EXHIBIT 18

TREATMENT EVALUATION CRITERIA – REFERENCE:
TAPE AND CTAPE DOCUMENT

Stormwater Treatment Technologies Approved through TAPE and CTAPE

Pretreatment

Pretreatment is generally applied to:

- Project sites using infiltration treatment
- Treatment systems where needed to assure and extend performance of the downstream basic or enhanced treatment facility

Intended to achieve **50% removal of fine** (50 micron-mean size) and 80% removal of coarse (125-micron-mean size) total suspended solids for influent concentrations greater than 100 mg/L, but less than 200 mg/L.

For influent concentrations less than 100 mg/L, the facilities are intended to achieve effluent goals of 50 mg/L of fine and 20 mg/L of coarse total suspended solids.

Basic Treatment

Intended to achieve a goal of 80% removal of total suspended solids for an influent concentration range of 100 mg/L to 200 mg/L.

For influent concentration less than 100 mg/L the effluent goal is 20 mg/L total suspended solids.

For influent concentrations greater than 200 mg/L a higher treatment goal is intended. Technologies listed in this section with a GULD designation are also approved for Pre-treatment in accordance with Volume V Section 6.2 of the Stormwater Management Manual for Western Washington (SWMMWW) and Section 5.2.1 of the Stormwater Management Manual for Eastern Washington (SWMMEW).

Enhanced Treatment

Intended to achieve a higher level of treatment than basic treatment. Enhanced treatment is targeted at removing dissolved metals.

Phosphorous Treatment

Intended to achieve a goal of 50% total phosphorus removal for an influent concentration range of 0.1 to 0.5 mg/L as well as achieving basic treatment.

E-3 Soil Amendments to Enhance Phosphorus Sorption

Minnesota Stormwater Manual

Principal mechanisms for phosphorus (P) removal in bioretention are the filtration of particulate-bound P and chemical sorption of dissolved P (see Hunt et al., 2012). Most stormwater control measures (SCMs) capture particulate P by settling or filtration, but leave dissolved P (typically phosphates) untreated. This untreated P accounts on average for 45 percent of total phosphorus in stormwater runoff and can be up to 95 percent of the total phosphorus, depending on the storm event (Erickson et al., 2012). Dissolved phosphorus is bioavailable and represents a significant concern for surface water quality.

Phosphorus sorbing materials contain a metal cation (typically di or trivalent) that reacts with dissolved phosphorus to create an insoluble compound by adsorption or precipitation or both (Buda et al., 2012). Soil components and amendments that have been shown to be effective in increasing chemical sorption of dissolved P include

- iron filings (Erickson et al., 2012);
- steel wool (Erickson et al., 2007);
- native iron rich soils such as those in the Piedmont of the Mid and Southern Atlantic USA (Hunt et al 2012), or Krasnozem soil in Australia (Lucas and Greenway, 2011);
- Drinking Water Treatment Residuals (WTRs), which are a by-product of drinking water treatment and a source of aluminum and iron hydroxides (O’Neill and Davis, 2012a and 2012b, Hinman and Wulkan, 2012; Lucas and Greenway, 2011; Lucas and Greenway, 2010); and
- sorptive media (Imbrium) (Balch et al 2013)

Caution: Acceptable amendments include the following.

- 5 percent by volume elemental iron filings above IWS or elevated underdrain;
- minimum 5 percent by volume sorptive media above IWS or elevated underdrain;
- minimum 5 percent by weight water treatment residuals (WTR) to a depth of at least 10 centimeters; and
- other P sorptive amendments with supporting third party research results showing P reduction for at least 20 year lifespan, P credit commensurate with research results

Buda et al. (2012) provide a literature review of P-sorption amendments. Characteristics of ideal P-sorption amendments include low cost, high availability, low toxicity for soil and water resources, potential for reuse as a soil amendment once fully saturated, and no toxicity to plants, wildlife, or children. It is also crucial that soil amendments not negatively impact soil infiltration rate and the ability to grow vigorous plants. Some P sorptive amendments, such as water treatment residuals (WTRs), are waste products turned into a resource to reduce P in bioretention (or agricultural) soils. Results from much of the research to date on use of P-sorbing materials to reduce nutrients in stormwater effluent are promising, but much remains to be learned about lifespan and long term effects of P-sorbing materials on soils and plants.

Benefits

P sorptive amendments have been shown to provide effective P retention for the expected lifetime of bioretention facilities (e.g. Lucas and Greenway, 2011; O'Neill and Davis, 2012a and 2012b). The presence of healthy vegetation plays a crucial role in extending P reduction lifespan of amendments.

Types of P-sorbing materials

The primary P-sorbing chemicals are calcium (Ca), aluminum (Al) and iron (Fe). These are found in a variety of materials.

Limestone or calcareous sand

Combinations of C 33 sand with limestone or calcareous sand were tested in laboratory columns by Erickson et al. (2007). Limestone or calcareous sand is not recommended as a P sorptive amendment in bioretention facilities because it clogged the columns, resulting in hydraulic failure.

Drinking Water Treatment Residuals (WTS)

Drinking-water treatment residuals are primarily sediment, metal (aluminum, iron or calcium) oxide/hydroxides, activated carbon, and lime removed from raw water during the water purification process (Agyin-Birikorang et al., 2009). WTRs are increasingly being used to control phosphorus in soils where phosphorus leaching may be problematic for water quality. Kawczyinski and Achtermann (1991) reported that landfilling is the predominant disposal method, followed by land application, sanitary sewer disposal, direct stream discharge, and lagooning. WTRs contain high concentrations of amorphous aluminum (Al) or iron (Fe), making them potential amendments for sorbing soil phosphorus.

Aluminum-based Water Treatment Residuals (WTRs)

O'Neill and Davis (2012a and 2012b) recommend a bioretention soil media of 5 percent WTR, 3 percent triple-shredded hardwood bark mulch, and 92 percent loamy sand for P reduction on the basis of batch, minicolumn, and large column studies. The life expectancy for this media was 20 years. In a comparison of bioretention soil medias (BSM's) with varying fines concentrations, they found that increasing the concentration of sand (i.e. decreasing fines) improved P reduction.

They also found that hardwood bark mulch, a source of organic matter typically low in P, further improved P reduction (O'Neill and Davis 2012a). The authors contend that an oxalate-extractable aluminum-, iron-, and phosphorus-based metric, the oxalate ratio, can be used to predict P sorption capacity, and suggest that a media oxalate ratio of 20 to 40 is expected to meet P adsorption requirements for nutrient sensitive watersheds. This media adsorbed 88.5 percent of the applied P mass, compared to a non-WTR amended control media for which effluent P mass increased 71.2 increased.

O'Neill and Davis (2012b) state "This media consistently produced total phosphorus effluent mean event concentrations less than 25 micrograms per liter and exhibited a maximum effluent concentration of only 70 micrograms per liter". Concentrations of P as low as 25 micrograms P per liter may be necessary to reduce eutrophication risk depending on receiving water conditions (U.S. Environmental Protection Agency (US EPA, 1986) in O'Neill and Davis, 2012a). References to additional studies are found in O'Neill and Davis (2012a and 2012b).

Iron-based Water Treatment Residuals (WTRs)

As reviewed in O'Neill and Davis (2012 a), one study of iron based WTRs found iron based WTRs to be ineffective to P reduction because they solubilized and released all adsorbed P in reducing conditions, but another more recent study found this may not be the case. According to Dr. Allen Davis (University of Maryland), iron based water treatment residuals "should work just as well, maybe better than Al. The concern with Fe is that if the media becomes anaerobic due to flooding or any other reason, the Fe can be reduced and will dissolve. It adds another layer of complexity to the system." This concern can be addressed by designing the bioretention practice to ensure the layer where P sorbtion will occur stays aerobic.

Iron filings

Research by Erickson et al. (2012) suggests that the lifespan for iron enhanced sand filtration (5 percent iron) with a typical impervious area ratio should be at least 30 years. Dissolved phosphorus capture should be greater than 80 percent for more than 30 years (Erickson, 2010). Many agricultural studies have also found several forms of iron enhancements to be effective to capture P (e.g. Chardon et al., 2012; Stoner et al. 2012; literature review in Buda et al. 2012). Research showing that native iron-rich soils also have high P sorption capacity further supports giving dissolved P removal credit (e.g. Lucas and Greenway, 2011). Stenlund (2013 personal communication) has observed that adding iron to soil causes the soil to harden to a rock like medium, and recommends augering holes for plant growth into soils that have been amended with iron.

Imbrium Sorptive®MEDIA

Imbrium Sorptive®MEDIA, a proprietary P sorbing amendment available from Contech, is an engineered granular media containing aluminum oxide and iron oxide that demonstrates substantial capacity for adsorption of dissolved phosphorus from stormwater runoff. A recent study reported results from monitoring P reduction of 5 bioretention mesocosms with varying concentrations of Imbrium Sorptive®MEDIA (Balch et al 2013). The study is summarized below.

Five individual bioretention cells were monitored, each with 50 cm (20 inches) depth of soil that consisted of sand and 15 percent peat moss. The authors state "Four of [the cells] had different concentrations of Sorbtive® Media (3, 5, 10 and 17 percent by volume). The fifth cell contained only the sand/peat soil mix and no amendment, and therefore represented a control that provided the ability to determine how much phosphorus was retained by the sand/peat mix alone. The total volume of spiked artificial stormwater applied to each cell approximated the volume of cumulative runoff generated in this region [Canada] over a two-year period by a drainage area five times the size of a bioretention cell. At every phosphorus concentration, all the cells amended with Sorbtive® Media demonstrated much higher percent removal of phosphorus compared to the control cell with no Sorbtive® Media. The performance gap between the amended cells and the control cell widened as the phosphorus concentration increased. At the 0.2 percent target phosphorus concentration, mean dissolved phosphorus removal ranged 79 to 92 percent for the amended cells compared to 54 percent for the control cell. At the 0.8 percent target phosphorus concentration, mean dissolved phosphorus removal ranged 86 to 98 percent for the amended cells compared to 20 percent for the control cell. In the final week of the study, with 0.8 percent target phosphorus concentration in the artificial stormwater, percent removal of dissolved phosphorus was 82 percent for the 3 percent amendment, 97 to 98 percent for the 5, 10, and 17 percent amendments, and 11 percent for the control. These results demonstrate that the Sorbtive® Media maintained high phosphorus adsorptive capacity throughout the study, especially at the 5 percent and greater amendment levels."

Researchers estimate that the lifespan for Imbrium should be at least 10 to 30 years, depending on P loading and performance goals (Garbon, 2013 personal communication; Contech Engineering, 2013). Contech Engineering (2013) estimated 45 percent dissolved P removal at 20 years after initial installation of 5 percent Sorptive media by volume.

Field studies with Imbrium are also underway in Wisconsin (Bannerman, 2013 personal communication). Additionally, Imbrium media has been used in an upflow filter on a North Carolina wet pond, resulting in greater than 80 percent removal of dissolved P during ten monitored storm events (Winston, 2013 personal communication).

To our knowledge, no field installations with Imbrium Sorptive®MEDIA have been monitored long term. Field studies to monitor long term performance of bioretention with P sorbing amendments are recommended to monitor clogging potential and P reduction performance over the bioretention lifespan.

E-3 Soil Amendments to Enhance Phosphorus Sorption

Examples of other innovative applications

Using P-sorptive amendments to reduce effluent P content from BMP's is a newly emerging field. Some applications of P-sorptive amendments that are promising but for which there is not sufficient research to recommend them as standard practices are discussed below.

Using by-products like gypsum, mining residuals, or drinking water treatment residuals in filters

Several researchers have developed ditch filters with P-sorbing materials to intercept surface and subsurface flow ditch water to trap dissolved P. The filters can be replaced as needed when the P-sorption sites are full (Schneider, 2013; Stoner et al., 2012). They report that "Overall, by-products that are elevated in oxalate Al or Fe, WS Ca [water soluble calcium], and BI [buffer index] serve as the best P sorbents in P removal structures, and screening for these properties allows comparison between materials for this potential use. The flow-through approach described in this paper for predicting design curves at specific [retention time] and inflow P combinations aids in predicting how much P can be removed and how long a specific material will last until P saturation if the P loading rate for a specific site is known." (Stoner et al., 2012)

Researching the use of such filters on effluent from bioretention systems is recommended, as this would likely be an effective technique for P reduction in bioretention systems on projects where use of filters and ability to replace them as needed is realistic and desirable. For research on by-products, testing of composition and leaching of potentially harmful chemicals (e.g. dissolved metals) should be undertaken to ensure public health.

Using drain pipes enveloped in Fe-coated sand

Groenenberg et al. (2013) tested the performance of a pipe drain enveloped with Fe-coated sand, a side product of the drinking water industry with a high ability to bind P from the (agricultural) drainage water. They report that "The results of this trial, encompassing more than one hydrological season, are very encouraging because the efficiency of this mitigation measure to remove P amounted to 94 percent. During the trial, the pipe drains were below the groundwater level for a prolonged time. Nevertheless, no reduction of Fe(III) in the Fe-coated sand occurred, which was most likely prevented by reduction of Mn oxides present in this material. The enveloped pipe drain was estimated to be able to lower the P concentration in the effluent to the desired water quality criterion for about 14 years. Manganese oxides are expected to be depleted after 5 to 10 years. The performance of the enveloped pipe drain, both in terms of its ability to remove P to a sufficiently low level and the stability of the Fe-coated sand under submerged conditions in the long term, needs prolonged experimental research." Application of this technique could also potentially be effective for reducing P in effluent from bioretention systems with underdrains. Unlike the filter application described in Schneider (2013), though, the iron around the pipe cannot easily be removed and replaced when the P binding sites are full. However, depending on P, Ca, and iron concentrations, there may be enough P sorption sites to last the lifespan of the bioretention system. This application is similar to bioretention systems currently being tested by Bannerman in Wisconsin (Bannerman, 2013 personal communication)

Rototilling Water Treatment Residuals into existing bioretention facilities

O'Neill and Davis (2012b) also suggest that established bioretention facilities could be retrofitted for increased P reduction by rototilling WTRs into the media, as agricultural surface application has been shown to be effective. Bioretention facilities may need to be re-planted after roto-tilling WTRs into the media, however, as rototilling would likely damage roots of existing vegetation. Alternatively perhaps a different way could be found to incorporate WTRs into existing bioretention facilities, such as, perhaps by air spading out some of the existing soil around existing vegetation, and replacing the soil that was removed with bioretention soil media amended with WTR's. This technique could perhaps be used to renew P sorption capacity of bioretention facilities when P sorption sites are filled.

Applicability

- Removal of dissolved phosphorus requires a comparatively high hydraulic retention time, and therefore a deeper media (Hsieh et al., 2007 in Hunt et al 2012). Media depth should therefore be at least 0.6 meters, with 0.9 meters recommended (Hunt et al., 2012).
- Infiltration rates between 0.007 and 0.028 millimeters per second (1 to 4 inches per hour) work best, as this increases the hydraulic retention time, allowing for more sorption to occur (Hunt et al 2012).
- If the media is saturated where phosphorus is stored, P is likely to leach out. So if an internal water storage (IWS) layer is used, it should be located below the P-sequestering portion of the media. Therefore, a 0.45 to 0.6 meter (1.5 to 2 foot) separation is recommended between the top of the IWS layer and the media surface (Hunt et al 2012). The P-sorptive amendment should be located at least 0.5 feet above the top of the IWS zone (Winston, 2013).

Life cycle properties

P sorptive amendments have been shown to provide effective P retention for the expected lifetime of bioretention facilities (e.g. Lucas and Greenway, 2011; O'Neill and Davis, 2012a and 2012b).

Maintenance needs

Soil amendments to enhance P sorption typically do not increase bioretention maintenance needs. Water treatment residuals (WTR's) are fine textured, so systems with WTR's should be designed to minimize clogging. Hinman and Wulkan (2012) recommend adding shredded bark at

15 percent by volume for each 10 percent WTRs added by volume to compensate for the fine texture of WTRs.

Iron filings can be obtained with a size distribution similar to sand. Erickson et al (2012) found that hydraulic conductivity of a sand filter was not negatively affected when operated for a year with up to 10.7 percent iron filings, which is enough iron to capture a significant percent of dissolved P.

Cost information

Soil amendments to enhance P sorption are a relatively low cost technique to improve long term dissolved P removal. Steel wool, for example, has been found to increase the material cost by 3 to 5 percent (Erickson et al., 2007). Iron filings cost less than steel wool per unit weight because they require less manufacturing to produce (Erickson et al., 2012). Since WTRs are byproducts of the water treatment process, they can often be procured for little or no cost.

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The following pages address incorporation of trees into stormwater management under paved surfaces

- Design guidelines for tree quality and planting - tree trenches and tree boxes
- Design guidelines for soil characteristics - tree trenches and tree boxes
- Construction guidelines for tree trenches and tree boxes
- Protection of existing trees on construction sites
- Operation and maintenance of tree trenches and tree boxes
- Assessing the performance of tree trenches and tree boxes
- Calculating credits for tree trenches and tree boxes
- Case studies for tree trenches and tree boxes
- **Soil amendments to enhance phosphorus sorption**
- Fact sheet for tree trenches and tree boxes
- Requirements, recommendations and information for using trees as a BMP in the MIDS calculator
- Requirements, recommendations and information for using trees with an underdrain as a BMP in the MIDS calculator

Minimum Bioretention Soil Media Depths

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Minimum bioretention soil media depths recommended to target specific stormwater pollutants. From Hunt et al. (2012) and Hathaway et al., (2011).
Link to this **table**

Pollutant	**Depth of Treatment with upturned elbow or elevated underdrain**	**Depth of Treatment without underdrain or with underdrain at bottom**	**Minimum depth**
Total suspended solids (TSS)	Top 2 to 3 inches of bioretention soil media	Top 2 to 3 inches of bioretention soil media	Not applicable for TSS because minimum depth needed for plant survival and growth is greater than minimum depth needed for TSS reduction
Metals	Top 8 inches of bioretention soil media	Top 8 inches of bioretention soil media	Not applicable for metals because minimum depth needed for plant survival and growth is greater than minimum depth needed for metals reduction
Hydrocarbons	3 to 4 inch Mulch layer, top 1 inch of bioretention soil media	3 to 4 inches Mulch layer, top 1 inch of bioretention soil media	Not applicable for hydrocarbons because minimum depth needed for plant survival and growth is greater than minimum depth needed for hydrocarbons reduction
Nitrogen	From top to bottom of bioretention soil media; Internal Water Storage Zone (IWS) improves exfiltration, thereby reducing pollutant load to the receiving stream, and also improves nitrogen removal because the longer retention time allows denitrification to occur underanoxic conditions.	From top to bottom of bioretention soil media	Retention time is important, so deeper media is preferred (3 foot minimum)

Minimum Bioretention Soil Media Depths

Particulate phosphorus	Top 2 to 3 inches of bioretention soil media.	Top 2 to 3 inches of bioretention soil media.	Not applicable for particulate phosphorus because minimum depth needed for plant survival and growth is greater than minimum depth needed for particulate phosphorus reduction
Dissolved phosphorus	From top of media to top of submerged zone. Saturated conditions cause P to not be effectively stored in submerged zone.	From top to bottom of bioretention soil media	Minimum 2 feet, but 3 feet recommended as a conservative value; if IWS is included, keep top of submerged zone at least 1.5 to 2 feet from surface of media
Pathogens	From top of soil to top of submerged zone.	From top to bottom of bioretention soil media	Minimum 2 feet; if IWS is included, keep top of submerged zone at least 2 feet from surface of media
Temperature	From top to bottom of bioretention soil media; Internal Water Storage Zone (IWS) improves exfiltration, thereby reducing volume of warm runoff discharged to the receiving stream, and also improves thermal pollution abatement because the longer retention time allows runoff to cool more before discharge.	From top to bottom of bioretention soil media	Minimum 3 feet, with 4 feet preferred

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www.hydrocad.net/pdf/MN-Simple-Method.pdf

Appendix L

Simple Method for Estimating Phosphorus Export

1. The Simple Method

The Simple Method is a technique used for estimating storm pollutant export delivered from urban development sites. The method was developed to provide an easy yet reasonably accurate means of predicting the change in pollutant loadings in response to development. This information is needed by planners and engineers to make rational non-point source pollution decisions at the site level.

The Simple Method Calculation is intended for use on development sites less than a square mile in area. As with any simple model, the method to some degree sacrifices precision for the sake of simplicity and generality. Even so, the Simple Method is still reliable enough to use as a basis for making non-point pollution management decisions at the site level.

Phosphorus pollutant loading (L, in pounds per year) from a development site can be determined by solving the equation displayed in Table L.1.

1.1. Depth of Rainfall (P)

The value of P represents the number of inches of precipitation that falls during the course of a normal year of rainfall. Long-term weather records around the state of Minnesota suggest that the average annual rainfall depth is about 26 inches. This can be used to estimate P or a user can substitute the average annual rainfall depth from the closest National Weather Service long-term weather station or other suitable locations for which a reliable record can be demonstrated (> 10 years).

1.2. Correction Factor (P_j)

The P_j factor is used to account for the fraction of the annual rainfall that does not produce any measurable runoff. Many of the storms that occur during the year are so minor that all of the rainfall is stored in surface depressions and eventually evaporates. As a consequence, no runoff is produced. An analysis of regional rainfall/runoff patterns indicates that only 90% of the annual rainfall volume produces any runoff at all. Therefore, P_j should be set at 0.9.

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1.3. Runoff Coefficient (R_v)

The R_v is a measure of the site response to rainfall events, and in theory is calculated as:

> $R_v = r/p$, where r and p are the volume of storm runoff and storm rainfall, respectively, expressed as inches.

The R_v for the site depends on the nature of the soils, topography, and cover. However, the primary influence on the R_v in urban areas is the amount of imperviousness of the site. Impervious area is defined as those surfaces in the landscape that cannot infiltrate rainfall consisting of building rooftops, pavement, sidewalks, driveways, etc. In the equation:

$$R_v = 0.05 + 0.009(I)$$

"I" represents the percentage of impervious cover expressed as a whole number. A site that is 75% impervious would use I = 75 for the purposes of calculating R_v.

1.4. Site Area (A)

The total area of the site (in acres) can be directly obtained from site plans. If the total area of the site is greater than one square mile (640 acres), the Simple Method may not be appropriate and applicants should consider utilizing other approaches, such as modeling or monitoring.

1.5. Pollutant Concentration (C)

Statistical analysis of several urban runoff monitoring datasets has shown that the average storm concentrations for total phosphorus do not significantly differ between new and existing development sites. Therefore, a pollutant concentration, C, of 0.30 mg/l should be used in this equation as a default. However, if good local data are available or an adjustment is needed, this factor can be customized for local condition.

Chapter 8 contains a range of C values for those interested in conducting a more detailed analysis of phosphorus export.

The Simple Method equation listed in Table L.1 can be simplified to the equation shown in Table L.2. Applicants with verified data indicating alternative values may choose to use the original Simple Method equation as represented in Table 1; otherwise, Table L.2 represents the revised Simple Method equation and associated values.

2. Calculating Pre-Development and Post-Development Phosphorus Load

The methodology for comparing annual pre-development pollutant loads to post-development pollutant loads is a six-step process (Table L.3).

Step 1: Calculate Site Imperviousness

In this step, the applicant calculates the impervious cover of the pre-development (existing) and post-development (proposed) site conditions.

Impervious cover is defined as those surfaces in the landscape that impede the infiltration of rainfall and result in an increased volume of surface runoff. As a simple rule, human-made surfaces that are not vegetated will be considered impervious. Impervious surfaces include roofs, buildings, paved streets and parking areas and any concrete, asphalt, compacted dirt or compacted gravel surface.

Step 2: Calculate Pre-Development Phosphorus Load

In this step, the applicant calculates stormwater phosphorus loadings from the site prior to development. Depending on the development classification, the applicant will use one of two equations (Table L.4). The equation to determine phosphorus loading in a redevelopment situation is based on the Simple Method. The equation to determine phosphorus loading in a new development situation utilizes a benchmark load for undeveloped areas, which is based on average phosphorus loadings for a typical mix of undeveloped land uses.

Step 3: Calculate Post-Development Pollutant Load

In this step, the applicant calculates stormwater phosphorus loadings from the post-development, or proposed, site. Again, an abbreviated version of the Simple Method is used for the calculations, and the equation is the same for both new development and redevelopment sites (Table L.5).

Table L.1 Phosphorus Pollutant Export Calculation

$$L = [(P)(P_j)(R_v)/12]\ (C)\ (A)\ (2.72)^*$$

Where:

L = Load of a pollutant in pounds per year
P = Rainfall depth per year (inches)
P_j = Fraction of rainfall events that produce runoff
R_v = Runoff coefficient, which expresses the fraction of rainfall which is converted into runoff. $R_v = 0.05 + 0.009(I)$
C = Flow-weighted mean concentration of the pollutant in urban runoff (mg/l)
A = Area of the development site (acres)

*12 and 2.72 are unit conversion factors

Table L.2 Simplified Pollutant Loading Calculation

$$L = (P)\ (R_v)\ (C)\ (A)\ (0.20)^*$$

Where:

L = Load of a pollutant in pounds per year
P = Rainfall depth per year (inches)
R_v = Runoff coefficient, which expresses the fraction of rainfall which is converted into runoff = 0.05 + 0.009(I)
I = Site imperviousness (i.e., I = 75 if site is 75% impervious)
C = Flow-weighted mean concentration of the pollutant (total phosphorus) in urban runoff (mg/l) = 0.30 mg/l**
A = Area of the development site (acres)

*0.20 is a regional constant and unit conversion factor
** The C factor can be customized if good local water quality data exist or if an adjustment in the 0.30 mg/l term is needed.

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Step 4: Calculate the Pollutant Removal Requirement

The phosphorus load generated from the post-development site must be reduced so that it is 90% or less of the load generated prior to development, In this example, a 10% reduction in phosphorus loading from pre-development conditions is used. This should not be construed as a recommended reduction for the State of Minnesota. Applicants should check with local stormwater authorities to determine if specific pre- to post-development phosphorus reduction requirements exist. The amount of phosphorus that must be removed through the use of stormwater BMPs is called the Pollutant Removal Requirement (RR). The equation in Table L.6 expresses this term numerically.

Table L.3 Process For Calculating Pre- and Post-Development Pollutant Loads

Step No.	Task
1	Calculate Site Imperviousness
2	Calculate the Pre-Development Phosphorus Load
3	Calculate Post-Development Pollutant Load
4	Calculate the Pollutant Removal Requirement
5	Identify Feasible BMPs
6	Select Off-Site Mitigation Option

Table L.4 Method For Calculating Pre-development Phosphorus Loading

New Development Phosphorus Loading, L_{pre} = 0.5 (A)

Where:

L_{pre} = Average annual load of total phosphorus exported from the site prior to development (lbs/year)
0.5 = Annual total phosphorus load from undeveloped lands (lbs/acre/year)
A = Area of the site (acres)

Redevelopment Phosphorus Loading, L_{pre} = (P) (R_v) (C) (A) (0.20)

Where:

L_{pre} = Average annual load of total phosphorus exported from the site prior to development (lbs/year)
P = Rainfall depth over the desired time interval (inches)
R_v = Runoff coefficient, which expresses the fraction of rainfall which is converted into runoff = 0.05 + 0.009(I_{pre})
I_{pre} = Pre-development (existing) site imperviousness (i.e., I = 75 if site is 75% impervious)
C = Flow-weighted mean concentration of the pollutant (total phosphorus) in urban runoff (mg/l) = 0.30 mg/l
A = Area of the development site (acres)

*0.20 is a regional constant and unit conversion factor

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Step 5: Identify Feasible BMPs

Step 5 looks at the ability of the chosen BMP to meet the site's pollutant removal requirements. The pollutant load removed by each BMP (Table L.7) is calculated using the average BMP removal rate (Table L.8), the computed post-development load, and the drainage area served.

If the load removed is equal to or greater than the pollutant removal requirement computed in Step 4, then the on-site BMP complies. If not, the designer must evaluate alternative BMP designs to achieve higher removal efficiencies, add additional BMPs, design the project so that more of the site is treated by the proposed BMPs, or design the BMP to treat runoff from an off-site area.

Table L.5 Method For Calculating Post-Development Phosphorus Loading

$$L_{post} = (P)\,(R_v)\,(C)\,(A)\,(0.20)$$

Where:

L_{post} = Average annual load of total phosphorus exported from the post-development site (lbs/year)
P = Rainfall depth over the desired time interval (inches)
R_v = Runoff coefficient, which expresses the fraction of rainfall which is converted into runoff = $0.05 + 0.009(I_{post})$
I_{post} = Post-development (proposed) site imperviousness (i.e., I = 75 if site is 75% impervious)
C = Flow-weighted mean concentration of the pollutant (total phosphorus) in urban runoff (mg/l) = 0.30 mg/l
A = Area of the development site (acres)

*0.20 is a regional constant and unit conversion factor

Table L.6 Computing Pollutant Removal Requirements

$$RR = L_{post} - 0.9(L_{pre})$$

Where:

RR* = Pollutant removal requirement (lbs/year)
L_{post} = Average annual load of total phosphorus exported from the post-development site (lbs/year)
L_{pre} = Average annual load of total phosphorus exported from the site prior to development (lbs/year)

*0.90 is suggested post-development phosphorus load reduction. Local requirements may vary.

Table L.7 Estimate of Pollutant Load Removed by Each BMP

$$LR = (L_{post})\,(BMP_{RE})\,(\%\ DA\ Served)$$

Where:

LR = Annual total phosphorus load removed by the proposed BMP (lbs/year)
L_{post} = Average annual load of total phosphorus exported from the post-development site prior to development (lbs/year)
BMP_{RE} = BMP removal efficiency for total phosphorus, Table 8 (%)
% DA Served = Fraction of the drainage area served by the BMP (%)

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Step 6: Select Off-Site Mitigation Option

If the pollutant removal requirement has been met through the application of on-site stormwater BMPs, the process is complete.

In the event that on-site BMPs cannot fully meet the pollutant removal requirement and on-site design cannot be changed, an offset fee should be charge (e.g. $X per pound of phosphorus).

Table L.8 Comparative BMP Phosphorus Removal Performance [a, e, f]

BMP Group	BMP Design Variation	Average TP Removal Rate[b]	Maximum TP Removal Rate[c]	Average Soluble P Removal Rate [d, g]
Bioretention	Underdrain	50%	65%	60%
	Infiltration	100	100	100
Filtration	Sand Filter	50	55	0
	Dry Swale	0	55	0
	Wet Swale	0	40	0
Infiltration [f,i]	Infiltration Trench	100	100	100
	Infiltration Basin	100	100	100
Stormwater Ponds	Wet Pond	50	75	70
	Multiple Pond	60	75	75
Stormwater Wetlands	Shallow Wetland	40	55	50
	Pond/Wetland	55	75	65

[a] Removal rates shown in table are a composite of five sources: ASCE/EPA International BMP Database (www.bmpdatabase.org); Caraco (CWP), 2001; MDE, 2000; Winer (CWP), 2000; and Issue Paper D P8 (William Walker, http://wwwalker.net/p8/) modeling

[b] Average removal efficiency expected under MPCA CGP Sizing Rules 1 and 3 (see Chapter 10)

[c] Upper limit on phosphorus removal with increased sizing and design features, based on national review

d Average rate of soluble phosphorus removal in literature

[e] See also Appendix N (link) and Chapter 12 for details.

[f] Note that the performance numbers apply only to that portion of total flow actually being treated; it does not include any runoff that by-passes the BMP

[g] Note that soluble P can transfer from surface water to ground water, but this column refers only to surface water

[h] Note that 100% is assumed for all infiltration, but only for that portion of the flow fully treated in the infiltration facility; by-passed runoff or runoff diverted via underdrain does not receive this level of treatment

IMPORTANT NOTE: Removal rates shown here are composite averages intended solely for use in comparing performance between BMP designs and for use in calculating load reduction in site-based TP models. They have been adapted, rounded and slightly discounted from statistical values published in BMP performance databases.

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3. References

Caraco, D. 2001. “Managing Phosphorus Inputs Into Lakes III: Evaluating the Impact of Watershed Treatment.” Watershed Protection Techniques. 3 (4): 791-796. Center for Watershed Protection. Ellicott City, MD.

Maryland Department of the Environment (MDE). 2000. 2000 Maryland Stormwater Design Manual. MDE. Baltimore, MD.

Winer, R. 2000. National Pollutant Removal Performance Database for Stormwater Treatment Practices. 2nd Edition. Center for Watershed Protection. Ellicott City, MD.

SIMPLE METHOD DESCRIPTION AND ANALYSIS
WETLAND B

Table L.1 Phosphorus Pollutant Export Calculation

$$L = [(P)(P_J)(R_V)/12]\ (C)\ (A)\ (2.72)^*$$

* 12 and 2.72 are unit conversion factors

Where,
L = Load of pollutant in pounds per year
P = Rainfall depth per year (inches)
PJ = Fraction of rainfall events that produce runoff
RV = Runoff coeefficient, which expresses the fraction of the rainfall which is converted into runoff. RV = 0.05 + 0.009 (I)
C = Flow-weighted mean concentration of the pollutant in urban runoff (mg/l)
A = Area of the development site (acres)

P	P_J	R_V	C	A	L
45.5	0.9	0.0504	0.3	13	1.83

Camas

Site Impervious (I) % = 47

Table L.2 Simplified Pollutant Loading Calculation

$$L = [(P)(R_V)\ (C)\ (A)\ (0.20)^*$$

* 0.20 is a regional constant and unit conversion factors

Where,
L = Load of a pollutant exported in pounds per year
P = Rainfall depth per year (inches)
R_V = Runoff coeefficient, which expresses the fraction of the rainfall which is converted into runoff. RV = 0.05 + 0.009 (I)
I = Site imperviousness (i.e., I=75 if site is 75% impervious)
C = Flow-weighted mean concentration of the pollutant (total phosphorus) in urban runoff (mg/l) = 0.30 mg/l**
A = Area of the development site (acres)

** The C factor can be customized if good local water quality data exist or if an adjustment in the 0.30 mg/l term is needed.

Table L.4 New Development Phosphorus Loading

$$L_{PRE} = 0.5\ (A)$$

A	L_{PRE}
31.2	15.6
13.0	6.5

Redevelopment Phosphorus Loading

$$L_{PRE} = [(P)(R_V)\ (C)\ (A)\ (0.20)^*$$

P	R_V	C	A	L_{PRE}
		0.30		0.0
		0.30		0.0

SIMPLE METHOD DESCRIPTION AND ANALYSIS
WETLAND B

Table L.5 Method for Calculating Post-development Phosphorus Loading

$$L_{POST} = [(P)(R_V)\ (C)\ \ (A)\ (0.20)*$$

* 0.20 is a regional constant and unit conversion factors

L = Average annual load of the total phosphorus exported from the post-development site (pounds per year)
P = Rainfall depth over the desired time interval(inches)
R_V = Runoff coefficient, which expresses the fraction of the rainfall which is converted into runoff. RV = 0.05 + 0.009 (I_{POST}
$I_{POST\,=}$ Post-development (proposed0 site imperviousness (i.e., I=75 if site is 75% impervious)
C = Flow-weighted mean concentration of the pollutant (total phosphorus) in urban runoff (mg/l) = 0.30 mg/l
A = Area of the development site (acres)

Impervious road = 6.07
I = 47%
I = 47

P	R_V	C	A	L_{POST}
45.5	0.05	0.30	13	1.8

Table L.6 Computing Pollutant Removal Requirements

$$RR = L_{POST} - 0.9\ (L_{PRE})$$

Where,

RR* = Pollutant removal requirement (lbs/yr)
L_{POST} = Average annual load of total phosphorus exported from the post-development site (lbs/yr)
L_{PRE} = Average annual load of total phosphorus exported from the site prior to development site (lbs/yr)

* 0.90 is the suggested post-development phosphorus load reduction. Local requirements may vary.

L_{POST}	$0.9L_{PRE}$	RR
3	14.04	-11.0
3	5.85	-2.9

Table L.7 Estimate of Pollutant Load Removed by Each BMP

$$LR = (L_{POST)}\ (BMP_{RE})\ (\%\ DA\ served)$$

Where,

LR = Annual total phosphorus load removed by the proposed BMP (lbs/yr)
L_{POST} = Average annual load of total phosphorus exported from the post-development site (lbs/yr)
BMP_{RE} = BMP removal efficiency for total phosphorus, Table 8 (%)
% DA Served = Fraction of the drainage area served by the BMP (%)

L_{POST}	BMP_{RE}	%DA	LR
3	0.55	1	1.65