Watershed Treatment Model (WTM) 2013 Documentation

Funding Provided By:
US EPA Office of Wetlands Oceans and Watersheds
Altria Foundation
Cooperative Institute for Coastal and Estuarine Environmental Technology

June, 2013
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CENTER FOR WATERSHED PROTECTION

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Chapter 1. Watershed Treatment

The watershed manager must meet multiple objectives of improving or maintaining water quality, enhancing habitat, satisfying the requirements of environmental regulations, maintaining water resources for enjoyment by watershed residents, and staying within a limited budget. In addition, watershed managers are frequently asked difficult questions about the effectiveness of their programs, to justify existing programs, develop future ones, or evaluate their progress. Thus, managers need to define the ability of their programs and practices to provide treatment. Watershed treatment is the benefit of a practice or program to a water resource, in terms of pollutant removal or habitat improvement. To illustrate the importance of defining treatment, a few examples of common questions posed by watershed managers are included below:

How do I meet the target load reductions for a TMDL?

How important are various bacteria sources in my watershed,
and how can they best be treated?

What sizing criteria should be in my community's stormwater ordinance,
and what site size should be regulated?

Which subwatersheds within a highly urbanized watershed
have the greatest potential for restoration?

How effective are investments in nutrient education and outreach programs?

How do nutrient loads in a coastal community that relies on septic systems
compare to loads in a sewered community, given reliable rates of maintenance?

What pollutant reduction was achieved by a Phase I municipal stormwater program?

What are the most effective practices to incorporate into a Phase II program?

Given current nonpoint source controls and programs, can my community meet a
nutrient reduction target for a lake system, in the face of watershed development?

What programs or practices should I consider to treat current
and future contaminant sources to a water supply reservoir?

In each case, the watershed manager must accurately estimate pollutant loadings and/or habitat conditions both now and at some time in the future. In addition, he or she needs to determine how conditions will improve in response to various treatment options. While most models, simple or complex, can estimate the loads from various current and projected land uses, they often do not incorporate some pollution sources, such as sanitary sewer overflows (SSOs) and illicit connections that may be critical in urban and urbanizing watersheds. In addition, most models are not particularly well-suited to evaluating the actual effect of watershed treatment, which ultimately depends on effort, staffing, design, and the inherent treatability of the different sources.

1.1 Challenges of Estimating Watershed Treatment

A number of factors make it difficult to estimate how much treatment is likely to actually occur in a watershed. First, a great deal of uncertainty exists in estimating both pollutant sources and watershed treatment options. Second, both the magnitude of pollutant sources and the effectiveness of watershed treatments depend on factors that vary both in time and among subwatersheds. Finally, an accurate estimate of watershed treatment needs to incorporate factors that are difficult to predict, such as human behavior.

Pollutant Sources

All pollutant sources vary over time, either due to changes in weather pattern, population, or economic trends. On top of this variability, each pollutant source is unique. While some can be predicted using readily available land use and climate data, others need to be estimated from other parameters. For example, loads from SSOs need to be extrapolated from available data about the sanitary sewer system, such as the age and extent. Similarly, predictions of habitat degradation need to incorporate changes in the forested buffer over time. Even with the most sophisticated modeling, none of these sources can be forecasted perfectly.

In addition, it is not always easy to compare pollutant loads because the nature of each source is different. While some sources are episodic in nature, others are more continuous. While some sources are found primarily in storm flows, others occur mostly within baseflow. In addition, impacts to habitat can be both episodic and continuous, and are difficult to compare or integrate with other pollutant source estimates.

Treatment Options

The watershed manager has a wide range of watershed treatment options to choose from, but often no way of estimating the benefits of many of these choices, since little monitoring data are available to assess their effectiveness. Consequently, the watershed manager cannot easily demonstrate the benefit of many programs, such as watershed education. Without some tool for estimating these benefits, it becomes difficult to justify the funds necessary to support these programs.

Even for practices where monitoring data is available, the watershed manager needs to estimate both the extent of treatment in a watershed, the *treatability*, and the level of implementation. Treatability reflects the fraction of a pollutant source that can realistically be served by a program or practice. For example, it is unrealistic to assume that the loads from every acre of managed turf can be reduced by a lawn care education program, or that every acre of land can be served by stormwater retrofits. This is because not every lawn owner over-fertilizes to begin with, and space and budget constraints make it unrealistic to design retrofits on every acre of land.

Another challenge is that most practice monitoring data reflect relatively well-designed and newly constructed practices. In reality, practice effectiveness will often be compromised due to the level of effort a community puts toward implementing and maintaining practices with budget and staffing limitations. Accounting for this imperfect practice application presents a challenge to the watershed manager.

1.2 OPPORTUNITIES

Despite these challenges, we have better data on most watershed variables now than at any time in the past. With the advent of readily available GIS data, watershed managers can rapidly characterize watershed land use. This data availability allows the watershed manager to characterize loads that are based on land use very rapidly (allowing more room in the budget towards programs) and more accurately characterize its true effectiveness.

In addition, regional and national averages are now available to characterize the flows and concentrations from many pollution sources, and the effectiveness of some practices, giving the watershed manager greater confidence in initial estimates. Finally, simple models such as the Simple Method (Schueler, 1987) are available that allow the watershed manager to effectively characterize the load given various treatment options, at least at the site level.

1.3 THE WATERSHED TREATMENT MODEL

The remainder of this document presents the Watershed Treatment Model (WTM), a simple spreadsheet-based approach that evaluates loads from a wide range of pollutant sources, and incorporates the full suite of watershed treatment options. In addition, the model allows the watershed manager to adjust these loads based on the level of effort put forth for implementation. Although the algorithms in this model are no substitute for more detailed watershed information, and model assumptions may be modified as the watershed plan is implemented, the WTM acts as a starting point from which the watershed manager can evaluate multiple alternatives for watershed treatment.

Chapter 2. What Is the Watershed Treatment Model?

The Watershed Treatment Model (WTM) is a simple tool for the rapid assessment and quantification of various watershed treatment options. The model has three basic components: Pollutant Sources, Treatment Options and Future Growth. The Pollutant Sources component of the WTM estimates the load from a watershed without treatment measures in place. The Treatment Options component estimates the reduction in this uncontrolled load from a wide suite of treatment measures. Finally, the Future Growth component allows the user to account for future development in the watershed, assuming a given level of treatment for future development. The model incorporates many simplifying assumptions that allow the watershed manager to assess various programs and sources that are not typically tracked in more complex models. The WTM 2013 is able to track sediment, nutrients, bacteria and runoff volume on an annual basis. This section outlines the basic components of the model and some caveats for its use.

2.1 Model Structure

The WTM completes modeling in four steps: 1) Calculating pollutant source loads; 2) Calculating the Benefits of Existing Practices; 3) Calculating the Benefits of Future Practices and 4) Accounting for Growth. (Figure 1). The results of these modeling phases are summarized in a single worksheet, as indicated by the purple boxes in Figure 1. This section describes the key model components, and later sections of this document describe model assumptions in more detail.

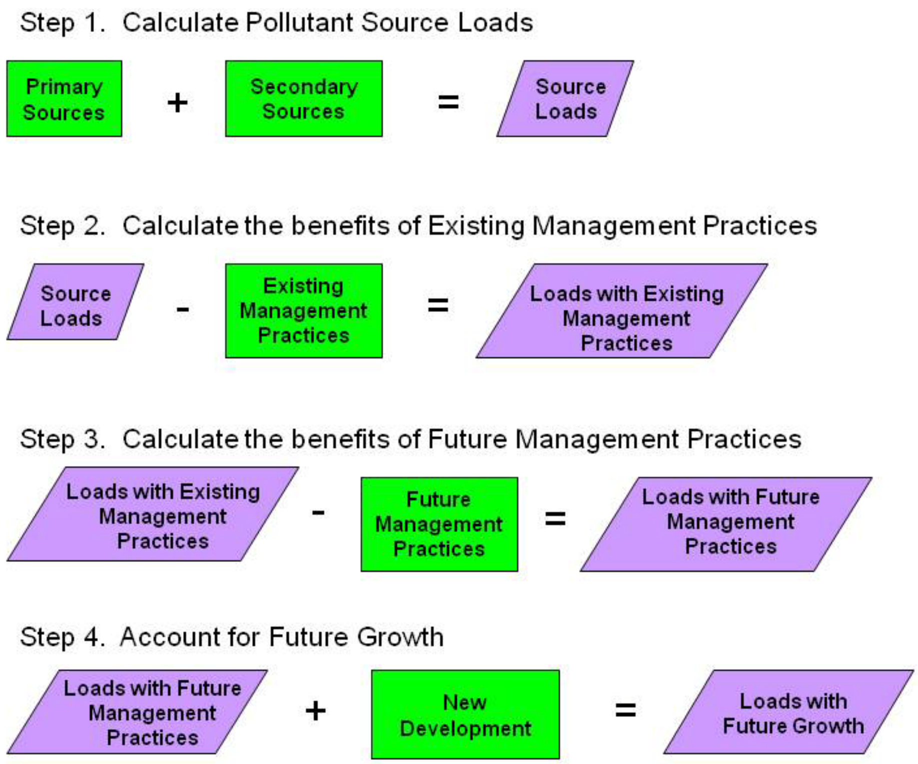

Figure 2.1 Model Structure

"Off the Shelf" versus "Custom" Versions

While some model users prefer to use the WTM as a screening level tool, others prefer to customize it for a specific purpose, and may even modify the base calculations in the model. To accommodate both types of users, there are two versions of WTM 2013: the "Off the Shelf" and "Custom" versions. (See Table 2.1 for differences in model structure).

The "Off the Shelf" version incorporates a user interface, and is more user-friendly, especially for someone who is new to using the WTM. Many of the calculations are hidden, and an interface allows the user to hide all but the necessary input sections. While the user can modify model default values in this version, changing calculations or adding new practices is not recommended when using this version.

In the "Custom" version, equations are more visible to the user, as are all input sections. This version is not as easy to use, and includes a companion "User's Guide" document. However, this version is recommended for users who want to greatly customize the WTM by, for example, modifying equations or adding new practices.

Table 2.1. Model Structure of "Off the Shelf" versus "Custom" Versions of WTM 2013

Sheet for "Custom" Version (From Figure 2.1)	Corresponding Sheet(s) for the "Off the Shelf" Edition
Primary Sources	Sources[1]
Secondary Sources	
Existing Management Practices	Existing Management Practices[1]
Future Management Practices	Future Management Practices[1]
New Development	New Development[1]
Source Loads	Results[1]
Loads with Existing Practices	
Loads with Future Practices	
Loads with Future Growth	

[1]The "Off the Shelf" version also include a "Defaults" sheet and a hidden "Calculations" sheet that contain model defaults and background calculations, which feed into all other calculations.

2.2 SOURCES

In the "Off the Shelf" edition, the "Pollutant Sources" worksheet allows the user to input data that is used to calculate loads from both Primary and Secondary sources of pollutants, but the "Custom" version includes separate "Primary Sources" and "Secondary Sources" tabs.

Primary Sources (Chapter 3)

Loads from primary sources can be determined solely by land use. It requires basic land use information and calculates surface runoff loads. In addition, it requires basic watershed data, such as annual rainfall, stream length, and soils distribution.

Secondary Sources (Chapter 4)

Secondary sources are pollutant sources that cannot be calculated based on land use information alone. Many of these sources, such as combined sewer overflows (CSOs) and SSOs, are at least partially composed of wastewater.

2.3 EXISTING MANAGEMENT PRACTICES (CHAPTERS 5-7)

This sheet reflects programs currently in place to control loads from urban land. Users need to input information about the effectiveness and level of implementation of various programs and practices. This sheet, and other sheets in the WTM that quantify program implementation, ask the user to input "discount factors" for each practice. "Discount factors" are used to reduce the ideal (i.e., literature value) load reductions for a practice that can rarely be achieved. For example, structural practices may lack space or have poor maintenance that can hamper practice effectiveness over time. For programmatic practices, such as lawn care education, only a fraction of the population may implement the recommendations put forward in the educational program. In both of these cases, specific design features for structural practices, or marketing approaches for education and outreach techniques can make the practice more effective. While some discount factors have default values, the WTM asks the user to input values for others. In each case, the model provides guidance to select appropriate values.

2.4 FUTURE MANAGEMENT PRACTICES (CHAPTERS 5-7)

This sheet reflects the planned extent of programs to control loads from urban land. By default, the model populates this sheet with values from the "Existing Management Practices" sheet. The user then enters data that describe proposed or "future" management practices given the same existing land use.

2.5 NEW DEVELOPMENT (CHAPTER 8)

This sheet calculates the loads from future development, based on future development in the watershed, and proposed future treatment. The sheet calculates new "primary source" loadings based on the increase in area of certain land uses, then asks the user to describe the types of stormwater controls on new development. Next, it adds secondary sources, such as loads from new septic customers and wastewater treatment plant loads. Finally, it calculates the loads from active construction as land is developed.

Chapter 3. Loads from Primary Sources

This chapter provides technical documentation on the WTM's calculation of primary source loads, such as stormwater runoff from urban, rural and forest lands, and open water. The WTM uses the Simple Method (Schueler, 1987) to calculate loads from urban stormwater runoff, and area loading factors to calculate loads from non-urban land uses. The chapter is organized by the following sections:

- Section 3.1 provides guidance and input data on using the Simple Method to calculate loads from urban runoff
- Section 3.2 includes data on pollutant loading rates from non-urban land
- Section 3.3 provides atmospheric deposition data that can be used to calculate loads from open water and
- Section 3.4 discusses checks in the code that maintain a minimum loading rate for low density residential land uses.

3.1 SIMPLE METHOD CALCULATIONS

The Simple Method estimates stormwater runoff pollutant loads on an annual basis (e.g., lb/yr), and uses the Simple Method to calculate the loads from primary sources. The Simple Method requires the following data:

- watershed drainage area
- impervious cover for the watershed (default values provided)
- stormwater runoff pollutant concentrations (default values provided)
- annual precipitation
- runoff coefficients (default values provided)

Urban land includes seven general categories: residential, commercial, industrial, forest, rural and open water. Residential land use is then broken into four more detailed land use categories: low-, medium-, and high-density and multifamily). The WTM then uses the Simple Method to calculate loads from each of these land uses. The Simple Method estimates pollutant loads for chemical constituents as a product of annual runoff volume and pollutant concentration, as:

$L = 0.226 \cdot R \cdot C \cdot A$

Where:

L	=	Annual load (lbs)
R	=	Annual runoff (inches)
C	=	Pollutant concentration (mg/l)
A	=	Area (acres)
0.226	=	A conversion factor

For bacteria, the conversion factor is modified, so that the loading equation is:

$L = 1.03 \times 10^{-3} \cdot R \cdot C \cdot A$

Where:

L	=	Annual Load (Billion Colonies)
R	=	Annual runoff (Inches)
C	=	Bacteria Concentration (#/100 ml)
A	=	Area (acres)
1.03×10^{-3}	=	A conversion factor

Annual Runoff

The Simple Method calculates annual runoff as a product of annual runoff volume and a runoff coefficient (Rv). Runoff volume is calculated as:

$R = P \cdot P_j \cdot Rv$

Where:

R	=	Annual runoff (inches)
P	=	Annual rainfall (inches)
P_j	=	Fraction of annual rainfall events that produce runoff (usually 0.9)
Rv	=	Runoff coefficient

In the Simple Method, the runoff coefficient is a function of both impervious and pervious cover. The runoff coefficients in WTM are derived from the "Runoff Reduction Method" as described in Hirschman et al. (2008). A weighted site runoff coefficient (Rv) is calculated for forested, turf and impervious land covers. If additional land uses are specified by the user (e.g. beyond the seven major land uses), the user will need to add in a Rv for these additional land uses. The weighted Rv is calculated as follows:

Land Cover Rv:

$Rv = \sum(A_{\text{land use i, soil type j}})(Rv_{\text{land use i, soil type j}})/A$

Where:

Rv = Runoff Coefficient

A = Drainage Area (acres)

$Rv_{\text{land use i, soil type j}}$ = The runoff coefficient for a particular land use and soil type (see Table 3.1)

$A_{\text{land use i, soil type j}}$ = Area of each land use and soil type intersection (acres)

The runoff coefficients provided in Table 3.1 were derived from research by Pitt et al (2005), Lichter and Lindsey (1994), Schueler (2001a), Schueler, (2001b), Legg et al (1996), Pitt et al (1999), Schueler (1987) and Cappiella et al (2005).

Table 3.1. Site Cover Runoff Coefficients (Rv)

Soil Condition	Hydrologic Soil Group			
	A	B	C	D
Forest Cover/Rural Land	0.02	0.03	0.04	0.05
Disturbed Soils/Managed Turf	0.15	0.20	0.22	0.25
Impervious Cover	0.95			

Impervious Cover Data

Default impervious cover/land use relationships are presented in Table 3.2. These data are derived from a study by the Center for Watershed Protection that assembled detailed impervious cover layers from several municipalities to develop impervious cover/land use relationships (Cappiella and Brown, 2000). Jurisdictions that maintain a thorough land use/land cover GIS database may have more detailed impervious cover information, or may apply other impervious cover/land use factors based on local or regional data.

Table 3.2 Impervious Cover (%) for Various Land Uses (adapted from: Cappiella and Brown, 2000)		
Land Use Category	**Sample Number (N)**	**Mean Impervious Cover (%)**
Agriculture	8	2
Open Urban Land	11	9
2 Acre Lot Residential	12	11
1 Acre Lot Residential	23	14
1/2 Acre Lot Residential	20	21
1/4 Acre Lot Residential	23	28
1/8 Acre Lot Residential	10	33
Townhome Residential	20	41
Multifamily Residential	18	44
Institutional	30	34
Light Industrial	20	53
Commercial	23	72
Roadway*	--	80
* % for roadway was obtained using best professional judgment		

Turf Cover

Although several researchers have investigated turf cover in the landscape, turf cover coefficients are not available to correspond to the impervious cover coefficients in Table 3.2. Two sources provide the basis for assumption in the WTM.

- Robbins and Birkenholtz (2003), found that the area of lawn on lots was equal to .816 (roughly 82%) times the *potential lawn area* (PLA). The PLA is defined as the lot area minus the house building footprint.
- Milesi et al. (2009) developed a regression between impervious cover (%) and turf cover (%), equal to: %Turf = 79.53-0.83(%Impervious)

As a simplification, the WTM assumes that turf is equal to 80% of pervious cover, *or*

%Turf = 0.80(100-%Impervious)

Stormwater Pollutant Concentrations

Stormwater pollutant concentrations can be estimated from local or regional data, or from national data sources. Tables 3.3 through 3.5 summarize urban runoff pollutant concentrations for Total Suspended Solids (TSS), Total Phosphorous (TP), and Total Nitrogen (TN) for primary urban land uses and identify model default values. In general, the selected data sources are nationwide in scope, or are summaries of several other studies. Some studies included in these data did not characterize stormwater concentrations for specific land uses, and instead reported a concentration for urban runoff. Although the WTM allows the user to enter concentration data for each land use, a watershed manager may alternatively use one "urban runoff" concentration for all land uses.

Fecal coliform is more difficult to characterize than other pollutants currently included in the WTM. Data are extremely variable even among samples taken at the same location. Because of this variability, it is difficult to establish different concentrations for each land use, although some source monitoring data exists (Steuer *et al.*, 1997; Bannerman *et al.*, 1993). Consequently, the model default is a median urban runoff value derived from National Urban Runoff Program (NURP) data (Pitt, 1998) of 20,000 MPN/100ml. For more information on sources and pathways of bacteria in urban runoff, consult Schueler (1999).

Table 3.3 Pollutant Concentrations by Land Use: Total Suspended Solids (mg/l)						
Source	**Land Use**					**Notes**
	Urban Runoff	**Residential**	**Commercial**	**Roadway**	**Industrial**	
Schueler (1987), mean	100[1]	-	-	-	-	This value reflects an estimate based on 25 data points from a wide range of watershed sizes. Data reflect instream concentrations. A small watershed size (i.e., 10 acres) was assumed to minimize the influence of the channel erosion component.
Gibb et al. (1991), mean	-	150	-	220	-	These values represent recommended estimates for planning purposes and are based on an analysis of mean concentrations from over 13 studies from the US and British Columbia.
Smullen and Cave (1998), median	55					This study probably represents the most comprehensive data set, with 3,047 event samples included from across the nation. Data includes pooled NURP, USGS, and NPDES sources. The value is a median of EMCs and applies to general urban runoff (i.e., mixed land uses). The low concentration relative to other data can be attributed to the fact that, while NURP data represent small watersheds where channel erosion may play a role, NPDES data are collected as "end of the pipe" concentrations for very small drainage areas of a uniform land use. The NPDES concentrations were approximately 70% lower than concentrations from NURP or USGS.
US EPA (1983), median	-	101	69	-	-	These values represent NURP data for residential and commercial land use. NURP data were collected in the early 1980s in over 28 different metropolitan areas across the US.
Claytor and Schueler (1996), mean	-	-	-	142	124	The roadway value is the un-weighted mean of 8 studies conducted by the FHWA. The industrial value is the mean value from 6 storms monitored at a heavy industrial site in Auckland, NZ.
Barrett and Malina (1998), mean	-	-	-	173	-	This data reflects a study of vegetative swales treating highway runoff in Austin, TX. Value represents average of the mean inflow concentrations measured at 2 sites. Data were collected over 34 storm events.

Table 3.3 Pollutant Concentrations by Land Use: Total Suspended Solids (mg/l)						
Source	**Land Use**					**Notes**
	Urban Runoff	**Residential**	**Commercial**	**Roadway**	**Industrial**	
Caraco and Schueler (1999), mean	242					This value represents an average of EMC data collected from 3 arid climate locales (Phoenix, Boise, and Denver). A total of 90 data points are used, with each site having at least 16 data points. Value applies to general urban runoff (i.e., mixed land uses).
Driscoll (1986), median	-	-	-	242	-	This value is the average of 4 median EMCs reported at highway sites in Nashville, Denver, Milwaukee, and Harrisburg. A total of 93 data points were used to develop value, with each site having at least 16 data points.
Shelley and Gaboury (1986), median	-	-	-	220	-	This value is the median value of 8 highway studies from across the US. Some of the data from the Driscoll (1986) study is included.
Whalen and Cullum (1988), mean	-	228	168	-	108	These data are from an assessment of urban runoff quality that looked at NURP and State of Florida data. The NURP data are presented. Residential and commercial values are mean values for specified land uses and reflect between 200 and 1,100 sampling events depending on the parameter and land use. Industrial values are from 4 NURP sites and generally represent light industrial land use.
Pitt et al. (2005), median	59	49	43	134	81	This report summarizes nationwide data collected as a part of the Phase I NPDES program. In addition to the data presented here, the report summarizes data by region, allowing the user to customize concentration data where appropriate.
Model Default Value		**49**	**43**	**134**	**81**	Uses data from Pitt et al. (2005) as a default.

Table 3.4 Pollutant Concentrations by Land Use: Total Phosphorus (mg/l)						
Source	**Land Use**					**Notes**
	Urban Runoff	**Residential**	**Commercial**	**Roadway**	**Industrial**	
Schueler (1987), mean	-	0.26	-	0.59	-	These values are taken from a Washington DC NURP study in 1980-81. At least 27 storm events were sampled at multiple sites within the specified land use.
Gibb et al. (1991), mean	-	0.33	-	0.59	-	These values represent recommended estimates for planning purposes and are based on analysis of mean concentrations from over 13 studies from the US and British Columbia.
Smullen and Cave (1998), median	0.26	-	-	-	-	This study probably represents the most comprehensive data set, with 3,047 event samples included from across the nation. The data includes pooled NURP, USGS, and NPDES sources. The value is a median of EMCs and applies to general urban runoff (i.e., mixed land uses).
US EPA (1983), median	-	0.38	0.201	-	-	These values represent NURP data for residential and commercial land use. NURP data were collected in the early 1980s in over 28 different metropolitan areas across the US.
Barrett and Malina (1998), mean	-	-	-	0.4	-	This data reflects a study of vegetative swales treating highway runoff in Austin, TX. Value represents average of the mean inflow concentrations measured at 2 sites. Data were collected over 34 storm events.
Caraco and Schueler (1999), mean	0.78					This value represents an average of EMC data collected from five arid climate locales (Phoenix, Boise, San Jose, Dallas, and Denver). The value applies to general urban runoff (i.e., mixed land uses).

Table 3.4 Pollutant Concentrations by Land Use: Total Phosphorus (mg/l)						
Source	**Land Use**					**Notes**
	Urban Runoff	**Residential**	**Commercial**	**Roadway**	**Industrial**	
Whalen and Cullum (1988), mean	-	0.62	0.29	-	0.42	These data are from an assessment of urban runoff quality that looked at NURP and State of Florida data. The NURP data summaries are what is shown. Residential and commercial values are mean values for specified land uses and reflect between 200 and 1,100 sampling events depending on the parameter and land use. Industrial values are from 4 NURP sites and generally represent light industrial land use.
Pitt et al. (2005), median	0.27	0.31	0.22	0.25	0.25	This report summarizes nationwide data collected as a part of the Phase I NPDES program. In addition to the data presented here, the report summarizes data by region, allowing the user to customize concentration data where appropriate.
Model Default Value		**0.31**	**0.22**	**0.25**	**0.25**	Uses data from Pitt et al. (2005) as a default.

Table 3.5 Pollutant Concentrations by Land Use: Total Nitrogen (mg/l)

Source	Land Use					Notes
	Urban Runoff	Residential	Commercial	Roadway	Industrial	
Schueler (1987), mean	-	2.0	2.17	-	-	These values are taken from a Washington DC NURP study in 1980-81. At least 27 storm events were sampled at multiple sites within the specified land use.
Gibb et al. (1991), mean	-	1.5	-	2.72	-	These values represent recommended estimates for planning purposes and are based on analysis of mean concentrations from over 13 studies from the US and British Columbia.
Smullen and Cave (1998), median	2.0	-	-	-	-	This study probably represents the most comprehensive data set, with 3,047 event samples included from across the nation. The data includes pooled NURP, USGS, and NPDES sources. The value is a median of EMCs and applies to general urban runoff (i.e., mixed land uses).
US EPA (1983), median	-	2.6	1.75	-	-	These values represent NURP data for residential and commercial land use. NURP data were collected in the early 1980s in over 28 different metropolitan areas across the US.
Barrett and Malina (1998), mean	-	-	-	3.48	-	This data reflects a study of vegetative swales treating highway runoff in Austin, TX. Value represents average of the mean inflow concentrations measured at 2 sites. Data were collected over 34 storm events.
Caraco and Schueler (1999), mean	4.06	-	-	-	-	This value represents an average of EMC data collected from 3 arid climate locales (Phoenix, Boise, and Denver). A total of 90 data points are used, with each site having at least 16 data points. The value applies to general urban runoff (i.e., mixed land uses).

Table 3.5 Pollutant Concentrations by Land Use: Total Nitrogen (mg/l)						
Source	**Land Use**					**Notes**
	Urban Runoff	**Residential**	**Commercial**	**Roadway**	**Industrial**	
Whalen and Cullum (1988), mean	-	2.03	2.3	-	2.53	These data are from an assessment of urban runoff quality that looked at NURP and State of Florida data. The NURP data summaries are shown. Residential and commercial values are mean values for specified land uses and reflect between 200 and 1,100 sampling events depending on the parameter and land use. Industrial values are from 4 NURP sites and generally represent light industrial land use.
Pitt et al. (2005), median	2.0	2.1	2.1	2.3	2.2	This report summarizes nationwide data collected as a part of the Phase I NPDES program. In addition to the data presented here, the report summarizes data by region, allowing the user to customize concentration data where appropriate.
Model Default Value		**2.1**	**2.1**	**2.3**	**2.2**	Uses data from Pitt et al. (2005) as a default.

3.2 LOADING RATES FROM NON-URBAN LAND USES

The WTM estimates loads from non-urban land, including rural land and forest, as a product of area and a loading rate. Table 3.6 includes available data on pollutant loading rates from these land uses. In general, rural land is characterized by pasture, rather than row crops. Data shaded grey represent loads derived from modeling studies. Modeling data were not used to determine default values. Most of the studies included in these tables include at least one year of continuous monitoring, and loads for both storm flow and baseflow. Fecal data are scarce, and the default values in Table 3.5 are based on only one study.

The WTM uses a simple procedure to partition the total annual loads reported in Table 3.6 into storm and non-storm components (see Table 3.7). The values reported in Table 3.7 are based on storm and non-storm loads from rural and forest basins in the Potomac River (Lizárraga, 1997). The watershed manager should modify these load partitioning coefficients if more accurate local data are available.

Table 3.6 Unit Loads for Forest and Rural Land

Source	Land Use by Pollutant								Notes:
	Forest				Rural				
	TSS	TP	TN	Bacteria	TSS	TP	TN	Bacteria	
	(lbs/acre/year)			(billion/ acre/year)	(lbs/acre/year)			(billion/ acre/year)	
Corsi et al. (1997)	333	0.74	-	-	491	0.99	-	-	These data come from a study that characterized four ecoregions within Wisconsin. Data were collected over 22 years on drainage areas of less than 200 square miles. At least one year of continuous monitoring data of sediment and phosphorous were available at each drainage area. Forest data represent the average of three watersheds in the Northern Lakes and Forests Ecoregion. The rural data represent the average of 25 watersheds within the three remaining ecoregions (all south of the Northern Lakes and Forests Ecoregion).
Clesceri et al. (1986)	-	3.3	0.1	-	-	-	-	-	These values are the result of a regional analysis for Wisconsin Lakes.
Horner et al. (1994)	77	0.1	1.8	12	305	0.12	3.7	39	These data represent median values from literature, and from data collected in the Pacific Northwest. The rural values represent a pasture land use.
Lizárraga (1997)	-	0.14	3.3	-	-	0.75	9.6	-	These values are estimated 1994-1995 export coefficients for several subbasins within the Potomac River Basin, ranging in size from 15 to 1,500 square miles. Flow was monitored at all stations, and concentration data were extrapolated from a few stations using a USGS regression method based on basin characteristics.
Omernick (1976)	-	0.71	3.9	-	-	-	-	-	The National Eutrophication Survey collected data on 928 nonpoint source watersheds. Omernick (1976) studied the relationships between concentrations of N and P in these streams and land use in their watershed using multiple linear regression analysis.

Table 3.6 Unit Loads for Forest and Rural Land

Source	Land Use by Pollutant								Notes:
	Forest				Rural				
	TSS	TP	TN	Bacteria	TSS	TP	TN	Bacteria	
	(lbs/acre/year)			(billion/ acre/year)	(lbs/acre/year)			(billion/ acre/year)	
Smith et al. (1991)	97	0.20	-	-	97	0.21	-	-	These values are export coefficients derived from government monitoring programs conducted between 1980 and 1989. Agriculture numbers are data for Rangeland
Ramos-Ginès (1997)	-	0.37	2.7	-	-	1.7	7.8	-	These data represent continuous monitoring during Water Year 1993 to estimate loading coefficients in subbasins of the Lago de Cidra in Puerto Rico ranging in size from 250 to 500 acres. The rural data represent the average of two subbasins characterized as "rural-ag."
Reckhow et al. (1980)	-	0.18	2.1	-	-	0.72	4.6	-	These values are medians of export coefficients from 23 studies of forested watersheds, and 14 studies of pasture (grazing) land.
Uttormark et al. (1974)	-	0.18	2.2	-	-	-	-	-	These data represent a compilation of values derived from small agricultural leaching and runoff plots.
Modified from Haith et al. (1992)	-	0.16	4.1	-	-	0.6	6.5	-	These values are modified from a model study of a watershed in Upstate New York. Rural data represent the average of export coefficients for pasture and inactive agriculture.
NVPDC (1980)	120	0.1	2.5	-	120	0.1	2.5	-	This is model data that represents both storm and non-storm loads. Channel erosion is not represented, and the rural numbers are values for Cow Pasture.
Model Default	**100**	**0.2**	**2.0**	**12**	**100**	**0.75**	**5.0**	**39**	

Notes:
Model defaults are roughly equal to the median of *monitored* data.
Grey cells are modeled results, and are placed in the table as a comparison to monitored data.

Table 3.7 Default Values to Partition Rural and Forest Loads		
Pollutant	**Fraction as Storm Load**	**Fraction as Non-Storm Load**
TSS[1]	0.9	0.1
TP[1]	0.7	0.3
TN[1]	0.5	0.5
Fecal Coliform[2]	1.0	0.0
[1]Data for TSS, TP, and TN derived from Lizárraga (1997) [2]The coefficient for FC is an assumed number		

3.3 ATMOSPHERIC DEPOSITION

The WTM determines the load from open water as the area of open water in acres times the rate of atmospheric deposition in pounds per acre per year. Default model values are included in Table 3.8. These data were constructed from NURP data for the Washington, DC area (MWCOG, 1983) and modified to account for regional variability in nitrogen deposition. It is assumed that data from Washington, DC are adequate to describe atmospheric deposition of TSS and TP. Nationwide data collected as a part of the National Atmospheric Deposition Program (NADP) suggest that this assumption cannot be made for nitrogen, however.

Nitrogen data were adjusted to reflect regional differences. NADP data suggest that atmospheric deposition of nitrogen in wetfall (i.e., falling as precipitation) is roughly 50% higher in the Northeastern US than the Western and Southern US (i.e., west of the Mississippi and south of North Carolina). Data from Washington, DC suggest that wetfall represents about 25% of total atmospheric deposition of nitrogen, with the remaining load as dryfall (i.e., particles falling between storm events). Using these two pieces of data, it was assumed that data in the Western and Southern US for nitrogen are 50% times 25% lower, or 12.5% lower, than data from the Northeast (Table 3.8).

Table 3.8 Atmospheric Deposition Unit Loading (lbs/acre/year)		
Pollutant	**Western and Southern US**	**Northeastern US**
TSS	155	155
TP	0.5	0.5
TN	11.2	12.8

For many locations, it may be possible to improve these estimates using local data. Two national networks are the NADP, which characterizes nitrate in wet deposition, and the Clean Air Status and Trends Network, which provides nitrate data in dry deposition. Data on TSS and TP, as well as organic nitrogen, are more difficult to obtain on a national basis.

Chapter 4. Loads from Secondary Sources

This chapter outlines the techniques used in the WTM to calculate loads from secondary sources. While the loads from these sources are not appropriately calculated using the Simple Method, the same basic methodology is used for most sources. That is, the load is calculated as a product of flow and concentration. There are some exceptions to this rule. For example, the load from road sanding is simply calculated as a fraction of the sand applied to the road surface. Table 4.1 outlines the basic methodology and data used to calculate the load from each source, and the remainder of this chapter provides background and examples of these calculations.

As flows from secondary sources are location-specific, the accuracy of estimates improves with additional information about the system being studied. For example, estimates on the flow generated from Onsite Sewage Disposal Systems (OSDSs) within a watershed will depend on the accuracy of inventories available to the watershed manager. For many secondary sources, an unconventional base unit of measurement is required to estimate flows, such as miles of sewer, number of OSDSs, or number of building permits. Local data may substantially improve these estimates. In particular, the estimates for CSOs, SSOs and illicit connections can be refined with more detailed local information.

Table 4.1 Methods to Calculate Secondary Source Loadings			
Secondary Urban Source Area Subcategories[1]	**Preferred Unit**	**Suggested Method for Defining Flow**	**Suggested Method for Defining Concentration**
OSDSs-Surface (NS) (Section 4.1)	Population	Multiply daily water use times unsewered population draining to failing systems.	Use raw sewage data and assumed delivery rates.
OSDSs-Subsurface (GW) (Section 4.1)	Population	Multiply daily water use times unsewered population draining to failing systems.	Assume a treatment efficiency and delivery ratio[2] based on depth to ground water and soil type.
Sanitary Sewer Overflows (S/ NS) (Section 4.2)	Miles of Sewer	Assume 140 overflows/1,000 miles of pipe (AMSA, 1994). Volume based on available data.	Use data for raw sewage.
Combined Sewer Overflows (S) (Section 4.3)	Combined Sewershed Characteristics	Complete a simple hydrologic and rainfall analysis of combined sewershed to determine CSO volume.	Use available literature values.
Household Illicit Connections (NS) (Section 4.4)	Population	Site specific info on number and size of illicit connections is preferable. As a default, assume that a fraction of individuals have illicit connections to the sewer system.	Use data for raw sewage.
Business Illicit Connections (NS) (Section 4.4)	Number of Businesses	Assume that a fraction of businesses have illicit connections, and that some fraction of these are wash water, while others are complete connections.	Use a mixture of wash water and sewage concentrations.
Channel Erosion (S) (Section 4.5)	Stream Survey Data	Three Methodologies: 1: Back calculate as the difference between loads calculated from monitoring data and loads calculated from other sources in the watershed. 2: Calculate based on an estimate of sediment contribution in the watershed. 3: Input data from a detailed geomorphic study. Associate nutrients based on typical soil enrichment.	
Hobby Farms/ Livestock (S) (Section 4.6)	Animal Density	Calculated based on the loading rates of coliform and nutrients for various animals.	
Marinas (NS) (Section 4.7)	Number of Boat Berths	Calculate based on boat use and per capita wastewater generation.	Use data for raw sewage.

Table 4.1 Methods to Calculate Secondary Source Loadings			
Secondary Urban Source Area Subcategories[1]	**Preferred Unit**	**Suggested Method for Defining Flow**	**Suggested Method for Defining Concentration**
Road Sanding (S) (Section 4.8)	Pounds of Sand	Assume a delivery ratio based on whether roads are open or closed section.	
Point Source Dischargers (NS) (Section 4.9)	Flow and Concentration Data from Monitoring Reports	Use flows reported in discharge monitoring reports.	Use concentrations reported in discharge monitoring reports.
[1]S and N refer to Storm and Non-Storm Loads [2]Delivery ratio refers to the fraction of a pollutant load that ultimately reaches the receiving water.			

Several of the secondary source calculations presented in this chapter require estimates of sewer use, as well as typical wastewater calculations. These data are used to calculate loads from failing OSDSs, sanitary sewer overflows, illicit connections, and marinas. Model default values for sewer use and wastewater concentrations are presented in Table 4.2.

Table 4.2 Wastewater Use and Concentration Data		
Model Input	**Model Default**	**Source(s)**
Individuals per Household	2.7	Reese (2000)
Sewer Use	70 gallons per capita per day (gpcd)	Metcalf and Eddy (1991)
TSS	400 mg/L	Based on a range of 237 to 600 mg/L (Metcalf and Eddy, 1991)
TP	10 mg/L	Based on a range of 10 to 27 mg/L (Metcalf and Eddy, 1991). The lower end of the range for phosphorus was used to account for programs to reduce phosphorus in wastewater.
TN	60 mg/L	Based on a range of 35 to 80 mg/L (Metcalf and Eddy, 1991)
FC	$1.0x10^7$	Based on a range of 10^6 to 10^{10} MPN/100mL (Metcalf and Eddy, 1991)

4.1 ONSITE SANITARY DISPOSAL SYSTEMS (OSDSS)

This section of the model calculates pollutant loads to surface water and groundwater from OSDSs. The WTM estimates a base load from working systems as a product of flow and concentration that is adjusted (e.g. increase or decrease from base load) using a number of factors entered by the user. The base load is referred to as the "untreated sewage from OSDSs" parameter. To estimate loads from OSDSs, the user needs to have the following information for the watershed (green cells):

- Percent of unsewered dwelling units in the watershed. The number of unsewered dwellings is calculated using the total number of dwelling units in the watershed multiplied by this fraction.
- Percent of OSDSs less than 100 feet from the waterway. A spatial data query using a GIS can provide this value if data layers are available for the stream network and system locations.
- Soil type. Two options are provided in a pull down menu (sandy soils or clayey mixed soils). Percent of OSDS types in the watershed.
- Level of maintenance. The user can select one of three levels of maintenance.
- Separation distance between OSDS and groundwater.
- Density of OSDSs in the watershed.

There are also a set of default values the user may change given the availability of local data (blue cells). The default values are based a literature review, or best professional judgment where data is insufficient. A description of the calculation methods and model parameters is provided below.

Calculation Methods and Model Parameters

The flow from OSDSs is estimated as the product of the number of functioning systems, the typical number of residents per household and per capita water use and pollutant concentration. The load is then a function of the flow, typical system effluent concentrations, a delivery ratio and proximity to waterways. The pollutant transport to groundwater varies depending on the soil characteristics, failure rate, system efficiency, soil characteristics, density of OSDSs and separation distance to groundwater. Some of these factors are given as default values, where the user can select values from a dropdown menu. Overall, the WTM provides these values to simplify calculations; however, these default data may be modified at the user's discretion. Please note that the wastewater generation for OSDSs is for a year-round system. In watersheds with seasonal homes, the numbers should be lower and adjusted accordingly.

Load Delivered to OSDSs

The WTM provides default values for wastewater generation and individuals per dwelling unit of 70 gpcd (gallons per capita per day) and 2.7 persons/dwelling unit, respectively. Table 4.2 lists the default wastewater concentration values. This raw sewage load is then partitioned between a surface load (i.e., a load from a failing system to the surface), and a groundwater load, which accounts for treated effluent from a working system that ultimately reaches the groundwater.

Within a watershed, the total load delivered to OSDSs for a given pollutant is determined as:

$$L_{\text{OSDS delivery}} = H \bullet IH \bullet C \bullet Q \bullet f \bullet (1 - \%sewer/100)$$

Where:

$L_{\text{OSDS delivery}}$ = Load delivered to OSDSs (lb/year or billion/year)

H = number of households

IH = Individuals/household (2.7 default)

C = pollutant concentrations in wastewater (see table 4.2 for default values; in mg/l for TN, TP and TSS; in MPN/100 mL for bacteria).

Q = average water use per capita (gallons/capita/day)

f = conversion factor ($1.03*10^{-3}$ for TN, TP and TSS; $1.38*10^{-5}$ for bacteria)

%sewer = percent of the population served by sewer

OSDS Failure Rate

The term "failure" as it relates to OSDSs has been used in various contexts. For example, some define failure only as systems that cause a "public health hazard," while others define failure as surface backup or groundwater contamination (US EPA, 2002). In the WTM, failure is defined as a surface discharge from the system. As a starting point, the WTM uses a "base" failure rate of 10% (US EPA, 2002).

The failure rate of OSDSs is influenced by factors reflecting improper siting and design or improper maintenance of the systems. Using results from a survey of available literature, three factors appeared to have a consistent and strong influence on system failure rates:

1) Separation distance from groundwater
2) Density of application (i.e., number of units per acre), and
3) Ongoing maintenance.

Separation Distance from Groundwater

One reason for failure is intersection with the groundwater table, which can cause the system to back up and surface (i.e., discharge effluent at the surface). According to a recent study in Northeastern Ohio, the probability of sanitary waste surfacing increased as the depth to groundwater decreased (Tumeo and Newland, 2009). Although not explicitly referenced, Day (2004) and Carr et al. (2009) found that 73% and 65%, respectively, of failed systems were sited on “improper soils.” In the WTM, the separation distance is characterized as an “on/off” variable, with a depth of less than 3’ to groundwater increasing the failure rate of systems installed in the watershed.

Density of Application

Many studies indicate that OSDS density has a strong impact on groundwater contamination (Brown and Bicki, 1987), but fewer data are available to relate the density specifically to system failure rates. One study (Leon County Public Health Unit, 1987) found very high failure rates for OSDSs applied at densities of greater than 1 system per ¼ acre, due to an artificially ponded groundwater table. The WTM assumes that failure rates increase when systems are applied at a density of greater than two systems per acre. In addition, Standley et al. (2008) found that residential ponds were more likely to be contaminated with bacteria when located near systems at higher residential densities.

Ongoing Maintenance

Many studies indicate that ongoing maintenance and inspection goes a long way toward improving system performance. For example, Ahmed et al. (2005) and Goontilleke (2002) found that 67% and 70%, respectively, of failed systems were in need of maintenance. The WTM assumes that excellent ongoing maintenance can improve the system failure rate, while poor maintenance can increase the number of systems failing.

Determining a Watershed-Wide Failure Rate

OSDS failure rate assumes a sliding scale, with 10% as the base failure rate, and 25% as the maximum. While higher failure rates have been reported, and can be entered directly, this value was selected to reflect a relatively high value among those reported nationally.

The failure rate is estimated by:

SF (%) = 10+SF1+SF2+SF3

SF = OSDS Failure Rate (%)
10 = 10% (base rate)
SF_1 = Maintenance and Operation Factor
(-5 for High maintenance, 0 for Average, 5 for Low)
SF_2 = Separation distance from groundwater
(5 if Depth <3’, 0 otherwise)
SF_3 = Density of OSDSs
(5 if Density >2/acre, 0 otherwise)

The SF factors are defined by the user using a pull-down menu of options in the WTM. The model default failure rate of 10% is adjusted according to the selection. The user is encouraged to use this method to adjust the “failure rates” parameter rather than entering a number directly.

Surface Load

Surface discharges of pollutants from OSDSs occur due to failing systems that discharge to the surface. The total load from failing systems is determined by two factors: the failure rate and the delivery ratio (i.e., the fraction of pollutant that reaches the waterway). The resulting load to surface waters from OSDSs is estimated by the following:

$$L_{surface\text{-}OSDS} = (L_{OSDS\ delivery}) \bullet SF \bullet D \bullet f$$

Where:

$L_{surface\text{-}OSDS}$	=	Load to surface waters from OSDSs
$L_{OSDS\ delivery}$	=	Load delivered to OSDSs
SF	=	OSDS failure rate (%)
D	=	Delivery ratio (i.e., fraction of effluent reaching surface waters)
f	=	Decay factor (i.e., fraction of pollutant that remains within the effluent after decay; applies to bacteria only)

Delivery and Degradation Factors

Even if a failing system surfaces, only a fraction of the pollutants discharged to the surface will ultimately reach surface waters, and the amount of pollutant delivered will depend on the distance between the OSDS and surface waters, as well as other features in the landscape. The WTM makes the assumption that 50% of the system effluent (and consequently 50% of the pollutant load) reaches the receiving water. Within 100’ of a stream or shoreline, it is assumed that 100% of the pollutant load is delivered to the receiving water. Thus, the delivery factor (D) for failing OSDSs is:

D = 1.0 (inside the buffer)

D = 0.5 (outside the buffer)

For bacteria, it is assumed that the bacteria have a decay rate of 1/day (Hydroqual, 2006), so that the degradation of the bacteria is directly related to the time of travel. Since surfacing OSDSs are conveyed to the stream primarily during storm events, it is assumed that, even within 100' of the waterbody, bacteria will take an average of 2 days to reach the stream during the inter-event period. For surfacing OSDSs outside of this buffer, a travel time of 6 days is assumed. The degradation factor, D, is determined as follows:

$$f = e^{-kt}$$

Where:

f = degradation factor (i.e., fraction of bacteria remaining)

t = time of travel (days); 2 days inside the buffer, 6 days within the buffer

k = decay rate (1/day)

The resulting degradation factors for bacteria are:

f = 0.13, inside the buffer

f = 0.02 outside the buffer

The WTM assumes that no degradation occurs for nitrogen or phosphorus from failing systems.

Load to Groundwater

The load of OSDSs to groundwater is the load treated by functioning systems that reaches the groundwater. Although the WTM calculates a "load to groundwater" it does not partition this load between shallow groundwater (i.e., baseflow) and deep groundwater. Consequently, the user must ultimately make this determination based on knowledge of local geology. The load delivered to OSDSs is removed by two factors: the system and the soil, so that the load is determined by the following equation:

$$L_{groundwater\text{-}OSDS} = (L_{OSDS\ delivery})*(1\text{-}SF/100)*(1\text{-}E_{system}/100)*(1\text{-}E_{soil}/100)$$

Where:

$L_{groundwater\text{-}OSDS}$ = Load to groundwater from OSDSs

$L_{OSDS\ delivery}$ = Load delivered to OSDSs as sewage

SF = OSDS failure rate (%)

E_{system} = System Efficiency (%)

E_{soil} = Efficiency of the soil below the leach field (%)

OSDS Efficiency

OSDS efficiency varies depending on the system type. Default values in the WTM are taken from Matuszeski (1997). The model also allows the user to enter system data in the "other" category. In the WTM, the efficiency of a system refers to its effectiveness at removing pollutants, measured at the point pollutants leave the leach field. Thus, additional removal can occur in the soils below the leach field.

Table 4.3 OSDS Efficiencies (Matuszeski, 1997)

System Type	TN Efficiency	TP Efficiency	TSS Efficiency	Bacteria Log Reduction
Conventional	28%	57%	72%	3.5
Intermittent Sand Filter	55%	80%	92%	3.2
Recirculating Sand Filter	64%	80%	90%	2.9
Water Separation System	83%	30%	60%	3.0
Other	User Enters Data			

<u>Adjusting system efficiency for density</u>

Several studies indicate that, on a watershed basis, increasing system density reduces the performance of OSDSs (Duda and Cromertie, 1982; Everette, 1982; Cahoon et al., 2006; Yates, 1985; Goonetilleke et al, 2002). The WTM adjusts the pollutant removal efficiency to account for systems applied at a high density (i.e., higher than a 1-acre lot size). Part of the reason for this increased pollutant delivery is simply that the total pounds of each pollutant are increased at a higher density. Another factor, however, is that leach fields can become saturated and are consequently less effective when they are undersized. The WTM assumes the total system efficiency is reduced when the sytems are applied at higher densities than one unit per acre.

In order to understand the potential impact of a partially functioning leach field, it is first necessary to understand the impact of the leach field in the context of total pollutant removal. Valiella et al. (1997) provide a detailed assessment of dissolved oxygen and nitrogen removal. This study found that 6.4% of the total nitrogen removal occurs in the septic tank of a conventional system, while 38.6% occurs in the leach field. The remainder of the nitrogen loss (46.6%) occurs in plumes below the field, and within the aquifer itself (8.4%). Since we define pollutant removal as "edge of field," approximately 86% (or 38.6% out of a 45% total cumulative removal after the leach field and the septic tank) occurs within the leach field. The WTM assumes that that the leach field can be compromised by between 30% and 50% due to improper siting (i.e., high density), so that the total removal would be reduced by between 25% and 43%. As a simplification, the WTM reduces the septic system efficiency by one third. This reduction is applied for nitrogen, phosphorus, and bacteria.

For bacteria, little data are available, but the reductions are primarily presented in log form. Since most systems achieve approximately a 3 log reduction, the WTM default assumption is that applying OSDSs at a very high density reduces the efficiency by one log (or 1/3 of the log reduction).

The efficiencies provided in Table 4.3 are then adjusted efficiencies are derived as follows:

- For nutrients and sediment: Multiply the efficiency in Table 4.3 by 2/3.
- For bacteria: Subtract 1 from the log reductions reported in Table 4.3.

Soil Filtering Efficiency

Another factor affecting pollutant removal in functioning OSDSs is filtering in the soil before it reaches the groundwater. The pollutant removal is different depending on the pollutant type, and also depends on the depth to groundwater and soil type. As a rule, coarse or sandy soils achieve a lower pollutant removal, and pollutant removal increases with increasing depth to groundwater. Some findings include the following:

- Bacteria removal is 100% as long as the soil has at least 15% clay content, and the depth to the vadose zone is at least one meter (approximately 3') (Scandura and Sobsey, 1997; Gill et al., 2009). The WTM assumes 100% removal for depths greater than 3'.
- Data for nitrogen removal in the soil is highly variable. For example, the US EPA (2002) reports TN removal ranges from 10% to 20% in a 3'-5' depth of soil below a drainfield, while Gill et al. (2009) find removals ranging from 59% to 89% (depending on soil type) in only one meter of soil below a trench. On the other hand, Ursin and Roeder (2008) found a wide range in the ability of soils to achieve nitrification and denitrification (0% to 100%) with a mean value of 33% in their study area. The WTM is fairly conservative with regard to nitrogen removal, and assumes no removal at less than 3' depth to groundwater, 10% at 3' to 5', and 20% at 5' and greater.
- There is also some variability for phosphorus, with US EPA (2002) reporting rates ranging from 0% to 100% (but typically 85% to 95%) within a 3'-5' soil depth. Again, Gill et al. (2009) find very high removals, ranging from 97% to 100% after only one meter of filtering below a trench. The WTM assumes 50% TP removal at depths less than 3', 80% at depths between 3' and 5', and 100% at depths greater than 5'. At the same time, Green (2001) documented several cases where phosphorus migrated to groundwater.

- Several studies report the importance of organic matter and clay soils for filtering both pollutants and bacteria (Ursin and Roeder, 2008; Scandora and Sobsey, 1997). The data were not completely consistent, but suggest significant differences across pollutant types. The WTM applies a discount factor for TN, TP, and bacteria of 50% for sandy or gravelly soils to accommodate this factor.
- Little data is available regarding migration of TSS to the groundwater, and it is assumed that 100% of the TSS load is removed by soil filtering.

The WTM synthesizes these findings into one set of assumptions for each pollutant-depth-soil type combination (Table 4.4).

Table 4.4 WTM Assumptions for Soil Filtering Efficiency[1]

Depth to Groundwater or Bedrock	<3’	3’-5’	>5’
TN Removal[1]	0%	5%/10%	10%/20%
TP Removal	25%/50%	40%/80%	50%/100%
TSS Removal	100%		
Bacteria Removal	25%/50%	50%/100%	

[1] The first number in each cell represents removal in sandy or gravelly soils, and the second represents removal in soils with some silt or clay content.

4.2 Sanitary Sewer Overflows (SSOs)

The WTM estimates the SSO load as a product of total flow from SSOs and concentrations for raw sewage. The WTM assumes that about 140 SSOs occur per 1,000 miles of sewer per year (AMSA, 1994). This number is multiplied by a typical SSO volume derived from data from six California municipalities (U.S. EPA, 1999). These volumes range from approximately 60,000 to 370,000 gallons per SSO, with an average volume of approximately 90,000 gallons. The model uses a default value of 90,000 gallons per SSO.

Unlike most urban pollutant sources, which can be classified as either storm loads or non-storm loads, SSOs occur both during and between storms. Some SSOs occur during or as a result of storm events, when runoff flows into the storm sewer system and exceeds capacity. Alternatively, SSOs can result from pipe breakages or blockages that cause flow between storm events. The WTM default assumption is that 50% of the load from SSOs occurs as a storm load, with the remainder as a non-storm load. The user may adjust this value.

This approach could be greatly improved with site-specific knowledge about the number and frequency of overflows on an annual basis. In addition, more detailed system information may help predict the flow associated with SSO events. If SSOs are a focus of the watershed analysis, the watershed manager may consider performing an inventory and perhaps modeling the system.

Example Calculation for SSOs - Phosphorus
A subwatershed includes 50 miles of sanitary sewer. The volume and frequency of SSOs in a typical year is unknown. Using model default values, the annual load (L_{sso}) is:
L_{SSO} = 50 miles •140 SSOs/1,000 miles•90,000 gallons/SSO •10 mg/l • (8.32×10^{-9})(conversion factor) = 53 lbs

4.3 Combined Sewer Overflows (CSOs)

The WTM also uses a modification of the Simple Method to calculate annual loads from CSOs. The primary assumption is that CSOs occur because runoff in the sewershed exceeds the total system capacity. As a default, the WTM assumes 65 CSO events per year, based on data reporting between 50 and 80 CSOs annually in communities with combined sewer systems (US EPA, 1994). For the Mid-Atlantic and Northeastern United States, approximately 65 storm events on an average annual basis exceed 0.1 inches (Driscoll et al., 1989). Combining these data, it is assumed that rainfall events greater than 0.1 inches can cause CSO events.

The volume of a typical CSO is based on the median storm event. In the WTM, any rainfall beyond the system capacity contributes to the CSO volume. Thus, this volume is calculated as the runoff caused by the difference between the median storm event depth and the rainfall depth that causes CSOs (assumed to be 0.1 inch). The runoff volume from this storm event is determined using the Simple Method. The load is the product of this volume, the number of CSO events, and typical concentrations in CSOs (Table 4.5).

Table 4.5 CSO Pollutant Concentrations		
Parameter	**Concentration**	**Source(s)**
TSS	200 mg/L	Maidment (1993): 184 mg/L Novotny and Chesters (1981): 100-2000 mg/L Driscoll (1986): 191 mg/L
TP	2 mg/L	Maidment (1993): 2.4 mg/L Novotny and Chesters (1981): 1.9 mg/L
TN	10 mg/L	Novotny and Chesters (1981): 9-10 mg/L
FC	$6.4X10^6$ MPN/100 mL	Schueler (1999): $6.4X10^6$ MPN/100 mL

This method makes several simplifying assumptions, and many of the default data vary significantly among jurisdictions. In addition, some CSOs are caused by local exceedances of capacity, rather than exceedance of the entire system. Finally, many jurisdictions have collected data on the magnitude, frequency, and quality of CSOs, particularly NPDES Phase I jurisdictions. If available, these data should always be used instead of any simplified modeling assumptions.

Example Calculation for CSOs- Fecal Coliform

A combined sewer system has a 1,000-acre sewershed with 40% impervious cover, a median storm of 0.4", and no data on the frequency or magnitude of CSO events. Using model defaults, the volume of each CSO in sewershed inches is calculated using the Simple Method (See Chapter 3) as:

$$V_{cso} = P_j \cdot (.05+.9\cdot I)(P_{median}-0.1")$$
$$= 0.9\cdot(0.05+0.9\cdot 0.4)(0.4"-0.1")$$
$$= 0.11"$$

This number is then multiplied by the number of events, the sewershed area, and CSO concentrations to determine annual loading, as:

$$L_{cso} = 65 \text{ events} \cdot 0.11"/\text{event} \cdot 1{,}000 \text{ acres} \cdot 6.4x10^6 \text{ MPN/100mL} \cdot 1.03x10^{-3} \text{ (conversion factor)}$$
$$= 4.7x0^7 \text{ billion per year}$$

4.4 Illicit Connections

To estimate the contribution from illicit connections, site-specific information on the average number and average size (either pipe size or flow estimate) of the connections per mile of storm sewer is preferred. For Phase I NPDES municipalities, some of this information will be available if illicit connection detection surveys were performed. In the absence of such data, it can be assumed that some fraction of total sewage flow contributes to illicit connections. The WTM makes separate assumptions for residential and business connections. For residential connections, the WTM's default assumption is that one in every 1,000 sewered individuals is connected to the sewer system via an illicit connection. This value is then multiplied by the number of individuals connected to the system, and then by typical per capita flow and concentration rates for raw sewage.

For businesses, illicit connections are tabulated as the sum of wash water connections and complete wastewater connections. The WTM's default values for characteristics of wash water and complete wastewater connections are provided in Table 4.6. The WTM extrapolates data from Wayne County, Michigan (Johnson, 1998), which found that 10% of businesses have illicit connections, and approximately 10% of those have direct sewage discharges. Concentration data for wash water were derived from US EPA (1980) data for water used by sinks or basins. "Total flow" concentrations are the weighted average of wash water flow and sewage data.

Table 4.6 WTM Assumptions for Business Illicit Connections

Characteristic		Connection Type	
		Wash Water[2]	**Wash Water and Wastewater[3]**
Number of Connections[1] (% of Businesses)		9%	1%
Flow (gallons/connection/day)		200	300
Pollutant Concentration	TN	15	30
	TP	10	10
	TSS	150	225
	FC	0	3,300,000

[1] Derived from Johnson (1998)
[2] Concentrations derived from U.S. EPA (1980).
[3] Concentrations are a flow-weighted average of wash water and raw sewage data.

Example Calculation for Illicit Connections- Nitrogen
A subwatershed has 2,000 sewered dwelling units and 200 businesses, and no data on illicit connections. The WTM would estimate the load (L_{IC}) as:
$L_{household}$ = (2,000 du) (2.7 people/du)(70 gpcd)(60 mg/l)(0.001connections/DU)($3.0x10^{-3}$) = 68 lbs/year
$L_{business}$ = (200)[(9%)(200 gpd)(15 mg/l)+(1%)(300 gpd)(30 mg/l)]($3.0x10^{-3}$) = 216 lbs/year
Therefore, L_{IC} = 284 lbs/year

4.5 Channel Erosion

Channel erosion is complicated and dependent upon a range of variables, including type and age of development, stream geomorphology, history of stream modification, and channel geometry. As a simple spreadsheet model, the WTM is unable to accommodate the complexity needed to accurately calculate channel erosion. Consequently, the WTM provides three options for calculating channel erosion, all of which are very simple, or rely on user input, as follows:

- Method 1: Estimate channel erosion as a fraction of total watershed sediment load
- Method 2: Back calculate based on known watershed sediment loading
- Method 3: Estimate based on other sediment study results

Regardless of the method used, the total sediment load is then multiplied by an "enrichment factor" that accounts for nitrogen and phosphorus content within stream channel sediment.

Method 1: Estimate Stream channel erosion as a fraction of total watershed sediment load

In this option, the WTM estimates stream channel erosion based on the condition of the channel (from stream channel surveys or observations), and uses this generalized assessment to estimate the sediment load from stream channels. Stream channel erosion can range from 25% of the total sediment load in relatively stable channels, up to 67% in highly degraded channels (Trimble, 1997). In this option, the WTM relates the stream channel erosion to total watershed sediment loading, using the percentages identified in Table 4.7.

Table 4.7 WTM Model Default Channel Erosion as a Fraction of Total Watershed Sediment Loads

Stream Degradation	Sediment Load (as a percentage of total watershed sediment loading)
High	67%
Medium	50%
Low	25%

It is important to note that the sediment load from stream channel erosion (L_{CE}) is a fraction of the *total* watershed load, and thus the equation for channel erosion is as follows:

$$L_{CE} = L_{OS}/(100/CE\%-1)$$

Where:

L_{CE} = Sediment load from channel erosion (lb/year)

L_{OS} = Sediment load from other urban sources (lb/year)

CE (%) = Channel erosion as a percent of the total urban watershed load

Method 2: Back calculate based on known watershed sediment loading

In this method, the user enters the total watershed sediment load (derived from monitoring data), and subtracts the load from other sources (calculated in the WTM), to determine the sediment load from channel erosion. The resulting equation is:

$$L_{CE} = L_{WS} - L_{OS}$$

Where:

L_{WS} = Total watershed sediment load (lb/year) as entered by the user

L_{OS} = Sediment load from other urban sources (lb/year)

Method 3: User Enters Data

In this option, the user enters the channel erosion in lbs/year, based on data from other studies. This option is most appropriate when a detailed geomorphic study or hydrodynamic model has been used to estimate channel erosion for the watershed being studied.

Estimating Nutrients in Channel Erosion

Channel sediments are enriched with nutrients and, as a result, stream channel erosion results in an associated nutrient load. This nutrient enrichment is derived from assumed nutrient concentration data. The user enters these data, ideally from sampling of stream bank sediment. Figures 4.1 and 4.2 can also be used as a default, and these figures.

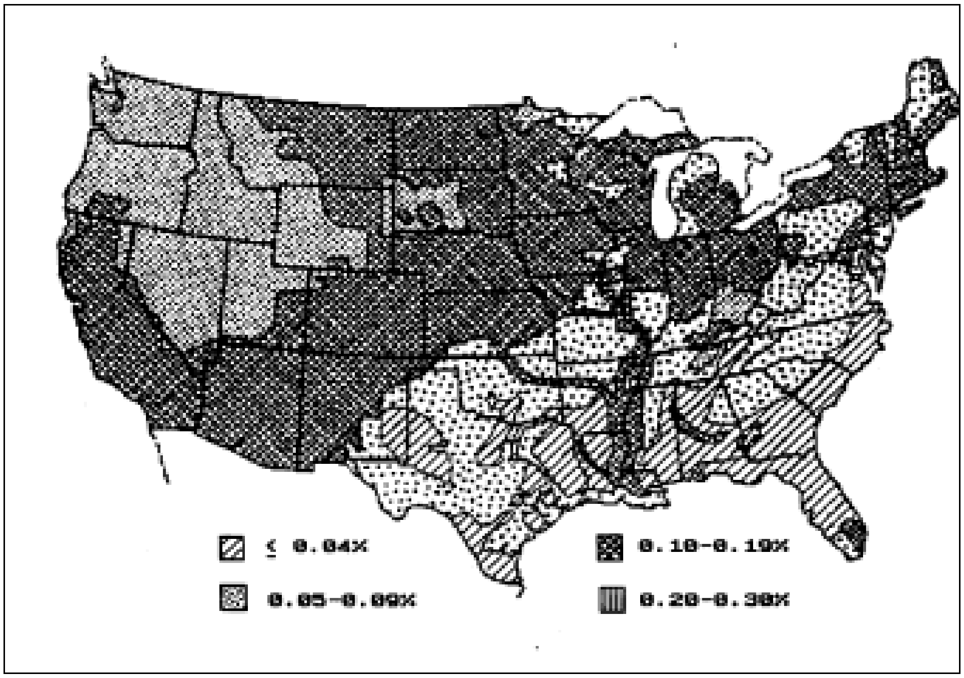

Figure 4.1. Phosphate (P_2O_5) as a % of Soil Mass in the Top 12" of Soil (Note that total Pis 44% P_2O_5 value). Source: Haith et al. (1992)

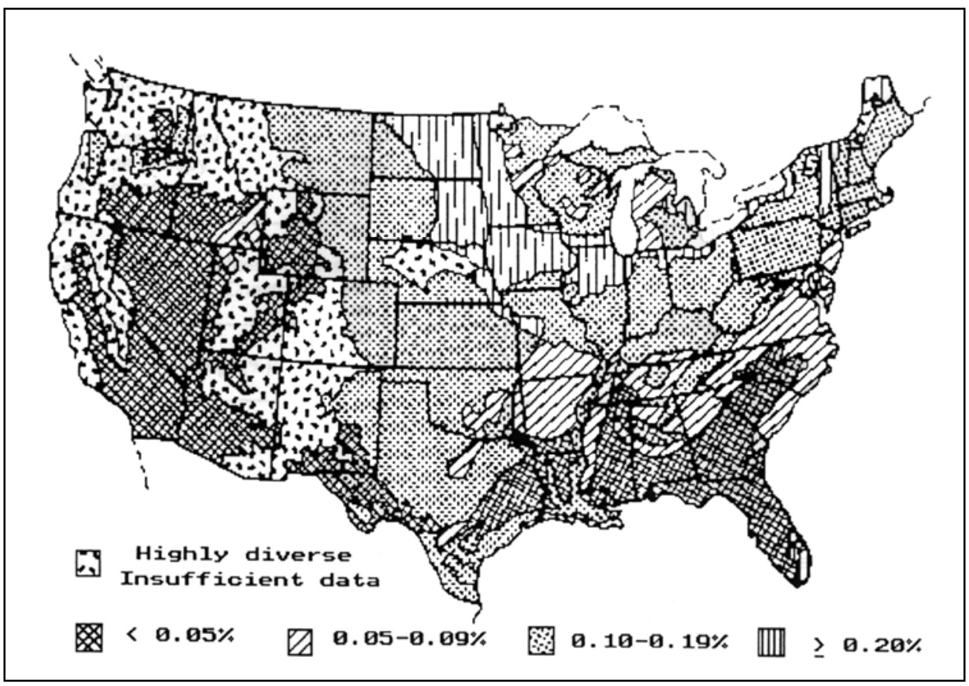

Figure 4.2. Nitrogen as a % of Soil Mass in the Top 12" of Soil. Source: Haith et al. (1992)

4.6 Hobby Farms/Livestock

The WTM uses loading factors on a per-animal basis to determine the impacts of livestock within a watershed. An estimate of the number of animals can be generated using data from a local extension agent. The estimate of the load delivered to the receiving water is simply the sum product of the number of each type of animal, loading rates and fraction exposed to runoff included in Table 4.9. These data are adapted from assumptions used by the Chesapeake Bay Program (Palace et al., 1998). The analysis is limited to animals that are confined. It is assumed that loading rates for pastured animals are reflected by pasture loading rates.

Delivery ratios for nutrients were determined by developing an areal loading rate per dairy using loading rates in manure from Palace et al. (1998), and multiplying this number by the 145 animal units per acre assumed in that publication. The resulting loading rates (in pounds per acre) were compared with typical loading rates (in pounds per acre) from dairy feedlots (Reckhow et al., 1980) to calculate delivery ratios of 15% for nitrogen and 10% for phosphorus. A 5% delivery ratio was used for bacteria to reflect diminished loading due to die-off. In addition, loading rates were adjusted based on the fraction of animals whose waste is exposed to runoff for each animal type, derived from Palace et al. (1998). Model default values are presented in Table 4.9. The total load for each animal type is the number of animals multiplied by the loading rate, delivery ratio, and fraction exposed to runoff.

Table 4.9 Pollutant Loading Rates from Confined Animals

Animal	Fraction Exposed to Runoff[1,2]	Bacteria (billions of organisms/year)[2]	N (lbs/year)[3]	P (lbs/year)[4]
Dairy Cattle	100%	2,000	175	30
Layers	15%	88	0.9	0.4
Broilers	15%	88	0.8	0.2
Turkeys	15%	47	3	0.8
Swine	100%	3,200	32	7.4
Delivery Ratio[3]		5%	15%	10%

Sources:
[1]Reflects fraction of animal waste exposed to runoff
[2]Metcalf and Eddy (1991)
[3]Palace et al. (1998)
[4]Judgment, derived from Palace et al. (1998) and typical loading rates for feedlots from Reckhow et al. (1980) for nutrients

4.7 Marinas

The WTM calculates the load from marinas as a product of the number of boating days and typical wastewater flow generation and concentration rates. The Rhode Island Sea Grant (1990) conservatively estimates that boats are occupied up to 50% of the boating season. This group recommends two people per boat for estimating purposes. For flow rates, it is assumed that a boat is similar to other recreational facilities, where per capita flow rates are approximately eight gpcd. The total flow is then multiplied by concentration data for raw sewage (see Table 4.2). This method assumes that no pump-out stations are available. Chapter 6 provides guidance on how to estimate the load reduction from pump-out facilities.

Example Calculation for Marinas - Fecal Coliform

A watershed analysis is being conducted in an urban lake that has a marina. The marina has 100 boat berths and the boating season is five months long. The fecal coliform loads (L_{MA}) can be calculated as:

L_{MA} = 100 boats • 2 people per boat• 8 gpcd • 5 months • 30 days/month • 50% (occupancy) • 10^7 MPN/100ml • $3.8x10^{-8}$(conversion factor)

= 45,600 billion per year

Note: The conversion factor for nutrients and sediment is $8.3x10^{-6}$

4.8 Road Sanding

Sediment loads from road sanding can be calculated simply, based on the total pounds of sand applied in a typical year. Data from past years are typically available from the local public works department. Although the example that follows reports data based on the total application in a community, road sanding data may also be available based on the loading rate per lane mile, which can then be aggregated to the watershed level when combined with a GIS roads layer. Since road sand is a relatively large sediment particle, not all of the sediment will reach the receiving water, particularly in open section roads. The default WTM assumption is that 90% of the sediment is delivered to the receiving water in closed section roads, while only 35% is delivered in open section roads.

Example Calculation for Road Sanding - Total Suspended Solids
A community applies 10 tons of road sand in a typical year. One half of the roads in the community are in the watershed being evaluated, and 75% of the roads are closed section. The TSS loads from road sanding in pounds per year ($L_{sanding}$) would be calculated as:
$L_{sanding}$ = (10 tons applied)•(0.5 applied in the watershed) • (2,000 lbs/ton) • [(0.75 closed section • 0.9 + (0.25 open section) • 0.35]
= 7,625 pounds per year

4.9 NPDES Dischargers

The loads from NPDES dischargers, such as wastewater treatment plants, can be estimated from flow and concentration data reported in Discharge Monitoring Reports required under NPDES regulations. Depending on the permit, different specific monitoring requirements may exist. For example, some facilities may require continuous monitoring, with composite flow-weighted samples, while others may only require monthly grab samples. In addition, some permits require that the discharger report pollutant load, rather than concentration. The annual load is the product of the average annual flow and the flow-weighted average pollutant concentration.

Example Calculation for Wastewater Treatment Plant - Phosphorus
A wastewater treatment plant discharges into a receiving watershed. The plant managers have collected daily flow and composite concentration data for phosphorus. After analyzing the data, it is determined that the plant has an average flow of 5 MGD, and a TP concentration of 0.05 mg/l. The annual phosphorus load in pounds per year from the plant is:
$L_{ww\text{-}treatment}$ = (5 MGD) • (3.78 X 10^6 liters/million gallons) •(365days/year)• (0.05 mg/l) • (1 lb/454,000 mg)
= 760 lbs/year

Chapter 5. Effectiveness of Stormwater Treatment Practices

In this document, the term “stormwater treatment practices” refers to structural practices, such as stormwater management ponds, used to treat stormwater runoff. This chapter provides estimates of the best achievable pollutant removal by various practices, and guidance on how to discount these removal rates. Throughout this chapter, a distinction is made between "existing structures" and "stormwater retrofits." Typically, stormwater treatment practices are put in place as development occurs, and designed along with the site. Retrofits, on the other hand, are implemented after development has occurred. The WTM treats these practices alike, with two exceptions. First, retrofits are treated as a future treatment practice calculated in a separate section of the model. Second, some retrofits may actually be retrofits of an existing facility, so that the total load reduction will be the relative *improvement* rather than the performance of the retrofitted practice.

5.1 TREATMENT EFFICIENCIES

More monitoring data are available to assess the performance of stormwater treatment practices than any other practice evaluated in the WTM. Still, some inferences from available data are needed. Table 5.1 summarizes the default values used in the WTM to account for pollutant removal by stormwater treatment practices. Note that the efficiencies reported in Table 5.1 rely on a combination of Runoff Reduction (Volume Reduction) and Filtering (Concentration Reduction), to produce a load reduction. The load reductions reported in Table 5.2 can be used to determine the load reduction for a combination of filtering and runoff reduction.

Table 5.1 Estimated Pollutant Removal Efficiencies (%) for Structural Treatment Practices[1]

Stormwater Treatment Practice	TSS[2]	TN[3]	TP[3]	Bacteria[4]	Runoff Volume[3]	Evapo-Transpiration[5]
Dry Pond	10%	5%	10%	0%	0%	0%
Dry Extended Detention	70%	10%	15%%	0%	0%/15%	0%
Wet Pond	85%	40%	75%	70%	0%	0%
Wetland	85%	55%	75%	80%	0%	0%
Filters	90%	45%	65%	80%	0%	0%
Green Roof	0%	0%	0%	0%	60%	100%
Rooftop Disconnection	0%	0%	0%	0%	25%/50%	0%
Permeable Pavement	25%	25%	25%	0%	45%/75%	0%
Grass (Open) Channel	40%	20%	45%	0%	10%/20%	0%
Dry Swale (bioswale, WQ swale)	40%	35%	40%	0%	40%/60%	0%
Wet Swale	40%	35%	40%	0%	0%	0%
Raintanks and Cisterns	0%	0%	0%	0%	40%	100%
Soil Amendments	0%	50%	0%	0%	75%/50%	0%
Sheetflow to Open Space	0%	0%	0%	0%	50%/75%	0%
Grassed Filter Strips	0%	0%	0%	0%	50/75%	0%
Bioretention	50%	60%	50%	50%	40%/80%	0%
Infiltration Practices	50%	15%	50%	50%	50%/90%	0%

1 The pollutant removal efficiencies presented in this table represent a “Filtering Efficiency” rather than a total pollutant removal (mass load) efficiency. To determine the Mass Load efficiency for each value and associated runoff reduction, use Table 5.2.

2 TSS Removals are derived from (CWP, 2007). In this summary literature review, 3rd Quartile values are used to represent good practice design and maintenance. Note that this publication provides mass removal rates, and filtering efficiencies are “backed out” by assuming ideal runoff reduction rates from Hirschman et al. (2008) and Table 5.2.

3 Data for TN, TP and runoff volume from Hirschman et al. (2008)

4 Bacteria data are highly limited, and it is assumed that most practices provide minimal bacteria removal. Practices with data are derived from CWP (2007) and Hathaway et al. (2009)

5 ET efficiencies are used to account for practices that provide runoff reduction but do not contribute to groundwater loads (See Section 5.3).

Table 5.2. Cumulative Efficiency (Load Reduction) versus Filtering and Runoff Reduction Efficiencies												
		Filtering Efficiency (%)										
		0%	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**
Runoff Reduction (%)	**0%**	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
	10%	10%	19%	28%	37%	46%	55%	64%	73%	82%	91%	100%
	20%	20%	28%	36%	44%	52%	60%	68%	76%	84%	92%	100%
	30%	30%	37%	44%	51%	58%	65%	72%	79%	86%	93%	100%
	40%	40%	46%	52%	58%	64%	70%	76%	82%	88%	94%	100%
	50%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%
	60%	60%	64%	68%	72%	76%	80%	84%	88%	92%	96%	100%
	70%	70%	73%	76%	79%	82%	85%	88%	91%	94%	97%	100%
	80%	80%	82%	84%	86%	88%	90%	92%	94%	96%	98%	100%
	90%	90%	91%	92%	93%	94%	95%	96%	97%	98%	99%	100%
	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

5.2 TREATABILITY AND DISCOUNT FACTORS FOR STORMWATER TREATMENT PRACTICES

The pollutant removal rates presented in Table 5.1 can rarely be achieved on a watershed-wide basis for a variety of reasons. The performance of stormwater treatment practices needs to be discounted to reflect the initial design and long-term maintenance of the practices. This chapter provides guidance for assessing the treatability of stormwater treatment practices and adjusting their performance to reflect actual practice implementation using “treatability factors” and “discount factors.”

Treatability Factor

The treatability factor is the fraction of a drainage area that can be treated by the stormwater treatment practice, calculated as the impervious cover captured by the practice divided by the impervious cover in the subwatershed. Some communities have detailed records of the locations, characteristics, and drainage areas of all of the stormwater treatment practices throughout a subwatershed. When a community does not have these records, a watershed manager may need to estimate the treatability based on the age of development in the subwatershed. For example, if stormwater management for water quality was not required in a community before 1975, and 60% of the development in the watershed occurred before this time, the treatability discount can be no greater than 0.4 (1 minus 0.6), unless stormwater retrofits have been implemented in the past.

For retrofit practices, the treatability factor is treated slightly differently. Rather than estimating a fraction of the watershed treated, the benefits of each retrofit practice are calculated individually, based on the volume captured by the practice. The model thus calculates an integrated "Treatability-Capture" discount factor, which is described later in this chapter.

Discount Factors

In the WTM, three discount factors are applied to stormwater treatment practices, and these reflect the fraction of the annual runoff volume captured by the practice (D_1), the practice design (D_2), and the long term maintenance (D_3) (Table 5.3).

Table 5.3 Discount Factors for Stormwater Treatment Practices

Discount Factor	Application	Calculation Method
D_1 Capture Factor	All	Fraction of annual rainfall captured by the structure
D_2 Design Factor	All	Factor applied based on the adequacy of existing design standards
D_3 Maintenance Factor	All	Factor based on the type of maintenance conducted on treatment practices

D_1 Capture Factor

The capture factor reflects the fraction of the annual rainfall captured by a stormwater treatment practice. This value can be determined based on the rainfall frequency spectrum in a region, and the size storm that is treated for water quality by a practice. The rainfall frequency spectrum represents the statistical distribution of runoff-producing (0.1") rainfall. By assembling all historical rainfall data, the user can determine the fraction of storms represented by a particular rainfall event. In many jurisdictions, the design storm for stormwater treatment practices is selected to capture a particular rainfall fraction. For example, in much of the Mid-Atlantic and Northeast of the United States, a 1” storm captures roughly 90% of the annual rainfall volume.

Treatability-Capture Discount for Retrofits

The calculation of benefits for stormwater retrofits is very similar to that for new stormwater treatment practices, except that the Capture Factor, D_1, and the treatability factor are combined into a single discount factor, based on the sizing and area treated by each individual practice. For retrofits, the following calculations are used:

$$T \bullet D_1 = WQv_{provided}/WQv_{watershed}$$

Where:

$WQv_{provided}$ = Water Quality Volume provided in the practice (cubic feet)

$WQv_{watershed}$ = Water Quality Volume in the watershed (cubic feet)

$$WQv_{watershed} = P_{target}*(A_{imp} \bullet .95 + A_{turf} \bullet Rv_{turf}) \bullet 3{,}630$$

Where:

P_{target} = Target design storm (inches) entered by user

A_{imp} = Impervious cover in the watershed (acres)

0.95 = Runoff coefficient for impervious cover

Rv_{turf} = Runoff coefficient for turf in the watershed (weighted by soil type; see Chapter 3 for a description).

In order to assist the user in determining the target water quality volume, the WTM calculates a default target volume as follows:

$$WQv_{target} = P_{target} \bullet (A_{imp\text{-}DA} \bullet .95 + A_{turf\text{-}DA} \bullet Rv_{turf\text{-}DA}) \bullet 3{,}630$$

Where:

P_{target} = Target design storm (inches) entered by user

$A_{imp\text{-}DA}$ = Impervious cover in the practice’s drainage area (acres)

$A_{turf\text{-}DA}$ = Turf cover in the practice’s drainage area (acres)

$Rv_{turf\text{-}DA}$ = Runoff coefficient for turf in the practice’s area, determined by a user-entered soil type (See Chapter 3 for a summary of Rv values based on soil type)

D_2 Design Factor

The design factor accounts for the design features incorporated into stormwater treatment practices. This discount factor is relatively subjective, and thus requires some judgment on the part of the watershed manager. It is assumed that excellent, enforceable design criteria will result in a practice with very high removal efficiencies (D_2 =1.0). A value of 0.8 is assigned to communities without legally binding standards, or without specific site standards. This value is chosen because median pollutant removal values are typically about 80% of the 3rd quartile values used as defaults. This value is used because improved design features may actually improve pollutant removal over the values reported in Table 5.1. Finally, it is assumed that communities with no design standards can achieve only 60% of the optimal design standard performance (i.e., another 20% reduction).

Table 5.4 Values of the Design Factor (D_2)	
Existing Stormwater Treatment Practices	
Specific design standards, including location, and performance-enhancing features. Legally binding and enforced.	1.0
Same as 1, but not legally binding.	0.8
Legally binding design standards exist, but do not specify site restrictions for treatment practices, or do not explicitly define design features to enhance performance.	0.8
No design standards.	0.6

D_3 Maintenance Factor

The maintenance factor reflects the declining performance of stormwater treatment practices over time as a result of poor maintenance. Little data are available to explicitly quantify this loss. The WTM default values are based on the assumption that up to 50% of practice efficiency can be lost if maintenance is not both specified in stormwater guidelines and legally enforceable.

Table 5.4 Values of the Maintenance Factor (D_3)	
Maintenance Program	**D_3**
Regular maintenance is specified in design guidance, and is regularly conducted by the community. Alternatively, a private owner conducts regular maintenance, and the community regularly inspects practices and has an enforcement mechanism.	0.9
Regular maintenance is specified in design guidance, but the community has a poor tracking system or limited staff to ensure that maintenance occurs.	0.6
There is no guidance specifying when and how maintenance will occur.	0.5

5.3 LOAD AND RUNOFF REDUCTION

The pollutant load reductions and runoff reductions from each practice are calculated slightly differently, using the following calculations:

Runoff Reduction

$$RR_{STP} = R_{ulu} \bullet T \bullet E_{RO}/100 \bullet D_1 \bullet D_2 \bullet D_3$$

Where:

RR_{ESTP} = Runoff reduction by stormwater treatment practices (inches)

R_{ulu} = Runoff from urban land uses in the watershed (

T = Treatability factor (unitless) (see above description)

E_{RO} = Runoff reduction efficiency (%) from Table 5.1

$D_{1,2,3}$ = Discount factors (see above description)

Pollutant Removal

Pollutant removal occurs as a combination of runoff reduction and filtering. The resulting equation is as follows:

$$LR_{STP} = L_{ulu} \bullet T \bullet [E_{RO} + (1 - E_{RO}) \bullet E_P] \bullet D_1 \bullet D_2 \bullet D_3$$

Where:

LR_{STP} = Load reduction by stormwater treatment practice (lbs or billion)

L_{ulu} = Load from urban land uses in the watershed (lbs or billion); includes load reductions from pollution preveiontin practices (See Chapter 7)

E_{RO} = Runoff reduction efficiency (%) from Table 5.1

E_p = Pollutant removal efficiency (%) from Table 5.1

Reductions by Retrofits of Existing Practices

With the exception of the combined Treatment/Capture factor, the benefits of new retrofits are calculated in exactly the same way as existing stormwater treatment practice. Retrofits of existing practices are slightly different, however, because their benefits are calculated from a baseline of the original practice, such that:

$$R_{R\text{-}Net} = R_{R\text{-}post} - R_{EP}$$

Where:

$R_{R\text{-}Net}$ = Runoff or load reduction of the retrofit

$R_{R\text{-}post}$ = Runoff or load reduction of the practice after it has been retrofitted.

R_{EP} = Runoff or load reduction of the existing practice (before the retrofit)

The load reductions of the existing and retrofitted practices are calculated using data for the practice type, discount factors, and design volumes, as described above.

5.4 INFILTRATED RUNOFF DELIVERED TO GROUNDWATER

Practices that provide runoff reduction, with the exception of green roofs and cisterns, infiltrate runoff to the groundwater, and have the potential to increase the total load to groundwater. The WTM accounts for this groundwater load separately. For stormwater treatment practices, the groundwater load is calculated as:

$$L_{GW} = L_{ulu} \cdot T \cdot E_{RO} \cdot (1 - E_P)(1-ET)(1-E_{SOIL}) \cdot D_1 \cdot D_2 \cdot D_3$$

Where:

L_{GW}	=	Load to groundwater (lbs or billion)
L_{ulu}	=	Load from urban land uses in the watershed (lbs or billion)
E_{RO}	=	Runoff reduction efficiency (%) from Table 5.1
E_p	=	Pollutant removal efficiency (%) from Table 5.1
ET	=	% or runoff reduction volume lost in evapotranspiration (Table 5.2)
E_{soil}	=	Filtering efficiency of the soil (described in the “OSDS” section of Chapter 4)

Chapter 6. Effectiveness of Stormwater Control Programs

Unlike stormwater treatment practices (Chapter 5), most stormwater control programs do not have a great deal of monitoring data to assess their performance. This chapter provides guidance to help the watershed manager quantify the benefits of these programs. The methodologies presented here are those used in the WTM. Assumptions are based on available national data and best professional judgment. In all cases, local information supplants model defaults. For each practice, we present a methodology that determines the best possible removal. Next, we define the treatability for each practice. Finally, we supply "discount factors", which account for the level of program implementation. Table 6.1 summarizes the overall methodology used to account for each treatment option, and Table 6.2 summarizes discount factors.

Table 6.1 Load Reduction Calculations for Stormwater Control Programs

Management Practice[1]	Target Pollutant(s)	General Procedures for Determining Program Efficiency
Residential Education (Section 6.1, S/NS)	Nutrients, Bacteria	Depending on the educational program, reduce the load associated with the behavior
Erosion and Sediment Control (Section 6.2, S)	Sediment, Nutrients	Assume 70% efficiency
Street Sweeping (Section 6.3, S)	Sediment, Nutrients	Reduce the concentration of pollutants in street and parking lot runoff depending on the type of sweeper and sweeping schedule
Impervious Cover Disconnection (Section 6.4, S)	All	Treat rooftop runoff using a filter strip or other practice
Riparian Buffers (Section 6.5, S)	Sediment, Nutrients	If buffers do not appear as forest on land use maps, convert them to a forest land use. Apply a load reduction efficiency
Storm Sewer/Catch Basin Cleaning (Section 6.6, S)	Sediment, Nutrients	Apply a reduction to the load from roadways based on cleaning frequency
Marina Pumpout (Section 6.7, NS)	Nutrients, Bacteria	Assume no dumping occurs for boats served by a pumpout station
Urban Downsizing (Section 6.8, S/NS)	All	Convert the unused urban land to a rural/ forest land use

[1] S = Reduces Storm Load; NS = Reduces Non-Storm Load

Table 6.1 Load Reduction Calculations for Stormwater Control Programs		
Management Practice[1]	**Target Pollutant(s)**	**General Procedures for Determining Program Efficiency**
Impervious Cover Reduction (Section 6.9, S)	All	Reduce impervious cover by an assumed fraction
Illicit Connection Removal (Section 6.10, NS)	All	Eliminate the load from illicit connections
CSO Repair/ Abatement (Section 6.11, S)	All	Reduce the load from CSOs depending on the type of program
SSO Repair/ Abatement (Section 6.12, S/NS)	All	Reduce the load from SSOs, depending on the type of program
OSDS Inspection /Repair (Section 6.13, NS)	All	Convert failing septics to working septics
OSDS Upgrade (Section 6.14, NS)	All	Change the efficiency of OSDSs
OSDS Retirement (Section 6.15, NS)	All	Change OSDSs to wastewater treatment
Stream Channel Protection (Section 6.16, S)	Sediment, Nutrients	Enter load reductions from individual practices
Point Source Treatment (Section 6.17, NS)	All	Requires user input
[1] S = Reduces Storm Load; NS = Reduces Non-Storm Load		

Table 6.2 Treatability and Discount Factors in the WTM		
Management Practice[1]	**Treatability**	**Discount Factor(s)**
Residential Education (Section 6.1, S/NS)	Fraction of the population in target audience	D_1: Awareness D_2: Interest
Erosion and Sediment Control (Section 6.2, S)	Fraction of sites regulated	D_1: Installation/ Maintenance
Street Sweeping (Section 6.3, S)	Fraction of streets swept	D_1: Frequency D_2: Technique
Impervious Cover Disconnection - Residential (Section 6.4, S)	Fraction of homes where the practice can be applied (future) Fraction of homes disconnected (current)	D_1: Awareness D_2: Interest
Riparian Buffers (Section 6.5, S)	Fraction of land that drains to current or proposed buffers	D_1: Design/ Maintenance
Storm Sewer/ Catch Basin Cleaning (Section 6.6, S)	Fraction of urban land served by cleaned sewers	D_1: Frequency D_2: Disposal
Marina Pumpout (Section 6.7, NS)	Fraction of boats served by pumpouts	D_1: Service D_2: Participation
Urban (Section 6.8, S/ NS)	Fraction of urban land eligible for reclamation	D_1: Implementation
Impervious Cover Reduction/ Better Site Design (Section 6.9, S)	Fraction of land eligible	D_1: Implementation
Illicit Connection Removal (Section 6.10, NS)	Assumed 100% illicit connection load	D_1: Survey D_2: Implementation
CSO Repair/ Abatement (Section 6.11, S)	Assumed 100% of program target reduction	D_1: Implementation
SSO Repair/ Abatement (Section 6.12, S/NS)	Assumed 100% of target reduction	D_1: Implementation
OSDS Inspection/Repair (Section 6.13, NS)	Assumed 100% of failing OSDSs	D_1: Survey D_2: Participation
OSDS Upgrade (Section 6.14, NS)	100% of OSDSs	D_1: Survey D_2: Participation
OSDS Retirement (Section 6.15, NS)	100% of OSDSs	D_1: Survey D_2: Participation
Stream Channel Protection (Section 6.16, S)	Fraction of stream miles stabilized	D_1: Flow Control
Point Source Treatment (Section 6.17, NS)	Load reduced	None
[1] S = Reduces Storm Load; NS = Reduces Non-Storm Load		

6.1 RESIDENTIAL EDUCATION

A variety of public education programs may help to reduce the concentrations of nutrients, sediment and bacteria in urban streams. In this chapter, we focus only on a few of these programs, including ones that address lawn care, OSDS maintenance, and pet waste. Several other residential pollution prevention programs improve water quality, but have little effect on nutrients, suspended solids, and bacteria specifically. For example, household hazardous waste programs are effective at reducing toxics but do not have a large impact on the loads of suspended solids, nutrients, or bacteria.

Effectiveness of Education

Residential pollution prevention programs are limited primarily by the community's ability to reach the public and change their behavior. The values of these factors depend on the type of program (e.g., pet waste versus lawn care) and the type of media used to distribute the message. Two discount factors that reflect the challenge of changing the public's behavior are as follows:

D_1: Awareness: Fraction who remember the message

D_2: Participation: Fraction who are willing to change their behavior

The awareness factor is dictated by the media type, while the participation factor differs depending on the activity, as described in each individual education practice.

D_1 Awareness Factor

Even if a message reaches the target audience, many of the individuals in the audience may not remember it. Research suggests a wide range of possible "recall rates," depending on the intensity of effort, the type of media used, and the population targeted. Table 6.3 estimates values of D_1 based on the media type.

Table 6.3 Values of the Awareness Factor for Various Media Types

Media	Recall Rate (Equal to D_1)	Reference
Television	0.4	Assing (1994) Elgin DDB (1996) Pellegrin Research Group (1998) Advanced Marketing Research (1997)
Radio	0.25	National Service Research (1998) Big Honking Ideas, Inc (BHI) (1997) Advanced Marketing Research (1997) Pellegrin Research Group (1998)
Billboard	0.13	Pellegrin Research Group (1998) Assing (1994)
Brochure/Pamphlet or Postcard	0.08	National Service Research (1998) Pellegrin Research Group (1998)

Lawn Care

Turfgrass (turf) is an extensive and increasing land cover in the US as agricultural and forested lands are converted to residential and other urban land uses. Extensive research on managed turf demonstrates that numerous factors affect pollutant loadings to groundwater and surface runoff. Despite this wide range of research, there remains large variability in the data on the role of turfgrass as a source area for pollutants because individual research studies evaluate different factors, or were performed on varying soils or turf conditions.

The factors and values used in the updated WTM are abstracted from a literature review to represent key factors and 'average' values. In this section, the pollutant loading to surface and subsurface waters from managed turf is based on the quantity of fertilizer applied and the condition of the turf. This section describes the type of data used to characterize these two general factors and their effect on the pollutant loading generated.

Base Fertilizer Application Rate

Fertilizer is the source of nutrients for managed turfgrass and the quantity of nitrogen and phosphorus applied to turf is estimated by multiplying the area turf cover in the watershed by an annual application rate (lbs/acre). A default annual application rate of 150 lbs/acre (or 2lbs/1000 ft^2), a commonly reported unit for fertilizer application rates in the literature, is given in the model. The recommended application rate will vary based on turfgrass species (see Table 6.4).

Table 6.4. Recommended Application Rates of Nitrogen for Various Turfgrass Species

Species	Application rate (lbs N/1000 ft^2/yr)	Timing
Tall fescue, bluegrass, rye grass	2	1lb/ft^2 applied in September 1lb/ft^2 applied in October
Fine fescue	1	1 lb/ft^2 applied in October
Zoysiagrass, Bermuda grass	1-2	1 lb/ft^2 applied in June Bermuda grass gets another 1 lb/ft^2 in July
Source: Turner et al. (2003)		

N Fertilizer Application Adjustment Factors

The application rate of nitrogen fertilizer may increase or decrease based on a number of factors listed in Table 6.5. It is acknowledged that other factors may influence runoff and groundwater loads from turfgrass (e.g. timing of applications, irrigation, turf management practices such as aeration, thatch layer, shoot density, clippings are bagged or left on the lawn, among others). The factors included in the model are those that can be readily measured or can be based on information acquired in local watersheds using surveys, site assessments and parcel data, and are integrative in nature. For example, the age of the home is used a proxy for the age of turfgrass. This factor is important because research has shown that lawns associated with new development typically have higher fertilizer inputs. (Easton and Petrovic, 2004; Law et al. 2005; Smetak et al. 2007).

Table 6.5 Summary of Factors Affecting the Annual Application Rate of Fertilizers for Residential Land Uses

Factor	Value	Source	Notes
Number of applications per year	1.1[1]	Augustin (2007) as cited in Soldat and Petrovic (2008)	
Percent of homes <10yrs old	User defined	Local parcel data, tax assessments	
Percent of turf that is highly managed	User defined	Based on local field/ site assessments	Refer to the Neighborhood Source Area assessment in Wright et al. (2005)

[1]values in italics are default model values

Based on the user input, the factors shown in Table 6.4 are weighted such that the N application rate is adjusted by the following calculation:

N Application Rate (lb/year) = Base Rate (150 lb N/year)•(1+F/6), where

F = F1+F2+F3
If Number of Applications <=1.1, F1 = 0
If Number of Applications >=1.1 and <4.0, F1 = Number of Applications/2
If Number of Applications >4.0, F1 = 2
F2 = (Fraction of homes <10 years old)•2
F3 = (Fraction of turf that is "highly managed")•2

This equation effectively acts as a scaling factor, with F being equal to a score ranging from 0 to 6, with an equal weight given to each of the three factors (number of applications, % of homes <10 years old, and % of turf "highly managed"). By including the scaling factor, the fertilizer application rate ranges from 150 (i.e., recommended rate), when all scaling factors are equal to zero, to 300 (i.e., double the recommended rate), when all factors are at their maximum value of one.

The user may also override the N application rate with local data, if available.

N/P Distribution in Fertilizer

The phosphorus applications rates are based on typical N/P content for various forms of fertilizer (based on Easton and Petrovik, 2004). The model assumes that 50% of the watershed population uses soluble/urea type fertilizers and another 50% uses a slow-release product as the default. This assumption may be changed by user as noted by the "blue" highlighted cells.

Table 6.6. Fertilizer Use and Nutrient Content Assumptions

Form	**% of Fertilizer Use (N Application)**	**N (lb/100 lb of fertilizer)**	**P (lb/100 lb of fertilizer)**
Organic	0%	0.8	0.3
Soluble/Urea	50%	35	3
Slow Release	50%	24	5
Phosphorus Free	0%	10	0

Determining Total Fertilizer N and P Application Rate

Total Nitrogen application is determined as:

Total Nitrogen Application = Nitrogen Application Rate (lb/acre/year) • Acres of Turf

Phosphorus application needs to be determined in two steps. First the application rate of each fertilizer type is determined based on the data in Table 6.6 and the Nitrogen Application Rate:

Fertilizer Application (100 lbs/acre) = (% of Nitrogen Application)•(Nitrogen Application Rate)/(N Fertilizer Nutrient Content)

Next, the total phosphorus application rate is determined by summing fertilizer application and associated phosphorus content:

Phosphorus Application Rate (lb/acre/year) = ∑ (Fertilizer Application Rate)•(Phosphorus Concentration in Fertilizer)

This values is then multiplied by the acres of turf, so that:

Total Phosphorus Application = Phosphorus Application Rate (lb/acre/year) • Acres of Turf

Surface and Subsurface Fertilizer Loads

In the WTM, the nutrient loss to surface runoff and leachate is determined by the fertilizer type, as reported in Easton and Petrovic (2004).

Table 6.7. Loss of Nitrogen and Phosphorus from Fertilizer to Surface and Subsurface Water

Fertilizer Type	Loss to Surface Runoff		Loss to Subsurface Leachate	
	N	P	N	P
Organic[1,2]	0.1%	0.1%	1.1%	1.2%
Soluble/Urea[1,3]	0.8%	0.9%	20.6%	12.8%
Slow Release[1,4]	1.3%	1.5%	25.5%	5.4%
Phosphorus Free[5]	0.8%	0.0%	20.6%	0.0%

[1]Values and fertilizer products taken from Easton and Petrovic (2004)

[2] Organic refers to a dairy compost

[3] Referred to as 'readily available' urea 35-5-5 ratio of N-P-K

[4] Referred to as 'controlled release' sulfur coated 24-5-11

[5] Values from soluble/urea in Easton and Petrovic (2004) with the phosphorus removed

The total loss (to the surface or subsurface) for each nutrient is defined as:

$$\text{Loss} = \sum[(\text{Fertilizer Nutrient Application Rate})\bullet(\text{Nutrient Loss})]/\text{Nutrient Application Rate}$$

In Easton and Petrovik's (2004) research, plots without any fertilizer application still had a baseline surface and subsurface nutrient load (See Table 6.8).

Table 6.8. Base Loading Rates for Nitrogen and Phosphorus (lb/acre)		
Type of Water	Nitrogen	Phosphorus
Surface	4.5	1.8
Subsurface	27	2.7

Adding the nutrient loss to the base load, the total pollutant load for each nutrient and pathway is:

$$\text{Load} = \text{Loss} + \text{Base Load}$$

Surface Runoff Volume

The runoff volume from turf is calculated using a runoff coefficient that is dependent on the soil type (Table 6.9). Compacted lawns increase the runoff volume, and a typical adjustment factor is to change the soil type (e.g., from a "B" to a "C" soil group) to reflect this increase in runoff. In the WTM, this is accomplished by increasing the runoff coefficient from new lawns by 0.03. For bare and compacted lawns, the runoff coefficient is changed to 0.5, regardless of soil type.

Table 6.9. Runoff Coefficients for Turf	
Hydrologic Soil Group	**Runoff Coefficient**
A	0.15
B	0.20
C	0.22
D	0.25

Management Practices

The WTM accounts for education programs with six separate messages, including:

- Reduce fertilizer to recommended levels
- Switch to non-phosphorus fertilizers
- Change to organic fertilizer
- Add soil amendments to lawns
- Convert 25% of lawn to forest or native vegetation
- Apply no fertilizer

For each practice, the WTM determines the area impacted by the practice as follows:

$$\text{Area Impacted}_{\text{practice i}} = (\text{Area}_{\text{turf}}) \bullet D1 \bullet D2_{\text{practice i}}$$

It is assumed that these practices are encouraged through public education, with the effectiveness of the outreach (i.e., the "awareness factor," D1, as taken from Table 6.3, depending on the media type. Each specific action is then assigned a "willingness to change" factor, D2, depending on the action. Table 6.10 summarizes how these actions are treated in the model as well as the D2 factor assigned to them.

Table 6.10. Summary of Willingness to Change Factors for Various Turf Management Practices

Practice	D2	WTM calculation
Reduce fertilizer use to recommended levels	0.5	Adjust N application rate to 150 lbs N/acre on turf area impacted by the program.
Switch to non-phosphorus fertilizer	0.25	Increase the % of turf where non-phosphorus fertilizer is applied to reflect the area impacted by the practice.
Change to organic fertilizer	0.1	Increase the % of turf where organic fertilizer is applied to reflect the area impacted by the practice.
Add soil amendments to lawns	0.1	Apply as a stormwater retrofit that reduces runoff volume by 67%, TN and TP by 50%, and TSS by 75%.[1]
Convert 25% of lawn to forest or native vegetation	0.1	Reduce the turf area by the appropriate amount, and convert this area to forest.
Apply no fertilizer	0.1	Adjust N application rate to 0 lbs N/acre on turf area impacted by the program.

[1] Soil amendment efficiencies taken from Hirschman et al. (2008)

OSDS Programs

OSDS education programs are designed to improve OSDS maintenance and management. In the WTM, OSDSs are treated as a secondary source, as described in Chapter 4. OSDS education programs reduce the failure rate, so that the failure rate initially present in the watershed is adjusted, as follows.

$$F_{ed} = F_0 \bullet (1-D_1 \bullet D_2)$$

Where:

F_{ed} = Failure Rate after OSDS Education Program

F_0 = Failure Rate Before OSDS Education Program

D_1 = Awareness Factor (see Table 6.3)

D_2 = Willingness to Change (typically approximately 40%; Swann, 1999)

Pet Waste

In the urban watershed, dogs are a significant contributor of bacteria, and may also contribute a substantial amount of nutrients. Ideally, a pet waste program would reduce this source to zero, with all homeowners properly disposing of waste. The potential load reduction of a pet waste system can be calculated as:

$$R_P = H \bullet W \bullet C_W \bullet f_1 \bullet f_2 \bullet 365$$

Where:

R_P = Potential Load Reduction from a Pet Waste Program (lbs/year; colonies per year)

H = Number of Households

W = Waste Production (lbs/dog/day; colonies/dog/day; see Table 6.10 for model defaults)

C_W = Concentration of a Pollutant in Dog Waste (lbs/lb; colonies/lb; see Table 6.10 for model defaults)

f_1 = Fraction of Households with a Dog (model default = 0.4)

f_2 = Fraction of a Pollutant Delivered to a Stream (model default = 0.35 for bacteria, 0.25 for N and 0.75 for P)

365 = Conversion Factor (days/year)

The following assumptions can be made regarding the potential contribution of pet waste to urban nonpoint source pollution:

- 40% of households own a dog (Swann, 1999; American Pet Products Manufacturing Association, 1998). ($f_1 = 0.4$)
- 65% of fecal coliform die before reaching the stream (based on a decay rate of 1/day and a decay time of one day on average; Hydroqual, 1996). ($f_{2-B} = 0.35$)
- 25% of nitrogen is delivered to the stream. ($f_{2-N} = 0.25$)
- 75% of phosphorus is delivered to the stream. ($f_{2-P} = 0.75$)
- Dog waste characteristics are described in Table 6.11.

Table 6.11. Dog Waste Characteristics

Characteristic	Value
Waste Production (lbs/dog/day); (W)[1]	0.32
Fecal Coliform (billion colonies/lb); (C_{W-B})[1]	10
Nitrogen (lbs/lb); (C_{W-N})[2]	0.23
Phosphorus (lbs/lb); (C_{W-P})[3]	0.01

[1]Source: Clean Water Campaign
[2]Source: Schueler, 1999
[3]Assumptions:
- 80% digestibility
- Mid-Size dog

Treatability (T)

The treatability for residential pollution prevention programs is defined as the fraction of the watershed that is in the target audience for a specific program. The fraction of the watershed in the target audience depends on the behavior being addressed. For pet waste, this is the fraction of pet owners that currently does not pick up after their dogs.

Table 6.12. Treatability of Pet Waste Education Programs	
Default Value	**Assumptions**
0.2	50% of dog owners walk their dogs (Swann, 1999; Hardwick, 1997) 40% of dog owners do not clean up after their dogs[1]
[1]Approximate median value from Swann (1999), Hardwick (1997), US EPA (1993)	

6.2 EROSION AND SEDIMENT CONTROL PROGRAM

The WTM default efficiency for erosion and sediment control is 70%. This efficiency is based on a best case scenario, defined as a sediment control program that emphasizes erosion control measures, including practices that limit clearing and grading or use of phased construction methods (Brown and Caraco, 1997), and requires advanced erosion and sediment control measures to reduce the concentration of sediment in runoff leaving the site. The 70% efficiency was derived using the following assumptions:

- The program would effectively reduce the acreage of land in active construction by 25% by requiring phasing or limiting clearing.
- Sedimentation practices on site would reduce the TSS concentrations from active construction by 60% (based on sedimentation basin data from Schueler, 1997).
- The same efficiency for sediment is applied to nutrient loads from construction sites.

Treatability

For erosion and sediment control, treatability is defined as the fraction of sites that are regulated by the program. The watershed manager can estimate this number by comparing the current site size regulated with construction start data for the watershed. The "treatability factor" reflects the fraction of land under construction that is affected by current regulations. Often, small construction sites are exempt from erosion and sediment control regulations. The other two discount factors reflect the imperfect application of erosion and sediment control regulations, either through non-compliance or improper installation and maintenance.

Discount Factors

The effectiveness of erosion and sediment control programs is limited by sites that are not regulated, and by improper design and installation of practices at the site level. These reductions in effectiveness are reflected in two discount factors (Table 6.12). The data in Table 6.12 are adapted from Patterson (1994). This study found that approximately 70% of practices were actually installed and that, of the practices that are installed, only about 65% (median) were installed properly. Some practices that performed particularly poorly were brush barriers and straw bales, with 0% and 50%, respectively, installed correctly. The values for properly maintained practices were even worse, with a median of approximately 60% proper maintenance. The data in Table 6.13 reflect expected discount factors for three levels of program implementation.

Table 6.13 Discount Factors for Erosion and Sediment Control

Discount Factor	Description	Value	
Installation/ Maintenance (D_2)	Fraction installed/ maintained properly	Few inspectors; no pre-construction meeting, poor practices allowed by codes and regulations.	0.3
		Inspectors can visit sites monthly; pre-construction for larger sites; regulations prohibit least effective practices.	0.6
		Inspectors visit sites weekly or on-site or certified inspectors are used; education programs for inspectors and contractors; practices that perform poorly are not permitted.	0.9

6.3 STREET SWEEPING

The WTM accounts for street sweeping by reducing the TSS, N and P concentrations in road runoff. The user inputs the acres of roadway swept for four types of streets: roadways (i.e., highways), residential streets, commercial streets, and industrial streets. For each street type, the load reduction from street sweeping is calculated by multiplying the load by the efficiency of street sweeping. The total load reduction from street sweeping (R_{SS}) is calculated as:

$$R_{SS} = L_{RW} \bullet E_{RW} + L_{IS} \bullet E_{IS} + L_{CS} \bullet E_{CS} + L_{RS} \bullet E_{RS}$$

Where:

$L_{RW,\ IS,\ CS,\ RS}$ = Load from Highway, Industrial, Commercial, and Residential Streets (lbs/year), respectively

$E_{RW},\ _{IS},\ _{CS},\ _{RS}$ = Street sweeping efficiency for each street type

The load from each street type swept is the product of the total load from the associated land use and the fraction of impervious area swept in that land use, such that:

$$L_{s\text{-}i} = L_i \bullet A_{s\text{-}i}/(A_i \bullet I_i)$$

Where:

$L_{s\text{-}i}$ = Load from the swept streets in land use i (lbs/year)

L_i = Total load from land use i (lbs/year)

$A_{s\text{-}i}$ = Street area swept in land use i (acres)

A_i = Area in land use i (acres)

I_i = Impervious fraction in land use i

The best case estimate of street sweeping efficiencies assumes weekly sweeping (Table 6.14). Sediment removals are derived from a modeling study conducted in Portland, Oregon (Claytor, 1999a). Other research suggests that the performance of street sweeping for phosphorus is roughly 80% of the performance for suspended solids (Kurahashi and Associates, 1997). The WTM assumes that the removal for nitrogen is the same as for phosphorus. This is a model simplification, since the performance for different constituents will vary depending on the performance of the sweeper at picking up various particle sizes.

Table 6.14 Washoff Reductions for Weekly Street Sweeping(%)		
Street Type/Sweeper Type	**TSS Removal**	**N and P Removal**
Residential Street		
• Mechanical	30%	24%
• Regenerative Air	64%	51%
• Vacuum Assisted	78%	62%
Major Road (applied to all but residential)		
• Mechanical	5%	4%
• Regenerative Air	22%	18%
• Vacuum Assisted	79%	63%
Sources: Claytor (1999a), Sutherland and Jelen (1997), Kurahashi and Associates (1997)		

Street Sanding Load Reductions

Loads from street sanding are seasonal, and composed mostly of large grained particles. Consequently, relatively infrequent sweeping and most types of sweepers can reduce these loads. In the WTM, it is assumed that 90% of street sanding loads can be reduced by monthly or greater street sweeping.

Treatability

For street sweeping, the treatability is the fraction of road swept. This factor is not explicitly calculated, but is reflected in the load reduction equations.

Discount Factors

Discount factors for street sweeping reflect the frequency of sweeping and technique (i.e., the amount of the street surface that is swept) (Table 6.15). The frequency factor (D_1) reduces effectiveness if sweeping is less frequent than once per week. Reducing sweeping frequency to monthly can reduce the efficiency to approximately 60% of the efficiency for weekly sweeping (Claytor, 1999a). This factor is not applied to reductions in sanding loads. The technique factor (D_2) accounts for reductions in efficiency caused when sweeper operators do not sweep the entire road surface. This typically happens when cars are parked on the streets, or when operators are improperly trained.

Table 6.15 Discount Factors for Street Sweeping			
Discount Factor	**Description**	**Value**	
Frequency (D_1)	Reflects monthly versus weekly sweeping frequency (not applied to road sanding reductions)	Weekly	1.0
		Monthly	0.6
Technique (D_2)	Reflects fraction of road surface swept	No parking restrictions; no operator training	0.5
		Parking restrictions; no operator training	0.75
		Parking restrictions; operator training	1.0

Example Calculation - Street Sweeping: Sediment

The phosphorus stormwater load from residential land is estimated to be 2,000 pounds per year. The subwatershed has approximately 2,400 acres of residential land, at approximately 23% impervious cover. The community plans to vacuum-sweep 100 acres of residential streets on a monthly basis (E = 62%; D_1 =0.6). The community has parking restrictions during sweeping, but does not have operator training (D_2 = 0.75) The phosphorus load reduction from street sweeping can be calculated as:

$$R_{SS} = 2{,}000 \text{ lbs} \bullet 62\% \bullet (100 \text{ acres})/(2{,}400 \text{ acres} \bullet 23\%) \bullet 0.6 \bullet 0.75$$
$$= 101 \text{ lbs/year}$$

6.4 IMPERVIOUS COVER DISCONNECTION

Impervious cover disconnection is an educational program that is also accounted for as a stormwater treatment practice (See Chapter 5). The educational program encourages individuals to implement rooftop or impervious cover disconnection, which is then accounted for as a stormwater retrofit. Disconnecting the runoff from residential rooftops can effectively reduce the total impervious cover in a drainage area. The WTM calculates the load reduction based on the ratio of rooftop area to total impervious cover in a subwatershed. The potential treatment area is as follows:

$$A_{RD} = A_H \bullet N/43{,}560$$

Where:

A_{RD}	=	Potential area of residential disconnection (acres)
A_H	=	Building footprint (square feet; model default is 2,000 sf)
N	=	Number of households
43,560	=	Conversion factor (sf/acre)

Treatability

When accounting for rooftop disconnections that have already occurred, the treatability is the fraction of buildings disconnected. If estimating load reduction from a program to be implemented in the future, however, the treatability factor is the fraction of buildings where rooftop disconnection can possibly be applied. For residential lots, it is assumed that assume that the lots must be greater than 1/8 acre for disconnection to be feasible.

Discount Factors

Discount factors for rooftop disconnection reflect the fraction of households where rooftop disconnection is applied Participation is estimated based on two discount factors: the fraction of land where the technique can be practically applied, the fraction of residents who are aware of the educational message, and the fraction of residents willing to participate in the program.

For residential rooftop disconnection, the model assumes that a broad education program is implemented, and that 25% of the individuals who hear the message are willing to implement the practice.

6.5 RIPARIAN BUFFERS

Little data are available to quantify pollutant removal of urban stream buffers for surface runoff. The data in Table 6.16 are removal rates for a vegetated filter strip, which functions via similar mechanisms. In a non-urban setting, where a significant amount of flow to streams is via subsurface pathways, much higher removal rates may be achieved.

Table 6.16 Approximate Pollutant Removal of Riparian Buffers (Hirschman et al., 2008; Uses Data for Sheetflow to Open Space)

Pollutant	Removal Rate (%)
TSS	0%
TN	0%
TP	0%
Runoff Volume	50% (C/D Soils)/ 75% (A/B Soils)

Treatability

The treatability factor represents the portion of the watershed land area that can be treated by the riparian buffer. The factor is based on data from Claytor and Schueler (1996), which suggests that a filter strip can treat an impervious area roughly equal to its own area. This fraction is expressed as:

$$T = 0.12 \bullet L \bullet W / (A \bullet I)$$

Where:

L = Buffer Length (miles) (length on each side; can be up to twice the total stream length)

W = Buffer Width (feet) (refers to width from the edge of stream to the edge of the buffer)

A = Watershed Area (acres)

I = Watershed Imperviousness

0.12 = Conversion Factor from Mile-Feet to Acres

The user is able to enter multiple stream buffers, to allow for different buffer widths along the stream length.

Discount Factors

The design factor for design and maintenance (D_1) accounts for differences in design requirements as well as ongoing maintenance of the buffer. In most buffer programs, the buffer is not maintained over time, largely because of alteration by adjacent land owners. One study of wetland buffers (Cooke, 1991) found that 100% of buffers were altered, and 43% were "severely altered." The values of D_2 in Table 6.17 assume that altering a buffer reduces its pollutant removal, and that an effective buffer ordinance can preserve most of the existing value of the buffer.

Table 6.17 Discount Factors for Riparian Buffers

Discount Factor	Description	Value or Default	
Treatability	Fraction of watershed area treated		
Design and Maintenance (D_1)	Reflects buffer disturbance by residents and design	The buffer ordinance has no restrictions on activities within the buffer, or no buffer ordinance in place.	0.4
		Buffer ordinance specifies acceptable and unacceptable activities, but has no signage or information requirements	0.6
		Buffer ordinance specifies acceptable and unacceptable activities in the buffer, and requires that signage and new information for homeowners.	0.9

6.6 CATCH BASIN CLEANING

The WTM estimates pollutant removal from catch basin cleaning as the product of the load from urban land and a pollutant removal efficiency. The model uses efficiencies for weekly cleaning, and then applies a discount factor to account for less frequent cleaning. Default efficiencies are as follows:

TSS Removal = 35%

Nutrient Removal = 15%

These data are derived from Pitt and Bisonnette (1985), who estimated removal for semi-annual cleaning as between 10 and 25% for TSS, and 5 and 10% for nutrients. Taking the average of these data, we estimated semi-annual pollutant removal as 17.5% for TSS and 7.5% for nutrients. A more recent study (Mineart and Singh, 1994) suggests that cleaning catch basins on a monthly basis can increase sediment recovery by between 50% and 200%, depending on the land use. The WTM default values above assume that monthly cleaning is twice as efficient (i.e., 100% more efficient) than semi-annual cleaning.

Treatability

The treatability factor represents the amount of land treated by catch basin cleaning, and is the fraction of impervious cover in the subwatershed treated by catch basin cleaning. This is expressed with the equation:

T = Impervious Cover Captured/ Watershed Impervious Cover

Discount Factors

Two discount factors are applied to catch basin cleaning efficiencies (Table 6.18), including frequency (D_1), and disposal (D_2). The frequency discount (D_1) applies a 50% discount factor for biannual cleaning, bringing the model default values in line with Pitt and Bisonnette's (1985) data for biannual cleaning (e.g., from 35 to 17.5%). In some communities, regulations prohibit landfilling of materials recovered from catch basins. With nowhere to place recovered materials, communities are forced to stop cleaning catch basins. The disposal factor (D_2) reflects the pollutant load reduction resulting when materials dredged from the catch basin cannot be landfilled. In this case, the sediment needs to be shipped to an approved hazardous waste landfill at higher cost, thus reducing clean-out frequency.

Table 6.18 Discount Factors for Catch Basin Cleaning		
Discount Factor	**Description**	**Value**
Frequency (D_1)	Reflects cleaning frequency	Biannual: 0.5 Monthly: 1.0
Disposal (D_2)	Applied when regulations prohibit landfilling of recovered sediment	Landfilling Prohibited: 0.5
		Landfilling Permitted: 1.0

Example Calculation - Catch Basin Cleaning: Sediment

A 2,500-acre, 22% impervious subwatershed is currently implementing a catch basin cleaning program. The urban stormwater load of sediment, after the removal from pollution prevention practices, is 800,000 lbs/year. Cleaned catch basins will capture runoff from 100 acres of impervious surfaces. The catch basins will be cleaned monthly.

D_1 = 1.0 and disposal is not a problem within this subwatershed (D_2 = 1.0).

Calculating T:

$$T = (100)/(2{,}500 \cdot 0.22)$$
$$= 0.18$$

Using model defaults, the removal from catch basin cleaning is calculated as:

$$R = 800{,}000 \text{ lbs/year} \cdot 35\% \text{ (removal) } 0.18 \cdot 1.0 \cdot 1.0$$
$$= 50{,}400 \text{ lbs/year}$$

6.7 MARINA PUMPOUT

The most optimistic pollutant removal from marina pumpout stations is the entire marina load calculated in Chapter 4. Two factors decrease this removal. First, the pumpout stations may not be sufficient to serve every boat. Second, every boat owner may not use them. The treatability factor (T) accounts for the number of boats a marina pumpout station can service.

Treatability

It is assumed that 160 boats can be served by one pump-out station, or:

T = 160 x Number of Pumpouts/ Number of berths

This estimate is based on the following assumptions:

1. Typical boat use includes of two people per boat, with waste production of eight gallons per capita per day, and is in use 50% of the days in the season (therefore, each boat produces an average of eight gallons of waste per day-these assumptions are documented in Chapter 4).
2. A typical tank holding size is 40 gallons.
3. Combining the first two assumptions, each boat needs to be serviced once every five days.
4. A typical pumpout station can service 32 boats in a day (Raritan, 1999).
5. Combining assumptions three and four (32 boats per day times five days), a pumpout station can service 160 boats.

Discount Factors

Even if a pumpout station is available, not everyone will use it, either because the boat owner is unaware, plans poorly, or does not have time to wait at the station. Little data is available to assess how often this happens. The default value for the participation factor (D_1) is 0.9, which assumes that 90% of boat owners will use the station.

Example Calculation - Marina Pumpout: Bacteria
The current fecal coliform load from boats at a marina with 300 berths is 136,000 billion per year. The marina owner is willing to install one pumpout station. Using model defaults, the load reduction is: R = 136,000•(14•160/300)•0.9 = 65,000 billion per year.

6.8 URBAN DOWNSIZING

With shifting and sometimes decreasing urban populations, particularly in many industrial cities, abandoned urban land represents a social, economic, and environmental problem. Consequently, some cities have converted abandoned or underused urban land to parks or open space. Although pollutant load and runoff reductions are typically not the driving force behind these land conversions, the WTM allows the user to convert land from an urban land category to a different category, such as forest. The benefit is simply the conversion in land use (e.g., from parking lot to forest cover).

Example Calculation - Land Reclamation: Sediment
Within a subwatershed, approximately 100 acres of vacant lots export sediment at 750 lbs/acre/year, contributing a total of 75,000 lbs/year of sediment. A land reclamation program will restore 50% of these lots by planting grasses, making the load more similar to a mixture of a rural and forest land use (roughly 200 lbs/acre/year). The total load reduction is:
$R = 100 \text{ acres} \bullet (750 \text{lbs/acre} - 200 \text{ lbs/acre}) \bullet 0.5$
$= 27{,}500 \text{ lbs/year}$

6.9 IMPERVIOUS COVER REDUCTION

Better site design techniques, such as narrowing street widths and reducing the number and size of parking spaces, can reduce the total impervious cover in the landscape (CWP, 1998). This reduction in impervious cover reduces the volume of surface runoff and, in the WTM, results in a corresponding load reduction. Better site design techniques can be incorporated into redevelopment projects, or into new development. For redevelopment projects, the load reduction (R_{BSD}) is simply the fraction of impervious cover removed from the landscape via redevelopment projects that reduce impervious cover, and is calculated as:

$$R_{BSD} = L_U \bullet A_{RD} \bullet IR/(A \bullet I)$$

Where:

L_U = Load from roadways and residential, commercial, and industrial land.

A_{RD} = Area redeveloped (acres)

IR = Impervious cover reduction for redevelopment (% of total site area)

A = Watershed area (acres)

I = Impervious cover in the subwatershed (%)

Again, the treatability is calculated as the amount of eligible land, and only one discount factor is applied. The implementation factor accounts for the fraction of projects implemented during the timeframe of the watershed analysis.

Example Calculation - Impervious Cover Reduction: Nitrogen
A community plans to redevelop approximately 200 acres within a 5,000 acre, 50% impervious watershed. The current urban stormwater nitrogen load in the watershed is 51,000 lbs/year. On redevelopment projects, the site impervious cover will be reduced by approximately 5%. 75% of these projects are expected to be implemented, so that the load reduction will be: R = 51,000•(200•5%)/(5,000•50%)•0.75 = 153 lbs/year

6.10 Illicit Connection Removal

Optimistically, an illicit connection program would remove the entire illicit connection load as calculated in Chapter 4. This reduction is then multiplied by two discount factors: a survey factor (D_1) which represents the fraction of the sewer system where the illicit connection survey is conducted, and an implementation factor (D_2), which represents the fraction of illicit connections found that will be removed.

Example Calculation- Illicit Connection Removal: Bacteria
The current fecal coliform load from illicit connections in a subwatershed is 750,000 billion bacteria per year. The community will survey half of the system, and repair all connections. Thus, the load reduction will be: R = 750,000 billion/year•0.5•1.0 = 375,000 billion/year

6.11 CSO REPAIR/ABATEMENT

There are several options to repair or abate CSOs, including separation of the sewer system, providing upland storage, or other options that reduce the flow to the system by reducing total surface runoff. The WTM is not programmed to determine the relative reduction in CSO loads resulting from specific management options. A community would need to conduct fairly complex modeling of the CSO system before being able to predict these results with any confidence. The input to the WTM is simply a target number of CSO events per year after implementation of watershed measures. The load reduction is then:

$$R_{CR} = L_{CSO} \bullet (1 - N_A/N_B)$$

Where:

R_{CR} = Load reduction from CSO repair

L_{CSO} = Load from CSOs before repairs (see Chapter 7).

N_A = Number of CSOs after repairs

N_B = Number of CSOs before repairs

This reduction is then multiplied by an implementation factor, which is the fraction of the repairs implemented.

Example Calculation - CSO Repair: Bacteria

In a subwatershed, the load from CSOs is approximately 10^6 billion bacteria per year. The target reduction is 50% removal. The community has the resources to achieve this goal. Thus, the removal will be calculated as:

$$R = 10^6 \text{ billion/year} \bullet 50\%$$

$$= 5.0 \times 10^5 \text{ billion/year}$$

6.12 SSO Repair/Abatement

Reduction of SSO loads is also difficult to predict, and may include practices such as repairing existing blockages, increasing the volume of the sanitary sewer, or lining pipes to prevent infiltration from adjacent soils. In the WTM, the user must input a target reduction as a percentage of the existing SSO load. This load reduction is then multiplied by an implementation factor, which represents the fraction of the repairs implemented. The WTM partitions this load reduction using a 50% factor. That is, 50% of the load reduction is subtracted from the annual storm load, and 50% from the annual non-storm load.

Example Calculation - SSO Repair: Bacteria
The load from SSOs is approximately 10,000 billion per year. The ultimate target reduction is 90% removal. The community has funding to complete 60% of the repairs necessary to achieve this goal, so: R = 10,000 billion/year • 90% •60% = 5,400 billion/year Of this load, approximately 2,700 billion/year would be subtracted from the annual storm load.

6.13 OSDS Inspection/Repair

This practice describes a program where the local government inspects OSDSs, and asks residents to repair failing systems. The WTM accounts for OSDS inspection and repair programs by moving OSDSs from the failing category to the functioning category by changing the concentration of OSDS effluent. This is accomplished by adjusting the failure rates described in Chapter 4. Assuming that OSDS education (See Section 6.1) has also occurred, the failure rates after septic repair are as follows:

$$F_{rep} = F_{ed} \bullet (1-Rf)$$

Where:

F_{rep} = Failure rate after repairs (%)

F_{ed} = Failure rate after education (if no education, equals initial failure rate)

Rf = Fraction repairing (a product of two discount factors described below)

Discount Factors

It may not be realistic to achieve this removal, either because the jurisdiction does not inspect all systems, or because citizens are unwilling or unable to replace failing systems. The WTM uses two discount factors to account for these situations (Table 6.19). The survey factor (D_1) is the fraction of systems that will be inspected and is input by the user. The participation factor (D_2) is the fraction of citizens willing to repair failing systems. Since failing OSDSs are inconvenient, homeowners are likely to replace them, particularly if an incentive (e.g., a cost share to repair a system, or a fine for not repairing one) is offered. Model default values are 60% participation without an incentive and 90% participation with an incentive.

Table 6.19 Discount Factors for OSDS Repairs

Discount Factor	Description	Value
Survey (D_1)	Fraction of OSDSs inspected during the watershed analysis	User Input
Participation (D_2)	Fraction of citizens willing to repair failing OSDSs	Incentive Offered 0.6 No Incentive Offered 0.9

6.14 OSDS Upgrade

In an OSDS upgrade program, conventional and failed OSDSs are replaced with more efficient technologies. This program has two effects: reducing the failure rate and shifting from conventional systems to more efficient technologies.

Failure Rate

The change in the failure rate depends on the number of upgraded systems that were failing, so that the revised failure rate is calculated as follows:

$$F_{UP} = F_{REP} \bullet (1 - U_f \bullet U_{fail})$$

Where:

F_{UP} = Failure rate after OSDS upgrade

F_{REP} = Failure rate after repairs and education

U_f = Fraction of systems upgraded (product of D_1 and D_2 below)

U_{fail} = Fraction of upgraded systems failing

Shift in Systems

The user is asked what system type existing systems are upgraded to, and this information is used to shift the fraction of total systems in each category as follows:

$$Con_U = Con_0 - F_{up}$$

Where:

Con_U = Initial Fraction of OSDS that are conventional septic systems

F_{up} = Fraction of systems upgraded

$$NS_U = NS_0 + F_{up}$$

Where:

NS_U = Fraction of systems in the "new system" category

NS_0 = Initial Fraction of Systems in the "new system" category

F_{up} = Fraction of systems upgraded

Discount Factors

The discount factors for OSDS upgrades are the same as those applied to OSDS repairs, except that the model default values for the participation factor (D_2) are lower because of the additional initial expense and/or the possible maintenance burden associated with installing an upgraded system. Model defaults for D_2 are:

No Incentive Offered = 0.1

Incentive Offered = 0.5

6.15 OSDS RETIREMENT

In this practice, areas served by OSDS are converted to municipal wastewater treatment. This process is similar to the OSDS upgrade or repair practice, with two differences: 1) the total number of OSDSs is reduced, and converted to a WWTP load; and 2) the number of systems adjacent to the waterway is considered.

Effect on Failure Rates

The failure rate is adjusted by removing failing systems from the total number of OSDSs, so that:

$F_{Ret} = (F_{up} - Ret_f \bullet Ret_{fail})/(1 - Ret_f)$

Where:

F_{Ret} = Failure rate after OSDS retirement

F_{up} = Failure rate after upgrades, repairs and education

Ret_f = Fraction retired

Ret_{fail} = Failure rate among retired systems

Note: if 100% of the systems are retired, the failure rate is 0%.

Effect on Number of Systems Adjacent to the Waterway

Systems within 100' of the waterway have an increased pollutant load delivery, and often OSDS retirement is concentrated in these areas. The fraction of systems near the waterway are adjusted so that:

$WW_{RET} = (WW_0 - Ret_f \bullet Ret_{ww})/ (1 - Ret_f)$

Where:

WW_{RET} = Fraction of systems adjacent to waterways after retirement

WW_0 = Fraction of systems initially adjacent to the waterway

Ret_f = Fraction retired

Ret_{ww} = Fraction of retired systems adjacent to the waterway

Effect on Total Load to OSDSs

Since this practice actually reduces the number of households served by OSDSs, the total load delivered to OSDSs is adjusted so that:

$L_{SS-RET} = L_{SS-0} \bullet (1 - Ret_f)$

Where:

L_{SS-RET} = Load to OSDSs after retirement (pounds or billions)

L_{SS-0} = Initial load to OSDSs (pounds or billions)

Ret_f = Fraction retired

Resulting Load From Wastewater Treatment Plants (WWTPs)

Since households served by retired OSDSs will be served by a WWTP, the resulting additional load is:

$$L_{WWTP} = (L_{SS\text{-}RET} - L_{SS\text{-}0}) \bullet (1 - E_{WWTP}/100)$$

Where:

L_{WWTP} = Load from the wastewater treatment plant (pounds or billions)

$L_{SS\text{-}RET}$ = Load to OSDSs after retirement (pounds or billions)

$L_{SS\text{-}0}$ = Initial load to OSDSs (pounds or billions)

E_{WWTP} = Treatment plant efficiency (%); user entered

6.16 STREAM CHANNEL RESTORATION

Stream channel restoration can include a wide range of practices, with varying effectiveness depending on the region, type of stream, and specific practices implemented. The WTM uses a very simplified approach that relies on user input to assess the effectiveness of stream channel restoration in a "Stream Restoration Worksheet." The worksheet simply calculates the benefits of each stream restoration project by the following equation:

$$R_{SR} = U_{SR} \bullet L_{SR}$$

Where:

R_{SR} = Pollutant reduction from stream restoration (lbs)

U_{SR} = Unit pollutant reduction for each practice (lb/ft)

L_{SR} = Stream restoration practice length (ft)

6.17 POINT SOURCE REDUCTION

This practice relies on user input, and reflects a reduction in load based on increased performance at NPDES point source dischargers or other point sources in the watershed.

Chapter 7. Load Reduction of Practices in Series

Chapters 5 and 6 describe methods to calculate the effectiveness of various stormwater treatment practices and programs. In many cases, the same runoff will receive the treatment benefits of more than one practice. For example, street sweeping may reduce surface runoff pollutant loads from a street, and then this same runoff may be directed to a structural stormwater treatment practice. Thus, the treatment practice does not act on the uncontrolled load, but on this load minus the load removed by street sweeping. The WTM accounts for this effect for four stormwater treatment practices by assuming that load reductions occurring before runoff reaches these practices can be achieved using one or more of seven pollution prevention practices (Table 7.1).

Table 7.1 Practices Treated as "In-Series" in the WTM

Treatment Practice	Pollution Prevention Practices Accounted For
Stormwater Treatment Practices (Existing)	▪ Turf Management and Turf Education ▪ Pet Waste Education ▪ Street Sweeping ▪ Catch Basin Cleanouts ▪ Urban Downsizing ▪ Redevelopment with Improvements
Stormwater Retrofits	▪ Turf Management and Turf Education
Riparian Buffers	▪ Turf Management and Turf Education ▪ Pet Waste Education ▪ Street Sweeping ▪ Urban Downsizing ▪ Redevelopment with Improvements

Ideally, the watershed manager would be able to forecast the future location of every stormwater treatment practice, and the impact of every education program. Since it is difficult to forecast this information, the model makes two simplifying assumptions:

- Within a subwatershed, stormwater treatment practices do not act in series. Rather, it is assumed that each practice acts as a "stand-alone" practice.
- Pollution prevention measures are distributed evenly throughout the subwatershed, so that the load reduced by a pollutant prevention practice can be subtracted from the total subwatershed stormwater load.

The resulting equation is:

L_T = $(L_{SW}-R_{PP})$

Where:

L_T = Load directed to a treatment practice

L_{SW} = Stormwater load within the subwatershed

R_{PP} = Load reduced by pollution prevention measures

Example Calculation
Assume that, within a subwatershed, the uncontrolled phosphorous load from stormwater runoff is 3,000 lbs/year. Impervious cover reduction has reduced this load by 120 pounds per year, and a lawn care education program has reduced it by another 150 pounds per year. The community will apply a retrofit program with an average efficiency of 30% Treatability, and the following discount factors: D_1 = 0.6 D_2 = 0.9 D_3 = 0.8 The load to be treated by the retrofits is calculated as: L_T = (3,000-120-150) lbs/year = 2,730 lbs/year Therefore, the total treatment by retrofits will be: R = (2,730)•(30%)•(0.3)•(0.6)•(0.9)•(0.8) = 106 pounds per year

Chapter 8. Loads from Future Development

In addition to reducing current pollutant loads to a target level, the watershed manager also needs to maintain that target in the face of new development. The WTM uses a simple methodology to predict future loads, and to account for control measures. The watershed manager only needs to enter the future area of various land uses, some information on septic systems, and a treatment option. The model first predicts the increase in the load from primary sources resulting from development, and then predicts the loads from five secondary sources: septic systems, active construction, road sanding, lawn subsurface flow, and channel erosion. This is a simplified methodology and does not account for the new loads from many secondary sources, such as illicit connections.

8.1 PRIMARY LOADS

Typically, converting land from forest or rural land uses to urban or residential uses results in an additional primary load (see Chapter 4 for a description of how to compute these loads). The WTM calculates the net primary load from new development (L) as the difference between the load from the new land use and the load from the original land use, such that:

$$L = L_{ND} - L_{CL}$$

Where:

L_{ND} = Load from new development

L_{CL} = Original load from converted rural and forest land

Methodologies for calculating these primary loads are the same as those described in Chapter 3. For the new land use, the watershed manager needs to enter the area converted to this land use, and an associated impervious cover value.

8.2 SECONDARY LOADS

Five secondary loads are added along with new development: septic systems, active construction, road sanding, lawn subsurface flow, and channel erosion (Table 8.2). With the exception of channel erosion, these loads are calculated using methodologies very similar to those described in Chapter 4 (Loads from Secondary Sources). For all of these loads, the base assumption is that the programs in place are the same as those proposed for all existing development with future practices by the watershed manager. For example, if a lawn care education program is proposed, the load from lawn subsurface flow will be reduced appropriately.

Table 8.2 Secondary Loads from New Development		
Secondary Load[1]	**Methodology**	**User Input(s)**
Septic Systems (NS)	Sum of the load from failing systems and functioning systems	▪ Number of households on septic ▪ Failure rate ▪ May enter efficiencies
Active Construction (S)	Average annual acres under construction multiplied by a loading rate based on future management practices; value reported is the difference between the future load and the load with future management practices	▪ None
Road Sanding (S)	Uses the same methodology as for current conditions; includes street sweeping	▪ Acres of new roads (Optional) ▪ Fraction swept
Lawn Subsurface Flow (NS)	Lawn acres multiplied by the load from existing lawns, including deductions from lawncare education	▪ Lawn acres (Optional)
Channel Erosion (S)	Derived based on assumptions about the rate at which stream systems enlarge in response to new development	▪ None

[1]S = Storm Load (Occurs during Storm Events); NS: Non-Storm (Occurs during Baseflow)

On-Site Disposal Systems (OSDSs)

The OSDS load is the sum of the load from working systems and the load from failing systems. The watershed manager must input the number of new septic system users. Model defaults are to maintain the fraction of systems failing, and septic system efficiencies from current conditions, although the watershed manager may also enter these values. The load from OSDSs, in pounds per year (L_{OSDS}), is calculated as:

$$L_{OSDS} = N \bullet P \bullet W \bullet C \bullet [f+(1-f)(1-E)] \bullet 3.04 \times 10^{-3}$$

Where:

N = Number of households

P = Individuals per household (model default is 2.7)

W = Wastewater per capita (gpcd); (model default is 70)

C = Concentration (mg/L; MPN/100mL for bacteria)

f = Failure rate

E = Working system efficiency

3.04×10^{-3} = Conversion factor (*1.38×10^{-5}* for bacteria to yield billions/year)

Example Calculation for Septic Systems

The watershed manager estimates that 15 new households will be on septic systems, with a 20% ultimate failure rate. The septic systems will be 67% efficient at reducing nitrogen. The total nitrogen load, using other model defaults, will be estimated as:

$$L_{OSDS} = 15 \bullet 2.7 \text{ people/house} \bullet 70 \text{ gpcd} \bullet 60 \text{mg/L} \bullet [0.2+(1-0.2)(1-0.67)] \bullet 3.04 \times 10^{-3}$$

$$= 381 \text{ lbs/year}$$

Active Construction

The annual load from active construction is the product of a loading rate and the average acreage in active construction during the planning horizon. The loading rate is determined based on the uncontrolled load, minus the load reduction from erosion and sediment control.The increased sediment load is multiplied by nutrient enrichment factors. (See Chapter 4 for a more detailed discussion of these factors).

Example Calculation
A subwatershed currently has five acres of land in construction. Based on zoning and population forecasts, the watershed manager predicts 150 acres of new development over the next 10 years. The estimated uncontrolled load from the initial five acres of construction is 6,600 lbs/year. The proposed ESC Program is estimated to achieve 55% sediment removal. The net additional land under construction in a typical year is: 150acres/10 years - 5 acres = 10 acres/year The average annual loading rate is: (6,600 lbs/year)•(1-55%))/5 acres = 590 lbs/acre/year Therefore, the net additional load from future construction is: (590 lbs/acre/year)•(10 acres) =5,900 lbs/year

Road Sanding

The WTM calculates the load from road sanding using a similar methodology to the one used for active construction. The load is the product of an area (i.e., the additional area of new roads built) and a loading rate (i.e., the anticipated annual loading rate from road sanding, including street sweeping). The watershed manager may input the total area of new roads and parking lots. The model default of 35% of total new impervious cover is also an option. The loading rate is calculated based on the current loading rate from road sanding, assuming the implementation of sweeping programs proposed by the watershed manager.

Example Calculation

Fifty acres of new roads are projected to be built over the planning horizon. 70% of these new surfaces will be swept. Currently, there are 525 acres of roads in the subwatershed. The current uncontrolled sediment load from road sanding is 3,700 lbs/year. Sweeping 50% of these roads and parking lots reduces the annual load by 1,650 lbs/year. Using these data, the loading rate can be calculated in three steps:

Uncontrolled Loading Rate = (3,700 lbs/year)/525 acres
= 7.0 lbs/acre/year

Load Reduced by Street Sweeping = 1,650 lbs/year/(525 acres)•[70%(new sweeping)/50% (old sweeping)]
= 4.4 lbs/acre/year

Total New Load = (7.0-4.4) lbs/acre/year•50 acres
= 130 lbs/year

Lawn Subsurface Flow

The WTM also calculates the subsurface nitrogen load from lawns as a product of an area and a loading rate. The area is the area of new lawns created, and the loading rate is the loading rate of lawn subsurface flow, including the load reduction from lawn care education programs. The WTM estimates the area of new lawns using the same assumptions described in Chapter 6 (i.e., 80% of the pervious surfaces from residential development are managed as lawn).

Channel Erosion

Channel erosion is a complicated process, and, unlike the other four secondary sources described in this chapter, cannot be predicted based on an areal loading rate. The methodology used by the WTM assumes that the change in hydrology caused by the addition of impervious cover to the urban landscape causes a predictable enlargement in the stream's cross-sectional area. The model uses the ultimate channel enlargement ratio, (RE) as a predictive tool. This term refers to the area a stream channel will ultimately reach, relative to the pre-developed channel cross-section. For example, if a channel is expected to reach an ultimate average channel cross-sectional area of 40 square feet, and the stream had an area of 10 square feet before development occurred, the value of RE would be 4.0.

Data collected from sites in Maryland, Texas, and Vermont suggest that the value of RE can be correlated with subwatershed impervious cover (Figure 8.1; MacRae and DeAndrea, 1999; Brown and Claytor, 2000). This relationship has significant variability, and was developed primarily for alluvial (i.e., not rock bed) stream systems. As a planning tool, however, it may be the best available predictor of future stream channel erosion, in the absence of detailed past information and extensive local knowledge about the system.

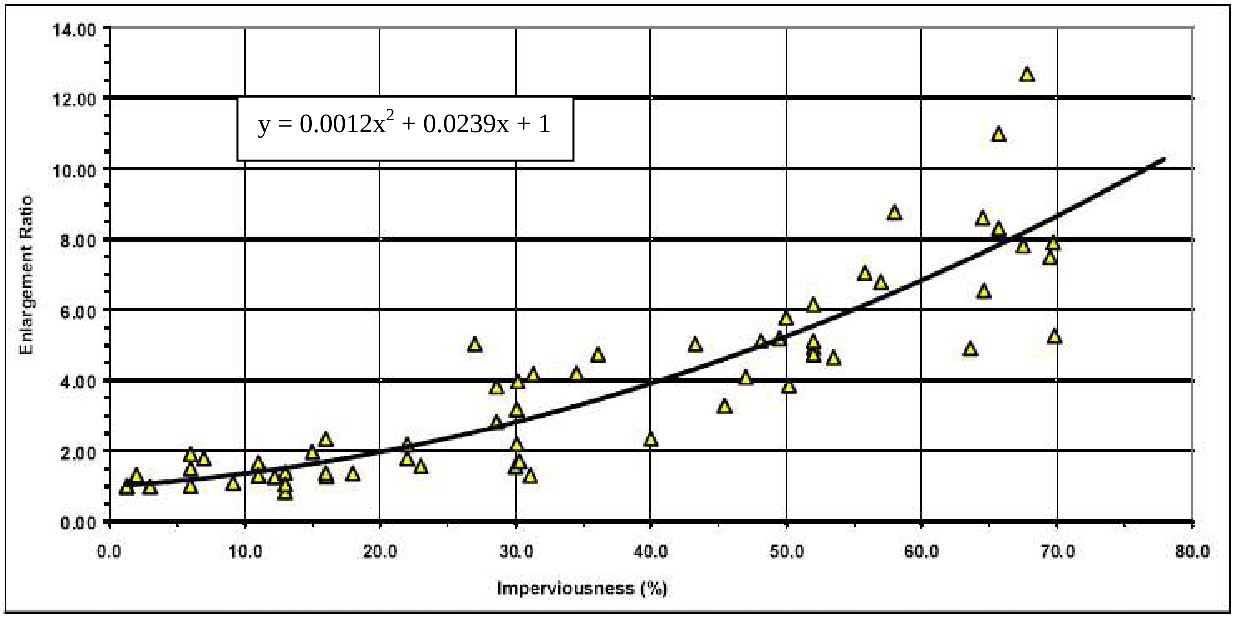

Figure 8.1 Channel Enlargement Ratio Versus Impervious Cover

The second assumption incorporated into this method is that an increase in the ultimate enlargement factor causes a corresponding increase in the erosion rate. Also, the model uses an RE value of 1.0 to represent a base erosion rate, such as the rate associated with forest, or another pre-development condition. The resulting equation is:

$$L_F = (L_C - L_B) \cdot [(RE_F - 1)/(RE_C - 1) - 1]$$

Where:

L_F = Additional sediment load from added impervious surfaces (lbs/year)

Lc = Current sediment load (lbs/year)

Lb = Load from a base condition (e.g., forest) (lbs/year)

RE_F = Enlargement ratio for anticipated future impervious cover

RE_C = Enlargement ratio for current impervious cover

Example Calculation
Growth in a subwatershed is anticipated to increase impervious cover from 20% to 25%. The initial estimated total channel erosion load in the subwatershed is 800,000 lbs/year. The base channel erosion rate, from a forested condition, is 250,000 lbs/year. Using Figure 8.1, the value of RE for each case is:
RE_F (25%) = 2.3
RE_C (20%) = 2.0
The net additional load would then be calculated as:
L_F = (800,000-250,000)•[(2.3-1)/(2.0-1)-1.0] = 165,000 lbs/year.

Finally, it is assumed that the enrichment factors used to associate nutrients with sediment (See Chapter 4) are retained in the future. Thus, an increase in sediment results in a corresponding increase in nutrients from channel erosion.

8.3 MANAGEMENT OPTIONS TO CONTROL FUTURE LOADS

A community may regulate several aspects of new development, using features such as stream buffers, various specific types of stormwater ordinances, and open space ordinances. Each of these decisions is important in terms of both pollutant removal and overall resource conservation. In order to ease the process, the WTM makes assumptions that lump these decisions into two major questions: 1) what type of stormwater management program will be instituted? and 2) will channel protection be required for new development?

For the first question, the WTM offers five broad options:

Option 1. Require Best Management Practices for Stormwater Quality

Option 2. Institute More Rigorous Design Standards for Stormwater Practices

Option 3. Require On-Site Load Calculation

Option 4. Option 3 with a Stormwater Offset Fee

Option 5. Option 3 with High Offset Ratios

These options represent five basic approaches to stormwater management and can be calculated as a base pollutant removal, multiplied by treatability and discount factors. The discount factors are the same ones used for stormwater management (see Chapter 5), including a capture factor (D_1), a design factor (D_2), and a maintenance factor (D_3).

Option 1. Require Best Management Practices for Stormwater Quality

In this option, the pollutant removal from structural practices is calculated by multiplying the load from urban primary sources (i.e., the sum of additional residential, roadway, commercial, and industrial loads) by an assumed practice pollutant removal. These data are then multiplied by the four discount factors. The average removal rate reflects practices currently in place in the subwatershed, and the discount factors reflect the existing program.

Example Calculation - Phosphorus

A community currently has a stormwater program in place, which requires stormwater management practices, mostly dry ponds, but has no maintenance or design criteria. Practices must capture half an inch per impervious acre (the 60% storm event), and 70% of all development will be regulated. The new load from urban land uses in the subwatershed is 500 lbs/year of phosphorus. Assume that:

$E = 25\%$ $T = 70\%$

$D_1 = 0.6$ $D_2 = 0.6$

$D_3 = 0.5$

The reduction can therefore be calculated as:

$$R = 500 \text{ lbs/year} \cdot 25\% \cdot 70\% \cdot 0.6 \cdot 0.6 \cdot 0.5$$
$$= 16 \text{ lbs/year}$$

Option 2. Institute More Rigorous Design Standards for Stormwater Practices

Option 2 is very similar to Option 1, except that more advanced practices are implemented, and the community has programs in place to maintain and inspect practices. Thus, the typical practice efficiency and the discount factors are both higher.

Example Calculation - Phosphorus

The watershed manager is considering an option for future development where the community would improve its stormwater program by requiring sophisticated stormwater practices, regulating smaller sites, instituting clear design criteria, and hiring staff to ensure proper maintenance. Practices must capture 1" per impervious acre (the 90% storm event), and 80% of all development will be regulated. As in the previous example, the new load from urban land uses in the subwatershed is 500 lbs/year of phosphorus.

$E = 60\%$ $T = 80\%$

$D_1 = 0.9$ $D_2 = 1.0$

$D_3 = 0.9$

The reduction can therefore be calculated as:

$R = 500 \text{ lbs/year} \cdot 60\% \cdot 80\% \cdot 0.9 \cdot 1.0 \cdot 0.9$

$= 194 \text{ lbs/year}$

Option 3. Require On-Site Load Calculation

In this option, the site designer is required to reduce the *net stormwater load* by a target percentage. For example, a designer may be required to reduce the load to "pre-development" levels, or reduce the net stormwater load by 100%. Typically, these programs do not take into account discount factors resulting from poor maintenance, and cannot adjust for sites that are not regulated. In the WTM, the watershed manager needs to enter the target efficiency, and multiply this efficiency by the four discount factors. Discount factors should reflect the programs in place.

Example Calculation - Phosphorus

The community is implementing a strategy where designers are required to demonstrate that the net stormwater load is reduced by 100%, based on practice efficiencies. Under current regulations, 70% of new development will be regulated, and 1" rainfall water quality storage is required (the 90% storm event). Design standards have not been updated in 10 years, and no maintenance standards are in place. The net stormwater load is 400 lbs/year.

$E = 100\%$ $\quad T = 70\%$

$D_1 = 0.9$ $\quad D_2 = 0.6$

$D_3 = 0.5$

The reduction is therefore:

$$R = 400 \text{ lbs/year} \cdot 100\% \cdot 70\% \cdot 0.9 \cdot 0.6 \cdot 0.5$$

$$= 76 \text{ lbs/year}$$

Channel Protection

Stream channel protection is treated separately from other stormwater management practices, and applies only to the increased load from stream channel erosion. The WTM calculates the effectiveness of erosion control on new development as the load from uncontrolled channel erosion, based on the increase in impervious cover, times the fraction of that new impervious cover that is treated by practices that either control small (e.g., one-year) storm events, or served by infiltration practices.

Example Calculation
Within a subwatershed, the expected additional channel erosion resulting from new development without management is 150,000 lbs/year. The community will implement channel protection controls on 50% of new sites ($D_1 = 0.5$), and 80% of unstable stream banks have been stabilized. The resulting reduction is: R = 150,000 lbs/year•80%•0.5 = 60,000 lbs/year

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