M E M O R A N D U M

To: WSSI Via E-mail

From: Nathan Staley

Date: June 5, 2013

Re: Chesapeake Bay Watershed Model – Update on Pollutant Reductions for Stream Restoration: Sample Calculations for Table 1

The following are sample calculations for Table 1 entries of the June 2013 Field Notes article entitled "New Protocols for Determining Nutrient Removal Associated with Urban Stream Restoration".

Removal rates for the "Old" and "Interim" rows were determined by multiplying set rates for each nutrient/pollutant by the total stream length – 1,000 lf was used for table computations.

<u>Old (2003) Removal Rates for Stream Restoration</u>
(Used in the current model.)

Total Nitrogen = 0.02 lb/lf/yr	X	1,000 lf =	20 lb/yr
Total Phosphorus = .0035 lb/lf/yr	X	1,000 lf =	3.5 lb/yr
Total Suspended Sediment = 2.55 lb/lf/yr	X	1,000 lf =	2,550 lb/yr

The 2011 rates are intended to replace the previous 2003 rates:

<u>Interim (2011) Removal Rates for Stream Restoration</u>

Total Nitrogen = 0.2 lb/lf/yr	X	1,000 lf =	200 lb/yr
Total Phosphorus = 0.068 lb/lf/yr	X	1,000 lf =	68 lb/yr
Total Suspended Sediment = 310 lb/lf/yr	X	1,000 lf =	310,000 lb/yr

> ***NOTE**: 2011 rates are one to two orders of magnitude greater than the 2003 rates! This is not a typo*!

Under the "New" multiple-protocol system restoration projects can achieve multiple levels of removal. The largest portion of possible removal is achieved by Protocol 1. Additional incremental removal credit may be allowed if a project meets certain requirements associated with application of Protocols 2 and 3. For the purposes of calculations in Table 1 the project was assumed to stabilize stream banks and reestablish the connection with the surrounding floodplain (Bank Height Ratio = 1.0) to create a natural bankfull recurrence interval. Thus, the example project meets the criteria of Protocols 1 and 2.

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Calculations for removal associated with Protocol 1 require stream condition assessment using the BANCS (Rosgen, 2001) system to quantify the Bank Erosion Hazard Index (BEHI) and Near-Bank Stress (NBS). This information is necessary to determine a lateral retreat rate based on the Bank Erosion Rate Curve developed by the USFWS. (See Appendix B-12 of Panel recommendations.) Moderate BEHI and NBS scores were assumed resulting in a lateral erosion rate of 0.3 ft/yr when using the USFWS curve. A four-foot average bank height was assumed. Half (50%) of streambanks within the project area were assumed to be categorized as actively eroding and meeting the above description. Therefore, the total volumetric erosion is calculated as:

$$1{,}000\ lf \times 2\ banks \times 0.5 \times 0.3 \frac{ft}{yr} \times 4ft \div 27\ \frac{cu.ft}{cu.yd} = 44.4\ \frac{cu.yd}{yr}$$

A soil bulk density of 1.2 ton/cu.yd was used. This value was taken from Appendix B of the Panel's recommendations and represents the average value for fine-grained material as noted by Van Eps et al. (2010). (A fine-grained bulk density was used to represent alluvial deposits commonly encountered in floodplain valleys throughout the mid-Atlantic.) Converting to tons of sediment per year:

$$44.4 \frac{cu.yd}{yr} \times 1.2 \frac{ton}{cu.yd} = 53.3 \frac{ton}{yr}\ \text{(or 106,600 lb/yr)}$$

Using phosphorus and nitrogen concentrations in streambank sediments as reported by Walter et al. (2007):

- 1.05 lb TP/ton sediment
- 2.28 lb TN/ton sediment

The total nutrient removal is:

Total Phosphorus: $53.3\ \frac{ton}{yr} \times 1.05 \frac{lb\ TP}{ton} = 56 \frac{lb\ TP}{yr}$

Total Nitrogen: $53.3\ \frac{ton}{yr} \times 2.28 \frac{lb\ TN}{ton} = 122 \frac{lb\ TN}{yr}$

A 50% removal efficiency is then applied for stream restoration based on data from the Baltimore County DEP Spring Branch study.

Therefore, the final Protocol 1 nutrient removal is:

TSS: $106{,}600\,\frac{lb}{yr} \times 0.5 = 53{,}300\,\frac{lb}{yr}$

Total Phosphorus: $56\,\frac{lb\ TP}{yr} \times 0.5 = 28\,\frac{lb\ TP}{yr}$

Total Nitrogen: $122\,\frac{lb\ TN}{yr} \times 0.5 = 61\,\frac{lb\ TN}{yr}$

Additional nitrogen removal is achieved through hyporheic exchange. This is accounted for in Protocol 2. The first step is determining the extent of floodplain reconnection. The example presented in Table 1 assumes that all areas of the restoration would achieve a bank height ratio of 1.0. The second step of Protocol 2 requires estimation of the extent of the "hyporheic box". The width of the box is measured from the thalweg to the edge of water at mean base flow, plus an additional 5 feet. If both sides of the stream are connected to the floodplain then the above width would be doubled. If mean base flow width from the thalweg to edge of water is assumed to be 3.5 ft and both sides of the stream have a bank height ratio of 1.0, then the box width is calculated as:

$$(3.5\ ft + 5\ ft) \times 2 = 17 ft$$

Protocol 2 assumes a 5-ft depth for the hyporheic zone. Therefore, the total volume of the hyporheic zone is:

$$17\ ft \times 5\ ft \times 1{,}000\ linear\ ft = 85{,}000\ cu.ft$$

Assuming a typical stream bed material bulk density of 125 lb/ft^3, the weight of material within the "hyporheic box" is:

$$\frac{85{,}000\ cu.ft \times 125\,\frac{lb}{cu.ft}}{2{,}000\,\frac{lb}{ton}} = 5{,}313\ tons$$

A hyporheic exchange rate of 0.000195 lb/ton/day of soil is then applied to determine the TN removal:

$$5{,}313\ tons \times 0.000195\,\frac{lb}{ton - day} \times 365\ days = 378\ lb/yr$$

This number is then added to the TN removal from Protocol 1 (61 lb/yr) for a total removal of 439 lb TN/yr.

In order to calculate the cost per pound presented in Table 1, a cost of $750/lf was assumed. This value is conservative and represents the increased cost associated with urban stream restoration, relative to restoration projects in less urbanized areas. Cost per pound for each constituent was then calculated as the total project cost ($750,000) divided by the pollutant removal in each category.

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