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# A correction of DIN uptake simulation by Michaelis–Menton saturation kinetics in HSPF watershed model to improve DIN export simulation

Ping Wang[a,*], Lewis C. Linker[b]

[a]UMCES/CBPO, 410 Severn Avenue, Suite 109, Annapolis, MD 21403, USA
[b]USEPA/CBPO, 410 Severn Avenue, Suite 109, Annapolis, MD 21403, USA

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**Abstract**

Plant uptake of dissolved inorganic nitrogen (DIN) has a major effect on the watershed export of DIN. Plant uptake depends on soil moisture. The literature describes plant uptake under two conditions. One condition, when moisture is deficient, increasing moisture may increase nitrogen (N) uptake (in mass per unit time). The other condition, when moisture is sufficient, i.e., at or above the field capacity, increasing it may dilute the solution and decrease N uptake. The two different observed relationships of moisture and uptake cannot be simply simulated by the Michaelis–Menton saturation kinetics under the current setting in the Hydrological Simulation Program – Fortran (HSPF) software. This paper first compares two methods of simulated plant N uptake. The current HSPF (Version 11) uses concentration (per unit time) as the unit of uptake rate for the entire range of moisture conditions, which is inappropriate for moisture-sufficient conditions and results in higher uptake and lower DIN export during higher flow days. An alternative method uses mass (per unit area per unit time) as the unit of uptake rate, resulting in a better DIN load-flow relationship. However, it overestimates uptake in moisture-deficient conditions. This paper presents an integral method, which simply combines the above two mechanisms to simulate plant uptake in different moisture saturation conditions to improve load-flow relationships. However, it is not optimal in the operation of HSPF. Ultimately, a synthetic method, which is operational through HSPF code modification, is introduced. The synthetic method results in a better relationship between moisture and uptake, and provides reliable exports of DIN under a range of hydrology conditions.


*Keywords:* HSPF model; Plant nutrient uptake; DIN export; Moisture effect; Michaelis–Menton kinetics

## Software availability

Name of software: HSPF (Hydrological Simulation Program – FORTRAN)
Developer: Aqua Terra Consultants
Contact address: 2685 Marine Way, Suite 1314, Mountain View, CA 94043-1115, USA. Phone (650) 962 1864, Fax (650) 962 0706, http://www.aquaterra.com
Program language: FORTRAN 77
Availability and cost: Version 11 (1997), free download at http://water.usgs.gov/software/water_quality.html; Revisions – under development by Aqua Terra, Dr. Anthony S. Donigian, donigian@quaterra.com. The modules associated with a proposed revision may be requested to the corresponding author.

* Corresponding author. Tel.: +1 410 267 5744; fax: +1 410 267 5777.
*E-mail address:* pwang@chesapeakebay.net (P. Wang).

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## 1. Introduction

The Hydrological Simulation Program – Fortran (HSPF) watershed model (Bicknell et al., 1997) has been widely used to estimate nutrient and sediment loads from watersheds (Rahman and Salie, 1993; Tsihrintzis et al., 1996; USEPA, 1997; Linker et al., 1998; Srinivasan et al., 1998; Brun and Band, 2000). To simulate nutrients, HSPF includes modules to simulate hydrology and nitrogen cycling processes, including nitrogen input, mineralization, nitrification, denitrification, immobilization, plant uptake, leaf fall, transport of nitrogen in soil layers and discharge.

Plant uptake plays an important role in nitrogen cycling in forests (Bormann and Likens, 1979; Kimmins, 1987; Likens and Bormann, 1995; Fenn et al., 1998; Wang et al., 2001). High uptake in the growing season causes less DIN export (Stoddard, 1994; Tinker and Nye, 2000). Hydrology is a driving force for DIN export (Bhuyan et al., 2003). Generally, more DIN mass is discharged in higher flows, especially during storm periods, as has been observed (Riggan et al., 1985; Belval et al., 1995; Fenn et al., 1998). Various regression models (Cohn et al., 1992; Wang and Linker, 1998; Preston and Brakebill, 1999) and numerical models (Rahman and Salie, 1993; Linker et al., 1998; Baginska et al., 2003; Wolf et al., 2003; Zhang and Jorgensen, in press) also confirm this pattern. The Phase 4 of Chesapeake Bay Watershed Model (CBWSM), which currently uses the HSPF V.11, yields positive relationships between flow and load from a model segment (Linker et al., 1998), consistent with what is normally observed (USGS, 1997). Such a relationship holds for cropland, which uses a production-based plant nitrogen uptake. However, a confounding relationship between flow and DIN load is found in forest land, i.e., the scenarios with lower evapotranspiration have higher flows but lower DIN load (Wang et al., 2001). There, Michaelis–Menton kinetic is used for plant DIN uptake. Therefore, we investigated the reason for HSPF causing negative relationship between flow and load when using Michaelis–Menton plant uptake.

DIN export from land is carried by flows. Therefore, the relationship between soil-moisture conditions and flow is of interest (Bhuyan et al., 2003). At the field capacity of a soil, the moisture content of the soil layer reaches the point at which the force of gravity acting on the water equals the surface tension (Fetter, 1988). Above the field capacity, a gravitational flow occurs. Below the field capacity, there is no discharge from the soil. This paper uses the term of moisture-deficient or -sufficient conditions to indicate the soil moisture to be below or above the field capacity, respectively.

This paper focus is on the problems with the modules of the software code of HSPF V.11 which use the Michaelis–Menton saturation kinetics, and provides a method to solve the problem. It also discusses kinetics associated with nitrogen uptake, especially plant uptake rate versus soil moisture.

Although many articles describe plant uptake with soil moisture (Kimmins, 1987; Likens and Bormann, 1995; Tinker and Nye, 2000), most focus on moisture-deficient conditions. There is insufficient analysis on the relationships among soil moisture, plant N uptake, DIN transport, and DIN export in moisture over-sufficient conditions, and how these can be incorporated into simulations. Instead of seeking a final detailed model of plant DIN uptake processes, this project is designed to improve the estimate of DIN export and provide a reasonable relationship among soil moisture, flow, plant uptake, and DIN export when the Michaelis–Menton kinetics is used in the HSPF watershed model.

Nitrate and ammonia are the two simulated plant uptake nitrogen components in HSPF. They are simulated with the option of different preferential uptakes, as well as with different behaviors in sorption and transport. This paper does not discuss these issues, but for simplicity generalizes nitrate and ammonia as DIN. The HSPF V.11 also uses the Michaelis–Menton saturation kinetics for DIN immobilization in soil and contains a similar miscalculation. We also modified the codes corresponding to DIN immobilization, however, this will not be discussed in this paper.

## 2. Methodology

We will first review the effect of soil moisture on plant DIN uptake. We will then evaluate the simulation of plant uptake by HSPF V.11 and by our modified methods. Our work is based on the HSPF V.11 code, including the simulation of hydrology and nitrogen cycles. We modified the HSPF code pertaining to plant DIN uptake using the Michaelis–Menton saturation kinetics and then ran the CBWSM using both the HSPF V.11 code and our modified codes.

The current CBWSM consists of 94 model segments (Fig. 1). Each segment simulates eight types of land uses including urban land, agricultural land, and forests. The flow and nutrient loads discharged from the forest land use to the water body (i.e., edge-of-stream load) of a model segment was output and analyzed. Since Segment 230 was used in our analysis of DIN export associated with gypsy moth defoliation (Wang et al., 2001), the external conditions and user-specified parameters in this study were based on those for forests of Segment 230 (Fig. 1) by the CBWSM Phase 4.3 calibration (http://www.chesapeakebay.net). The models were run for 10 years, from 1985 to 1994 with a 1-h time interval. Since the HSPF V.11 code in hydrology processes was not modified, our modified codes and the