Evaluation of a distributed hydrology model to support restoration efforts in small watersheds with limited data: from research scale to management scale

E.S. Brooks[1] and J. Boll[1]

Introduction

Throughout the Pacific Northwest region of the United States there has been an increasing awareness of the impact of point and non-point source pollution on stream and lake water quality. In Idaho over 900 streams have been listed on the 303(d) list for exceeding the total maximum daily loads (TMDL) as defined by the Clean Water act for a number of pollutants, including suspended sediment, phosphorous and water temperature. In order to decrease pollutant loading to acceptable levels, each stream or lake segment has been assigned a Watershed Advisory Group (WAG) who is responsible for developing a watershed implementation or management plan. The challenge in developing these plans is determining which areas in the watershed should receive the greatest amount of restoration in order to bring about the largest decrease in loading. Due to limited time allowances to properly monitor the problem, WAG's must rely on general observations or computer modeling to assist in decision making.

Distributed hydrologic modeling in geographic information systems (GIS) has shown promise as a tool watershed managers can use to identify spatially within a watershed the location of runoff generating areas (Boll et al., 1998; Frankenberger et al., 1999). In general, there are some obvious disadvantages to computer modeling. Typically models require an excessive number of input parameters not readily available in a watershed database, they operate at too coarse of a spatial or temporal scale, or they require excessive calibration, or they are not based on the dominant hydrologic processes in the watershed. It is essential that a model predicts surface runoff with acceptable accuracy before considering erosion or nutrient modeling. Reasonable application of hydrologic models requires limited calibration and data collection for the watershed manager.

This project focuses on testing and developing a distributed hydrologic model which can be used to simulate the hydrology of small watersheds with minimal calibration and publicly available data. This model can then be used to identify regions within a watershed having a high risk of runoff or pollutant transport to assist the watershed manager in directing watershed restoration efforts.

Objectives

The primary objectives are:

1.) Evaluate a GIS-based distributed hydrology model to a small (~2 ha) research scale watershed using publicly available data and detailed spatial measurements of soil hydraulic properties without calibration;

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[1] Department of Biological and Agricultural Engineering, University of Idaho, Moscow, ID 83844-0904, USA, broo2789@uidaho.edu, jboll@uidaho.edu

2.) Apply the same distributed model to a management scale (~100 km^2) watershed without calibration using publicly available input data and the grid scale hydraulic properties from the research scale watershed.
3.) Quantify the spatial and temporal changes in the risk of runoff throughout the management scale watershed.

The soil moisture routing model

The Soil Moisture Routing (SMR) model was adopted and modified for this analysis. The soil types that best fit this model consist of a relatively thin, permeable soil layer over a much less permeable fragipan, bedrock, or other restricting layer. This profile is typical of upland soils in the glaciated regions of the USA where a fragipan or bedrock limits root growth and water movement. The model is most effective in areas of steep topography, where slopes are significant enough to be the main cause of lateral flow.
SMR is based on a water balance at each time step for each grid cell of the area of interest. The original SMR model is run on a daily time step. Soil moisture content for each cell is predicted, and any moisture above saturation results in surface runoff. Inputs to each cell are daily precipitation and lateral flow from uphill cells, while outputs are lateral flow to downhill cells, percolation into the subsurface, evapotranspiration, and surface runoff. For each cell, the water balance equation is written as

$$D_i \frac{d\theta_i}{dt} = P(t)_i - ET(t)_i + \sum Q_{in.i} - \sum Q_{out.i} - L_i - R_i \qquad (1)$$

where

i = cell address
D_i = depth of root zone of the cell
$\square_i$ = volumetric moisture content of the cell
P = precipitation (rain + snowmelt)
ET_i = actual evapotranspiration
$\Sigma Q_{in.i}$ = lateral inflow from surrounding upslope cells
$\Sigma Q_{out.i}$ = lateral outflow to surrounding downslope cells
L_i = leakage out of the surface soil layer to bedrock
R_i = surface runoff
t = time

Calculation of the water balance is facilitated by the GIS, which keeps track of input parameters such as elevation, soil data, slope, land use and flow direction as well as the moisture stored in each cell at each time step using simple GIS commands. More details on the SMR model can be found in Boll et al. (1998) and Frankenberger et al. (1999).

Research scale watershed (Troy, ID)

The SMR model was first tested on a research scale watershed, approximately 2 ha in size, near Troy, Idaho. The site is typical of the Palouse Region with a perched water table due to a fragipan at shallow depth. Land use in the watershed is undisturbed grassland, part of the Conservation Reserve Program. The soils in the watershed are classified as the Santa Series, which consist of moderately well-drained soils with a moderately deep profile extending to a fragipan. The mean annual precipitation for the eastern Palouse ranges from 500 mm in the west to over 830 mm in the east. More than 60% of the annual precipitation occurs from November to April with low intensity rainfall or snowmelt. A 10m x 15m grid was established in the test watershed for installation of piezometers. Soil samples were used to identify genetic horizons and their thickness at each piezometer. In addition, the following soil properties were determined in the laboratory for each horizon: saturated hydraulic conductivity, porosity, field capacity, and wilting point. Fragipan conductivity (K_{sub}) was derived from Soil Survey report (Barker, 1981). Perched water table levels are monitored twice daily at ~130 locations. Hourly weather data including (precipitation, relative humidity, wind speed, air temperature, solar radiation and soil temperature) are measured at the site. A flume located at the catchment outlet monitors surface runoff leaving the catchment. Snow water equivalent depths are measured at the site on approximately a weekly basis. An isolated (~18 m x 32 m) hillslope plot was installed at the site to monitor the subsurface lateral flux of water above the fragipan layer. Using these data, grid scale lateral saturated hydraulic conductivity was determined with depth above the fragipan (Brooks et al., 2000).

The accuracy of the SMR model will be assessed using both the perched water table fluctuations and the flume outflow. Figure 1 shows predicted versus observed water table flucations at the site using the SMR model (taken from Boll et al., 1998).

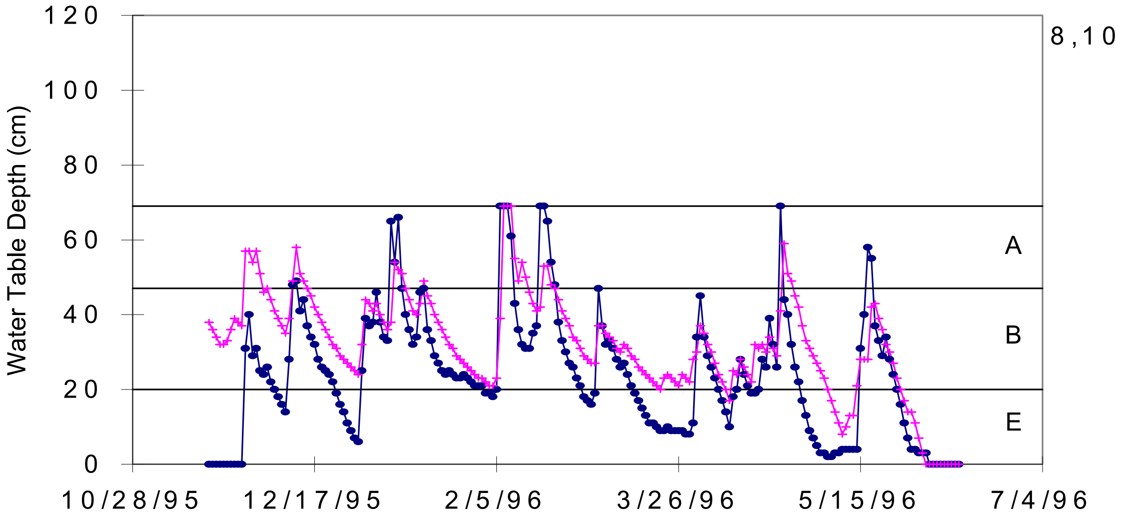

Fig. 1. Predicted (+) versus observed (•) water table depth above the restricting soil layer based on the SMR model with three soil layers.

Management scale watershed (Paradise Creek Watershed)

The management scale watershed in this project is the Paradise Creek Watershed. This watershed is located roughly 10 km west of the Troy, ID research scale watershed. The dominant land practice is dry land farming of wheat, peas, and lentils. Logging occurs in the headwater region of the watershed and the city of Moscow is situated just upstream of the watershed outlet. Paradise Creek exceeds the total maximum daily load limit for water temperature, sediment, and phosphorus. Both state and county soil

conservationists are currently identifying regions within the watershed to implement management practices aimed at reducing the runoff and sediment loading to the creek.
A long term catchment scale monitoring project was started in July 2000. Three stream gages were installed throughout the watershed to isolate the contribution of flow from forest, agriculture, and urban regions. These stream gages record 15 min streamflow, turbidity, and temperature. An automated water sampler grabs flow proportional samples which are used to develop rating curves between turbidity and suspended sediment concentration. Within the watershed a detailed network of both automated and manual weather stations have been installed.
The SMR model will be applied to this watershed and model accuracy will be assessed based at each of the stream gage stations using the stream flow measurements.

Risk analysis

The output from the SMR model will be described in terms of risk of runoff. The probability of runoff will be assessed using a 10 year simulation. The watershed will be delineated into regions which have the highest potential for the transport and delivery of pollutants.

Summary

The increasing need for timely stream and watershed restoration within the United States requires watershed managers to conduct large scale watershed assessment. Distributed hydrologic modeling can be a useful alternative if the model can be used with minimal calibration and publicly available data. This project describes a model which can be used to spatially predict the risk of runoff throughout a watershed. It has been demonstrated to be applicable at the smaller research scale and at the larger management scale.

References

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