Chapter 9

Calculations and Methodology

This chapter describes design methods to calculate the level of control needed using LID techniques and how to select BMPs to meet those conditions. Chapters 6 and 7 provide detailed design criteria for each BMP. As described previously, LID designs are based on mimicking the presettlement hydrology as defined by groundwater recharge, stream channel stability, and flooding. LID methodology also provides treatment of pollutants carried in stormwater runoff.

Several methods of analysis may be used to produce a LID based site design. This manual will discuss many of them and the conditions where each may be most useful. The Curve Number method is widely used and is recommended for typical LID design calculations. The Curve Number (CN) method will be used throughout this chapter and on the associated worksheets to illustrate the design process.

The design process described here takes the user through full implementation of LID on a site. Users may choose to partially implement LID or implement some LID practices for specific purposes or to meet unusual site conditions. Some site conditions requiring special attention are addressed in Chapter 8 as well as modifications to the LID design process for those site conditions.

Throughout this document, the term "presettlement" is used to describe the initial condition of a site before development occurs. Defining the initial condition is important to determine the appropriate level of LID controls needed. Defining precisely what the appropriate initial condition was can be difficult. The term "predevelopment" is used routinely in other LID guidance documents as a generic statement referring to the site condition before development. "Presettlement" is a specific reference to that time period before significant human change to the landscape. For the purpose of LID design, this chapter defines presettlement as the presettlement site condition. To simplify LID design calculations, presettlement is further defined as either woods or meadow in good condition. This definition will not represent the actual presettlement condition of all land in Michigan. It does provide a simple, conservative value to use in site design that meets common LID objectives. Predevelopment may be defined in other ways based on site specific or watershed-specific study.

However, care should be given to apply consistent criteria throughout any given watershed in order to maintain a stable storm runoff response from the watershed.

Implementing a Community Stormwater Regulation

Stormwater management is a necessary component of water quality improvement and protection in a growing number of communities. Some communities may chose to adopt standards (e.g., through ordinance, engineering standards, rules) that would be implemented throughout the community. Appendix H contains a model stormwater ordinance that incorporates various elements of LID, including standards.

In developing a stormwater regulation, the following steps should be considered:

Step 1: Discuss and decide on water quality and quantity outcomes. Local communities need to consider the importance of achieving certain outcomes, including water quality protection, groundwater recharge, stream channel protection, and flood control. LID is a means of achieving all of these outcomes by mimicking presettlement hydrology.

Step 2: Adopt design standards that achieve desired outcomes. After determining the applicable outcomes, the next step is developing standards for the community. The recommended criteria presented in this chapter are designed to meet comprehensive water quantity (total volume and peak rate) and water quality objectives. Other factors that should be discussed include waivers for certain site considerations, how to address redevelopment, and the need to address flooding concerns.

Step 3: Select the stormwater methodologies to meet the design standards. A final decision is determining the acceptable calculation methodologies that can be used to meet the standards.

LID Design Criteria

Defining the hydrology of the site is based on three criteria — groundwater recharge, stream channel protection, and flood control. A fourth criterion — water quality protection — is used to determine the level of treatment necessary to remove pollutants from stormwater runoff. Each is defined in the following ways.

Groundwater recharge

According to U.S. Geological Survey and others, over 90 percent of annual precipitation infiltrates into the soil in Michigan watersheds under natural (presettlement) conditions. More than half of this infiltration volume is taken up by vegetation and transpired or evaporated. The rest of this infiltrated water moves down gradient to feed local wetlands, lakes, springs and seeps, and surface streams as base flow, and/or enters the deeper aquifers that supply drinking water wells.

Although groundwater recharge volumes and percentages vary around the state, recharge remains a vitally important element of the water cycle in most areas. Without the continuous recharge of groundwater aquifers from precipitation, surface stream flows and groundwater in wells would be reduced or even disappear during drought periods and would be impacted year-round.

Groundwater design criteria: Instead of developing a separate groundwater recharge criteria, this can be accomplished by implementing a volume control criteria and maximizing the use of infiltration BMPs.

Stream channel protection

Stream channels develop their shape in response to the volume and rate of runoff that they receive from their contributing watersheds. Research has shown that in hydrologically stable watersheds, the stream flow responsible for most of the shaping of the channel (called the bankfull flow) occurs between every one to two years. When land is developed, the volume and rate of runoff from that land increases and the stream channel will adapt by changing its shape. As the stream channel works to reach a new stable shape, excess erosion occurs.

Channel protection is achieved by matching the post construction runoff volume and rate to the presettlement condition for all runoff events up to the bankfull flow. In a stable stream channel, the channel-forming flow would often correspond to the rain event of the same frequency. So a 1.5 year flow would roughly correspond to a 1.5 year rain event. Site specific channel forming flows could be determined through a morphological analysis of the stream channel receiving the stormwater runoff. Nearly all channel forming flows in hydrologically stable watersheds occur with a frequency of between one and two years. The return frequency for channel forming flow for most streams in Michigan is 1.5 years. To choose design condition for stream channel protection it would be best to have a site specific morphological study identifying the most accurate return frequency for the channel forming flow.

Channel protection criteria: Without a site specific study or analysis, LID site design based on no increase of the presettlement runoff condition for all storms up to the two-year, 24-hour return frequency storm provides the most assurance that the stream channel will be protected.

In addition to channel protection, this criterion provides the following LID design benefits:

- The two-year event encompasses about 95 percent of the annual rainfall volume (Figure 9.1) across the state and equals or exceeds presettlement groundwater recharge volumes.
- Volume reduction BMPs based on this standard provide a storage capacity to substantially reduce the increase in peak flow rates for larger runoff events (most out-of-bank events and many so-called extreme events).
- If this volume control is accomplished through infiltration/vegetative BMPs, water quality criteria, including temperature control, is achieved as well.
- The two-year, 24-hour storm is well defined and data ares readily accessible for use in stormwater management calculations.

In waterbodies that are so large that the added volume from localized stormwater runoff is insignificant, or where channel erosion will not occur for other reasons, channel protection criteria become unnecessary. These waterbodies include the Great Lakes and their connecting channels and lakes with rock or concrete-lined channels leading to the Great Lakes (e.g., Muskegon Lake). Implementing the channel protection criteria may still be desired in these situations to maintain groundwater recharge or control localized flooding.

As stated previously, maintaining the presettlement runoff volume is most often accomplished using infiltration BMPs. There are a number of site conditions that will either limit infiltration or eliminate it as an option altogether. Volume reduction can still be accomplished in these circumstances through the use of BMPs that provide significant interception and evapotransporation such as vegetated roofs and bioretention, and capture and reuse of stormwater. Off-site or nearby regional volume control consistent with LID concepts may also be appropriate.

However, on some sites maintaining the presettlement runoff volume may not be possible within a reasonable cost. When this occurs, volume reduction should still be maximized to the extent practicable, and the one-year, 24-hour storm event should be detained and released over at least a 24-hour period (i.e., extended detention of the one-year, 24-hour storm must be provided). Simply maintaining the presettlement peak rate of runoff is not protective of stream channels in many cases and, therefore, extended detention **greater than is needed to maintain the predevelopement peak rate should be provided at a minimum** (see Center for Watershed Protection's "Manual Builder" at www.stormwatercenter.net/Manual_Builder/Sizing_Criteria/Channel%20Protection/Stream%20Channel%20Protection%20Volume%20Requirements.htm).

Whenever possible, this detention should be provided using infiltration practices that are lined, underdrained, and ultimately discharge. In this way, detention lowers the peak rate of multiple storms up to the design runoff condition, is not subject to the same clogging concerns, and provides better water quality treatment.

Maximizing volume reduction to the extent possible, even if less than the two-year volume, will reduce the size of peak runoff rate controls and water quality controls and are recommended for any LID site design. Similarly, maintaining time of concentration in new development and lengthening time of concentration in site redevelopment will assist in peak runoff rate control and should also be pursued.

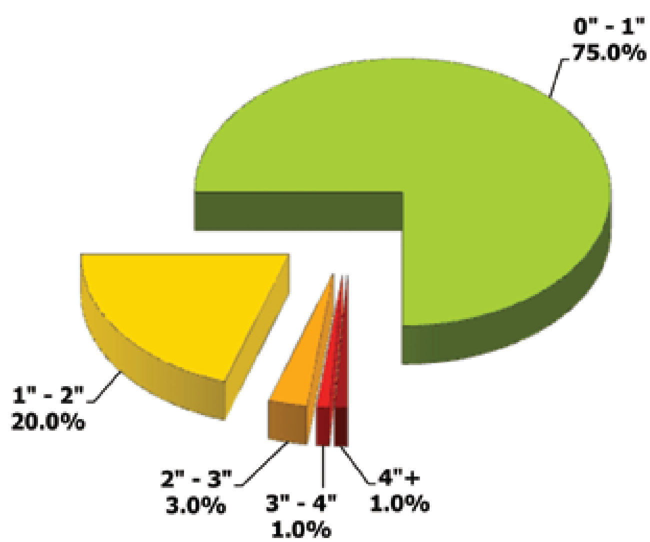
Including waivers in your stormwater regulation

Communities implementing a volume control standard based on this manual need to provide for alternatives from the standard to account for constraints on certain sites. Site constraints include but aren't limited to: poor draining soils, contaminated soils, bedrock, karst geology, highwater table, or other constraints where commonly used LID BMPs would either be impractical, pose a threat of groundwater contamination, and stormwater reuse is not feasible. Communities should require documentation of the reason an alternative design standard is being used such as site infiltration testing, evaluation of reuse alternatives or potential for evapotransporation mechanisms such as green roofs. A community may wish to identify an alternative standard to areas which have specific, known design limitations.

At a minimum for qualifying sites, an alternative standard should be applied that requires detention of the one-year, 24-hour storm with release at the pre-settlement peak runoff rate. A water quality treatment volume should also be specified.

The model ordinance (Appendix H) provides language that includes these exemptions.

Figure 9.1.
Rainfall Distribution by Storm Size for Lansing, MI based on Daily Precipitation Values from 1948-2007. The two-year, 24-hour storm is 2.42 inches.



Flood control

Flood control is based on protecting life and property. Mimicking the presettlement hydrology with respect to flooding will reduce the frequency and intensity of flooding, but out-of-bank flows are a natural process and will still occur. Flood control criteria are ultimately determined locally based on drainage needs and flood risk of any particular area and may go beyond LID design criteria to achieve the necessary level of flood protection.

Where runoff volume is maintained to the presettlement value for any given storm, the presettlement peak runoff rate will also be maintained up to the same storm. Additionally, runoff volume controls implemented for small storms but not larger, less frequent storms will reduce the size of peak runoff rate control for larger storms. Where peak rate runoff control is used alone with a fixed rate of release, runoff from storms smaller than the design storm receive limited or no peak rate reduction.

Maintaining the presettlement runoff volume by implementing LID-based site designs for the entire range of design runoff events has several benefits. However, as storms increase in size the incremental benefit of volume control for each larger storm becomes less significant and, at some larger storm event, the control of peak runoff rate becomes the only critical basis for design. When additional flood protection is needed beyond maintaining the presettlement hydrology, additional peak runoff rate control is applied.

Flood protection criteria: Maintain presettlement runoff volume and rate for all storms up to the two-year event. Maintain presettlement runoff volume for additional storms as practicable for the site conditions up to the 100-year event or the event determined by local standard. Maintain the presettlement peak runoff rate for all storms up to the 100-year event or the event determined by local standard.

Water quality protection

Impervious (and some pervious) surfaces associated with land development are known to generate a wide range of potentially harmful loads of nonpoint source pollutants. These surfaces accumulate pollutants that are picked up by stormwater runoff and carried to our lakes and streams. Examples of these pollutants include:

- Bacteria from pet waste, goose droppings, and other wildlife.
- Nutrients from excessive fertilizer left on streets, sidewalks, and lawns.
- Suspended solids from erosive stream banks, roadways, and construction sites.
- Hydrocarbons and trace metals from leaky vehicles.
- Chlorides from road salt.

Runoff picks up or washes off pollutants during the course of a storm event. After some time during an event most of the pollutants are carried away and the remainder of the runoff is relatively clean. This concentration of pollutants in the initial stormwater runoff is often called a "first flush" and is particularly true of impervious surfaces. Exposed soil, however, could wash off soil particles for the entire duration of an event.

Additional flood information for your stormwater regulation

Community stormwater standards for flood control are based on protecting life and property above all else. When developing flood protection standards, a community must first identify the level of flood protection needed. Many factors will determine the level of flood control needed such as location in a watershed, proximity to a waterbody, and type of current drainage. It is not cost effective to require or provide flood protection above a certain size, infrequent storm. In Michigan, many communities provide some level of control up to the 100-year storm.

Computer simulations are used to determine the effect of controls on the extent or frequency of flooding for the storms of interest.

Many existing flood control standards are based on maintaining some fixed rate of runoff from an area or site for a given storm. Using the LID design criteria described in this manual will often meet or exceed these criteria. However, there are some areas where LID controls may not be sufficient to reduce the risk of flooding necessary to offer the level of protection identified by the local community. Additional control may be provided through additional volume control for larger less frequent storms or fixed-rate control.

Local standards should define the level of flood control needed and provide that appropriate controls are applied as necessary in addition to LID controls to meet the flood criteria when LID controls alone are insufficient.

A community may also allow exemptions from the flood standard for such issues as small sites or direct discharge to a major river or lake.

The model ordinance (Appendix H) provides language that includes additional considerations.

The nature of stormwater runoff makes it difficult to sample actual runoff quality and treatment efficiency for individual practices on a routine basis. An acceptable alternative to determine if adequate treatment is provided is to calculate the volume of water expected to carry the majority of pollutants at the beginning of a rain event and treat that volume with BMPs that will remove the pollutants expected from that source of runoff. An accepted quantitative goal to determine adequate water quality protection is to achieve an 80 percent reduction in post-development particulate associated pollutant load as represented by Total Suspended Solids based on post-development land use.

The expected treatment of many BMPs applied to LID designs is based on removing solids. Many pollutants are attached to solids or are removed by similar treatment mechanisms. Therefore, removing solids can act as a surrogate for the expected removal of other particulate pollutants. Often multiple BMPs will be necessary to remove successively smaller particle sizes to achieve the highest level of treatment.

The water quality volume is normally, but not always less than the channel protection volume. Where infiltration BMPs are used to fully obtain the channel protection volume, the water quality volume should be automatically addressed. There are a number of ways to determine the volume of runoff necessary to treat for water quality.

- **0.5 inch of runoff** from a single impervious area. This criterion was one of the first to define the "first flush" phenomenon by studying runoff from parking lots. It was been widely used as the design water quality volume. Additional research has found that this criterion for water quality volume only applies to runoff from a single impervious area, such as the parking lot to a single development. It is the minimum value that could be expected to capture the runoff containing the most pollutants. It is not appropriate for a mixture of impervious areas and pervious areas. It is also not appropriate to use for multiple impervious areas treated by a single BMP or multiple BMPs. Although it may have applications in some limited circumstances, it is not recommended that this method be used to calculate water quality volume.
- **One inch of runoff from all impervious areas and 0.25 inches of runoff from all disturbed pervious areas**. This method provides reasonable certainty that the runoff containing the majority of pollutants from impervious areas is captured and treated by applying a simple calculation. It assumes that disturbed pervious areas contribute less runoff and therefore less pollutant to the BMPs selected. This method is recommended when the percentage of impervious area on a site is small and both pervious and impervious areas are treated by the same BMP.
- **One inch of runoff from disturbed pervious and impervious areas**. This is the most conservative water quality volume calculated with a simple formula. It virtually assures that all of the first flush from any site will be captured and treated. However, when calculated this way the water quality volume may exceed the channel protection volume. The volume determined using this method should always be compared to the channel protection volume to determine if additional water quality treatment is necessary. This method is an appropriate way for any site to calculate a simple yet rigorous water quality volume. It eliminates the need for detailed soil/land cover descriptions, choosing an appropriate storm, and rainfall-runoff calculations. The resulting volume will typically be less than the "one inch of runoff from disturbed pervious and impervious areas" and slightly more than the "90 percent of runoff producing storms" method listed below.
- **90 percent of runoff producing storms**. This method determines the water quality volume by calculating the runoff generated from the 10 percent exceedence rain event for the entire site. In Michigan, that event varies from 0.77 to 1.00 inch. This method provides a more rigorous analysis based on the response of the land type of the site. In order to accurately represent the pervious portion of runoff needing treatment, the runoff calculation for this method must use the small storm hydrology method described later in this chapter. The water quality volume calculated in this way produces a lower volume than using one inch of runoff but still ensures treatment of the first flush. The 10 percent exceedance storm values for 13 climatic regions of the state can be found in Table 9.1. This method is recommended when a precise estimate of water quality volume is desired or for multiple distributed sites treated by one BMP.

Table 9.1
90 Percent Nonexceedance Storm Values

Weather Station	Kenton	Champion Van Riper	Newberry	Kalkaska	Mio	Baldwin	Alma	Saginaw Airport	Cass City	Gull Lake	Lansing	East Lansing	Detroit Metro
Station Number	4328	1439	5816	4257	5531	0446	0146	7227	1361	3504	4641	2395	2103
Zone*	1		2	3	4	5	6	7		8	9		10
90 percent nonexceedance storm	0.95	0.87	0.84	0.77	0.78	0.93	0.93	0.92	0.87	1.00	0.90	0.91	0.90

Source: Dave Fongers, Hydrologic Studies Unit, Michigan Department of Environmental Quality. Memo: 90 Percent Annual Nonexceedance Storms. March 24, 2006. http://www.michigan.gov/documents/deq/lwm-hsu-nps-ninety-percent_198401_7.pdf
*See Figure 9.2 Climatic Zones for Michigan

Other water quality issues. Additional issues must be considered when protecting water quality, including soluable pollutants and high risk areas.

- **Soluble pollutants**. Materials that dissolve in stormwater are of special concern in those areas where soils are rapidly draining (e.g., Hydrologic Soil Group A) with cation exchange capacity values of less than 10 milliequivalents per 100 grams. In these cases, groundwater protection requires that volume control BMPs that are infiltrating provide additional measures, such as inclusion of organic filtering layers, in their design. Additionally, the use of soluble substances such as road salt (chlorides) and fertilizers (nitrates) on areas treated by infiltration BMPs should be limited or less soluble alternatives found.
- **Hot spot and high risk areas**. Some areas of a site, such as karst topography or proximity to drinking water wells may be particularly susceptible to stormwater contaminants. Conversely, sites may be contaminated with pollutants that should not be transported off site in storm runoff. When development is planned for these sites, specific BMPs or design modifications should be included in the overall stormwater plan to ensure protection of both surface and groundwater systems.

Evapotranspiration (ET) and the natural hydrologic/water cycle

The previous design criteria are often quantified in terms of the water cycle factors of runoff and infiltration, but the additional cycle variables of evaporation and transpiration also are critical. Development that results in clearing the existing vegetation from a site removes the single largest component of the hydrologic regime — evapotranspiration (ET). The post-development loss in ET can significantly increase not only runoff, but also groundwater recharge that may have impacts on existing developments (i.e., basement flooding) and certain groundwater dominant rivers and streams. Vegetated swales and filter strips, tree planting, vegetated roof systems, rain gardens, and other "green" BMPs help replace a portion of lost ET.

Evapotransporation is difficult to quantify. The design criteria recommended here is to minimize the loss of ET by protecting existing vegetated areas and replacing vegetation lost or removed with vegetation exhibiting similar ET qualities as much as possible.

Selecting design criteria

LID design is based on reproducing the presettlement hydrology of a site. Specific selection of design criteria should be based on achieving this goal while meeting local, state, and federal regulations. The criteria described here will apply to the majority of situations in Michigan. However, site specific or watershed studies may provide suitable alternative design criteria to achieve the same result. Additionally, some sites will be constrained by conditions that either limit the use of LID or require design and implementation of additional or alternative measures to meet LID goals.

Reducing disturbed areas and protecting sensitive areas

The first step of any LID site design is to minimize the area of disturbance for a site. Any portion of a site that can be maintained in its presettlement state will not contribute increased stormwater runoff and will reduce the amount of treatment necessary. This manual includes nonstructural BMPs that describe methods to protect sensitive areas. Any area that is protected as described in those BMPs may be subtracted from site development for purposes of designing LID-based treatments.

Credits

Credits are used in the design process to emphasize the use of BMPs that, when applied, alter the disturbed area in a way that reduces the volume of runoff from that area. Credits are given for five BMPs because they enhance the response of a piece of land to a storm event rather than treat the runoff that is generated. These BMPs are encouraged because they are relatively easy to implement over structural controls, require little if any maintenance, and the land they are applied to remains open to other uses. The credit only works with designs based on the Curve Number or CN method of analysis described later in this chapter. Credit is applied by modifying the CN variable so that the amount of runoff generated from an event is reduced.

The BMPs that generate a design credit are:

- Minimize Soil Compaction
- Protection of Existing Trees (part of Minimize Disturbed Area)
- Soil Restoration
- Native Revegetation
- Riparian Buffer Restoration

Calculating runoff

Many methodologies have been developed to estimate the total runoff volume, the peak rate of runoff, and the runoff hydrograph from land surfaces under a variety of conditions. This section describes some of the methods that are most widely used in Michigan and throughout the country. This is not a complete list of procedures nor is it intended to discourage using alternative methods as they become available.

The runoff Curve Number (CN) method is widely applied for LID designs around the country and is applicable for most site designs in Michigan. This manual recommends the use of the CN method for LID design and applies that method in design guidance and examples. The other methods discussed here may be equally as applicable within the limitations of each method. The ultimate selection of the method used should be determined on the applicability of the method to the site design, the preference of the user, and local requirements.

There are also a wide variety of public and private domain computer models available for performing stormwater runoff calculations. The computer models use one or more calculation methodologies to estimate runoff characteristics. The procedures most commonly used in computer models are the same as those discussed below.

In order to facilitate a consistent and organized presentation of information throughout the state, assist design engineers in meeting the recommended site design criteria, and help reviewers analyze project data, a series of worksheets are included in this chapter for design professionals to complete and submit with their development applications.

Methodologies for runoff volume calculations

Numerous methodologies available for calculating runoff volumes. Runoff curve number, small storm hydrology method, and infiltration models are described below.

Runoff Curve Number (CN) Method (Recommended)

The Runoff Curve Number Method, sometimes referred to as TR55 and developed by the Soil Conservation Service (now the Natural Resources Conservation Service), is perhaps the most commonly used tool in the country for estimating runoff volumes. In this method, runoff is calculated using the following formula:

$$Q_v = \frac{(P - I_a)^2}{(P - I_a) + S}$$

where:

Q = runoff volume (in.)

P = rainfall (in.)

I_a=initial abstraction (in.)

S=potential maximum retention after runoff begins (in.)

Initial abstraction (I_a) includes all losses before the start of surface runoff: depression storage, interception, evaporation, and infiltration. SCS has found that I_a can be empirically approximated for typical land uses by:

$$I_a = 0.2S$$

Therefore, the runoff equation becomes:

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

Finally, S is a function of the watershed soil and cover conditions as represented by the runoff curve number (CN):

$$S = \frac{1000}{CN} - 10$$

Therefore, runoff can be calculated using only the curve number and rainfall.

Curve numbers are determined by land cover type, hydrologic condition, antecedent runoff condition (ARC), and hydrologic soil group (HSG). Curve numbers for various land covers based on an average ARC for annual floods and I_a = 0.2S can be found in *Urban Hydrology for Small Watersheds* (Soil Conservation Service, 1986) and various other references. Table 9.2 includes some of the more commonly used curve numbers from *Urban Hydrology for Small Watersheds*.

Note that the hydrologic soil group is sometimes mapped with a dual specification such as A/D, B/D, etc. This refers to soils that are specified as D soils in an undrained state and a specification with higher infiltration capacity when they are drained. For designing LID controls, it is important to use the same hydrologic soil group to calculate presettlement runoff as the post-development runoff. The user must pick the most appropriate hydrologic soil group to apply to both conditions.

Often a single, area-weighted curve number is used to represent a watershed consisting of subareas with different curve numbers. This approach is acceptable only if the curve numbers are similar. When curve numbers differ by a significant margin, the use of a weighted curve number significantly reduces the estimated amount of runoff from the watershed. This is especially problematic with pervious/impervious combinations "combination of impervious areas with pervious areas can imply a significant initial loss that may not take place." (Soil Conservation Service, 1986) Therefore, the runoff from different subareas should be calculated separately and then combined or weighted appropriately. At a minimum, runoff volume from pervious and directly connected impervious areas should be estimated separately for storms less than approximately four inches. (NJDEP, 2004 and PADEP, 2006)

Table 9.2
Commonly used curve numbers (CNs) from TR-55

Runoff curve numbers for urban areas[1]				
Cover Description	**Curve numbers for hydrologic soil group**			
Cover Type and hydrologic condition*	A	B	C	D
Open spaces (parks, golf courses, cemeteries, etc.)[2]				
Poor condition (grass cover < 50%)	68	79	86	89
Fair condition (grass cover 50% to 75%)*	49	69	79	84
Good condition (grass cover > 75%)*	39	61	74	80
Impervious Areas:				
Paved parking lots, roofs, driveways, etc. (excluding right of way)	98	98	98	98
Streets and Roads				
Paved; curbs and storm sewers (excluding right of way)	98	98	98	98
Paved, open ditches (including right of way)	83	89	92	93
Gravel (including right of way)	76	85	89	91

1 Average runoff condition, and I_a = 0.2S.
2 CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.

Table 9.2 Contiuned

Runoff curve numbers for other agricultural lands[1]						
Cover Description		**Curve numbers for hydrologic soil group**				
Cover Type*	**Hydrologic condition**	A	B	C	D
Pasture, grassland, or range – continuous forage for grazing.[2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow – continuous grass, protected from grazing and generally mowed for hay.		30	58	71	78
Brush – brush-weed-grass mixture with brush the major element.[3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30[4]	48	65	73
Woods-grass combination (orchard or tree farm).[5]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods.[6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30[4]	55	70	77
Farmsteads – buildings, lanes, driveways, and surrounding lots.		59	74	82	86

1 Average runoff condition, and $I_a = 0.2S$.

2 Poor: <50% ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: > 75% ground cover and lightly or only occasionally grazed.

3 Poor: <50% ground cover.
Fair: 50 to 75% ground cover.*
Good: >75% ground cover.*

4 Actual curve number is less than 30; use CN = 30 for runoff computations.

5 CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.

6 Poor: Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

* To account for the land development process, all disturbed pervious areas that are not restored using one of the techniques in Chapter 7 should be assigned a curve number that reflects a "fair" hydrologic condition as opposed to a "good" condition for post-development volume calculations. For example, lawns should be assigned curve numbers of 49, 69, 79, and 84 for soil groups A, B, C, and D respectively.

The Curve Number Method is less accurate for storms that generate less than 0.5 inch of runoff; the Soil Conservation Service (1986) recommends using another procedure as a check for these situations. For example, the storm depth that results in 0.5 inch of runoff varies according to the CN. For impervious areas (CN of 98) it is a 0.7-inch storm; for "open space" in good condition on C soils (CN of 74) it is 2.3 inches; for woods in good condition on B soils (CN of 55) it is over 3.9 inches. The CN methodology can also significantly underestimate the runoff generated from smaller storm events. (Claytor and Schueler, 1996 and Pitt, 2003) An alternate method for calculating runoff from small storms is described below.

Recently, some researchers have suggested that the assumption that $I_a = 0.2S$ does not fit the observed rainfall-runoff data nearly as well as $I_a = 0.05S$. Incorporating this assumption into the Curve Number Method results in a new runoff equation and new curve numbers. Woodward et al. (2003) describe the new runoff equation and a procedure to convert traditional CNs to new values based on $I_a = 0.05S$. They also describe a plan to implement these changes into all appropriate NRCS documents and computer programs. The most notable differences in runoff modeling with these changes occur at lower curve numbers and lower rainfalls (using the traditional curve number assumption of $I_a = 0.2S$ results in higher initial abstractions and lower runoff volumes under these conditions). When used to predict runoff from developed sites in Michigan during typical design storms, the difference is likely to be insignificant. It is recommended that the traditional relationship of $I_a = 0.2S$ be used until additional research supports the new method.

The Curve Number Method, applied with appropriate CNs and the above considerations in mind, is recommended for typical runoff volume calculations and is used in the design worksheets at the end of this chapter.

Small Storm Hydrology Method

The Small Storm Hydrology Method (SSHM) was developed to estimate the runoff volume from urban and suburban land uses for relatively small storm events. (Other common procedures, such as the Runoff Curve Number Method, are less accurate for small storms as described previously.) The SSHM is a straightforward procedure in which runoff is calculated using volumetric runoff coefficients. The runoff coefficients, R_v, are based on extensive field research from the Midwest, the Southeastern U.S., and Ontario, Canada, over a wide range of land uses and storm events. The coefficients have also been tested and verified for numerous other U.S. locations. Runoff coefficients for individual land uses generally vary with the rainfall amount – larger storms have higher coefficients. Table 9.3 lists SSHM runoff coefficients for seven land use scenarios for 0.5 and 1.5-inch storms.

Runoff is calculated by multiplying the rainfall amount by the appropriate runoff coefficient (it is important to note that these volumetric runoff coefficients are not equivalent to the peak rate runoff coefficient used in the Rational Method, discussed below). Since the runoff relationship is linear for a given storm (unlike the Curve Number Method), a single weighted runoff coefficient can be used for an area consisting of multiple land uses. Therefore, runoff is given by:

$$Q = P \times R_v$$

Where: Q = runoff (in.)

P = rainfall (in.)

R_v= area-weighted volumetric runoff coefficient

Table 9.3
Runoff Coefficients for the Small Storm Hydrology Method

Rainfall (in.)	Volumetric Runoff Coefficients, R_v						
	Impervious Areas				Pervious Areas		
	Flat Roofs/ Large Unpaved Parking Areas	Pitched Roofs	Large Imperv. Areas	Small Imperv. Areas and Uncurbed Roads	Sandy Soils (HSG A)	Silty Soils (HSG B)	Clayey Soils (HSG C & D)
0.5	0.75	0.94	0.97	0.62	0.02	0.09	0.17
1.5	0.88	0.99	0.99	0.77	0.05	0.15	0.24

Source: Adapted from Pitt, 2003.

Infiltration models for runoff calculations

Several computer packages offer the choice of using soil infiltration models as the basis of runoff volume and rate calculations. Horton developed perhaps the best-known infiltration equation – an empirical model that predicts an exponential decay in the infiltration capacity of soil towards an equilibrium value as a storm progresses over time (Horton, 1940). Green and Ampt (1911) derived another equation describing infiltration based on physical soil parameters. As the original model applied only to infiltration after surface saturation, Mein and Larson (1973) expanded it to predict the infiltration that occurs up until saturation (James, et al., 2003). These infiltration models estimate the amount of precipitation excess occurring over time. Excess precipitation must then be transformed to runoff with other procedures to predict runoff volumes and hydrographs.

Methodologies for peak rate/hydrograph estimations

There are numerous methods for estimating peak rate, including the Rational Method, NRCS Unit Hydrograph method, and Modified Unit Hydrograph Method. This manual recommends the use of the NRCS (SCS) Unit Hydrograph method to calculate peak runoff rate for LID design and applies that method in design guidance and examples. The other methods discussed here may be equally as applicable within the limitations of each method. The ultimate selection of the method used should be determined on the applicability of the method to the site design, the preference of the user, and local requirements.

Regardless of the method of analysis selected, the same method must be used to calculate pre- and post-development runoff.

NRCS (SCS) Unit Hydrograph Method (Recommended)

In combination with the Curve Number Method for calculating runoff volume, the Soil Conservation Service (now NRCS) also developed a system to estimate peak runoff rates and runoff hydrographs using a dimensionless unit hydrograph (UH) derived from many natural unit hydrographs from diverse watersheds throughout the country (NRCS Chapter 16, 1972). As discussed below, the SCS methodologies are available in several public domain computer models including the TR-55 computer model (WinTR-55, 2005), TR-20 Computer Program (WinTR-20, 2005), and is an option in the U.S. Army Corps of Engineers' Hydrologic Modeling System (HEC-HMS, 2006).

Modified Unit Hydrograph Method for Michigan

The Michigan Department of Environmental Quality has developed a modified unit hydrograph method that better represents conditions in Michigan and addresses the fact that the traditional NRCS UH "consistently overestimates discharges when compared to recorded gage flows for Michigan streams." (*Computing Flood Discharges For Small Ungaged Watersheds*, MDEQ 2008, available online at www.michigan.gov/documents/deq/lwm-scs_198408_7.pdf.

The result is a relatively simple equation for calculating the unit peak flow rate from the time of concentration:

$$Q_{up} = 238.6 \times T_c^{-0.82}$$

Where:

Q_{up}= unit peak discharge (cfs per inch of runoff per square mile of drainage area)

T_c= time of concentration (hours) Note: Tc must be at least one hour. If Tc is less than one hour, use TR-55 or HEC-HMS.

The unit peak discharge (cfs/in./mi^2) calculated above can be converted to the peak runoff rate (cfs) by multiplying by the drainage area in square miles and by the runoff in inches (calculated by the Runoff Curve Number Method described in section 9.2.1):

$$Q_p = Q_{up} \times A \times Q_v$$

Where:

Q_p= peak runoff rate (cfs)

A = drainage area (square miles)

Q_v= total runoff volume from CN method (in.)

The Modified UH Method for Michigan is recommended for calculating the peak rate of runoff for presettlement conditions and undisturbed areas.

The Rational Method

The Rational Method has been used for over 100 years to estimate peak runoff rates from relatively small, highly developed drainage areas. The peak runoff rate from a given drainage area is given by:

$$Q_p = C \times I \times A$$

Where:

Q_p= peak runoff rate (cubic feet per second, cfs)

C = the runoff coefficient of the area (assumed to dimensionless)

I = the average rainfall intensity (in./hr) for a storm with a duration equal to the time of concentration of the area

A= the size of the drainage area (acres)

The runoff coefficient is usually assumed to be dimensionless because one acre-inch per hour is very close to one cubic foot per second (1 ac-in./hr = 1.008 cfs). Although it is a simple and straightforward method, estimating both the time of concentration and the runoff coefficient introduce considerable uncertainty in the calculated peak runoff rate. In addition, the method was developed for relatively frequent events so the peak rate as calculated above should be increased for more extreme events. (Viessman and Lewis, 2003) Because of these and other serious deficiencies, the Rational Method should only be used to predict the peak runoff rate for very small (e.g., 1 acre) highly impervious areas. (Linsley et. al, 1992)

Although this method has been adapted to include estimations of runoff hydrographs and volumes through the Modified Rational Method, the Universal Rational Hydrograph, the DeKalb Rational Hydrograph, etc., these are further compromised by assumptions about the total storm duration and therefore should not be used to calculate volumes related to water quality, infiltration, or capture/reuse.

Computer models for calculating runoff

Numerous models are available that assist in estimating runoff from a site. These include:

- HEC Hydrologic Modeling System (HEC-HMS)
- SCS/NRCS Models: WinTR-20 and WinTR-55
- Storm Water Management Model (SWMM)
- Source Loading and Management Model (SLAMM)

HEC Hydrologic Modeling System (HEC-HMS)

The U.S. Army Corps of Engineers' Hydrologic Modeling System (HEC-HMS, 2006) supersedes HEC-1 as "new-generation" rainfall-runoff simulation software.

HEC-HMS was designed for use in a "wide range of geographic areas for solving the widest possible range of problems." The model incorporates several options for simulating precipitation excess (runoff curve number, Green & Ampt, etc.), transforming precipitation excess to runoff (SCS unit hydrograph, kinematic wave, etc.), and routing runoff (continuity, lag, Muskingum-Cunge, modified Puls, kinematic wave).

SCS/NRCS Models: WinTR-20 and WinTR-55

WinTR-20 model is a storm event surface water hydrologic model. It can be used to analyze current watershed conditions as well as assess the impact of proposed changes (alternates) made within the watershed. Direct runoff is computed from watershed land areas resulting from synthetic or natural rain events. The runoff is routed through channels and/or impoundments to the watershed outlet. TR-20 applies the methodologies found in the Hydrology section of the National Engineering Handbook (NRCS, 1969-2001), specifically the runoff Curve Number Method and the dimensionless unit hydrograph. (SCS, 1992) .

Technical Release 55 (TR-55) generates hydrographs from urban and agricultural areas and routes them downstream through channels and/or reservoirs. WinTR-55 uses the TR-20 model for all of its hydrograph procedures. (NRCS, 2002).

Storm Water Management Model (SWMM)

The EPA Storm Water Management Model (SWMM) is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. The runoff component of SWMM operates on a collection of subcatchment areas that receive precipitation and generate runoff and pollutant loads. The routing portion of SWMM transports this runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators. SWMM tracks the quantity and quality of runoff generated within each subcatchment, and the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period comprised of multiple time steps.

Source Loading and Management Model (SLAMM)

The Source Loading and Management Model (SLAMM) is designed to provide information about the sources of critical pollutants in urban runoff and the effectiveness of stormwater BMPs for controlling these pollutants. SLAMM was primarily developed as a planning level model to predict flow and pollutant discharges from a wide variety of development conditions using many combinations of common stormwater BMPs. Because of their importance for pollutant loading, SLAMM places special emphasis on small storms and uses the Small Storm Hydrology Method to calculate surface runoff (Pitt and Voorhees 2000).

Continuous modeling

The methodology included in this chapter is based on single-event calculations using hypothetical design storms (e.g., the two-year, 24-hour NRCS Type II storm) because they are relatively simple and widely accepted, have been used historically, and are the basis of many of the local standards throughout Michigan. However, the advent of better computer models and faster processors has made the continuous simulation of long periods of recorded climate data quite feasible. While continuous simulations require extensive precipitation data and generally require much more time to develop, they offer the benefit of analyzing actual long-term conditions rather than one or more hypothetical storms. Legitimate continuous modeling may be a more accurate simulation of performance to the site design criteria listed in this chapter. In fact, some jurisdictions in the country are beginning to require continuous simulation to demonstrate compliance with stormwater standards. That being said, the single-event methodology recommended here - with the appropriate assumptions included - is a cost-effective, defensible approach for most Michigan projects.

Calculating peak rate by utilizing volume control

The use of volume reduction BMPs and LID practices reduces or eliminates the amount of storage required for peak rate mitigation because less runoff is discharged. However, quantifying the peak rate mitigation benefits of LID can be difficult and cumbersome with common stormwater models/methodologies. This section discusses some available tools for quantifying the benefits of LID (see also Worksheet 7).

In its Surface Water and Storm Water Rules Guidance Manual (available at www.mmsd.com/stormwaterweb/index.htm), the Milwaukee Metropolitan Sewerage District (MMSD) describes five methods of accounting for "distributed retention" or LID, based on the NRCS Unit Hydrograph Method. MMSD developed a spreadsheet model called LID Quicksheet 1.2: "Quicksheet allows the user to quickly evaluate various LID features on a development site to reduce … detention requirements…LID features included in the Quicksheet include rain gardens, rain barrels, green roofs, cisterns, and permeable pavement."

While Quicksheet seems to be a useful tool, the current version does not appear to directly account for ongoing infiltration during the storm event and, therefore, may not fully credit LID practices that achieve significant infiltration. (The ongoing infiltration volume could be added to the capacity of the LID Retention Features to make up for this.)

Some other resources on LID calculations include:

BMP Modeling Concepts and Simulation (USEPA, 2006): www.epa.gov/nrmrl/pubs/600r06033/epa600r-06033toc.pdf

Stormwater Best Management Practice Design Guide, Vol. 2 (USEPA, 2004): www.epa.gov/nrmrl/pubs/600r04121/600r04121.htm

Mecklenburg County BMP Design Manual, Chapter 4 (2007): www.charmeck.org/Departments/StormWater/Contractors/BMP+Standards+Manual.htm

The Delaware Urban Runoff Management Model - DURMM (Lucas, 2004): www.swc.dnrec.delaware.gov/SedimentStormwater.htm

Low-Impact Development Hydrologic Analysis (Prince George's County, MD, Dept. of Environmental Resources, 1999): www.epa.gov/nps/lid_hydr.pdf

Precipitation data for application in stormwater calculations

Accurate rainfall frequency data are necessary to determine a reliable design. At the time of this writing, the most reliable source of rainfall frequency data is the *Rainfall Frequency Atlas of the Midwest* (Huff and Angel, 1992); available for free download at www.sws.uiuc.edu/pubdoc/B/ISWSB-71.pdf. Table 9.4 includes selected 24-hour event data for the entire state.

In terms of measured precipitation data, long-term daily and monthly precipitation data for about 25 stations throughout Michigan are available free from the United States Historical Climatology Network (USHCN) at cdiac.ornl.gov/epubs/ndp/ushcn/state_MI.html. If local rainfall data are used, the period of record must be of sufficient length to provide a statistically valid result.

Table 9.4
Rainfall Events of 24-Hour Duration in Michigan

Zone*	Rainfall frequencies, 24-hour duration (rainfall in inches)						
	1-year	2-year	5-year	10-year	25-year	50-year	100-year
1	1.95	2.39	3.00	3.48	4.17	4.73	5.32
2	1.66	2.09	2.71	3.19	3.87	4.44	5.03
3	1.62	2.09	2.70	3.21	3.89	4.47	5.08
4	1.71	2.11	2.62	3.04	3.60	4.06	4.53
5	1.77	2.28	3.00	3.60	4.48	5.24	6.07
6	1.86	2.27	2.85	3.34	4.15	4.84	5.62
7	1.75	2.14	2.65	3.05	3.56	3.97	4.40
8	1.95	2.37	3.00	3.52	4.45	5.27	6.15
9	2.03	2.42	2.98	3.43	4.09	4.63	5.20
10	1.87	2.26	2.75	3.13	3.60	3.98	4.36

Source: Huff and Angel, 1992. *Rainfall Frequency Atlas of the Midwest*

*See Figure 9.2 Climatic Zones for Michigan

Design calculation process

The design calculations detailed below provide the steps necessary to perform a site analysis and complete a LID-based site design. Users should also refer to Chapter 5 "Incorporating LID into the Site Design Process" for additional steps.

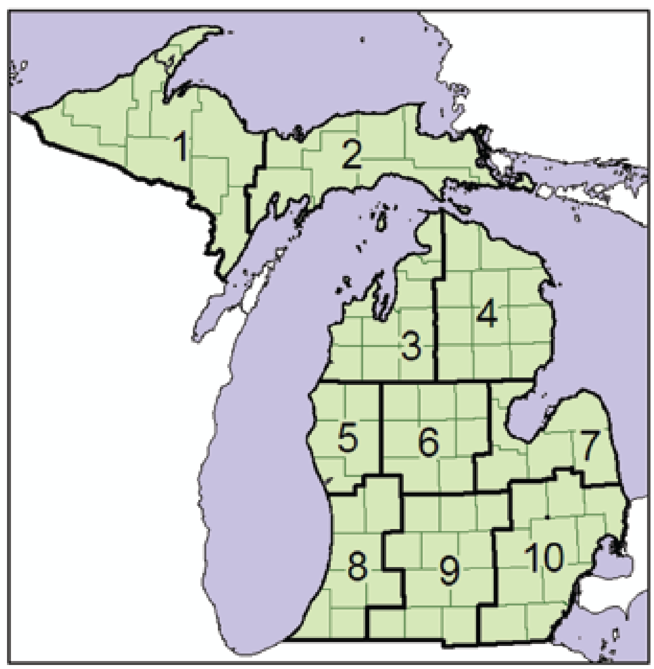
Credits

Design credits are identified for several nonstructural BMPs. When these BMPs are implemented according to the guidance provided, they may generate credits that affect the design calculations by reducing the value of the CN of a portion of contributing area. These credits may only be applied when using a calculation based on the CN Method.

Those BMPs that generate a design credit are listed below at the appropriate step in the design process. CN changes due to design credits are determined in Worksheet 3.

Flow Chart A (*Stormwater Calculation Process*) is provided to guide the user through the first steps of the stormwater calculation process and can be thought of as a series of steps executed through a series of worksheets.

Figure 9.2
Climatic Zones for Michigan



Source: Sorrell, Richard C., Computing Flood Discharges for Small Ungaged Watersheds

Step 1: Provide general site information (Worksheet 1)

- This is basic identifying information, e.g., name, location, and waterways. It also includes information about the watershed from a number of state resources.

Step 2: Map the existing features of the site

- More than one map may be necessary. Collect any necessary design information.
- Identify waterbodies, floodplains, and natural flow paths. Identify existing structures and infrastructure. Identify hydrologic soil types. Show elevations and identify critical slopes of 15 percent to 25 percent and above 25 percent. Show areas of known contamination. Identify karst topography and bedrock outcroppings.
- Identify the total area of impervious surface existing prior to development.
- Note the seasonal high groundwater level.
- Identify type and area of existing sensitive resource areas on Worksheet 2. Identify the area of sensitive resource areas to be protected. The following nonstructural BMPs identify how to properly protect sensitive areas so they maintain their presettlement state and runoff characteristics.
  - Protect Sensitive Areas
  - Protect Riparian Buffers
  - Minimize Total Disturbed Area
  - Protect Natural Flow Pathways
  - Cluster Development
- Record the sum of the protected sensitive areas from Worksheet 2 on the space provided for it on Worksheet 3.

Step 3: Lay out the proposed development avoiding the protected areas

- If after the development is sited, additional sensitive areas are impacted, modify Worksheet 2.

Step 4: Determining the disturbed area size

- On Worksheet 3 subtract the sum of the Protected Sensitive Areas on Worksheet 2 from the total site area. Use this as the new disturbed or modified area requiring LID controls. Apply the following BMPs, as appropriate, to determine runoff reduction credits.
  - Minimize Soil Compaction
  - Protection of Existing Trees (part of Minimize Total Disturbed Area)
  - Soil Restoration
  - Native Revegetation
  - Riparian Buffer Restoration
- Continue on Worksheet 3 to record the area, soil type, existing CN and modified CN for each Runoff Reduction Credit generated.

Step 5: Calculate the level of volume control needed for channel protection

- On Worksheet 4 record the two-year 24-hour rainfall for your area from Table 9.4 as well as the Total Site Area, Protected Site Area, and the Area to be Managed from Worksheets 2 and 3 in the spaces provided. Record the presettlement condition by filling in the area of each soil type and cover type.
- Calculate the runoff volume for the presettlement condition of each soil type and cover type using this formula:

  Runoff Volume (ft^3) = Q_v x 1/12 x Area

  Where

  Q_v = Runoff (in) = $(P - 0.2S)^2/(P + 0.8S)$

  P = 2 Year, 24 Hr Rainfall (in)

  S = 1000/CN – 10
- Sum the individual volumes to obtain the total presettlement runoff volume.
- Continue on Worksheet 4 to record the post-development area of each soil type and cover type. Use the same formulas to calculate the post-development runoff volume for the site and record in the space provided.
- Subtract the presettlement runoff volume from the post-development runoff volume and record the result in the space for "2 Year Volume Increase." This is the volume that must be removed by infiltration, interception, evaporation, transpiration or capture and reuse.

Step 6: Select volume control BMPs

- Worksheet 5 includes a list of the BMPs from this manual that provide volume removal and tracks the volume removed of each practice and total sum of volume removed for all practices. Select and Design Structural BMPs that provide volume control for the applicable stream channel protection volume increase indicated on Worksheet 4. Indicate the volume reduction provided by the proposed BMPs.

- Proceed to Flow Chart B, Peak Rate Calculations.

Step 7: Peak rate exemption for small sites

- The peak rate calculation for channel protection is not necessary for sites that have a small proportion of imperviousness and can maintain the presettlement runoff volume. Worksheet 6 provides a checklist of criteria that if met, would eliminate the need for most peak rate conditions. Peak rate calculations may still be necessary for larger storms to address flooding in some areas. If peak rate calculations for channel control are necessary, follow step 8 and Worksheet 7 to provide the necessary peak rate control.

Step 8: Calculate peak rate control

- Use Worksheet 7 and the NRCS Unit Hydrograph Method (or other appropriate runoff model) and determine peak rate control for all storms up to the 100-year storm or according to local requirements.
- List the design criteria used (local requirement, LID guidance or other) and what it specified.
- List the presettlement and post-development peaks for each design storm in the space provided.
- If time of concentration is more than one hour, the following formula can be used.

  $Q_p = Q_v * A * 238.6 * Tc^{-0.82}$

  Where;

  Q_p = Peak flow rate in cfs

  Q_v = surface runoff in inches

  A = Drainage area in square miles

  Tc = Time of concentration in hours. If Tc is less than one hour, use TR-55 or HEC-HMS.

- Time of concentration in the case of LID design is the time it takes a drop of water to move from the furthest point in the disturbed area to its discharge from the disturbed area. Time of concentration can be affected by adjusting the length or roughness of natural flow paths and routing through BMPs.

  If time of concentration is kept constant for the presettlement and post development condition, the peak rate is completely dependent on the volume of surface runoff and can be completely controlled by implementing additional volume control. Repeat steps 5 and 6 for the larger storms and determine if additional volume control can be implemented to control the peak rate.

Other recommended methods of determining the effects of volume control on peak rate mitigation are listed below.

- **Simple Volume Diversion**. This is a very simple way to partially account for the effect of volume control BMPs on peak runoff rates. Many computer models have components that allow a "diversion" or "abstraction." The total volume reduction provided by the applicable structural and nonstructural BMPs can be diverted or abstracted from the modeled runoff before it is routed to the detention system (if detention is needed). This approach is very conservative because it does not give any credit to the increased time of travel, fully account for ongoing infiltration, etc. associated with the BMPs. Even this conservative approach can reduce the detention storage requirements significantly. This method can and should be used in conjunction with Travel Time/Time of Concentration Adjustment explained below.
- **Travel Time/ Time of Concentration Adjustment**. The use of widely distributed, volume-reducing BMPs can significantly increase the post-development runoff travel time and therefore decrease the peak rate of discharge. The Delaware Urban Runoff Management Model (DURMM) discussed previously calculates the extended travel time through storage elements, even at flooded depths, to adjust peak flow rates (Lucas, 2001). The extended travel time is essentially the residence time of the storage elements, found by dividing the total storage by the 10-year peak flow rate. This increased travel time can be added to the time of concentration of the area to account for the slowing effect of the volume-reducing BMPs. This can significantly reduce or even eliminate the detention storage required for peak rate control. This method can and should be used with Simple Volume Diversion explained above.
- **Composite BMPs w/Routing**. For optimal stormwater management, this manual suggests widely distributed BMPs for volume, rate, and quality control. This approach, however, can be very cumbersome to evaluate in detail with common computer models. To facilitate modeling, similar types of BMPs with similar outlet configurations can be combined within the model. For modeling purposes, the storage of the combined BMP is simply the sum of the BMP capacities that it represents. A stage-storage-discharge relationship

(including ongoing infiltration) can be developed for the combined BMP based on the configuration of the individual systems. The combined BMP(s) can then be routed normally and the results submitted. BMPs that are grouped together in this manner should have similar drainage area to storage volume ratios to ensure the individual BMPs function properly. This method should not be used in conjunction with Travel Time / Time of Concentration Adjustment method described above.

- **Full BMP Routing including ongoing infiltration**. For storms where additional volume control is not possible or where the post-development Tc is shortened, select and design BMPs that detain storm runoff and release at the presettlement rate. See the Detention BMP and Infiltration BMPs that are underdrained to a storm collection system or waterway.
- Proceed to Flow Chart C, Water Quality Process.

Step 9: If Needed– Determine water quality volume and select appropriate BMPs.

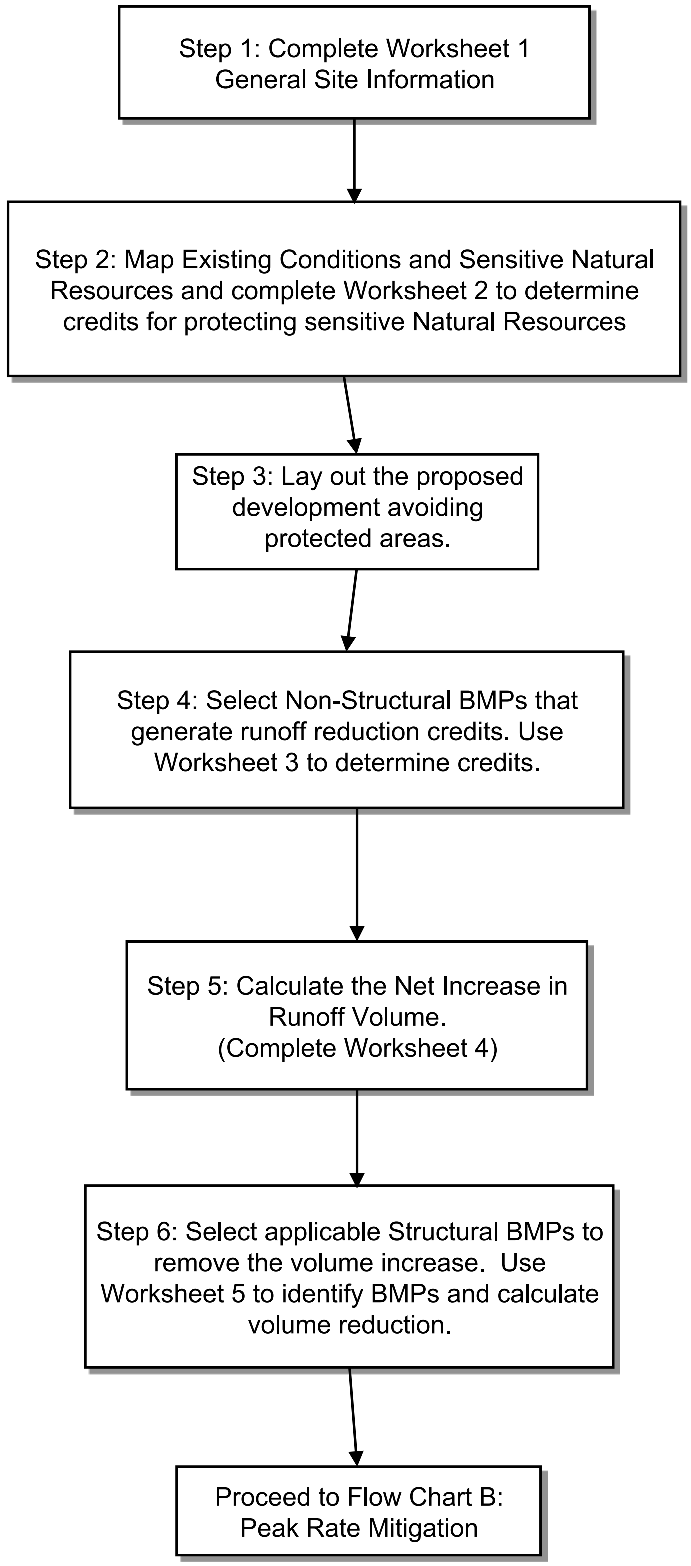
- When the channel-forming volume is controlled with BMPs that also remove expected pollutants, often no additional calculation or BMP implementation is necessary. If the channel-forming volume is not controlled, calculate the water quality volume that provides for the most reasonable amount of control of the volume carrying the most pollutants. This manual recommends using one inch of runoff from the entire site as the channel-control volume. The other methods of calculating water quality volumes described above may be appropriate for your site.
- The water quality volume calculation is necessary if the one-inch runoff method is used or the channel protection volume is not controlled. Use Worksheet 8 and record each contributing area needing treatment and calculate the water quality volume. Select BMPs that will remove the expected pollutants for the land use type. Often, multiple types of BMPs used in series will be required to provide adequate treatment. Design the BMPs in conjunction with any detention control if possible. As a guide, use a series of BMPs that will achieve 80 percent removal of solids or better (Table 9.5).

Table 9.5
Pollutant removal efficiencies for various stormwater BMPs

Pollutant	Infiltration Practices	Stormwater Wetlands	Stormwater Ponds Wet	Filtering Practices	Water Quality Swales	Stormwater Dry Ponds
Total Phosphorus	70	49	51	59	34	19
Soluable Phosphorus	85	35	66	3	38	-6
Total Nitrogen	51	30	33	38	84	25
Nitrate	82	67	43	-14	31	4
Copper	N/A	40	57	49	51	26
Zinc	99	44	66	88	71	26
TSS	95	76	80	86	81	47

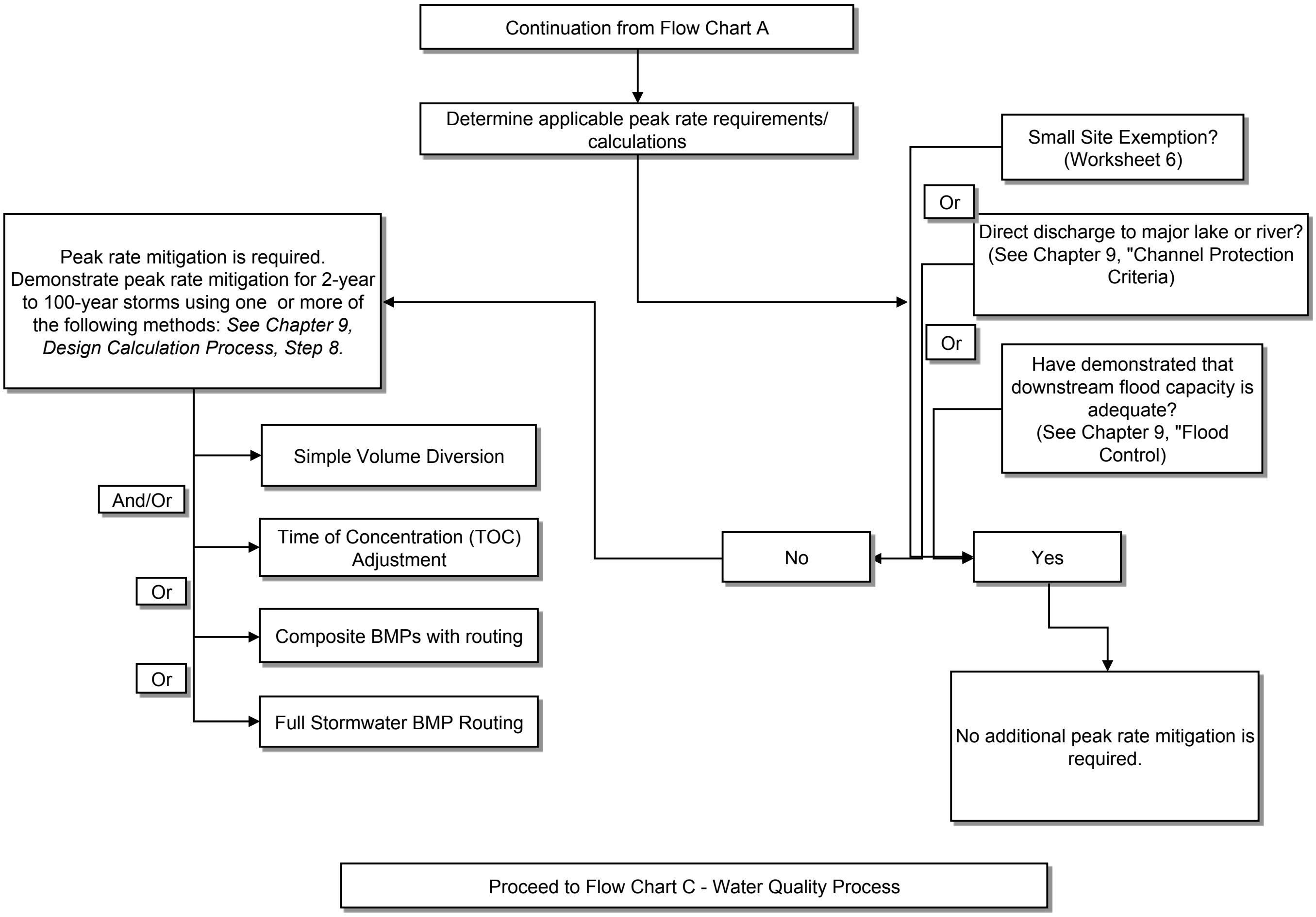
Source: "National Pollutant Removal Performance Database for Stormwater Treatment practices" Center for Watershed Protection, June 2000

FLOW CHART A
Stormwater Calculation Process

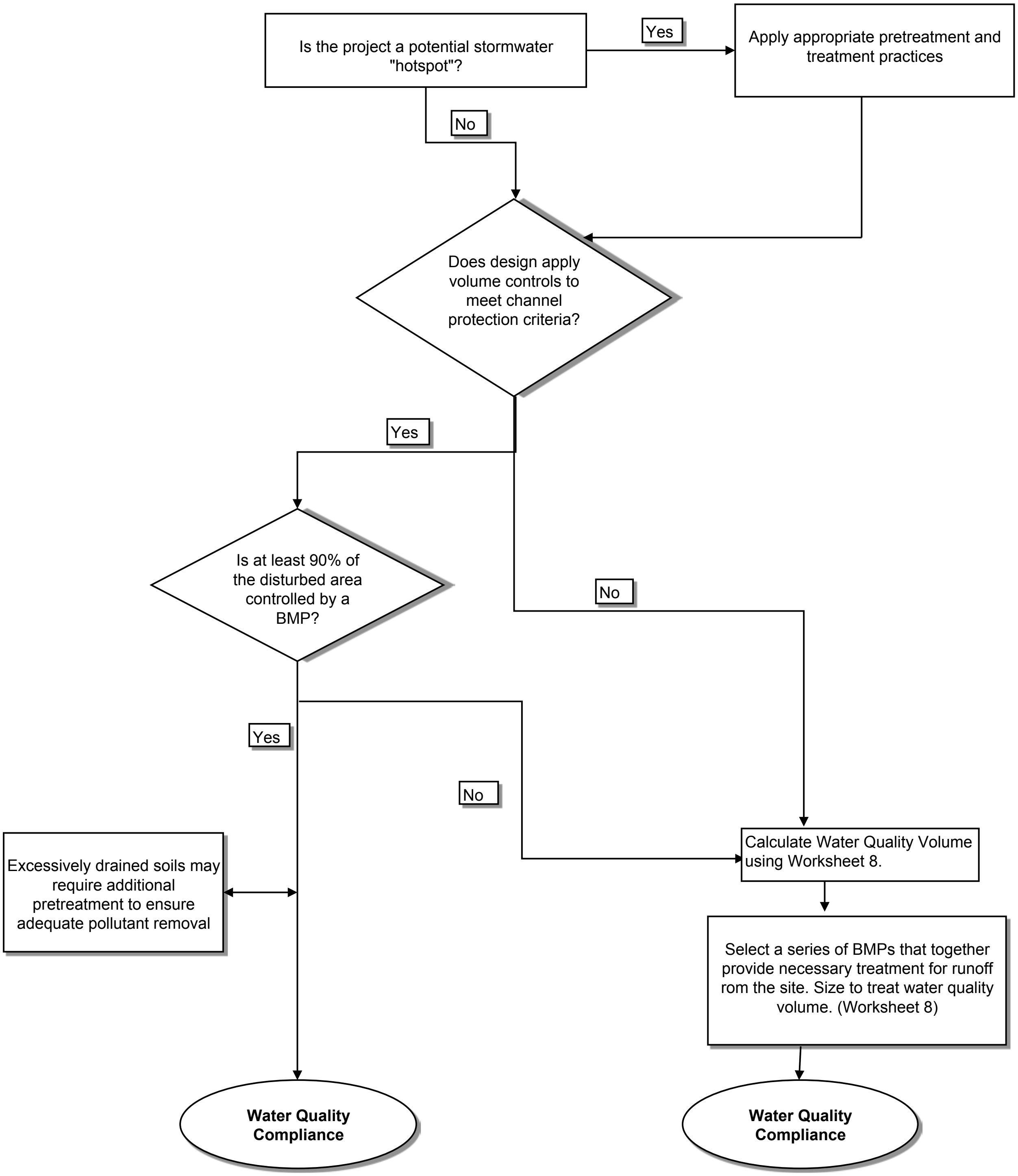


Flow Chart B

Peak Rate Mitigation



Flow Chart C
Water Quality Process



Worksheet 1. General Watershed/ Site Information

NOTE: If the project extends over more than 1 Watershed, fill out Worksheet 1 for each Watershed

Date: ______________________

Project Name: ______________________

Municipality: ______________________

County: ______________________

Total Area (acres): ______________________

Major Watershed: ______________________

http://cfpub.epa.gov/surf/state.cfm?statepostal=MI

Subwatershed: ______________________

Nearest Surface Water(s) to Receive Runoff: ______________________

Part 4 - Designated Water Use: (OSRWS, Cold water, etc.) ______________________

http://www.state.mi.us/orr/emi/admincode.asp?AdminCode=Single&Admin_Num=323010
41&Dpt=EQ&RngHigh=

Michigan Natural Rivers watershed? Yes ☐ No ☐

http://www.michigan.gov/dnr/0,1607,7-153-30301_31431_31442-95823--,00.html

Impaired according to Chapter 303(d) List? Yes ☐ No ☐

http://www.deq.state.mi.us/documents/deq-wb-intreport-appendixj.pdf

List Causes of Impairment:

Is project subject to, or part of:

Phase I or Phase II Municipal Separate Storm Sewer System (MS4) Requirements? Yes ☐ No ☐

http://www.michigan.gov/deq/0,1607,7-135-3313_3682_3716-24366--,00.html

Existing or planned drinking water supply? Yes ☐ No ☐

If yes, distance from proposed discharge (miles): __________

Approved Watershed Management Plan? Yes ☐ No ☐

http://www.michigan.gov/deq/0,1607,7-135-3313_3682_3714_4012-95955--,00.html

Worksheet 2. Sensitive Natural Resources

INSTRUCTIONS:

1. Provide Sensitive Resources Map for the site. This map should identify waterbodies, floodplains, riparian areas, wetlands, woodlands, natural drainage ways, steep slopes, and other sensitive natural features.

2. Summarize the existing extent of each sensitive resource in the Existing Sensitive Resources Table (below, using Acres).

3. Summarize total proposed Protected/Undisturbed Area. Use the following BMPs to define Protected/Undisturbed Area; protect sensitive areas, protect riparian buffers, protect natural flow pathways, cluster development, and minimize disturbed area.

4. Do not count any area twice. For example, an area that is both a floodplain and a wetland may only be considered once (include as either floodplain or wetland, not both).

EXISTING NATURAL SENSITIVE RESOURCE	MAPPED? (yes, no, n/a)	TOTAL AREA (Ac.)	PROTECTED/ UNDISTURBED AREA (Ac.)
Waterbodies			
Floodplains			
Riparian Areas			
Wetlands			
Woodlands			
Natural Drainage Ways			
Steep Slopes, 15% - 25%			
Steep Slopes, over 25%			
Special Habitat Areas			
Other:			
TOTAL EXISTING:			

Worksheet 3. Runoff Reduction Credits

PROTECTED/ UNDISTURBED AREA

Protected/Undisturbed Area* (from WS 2) ________ **Ac.**

TOTAL PROPOSED PROTECTED/UNDISTURBED AREA ________ **Ac.**

Total Site Area	*minus*	Protected/ Undisturbed Area	*equals*	Disturbed Area (To be managed)
[ ]	-	[ ]	=	[ ]

This is the area that requires stormwater management

Transfer to WS 4

NON STRUCTURAL BMP CREDITS**

BMP: Minimize Soil Compaction Area: ________ **Ac.**

Soil Type ________ Existing CN ________ Credited CN ________

BMP: Soil Amendment and Restoration Area: ________ **Ac.**

Soil Type ________ Existing CN ________ Credited CN ________

Areas complying with the requirements of these BMPs can be assigned a Curve Number (CN) reflecting a "Good" condition instead of "Fair" as required for other disturbed pervious areas. For example, lawn areas with B soils would be given a CN of 61 instead of 69; lawns with C soils a CN of 74 instead of 79.

Protect Existing Trees within Disturbed Area (part of Minimize Disturbed Area)

Number of Trees: ________

Total Area: ________ **Ac.**

Soil Type ________ Existing CN ________ Credited CN ________

Trees protected under the requirements of this BMP can be assigned a Curve Number (CN) reflecting a Woods in "Good" condition for an area of 800 SF per tree or the entire area of the tree canopies protected, whichever is greater.

BMPS: Native Revegetation and Riparian Corridor Restoration

Number of Trees: ________

Number of Shrubs: ________

Total Area: ________ **Ac.**

Soil Type ________ Existing CN ________ Credited CN ________

Proposed trees and shrubs to be planted under the requirements of these BMPs can be assigned a Curve Number (CN) reflecting a Woods in "Good" condition for an area of 200 SF per tree or the estimated tree canopy, whichever is greater. For shrubs, an area of 25 SF per shrub.

^^ *A checklist is provided for each BMP in chapter 6 and 7 to ensure certain criteria is being met and credit can be given.*

WORKSHEET 4. Calculations for Volume Criteria

PROJECT NAME: ______________________ **Sub-basin:** ____________

2-Year, 24-Hour Rainfall): ________ **in**

(Site specific rainfall event may be substituted if applicable)

Total Site Area: ________ **acres**

Disturbed Area to be managed: ________ **acres**

Pre-Development Conditions

Cover Type	**Soil Type**	**Area (sf)**	**Area (ac)**	**CN (from TR-55)**	**S**	**Q Runoff[1] (in)**	**Runoff Volume[2] (ft^3)**
Woods / Meadow	A			30	23.3		
Woods	B			55	8.2		
Meadow	B			58	7.2		
Woods	C			70	4.3		
Meadow	C			71	4.1		
Woods	D			77	3.0		
Meadow	D			78	2.8		
Impervious	N/A			98	0.20		
Other:							
TOTAL:	**N/A**			**N/A**	**N/A**	**N/A**	

Post-Development Conditions

Cover Type	**Soil Type**	**Area (sf)**	**Area (ac)**	**CN***	**S**	**Q Runoff[1] (in)**	**Runoff Volume[2] (ft^3)**
TOTAL:	**N/A**			**N/A**	**N/A**	**N/A**	

Runoff Volume Increase (ft^3):	

Transfer to WS 5

Runoff Volume Increase = (Post-Dev. Runoff Volume) MINUS (Pre-Dev. Runoff Volume)

1. **Runoff (in)** = $Q = (P - 0.2S)^2 / (P + 0.8S)$ where:
   - P = 2-Year, 24-Hour Rainfall (in)
   - S = 1000/ CN - 10
   - CN = Curve Number
   - Q = Runoff (in)
2. **Runoff Volume (ft^3)** = Q x 1/12 x Area
   - Area = Area of specific land cover (ft^2)

* Runoff Volume must be calculated separately for pervious and impervious areas (without using a weighted CN), unless Non-Structural BMP Rooftop/Downspout Disconnection is applied.

WORKSHEET 5. STRUCTURAL BMP VOLUME REDUCTION*

PROJECT: ______________________________

Subwatershed: ______________________________

Runoff Volume Increase (cubic feet) *from Worksheet 4*: ____________

Proposed BMP[A]	Area (ft^2)	Permanently Removed Storage Volume[B] (ft^3)	Ave. Design Infiltration Rate (in./hr.)	Infiltration Volume During Storm[C] (ft^3)	Total Volume Reduction[D] (ft^3)
Porous Pavement					
Infiltration Basin					
Subsurface Infiltration Bed					
Infiltration Trench					
Bioretention					
Dry Well					
Vegetated Swale					
Retentive Grading					
Vegetated Roof			N/A	N/A	
Capture and Re-use			N/A	N/A	

Total Volume Reduction Credit by Proposed Structural BMPs (ft^3): ____________

Runoff Volume Increase (cubic feet) *from Worksheet 4*: ____________

*** FOR PERMANENTLY REMOVED VOLUME ONLY, TEMPORARY DETENTION VOLUMES ARE NOT INCLUDED HERE.**

[A] Follow design guidance and Protocols from Manual for each Structural BMP type

[B] Storage volume as defined in individual BMP writeups - this represents permanently removed volume, not detention storage

[C] Can be approximated as the average design infiltration rate over 6 hours multiplied by the BMP area:

Design Infiltration Rate x 6 hours x BMP Area x Unit Conversions = Infiltration Volume (ft^3)

[D] Total Volume Reduction is sum of Storage Volume and Infiltration Volume During Storm.

Other Proposed BMPs *Not Volume Reducing*	Area (ft^2)
Constructed Filter	
Constructed Wetlands	
Wet Detention Pond	
Dry Extended Detention Basin	
Water Quality Devices	
Level Spreader	

WORKSHEET 6. SMALL SITE / SMALL IMPERVIOUS AREA EXEMPTION FOR PEAK RATE MITIGATION CALCULATIONS

NOTE: This does not exempt small projects from stormwater management, only the peak rate mitigation calculations.

The following conditions must be met for exemption from peak rate analysis for small sites:

______ The 2-Year, 24-hour Runoff Volume increase must be controlled in BMPs designed in accordance with manual guidance.

______ Total project impervious area may not exceed **1 acre**.

______ Maximum proposed disturbed area is **10 acres**.

______ Maximum proposed impervious cover is 50%.

______ Project shall not be a part of a larger phased project.

______ Infiltration BMPs must have a design infiltration rate of at least 0.25 in/hr.*

Example project configurations that may be eligible for exemption:

Porposed Disturbed Area	Percent Impervious	Total Impervious
10 acre	10%	1 acre
5 acre	20%	1 acre
2 acre	50%	1 acre
1 acre	50%	0.5 acre
0.5 acre	50%	0.25 acre

*Although this infiltration rate is higher than the minimum recommended in the manual, for site seeking a peak rate exemption a higher infiltration rate is warrented.

WORKSHEET 7. PEAK RATE MITIGATION SUMMARY SHEET

PROJECT: ____________________

Subwatershed: ____________________

Applicable Peak Rate Criteria (e.g. pre- vs. post, release rate): ____________________

Additional Flood Control Criteria (if applicable): ____________________

Storm Event	Storm Duration (hr)	Are criteria applicable to this storm? (Yes / No)	Post-Settlement Peak Discharge Rate[1] (cfs)	Pre-Settlement Peak Discharge Rate[1,2] (cfs)	Other peak rate criteria, if applicable (cfs)	Are the criteria met? (Yes / No)
1-year	24					
2-year	24					
5-year	24					
10-year	24					
25-year	24					
50-year	24					
100-year	24					

1 - As determined by computer simulation, acceptable calculation methods, etc.

2 - If applicable to the peak rate criteria.

Notes, Special Conditions, etc.: ____________________

WORKSHEET 8. WATER QUALITY WORKSHEET

PROJECT: ____________________

Subwatershed: ____________________

This worksheet calculates water quality volume based on the criteria of 1 inch of runoff from impervious areas and 0.25 inch of runoff from disturbed pervious areas.

A	B	C	D	E	F
Total Disturbed Area (ft^2)	**Impervious Area (ft^2)**	**Disturbed Pervious Area (ft^2)**	**Water Quality Volume for Impervious Area (ft^3)** **Col B x 1 inch/12**	**Water Quality Volume for Pervious (ft^3)[B]** **Col C x 0.25 inch/12**	**Total Water Quality Volume to BMPs (ft^3)[C]** **Col D + Col E**

If 2 or more water quality BMPs are proposed in series, any that are rated "Low/Medium" or better for TSS Removal are acceptable. List proposed BMPs here:

____

If only 1 water quality BMP is proposed for a given area, then it must be rated "High" for TSS Removal. Check off the proposed BMP here:**

- ______ **Bioretention**
- ______ **Capture/Reuse**
- ______ **Constructed Wetlands**
- ______ **Wet Ponds**
- ______ **Constructed Filters**
- ______ **Porous Pavement (with appropriate pretreatment to prevent clogging)**
- ______ **Infiltration Systems (with appropriate pretreatment to prevent clogging)**

*** Proprietary, manufactured water quality devices are not acceptable unless they have been field tested by a third-party according to approved testing protocols.*

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