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Comparisons of measured stream flow with drainage and runoff simulated by a soil-vegetation-atmosphere transport model parameterized with GLOBE student data

Jeffrey Melkonian [a,*], Susan J. Riha [b], Jessica Robin [c], Elissa Levine [d]

[a] *Department of Crop and Soil Sciences, 1123 Bradfield Hall, Cornell University, Tower Road, Ithaca, NY 14853-1901, United States*
[b] *Department of Earth and Atmospheric Sciences, 1123 Bradfield Hall, Cornell University, Ithaca, NY 14853-1901, United States*
[c] *SSAI, NASA/Goddard Space Flight Center, Greenbelt, MD, 20771, United States*
[d] *NASA/Goddard Space Flight Center, Greenbelt, MD, 20771, United States*

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Summary Predicting runoff and drainage from landscapes and correlating these with stream flow can be a powerful watershed management tool. We examined the feasibility of using runoff and drainage output of a simple soil-vegetation-atmosphere (SVAT) model as a predictor of monthly and daily changes in measured stream flow. Six watersheds in the eastern US were analyzed, located from approximately 35°N to 43°N. They ranged in area from 23 to 2463 km^2 and were 35–65% forested. The SVAT model was parameterized with weather, soils and phenological data largely obtained from a secondary school in each watershed that is participating in the Global Learning and Observations to Benefit the Environment (GLOBE) program. This program is a United States government science education effort promoting scientific inquiry in grades K-12 by providing protocols for collecting environmental data. Monthly measured stream flow and simulated runoff + drainage over a one year period were normalized to the largest value in that period and were compared using linear regression. Simulated monthly runoff + drainage explained between 37% and 76% of the variability in monthly stream flow. Changes in daily

Abbreviations: AEvap, actual evaporation; AT, actual transpiration; ET, evapotranspiration; GLOBE, Global Learning and Observations to Benefit the Environment; PET, potential evapotranspiration; PT, potential transpiration; PEvap, potential evaporation; SVAT, soil-vegetation-atmosphere transport; USGS, United States Geological Survey.

* Corresponding author. Tel.: +1 607 227 9172; fax: +1 607 255 2106.
E-mail address: jjm11@cornell.edu (J. Melkonian).

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simulated runoff + drainage and measured stream flow depended on the simulated volumetric soil water content (θ_v). At low θ_v, large precipitation events (>20 mm) did not result in increased daily simulated runoff + drainage or measured stream flow. At high or saturating θ_v, large precipitation events resulted in increased daily simulated runoff + drainage followed by increased measured stream flow within two days.

Introduction

Large precipitation events can trigger significant drainage/runoff fluxes into surface waters within a watershed. Determining when these fluxes are likely to occur could be a useful tool for predicting the timing and, possibly, quantity of chemical and sediment losses associated with those fluxes. For example, inorganic nitrogen (N), in the highly soluble nitrate form, moves by mass flow with soil water. In agricultural areas under row crop production, N is relatively inefficiently used by the crop. At volumetric soil water contents (θ_v) near or at saturation, precipitation events can cause significant N losses to surface water and groundwater resources (Balkcom et al., 2003; Sogbedji et al., 2001). These losses can also occur in non-agricultural areas of the eastern US that receive significant wet and dry N deposition (Carpenter et al., 1998). Dynamic simulation modeling is an appropriate tool for determining when large runoff and drainage fluxes from soils may occur since these fluxes are the result of factors (evapotranspiration, soil moisture status and soil profile characteristics, vegetative cover, and phenology) which interact in a dynamic and complex way. Soil-vegetation-atmosphere-transport (SVAT) models can be applied within a watershed for this purpose if there is a good relationship between runoff/drainage predicted by the SVAT models with changes in stream flow. Information on the potential for large-scale runoff/drainage events is particularly important at those times when agricultural N applications and tillage typically occur (spring/fall). During this period, crop demand for N is low and precipitation often exceeds potential evapotranspiration for many parts of the US resulting in potentially significant N leaching and sediment losses from agricultural production areas (Sogbedji et al., 2001). Information from the SVAT models could be used by farm managers in that watershed to adjust management practices and minimize N losses by, for example, avoiding N applications to fields when the SVAT models indicate that weather and soil factors could lead to large drainage/runoff events. These models could also be used as components of larger, watershed-scale models for predicting chemical or sediment loading into regional watersheds such as the Susquehanna River watershed (Chesapeake Bay Program, www.chesapeakebay.net) as well as exploring possible remediation strategies for those watersheds.

Application of SVAT models to the analyses of water fluxes in watersheds will depend on the availability of soils, weather, land cover and plant phenology data within a watershed. One potentially valuable source of these data are the Global Learning and Observations to Benefit the Environment (GLOBE) program (www.globe.gov), a US federal interagency program sponsored by the National Aeronautics and Space Administration, National Science Foundation, Environmental Protection Agency, and the State Department, and managed by Colorado State University and University Corporation for Atmospheric Research. The GLOBE program promotes science education by providing participating schools with protocols for collecting environmental parameters including weather, soils, land cover, hydrology and plant phenology data. These protocols were developed and vetted by scientists in the appropriate disciplines and can provide scientifically valid data. GLOBE data from reporting schools are posted on the GLOBE website in a format that can easily be imported into spreadsheet applications for additional processing.

The objective of this study was to use regression analysis to determine how much of the variability in measured monthly stream flow in six watersheds in the eastern US could be explained by changes in monthly sums of runoff + drainage simulated by a simple SVAT model requiring relative few input data. The SVAT model used in this study was GAPS (General-purpose Atmosphere-Plant-Soil simulator; Riha, 2003), a menu-driven model of the soil-vegetation-atmosphere continuum. Soils, air temperature, precipitation and phenology data collected by a GLOBE school located in each of the six watersheds were used to parameterize the SVAT model. Monthly stream flow data were collected from the nearest instrumented water course (United States Geological Survey (USGS) Water Resources, Surface Water Data for the US) to the GLOBE school within each watershed. We also examined the relationship between daily simulated runoff + drainage, and measured stream flow at different simulated θ_v in the spring (when agricultural management decisions are typically made) and mid- to late summer.

GLOBE schools and watersheds

Data from six GLOBE schools (one school in each of six watersheds) were used to parameterize the SVAT model. The GLOBE schools were all located in the eastern US and were selected based on the completeness and coverage of soils, weather, and phenology data reported on the GLOBE website. (We should note that additional GLOBE schools were located in most of the six watersheds. However, these schools did not collect soils data or sufficient weather and phenology data to be included in this study.) Another selection criterion was that the schools be located in the drainage area of a river or stream with a USGS stream flow gage station that reported daily and monthly average stream flow (http://nwis.waterdata.usgs.gov/usa/nwis). Only those watersheds with at least one year's overlap between the USGS stream flow data and data collected by the GLOBE school were selected. The names and locations of the watersheds, rivers or streams, and GLOBE schools are shown in Table 1a. The total land area and the general