SYNOPSIS

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Title: A Problem-solving Tool for Mitigating the Impact on Water Quality of Management Practices in Small Rural Watersheds.

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Congressional District: 5^{th} Washington; 1st Idaho

Focus Category: HYDROL, M&P, NPP

Descriptors: Water Quality, Winter Hydrology, Decision Models, Watershed Management

Problem and research objectives:
A productive approach for watershed water quality improvement is to act at relatively low levels of integration (i. e., small watersheds). At this scale, the number of landowners and water quality issues involved is limited. Analysis and implementation of corrective solutions are more manageable than when evaluating large basins as a whole. Evaluating water quality changes in smaller watersheds also means that changes in watersheds within a larger basin can be compared and analyzed. The objective of this project is to develop a computer-based tool for small watershed analyses applicable to the Pacific Northwest (PNW) where rain and snowmelt, often on frozen soil, dominate runoff and sediment production. However, the framework must be generic enough for applications elsewhere.

Methodology:
The following tasks will be accomplished to address the objective of this study:

1. Develop a geographic information system for data management and display.
2. Finalize and test a weather generator to produce long-term series of daily weather data.
3. Develop a hydrologic model that includes the effects of snow accumulation/melting and frozen soil conditions as they occur in the Pacific Northwest.
4. Develop a cell-based surface and subsurface-hydrology simulator, including overland water and contaminant flow, and groundwater loading estimates.
5. Improve and test a simulator of productivity and water and nutrient balances for crop, range, and forestlands to be applied in each cell.
6. Develop a state-of-the-art user interface to handle the GIS-based watershed database and weather records, parameterize the simulators, specify changes in management practices over crop, range, or forested lands, and provide utilities for output customization, risk, and frequency analyses.
7. Apply the tool to a real watershed as a case study.

Principal findings and significance:
The development of a protocol for interfacing simulation models with ARC/INFO GIS software was completed. The Spatial Analyst for ARCView, a commercially available and widely used software package was customized for geographical/spatial hydrologic analyses that are relevant to this project. Integration of ArcView and the GIS functions required by the watershed analysis tool was also completed.

The technical development, testing, and the development of a user-friendly software package for ClimGen (weather generator) was finalized, including additional features to improve temperature generation and to estimate solar radiation and vapor pressure deficit from temperature data, the latter allowing the application of the watershed model to areas with limited availability of weather records.

The Hydrology Component

In the Pacific Northwest (PNW), the risk of large runoff and erosion events is often complicated by the occurrence of three or four cycles of freezing and thawing during the winter. High runoff events are usually associated with fast thaw of the soil due to rising temperatures or warm precipitation over the watershed. In addition, due to migration of water to the frozen layers, when the soil thaws, it becomes saturated and very susceptible to erosion. As soil freezes, the infiltration is reduced, the stability of the aggregate is decreased, and consequently, runoff, erosion, and non-point pollution are expected to increase. To incorporate these effects in the watershed model, a soil freezing/thawing submodel based on the Stefan solution with heat storage was developed. This submodel was tested against field data and the SHAW model (a detailed energy balance-based, short time step model) outputs for the same set of conditions. Simulated values of duration of the freezing periods, number of freezing cycles per season, and frost depth were compared with measurements. Snow and soil frost data were measured at the Palouse Conservation Field Station (PCFS) near Pullman, WA from 1983 to 1991. Climatic data, including daily air temperature, precipitation, radiation, and other variables were also available. The submodel performed well in predicting soil freezing under the conditions of the PNW. The number of soil frost cycles was simulated well while the average length of the cycles was somewhat overestimated. The SHAW model further overestimated the average length of the frost cycles compared with our submodel. The high variation in the length of the cycles was well simulated by both models. Similarly, the timing of the date where freezing starts was also satisfactorily simulated. A lag of around 5 and 3 days, for the SHAW and our submodel, respectively, was obtained. The frost depth was overestimated, on the average, by 1.2 cm, with a range from 12.2 cm underestimation to 8.9 cm overestimation. The SHAW model underestimated frost depth by 6.0 cm on the average, with a range from 19.0-cm underestimation to 6.1-cm overestimation. Adequate prediction of snow depth appeared critical in the simulation of frost depth.

Also in terms of hydrologic modeling, a one-dimensional finite difference numerical solution for water flow in the vadose zone was completed, including greater flexibility in boundary conditions, time step, and soil layering with the purpose of increasing the robustness of the numerical solution and/or computational speed. A sub-model to disaggregate daily rainfall into

30-minute intervals was finished. A numerical model (NM) for runoff calculations was implemented and compared with the traditional curve number approach (CN). Both methods were tested using 13 years of field data that included several soil surface conditions. The NM model showed the best agreement with the observed data, although some overestimation of the runoff for conditions that include residue and grass was found during the winter and, more markedly, in spring. Underestimation was found under bare soil conditions, which was attributed to soil surface sealing. The performance of the model improved when the hydraulic conductivity of the top layer was reduced by a 10-fold to indicate degradation of surface structural conditions. The model seems sensitive to this parameter, which may show significant spatial and temporal variation. Temporal variations can be attributed to soil structure deterioration after winter runoff, producing crusting and soil sealing that leads to less infiltration capacity. The CN model performed adequately for bare soil, but it overestimated runoff for the rest of land uses. This model could be an alternative if the numerical solution is not available, provided that calibration of the curve number could be performed to better represent residue and grass cover conditions. The original CN model did not simulate adequately runoff and clearly underestimated for all land uses but grass.

Other activities for this year included the continuation of testing and validation of a sub-surface hydrology component for the model. As described in the last progress report, the lateral hydraulic conductivity is a sensitive parameter in the model. This discussion was presented at the 1999 Fall meeting of the American Geophysical Union with a poster entitled "Using Field Measurements to Address Scale Problems with the Ksat Parameter in a GIS-Based Distributed Hydrologic Model." To further understand the magnitude of lateral saturated hydraulic conductivity in the Palouse region, a 18 m x 30 m isolated hillslope plot, similar to that presented by Parlange and others was installed at the Troy catchment. Upslope lateral flow was diverted using a tile line installed on the hydraulically restrictive fragi-pan located approximately 0.75 m below the soil surface. The downslope lateral flow was collected in a tile line and measured using an automated tipping bucket installed in an insulated winter shelter. A surface runoff trough was installed and plumbed to a tipping bucket to quantify the magnitude and timing of surface runoff. The plot boundary was isolated using sheet metal plot borders. To ensure subsurface water did not bypass the tile lines, plastic sheeting was installed along the borders from the fragi-pan to the soil surface. Three automated piezometers measured perched water table fluctuations twice a day while five piezometers were measured during each site visit to identify the drawn down curve of the water table to the downslope tile line.

The data collected from the plot will be used for several purposes. First, a mass balance of the water in the plot will give an estimate of the amount of water that vertically percolates through the fragi-pan layer. Secondly, the rate at which the plot drains during the spring melt will be used to calculate the effective lateral hydraulic conductivity of a 18 x 30 m block of soil in a landscape. The calculated lateral hydraulic conductivity will be compared to watershed scale estimates using drought flow analysis and soil core scale (< 10 cm) hydraulic conductivity. These results can also be used to assess the sensitivity of the model to scale. This work is currently being completed.

A bromide tracer study was conducted within the hillslope plot during melt conditions. Bromide was placed 7 m upslope of the tile line. The first bromide was detected at the tipping bucket after 9 hours, indicating a travel time of approximately 19 m/day. The peak bromide concentration occurred after 60 hrs. Both these findings confirm the large influence of subsurface lateral flow on the hydrology of the catchment. This experiment will be further analyzed to calculate lateral hydraulic conductivity for the site.

In addition to the hillslope plot, monitoring continued at the Troy ID catchment including automated perched water table measurements throughout the 2 ha catchment, surface runoff measurements at the outlet, and a complete set of meteorological parameters. In order to test and validate the snow melting algorithm in the model snow water equivalent depth was measured at three locations representing different solar incident angles and snow drift patterns. Measurements were made weekly during snow accumulation and more intensively during melting conditions. Snow depth measurements were also made at each piezometer location (140 total) on two different days during snow melting conditions to validate how well the model can represent the spatial distribution of snow melting.

As discussed above, in the Palouse region the runoff and erosion is highly accelerated by a shallow frozen soil layer. When a soil freezes the soil pores fill with ice which significantly reduces infiltration and increases runoff. In order to quantify the reduction in infiltration due to a frozen soil layer infiltration experiments were conducted using a rainfall simulator. Runoff was measured from 1 m^2 plots installed before the soil froze in bare and tilled soil. Winter experiments could only be conducted on soil with a relatively thin (<10 cm) frozen soil layer due to the warm winter. The experiments showed that the infiltration on average was limited for a short period of time (~10 minutes) before macro-pores thawed and conducted the water through the frozen soil layer.

An analytical solution was developed for overland flow over a hillslope based on the Saint-Venants equations. This solution was designed specifically for the application in a GIS cell-based model. The analytical solution was first tested using published data using a hillslope elsewhere. In the final phase of the project, we will include this solution in our cell-based model to provide flow depth and velocity on an event-basis.

The Erosion Component

As described in the last progress report sediment detachment, transport, and deposition is based on the stream power approach similar to that presented by Hairsine and Rose. In order to apply and test the erosion component it was necessary to conduct field experiments under typical thawing conditions of the Palouse region. Rill erosion experiments similar to the WEPP cropland soil field erodibility experiments were conducted in the summer on unfrozen tilled soil, in the winter of partially frozen soil, and in the spring on near saturated soil which had settled over the winter due to freeze/thaw cycles. The sediment samples from these experiments are currently being analyzed. These experiments will be used to determine the change in the erodibility of a Palouse soil during distinct seasons of the year.

A simple theoretical algorithm based on the work by Hairsine and Rose was developed and can be included in the model as soon as flow depth and flow velocity are determined by the surface runoff module. Inclusion in the model is expected in the final phase of the project.

CROPSYST Watershed Model validation

The watershed model is currently operational. A first complete version of the user interface, data handling, simulation control, and output handling is available. Current work is focusing on improving the program as the model is tested. Data from the Troy, ID site are being used to validate the current version of the watershed model. Main concern continues to be computational speed and efficiency to increase the relative size of watersheds to be simulated. Additional testing will be performed before the end of the project.

Information Transfer Activities:

Activities in this project have been presented to meetings of the American Geophysical Union and the American Society of Agricultural Engineers.

Publications:

Brooks, E.S., P.A. McDaniel, and J. Boll. 1999. Using Field Measurements to Address Scale Problems with the Ksat Parameter in a GIS-Based Distributed Hydrologic Model, Poster presented at the Fall Meeting of the American Geophysical Union, San Francisco, CA.

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Wang, G., S. Chen, J. Boll, C.O. Stöckle and D.K. McCool. 2000. Modeling overland flow based on Saint-Venant equations using a discretized hillslope approach. Submitted to Water Resour. Res.

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