A WATERSHED MODELING FRAMEWORK FOR MILITARY INSTALLATIONS: ASSESSMENT OF THE HYDROLOGIC AND SEDIMENT WASHOFF IMPACTS OF MILITARY MANAGEMENT ALTERNATIVES

Anthony S. Donigian Jr., President, AQUA TERRA Consultants, Mountain View, CA, donigian @aquaterra.com;
John Imhoff, Vice President, AQUA TERRA Consultants, Ouray, CO, jcimhoff@aquaterra.com;
Anurag Mishra, Associate Engineer, Mountain View, CA, anmishra@aquaterra.com;
Patrick Deliman, Director of Environ. Modeling, USACE ERDC,Vicksburg, MS, Patrick.N.Deliman@erdc.usace.army.mil;
Eileen Regan, Senior Scientist, AQUA TERRA Consultants, Golden, CO, ecregan@aquaterra.com

Abstract

The Strategic Environmental Research and Development Program (SERDP) identified the need to provide Fort Benning, Georgia (and eventually other military installations) with immediately usable and effective models that can be implemented for compliance and long-term watershed planning and management. The subject of this paper is a SERDP-funded project that focuses on the development of a watershed modeling system for Fort Benning, GA using the U.S. EPA BASINS framework. The objective of this four-year effort is to identify, adapt, and develop watershed management model(s) for Fort Benning that address impacts on watershed hydrology, sediment, water quality and related ecosystem processes and outcomes resulting from military activities and natural resources management.

The 2005 Base Realignment and Closure (BRAC05) decisions realigned thousands of additional troops and hundreds of military vehicles to Fort Benning and other military facilities, increasing the impact of military operations on the base watersheds. Soils within the Fort Benning watersheds, in general, are highly erodible, and a number of streams are currently listed as sediment impaired under the Federal Clean Water Act Section 303(d). The demands of BRAC05 have direct impacts on runoff, sediment and pollutant generation and transport throughout the watershed. Prudent planning is needed using analysis methods capable of linking land disturbance activities to sediment washoff, and instream impacts on water quality and ecological endpoints.

During the first two years of this project, a baseline Fort Benning Watershed Model was developed and applied to current watershed conditions. Concurrently necessary enhancements to two of the BASINS models (HSPF and AQUATOX) were identified. Enhancements that have been undertaken include the following:

- Generalized 'hybrid modeling' capability that enables use of HSPF in parallel with smaller-scale, more detailed models for specific land use disturbance models

- Integration of more robust models for channel flow (EFDC) and channel sediment transport (SEDZLJ), as well as the capability to represent channel bank erosion
- Development of a multi-compartment plant canopy module within HSPF
- Incorporation of the capability to simulate the EPT macroinvertebrate sensitivity metric within AQUATOX

The final two years of the project are devoted to implementing model science enhancements, and using the resulting enhanced model to investigate the land management scenarios that are most relevant to Fort Benning during and directly after the implementation of BRAC05: military training exercises, construction activities (particularly roads), prescribed burning, and timber harvest. This paper describes the project approach and the enhancements that are currently being implemented. Finally, preliminary results that have been achieved by taking advantage of one of the improved modeling capabilities (hybrid modeling of forest roads) are presented and discussed.

INTRODUCTION

Watershed modeling systems are becoming critical tools to support military readiness and advance the sustainability of testing and training lands. Sustainability involves balancing land use and resource protection within the carrying capacity of the watershed. This project (SERDP Project SI 1547) focuses on the development of a watershed modeling system for Fort Benning using the U.S. EPA BASINS (BASINS) framework (USEPA, 2007; Duda et al., 2006). The overarching objective of the project is to identify, adapt, and develop watershed management model(s) for Fort Benning that address impacts on watershed hydrology and water quality and related ecosystem processes and outcomes resulting from military activities and natural resources management.

BASINS is a multipurpose environmental analysis system designed for use by regional, state, and local agencies performing watershed and water quality-based studies. BASINS integrates environmental data, analytical tools, and modeling programs to support development of solutions to watershed management and environmental protection problems. Within BASINS are a suite of modeling packages and tools, ranging from simple to sophisticated. The U.S. EPA's Hydrological Simulation Program-FORTRAN (HSPF) (Bicknell et al., 2005) is the primary watershed model included in the EPA BASINS modeling system, and is the watershed modeling software selected for this application.

HSPF is a comprehensive watershed modeling software package for hydrology and water quality that enables modeling of both land surface and subsurface hydrologic and water quality processes, linked and closely integrated with corresponding stream and reservoir processes. It is considered a premier, high-level model among those currently available for comprehensive watershed assessments. HSPF has enjoyed widespread usage and acceptance, since its initial release in 1980, as demonstrated through hundreds of applications across the U.S. and abroad. HSPF is jointly supported and maintained by both the U.S. EPA and the USGS. This widespread usage and support has helped to ensure the continuing availability and maintenance of the code for more than two decades, in spite of varying federal priorities and budget restrictions. HSPF has been, or is currently being used for watershed studies in the majority of U.S. states, as well as

Canada and Australia.

In addition to HSPF, an ecosystems effects model also contained within BASINS (AQUATOX) is being applied to selected waterbodies at Fort Benning as a component of the project. AQUATOX predicts the fate of various pollutants, such as nutrients and organic chemicals, and their effects on the ecosystem, including fish, invertebrates, and aquatic plants. AQUATOX can be used in conjunction with HSPF to evaluate impacts of land-based activities and management practices on aquatic ecosystems by means of either indicators (e.g., chlorophyll a, clarity) or ecological endpoints (e.g., fish). BASINS provides a direct linkage between HSPF results and AQUATOX.

Fort Benning is a United States Army Installation, located mostly in west-central Georgia with a small portion in east-central Alabama (Figure 1). Fort Benning is southwest of Columbus in Muscogee and Chattahoochee counties in Georgia and Russell County, Alabama. Fort Benning encompasses approximately 285 square miles within the USGS Hydrologic Unit 03130003, Middle Chattahoochee-Walter F. George Reservoir. The Chattahoochee River runs through the western portion of the Installation. Most of the Installation drains into the Upatoi Creek, a tributary to the Chattahoochee River just downstream of Columbus, GA.

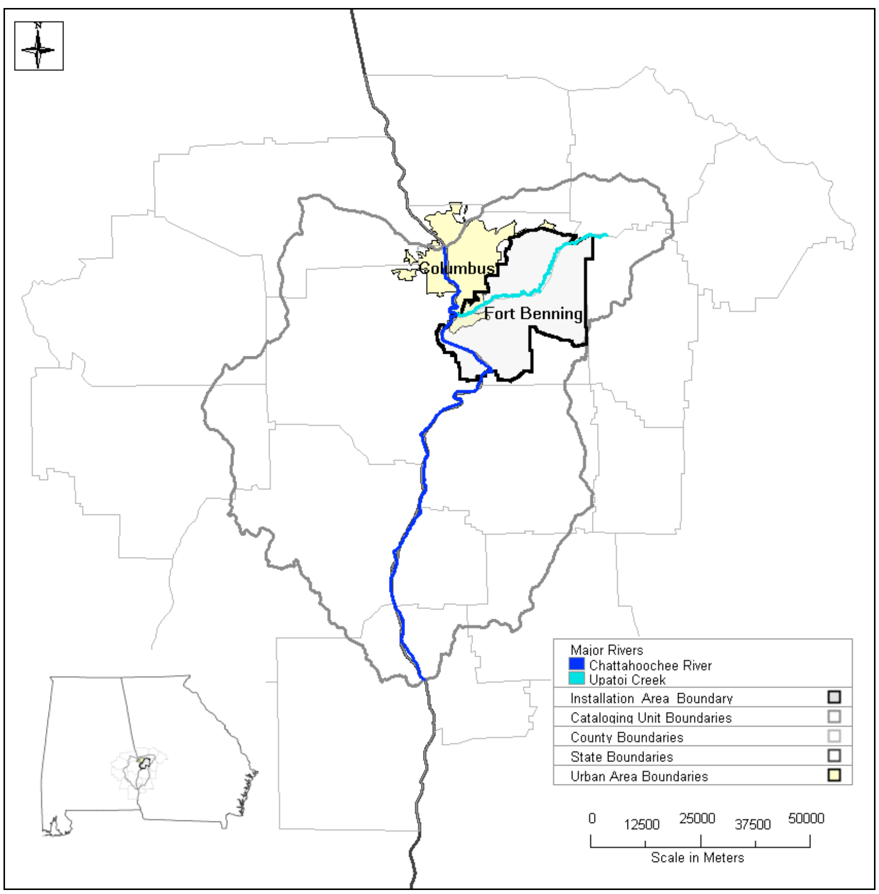

Figure 1 Fort Benning location, municipalities, and major rivers.

METHODOLOGY

The project approach has used the BASINS modeling system as the toolkit for pursuing two interrelated 'paths', an application path and a research path (Figure 2). The application path is focused on integrating existing data and products into BASINS; development of an initial calibrated model of Fort Benning; and identification of apparent model/system limitations. The research path directs its focus on designing and implementing model enhancements that improve on recognized watershed model weaknesses, and more fully developing capabilities relevant to representing and evaluating military land uses and activities. Phase 1, which has been completed, resulted in an initial calibrated baseline model of Fort Benning, and the identification and selection of modeling and model code enhancements. Phase 2 focuses attention on refining strategies and model scenarios that take advantage of the enhancements to the data base, tools and watershed models that have been achieved throughout the first two years of the project; detailed design, implementation and testing of model enhancements; and demonstrating the operation and significance of the model enhancements. This paper describes the model enhancements that are currently under development and suggests the opportunities and benefits that they will offer to the Fort Benning project in particular, but also to other military installations as well as a broader audience of BASINS users.

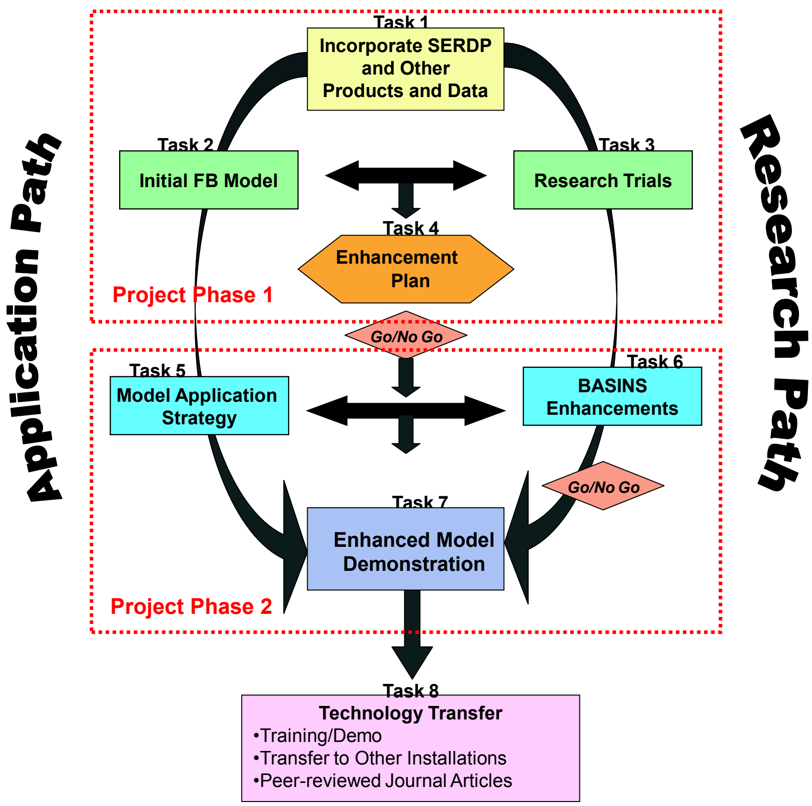

Figure 2 Dual pathway approach for developing a military BASINS modeling system.

MODEL ENHANCEMENTS

Project Research Topics

The model enhancements that this paper describes resulted from investigation of eight research topics:

1. Multiple spatial scales: Techniques and model capabilities that improve a modeler's ability to represent and evaluate combinations of sources and endpoints that have significantly different spatial scales.
2. Sediment washoff/erosion related to military training activities: Enhanced sediment washoff/erosion modeling science to accommodate impacts from military maneuvers and associated equipment.
3. Sediment washoff/erosion related to forest road construction and maintenance activities: Enhanced sediment washoff/erosion modeling science to accommodate impacts from unpaved roads.
4. Channel phenomena. This research topic includes three components:
    a. channel flow: improved methods for modeling dynamic channel flows (particularly low and high flow events);
    b. sediment transport: improved methods for modeling channel sediment transport (particularly for coarse sediments) and
    c. stream bank erosion: integration of methods that enable representation of sediment loads introduced to streams by bank erosion or failure phenomena.
5. Linkages to ecological indicators: Development/integration of methods and tools that enable modelers to link watershed management practices to indicators of aquatic and terrestrial ecosystem impacts.
6. Representation of forest canopy compartment and fire: Improved representation of hydrologic and water quality processes for above-ground vegetation and forest canopy compartments. Improved methods/capabilities for representing the watershed effects of prescribed burning or wildfires.
7. Diagnostic mode capabilities: Improved methods/capabilities for using watershed models in a diagnostic mode to help clarify and quantify source-impact relationships.
8. Rating curve development and integration: Investigate the value of additional flow rating curves to the overall watershed simulation of Fort Benning, and infer the implications for technology transfer to other military installations.

Phase I of the research path assessed each of these research topics in terms of the nature of the enhancements needed, available supporting resources and methodologies, viable enhancement alternatives, and a recommended path forward. Four model code enhancements to the BASINS system (and its individual models) were deemed highly beneficial to improving BASINS' ability to support the evaluation of Fort Benning's critical management issues.

Although significant model code enhancements will not be undertaken to address the other research topics, it should be noted that they remain high priority areas for enhancing the Fort Benning baseline model. These areas have been addressed in part by the Phase I application path, and/or other methods have been identified for incorporating new science and/or data into the baseline model in future efforts. For instance, not enough data are available to characterize the impact of military training on watershed processes to allow for a justifiable code enhancement. However, this issue will be addressed by parameterization and use of current model capabilities to approximate the frequency, intensity, and timing of military training activities.

Selected Research Enhancements

One of the four enhancements selected for implementation required a relatively low level of effort and was implemented in the aquatic ecosystems effects model AQUATOX: the capability to simulate the Ephemeroptera/Plecoptera/ Tricoptera (EPT) macroinvertebrate sensitivity metric was incorporated. The other three enhancements, which are much more complex in nature, are all being implemented in HSPF, and their description comprises the remainder of this paper.

The three research topics that are being addressed during Phase 2 by means of significant model code enhancements and subsequent refinement of the Fort Benning HSPF Watershed Model are as follows:

1. multiple spatial scales,
2. channel phenomena, and
3. forest canopy compartment and canopy management.

Multiple Spatial Scales A need is shared by many watershed managers, including the managers of military installations such as Fort Benning, for techniques and model capabilities that improve the ability to represent and evaluate combinations of sources and endpoints that have significantly different spatial scales. Watershed models and modeling efforts need improved ability to assess management-scale impacts within a larger watershed-scale context. To address this issue, we have implemented a general capability to perform hybrid model applications in which HSPF is used for modeling catchment-scale phenomena, while one or more field- or hillslope-scale models featuring more detailed process formulations for specific activities, sources, or land uses are run in parallel to HSPF, to provide time series flow and loadings for smaller areas with potentially large runoff or water quality impacts. The output from the small scale models is subsequently linked to HSPF in the form of discrete point sources to targeted land segments or channel reaches. Figure 3 provides a schematic representing the communication structure between HSPF and the smaller-scale models.

Certain land uses, such as forest roads, command a multi-spatial scale approach to anaysis. It is a repeated message throughout forestry literature that road erosion is commonly the largest contributor to sediment production within forest watersheds. Design, construction and management of unpaved roads at Fort Benning requires the use of credible methods and models for estimating sediment erosion and its impacts, and these models require a level of smaller-scale detail that surpasses the capabilities currently provided by HSPF. The forestry community considers USDA's WEPP:Road (Elliot et al., 1999) model as the state-of-the art model for estimating sediment yield from unpaved forest roads. To make available a more robust set of

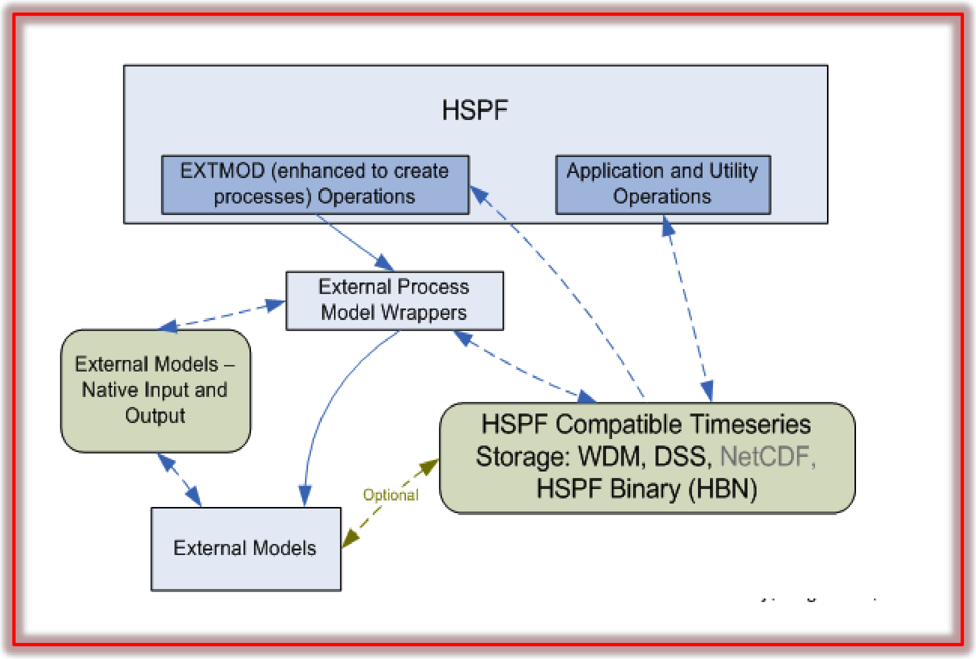

Figure 3 Communication structure between HSPF and small-scale models.

formulations for simulating sediment washoff from Fort Benning's unpaved forest roads, the Project Team is using WEPP:Road as a demonstration application of the hybrid modeling capability that has been developed for HSPF. WEPP:Road enables relatively detailed characterization of road attributes as a means of estimating parameter values for the sediment erosion formulations of the USDA's WEPP model (Flanagan and Livingston, 1995), and hence we believe that it offers a significantly improved capability over HSPF for representing and evaluating road construction Best Management Practices.

Channel Phenomena Improvements to three aspects of HSPF will provide significant benefit to model applications at Fort Benning and other installations. These enhancements relate to simulation methods for instream flow, instream sediment transport, and bank erosion. Previous observations and studies have identified the vulnerability of Fort Benning's stream banks to erosion and failure under both wet and dry weather conditions (Maloney et al., 2006). Representing the additional stream load caused by these sediment-generating phenomena requires improved algorithms for bank erosion, as well as instream sediment scour and deposition of multiple size classes of sediment.

To improve the flow module in HSPF, a hydrodynamic model is in the process of being added. The hydrodynamic model will provide a more accurate calculation of the flow field and resulting bed shear stresses (particularly during runoff events when the flow is unsteady and typically accelerates rapidly during the rising limb of the flow hydrograph) than is achievable with the hydraulics-based, flow routing routine currently in HSPF. To meet this need, relevant capabilities of the Environmental Fluids Dynamics Code (EFDC) (Hamrick, 2007) are currently being integrated into HSPF.

The sediment transport module in HSPF is also being upgraded to add improved capabilities for simulating scour and deposition by integrating the SEDZLJ sediment transport model developed by Jones and Lick (2001) with HSPF. SEDZLJ is an advanced, state-of-the science sediment transport model that represents the dynamic processes of erosion, bedload transport, settling, bed sorting, armoring, consolidation of fine-grain sediment dominated sediment beds, and deposition. Multiple size classes of both fine-grain (i.e., cohesive) and non-cohesive sediments can be represented in the sediment bed that is divided into a user specified number of bed layers.

Currently the Fort Benning HSPF watershed model lacks a method for representing the generation of sediment loads due to events of bank erosion/failure. An empirical-based bank erosion model (Ikeda et al., 1981) is being added to EFDC such that the estimated sediment mass from the eroding bank is added to the sediment bed for the channel reach where the eroding bank is located. This empirical model will calculate the lateral bank erosion rate (in units of bank length/day) as a linear function of the difference between the near-bank, depth-averaged velocity and the reach-averaged velocity at bank-full flow.

Further details on this ongoing effort to enhance HSPF capabilities for modeling channel phenomena are provided in a paper presented by Hayter (2010) at this same conference.

Forest Canopy and Fire In a comprehensive environmental assessment of military training facilities such as Fort Benning, watershed modeling needs to take into account many aspects of the environment, most notably the plant community, as impacted by forest management and prescribed burning treatment, in order to fully evaluate the hydrological consequences and ecological outcomes. Currently, HSPF represents the plant community via simple expressions of its functional relationship with other components of the hydrologic cycle and the nutrient cycle. This approach generally suffices in a hydrologic and water quality study; however, intensively disruptive events, such as prescribed burning, timber harvesting, etc., call for more complete representation of the plant community in terms of temporal dynamics related to physical presence (e.g. canopy) for both overstory and understory vegetation, and substrate fluxes between the plant community and its soil environment. Increasing the level of explicit representation of these dynamic processes will provide HSPF with an ability to comprehensively evaluate the impact of prescribed burning and forest management, and also the potential ability to quantitatively evaluate ecological performance of a given landscape from a vegetation perspective. We are currently pursuing two enhancements related to forest canopy and the impacts of fire:

1. Refine canopy processes in HSPF to accommodate multi-level forest conditions consistent and compatible with the current representation, and based on relatively simple model inputs comparable to the current HSPF formulations, i.e., adding another canopy (or multiple) layer for understory vegetation.
2. Refine the model's ability to accommodate fire impacts, either through refined model capabilities or development of a separate 'fire' module to oversee and impose adjustments to reflect fire occurrence, intensity, and areal distribution within the watershed. A 'fire' module would provide users with the flexibility to define the rate of return/regrowth, parameter adjustments for canopy and soil, and fire intensities, along with other needed information.

STATUS AND PRELIMINARY RESULTS

At the time of writing of this paper (January 2010), results are not yet available for the enhancements related to channel phenomena and forest canopy compartments. EFDC and SEDZLJ have been statically coupled to HSPF, and the empirical bank erosion algorithm has been added to EFDC (see Hayter et al., (2010) for details). At present, EFDC and SEDZLJ are being set up to simulate the hydraulics and sediment transport in a portion of the Fort Benning watershed (Upatoi Creek) as a test case for the enhanced version of BASINS. Measurements need to be taken at the site to determine the coefficients in the empirical bank erosion equation. The forest canopy compartment enhancement is still under design. Results for these two enhancements will be presented in subsequent papers. However, preliminary results have been achieved for the hybrid modeling demonstration using a stand-alone application of WEPP:Road.

The current WEPP:Road results (Table 1) have been achieved using the model in a stand-alone manner to estimate unit area erosion for representative road and fillslope modeling segments. Results for the 14 modeling segments fall in a similar range (1.8 – 8.2 tons/ac/yr) to those generated using the 'high' target loading sediment value in the HSPF watershed baseline simulation (2.3 – 6.1 tons/ac/yr). Imhoff et al. (2010) discusses the method used to establish high and low sediment target values and how the targets are used in the HSPF simulation. Figure 4 illustrates the sensitivity (as computed by WEPP:Road) of road erosion at Fort Benning to road segment length and slope, and Figure 5 illustrates the sensitivity of sediment delivery to the stream channels to forest buffer flow length and slope. (Road length estimates correspond to the average length of run for a road before it reverses slope direction.)

Table 1 Comparison of sediment erosion model results for HSPF and WEPP:Road (tons/acre/year)

Fort Benning Model Region	Road area (acres)	Erosion Estimates from Road & Fillslope (tons/acre/yr)	
		HSPF	WEPP:Road
Hastings Range	165	1.0-3.8	4.32
Hastings Range – Military	365	0.8-5.1	4.32
Carmouche Range	631	0.6-6.0	3.54
Carmouche Range – Piedmont	39	0.6-5.0	3.54
Hastings-Range - Piedmont	168	pending	pending
Malone Range # 22	281	0.5-5.0	3.95
McKenna MOUT Site	483	0.9-2.3	2.29
Cactus Microwave Tower	581	0.7-5.1	6.65
Natural Resources Office	302	0.5-3.4	4.58
Lawson AAF	278	0.5-5.9	1.83
Pre-Ranger Site	464	0.6-5.1	4.21
Grisworld Range	300	0.5-4.7	4.59
Alabama Site	68	0.3-2.9	2.09
Columbus Metro AP	36	0.7-6.1	8.24

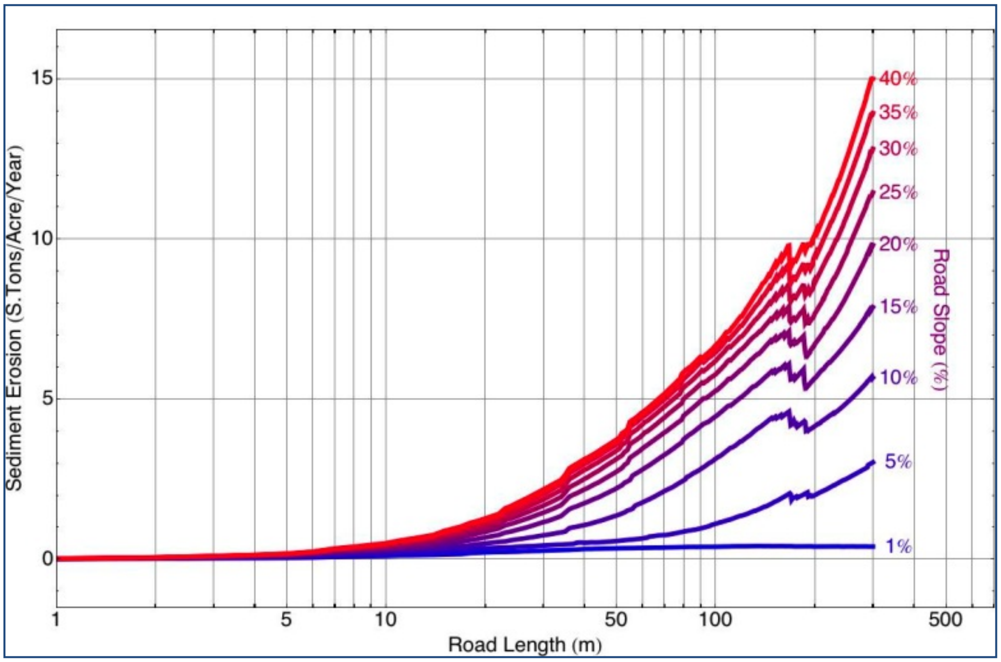

Figure 4 Sensitivity of WEPP:Road erosion estimates to road segment length and slope.

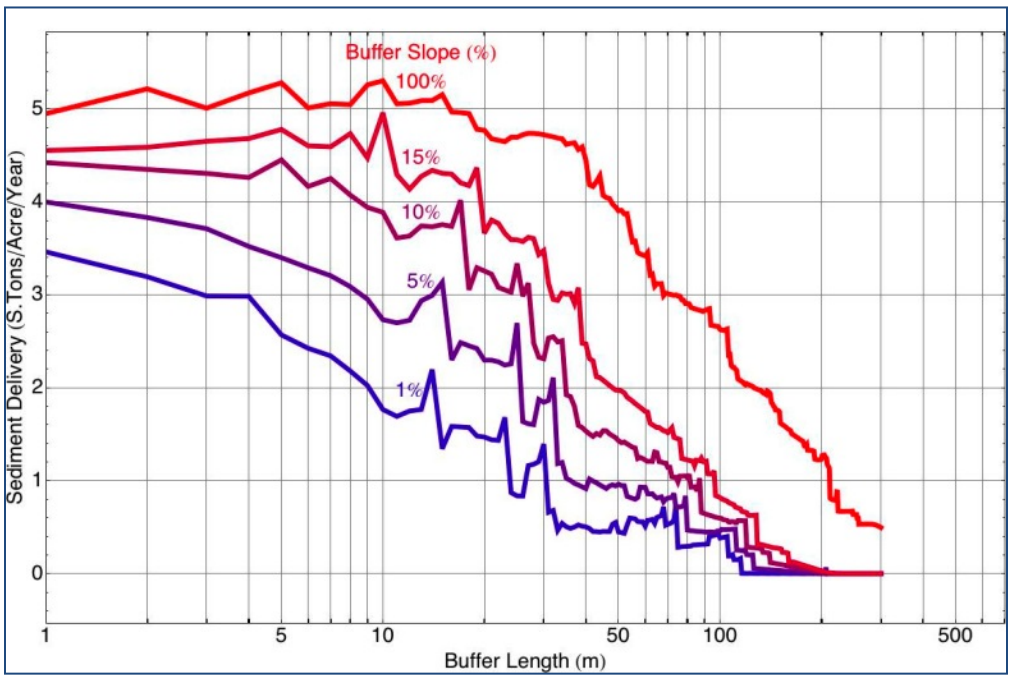

Figure 5 Sensitivity of WEPP:Road sediment delivery estimates to forest buffer flow length and slope.

Additional simulations using WEPP:Road will enable representation and evaluation of management decisions such as increased buffers, alternative road construction or gravel additions to existing roads. The final hybrid modeling simulations will enable the evaluation of the relative impact of alternative road scenarios from a broader watershed perspective.

The path forward during the remainder of 2010 for this model refinement and demonstration effort will entail re-running the final WEPP:Road simulations using the HSPF EXTMOD hybrid modeling capability (see Figure 3) to enable evaluation of watershed-scale impacts; evaluating watershed-scale impacts of unpaved roads in the baseline watershed model; and developing and evaluating alternative scenarios for unpaved roads (new construction and/or alternative road design).

CONCLUSIONS

This paper has described model science enhancements that are being implemented to support a four-year effort to develop the Fort Benning Watershed Model. At the onset of the project it was an expressed objective of the funding organization (SERDP) to *both* improve watershed model science and modeling, in general, *and* to provide the watershed managers at Fort Benning with an effective tool for meeting their planning and regulatory needs. SERDP recognized that success in these activities required that the managers at Fort Benning and other installations have a better means of understanding and evaluating the impacts on watershed hydrology, water quality and related ecosystem processes and outcomes that result from military activities and natural resources management actions. The enhancements that are underway with respect to (1) hybrid spatial scale modeling, (2) improved science for channel phenomena and (3) more detailed representation of forest canopy compartments and fire phenomena offer considerable opportunity for achieving SERDP's objective.

Parallel to the model code enhancements, efforts are underway in Phase II of this project to develop modeling strategies for the Fort Benning watershed that take full advantage of the new capabilities to provide a better planning tool to support the Installation's land management decisions. The demonstration studies that are being designed and performed will serve as a catalyst for application of a military-enhanced BASINS modeling system at other installations.

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The Principal Investigator (PI) for this project is Mr. Anthony S. Donigian, Jr. with AQUA TERRA Consultants, and Dr. Patrick N. Deliman serves as the Co-PI for ERDC.

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