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MODELING SEDIMENT IMPACTS OF TRAINING ACTIVITIES ON MILITARY INSTALLATIONS: APPROACH AND BASELINE MODEL RESULTS

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ABSTRACT: Watershed modeling systems are becoming a critical component of efforts to support military readiness and advance the sustainability of testing and training lands. The Strategic Environmental Research and Development Program [SERDP] Ecosystem Management Project (SEMP) 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.

This project focuses on the development of a watershed modeling system for Fort Benning using the U.S. EPA BASINS framework. The objective of this 4-year effort is to identify, adapt, and develop watershed management model(s) for Fort Benning that address impacts on watershed hydrology, sediment, and water quality and related ecosystem processes and outcomes resulting from military activities and natural resources management.

The 2005 Base Realignment and Closure (BRAC) 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). 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.

This paper presents the preliminary application of the baseline model of BASINS/HSPF to the Fort Benning watersheds, using existing data with specific focus on sediment impacts, sources, and transport modeling. The baseline model application provided the foundation for addressing the model limitations and weaknesses related to representing military training activities, and forest management activities such as prescribed burning.

INTRODUCTION

Watershed modeling systems are becoming a critical component of efforts 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. The project approach uses the BASINS modeling system as the toolkit for pursuing two interrelated 'paths', an application path and a research path (Figure 1). The application path is focused on integrating existing SERDP 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; more fully developing capabilities relevant to representing and evaluating military land uses and activities; and developing and applying modeling strategies that demonstrate the military-enhanced BASINS capabilities. This paper discusses the application path of developing the initial calibrated model of Fort Benning; and identification of model/system limitations.

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MODEL SET UP

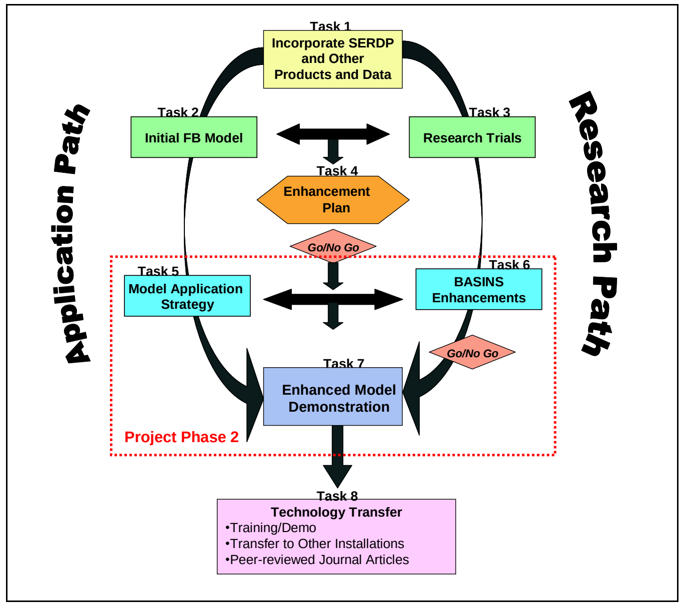


Figure 1. Dual pathway approach for developing a military BASINS modeling system

One of the most important datasets required to conduct HSPF (Bicknell et al., 2005) simulation is precipitation at hourly or shorter time steps. Long term precipitation data at 10 stations was collected at half hour intervals as part of the Ecosystems Characterization and Monitoring Initiative (ECMI) inside Fort Benning. The longest period of rainfall record was from August 1999 to December 2006. BASINS provides a comprehensive database of precipitation records that included hourly precipitation data from Columbus Metro airport in the northwestern part of the watershed, and daily precipitation data on the east side of watershed. These stations were used to fill any gaps in the precipitation data in the ECMI stations. The average annual precipitation recorded at Columbus Metro airport, and Buena Vista was 48.50 in, and 49.89 in, respectively. The precipitation data from these stations were applied to different parts of the modeled watersheds as described later. Pan evaporation data, used to estimate lake evaporation, was available from three US Surface airways monitoring stations located outside the watershed at distances of 37 km, 75 km, and 100 km from the nearest watershed boundary. BASINS also provided the Potential Evaporation (PET) data calculated using Hamon formula (Hamon, 1961), for the 10 active computed PET stations near the study area, of which two were inside the watershed area. Pan evaporation and PET data were less variable and hence the PET data from only the stations located inside the watershed were used for the model simulation. BASINS provided other meteorological inputs including air temperature, cloud cover, dewpoint temperature, wind speed, and solar radiation at two stations within the study area. The ECMI stations also recorded wind and solar radiation data.

Long term streamflow data is important to calibrate the model hydrology. Two stations; Upatoi Creek at Fort Benning, GA (drainage area 447 sq. mi), and Uchee Creek near Fort Mitchell, AL (drainage area 342 sq. mi) had long term streamflow data. Much of the drainage area of Uchee Creek is outside the base, and therefore Upatoi Creek at Fort Benning was used as the primary location for hydrology calibration. Streamflow data was also available at six ECMI hydrological stations from August 1999 to July 2002. These data were not long term and were used to supplement the overall hydrologic calibration effort. Water quality data on Upatoi Creek is available from 1978 to 1984. Some stations in the watershed have intermittent water quality data recorded under different projects. Some projects are continuing in Fort Benning that collect the water quality data either continuously or per storm basis.

When HSPF, or any watershed model, is applied to a watershed, the entire study area must undergo a process referred to as ‘segmentation’. The purpose of watershed segmentation is to divide the study area into individual land and channel segments, or pieces, that are assumed to demonstrate relatively homogenous hydrologic/hydraulic and water quality behavior. This segmentation provides the basis for assigning similar or identical input and/or parameter values or functions to where they can be applied logically to all portions of a land area or channel length contained within a model segment. Since HSPF and most watershed models differentiate between land and channel portions of a watershed, and each is modeled separately, each undergoes a segmentation process to produce separate land and channel segments that are linked together to represent the entire watershed area.

Elevation data in the form of National Elevation Dataset (NED) was obtained through seamless data distribution site (http://seamless.usgs.gov), and SEMP with a resolution of 30m and 10m, respectively. The SEMP layer was available for most of the watershed area except some portions in Alabama, where NED were used. The SERDP ECMI established a set of Watershed Management Units (WMUs) for the area around and including the Fort Benning Installation area. The WMUs and associated streams contain about 682 square miles and are used to define the study area for this project. In addition, the NHDPlus (National Hydrography Dataset Plus) hydrography data that is accessible through the BASINS interface also provided layers of catchments averaging about one-half square mile in area each, along with associated stream segments. The NHDPlus catchments were merged to provide 3rd order or smaller watersheds inside the Fort Benning installation area, and 4th order watersheds outside the installation area (Figure 2). Some of the northern upstream watersheds were divided approximately along the boundary of physiographic regions commonly referred to as the 'Fall Line.' Also, to further segregate the effect of activities within the base versus outside the base, some headwater watershed streams and areas were divided near the installation boundary. The segmentation efforts resulted in 129 subbasins, with an average size of about 3.5 sq. mi within the Base and 8.1 sq. mi outside the Base.

These subbasins were overlaid with Thiessen network boundaries to define meteorological regions across the watershed. The Thiessen network boundaries were developed using the location of 11 ECMI meteorological stations in and around Fort Benning. The subbasins were assigned to each meteorological station based on their location and the polygon area derived from the Thiessen network (Figure 2). During the modeling, precipitation from each meteorological station is applied to the neighboring subbasins based on the Thiessen analysis.

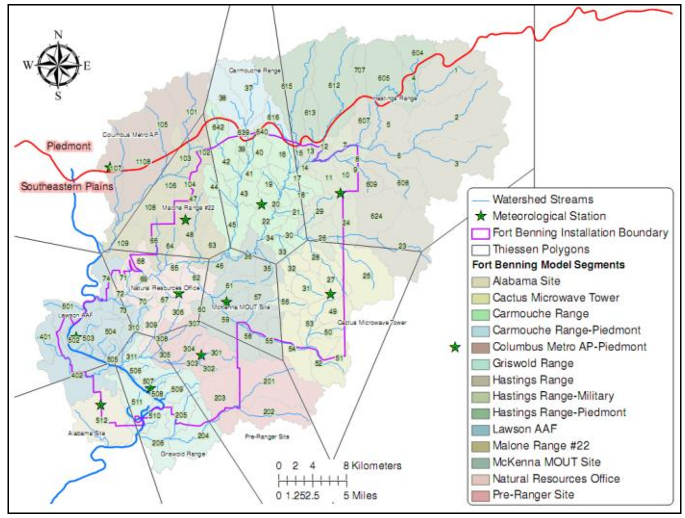


Figure 2. Fort Benning watershed segmentation

Land use affects the hydrologic response of a watershed by influencing interception, infiltration, surface storage, and runoff, and water losses from evaporation or transpiration by vegetation. The movement of water through the system, and subsequent erosion and chemical transport, are all affected significantly by the vegetation, (*i.e*., crops, pasture, or open) and associated characteristics. Land use data was available from SEMP and National Land Cover Dataset (NLCD) 2001. Both layers could adequately represent the study area for general modeling purposes, but the NLCD 2001 data layer contained an explicit wetlands category; and knowing that issues related to wetlands may be significant in the model area we considered NLCD land use data layer as the primary basis for modeling. Some grouping was conducted to simplify the land use distribution.

However, neither of these land use layers provided a comprehensive coverage of categories representing the extensive road network, tank trails, or other military activities which are the direct focus of the study. The road data layer was obtained from the transportation page of the SEMP data repository. This data source includes two categories of roads within the Fort Benning installation: some roads designated as unpaved roads and others designated as trails. Outside the Base, the roads layer was obtained from seamless data distribution site. The tank trails layer was provided by Fort Benning (H. Westbury, personal communication, 2008). In addition, a military land use map developed by Dr. Virginia Dale (U.S. Army Fort Benning, 2006) indicated tracked vehicle areas, wheeled vehicles areas, drop and landing zones, bivouac areas and other land use categories.

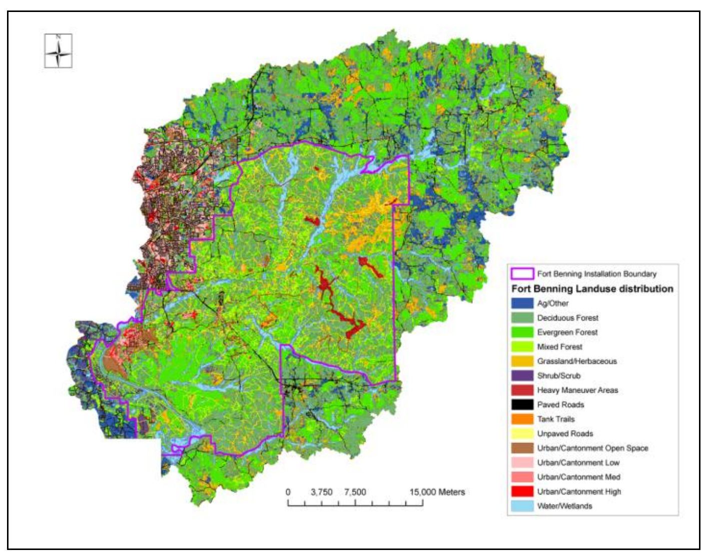


Figure 3. Land use map of Fort Benning watershed

The information on military land uses from these multiple sources was assimilated into a single land use GIS layer. Imagery from Google Earth™ was consulted when conflicts arose. Also, to determine the area of unpaved roads and tank trails within the watershed, since only line coverage was available, an assumption was made that the tank trails are 10m wide, and the paved roads are 30m wide, with 85% impervious paved surface and 15% adjacent pervious buffer. The resulting comprehensive land use map for the entire watershed is illustrated in Figure 3.

Land management at Fort Benning, GA includes prescribed burning to promote healthy habitat for the Red-Cockaded Woodpecker (RCW) currently on endangered species list. Prescribed burning removes the herbaceous and woody shrubs beneath the forest stands that provide cover for the RCW predators; it also improves access for military training, timber management, and reduces fuel for wildfires. The land managers at Fort Benning follow a three year prescribed burn cycle, where about 30% of the forested areas in Fort Benning are burnt every three years. GIS data obtained from SERDP indicated the areas that were burnt during each fiscal year (FY) in Fort Benning. The prescribed burn data for 7 FYs from 1999 to 2006 were compiled to estimate the areas that are burnt at regular intervals. All the areas that were subjected to at least one prescribed burn were assigned to one of three burn cycles; cycle 1 (FY 1999, FY 2002, and FY 2005), cycle 2 (FY 2000, FY 2003, and FY 2006), and cycle 3 (FY 2001, FY 2004, and FY 2007). These cycles were combined with the land use data to obtain the type of forest burnt in each cycle. Table 1 shows the acreage of aggregated land use categories in the complete watershed and Base including the military training categories.

The river channel network in the Fort Benning study area is the major pathway by which flow, sediment and contaminants are transported from the watershed to the Chattahoochee river downstream. The river reach segmentation process requires consideration of river travel time, riverbed slope continuity, cross section and morphologic changes, and entry points of major tributaries. In addition, Section 303(d) reaches need to be represented as model reach boundaries so that flows, water balance, and volume information can be generated for use in TMDL assessments. The channel network in Fort Benning was divided into 127 stream reaches, corresponding to the 129 subbasins (two subbasins do not have a reach and flow into the upstream end of the downstream subbasin) (Figure 2). The drainage area of each reach was derived by summing the area of subwatersheds flowing into a reach, and the drainage area of upstream reach.

The reach hydraulic behavior is defined in HSPF by a function table (FTABLE) for each stream reach, which contains the reach surface area, volume, and discharge as functions of depth, i.e. an expanded rating curve. These tables are generally developed from a rating table applicable to the reach, or by using the Manning equation along with channel cross-section and roughness data. Rating tables were used to generate these FTABLES for gage sites where they are available. The rest were estimated using the regional curve equation and cross sections at the streams obtained by DEM data. Manning's coefficient for different channel conditions was estimated from field surveys, photos and literature values.

Table 1. Detailed land use distribution in the Fort Benning watershed.

Landuse description	Area (ac.) in the complete watershed	Percent of area in complete watershed	Area (ac.) in the base	Percent of area in the base	Area (ac.) outside the base	Percent of landuse that is outside the base
Urban/Cantonment	40445.4	9.3	10410.7	5.7	30034.7	74.3
Evergreen Forest	99128.2	22.8	38840.6	21.3	60287.6	60.8
Deciduous Forest	134906.0	31.0	60304.8	33.1	74601.2	55.3
Mixed Forest	36816.3	8.5	22361.4	12.3	14454.9	39.3
Shrub/Scrub	12875.1	3.0	4784.4	2.6	8090.7	62.8
Grassland/Herbaceous	31638.7	7.3	13354.4	7.3	18284.2	57.8
Ag/Other	26566.2	6.1	0.0	0.0	26566.2	100.0
Paved Roads	10153.8	2.3	3000.4	1.6	7153.4	70.5
Tank Trails	241.0	0.1	241.0	0.1	0.0	0.0
Heavy Maneuver Areas	2289.6	0.5	2289.6	1.3	0.0	0.0
Water/Wetlands	28769.5	6.6	15204.8	8.3	13564.7	47.1
Unpaved Roads	11699.9	2.7	11640.8	6.4	59.2	0.5
Total	435529.6		182432.8		253096.9	

MODEL CALIBRATION

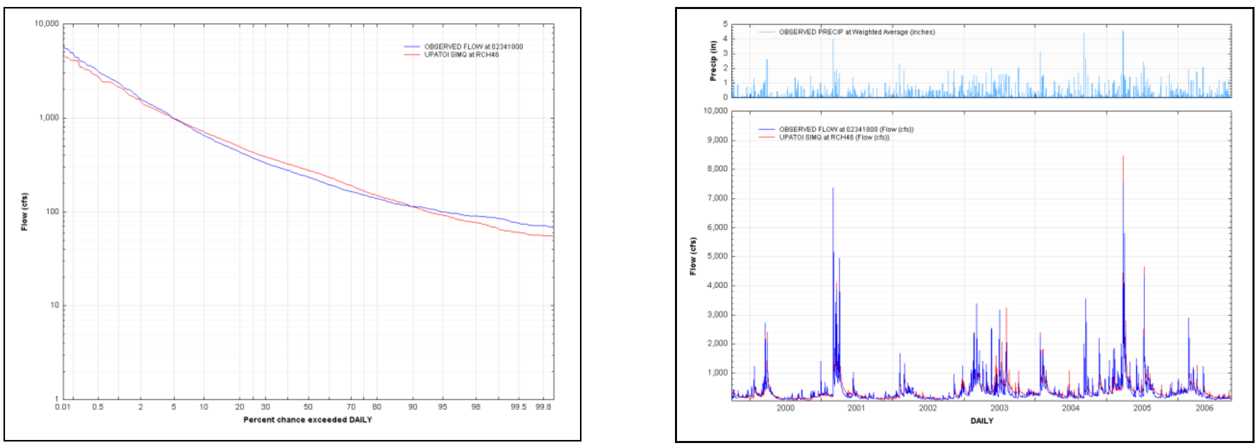
Water years 2000 to 2006 were identified as the period for which the most meteorological and streamflow data was available, and hence this period was selected as the model calibration period. Model hydrologic calibration was conducted by comparing the observed daily streamflow at Upatoi Creek at Fort Benning and simulated streamflow and adjusting the relevant model parameters. Tables 2 and 3 show the comparison of observed and simulated data for the hydrology calibration. The comparison between observed and simulated flows is illustrated in Figure 4.

Table 2. Comparison of observed and simulated flow annually for the simulation period.

Year	Precipitation	Simulated	Observed	Residual	%Error
2000	31.37	9.24	9.99	-0.74	-7.44
2001	41.11	15.39	15.25	0.13	0.86
2002	32.51	7.45	7.88	-0.43	-5.46
2003	58.11	21.53	19.00	2.54	13.35
2004	44.04	15.05	12.91	2.14	16.59
2005	53.49	24.66	23.82	0.84	3.54
2006	37.37	12.67	10.82	1.85	17.14
Mean	41.57	15.14	13.36	0.90	5.51

Table 3. Daily and monthly flow statistics for the simulation period.

	Daily	Monthly
Correlation Coefficient	0.91	0.96
Coefficient of Determination	0.83	0.91
Mean Error	22.62	22.22
Mean absolute Error	107.89	67.75
RMS Error	200.64	87.58
Model Fit Efficiency	0.83	0.90



(a) (b)

Figure 4. Comparison of observed and simulated (a) flow duration frequency curve, and (b) daily flow.

Data for total suspended solids (TSS) was available for only few storms during this calibration period at few locations including the Upatoi Creek gage. The sediment calibration process involved establishing reasonable initial values for the parameters in HSPF surface sediment washoff formulations, and then adjusting them to gain agreement between computed loading rates and established loading rates. For details on sediment calibration on a HSPF model, please refer to Donigian and Love (2003). As a first step to conduct sediment calibration, sediment loading targets were established as a function of topography, soils, landuse, and management practices using USLE and literature review. The preliminary sediment calibration results are illustrated in Table 4.

CONCLUSIONS AND RECOMMENDATIONS

The preliminary application of BASINS/HSPF to the Fort Benning watersheds to develop a baseline model required utilization of existing data provided by BASINS, and SEMP. The hydrologic and sediment concentration data, and sediment detachment targets were used to calibrate the model. The correlation coefficient of daily and monthly flow was greater than 0.9, and model fit efficiency for daily and monthly flow was greater than 0.8. Early calibration results indicate that although the military landuse is only 3.3% of entire watershed, it is responsible for as much as 43.5% of sediment loading at the outlet. The calibration results were acceptable for the preliminary model application. This model application presented us with unique challenges and provided an opportunity to identify the refinements and enhancements for comprehensive watershed management model for Fort Benning. The identified research topics are listed as follows.

Table 4. Sediment loading rates and percent contributions at Upatoi Creek at Fort Benning*

Landuse	Washoff (tons/acre/year)	Total (tons/year)	Percent of Total Load	Landuse Groups	Landuse group percent
Urban/Cantonment	0.29	1514.73	1.74	Urban	1.74
E Forest	0.10	5567.86	6.38		
D Forest	0.11	7596.21	8.71		
M Forest	0.10	1584.00	1.82	Forest	16.90
Shrub/Scrub	0.27	1460.47	1.67	Shrub/Scrub	1.67
Grass/Herb	0.27	5663.86	6.49	Grass/Herb	6.49
Ag/Other	1.48	25644.20	29.39	Ag/Other	29.39
Paved Roads	0.22	179.51	0.21	Paved Roads	0.21
Tank Trails	7.02	1000.22	1.15		
Heavy Maneuver	12.12	19596.86	22.46		
Unpaved Roads	3.31	17320.89	19.85	Military	43.46
Water/Wetlands	0.01	127.33	0.15	Water/Wetlands	0.15
Total/WtdAvg	0.41	87195.95	100.00		

*These results are from preliminary sediment calibration after setting up the baseline watershed model. Please contact the authors before referencing these values.

1. **Multiple spatial scales:** As noted in the early model calibration, processes occurring on military landuses are very important although they are on very small area. To simulate the process occurring at smaller scales in an overall watershed modeling project, an ability to conduct model simulations at multiple spatial scales is sought. In this hybrid approach, watershed scale model can be used to model the overall watershed, whereas a field- or hillslope-scale model featuring more detailed process formulations for specific activities, sources, or land uses can be run in tandem and provide time series and pollutant loadings to the overall watershed scale model. Examples of activities in Fort Benning that occur in localized areas but have the potential to significantly affect the overall sediment loading are unpaved roads, tank trails, military training etc.

2. **Enhanced sediment simulation capabilities:** Enhancements relate to simulation methods for instream flow, instream sediment transport, and bank erosion in HSPF are sought. 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. Representing the additional stream load caused by these sediment-generating phenomena require incorporation of bank erosion estimation techniques, as well as improved instream sediment erosion and deposition of multiple size classes of sediment.

3. **Vegetation growth and management:** HSPF does not have the capability to simulate the dynamic nature of watershed-specific management activities like prescribed burning, harvesting, clear cutting etc. on watershed hydrology. HSPF represents vegetation via simple expressions of its functional relationship with other components of the hydrologic cycle and the nutrient cycle. Preliminary model results suggest that significant benefits could be achieved by representing additional dynamic processes (e.g., plant growth) in HSPF, additional model compartments for both overstory and understory vegetation, and substrate fluxes between the plant community and its soil environment.

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