Integrating Data and Models from the Cannonsville Watershed to Assess Effects of Phosphorus BMP's

T.S. Steenhuis[1], C.A. Shoemaker[1], Z.M. Easton[1], J.R. Stedinger[1], S.W. Lyon[1], N. Rao[1], D. Cowan[1], D. Fuka[1], F. Flores-Lopez[1], and B.A. Tolson[2]

[1]Cornell Univ. Ithaca, NY 14853 USA, [2]Univ. of Waterloo, Waterloo, Ontario, N2L 3G1 Canada

Introduction

The Cannonsville Reservoir, located in the Catskill Mountains of New York and a part of the New York City water supply system, is considered vulnerable to problems of eutrophication from phosphorus (P). Results of simulations using SWAT2000 (Tolson, 2005) showed current activities in the watershed will increase P loading to the reservoir by 9% over ~50 years.

Best management practices (BMP's) have proven cost effective in reducing non-point P loading to surface waters at the field and farm scale. However, little research has explored BMP's efficiency at the watershed scale. We are evaluating the impact of P BMP's in the Cannonsville Reservoir.

A BMP database is being integrated with the extensive flow/water quality data, data on P sources, landuse/management, and manure handling, allowing us to quantify the impacts of P BMP's in the basin, while controlling for exogenous factors such as weather, runoff mechanisms, farm P balance, and changes in dairy herd populations. We will rank the impacts of BMP's using calibrated models.

Cannonsville Basin

- Delaware County, NY
- Draining1177 km^2
- Elevation 350 m to 1019 m
- 95.7 billion gallon capacity
- Soils are mainly hydrologic groups C and D, shallow glacial tills that overly a fragipan or bedrock in uplands, and deeper and well-drained in the West Branch of Delaware River floodplain
- Land use in the watershed is 70% forest, 28% active agriculture, and 1% water (Schneiderman et al., 2002)
- Agriculture is thought to be the largest P contributor

An Example of Model Application using VSLF

The original GWLF (Haith and Shoemaker 1987), developed as "an engineering compromise between the empiricism of export coefficients and the complexity of chemical simulation models" conceptualizes the watershed as a system of land areas (Hydrologic Response units, HRUs) that produce runoff.

- SCS-CN to model runoff → lumped by soil/landuse
- Neglects variable source areas (VSA)

The Variable Source Loading Function (VSLF) model (Schneiderman et al., 2005) recognizes VSA hydrology, sub-dividing the watershed into classes by mapping a wetness index using the topographic index.

- SCS-CN still used to model runoff → volumes are identical but distributed via wetness classes
  - Provides a more realistic distribution of runoff

The main hydrological difference between VSLF and GWLF is that VSLF distributes storm runoff according to a moisture storage distribution rather than by landuse/soil type. This has important implications for predictions of chemical constituents of runoff.

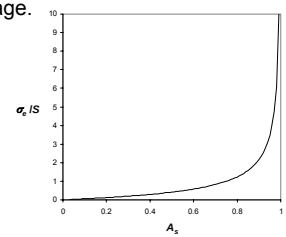
- Nutrient loss in VSLF is predicted using extraction coefficients

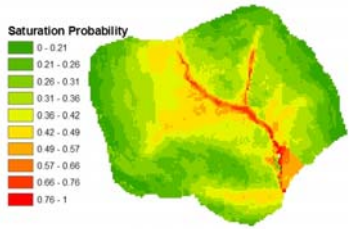
How Runoff is Distributed Spatially in VSLF

The CN equation can be interpreted as a saturation-excess runoff generation process Steenhuis et al. (1995), characteristic of a relative soil moisture distribution that is invariant from storm to storm:

$$\frac{\sigma_e}{S} = \left(\sqrt{\frac{1}{(1-A_s)}} - 1\right) \qquad 1$$

where σ_e is the soil water storage at a point in the watershed when runoff begins, S is the average available storage for the entire watershed, and A_s is the fraction of watershed with lower local moisture storage than the point location. Figure below shows the relative moisture distribution curve of eq. 1 against local moisture storage.





Distributed runoff q at a point location in the watershed is:

$$q = P - I_a - \sigma_e \quad \text{for } P > \sigma_e + I_a \qquad 2$$

where P is precip and I_a is initial abstraction. Given the CN-based relative moisture distribution, runoff for any point location along the A_s local moisture storage axis is:

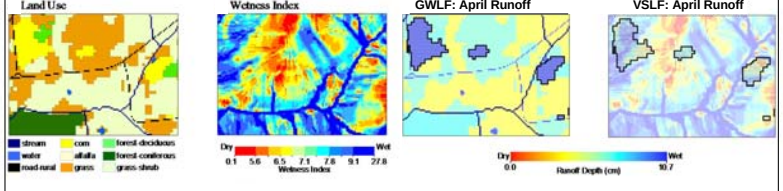
$$q = P - \left(\sqrt{\frac{1}{(1-A_s)}} - 0.8\right) \cdot S \qquad 3$$

Runoff q_i for a discrete wetness index class, bounded on one side by the fraction of the watershed that has lower local moisture storage, $A_{s,i}$, and on the other side by the fraction of the watershed that has greater local moisture storage, $A_{s,i+1}$, is given by:

$$q_i = P - \left[\frac{2\cdot(\sqrt{1-A_{s,i}} - \sqrt{1-A_{s,i+1}})}{(A_{s,i+1} - A_{s,i})} - 0.8\right] \cdot S \qquad 4$$

A wetness index class may coincide with multiple landuses. While runoff depth within an index class in VSLF will be the same irrespective of landuse, the concentration of pollutant in runoff vary by landuse and index class. Wetness index classes are subdivided by landuse to define HRUs with unique combinations of wetness class and landuse.

Schneiderman et al., 2005



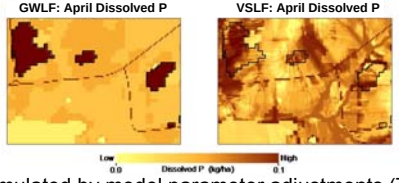
For the watershed, runoff depth Q is the areally-weighted sum of runoff depths q_i for all contributing areas:

$$Q = \sum_{i=1}^{n} q_i (A_{s,i+1} - A_{s,i}) \qquad 5$$

Simulating Phosphorus BMP's with VSLF

Whole farm P BMP's were implemented in 1997/1998 on a small scale. Implementation has increased greatly since 2000/2001, there are currently 200+ farms involved.

P runoff from the landscape is simulated using an export coefficient approach, (i.e., runoff * expected P concentration from the landuse) and distributed spatially according to the wetness index/landuse classification.

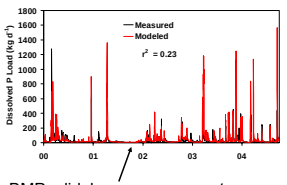


BMPs are simulated by model parameter adjustments (Table 1). For example, hydrologic effects of watershed management and BMPs may be expressed through modifications in curve number (runoff), soil water capacity (percolation), melt coefficient (snowmelt) or vegetative cover coefficients (ET). Water quality effects of BMPs are expressed by modifying HRU-specific nutrient concentrations in runoff, nutrient concentration in baseflow, point source concentrations, septic system failure rates, and HRU-specific P levels in soils.

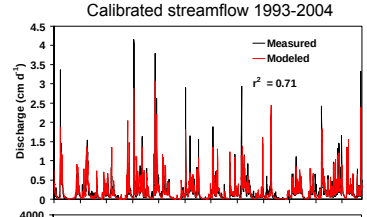
Table 1. Watershed agricultural BMP's, and corresponding dissolved P reduction factors (Schneiderman, 2005).

Agricultural BMPs	Dissolved P Removal Rate	% Landuse Area affected by BMP: Corn	Alfalfa	Grass	Barnyard
Animal Waste System	10.0%	4.3%	4.3%	1.1%	
Barnyard Runoff Management	30.0%				94.4%
Conservation Tillage	-42.0%	1.6%	1.6%	0.2%	
Contour Strip Crop	35.0%	0.3%	0.3%	<0.1%	
Grass Filter Strip	26.0%				94.4%
Nutrient Management Plan	27.0%	94.4%	94.4%	39.3%	
Riparian Forest Buffers	62.0%	1.6%	1.6%	12.0%	
% Reduction by Land Use ->		25.6%	25.6%	16.0%	45.9%

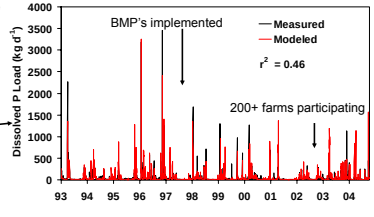
BMP's did not appear to alter flows in the watershed. Flows are as accurately modeled after BMP's (00-04) as before (93-00)



Calibrated streamflow 1993-2004



BMPs did, however, appear to reduce P loss from the landscape to the stream in the post BMP period 2000-2004. Model calibrated in pre-BMP period overestimates P loss.



Model calibrated in the pre-BMP period captures P loads well from 93-00.

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