Watershed Modeling to Evaluate Water Quality at Intakes of Small Drinking Water Systems

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Summary

Water quantity and quality at surface water supply intakes are of serious concern nationwide, however, there exists no research on evaluation of water quantities and qualities at surface water supply intakes and development of comprehensive watershed modeling tools to do so. Furthermore, no existing model is capable of comprehensively simulating all of the hydrologic, upland soil and stream bank erosion, sediment transport, and fate and transport of nutrients and pesticides processes that are necessary to comprehensively assess the water quantity and quality problems and help make the best management decisions to eliminate or minimize them.

These issues are addressed here and, being a premiere study, major efforts were devoted to the fundamental issues and goals, e.g., review and selection of the most suitable long-term continuous watershed simulation model, investigating its theoretical bases, formulations, and major weaknesses, setting up the model, learning its procedures, and making it operational (normally a minimum of one-man-year process), selecting a complimentary and compatible storm event watershed model to enhance storm event simulations of the former, selecting a watershed in Illinois suitable for the study, calibration and validation of both the models to the selected watershed based on limited data available, and assessments of long-term water quantities and qualities at intakes of all the small public water supply systems within the watershed, as examples.

The Soil and Water Assessment Tool (SWAT) was found to be the most promising long-term continuous watershed simulation model and for enhancement into a more comprehensive model. SWAT is a well-documented and user-friendly tool and is available at: http://www.epa.gov/waterscience/basins/bsnsdocs.html#swat. A storm event hydrologic model was selected to enhance SWAT's storm event hydrologic simulations.

The 8,400 km^2 Little Wabash River watershed in southeastern Illinois was chosen because its favorable water supply and watershed attributes. SWAT was run on the Little Wabash River watershed using GIS data on topography, soil, and land use retrieved from links provided at the USEPA's BASINS database and daily precipitation and air temperature data at fourteen precipitation gages obtained from the National Climatic Data Center. The model was calibrated and validated using daily flow records at four gauging stations – Effingham (620 km^2), Wayne City (1,200 km^2), Clay City (2,930 km^2), and Carmi (8,000 km^2) – obtained from the USGS, and water quality measurements made by Illinois Environmental Protection Agency in cooperation with Illinois Department of Natural Resources at these stations. The storm event hydrology model was validated only for the uppermost portion of the watershed draining to Effingham using storm event rainfall data at two of the gages located there, storm event flow records at Effingham, and parameters from calibration and validation of the SWAT.

The long-term continuous hydrologic simulations were evaluated by comparing simulated monthly average flows with monthly observed flows at the four stations. Coefficient of determination and Nash-Sutcliffe coefficient for the individual years, cumulatively for the 5-year calibration period (1995-1999), and cumulatively for the entire 8-year simulation period (1995-2002) at the four stations were calculated. Values for three of the stations were above or near 0.5 and, therefore, had reasonable overall predictions of monthly flows. Although the overall statistical values for Wayne City were low (0.26-0.37), values for five out of the eight individual years were over or close to 0.5. Therefore, overall model performance at Wayne City in simulating monthly flows can also be considered reasonable. To the best of our knowledge, this is the first time that such spatially and temporally distributed statistical evaluation of watershed model results have been done.

Visual comparisons of simulated and observed monthly flow hydrographs showed that the model reasonably predicted monthly average flows with some discrepancies, especially with peak flows. Therefore, SWAT is a promising long-term continuous simulation model which needs enhancements in storm event simulations for improving its peak flow predictions. A storm event hydrologic model was made to be complimentary and compatible with SWAT using of a smaller (15-minute) time step and a unique combination of the runoff curve number method for rainfall excess computations and kinematic wave equations for flow routing and physical bases of these routines with the convenience of only three parameters (*CN*, *n*, and *ELSHC*) to calibrate are responsible for predicting more accurate high and peak flows during intense storms. Additions of these routines to SWAT would be a significant enhancement as these parameters are interchangeable and the models are compatible and complementary, which is unique.

Calibration of the water quality component of SWAT was based on limited data: since the water supplies no longer analyze water at their intakes, modeling was done using sporadic concentration measurements taken approximately once a month at only the four stations. Visual comparisons of simulated and observed (estimated) monthly sediment, total phosphorous, nitrate N, and ammonia N loads at the four stations and TKN only at Carmi during the 5-year period (1995-1999) were mixed and uncertainty of the water quality results was of a serious concern and, therefore, no attempt was made to evaluate the potential effects of management practices.

For enhancing SWAT with NOAA high resolution (4-km grid) daily radar precipitation data, radar and gage precipitation data at 7235 stations around the continental United States were first compared. Unfortunately, the comparisons showed wide scatter of the data showing that research and efforts are needed to improve the radar estimations of precipitations, therefore, SWAT was not enhanced for use of these data.

Being a premier study, additional SWAT enhancements in storm event soil erosion, stream bed and bank erosion, and transport of sediment, nutrient and pesticide simulations were identified. Uncertainties resulting from deterministic modeling of natural processes and measurements or observations of data used in modeling, must be considered when using model results in management decisions and policy makings, which are subjects of future research. Training for using the modeling tools needs to be given to the scientific or engineering consultants working for the small public water supply systems as part of continued extension work.