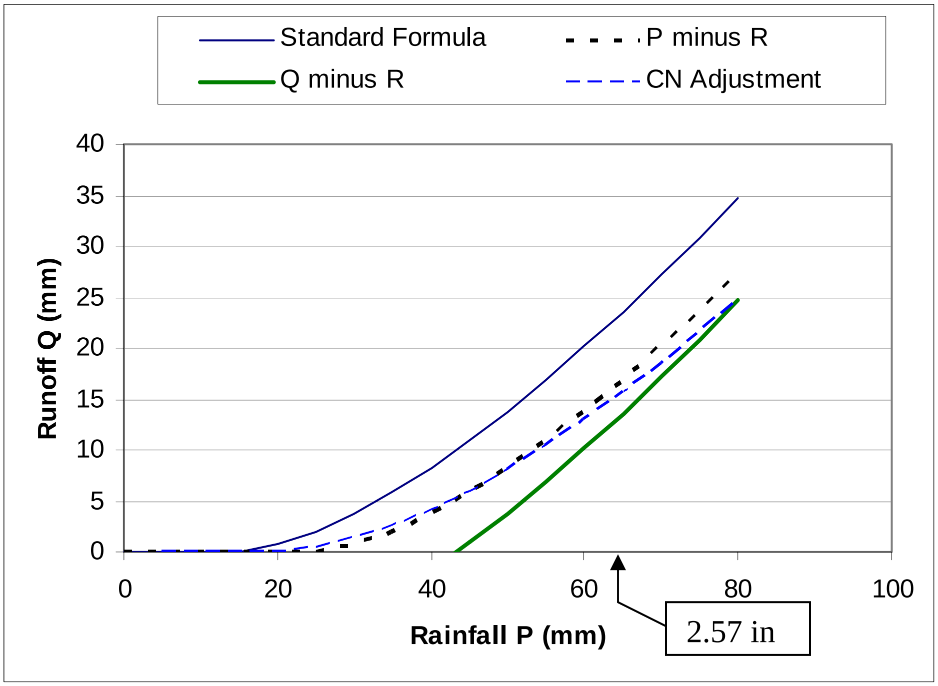

Figure A6. Comparison of depth of runoff calculations
(CN = 80; overall retention depth = 10 mm)

Runoff Peak Comparisons

A comparison of the effect of the five options on the runoff peak is illustrated in Figure A7. The chart shows that accounting for the runoff volume as described in Option 4 results in the least amount of runoff for all but the highest levels of peak runoff reduction, and, overall, is nearly as efficient as detention in terms of achieving a relative reduction in peak flow for a given volume of storage. Option 4 was selected for implementation in the LID spreadsheet.

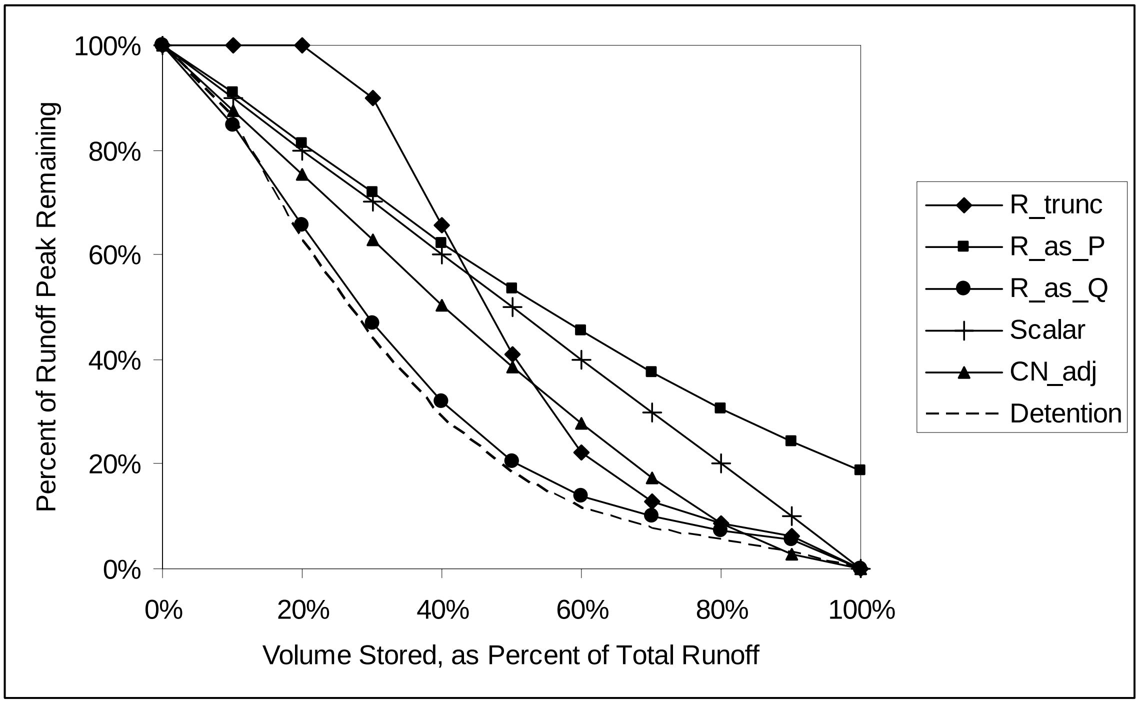

Figure A4. Comparison of different methods to account for runoff storage (CN = 75, Tc=1 hr, D.A. = 1 km^2)

Appendix B.

Summary of Spreadsheet Contents

Normally visible sheets:

1. *ReadMe* Describes basic program purpose and identifies developer.
2. *MainPage* Two-page user interface.
3. *SubareaCheck* Confirms that all retention volumes will be filled.
4. *RainDistribution* For inputting the temporal rainfall distribution.
5. *OutputHydrograph* Runoff hydrograph for the LID site design.

Normally hidden sheets:

6. *PlotData* Hydrograph data plotted on the output page.
7. *Convolve* Convolution calculations in metric (SI) units.
8. *RainfallPlot* Chart showing cumulative rainfall distribution for Type II storm.
9. *SplitFlow* Calculates area of LID hydrograph above peak flow target.

Convolve receives user input from *MainPage*, performs computations in metric units and returns the output values in English units.

Appendix C.

Curve Numbers and Subsurface Storage
for Porous Pavement and Permeable Pavers

NRCS Runoff Curve Numbers for Porous Pavement

Gravel Subbase Thickness	Curve Number for Various Hydrologic Soil Groups			
(inches)	A	B	C	D
10	57	66	69	75
12	56	64	68	74
14	55	63	67	72
16	54	62	65	70
18	53	61	64	69
20	52	60	63	68
24	52	58	61	66
30	49	55	57	61
36	47	52	55	58

Notes

- Source: Engineering Field Manual Notice – NENTC 25, released by the Northeast National Technical Center of the USDA Soil Conservation Service, June 22, 1986.
- The *CN* values are based on Antecedent Moisture Condition II and an I_a of 0.25 inches.
- All the *CN* values are for properly maintained porous pavement. The *CN* values for porous pavement that is not properly maintained is the default *CN* for pavement, which is 98.

Limitations

- The infiltration rate of asphalt layer is not limiting. Minimum infiltration rate is 0.27 in/hr.
- The season high water table is greater than 2.0 feet below the gravel layer.
- There is at least 2.0 feet of soil below the gravel layer.
- The potential maximum retention after runoff begins includes storage in pavement gravel and soil.

General Suggestions Regarding Permeable Paver Systems

"There are […] no specific curve numbers for permeable pavements. […] CN = 65 is an average number based on the fact that virtually all permeable pavements can store about 2 inches of rainfall (in the base layer) before infiltrating it or draining it elsewhere (either into the subgrade, if permeable, or into a drainage system). This is an estimate based on storage capacity within open-graded bases (typically 30-40% of the total base volume).

"Many permeable pavements will be built on A or B soils and we know that thicker bases means more storage capacity, and when placed on A or B soils, there will be infiltration rather than runoff. However in any underlying soil case, the infiltration rate and storage capacity of the base will be greater than that of the underlying soil. Therefore, the *CN* for permeable pavers will be lower than the underlying soil (substantially in some cases). The CN 65 is considered a starting point (conservative) considering the infiltration rate of permeable pavements are based on various factors - design storms, underlying soil, supplemental drainage (if used), pavement load, climate, etc. Unfortunately there isn't one uniform design.

"The 65 number was derived from TR - 55 Urban Hydrology for Small Watersheds, Table 2-1 Runoff depth for selected CNs and rainfall amounts. It is based on the fact that virtually any permeable pavement will infiltrate and store up to 2 inches of rainfall (virtually no runoff). In many cases, as I've mentioned it can store much more, resulting in an even lower curve number. You may be able to extrapolate from this to assign numbers for various soils.

"Though pervious pavements have been around awhile (asphalt and ready-mix concrete), interlocking permeable pavers have only been around (in the U.S.) for about 10 years, with most use over the last few years. Perhaps they will be measured in the future for CN values, though because of the variables, it might take a lot of testing over the entire country to get good average parameters. "

Donna DeNinno
UNI-GROUP U.S.A.
May 15, 2003

Appendix D.

Runoff Storage Capacity of Vegetated Roofs

See paper by Charlie Miller on the following pages.
Edited slightly as indicated by brackets.
Used by permission.

Disclaimer: This paper is provided here for informational purposes only. Providing this information does not constitute an endorsement of Roofscapes, Inc. by MMSD. Nor does it constitute an endorsement by Roofscapes, Inc., of the method of analysis associated with the *LID Quicksheet*.

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Use of Vegetated Roof Covers in Runoff Management

By Charlie Miller, P.E.

The effectiveness of green roofs in reducing runoff impacts, especially in densely developed areas, is one of the principal reasons that they are so popular with city engineers in Germany. In Germany alone, more than 20 million square feet of new green roof are installed every year. Many cities require green roofs for buildings in districts that are plagued by chronic runoff-related problems.

Initial abstraction is an engineering term that describes the quantity of rainfall that must occur before appreciable runoff will commence. An approximate rule-of-thumb for a wide range of green roofs is that the initial abstraction will equal about 1/3 of the maximum water capacity, MWC, of the growing medium. The MWC is a benchmark number that is measured in a specific test used in Europe [and available in the United States]. For example, a green roof with an MWC of 1.5 inches will not generate significant runoff until at least 0.5 inches of rainfall has occurred.

Vegetated roof covers are very effective in reducing total runoff volume. A predictor of the percent reduction in total annual runoff volume is:

$$\text{Pct. Reduction} = 100 \times 0.45 \times \text{MWC}^{1/3}$$

A typical green roof with about 3 inches of growing media can be designed to reduce annual runoff by more than 50 percent. However, it is very important to keep in mind that this information is based on experience in temperate climates with a rainfall pattern similar to the American Northeast. For instance in the Pacific Northwest, where rainfall tends to occur in steady long-duration events, the reduction in runoff volume may be not be as great.

Another property of interest is field capacity. This is the quantity of water absorbed by the green roof during a rainfall event that will not be later released as runoff. This water will eventually be evapotranspired by the plants. The difference between the field capacity and the MWC determines how effective a green roof will be in suppressing peak rates of runoff during storms. For many types of green roof media, the field capacity is equal to about ½ of the MWC.

Runoff Control Using Thin Vegetated Covers

A critical aspect of using vegetated roof covers is to clearly identify the management goals and develop suitable design criteria. It has been demonstrated in Germany that the 3-inch vegetated roof cover has the highest benefit to cost ratio. A properly designed 3-inch vegetated roof cover will provide a durable, low maintenance system that can achieve the objectives of moderating temperature, reducing runoff, and prolonging the life of the underlying waterproofing materials. Furthermore, these systems can be added to most existing buildings, often without having to reinforce or otherwise alter their structural design.

The value of green roofs in reducing the rate of runoff depends upon the design rainfall events that are considered. For communities where runoff rates are computed using the rational method (which emphasizes the impact of intense short-duration rainfall events), thin vegetated covers can typically satisfy runoff management goals for 10-, 25-, and in some cases even 50-year return design storms. Where design storms are based on 24-hour events, it is generally possible to demonstrate control of runoff to pre-development levels for storms up to several inches in magnitude (i.e., a two-year storm magnitude in southeastern Pennsylvania). It is also helpful to keep in mind that in southeastern Pennsylvania 24-hour storms with magnitudes of less than 1.5 inches contribute more than 90 percent of all rainfall.

In Germany the standard design event for urban runoff management is one inch of rainfall falling in 15 minutes. This would be a 10-year return frequency event in southeastern Pennsylvania. In our opinion, the runoff requirements for urban areas that are undergoing redevelopment should be based on the type of the storm that is linked to chronic runoff-related problems (e.g., nuisance flooding, combined serer overflow, TMDL exceedances). By-and-large these are summer downpours. Therefore, runoff abatement programs should focus on these storms. Green roofs can be a powerful tool for achieving this benefit.

Deep Vegetated Covers and Zero Discharge Installations

A typical 14-inch deep green roof can be relied on to reduce total annual runoff by 85 to 95 percent in temperate climates. In combination with other water management techniques, zero discharge is a readily attainable goal. The following are excellent examples of the integration of a variety of techniques to eliminate off-site discharge of rainfall runoff. These techniques include green roofs, cisterns, facade planters, reflecting pools, infiltration beds, and utility water recycling systems. Unfortunately, all of the information concerning these systems is in German. However, we have summarized some of these in English. The important points to remember are that: 1) these integrated building systems are a reality in Germany and that 2) a variety of techniques must be deployed in unison to achieve the goal. Although factors such as climate and geologic conditions will influence the design, there will always be a way to achieve the objective.

Cross Savings Bank (Kreissparkasse) in Weilburg

This building occupies a 3,250 square-foot area. The management system utilizes a combination of green roof landscapes, ranging in size from 2 to 6 inches in thickness. Cisterns are used to capture excess runoff for reuse in irrigation during dry periods.

Europe Park (Europapark) in Rust

This project also has a footprint of 3,250 square feet. Green roofs in combination with cisterns and low-head irrigation pumps, powered by photovoltaic panels, characterize this project.

New Convention Center (Neue Messe) in Munich

The Convention Center is a 409,000 (9 acre) square-foot complex. This is a very exciting project that integrates many management techniques. Green roofs are an essential part of the zero-discharge design and are responsible for up to 85% of the reduction in runoff. The remaining runoff reduction is accomplished by recycling runoff for utility uses and by infiltration. The Optigrün *RWS* computer simulation program was used to estimate the efficiency of the green roofs so that the other practices could be properly sized.

Commercial Center in Bondorf

This is a 40-acre development with zero runoff discharge. This stringent requirement was the result of the inability of the local wastewater treatment plant to absorb additional water from runoff. Fully 70 percent of the total area is covered with impermeable surfaces. In addition to green roofs and water recycling, this project relies on large infiltration galleries and landscape pools to infiltrate water.

[…]The following projects are also noteworthy.

Prisma building in Nurnberg

The water management system for this project incorporates green roofs, cisterns, façade planters, water-curtain climate control, gray water recycling, and infiltration. Water management is made part of an overall artistic statement. This project was described recently in the *ASLA Professional Interest Group Water Conservation*, Vol. III, No. 1, 1999.

Pottsdamer Platz in Berlin

While not strictly an example of zero discharge, this ultra-urban development points the way to the possibilities of integrated runoff design. The design beautifully integrates extensive green roofs (2 to 3 inches) with reflecting pools, created wetlands, cisterns, and water recycling. The primary limitation of this project was the deliberate decision not to treat runoff from roads and main thoroughfares. Infiltration opportunities were also very limited due to the high water table on the floodplain of the river Sprey.

National Bank of Baden-Würtenberg (Landesbank) in Stuttgart

This is another Optigrün project, which involves covering half of the 43,000 square-foot site with green roofs. A very lovely and diverse roof landscape is used to eliminate all but about 5% of annual runoff. Profiles range form 4 to 16 inches in depth.

[…]

The following table summarizes output from the [empirical Optigrün-]*RWS* computer simulation program for a 3.25-inch thick proto-type installation for the Fencing Academy of Philadelphia. This simulation utilized a one-year, 5-minute digital rainfall record. Two standard design storms were also inserted into the rainfall record. The predictions of the simulation were verified by field observation of the proto-type. The output illustrates that this thin green roof is much more effective in controlling brief rainfall events than long-duration storms. However, significant runoff rate suppression was achieved for all storm events. Similar analyses can be conducted as part of the feasibility phase of other projects.

Selected Storms: *RWS* Simulation of One-Year Rainfall Record

3.25-inch (8 cm) Deep Extensive Vegetated Roof Cover

Rainfall record for Reading, Pennsylvania (1994)

Rainfall 15-min Peak Rate in/hr	Rainfall 24-hour Volume in	15-min Peak Discharge in/hr	Attenuation	Comments
1.6	0.9	negligible	100%	"cloud burst:" peak occurs in first 25 min.
0.4	1.1	0.1	63%	
0.4	1.0	0.2	59%	
0.8	1.2	0.2	72%	
0.8	1.5	0.4	56%	
1.2	0.6	0.4	63%	
1.2	1.3	0.7	39%	
1.6	1.1	0.3	81%	
1.6	1.0	0.5	69%	
2.4	1.3	0.7	71%	
3.2	3.4	1.4	57%	
3.5	2.8	1.3	61%	Standard 2-year: type II rainfall distribution
5.4	4.9	2.8	47%	Standard 10-year: type II rainfall distribution