Technical Memo

To: Water Quality Goal Implementation Team, Forestry Workgroup, Urban Stormwater Workgroup

From: Tree Canopy Expert Panel

Date: September 4, 2015

Re: *Chesapeake Bay Program Tree Canopy Expert Panel Recommendations for Tree Canopy Land Use Loading Rates*

To better represent the water quality benefits of tree canopy, the Chesapeake Bay Program formed an expert panel to recommend nutrient and sediment loading and efficiency estimates for an urban tree canopy BMP. The expert panel convened in March 2015 and is still underway (see Attachment A for panel membership). Final report recommendations from the expert panel based on its scope are expected by December 2015. While the scope of the expert panel did not initially include recommendations for a tree canopy land use loading rate, it became apparent during the expert panel process this need still existed and there was a need to distinguish the tree canopy BMP from a tree canopy land use. The recommendations provided in this Technical Memo are provided at the request of the Forestry Work Group and Water Quality Goal Implementation Team to support implementation of tree canopy as a new land use in the Phase 6 Chesapeake Bay Watershed Model (CBWM).

A tree canopy land use is recommended for inclusion in the Phase 6 CBWM to differentiate the water quality benefits of tree canopy from forests and other pervious land uses. While recommendations by the panel later this year will determine how to best align the tree canopy land use with an annual tree canopy BMP, this document provides recommendations from the Panel based on its August 26th and September 3rd, 2015 meetings on the relative land use loading rates for tree canopy. The expert panel at its July meeting agreed that he water quality benefits of tree canopy should be quantified for tree canopy over pervious and impervious land uses because the runoff characteristics of each land cover type differ and therefore affect the ultimate runoff and pollutant load from these areas when tree canopy is present (see Wang et al. (2008), Armson et al. (2013), Herrera Environmental Consultants (2008)). Further, the panel finds that tree canopy would be most effectively tracked as a land use, using periodically updated imagery, rather than an annually reported BMP. Annual reporting of tree planting does not account for losses of trees due to mortality, land use conversion, and other factors. Net changes in tree canopy are best tracked using high-resolution imagery.

Land uses in the CBWM are assigned an annual target loading rate based on published studies and expert review. The ultimate loading rates for each land use are products of model calibration against long-term water quality monitoring data. It is assumed that the nutrient and sediment loads from tree canopy land uses are greater than that for forests, but lower than those for open space, turf grass, or impervious surfaces. However, limited research studies are available to quantify the nutrient and sediment benefits of tree canopy directly. Based on the literature, the panel agreed that the nutrient and sediment load reductions could best be inferred from runoff volume reduction through modeling. For example, a common model, the Simple Method (Schueler, 1987), estimates stormwater pollutant loads as the product of mean pollutant concentrations and runoff volume over specified periods of time (usually annual or seasonal). Therefore, the assumption is that <u>pollutant loads will be reduced proportional to reductions in annual runoff volume</u>. This same assumption provides the basis for recommendations made by other expert panels (see Schueler and Lane, 2012) and by state stormwater regulations such as Virginia's Runoff Reduction method (Hirschman et al. 2008). While individual storm events will differ in the amount of runoff produced, the time step of interest for modeling purposes is annual.

In order to quantify tree canopy's effect on annual runoff volume reduction, an approach outlined in Herrera (2008) was applied, with some modifications based on the panel's best professional judgment and literature specific to the Chesapeake Bay region. This approach accounts for annual interception and transpiration by the tree as well as infiltration and evaporation from the underlying land cover. The method does not account for any additional infiltration provided by the tree roots or pollutant uptake by the trees because there is insufficient data to assign a value based on the literature review. Therefore the resulting values are considered to be a conservative estimate of the runoff reduction provided by tree canopy. Further, the panel concluded based on its literature review (see Attachment B), that recent studies document the available supply of leaf litter in urban areas and the potential to contribute to runoff loads. However, there remain significant gaps in understanding the fate of nutrients from leaf litter as part of the stormwater pollutant load. The final report from the expert panel will identify further research needs that may address the issue to better quantify the fate, transport, and processing of leaf litter in urban watersheds and how to best account for this source as part of an urban nutrient mass balance.

The values used in Herrera (2008) were specific to evergreens in the Pacific Northwest and are substituted with those from studies of urban (and primarily deciduous) trees in the Chesapeake Bay region. "Runoff reduction" is defined as the relative difference in runoff volume from an area with tree canopy compared to runoff volume from the same area without tree canopy. The runoff reduction without tree canopy is represented by the runoff coefficient, or the percentage of annual rainfall that becomes runoff. For the purposes of the expert panel, the modeling environment included two possible conditions: tree canopy over pervious cover and tree canopy over impervious cover. Therefore, the method described here results in an estimate of: 1) the annual runoff volume reduced by tree canopy over pervious cover, and 2) the annual runoff volume reduced by tree canopy over impervious cover.

The equations below illustrate how these results are calculated.

Equation 1. Site Runoff with Canopy (inches) = Rainfall – Interception – Evaporation/Infiltration

Where:

- Interception by tree canopy is 17% of annual rainfall
- Rainfall – interception = throughfall
- Infiltration and evaporation for pervious cover is 80% of throughfall (based on runoff coefficient of 0.2) and for impervious cover is 5% of throughfall (based on runoff coefficient of 0.95)

Equation 2. Site Runoff without Canopy (inches) = Rainfall *Runoff Coefficient

Where:

- Runoff coefficient for pervious cover is 0.2 and for impervious cover is 0.95

The percent surface runoff reduction is estimated as the relative difference between runoff reduced and the site runoff without tree canopy as shown below in Equation 3.

Equation 3. Runoff Reduction (%) = (Site Runoff without canopy – Site Runoff with canopy)/ Site Runoff without canopy

The transpiration loss from the tree canopy land use is applied to the subsurface flow, or interflow. Transpiration is the removal of water from the subsurface via plant roots to leaves where it is lost as water vapor to the atmosphere. Deeply rooted trees can withdraw water from the entire soil profile and even shallow groundwater. This withdrawal reduces interflow and throughflow to the soil. It is reasonable to assume that during rainfall events the atmosphere is saturated so there is no potential gradient driving transpiration and hence no abstractive losses during a rain are due to transpiration. Based on the literature review, rainfall interception, advection, turbulent transport, total leaf surface area and available water capacity are all factors that combine to control evapotranspiration rates, and the relative importance of each variable can fluctuate due to climate, soils and vegetative conditions. Because of the numerous factors affecting transpiration, transpiration loss was conservatively estimated at 5%. Herrera Environmental Consultants (2008) propose the 5% value for deciduous trees based on unpublished data provided by Professor Qingfu Xiao (Xiao, unpublished). While other watershed studies of forested landscapes estimate much higher evapotranspiration values (for example, 77% found by Boggs and Sun, 2011), the evaporation component is accounted for elsewhere in the panel's recommended method and the applicability of such studies to tree canopy over developed land uses could not be directly assessed. The recommended method uses the percent transpiration loss as a surrogate for the reduction of interflow. Further, the reduction in interflow only applies to the relative loading rate for the soluble fraction of total nitrogen.

Equation 4. % Interflow reduction = (transpiration * annual precipitation) * 0.3 * 100

Where:

- Transpiration by tree canopy is 5% of rainfall
- Reduction discounted by 30% for fraction TN that is soluble

Examples to illustrate these calculations are shown in Box 1 and Box 2 below.

Box 1. Tree Canopy Over Impervious Cover Example

(expressed in inches, unless otherwise noted)

Equation 1. Site Runoff with tree canopy:

Rainfall – interception = throughfall

42 – 7.14 = 34.86 inches

Infiltration/evaporation = 5% of throughfall

34.86* 0.05 = 1.74 inches

Throughfall – infiltration/evaporation = site runoff

34.86 - 1.72 = 33.14 inches

Equation 2. Site Runoff without tree canopy (e.g., pavement only):

Rainfall * Runoff Coefficient

42 * 0.95 = 39.9 inches

Site runoff without tree canopy – site runoff with canopy = runoff reduced in inches

39.9 – 33.14 = 6.76

Equation 3. Surface Runoff reduction % = (runoff reduced/ site runoff without tree canopy) * 100

(6.76/39.9)* 100 = 16.95%

Equation 4. Additional reduction from interflow (applicable to TN only)

Interflow

= 0.015 x rainfall (assume transpiration is a surrogate for uptake of interflow volume)

= 0.63

% load reduction = 16.95 + (0.63/39.9) *100

= 16.95% + 1.57%

= 18.5%

Box 2. Tree Canopy Over Pervious Cover Example

(expressed in inches, unless otherwise noted)

Equation 1. Site Runoff with tree canopy:

Rainfall – interception = throughfall

42 – 7.14 = 34.86 inches

Infiltration/evaporation = 80% of throughfall

34.86* 0.8 = 27.88 inches

Throughfall – infiltration/evaporation = site runoff

34.86 - 27.88 = 6.97 inches

Equation 2. Site Runoff without tree canopy (e.g., turf only):

Rainfall * Runoff Coefficient

42 * 0.2 =8.4 inches

Site runoff without tree canopy – site runoff with canopy = runoff reduced in inches

8.4 – 6.97 =1.4

Equation 3. Surface Runoff reduction % = (runoff reduced/ site runoff without tree canopy) * 100

(1.4/8.4)* 100 = 16.7%

Equation 4. Additional reduction from interflow (applicable to TN only)

Interflow

= 0.015 x rainfall (assume transpiration is a surrogate for uptake of interflow volume)

= 0.63

% load reduction= 16.7%+ (0.63/39.9) *100

= 16.7% + 1.57%

= 18.2%

The resulting runoff reduction benefit of the tree canopy is summarized in Table 1.

Table 1. Proposed Modifiers to Relative Loading Rates for Tree Canopy over Pervious and Impervious for TN, TP and TSS.

Parameter	Tree Canopy over Pervious (%)	Tree Canopy over Impervious (%)
TN	18.2	18.5
TP	17	17
TSS	17	17

The literature review completed by the Center for Watershed Protection and used by the Tree Canopy Expert Panel to derive these values included over 75 sources, but applicable data to inform the values is limited. The estimate of 17% rainfall interception came from two key sources that focused on urban trees and were modeling studies from the Chesapeake Bay region (Wang et al. 2008, Band et al n.d.). The range of canopy interception values from these studies is 14.5% to 19.6, with 17% as the average value; see Table 1 in Attachment B). The additional studies of urban tree interception from outside the Bay region showed that urban deciduous trees intercept from 6.5-27% of annual rainfall while the literature on interception by deciduous forests reported a range of 8-20%. While these values are useful in estimating annual interception from natural forests or for trees in semi-arid climates, only the Wang and Band et al. studies have direct relevance to the question of water quality benefits of urban trees in the Chesapeake Bay watershed. Similarly, studies of water yield from forested watersheds have shown higher reductions from forest land (for example, Hibbert 1967); however, these studies account for all water losses from the canopy and underlying forest soil, while the method described in this memo estimates runoff reduction associated with just the canopy; therefore the values are not comparable. The estimate of annual transpiration for deciduous trees is from Herrera (2008) and was based on unpublished data from Quingfu Xiao.

To use these values in the Chesapeake Bay Watershed Model, the Panel recommends that tree canopy should be treated as a land use and modify the pollutant loading rate of the underlying land use based on the runoff reduction attributed to the tree canopy. The water quality benefit of tree canopy would be captured as a land use and defined as an efficiency that reduces the loading rate of the understory land use.

The need to distinguish Tree Canopy by pervious and impervious understory

While tree canopy's ability to capture and use rainfall (17% of annual rainfall is intercepted; 5% is transpired) is the same whether that canopy is over pervious or impervious, the resulting reduction in runoff volume (and therefore pollutant load) is different for canopy over pervious versus impervious cover because of the differences in loading rates from the underlying land cover.

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ATTACHMENT A

Panel membership and support		
Name	**Role**	**Affiliation**
Karen Cappiella	Panel member and CWP support	Center for Watershed Protection
Sally Claggett	Panel member	US Forest Service, CBPO
Keith Cline	Panel member	Fairfax County (VA)
Susan Day	Panel member	Virginia Tech
Michael Galvin	Panel member	SavATree
Neely Law	Panel Chair	Center for Watershed Protection
Peter MacDonagh	Panel member	Kestrel Design Group
Jessica Sanders	Panel member	Casey Trees
Thomas Whitlow	Panel member	Cornell University
Qingfu Xiao	Panel member	University of California-Davis
Panel support		
Jeremy Hanson	Panel Coordinator	Virginia Tech, CBPO
Brian Benham	Virginia Tech Project Director	Virginia Tech
Marcia Fox	WTWG rep	DE DNREC
Ken Hendrickson	Regulatory Support	EPA Region 3
Jeff Sweeney	CBP modeling team rep	EPA, CBPO
Ari Daniels	CWP support	CWP
Peter Claggett	CBP modeling team	USGS, CBPO
Bill Stack	CWP support	CWP