FINAL REPORT

A Watershed Modeling System for Fort Benning, GA Using the US EPA BASINS Framework

SERDP Project RC-1547

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14. ABSTRACT

Sediment erosion/runoff can be a major impairment to streams on Fort Benning and other military installations due to both on-site and off-site land uses. On Fort Benning, military training, forested areas subjected to prescribed burning, unpaved roads and construction are primary sources of sediment loads. Urban encroachment or the expansion of urban centers upstream of the Installation also can contribute to sediments loads measured in Fort Benning's streams. Military installations are concerned about sustainability of their training lands, maintaining compliance (i.e., related to Clean Water Act, Energy Independence and Security Act Section 438, and Endangered Species Act) and justification of budgets associated with best management practices designed to reduce sediment loads and its associated impacts.

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EXECUTIVE SUMMARY

Sediment erosion/runoff can be a major impairment to streams on Fort Benning and other military installations due to both on-site and off-site land uses. On Fort Benning, military training, forested areas subjected to prescribed burning, unpaved roads and construction are primary sources of sediment loads. Urban encroachment or the expansion of urban centers upstream of the Installation also can contribute to sediments loads measured in Fort Benning's streams. Military installations are concerned about sustainability of their training lands, maintaining compliance (i.e., related to Clean Water Act, Energy Independence and Security Act Section 438, and Endangered Species Act) and justification of budgets associated with best management practices designed to reduce sediment loads and its associated impacts.

The Strategic Environmental Research and Development Program (SERDP)-funded project (RC-1547) began with the vision of providing a management tool for addressing watershed and water quality impacts of activities on military installations and initially for Fort Benning, while concurrently advancing the application of science to watershed modeling. This document, as a final report of this effort, presents the project's objectives, approach, results, and conclusions, and defines the next steps needed to advance the resulting military-enhanced watershed modeling system (i.e., BASINS.MIL).

Sediment erosion/runoff, determined to be the main culprit of military land uses in general, and specifically on Fort Benning, became the focal point of our modeling simulations. With this focus, four major products were produced:

- A fully calibrated/validated watershed model of Fort Benning's baseline conditions (i.e., **FB Baseline Model**) which was used as a benchmark for assessing the relative performance of model enhancements.
- An Enhanced Baseline Model (EBM) of Fort Benning watersheds (i.e., **FB EBM**) which incorporates model enhancements into the Fort Benning Baseline Model for the evaluation of management alternatives.
- **Proof-of-principle applications** using the FB EBM which provide estimates of sediment loads associated with changes in land use and best management practices.
- A military-enhanced watershed modeling system (i.e., **BASINS.MIL**) that provides options for data/methodologies and software refinements specific to military considerations and compliance issues.

Central to the products listed above is the use of the U.S. EPA Better Assessment Science Integrating Point & Non-point Sources (BASINS) modeling system. The BASINS system contains a geographical information system (GIS) *MapWindow*, linkages to national databases, and data analysis and modeling codes. Collectively, the system is designed to support watershed-based analyses. Two BASINS' modeling codes were applied in our project, the Hydrological Simulation Program– FORTRAN (HSPF) and AQUATOX, an aquatic ecosystem model.

HSPF is a comprehensive model of watershed hydrology and water quality that allows the integrated simulation of land and soil runoff processes with in-stream hydraulics and sediment-chemical interactions. HSPF provides a time history of the runoff flow rate, sediment load, and contaminant concentrations (i.e., nutrients and toxicants), along with a time history of water quantity and quality at any point in a watershed. AQUATOX extends the model endpoints of HSPF and simulates aquatic ecosystems processes to predict the environmental fate and ecological effects of environmental stressors on aquatic biota.

The research-focused component of our project investigated six areas of model enhancements. Based on the outcome and specific objective of each model enhancement investigation, most of these enhancements were incorporated in the FB Baseline Model which then became the FB Enhanced Baseline Model (EBM).

1. WEPP/WEPP Road Enhancement – A hybrid modeling technique was developed that improves the ability to represent and evaluate combinations of sources and endpoints that have significantly different spatial scales. This technique incorporated the USFS Water Erosion Prediction Project (WEPP) Model and its interface WEPP:Road to generate sediment loads from unpaved roads at a finer scale than the HSPF watershed model. These finer-scale results were integrated into the watershed-scale HSPF model to more accurately depict the sediment contribution from unpaved roads.
2. Military Training Intensity Methodology – A methodology was developed to quantify the impact of military training activities on soil compaction and vegetation, so that its subsequent impacts on runoff and sediment washoff/erosion rates are modeled by adjusting infiltration rates and land cover based on the training intensity level.
3. Complex channel modeling – The combination of Environmental Fluid Dynamics Code (EFDC)/ Sediment transport algorithm for EFDC (SEDLZJ) and a bank erosion algorithm were investigated to determine the improvement to channel flows (particularly low and high flow events), sediment transport and stream bank erosion.
4. AQUATOX Linkage – Linkages to ecological indicators using AQUATOX to simulate impacts of watershed management practices to indicators of aquatic health were investigated.
5. Multi-level Canopy Compartment – Improved representation of hydrologic and water quality processes for above-ground vegetation and forest canopy compartments was developed.
6. Additional Flow Data – The value of incorporating additional flow data and rating curves at Fort Benning for calibration of component sub-watersheds, and implications for technology transfer to other military installations was investigated.

The hybrid modeling technique using WEPP and WEPP:Road (i.e., #1); the military training intensity methodology (i.e., #2), the improved forest canopy compartment (#5), and data from additional rating curves (i.e., #6) became part of the FB Enhanced Model and its applications. Three sets of management alternative evaluations were conducted to demonstrate proof-of-principle of the FB Enhanced Model: (1) impacts of 2005 BRAC (Base Realignment and Closures) Implementations (i.e., increased area of heavy maneuver training exercises); and (2) impacts of best management practices (BMPs) on a single maneuver training area (i.e., the Good Hope Mechanized Training Area, GHMTA), and (3) linkage to AQUATOX.

The simulation results from the proof-of-principal model applications indicate that the FB Enhance Model performed within an acceptable/reasonable range; it is judged to be a reliable tool to account for cumulative impacts across the entire installation and to distinguish between off-site and on-site contributions. As expected, the model results from the 2005 BRAC Implementation management scenario identified unpaved roads and military training in heavy maneuver areas as the largest contributors to sediments loads. The proof-of-principle application for the GHMTA demonstrated that the model can be used to address specific management decisions regarding BMPs and has the scientific rigor to support budget analyses and requests for BMP implementation. The proof-of-principle application involving AQUATOX demonstrated a means for generating biotic endpoint information that can support regulatory compliance regarding aquatic species of concern.

The combined products of our SERDP project are encompassed in BASINS.MIL which is the BASINS framework modified for military considerations and land uses. BASINS.MIL can be used by a military resource manager to identify the options for data/methodologies and software to build a HSPF model for a military installation. The transferability of BASINS.MIL includes all of the national extent of BASINS supporting data bases, and the system's development philosophy that produces/uses tools and models that can be applied to very different locations via selection of local time series and model parameter values that allow customizing each model application to fit its specific setting (climate, topography, soils, vegetation, ecohabitats).

Watershed models can be valuable tools to manage Department of Defense (DoD) operations, activities, and lands to avoid or minimize impacts to wetlands, groundwater, and surface waters or adjacent to installations. However, a significant financial investment associated with data requirements and expertise is needed to develop and apply a watershed model on an installation. Under the current budget allocation process on DoD Installations, funding must be strictly connected to a specific regulatory requirement and need. Thus, the tool used for a watershed modeling approach needs to be accepted by the regulatory community and designed to address the key regulatory concerns. The BASINS modeling system, developed by EPA to address Clean Water Act (CWA) issues, fills this fundamental requirement. However, before BASINS.MIL is fully transferable, in-depth modeling applications that span the full capability of the military-enhanced modeling system and a more cost-efficient development of a baseline model on another military installation are needed to transition the technology towards full acceptance and utilization across DoD.

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FIGURES

TABLES

LIST OF ACRONYMS

ACOE – Army Corps of Engineers
AQUATOX – Aquatic ecosystem simulation model
ARRM – Army Range Requirements Model
BASINS – Better Assessment Science Integrating point & Non-point Sources
BASINS.MIL – Military Enhanced BASINS Modeling System
BH – Bottomland hardwoods
BMP – Best Management Practice
BRAC – Base Realignment and Closure
CAT – US EPA Climate Assessment Tool
CERL – Construction Engineering Research Laboratory
3D – Three dimensional
DCERP – Defense Coastal/Estuarine Research Program
DoD – Department of Defense
DSAMMt Model – Dynamic Stream Simulation and Assessment Model with heat transfer submodel
DUSD(I&E) – Deputy Under Secretary of Defense for Installations and Environment
EBM – Enhanced Baseline Model
EISA – Energy Independence and Security Act
EFDC – Environmental Fluid Dynamics Code
EL – Environmental Laboratory
EPA – Environmental Protection Agency
EPT – Ephemeroptera, Trichoptera, and Placoptera
ERDC – Environmental Research and Development Center
ESTCP – Environmental Security Technology Certification Program
ET – Evapotranspiration
EXTMOD – External Model(s)
FAPH – Fort AP Hill
FB – Fort Benning
FTABLE – Function table for HSPF
GA – Georgia
GHMTA – Good Hope Mechanized Training Area
GIS – Geographic information system
GPP – Gross primary productivity
HMA – Heavy Maneuver Area
HSPF – Hydrological Simulation Program – FORTRAN
INFILT – Infiltration parameter for HSPF
LD – Local drainage
LID – Low impact development
MA – Massachusetts
MCoE – Military Construction Engineering
METL – Mission Essential Task List
MIM – Mission Essential Task List
MSL – Mean Sea Level
NCDC – National Climatic Data Center
NEPA – National Environmental Protection Act
OFE – overland flow elements
OLE – overland flow element
PET – Potential Evapotranspiration

PI – Principal investigator
RBP – Rapid bioassessment protocols
RC – Resource Conservation
RCHRES – Reach segment in HSPF
RCW – Red-cockaded woodpecker
RFMSS – Range Facility Management Support System
RTLA – Range and Training Land Assessment
RVSM – Runoff Volume Simulation Model
SEDZLJ – Sediment transport algorithm for EFDC
SEMP – SERDP's Ecosystem Management Project
SERDP – Strategic Environmental Research and Development Program
SON – Statement of Need
SWAT – Soil and Water Assessment Tool
TMDL – Total Maximum Daily Load
TN – Total Nitrogen
TNC – The Nature Conservancy
TP – Total Phosphorus
TSS – Total Suspended Solids
USEPA – United States Environmental Protection Agency
USFS – United States Forest Service
USGS – United States Geological Survey
UZSN – Upper Soil Zone Moisture Storage term in HSPF
VCF – Vehicle conversion factor
WEPP – Water Erosion Prediction Project
WEPP:Road – WEPP Interface for Predicting Forest Road Runoff, Erosion and Sediment Delivery
WDM – Watershed data management
WY – Water year

KEYWORDS

AQUATOX
BASINS
BASINS.Mil
BRAC
Canopy
EFDC/SEDZLJ
Fort Benning
HSPF
Hybrid Modeling
Military Training
Sediment
Watershed Modeling
WEPP
WEPP:Road

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Direct contributors to this report included Mr. Anthony Donigian, Jr., Mr. John Imhoff, Dr. Anurag Mishra, Ms. Eileen Regan, and Ms. Nicole Belle Isle at AQUA TERRA Consultants; Dr. Patrick Deliman, and Dr. Earl Hayter at ERDC; and Dr. Richard Park at Eco Modeling.

ABSTRACT

Objective: 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) identified the need to provide Fort Benning, Georgia (and eventually other military installations) with an effective watershed model that can be implemented for compliance and long-term watershed planning and management. The intensity of this need was due in part to 2005 Base Realignment and Closure decisions, which realign thousands of troops and equipment to Fort Benning. The impacts of military operations and land management activities along with existing compliance requirements needed to be evaluated for the Fort Benning watersheds.

The objective of this project was to identify, adapt, and develop watershed management models for Fort Benning that address impacts on hydrology, water quality, and related aquatic ecosystem endpoints resulting from military activities and natural resources management. Technical objectives include (1) providing an open source modeling system for watershed management, (2) building and calibrating a Fort Benning watershed model application, (3) designing and implementing model enhancements that improve on recognized watershed model limitations, and (4) supporting product transition and technology transfer.

Technical Approach: The use and enhancement of the U.S. Environmental Protection Agency (USEPA) Better Assessment Science Integrating point and Non-point Sources (BASINS) modeling system was the cornerstone of this project. The approach implemented two interrelated paths: an application path and a research path. The application path entailed developing an initial calibrated model of Fort Benning, and identifying apparent model/system limitations. The research path involved 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 generating and applying modeling strategies that demonstrate the military-enhanced BASINS (i.e., BASINS.MIL) capabilities.

Results: The simulation results from the proof-of-principal model applications indicate that the Fort Benning Watershed Model with the incorporated research enhancements (1) performed within an acceptable/reasonable range, (2) provided a reliable tool to account for cumulative impacts across the entire installation and to distinguish between off-site and on-site contributions, (3) identified unpaved roads and military training in heavy maneuver areas as the largest contributors to sediments loads, (4) can be used for specific management decisions regarding best management practices (BMPs), (5) has the scientific rigor to support budget analyses and requests for BMP implementation, and (6) when linked with AQUATOX demonstrated a means for generating biotic endpoint information that can support regulatory compliance regarding aquatic species of concern.

Benefits: Through this project, a watershed modeling system is available to Fort Benning to address Clean Water Act issues and requirements. The BASINS.MIL system enables holistic evaluations of issues related to natural resources management and the impacts of military activities on hydrologic, water quality, and ecological endpoints. Improvements in model formulations benefit model applications at Fort Benning by better simulating military-related stressors and, at the same time, correct weaknesses that are currently shared among commonly used watershed models. The Fort Benning model setup and application procedures, as described in the project and model documentation and the Final Report, provide parameter values, land activity characterizations, and evaluation procedures relevant and transferable to other installations.

SECTION 1.0
OBJECTIVES

Strategic Environmental Research and Development Program (SERDP) Project Number RC-1547 (originally SI-1547 prior to renaming the program area) was initiated in April of 2007 with the goal to develop a watershed modeling system for Fort Benning, GA that addresses impacts on hydrology, water quality and related ecosystem processes and outcomes resulting from military activities and associated natural resources management.

RC-1547 was funded in response to the 2005 SERDP Statement of Need (SON) (SERDP, 2005) which recognized that military installations needed the identification, adaptation, and development of watershed management models that address interactions of watershed hydrology with military land management activities, natural resources management, and related ecosystem processes and outcomes. Further, the SON specifically requested a prototype operational modeling system designed and calibrated for Fort Benning but transferable to other installations. The priority driver for the SON was, and remains, to enable military installations to fully evaluate and enhance watershed management programs designed to meet the goals of the Federal Clean Water Act (CWA).

Integral to the 2005 SON was the SERDP Ecosystem Management Project (SEMP), a SERDP initiative established in 1998. SEMP had two primary goals: (1) to establish site(s) on Department of Defense (DoD) facilities for long-term ecosystem monitoring, and (2) to pursue ecosystem research activities relevant to sustaining DoD mission capabilities. To accomplish these goals the Strategic Plan for SEMP (2005) notes the need for both fundamental and applied (adaptive) research; this need is reflected in both our project objectives and our approach (Section 3.1). While the project encompasses science and technical research issues that are critical to numerical modeling and effective use of information technology, the nature of this particular project required that the cornerstone of the effort be 'adapting' the results of fundamental research on a broad range of topics so that they may be integrated into a modeling system that is of "known reliability" (pg. 10 of SEMP Strategic Plan), and that is "relevant to installation management" (pg. 17 of SEMP Strategic Plan). Our SERDP project addresses the "Modeling and Decision-Support Objective," one of the four primary goals established by the SEMP Strategic Plan. This objective recognizes that "ecosystem and watershed management….depends heavily on the existence, organization, retrieval, display, and timely analysis of data and knowledge."

Our SERDP project was designed under several working hypotheses. (1) The US Environmental Protection Agency (USEPA)-developed modeling system, Better Assessment Science Integrating point and Non-point Sources (BASINS), is well suited to provide the framework to address the SON since it was originally designed as a tool kit for evaluating compliance issues related to the CWA (i.e., Total Maximum Daily Loads or TMDLs). Moreover, BASINS contains the widely used modeling code, Hydrological Simulation Program – FORTRAN (HSPF) (Bicknell el al, 2005), a variety of associated and relevant modeling tools, and easy access to national databases. These all enhance the opportunity for transferring the resulting technology to other installations across the country. (2) To accurately simulate the cumulative impact of military operations (i.e., training and natural resource management activities) and appropriately apply a watershed simulation model to military-relevant issues requires enhancements to the standard set of watershed modeling tools and simulations. (3) A select group of focused model enhancements can be implemented and demonstrated at Fort Benning as part of a proof-of-concept application of the utility of overall methodology for

assessing impacts of military activities. Based on these working hypotheses, our project embraced four primary objectives.

1. Fort Benning Calibrated/Validated Watershed Model: Build and calibrate a Fort Benning watershed application (using BASINS) that represents erosion/sedimentation, nutrient and toxicant loadings, instream water quality, and aquatic ecosystem responses from watershed land uses both within and outside the Installation.
2. Military-Enhanced Watershed Modeling System: Design and implement model enhancements that improve on recognized watershed model limitations and more fully develop capabilities relevant to representing and evaluating military land uses and activities.
3. Military-Enhanced Watershed Model Applications: Develop and apply modeling strategies that demonstrate the military-enhanced BASINS capabilities.
4. Transferable Management Tool: Provide product transition and technology transfer by training installation managers in model application, preparing a strategy for transferring the Fort Benning results to other installations, and developing peer-reviewed journal articles.

SECTION 2.0
BACKGROUND

2.1 PROJECT BACKGROUND

In accordance with the guidelines and goals established in the Unified Federal Policy for a Watershed Approach to Federal Land and Resource Management, the DoD Instruction 4715.03 (dated March 28, 2011; signed by Under Secretary of Defense for Acquisition, Technology and Logistics) calls for a watershed-based approach to manage operations, activities, and lands to avoid or minimize impacts to wetlands, ground water, and surface waters on or adjacent to installations. Watershed modeling systems are a critical component of efforts to support this mandate, military readiness and to advance sustainability of testing and training lands. Towards these aims, watershed modeling systems help determine the appropriate balance between land use and resource protection within the carrying capacity of the watershed.

SERDP identified the need to provide Fort Benning, Georgia (Figure 2.1) with immediately usable and effective watershed models that can be implemented for regulatory compliance and long-term watershed planning and management. The immediacy of this need is due in part to the 2005 Base Realignment and Closure (BRAC) decisions, which realign thousands of troops and hundreds of military vehicles to Fort Benning. As a result of BRAC, the total vehicle inventory (tracked and wheeled), and associated training activities, at Fort Benning increased dramatically over the last several years.

Within the Installation, facility development, training activities and resource management must be carried out in a manner that assures the Installation's ability to sustain its primary functions of military training. At the same time Installation planning and management must minimize both (1) the deterioration of on-site terrain and waters, and (2) disturbance or alteration of the resident ecosystem structures. Assuring that the Installation's environment is sustained also requires evaluation of the effects of land use activities and changes outside the Installation boundaries on the waters that flow into and through the Installation. Conversely, the effects of the Installation's activities on the overall health of the watershed in which it is located must also be quantified, and the effects of the Installation's activities must be compared to those of other watershed stakeholder activities in the remainder of the watershed in order to meet the goals of the Federal CWA.

Within the Installation, facility development, training activities and resource management must be carried out in a manner that assures the Installation's ability to sustain its primary functions of military training. At the same time Installation planning and management must minimize both (1) the deterioration of on-site terrain and waters, and (2) disturbance or alteration of the resident ecosystem structures. Assuring that the Installation's environment is sustained also requires evaluation of the effects of land use activities and changes outside the Installation boundaries on the waters that flow into and through the Installation. Conversely, the effects of the Installation's activities on the overall health of the watershed in which it is located must also be quantified, and the effects of the Installation's activities must be compared to those of other watershed stakeholder activities in the remainder of the watershed in order to meet the goals of the Federal CWA.

During the past decade, intensive collaborative efforts have resulted in the development of effective watershed modeling systems. USEPA's BASINS watershed modeling system (USEPA, 2007a) meets SERDP's need for analysis tools to assure Installation sustainability through informed watershed management. BASINS provides an adaptive management tool kit

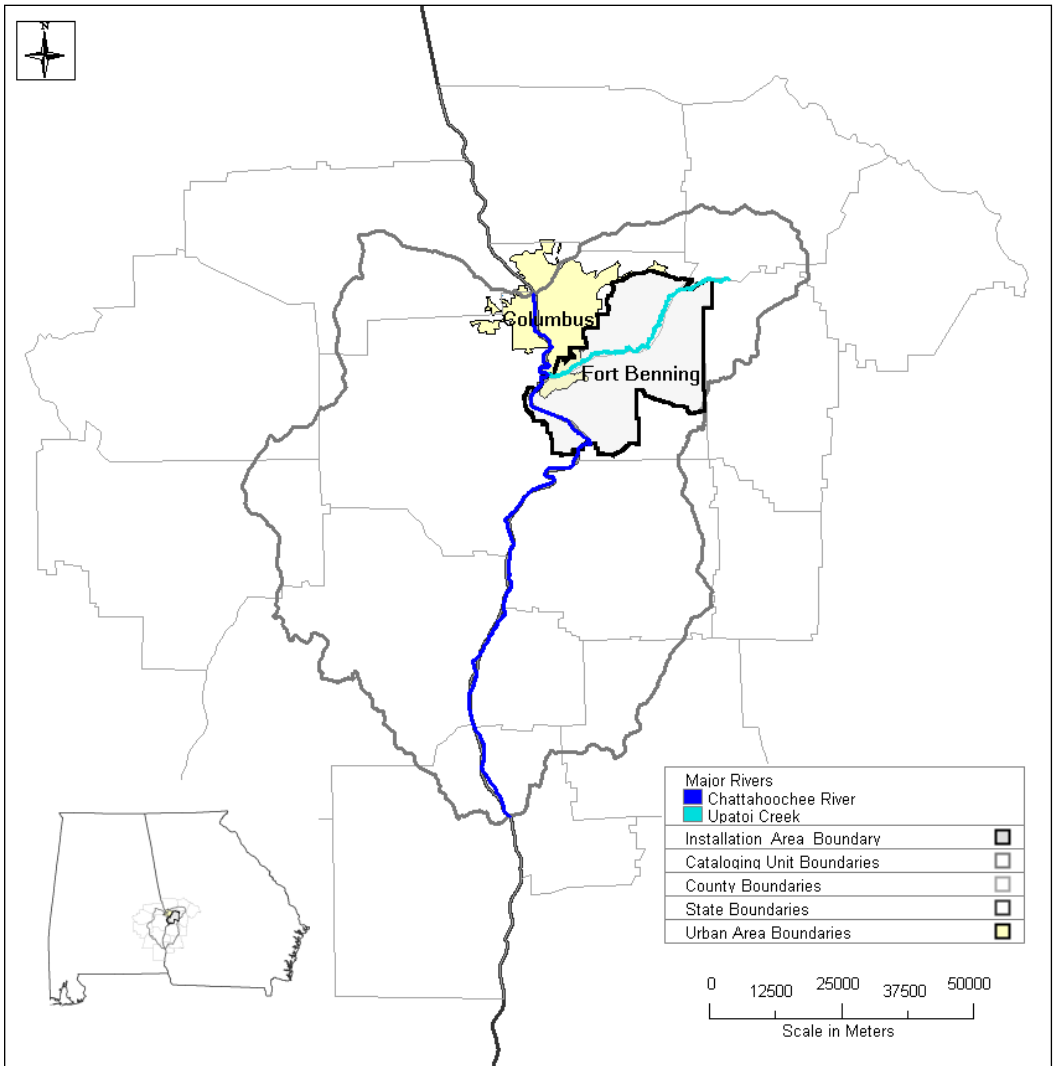

Figure 2.1 Fort Benning Location, Municipality of Columbus, and Major Rivers

that integrates terrestrial and aquatic processes to determine the effectiveness of management actions and can begin to address issues of installation sustainability. BASINS also provides a highly supported and robust mechanism for developing and integrating new methods, tools and data that enables continued improvement in both the state of the art of watershed management and the efficiency and effectiveness with which Installation management decisions can be made concerning military operations, natural resource issues and ecosystem management. Using BASINS as the core of the military watershed modeling system enables immediate access to accepted modeling science for agriculture, forestry, urban & other land uses that already exists in BASINS models. Installation managers are able to leverage a wealth of user knowledge for representing and evaluating land uses that are not unique to the military by using the BASINS modeling system.

BASINS applications are implemented by a streamlined ensemble of the models, tools and data necessary to evaluate a particular watershed or set of watersheds. BASINS also enables efficient area- or site-specific expansion of the database information using supplemental data available for a project location. In the case of the Fort Benning BASINS project, the supplemental data are extensive. BASINS provides Installation land managers with a single modeling environment containing multiple models and tools, some already accepted and used

by a broad range of public watershed managers, others integrated as the system is extended to meet military needs. It also enables a suite of evaluation options that recognize the spatial and temporal heterogeneity inherent between and among external land use practices, Installation operations, resource management practices, and ecosystem effects.

2.2 REPORT CONTENT

In summary, the project produced four main products: a calibrated baseline model for Fort Benning, an enhanced version of the baseline model by incorporation of the model and modeling enhancements, modeling application proof-of-concept demonstrations, and technology transfer activities. Components of these products are listed in Table 2.1.

Table 2.1 List of Products and their Components

Products	Components
Fort Benning Baseline Model (FM Baseline Model)	Model set up Calibration and validation results Initial AQUATOX results
Fort Benning Enhanced Baseline Model (EBM)	Military training intensity methodology Hybrid modeling WEPP application Multi-level plant canopy simulation module Channel sediment enhancement (not used for scenarios) Additional rating curve data
Fort Benning Enhanced Model Applications	Enhanced Baseline and BRAC model scenarios AQUATOX Applications Good Hope Maneuver Training Area Evaluation
Technology Transfer Activities	Journal articles Webinar of project's products to Ft. Benning Staff One-day training seminar at Ft. Benning

The next section describes the project approach by task and more details of the techniques applied to the model enhancements, subsequent model applications using the FB Enhanced Baseline Model (EBM), and technology transfer activities. Section 4 presents the project results and discussion of the implications and relevance of those results and products. Section 5 provides a synthesis of the overall results and conclusions of the project with a focus on implications for future research and implementation. Existing knowledge gaps, remaining research questions, lessons learned, implications to DoD, and recommendations are discussion in this section. Lastly, all literature cited in this document is listed in Section 6. Appendices provide additional supporting results, data and information for specific components of the project as referenced in individual sections of this document.

SECTION 3.0
MATERIALS AND METHODS

This section presents the overall project approach by task, along with more detailed descriptions of the specific approaches for the four selected areas of model enhancements.

3.1 PROJECT APPROACH

The project approach applied the US EPA BASINS modeling system (Figure 3.1) which is an integrated system of modules that represent hydrology, sediment erosion, instream sediment transport and numerous water quality constituents. These models/modules have been used to evaluate land use impacts and management practices on literally hundreds of watersheds across the US and abroad. BASINS also provides a highly supported and robust mechanism for developing and integrating new methods, tools and data.

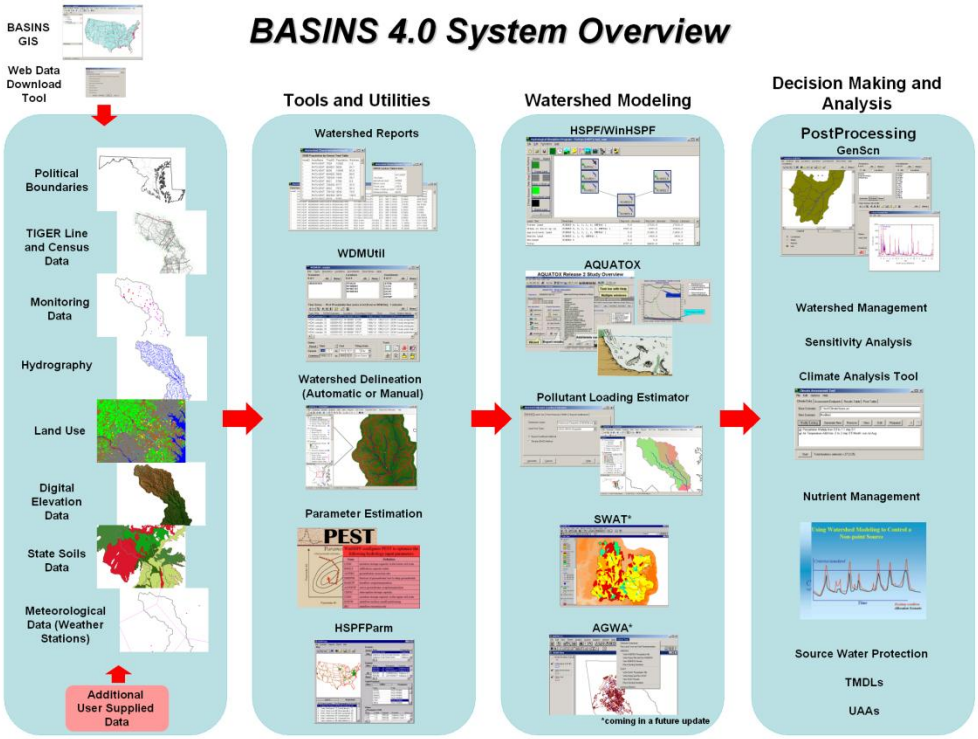

Figure 3.1 BASINS Version 4 Overview

One component of BASINS is the HSPF watershed model. HSPF is a comprehensive watershed model of hydrology and water quality that includes 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 US Geological Survey (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 is currently being used for watershed studies in more than 25 states, Canada, and Australia.

Another component model of BASINS, AQUATOX, provides a comprehensive ecological effects model that uses the chemical and sediment loadings generated by the watershed models as input, models ecosystem processes, and predicts the effects of these loadings on biotic endpoints (Clough, 2004). 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.

The project approach uses the BASINS modeling system as the toolkit for pursuing two interrelated 'paths', an application path and a research path (Figure 3.2). 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.

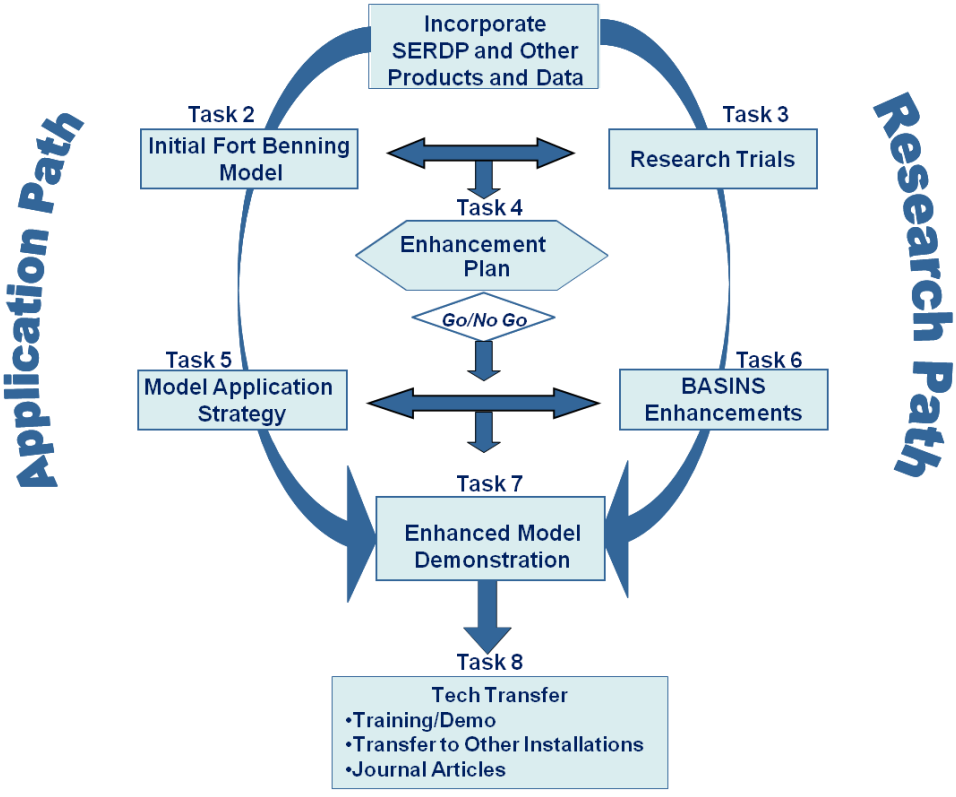

Figure 3.2 Dual Pathway Approach for Developing a Military BASINS Modeling System

Table 3.1 summarizes the major accomplishments and key documentation that resulted from each task that comprised the overall project. Further description of the activities conducted for each task follows.

Table 3.1 Project Accomplishments by Task and Associated Documentation for Each

Task No.	Title	Major Accomplishment	Key Reference(s)
Task 1	Identifying and Reviewing Existing Military Resources	Examined the outcomes of previous studies and identified how they could be incorporated into project tasks.	Development of a Watershed Modeling System for Fort Benning Using the USEPA BASINS Framework: Resources Integration Report (AQUA TERRA Consultants, 2008)
Task 2	Develop Baseline Model	Developed a calibrated/validated model for the watersheds on and surrounding Fort Benning.	Simulation Plan for the Fort Benning BASINS/HSPF Watershed Model (AQUA TERRA Consultants, 2007); BASINS/HSPF Watershed Model for Fort Benning, Georgia: Baseline Model Development and Application (AQUA TERRA Consultants, 2010a)
Task 3	Refine Research Enhancements	Evaluated watershed model enhancements that correspond to eight research areas.	Refine Research Enhancements and Develop Enhancement Plan: Task 3 & 4 Report (AQUA TERRA Consultants, 2009)
Task 4	Develop Enhancement Plan	Developed a unified vision of the dominant limitations, and thereby identified the most needed enhancements, for a military-enhanced BASINS modeling system.	Refine Research Enhancements and Develop Enhancement Plan: Task 3 & 4 Report (AQUA TERRA Consultants, 2009)
Task 5	Model Application Strategy	Identified management evaluations that can be translated into model scenarios to demonstrate the capabilities of the enhanced model.	Technical memorandum to Fort Benning Staff (AQUA TERRA, 2010b); this document.
Task 6	BASINS Enhancements	Developed enhancements identified in Task 4.	This document.
Task 7	Enhanced Model Demonstration	Conducted proof-of-concept model applications to demonstrate the capability of the enhanced model.	This document.
Task 8	Technology Transfer	Transferred the technology to the Fort Benning Staff and defined the next steps needed for demonstration/ validation of the enhanced modeling system.	This document; Webinar presented on 7/17/2012; and one-day training seminar (date TBD), material development in progress.

3.1.1 Task 1: Identifying and Reviewing Existing Military Resources

The objective of Task 1 was to identify opportunities to integrate data, methods, results and approaches from previous military studies that have addressed the impact of military activities and land management practices on or around the Fort Benning Installation. Task 1 was designed to examine the outcomes of previous studies and identify how they can be incorporated into three tasks focused on the development of (1) the Fort Benning Baseline Model (Task 2), (2) model enhancements associated with six research areas (Task 3), and (3) development of future management scenarios (Task 5).

In evaluating available resources, we actively searched for all of the following: (1) methods useful for understanding or characterizing the watershed or watershed processes; (2) findings of related research projects that clarify Fort Benning watershed responses, issues and/or management methodologies; (3) information useful for model parameterization; (4) data useful for model calibration; and (5) data useful for testing or developing new process algorithms.

Over 900 datasets and over 300 manuscripts from the military literature were investigated to satisfy the objectives of Task 1. Our first and foremost attention focused on the SEMP Repository, which is the primary collection of information resources for Fort Benning that have resulted from SERDP projects. Communications between the Project Team and numerous investigators, contractors and installation personnel led us to identification of critical data that are included among the 1800+ data holdings currently contained in the Repository. The comprehensive report entitled “SERDP Ecosystem Management Project Research Initiative at Fort Benning: Synthesis and Summarization of Findings” (Imm et al., 2007) provided a starting point for pursuing additional resources that were not already identified by our personal communications, or within the Repository.

Search for useful military data not contained in the Repository was expanded by reviewing fact sheets and summary information for SERDP-funded projects outside of the SEMP Initiative. In cases that warranted more thorough investigation, selected project reports were reviewed. Sources used to identify relevant studies for review included 1) the SEMP Document Library, 2) SERDP Online Library, 3) reference lists contained within individual documents, and 5) the Defense Coastal/Estuarine Research Program’s (DCERP) bibliography from an initial literature search.

Task 1 resulted in the report titled: Development of a Watershed Modeling System for Fort Benning Using the USEPA BASINS Framework: Resources Integration Report (AQUA TERRA Consultants, 2008).

3.1.2 Task 2: Baseline Model Development

The initial Fort Benning Model (herein referred to the FB Baseline Model) provides the critical foundation for all subsequent tasks (Tasks 3-8) to accomplish the overall project goal — to build a military-enhanced watershed model to understand and to perform analyses of management alternatives. The Fort Benning Baseline Model simulates the watershed hydrology and in-stream hydraulics, as well as sediment, water temperature, bacteria and nutrients. It represents the essential conditions of the watersheds on and surrounding Fort Benning within the initial calibration period (2000-2006). The model incorporates available time series and spatially-explicit data to characterize the meteorological, stream flow, water quality and land use/land cover conditions. The study area was divided into individual land and channel segments, which are assumed to demonstrate relatively homogenous hydrologic/hydraulic and water quality behavior. Figure 3.3 shows the extent of the modeled area, the Installation’s boundaries and the model segmentation used for the Fort Benning Baseline Model.

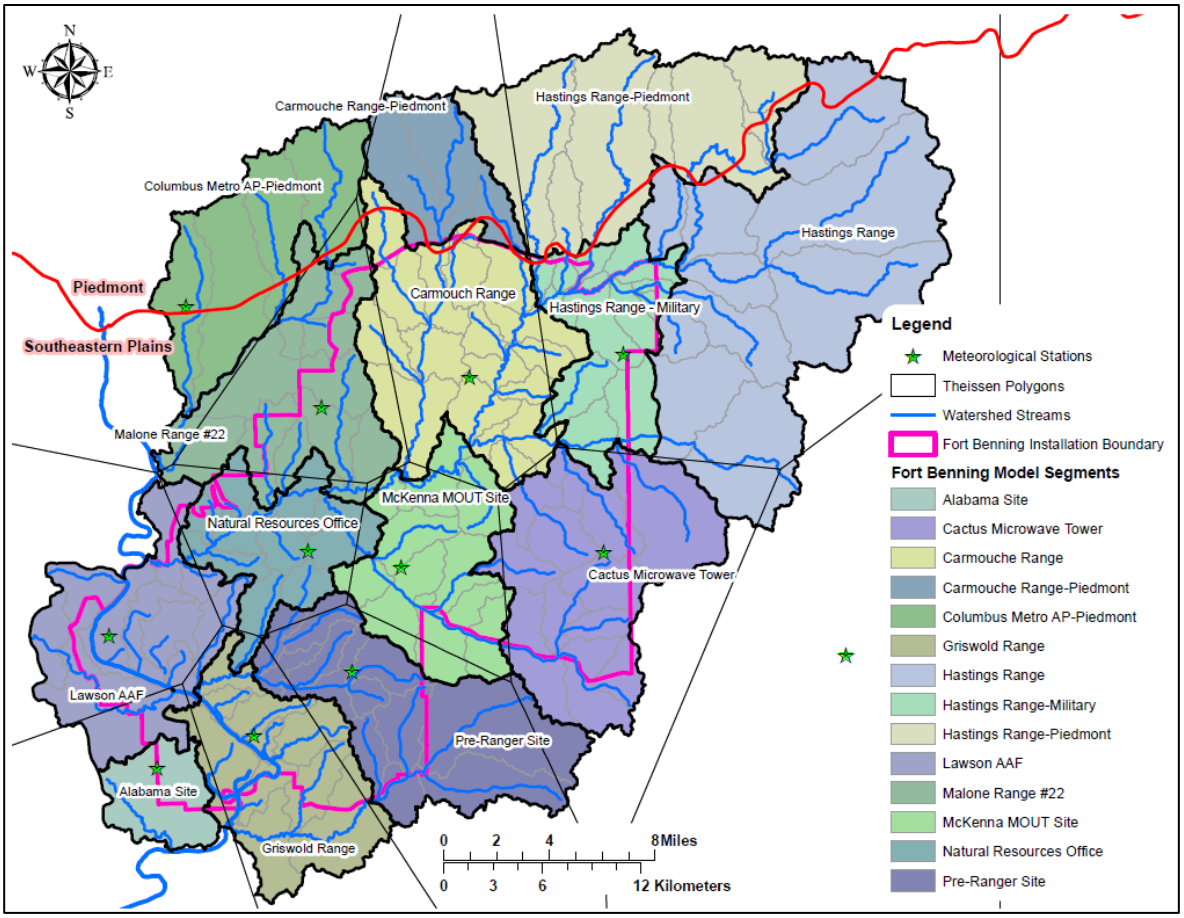

Figure 3.3 Fort Benning Watersheds, Installation Boundary, and Model Segmentation

Model segmentation provided the basis for assigning similar or identical input and/or parameter values where they can be applied logically to all portions of a land area or channel length contained within a model segment. Multiple sources of information on military land uses were used to produce a single land use/land cover GIS layer and provided a comprehensive coverage of categories representing the extensive road network, tank trails, and other military activities. The model applies a relatively simplistic characterization of military training by assuming that the significant impacts from training activities reside primarily in the areas designated as heavy maneuver areas, tank trails and unpaved roads as shown in Figure 3.4.

Calibration was performed for the water years (WY) 2000 to 2006 which corresponded to the period of time with the most extensive meteorological, stream flow, and water quality data. Model validation procedures were performed for the period between WY 1990 to 1999. The model was calibrated using a literature-based sediment loading rate for areas designated as military land use.

Using a weight-of-evidence approach that involved both graphical and statistical tests, the Fort Benning Baseline Model was shown to provide a fair-to-good representation of the watershed hydrology, both calibration and validation, and a fair-to-poor representation of the overall water quality. The primary limitation on the water quality simulation was due to limited data availability during storm events for sediment and especially nutrients. In summary, through the various model analyses and comparisons with available data, the current Fort Benning Baseline Model

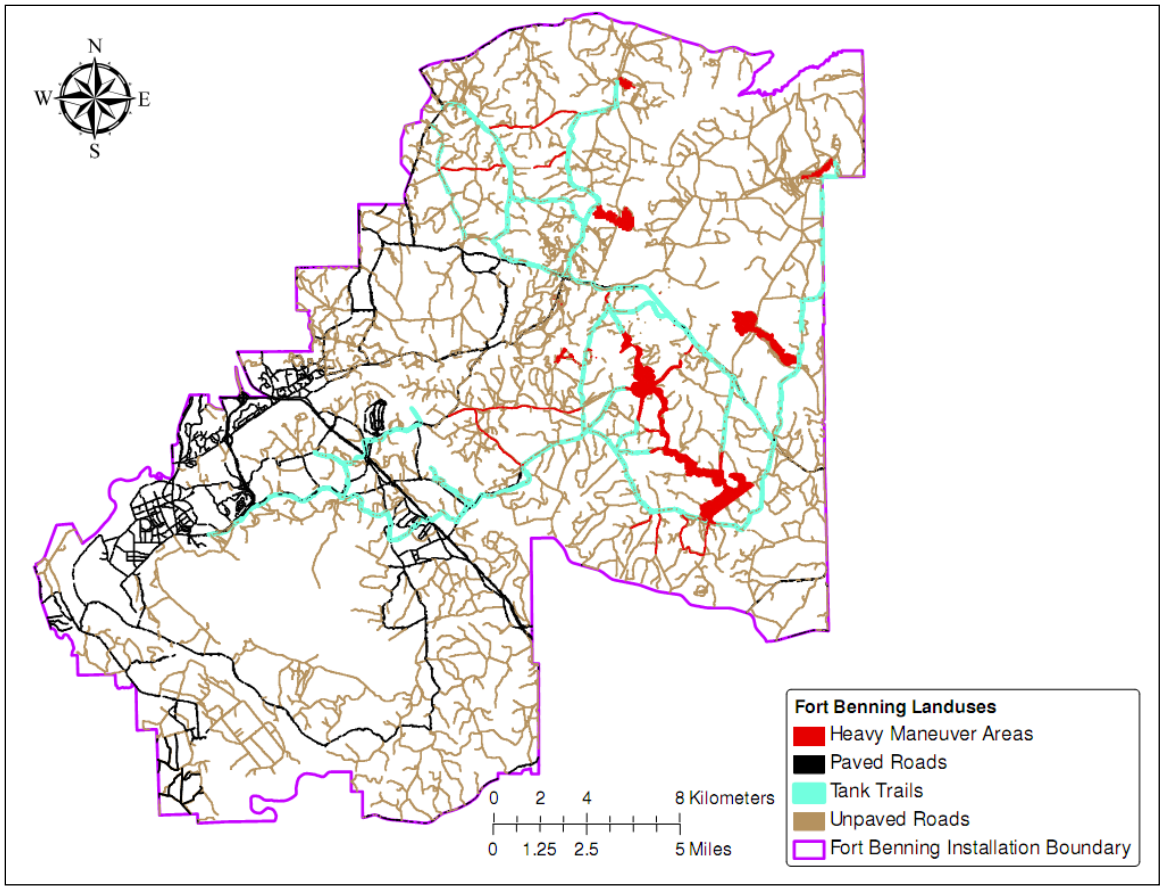

Figure 3.4 Fort Benning Military Land Uses

is deemed to provide a reasonable basis to conduct hydrologic and water quality analyses. See Task 2 Report for more detail on the Fort Benning Baseline Model (AQUA TERRA Consultants, 2010a).

3.1.3 Task 3: Refine Research Enhancements

Task 3 evaluated watershed model enhancements that correspond to the following eight research areas:

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 model 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 model science to accommodate impacts from unpaved roads.
4. Channel phenomena. This research topic includes three components: (1) channel flow: improved methods for modeling dynamic channel flows (particularly low and high flow events); (2) sediment transport: improved methods for modeling channel sediment

transport (particularly for coarse sediments) and (3) 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 identify and quantify contaminant sources and the primary associated impacts.
8. Rating curve development and integration: Investigate the value to the overall watershed simulation of having/using more or fewer flow rating curves at Fort Benning, to provide a basis for calibration of component subwatersheds and potential for technology transfer to other military installations.

Each research area was assessed in terms of the nature of the enhancements needed, available supporting resources and methodologies, viable enhancement alternatives, and a recommended path forward.

The objective of Task 3 was to develop a unified vision of the dominant limitations, and thereby identify the most needed enhancements for a military-enhanced BASINS modeling system. The process required assessing the feasibility of applying and incorporating solutions to the limitations that have been identified by means of both the application and research pathways, i.e., as a result of the Fort Benning Model applications (Task 2) and further evaluation of research product/methods (Task 3).

3.1.4 Task 4: Development of an Enhancement Plan

The Enhancement Plan developed under this task provided a methodology and a pathway for prioritizing among the potential enhancements. The Enhancement Plan described the recommended enhancements to the BASINS system (and its individual models) that were judged most beneficial to improving BASINS' ability to support the evaluation of Fort Benning's critical management issues. As well, the Enhancement Plan characterized the potential enhancements in terms of expected benefits, benefit relative to other recommended enhancements, estimated development effort/costs, and approach to development.

The following categories of enhancements were identified as project priorities for development as described in the Task 3&4 Report (AQUA TERRA Consultants, 2009).

<u>Hybrid Modeling and Unpaved Roads</u>

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, a general capability to perform hybrid model applications was proposed in which HSPF would be 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 would

be 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 model(s) would be incorporated into HSPF expressed as point sources to targeted land segments or channel reaches.

Road erosion is commonly the largest contributor to sediment production within forest watersheds. Proper understanding, 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 is incompatible with the watershed-scale application currently provided by HSPF for the Fort Benning watersheds. The forestry community considers USDA's WEPP:Road model as the state-of-the art model for estimating sediment yield from unpaved forest roads. To make available a more robust set of formulations for simulating sediment washoff from Fort Benning's unpaved forest roads, the WEPP:Road was proposed as a demonstration application of the hybrid modeling capability developed for HSPF.

In-channel and Bank Erosion Modeling

Improvements to three aspects of HSPF baseline model offered promise to significantly benefit model applications at Fort Benning and at other installations. These enhancements relate to simulation methods for instream flow, instream sediment transport, and bank erosion.

The integration of a hydrodynamic model into the Fort Benning modeling system was proposed to 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 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) were further investigated in hopes of integrating into HSPF (Hamrick, 2007a, 2007b, and 2007c).

The SEDZLJ sediment transport model developed by Jones and Lick (2001) was proposed to improve HSPF capabilities for simulating scour and deposition. 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 noncohesive sediments can be represented in the sediment bed that is divided into a user specified number of bed layers.

Previous observations and studies 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 required improved algorithms for bank erosion.

Lacking a method for representing the generation of sediment loads due to events of bank erosion/failure, an empirical-based bank erosion model was proposed to be added to HSPF such that the estimated sediment mass from the eroding bank supplements the sediment bed for the channel reach where the eroding bank is located. This empirical model calculates 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.

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. 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 most hydrologic and water quality studies; 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 would 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.

3.1.5 Task 5: Development of an Enhanced Model Application Strategy

Task 5 focused on the development of an enhanced model application strategy for the Installation that takes full advantage of the new capabilities. The effort was built on the working hypothesis that the proposed enhancements identified in Task 4 would result in a significant improvement in watershed models and modeling, in general, and expand the capabilities related to hybrid modeling, spatial scale issues, prescribed burning, and sediment generation/erosion/transport processes.

A model application strategy was developed based on two primary objectives (1) to demonstrate the ability of the of the model enhancements to improve simulation results of the Fort Benning Baseline Model when compared to observed data, and (2) to develop modeling strategies for a select set of management alternatives for evaluating the impact of those management alternatives on key aquatic endpoints.

Thus, the modeling strategy provided a blueprint for comparing the Fort Benning Baseline Model with the Enhanced Baseline Model to identify the differences between the outputs of the two models and to discern whether the enhancements to the Fort Benning Baseline Model actually improve the simulation of the study area. Simulations from both models were compared to the observed data to demonstrate and quantify the degree to which the Enhanced Baseline Model reduces the gap between simulated and observed data.

The selection of management alternatives was initiated by a technical memorandum (AQUA TERRA Consultants, 2010b) sent to Fort Benning land managers and the SERDP Program Office that outlined a proposed set of management alternatives, modeling endpoints and locations for reporting endpoint results. A copy of the technical memo is provided in Appendix F. Discussion that ensued with these parties and the project team identified the following issues to guide our selection and design of management alternatives.

- BRAC 2005 Management Alternative – The most pressing management issue on Fort Benning is related to the implementation of BRAC 2005 recommendations.
- Road Maintenance – Two types of road maintenance activities are under consideration at Fort Benning: those related to post-construction BMPs and those related to accomplishing the mission such as leveling ruts (i.e., grading) to ensure that vehicles do not get stuck. The latter can cause a significant increase in sediment erosion especially if grading is conducted during, or immediately prior to a rain event.
- Road Design and Location – Currently, the road design and location for new roads on Fort Benning has been set and is unlikely to change. A management alternative focused on changes in road design and location is not warranted.

- Subwatershed-scale Analysis – Part of determining the model's capability is to design a management alternative at a subwatershed-scale.
- Timber Harvesting – Since data are sparse to null for timber harvesting on Fort Benning, it is appropriate to assume that relevant forest stands are thinned on an average cycle of every ten years.
- Prescribed Burning – An evaluation of a range of burn cycles (e.g., every 1, 3 or 5) would be helpful to determine the optimum burn rate for the forest stands on Fort Benning.
- Pre-development Hydrology – As a result of EISA Section 438 requirements, a management alternative that evaluates a relatively intact subwatershed would help to establish a pre-development hydrologic baseline.
- Good Hope Area – A management alternative that focuses on the Good Hope Area before and after the Armor School is implemented would be very helpful to determine the number and location of BMPs needed.
- Off-site Contributions – Sediment contribution from off-site sources is an important compliance consideration and should be included in modeling results for evaluation of management alternatives.
- Cost/Benefit of Additional Data – An evaluation focused on how the model's performance increases by incorporating new USGS rating curve data is needed.
- Stream Crossings – Related to the changes in the Good Hope Area is the expectation that a large number of stream crossings will be installed. A management alternative that addresses the impact of stream crossings would be helpful.

From the above list of issues, a set of management alternatives were fashioned that individually address one or more of the stated issues. However, not all of the issues could be addressed within the scope and budget of the project, and those which could not are discussed as areas that need further investigation. The incorporation of the new USGS rating curve data is addressed under results (see Section 4.5).

The resulting modeling strategy identified three sets of management alternatives:

Enhanced Baseline and BRAC Model Scenarios – Results provide sediment loads due to land use changes from the implementation of BRAC 2005 recommendations.

AQUATOX Applications – Results indicate the impact of the water quality and flow on specific aquatic species at key locations within the Installation.

Good Hope Maneuver Training Area (GHMTA) Model Scenarios – Results provide sediment loads to stream before and after the placement of BMPs. Results also characterize the impacts of the area of Fort Benning that is most profoundly impacted by BRAC 2005.

These management alternatives are presented in Section 4.6, 4.7 and 4.8, respectively.

3.1.6 Task 6: Implementation of the BASINS Enhancement Plan

Based on the Enhancement Plan developed in Task 3 and 4, the Fort Benning Baseline Model was enhanced by incorporating four types of model enhancements: 1) military training intensity methodology, 2) unpaved road impacts using a hybrid modeling technique, 3) a multi-level plant canopy simulation module, 4) channel sediment modeling. Brief summaries of these areas of refinement are provided below. Detailed description of each model enhancement is provided in Section 3.2. Additional flow data and rating curves from five new gaging stations helped further

refine the Fort Benning Baseline model. These data and the impact these data have on model performance is presented and discussed in Section 4.5 (i.e., Complementary USGS Monitoring Program).

Military Training Intensity Methodology

A military training load intensity methodology has been added to the Fort Benning Baseline Model to improve the simulation of military training impacts. The methodology correlates training activities to a change in vegetation cover, soil compaction and infiltration. Thus, sediment loading rates depend on the estimated training load intensity rather than a literature-based value. An estimate of the intensity of military training is determined by incorporating on-site training schedule information and translating it into Mission Essential Task List (MIM) using methods developed by Sullivan and Anderson (2000). This translation is based on the relationship that one MIM has the equivalent impact on soil erosion as an M1A2 tank driving one mile in an Armor battalion FTX. MIMs are used to compare the relative impact of current training at Fort Benning with several scenarios of increased training load. As a component of this project's research the impact of a MIM was correlated to changes to HSPF parameters related to soil compaction and infiltration. Further discussion of this enhancement is provided in Section 3.2.1.

Hybrid Modeling and WEPP

Given that road erosion is commonly the largest contributor to sediment production within forest watersheds, USDA's WEPP:Road model, the state-of-the art model for estimating sediment yield from unpaved forest roads, was linked with HSPF within a 'hybrid modeling' framework.

The hybrid modeling technique applies HSPF catchment-scale phenomena to the other 23 land use types that are represented in the Fort Benning Model, while WEPP-Road is applied to unpaved forest roads to take advantage of more detailed hillslope-scale process formulations. The output from WEPP-Road is linked to HSPF in the form of discrete point sources that are introduced into the appropriate channel reaches of the watershed model. The hybrid modeling approach enables the analysis of environmental 'hot spots' using models that offer a finer scale and a greater level of process detail, while at the same time providing a means of understanding the impact of the hot spots throughout the watershed in which they are located. Further discussion of this enhancement is provided in Section 3.2.2.

Multi-level Plant Canopy Simulation Module

A canopy/fire capability was added to HSPF to enhance the model's ability to simulate the effects of multi-layer canopy cover and burning. Originally, the model represented the effect of canopy as percent canopy cover for a single lumped canopy/above-ground compartment. The canopy enhancement allows representation of up to 5 levels of above-ground canopy cover so that overstory, understory, and a litter layer can be represented. This enhancement impacts interception and erosion by changing the formulations for vegetation interception, storage and cover. Further discussion of the multi-level plant canopy is found in Section 3.2.3.

Channel Sediment Enhancements

The Environmental Fluids Dynamics Code (EFDC), the SEDZLJ sediment transport model and an empirical bank erosion model (Ikeda et al, 1981) were incorporated under the channel model enhancement. These models provide improved algorithms for instream sediment erosion, deposition and transport of multiple size classes of sediment, and bank erosion.

EFDC enables more accurate calculation of the flow field and resulting bed shear stresses. SEDZLJ sediment transport model represents the dynamic processes of mixed grain bed erosion/scour, bedload transport, settling, bed sorting, armoring, deposition, and consolidation

of cohesive sediments. Ikeda's (1981) bank erosion model estimates sediment mass from the eroding bank to the sediment bed. Further discussion of this enhancement is provided in Section 3.2.4.

Additional Rating Curve Data

Five additional USGS stream gages were installed in the Fort Benning watersheds and started collecting data in October 2008. Flow data and rating curves from these locations provide the basis for refining the Fort Benning Baseline model. The rationale and use of this complementary USGS Monitoring program and the benefit gained in model performance for the cost of data is discussed in Section 4.5.

3.1.7 Task 7: Enhanced Modeling System Demonstrations

Based on the Modeling Strategy developed in Task 5, the Enhanced Baseline Model was applied to simulate specific management alternatives (3) to provide proof-of-concept demonstrations of the enhanced model as a tool to evaluate impact of those management alternatives on streams and key aquatic endpoints. The results of the enhanced model applications are presented in Sections 4.6, 4.7, and 4.8.

3.1.8 Task 8: Technology Transfer Efforts

Journal articles have been the primary mechanism to transfer the science and technology of the Enhanced Modeling System to the greater science and engineering community. Training of Fort Benning Staff who are responsible for watershed management on the Installation is the current target of technology transfer efforts. A webinar was recently conducted and a one-day seminar is planned to provide training on how the Enhanced Modeling System can support some of the Installation's watershed management objectives. Technology transfer efforts are presented and discussed in Section 5.8.

3.2 MODEL ENHANCEMENTS

During the first two years of the project eight research topics were investigated, six of which were specifically identified in the project Statement of Need (SON):

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. (SON Identified)
2. Sediment washoff/erosion related to military training activities: Enhanced sediment washoff/erosion model science to accommodate impacts from military maneuvers and associated equipment. (SON Identified)
3. Sediment washoff/erosion related to forest road construction and maintenance activities: Enhanced sediment washoff/erosion model science to accommodate impacts from unpaved roads.
4. Channel phenomena. This research topic includes three components: (1) channel flow: improved methods for modeling dynamic channel flows (particularly low and high flow events); (2) sediment transport: improved methods for modeling channel sediment transport (particularly for coarse sediments) and (3) stream bank erosion: integration of methods that enable representation of sediment loads introduced to streams by bank erosion or failure phenomena. (SON Identified)

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. (SON Identified)
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. (SON Identified)
7. Diagnostic mode capabilities: Improved methods/capabilities for using watershed models in a diagnostic mode to help clarify and quantify source-impact relationships. (SON Identified)
8. Rating curve development and integration: Investigate the value to the overall watershed simulation of having additional flow rating curves at Fort Benning, to provide a basis for calibration of component sub-watersheds, and implications for technology transfer to other military installations.

This project's Task 3/4 Report (AQUA TERRA Consultants, 2009) assessed each of these research areas in terms of the nature of the enhancements needed, available supporting resources and methodologies, viable enhancement alternatives, and a recommended path forward. As a result of this analysis an Enhancement Plan for the Fort Benning Watershed Model was developed (also AQUA TERRA Consultants, 2009). The Enhancement Plan is focused on the sub-set of research topics for which we identified the most beneficial and practical improvements (methodologies and/or model code enhancements) to support watershed model applications at military Installations. Research topics and improvements that comprised the enhancement effort are the following:

1. Sediment washoff/erosion related to military training activities. The potential for obtaining usable information to characterize military training activity was investigated, and a relationship between training intensity and changes to model parameters critical in estimating sediment washoff was developed.
2. Multiple spatial scales and Sediment washoff/erosion related to unpaved forest roads: A framework that enables communication of the HSPF model with another model of smaller spatial scale was conceptualized, coded and tested. The methodology and mechanics of performing a hybrid modeling exercise were demonstrated by importing sediment erosion results that were generated by an existing hillslope-scale model for unpaved forest roads into the Fort Benning Watershed Model to represent the unpaved road areas, while the watershed model estimated the sediment washoff resulting from the other 23 land use types.
3. Representation of forest canopy compartment and fire: A multi-layer plant canopy module was designed, coded and tested as an enhancement to HSPF. The model enables simulation of the sequential effects on hydrology of interception and evaporation resulting from the movement of precipitation through the overstory, understory and groundcover layers of forest lands. Similarly, the sequential characterization of vegetative cover contributed by the overstory, understory and forest floor layers can be represented and effects on restricting forest floor sediment erosion can be represented and evaluated. The new multi-layer canopy module was demonstrated in an application that addressed prescribed burning practices and impacts.
4. Channel phenomena: A hydrodynamic model was linked to the Fort Benning Watershed Model that provided a more accurate calculation of the flow field and resulting bed shear stresses than is achievable with the hydraulics-based, flow routing routine currently in

HSPF. An advanced, state-of-the science sediment transport model was linked to the hydrodynamics model enabling the representation of dynamic processes of erosion, bedload transport, settling, bed sorting, armoring, consolidation of fine-grain sediment dominated sediment beds, and deposition. An empirical-based bank erosion model was added to the hydrodynamic/sediment models.

5. Rating curve development and integration: Five new USGS stream flow gaging sites were installed and monitored for a three year period, and a rating curve was developed for each of the five sites. The rating curves were used to improve the stage-discharge information used as input to the Fort Benning Watershed Model.

The need and approach for each of these individual enhancements follows. In addition, we have provided recommendations for future model enhancements that were not accomplished in the effort for this SERDP project. These recommendations are provided in Section 5.0.

Note also that considerable additional information has been developed related to the investigations that were performed for a number of the enhancements. This information is available in appendices noted in the summary descriptions that follow.

3.2.1 Military Training Intensity Representation

Appendix B provides detailed reporting of the quantification of vehicular impacts from military training. Salient aspects of the need, research approach and implementation methodology are presented here.

For the baseline (Year 2004 condition) Fort Benning Watershed Model simulation, all three model segment types classified as “military land uses” (i.e., heavy maneuver areas (HMAs), unpaved roads, tank trails) were assigned sediment load targets based on literature reviews (AQUA TERRA Consultants, 2009). For each of the model’s meteorological segments, sediment washoff from the HMA areas was calibrated to achieve the best overall fit to target values. The range of sediment washoff that was targeted for HMAs in the calibration process for the baseline simulation was 2.5 to 7.5 tons/ac/yr. Variability in simulated washoff depended on areal differences in precipitation, topography and soils. Note that this approach did not consider or use information related to training activities or intensity. The total area of HMAs represented in the baseline model for the Upatoi watershed was approximately 2300 acres, and the model estimated that sediment washoff from the HMAs contributed 10% of the Installation’s total sediment contributions to the channel network.

For the Fort Benning Enhanced Baseline Model (FB EBM) the potential for improvements to sediment simulation for the HMAs and the unpaved roads was further investigated. Simulation methods for the third military use type (tank trails) remained unchanged in the FB EBM.

3.2.1.1 Need

The utility of a watershed model is in its ability to estimate the sediment washoff phenomena that correspond to different intensities of training. Doing so requires (1) agreeing upon the most important processes that control land surface erosion and (2) developing a justifiable methodology for modifying model parameter values that are associated with the formulations that the model uses to estimate these processes. The primary research question that was addressed is the following: To what extent can watershed models utilize training intensity data as the basis for estimating time-varying sediment washoff? (Note that watershed models are already capable of representing the spatial and temporal aspects of land disturbance data – the missing links are (1) limitations on the availability of training data and (2) defining the relationships between training intensity and impacts.)

3.2.1.2 Research Approach

Estimating Training Intensity

ACOE's Construction Engineering Research Laboratory (CERL) recommended an approach to estimating training intensity and then relating it to watershed model parameter values that utilized a metric that is already in common use among Army planners: the Maneuver Impact Mile (MIM). Estimates of the total annual MIMs performed at each Installation are readily available, whereas information on spatial distribution of the MIMs among any Installation's training areas is somewhat more difficult to obtain. The calculation of the MIM is determined using Equation 2-1:

MIM =

(3-1)

where:

MIM = normalized training load (maneuver impact miles)
E = Event (dimensionless)
e = number of events (dimensionless)
V = vehicle type (dimensionless)
v = number of types of vehicles in event E (dimensionless)
Mileage = daily mileage for vehicle type V for event type E (miles
Number = number of vehicles of typed V (dimensionless)
VSF = Vehicle Severity Factor for vehicle type V (dimensionless)
VOF = vehicle off-road factor for vehicle type V (dimensionless)
VCF = vehicle conversion factor for vehicle type V (dimensionless)
LCF = local condition factor for event E ((dimensionless)
Duration = number of day for event type V (days)
ESF = event severity factor for event type V (days)

The ESF, VSF, VOF and LCF values are currently derived using expert opinion. The VCF values are based on published vehicle tire/track widths (Sullivan and Anderson, 2000).

At its most basic level the MIM is defined as the impact caused by an M1 Abrams tank moving one mile. However, other tactical vehicle impacts have been related to the MIM via a vehicle conversion factor (VCF) and therefore vehicle impact information exists for all tactical vehicles and can be quantified for non-vehicular impacts such as foot traffic (Whitecotton et al, 2000 and McDonald and Glen, 2007). For the methodology developed to support the Fort Benning application, non-vehicle military impacts were ignored as comparatively they are observed to cause significantly less damage relative to vehicle military impacts. One MIM impacts 0.5 acres of land surface: two MIMS constitute a single pass across a single acre of HMA.

Estimating Training Impact on Infiltration and Ground Cover

The Project Team identified infiltration rate and loss of vegetative cover as the key determinants of sediment washoff potential from HMAs that are altered by off road vehicular training. Accordingly, the methodology focused its attention on relating the number of tank passes to reduction in the values for corresponding HSPF model process parameters: INFILT for infiltration rate and COVER, for land surface vegetative cover.

'INFILT' is defined as the index to mean soil infiltration rate (in/hr). Standard modeling procedure is to estimate, then calibrate the INFILT value. INFILT is the parameter that effectively controls the overall division of the available moisture from precipitation (after interception) into surface and subsurface flow and storage components. Thus, high values of INFILT will produce more water in the lower zone and groundwater, and result in higher

baseflow to the stream; low values of INFILT will produce more upper zone and interflow storage water, and thus result in greater direct overland flow and interflow. A 'typical' range of 0.01 to 0.25 in/hr has been defined for INFILT, and therefore a reasonable value for minimum infiltration rate is 0.05 in/hr (EPA, 2000). Fontaine and Jacomino (1997) show sediment and sediment-associated transport to be sensitive to the INFILT parameter since it controls the amount of direct overland flow transporting the sediment.

'COVER' is defined as the fraction of land surface which is shielded from rainfall (unitless), and is therefore not susceptible to soil fines detachment by raindrop impact. A 'typical' range of 0.01 to 0.98 has been defined for COVER, and therefore a reasonable value for minimum vegetative cover is 0.01 (EPA, 2006).

CERL reviewed and summarized existing literature regarding training impacts on infiltration rate and vegetative loss. Existing information was supplemented in 2010 with additional field testing at Eglin Air Force Base that entailed measuring the decrease of infiltration rate resulting from each of four passes of an M1A2 Abrams tank across a length of soil of similar texture to that prevalent at Fort Benning (Svendsen, 2012). The study at Eglin AFB measured decreases in soil infiltration that were approximately 20% for each tank pass. (Note that this value will change as general soil type changes, but can be estimated if compaction or bulk density information can be obtained for an area). It is assumed that a multiplicative relationship exists between soil infiltration rate and the number of vehicles passes.

Range and Training Land Assessment (RTLA) data was used to calculate the differences in ground cover between disturbed and undisturbed portions of field transects. For this investigation undisturbed portions of transects had no military disturbance. Disturbed portions of transects only had single pass vehicle disturbance. Only single pass portions of transects were considered so that differences between disturbed and undisturbed portions of transects would be an estimate of resource damage associated with single pass vehicle tracking events. Results indicated that the first pass resulted in approximately a 52.6% loss of ground cover. As was the case with soil infiltration rate, it is assumed that a multiplicative relationship exists between groundcover loss and the number of vehicles passes.

3.2.1.3 Implementation Methodology

Figure 3.5 summarizes the resulting methodology that has been developed for relating military training intensity to changes in infiltration rate and vegetative cover in HMAs. Elements of the methodology are described sequentially below.

The necessary information regarding military training load is derived from two sources. The Army Range Requirements Model (ARRM) provides annual estimates of the total MIMs that occur at each Installation. The Range Facility Management Support System (RFMSS) can provide information on the distribution of an Installation's total load among its training units. (The Installation map contained in Figure 3.5 illustrates MIM distribution at this stage in the methodology.) The reference for both ARRM and RFMSS is AR 350-19 (no date provided). These two systems function as planning, logistics and reporting tools for deciding how to disperse military units over the landscape such that those units can meet their training requirements and feedback as to how those units were spatially distributed to fulfill those training requirements. Given that tracking the fulfillment of training requirements is the primary function of the RFMSS data, the information contained in RFMSS is not organized or expressed in a manner that directly supports its use for assessing land disturbance. However, as a resource for this SERDP project, Fort Benning and CERL personnel collaborated to achieve a characterization of the distribution of off road vehicular training among Fort Benning's training units for one year (2004) (Keane and Balbach, 2008). To our knowledge this was the first and

only attempt to date of using RFMSS data as a primary data source for a watershed model application.

Once the distribution among training units has been achieved, a spatial conversion of this information can be made using the assumption (at least for the Fort Benning watershed model application) that all the MIMs are imposed on the acreage that has been set aside as HMAs. In lieu of spatial distribution data or estimates, a uniform distribution of training load intensity throughout all of an Installation's HMA acreage can be used as an approximation, and this was the approach used for investigating management alternatives modeled for the Fort Benning Watershed Model.

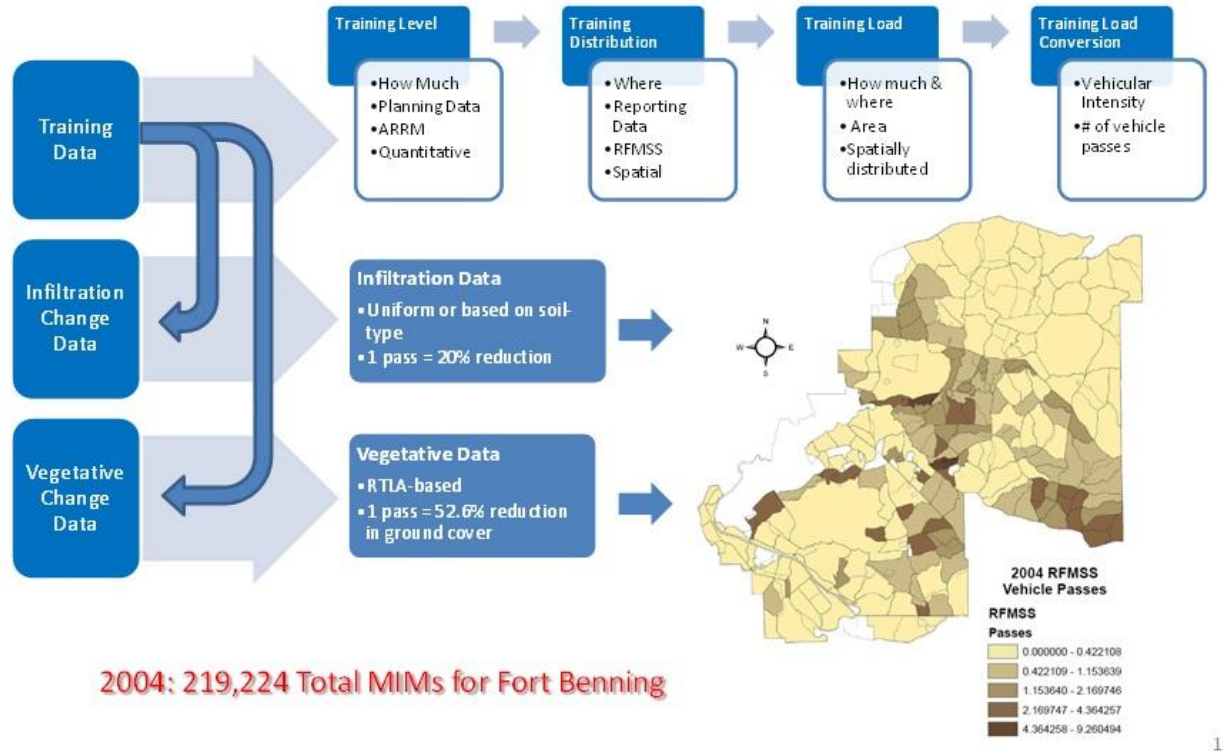

Figure 3.5 Methodology for Relating Military Training Intensity to Changes in Infiltration Rate and Vegetative Cover in Heavy Maneuver Areas (HMAs)

To relate the MIM estimates to HMA acreage, MIMs are expressed in terms of number of tank passes, and the infiltration and vegetative cover values for the model's HMAs are adjusted according the aforementioned reduction factors using a multiplicative assumption for multiple passes. Note the field data and derived reduction factors suggest that only a few passes will result in minimum infiltration conditions and nearly full loss of vegetative cover.

The result of applying the military training intensity methodology is discussed in Section 4.1.

3.2.2 Hybrid Modeling and WEPP Demonstration

One of the needs that SERDP identified for the Fort Benning project was for 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. The issue of differences in spatial scale most often gains relevance in model-based evaluations when a watershed contains one or more land use types that comprise a relatively small amount of a watershed's

total area, but potentially contribute a relatively large amount of the watershed's loadings for a particular constituent. In such instances, application of a small-scale model with greater detail in terms of both spatial resolution and process representation may provide beneficial improvements in estimating loading generation. However in many, if not most instances, the impact of these loadings also needs to be evaluated in a full-watershed context that considers of evaluation endpoints that are located a considerable distance away from the source areas.

The baseline simulation for Fort Benning estimated that 28 percent of the total sediment erosion for the Installation's watershed was attributable to the less than 3 percent of land that comprises the unpaved road network (AQUA TERRA Consultants, 2010). These results established unpaved roads as a land use type for which a small-scale, more detailed model had significant potential to improve simulation results and increase the overall watershed model's utility for use as a management tool.

3.2.2.1 Need

Watershed models and modeling efforts need improved ability to assess management-scale impacts within a larger watershed-scale context. In some instances the need may require only a finer spatial resolution of modeling subunits, while in other situations both finer resolution and improved process formulations may be required.

The design, construction and management of unpaved roads at Fort Benning require methods and models for estimating road erosion that provide a level of detail that surpasses the capabilities currently provided by HSPF and similar watershed-scale models. Nonetheless, the full impact of road management measures ultimately needs to be evaluated within the holistic watershed context.

3.2.2.2 Research Approach

Our investigation approach to spatial scale issues has been previously reported (AQUA TERRA Consultants, 2009). The approach included three components:

1. Increasing the number of model segments used to represent the Fort Benning watershed and channel network. This component focused on the improvement in modeling results that can be achieved (1) without changing the lumped-parameter modeling approach used by HSPF and (2) in the absence of enhancing the model's process formulations.
2. Investigating the opportunities and limitations of selected watershed models that have started from a lumped parameter approach and attempted to incorporate distributed-parameter capabilities.
3. Investigating the opportunities and advantages of implementing the 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 are run, either in parallel to, or jointly with HSPF to provide timeseries flow and loadings for significant smaller-scale activities and conditions. The investigation included evaluating the utility of existing small-scale models that offered potential benefit for improving watershed applications to evaluate Installation issues.

This section describes a model enhancement that resulted from the latter investigation and a demonstration of the methodology and mechanics that were involved in performing a hybrid modeling application. In our investigation of small-scale models (SSMs), we assumed that our ultimate development approach would be to implement a generalized capability in HSPF that enables hybrid modeling applications that utilize a variety of small-scale models. In fact this

capability would enable the use of *any* conceptually compatible, user-selected field-scale or hill-slope model in conjunction with HSPF, as long as that model was capable of generating timeseries output that can be linked back into HSPF's land and channel segments.

To demonstrate the methodologies and mechanics of performing a hybrid model application, we addressed the issue of sediment erosion from unpaved forest roads. To make available a more robust set of formulations for simulating sediment washoff, USDA's Watershed Erosion Prediction Project (WEPP) Model (Flanagan and Steele, 1995) was used a modeling 'partner' for HSPF. The WEPP application utilized modeling assumptions and data that are specific to unpaved roads and are components of the WEPP:Road interface developed by the U.S. Forest Service (Elliot et al., 1999). It should be noted that the most significant benefit that we perceived to introducing WEPP:Road into the Fort Benning modeling framework was not expectation of more accurate estimates of sediment washoff for unpaved roads. Rather, the most attractive aspect of the model was its greater level of detail in characterizing a variety of road types, and therefore its potential utility in supporting the representation and evaluation of a sediment washoff from variety of alternative road management practices.

Watershed- versus Hillslope-Scale Modeling

Unpaved roads are one of 24 unique land segment types in the Fort Benning model. For modeling purposes, the model divided the watershed into 14 different weather regimes, and generalized characteristics (e.g., overland flow length, overland flow slope) for unpaved roads in each of the meteorological areas were developed. Unit area erosion from a representative unpaved road condition for each meteorological segment was simulated, and the results were combined with each segment's total road area to estimate sediment loadings. Target sediment loading values for the road segments were determined based on established literature values. The fraction of the computed sediment washoff from the road that was delivered to the active channel (i.e., the delivery ratio) was estimated using empirical data related to the size of the watershed being modeled. Literature values were reduced by the delivery ratio to establish the target values used to calibrate sediment simulation parameters. Sediment loadings resulting from land segment simulations were introduced directly into the appropriate channel reach.

In WEPP, sediment is eroded by precipitation (interrill erosion) and scoured by runoff (rill erosion) along an overland path comprised of three overland flow elements (OFEs): road surface, fillslope, and forest buffer. The estimated erosion/deposition along the overland flow path corresponds directly to the predicted physical transport of sediment. Hence, the delivery ratio is achieved by means of the modeled re-deposition of sediments in the buffer OFE. All the sediment eroded from the road surface OFE leaves the road surface and enters either (1) the drainage ditch of an insloped road or (2) directly to the fillslope OFE for an outsloped, unrutted road. Depending on the physical characteristics of the fillslope, additional erosion can occur in the fillslope OFE. The net sediment export from the combined road and fillslope erosion/ deposition phenomena enters the forest buffer OFE. Additional erosion can occur at the beginning of the overland flow path through the buffer, typically followed by deposition that either partially or wholly diminishes the sediment load produced by upgradient erosion that eventually enters the active channel system.

3.2.2.3 Implementation Methodology

Generalized Hybrid Model Capability

A generalized capability was developed within HSPF that enables performing hybrid model applications in which HSPF can be used for modeling catchment-scale phenomena, while one or more field- or hillslope-scale models are run in parallel to HSPF. Using this hybrid modeling capability, the SSMs can provide time series flow and/or loadings for localized areas with

potentially large runoff or water quality impacts. These results are introduced into HSPF as point sources, the impact of which can then be evaluated in a watershed context. The areas of the land use type that are modeled using SSMs are eliminated from HSPF computations in a 'cookie-cutter' fashion to avoid double counting.

The newly developed HSPF EXTMOD module allows hybrid model applications utilizing the catchment-scale capabilities found in HSPF and the field- or hillslope- scale capabilities found in SSMs like WEPP:Road. EXTMOD was designed to allow for the SSM to be used 'natively' - without changes to its input or output. This allows the SSM developers to be comfortable with the implementation of their model in parallel with HSPF, as there are no changes needed to the small-scale model. Integration of a SSM into a HSPF model requires a 'wrapper'. The wrapper has three functions - write all input needed by the SSM based on input provided by HSPF or in external files, execute the SSM, read results produced by the SSM and format them into a HSPF compatible format. HSPF EXTMOD provides 'accounting' services following HSPF conventions to keep track of fluxes and mass balances for the portion of the watershed being modeled by the SSM.

An EXTMOD operation (Figure 3.6) reads timeseries created by a SSM wrapper along with any associated metadata and stores them internally in the HSPF operation status vector, accumulates fluxes to user specified reporting intervals, following the conventions used in other HSPF modules, and reports accumulated fluxes and state variables to text and binary files as requested by the user. Timeseries defined in an EXTMOD operation are available for use in any other operation present in the HSPF run. This allows some portions of a catchment to be modeled by a SSM and other portions to be modeled by the existing HSPF code.

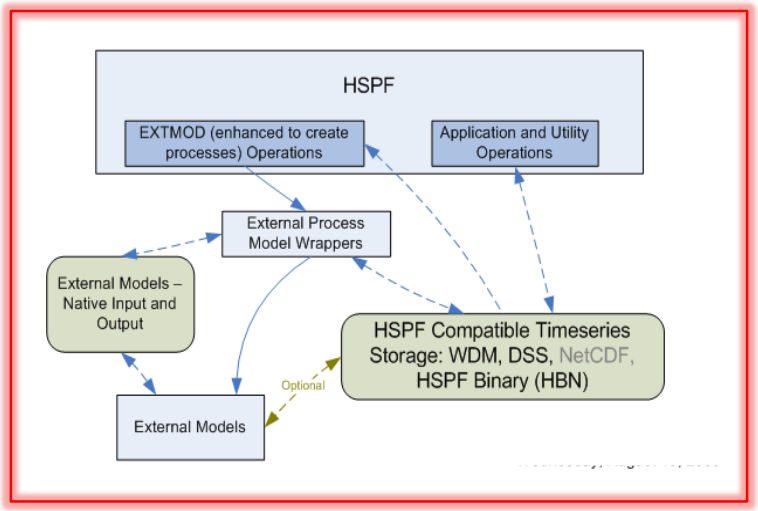

Figure 3.6 Communication Structure between the HSPF Watershed Model and Smaller-Scale Models

WEPP-Road Application to Fort Benning

Figure 3.7 provides a flowchart of the application components and sequencing required for the Fort Benning demonstration application. The approach featured the following requirements and/or assumptions:

1. In a parallel manner to the watershed-scale HSPF simulation scheme for unpaved roads (and other land use types), a 'representative' road segment was selected for each of the 14 different weather segments into which the watershed model is divided. Net unit area

erosion delivered to the stream system by travel across the flow path (road surface, fill slope, forest buffer) for each of the representative road segments was simulated.

2. For the purpose of mapping WEPP:Road results to the previous HSPF results, the unpaved road area estimates for each of the 14 sub-areas were assumed to include both the road surface and fill slope OFEs represented in the WEPP:Road modeling scheme. Thus, the forest buffer OFE associated with each road segment was not considered to be a component of the road area for purposes of computing unit area sediment delivery to the stream system.

3. The WEPP:Road interface typically utilizes regionalized *daily* weather data, whereas the Fort Benning Watershed Model utilizes 14 much more localized *hourly* observed weather datasets to represent the sub-areas of the Installation. In the context of the Fort Benning hybrid modeling exercise the localized weather data were reformatted (using a "wrapper") into a breakpoint file, which enabled WEPP to perform its simulations using the same hourly data that drives the HSPF model.

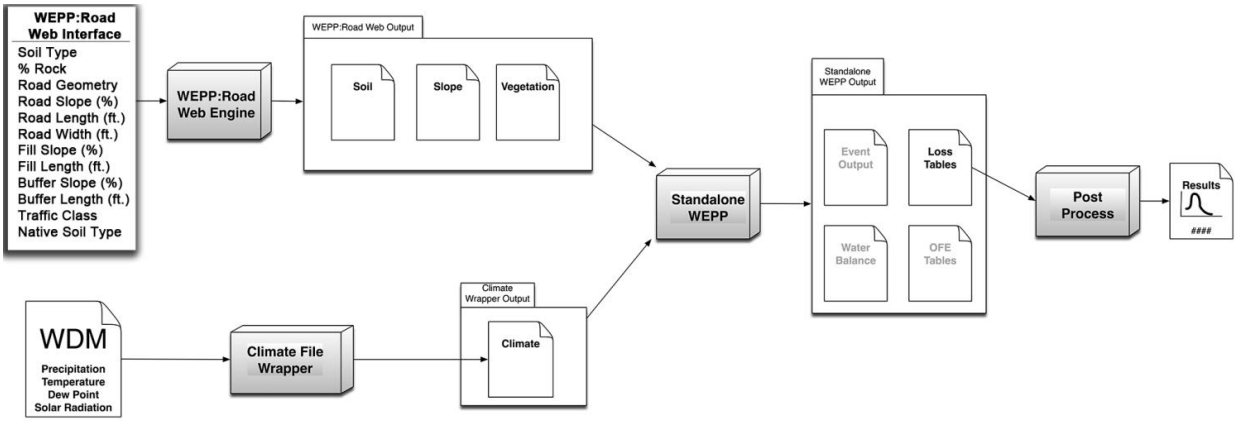

Figure 3.7 Flowchart for Application of WEPP:Road to Estimate Sediment Loadings from Fort Benning's Unpaved Roads

4. After de-coupling the weather data that are typically provided by the WEPP:Road Interface to the WEPP Model, it was still necessary to provide to WEPP:Road input parameter values that define the road characteristics and physical settings for each of the 14 representative road segments so that the Interface could translate and generate the contents of three input files (Soils, Slope, Vegetation) that provide values for all the rest of the input required by the WEPP Model. Our approach was to maintain as much consistency between the physical meaning implied/imposed by parameters/values that were originally used for modeling unpaved roads using HSPF and the parameters/values subsequently required for modeling the same unpaved roads using WEPP:Road.

5. The input provided to WEPP:Road for all representative road segments at Fort Benning characterized the roads as outsloped; comprised of native materials and lacking addition of gravel or rock; and subject to heavy traffic.

Calibration of WEPP:Road to Fort Benning's Unpaved Roads

Refinements of the HSPF sediment washoff calibration for all land use types progressed to a point where confidence was gained in the estimates that the model generates for unit area sediment washoff. When this had been accomplished, it was justifiable to use the HSPF annual

unit area sediment washoff results (expressed as tons/ac/yr) that were estimated for unpaved roads using HSPF as calibration targets for the parallel WEPP:Road simulations. (Recall that the primary objective of introducing WEPP:Road into the Fort Benning modeling framework was not expectation of more accurate estimates of sediment washoff for unpaved roads, but rather having available its greater level of detail in characterizing a variety of road types, and therefore its potential utility in supporting the representation and evaluation of a variety of alternative road management practices.)

A list and description of the model parameters for which a WEPP:Road user may supply input values, and hence to some extent calibrate model runoff/erosion response is provided in Appendix A. The WEPP:Road software package provides graphical tools that enable visualization of model sensitivity for two of these user-defined parameters: road slope and flow length. (Road length estimates correspond to the average length of run for a road before it reverses slope direction.) We used these graphical tools to evaluate sensitivity for these two parameters within the Fort Benning setting and determined that adjustment of values for these two parameters would not be effective in a calibration effort (see Appendix A). Consideration of the remaining input parameters allowed by WEPP:Road led us to conclude that they also could not provide the doorway to WEPP's process formulations that we needed to effectively represent the runoff/erosion response of the Installation's unpaved roads using observed hourly precipitation records as the driver. As a result, we identified the need to circumvent the parameterization scheme of WEPP:Road and interact directly with WEPP to establish value for three key WEPP parameters. Calibration of the WEPP:Road simulations for the 14 meteorological segments focused on adjustment of parameter values for the interrill erodibility coefficient, the rill erodibility coefficient and the baseline shear coefficient. The calibration goal was to reproduce the annual unit area sediment washoff estimated by the baseline HSPF model for unpaved roads in each of the 14 meteorological segments within plus or minus 15 percent.

Integrating WEPP Results into HSPF to Achieve Hybrid Modeling

Figure 3.8 depicts the logistical linkage that was established for demonstrating a hybrid modeling methodology using the WEPP model to provide unit area sediment washoff data for the HSPF watershed model. The EXTMOD module was not used for this demonstration; instead the approach was taken to suppress the sediment washoff loadings that the HSPF model was estimating and to introduce as their replacement the sediment washoff loadings that were generated by the WEPP model. Both loading estimates relied on the simulated HSPF flow values. The mechanics of this process were as follows:

- Output from 14 WEPP simulations was processed to get daily loads (kg/m^2) at the edge of the fill slope overland flow element (OLE).
- Daily loads were imported to the watershed data management (WDM) file and units were converted from kg/m^2 to tons/acre.
- Daily loads were distributed to hourly intervals using according to the hourly input precipitation pattern, with an initial set aside of 0.2 inch to accommodate for depression storage.
- Hourly unit area loads were multiplied by unpaved area acreages and used as input to each HSPF stream reach.

Results related to developing a generalized hybrid modeling capability and to modeling sediment erosion of unpaved roads are presented and discussed in Section 4.2.

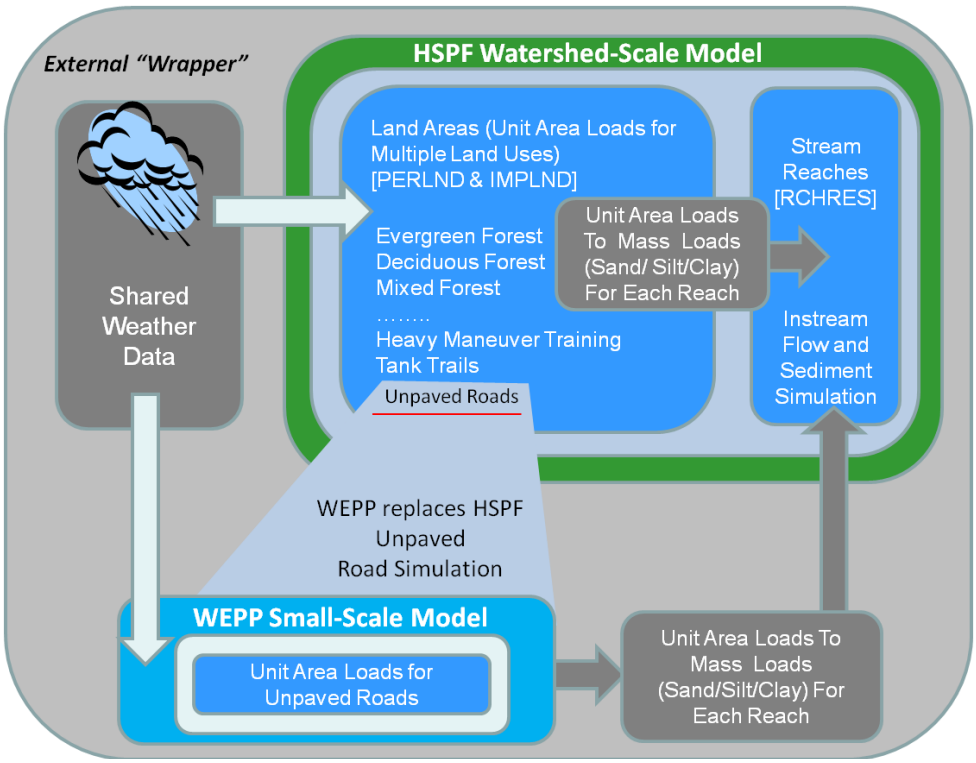

Figure 3.8 HSPF/WEPP Linkage for Performing Hybrid Modeling

3.2.3 Multi-Level Plant Canopy in HSPF

The research investigation and resulting enhancements to the HSPF model and the Fort Benning modeling system that are described in this section address the capability to dynamically represent alterations in runoff and sediment erosion from forest areas that are subjected to disruptive events such as prescribed burning and timber harvesting.

3.2.3.1 Need

Training and resource management activities at military installations can result in significant disturbance to the natural ecosystem on both biotic and abiotic spheres, and on a multitude of levels. Local flora and fauna can potentially suffer long lasting damages to their vitality and sustainability. Fort Benning, like other military training facilities, is challenged to mitigate disturbance of local ecosystems ranging from soil structure damage and erosion to decline of natural habitat for endangered species (e.g. red-cockaded woodpecker) to impacts of forest management practices (e.g. timber harvest, planting, thinning). In response, various efforts have been put forth in overall forest management to combat negative impacts and promote general health, and hence sustainability, of the natural environment. One habitat management practice of particular importance at Fort Benning is the prescribed burning of underbrush in forest stands to remove understory habitat used by predators of the red-cockaded woodpecker (RCW).

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 composite plant community via simple expressions of its functional relationship with other components of the hydrologic cycle and the nutrient cycle, e.g. rainfall interception, soil cover protection (for sediment erosion), and nutrient uptake. 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 of physical presence (e.g. canopy) for both overstory and understory vegetation. Increasing the level of explicit representation of these dynamic processes can not only provide HSPF an ability to comprehensively evaluate the impact of prescribed burning and forest management, but also the potential ability to quantitatively evaluate ecological performance of a given landscape from a vegetation perspective.

3.2.3.2 Research approach

Our investigation approach for meeting this research need has been previously reported (AQUA TERRA Consultants, 2009). New modeling approaches and components were identified to address the need for an improved capability by HSPF to model impacts from prescribed burning and forest management on hydrology, sediment, water quality and ecosystem response. In doing so, careful consideration was given to the full effort involved in developing and employing state-of-science algorithms, since more complex enhancements require increasingly large development efforts and application costs. The effort needed for model development and testing, parameterization of new algorithms, and model calibration was also considered.

Three approaches were investigated for modeling the eco-hydrology of the forest community and associated prescribed burning and other management practices using HSPF:

1. modify pertinent HSPF parameter values to represent the effects from management practices;
2. incorporate simple algorithms, or enhancements, to provide a fuller dynamic description of the related processes; or
3. incorporate or couple sophisticated models describing growth dynamics of the forest community and the associated management impacts.

In addition to prescribed burning activities, other forest practices at Fort Benning include thinning, planting, and timber harvest, with the latter being the most disruptive of the landscape and potentially the greatest impacts on sediment and nutrients. To address this concern, we performed a pre-modeling assessment of potential environmental impacts associated with timber harvesting at Fort Benning. Our analysis concluded that sediment erosion attributable to timber harvest, even using traditional harvest methods, is expected to be relatively less intense (on a per acre basis) than many of the other land activities represented in the Installation's watershed. Combined with the fact that such a small area of forest is harvested at Fort Benning (typically less than 1% each year), we feel that Fort Benning's harvest areas can be adequately represented in a lumped manner within model segments that represent larger undisturbed forest areas.

A detailed model comparison was performed among existing models with respect to their capabilities in simulating the abiotic and biotic elements of a forested environment (see AQUA TERRA Consultants, 2009). Comprehensive stand-alone models were identified and compared with respect to capabilities of plant growth simulation, basic hydrologic processes such as rainfall-runoff-soil water content dynamics, and nutrient (mostly nitrogen) cycling. Noteworthy among these single-species models are the WEPP model which is a state-of-the-science, fully process-based hydrologic model that is specialized in soil erosion modeling. It started out as a hillslope model, and recent development has led to a watershed-scale version. The SWAT model is a comprehensive agricultural hydrologic model that is fully process-based and is widely used for water quality assessment of various landscapes. It is a watershed-scale model.

More complex multi-species plant growth models were also investigated and their process representations were compared. Employing detailed forest/undergrowth models would allow HSPF to better represent the more direct causal effects of the management options. However, implementing a detailed forest/undergrowth capability in HSPF depends on the availability of resources and data for application, along with the availability of theoretical and formulation information from the reviewed models.

As an intermediate alternative, instead of considering all of the plant processes, only those directly related to relevant HSPF processes, and conditions/practices at Fort Benning, can be formulated and incorporated into HSPF for an improved dynamic simulation of relevant canopy processes.

3.2.3.3 Implementation Methodology

The enhancement methodology that was implemented was a refinement of 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 the capability to represent multiple layers of vegetation, including the understory vegetation that is susceptible to prescribed burning. This approach, along with direct parameter adjustments, relies on literature review for fire impacts – timing, intensity, frequency - on the soil environment and plant community. Then, suitable parameter ranges are identified for modification and perhaps further calibration of model runs. Both the model multi-story capability enhancement and the improved ability to accommodate fire impacts, through the use of time series input that reflects fire occurrence, intensity, and areal distribution within the watershed are further discussed below. Implementation and use of the time series input approach allows maximum flexibility in representing a broad range of potential fire impacts.

Methodology for Multi-Layer Canopy Representation

Figure 3.9 illustrates the multi-layer approach that was implemented for canopy impacts on hydrology and sediment. For hydrologic simulation, a simple bucket approach for each canopy layer was adopted with a basic storage capacity in term of inches of rainfall during each time step; subsequent overflow enters the next lower layer down in the canopy. Potential evaporation is considered in each time step that serves to reduce the actual storage of rainfall for a given layer. Hence, the overflow is the difference of total potential interception storage (i.e. previous storage plus rainfall inputs during the time step), minus the evaporation from the wetted canopy, and less the storage capacity for that layer, in each time step. That is, the overflow is the excess once the evaporation has been deducted and the capacity has been filled. A five-layer canopy storage was implemented in the HSPF code. The interception storage capacity for each layer can be provided as a constant value, monthly varying value, or a time series.

For sediment simulation, a simple umbrella approach was developed to allow multiple cover layers (maximum five) within the plant compartment in the HSPF code. Each cover layer specifies the fraction of water that can reach the next layer and finally to the soil layer to cause raindrop impacts and subsequent erosion. The number of cover layers is the same as the number of canopy layers. Similar to canopy layers, the variation in cover can be provided by a constant value, monthly table, or a time series.

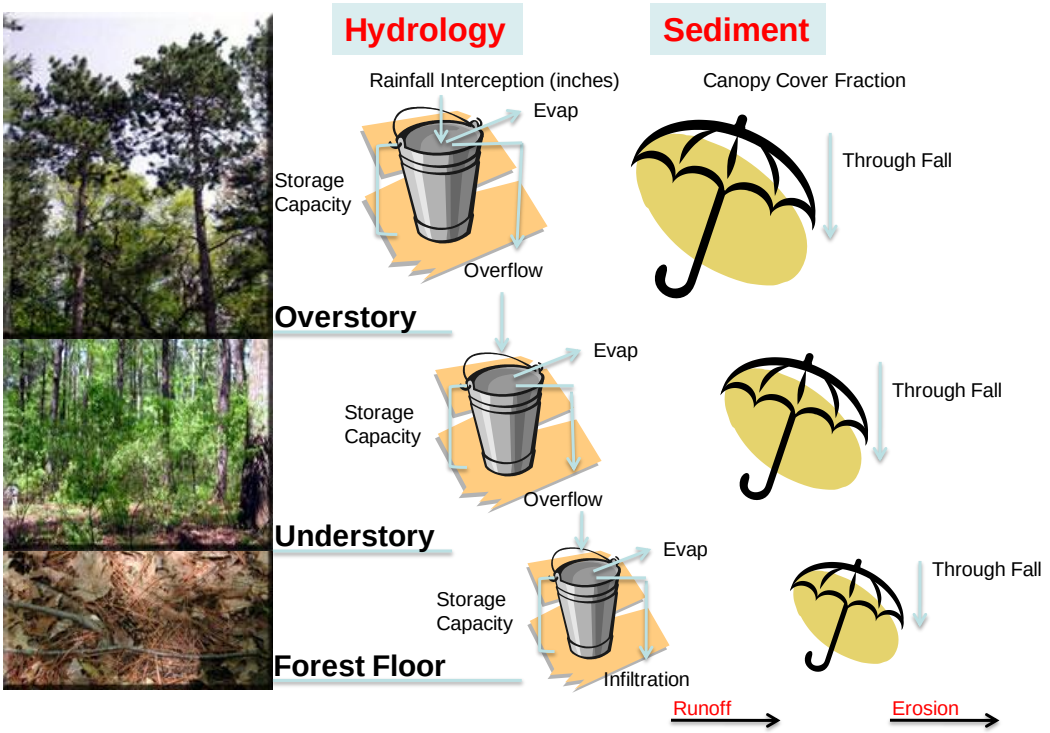

Figure 3.9 Multi-level Canopy Enhancement for HSPF

Methodology for Representation of Prescribed Burning Impacts on Hydrology

As noted above, prescribed burning at Fort Benning is conducted on a regular basis to meet several ecological objectives. The practice includes burning of under-brush (understory), which is the habitat for predators to the red-cockaded woodpecker (RCW) that is on the endangered species list and hence protected by several regulations.

The forest areas that are burnt under prescribed burning were assumed to have three layers of canopy; overstory, understory and forest floor. The overstory canopy was numbered as layer 1 in the HSPF model, understory canopy was numbered as layer 2, and forest floor was numbered as layer 3. The overstory layer is least affected by prescribed burning and therefore the time series of interception storage capacity from overstory layer was assumed to be affected by seasons only. The understory layer is burnt during prescribed burning following different yearly cycles, and therefore the effect of prescribed burning was represented using three time series, one for each cycle. The forest floor canopy cover also changes due to the season and prescribed burning; however, in the Fort Benning watershed model, the forest floor compartment and its behavior was implicitly represented by the parameter for depression storage and upper layer soil moisture storage, UZSN (Upper Zone Nominal Storage), when the baseline model was developed. Consequently we retained the values of UZSN obtained through calibration, and opted not to implement an additional forest floor storage layer, which would have been a double-counting of the storage amounts.

The maximum interception capacity of all kinds of forests obtained from HSPF parameter guidance (US EPA, 2000), and prior experience in the baseline model was 0.16 in (4.06 mm). Sixty percent of interception capacity was assumed to be because of overstory and 40% was assumed to be from understory. Therefore, the maximum interception capacity of overstory was 0.096 in (2.44 mm) and the maximum interception capacity of understory was 0.064 in (1.63 mm).

Overstory Canopy

The canopy cover in the overstory is a function of season and the type of forest. Forested areas In the Fort Benning watershed have been classified as evergreen, deciduous, and mixed for representation in the watershed model. The time-varying change in interception storage capacity is illustrated in Figure 3.10. As shown in the figure, the variation in interception storage capacity of evergreen forests varies least over the year, and the interception storage capacity of deciduous forests varies most.

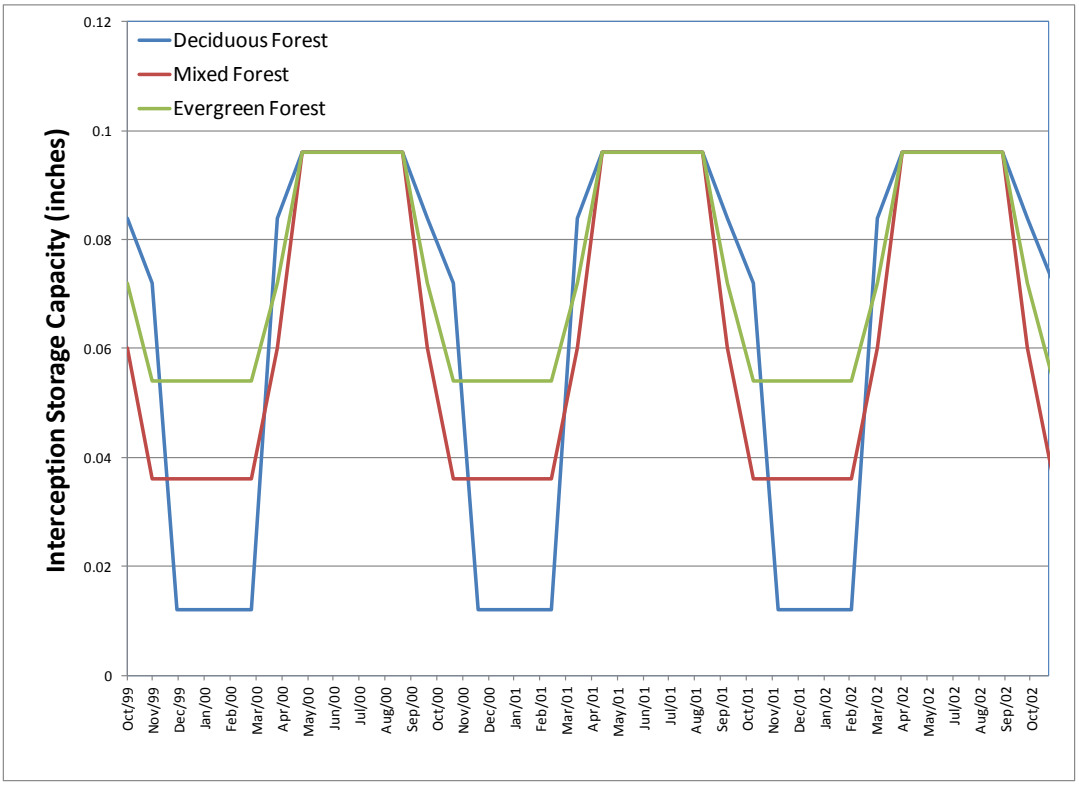

Figure 3.10 Change in Interception Storage Capacity of Overstory (in inches) for the Period of Simulation

Understory Canopy

Fort Benning (Michele Elmore, personal communication, 2008) provided us with shapefiles that contained maps of the areas that were burnt for the water years (WY) 1999 to 2007 under the prescribed burning plan (e.g., Figure 3.11). (Note that Water Year 1999 begins on October 1, 1998 and ends on September 30, 1999.) Typically, the forest areas are burnt under three year cycles (with few exceptions) i.e. the same areas are burnt after three years. About 35,000 acres of forest area is burnt every year under prescribed burning. Using the maps of prescribed burning for all the years, a consolidated map was developed that showed the areas under different prescribed burn cycles (Figure 3.12).

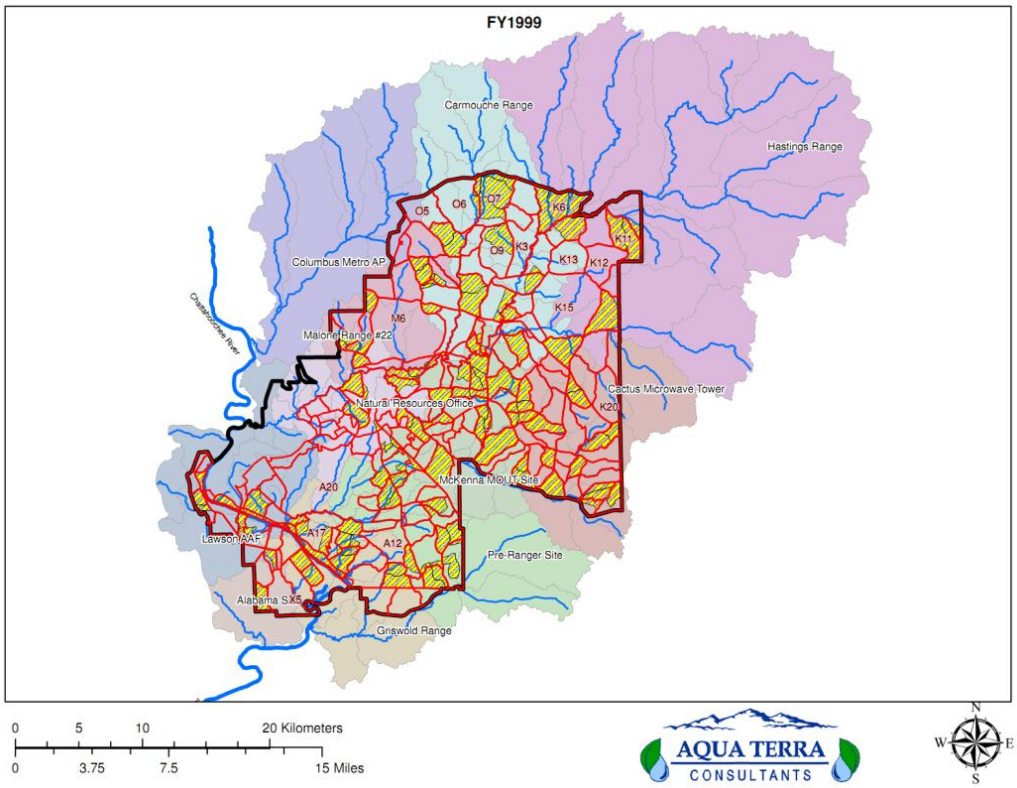

Figure 3.11 Fort Benning Areas that were Burnt in the WY1999 under Prescribed Burning Plan

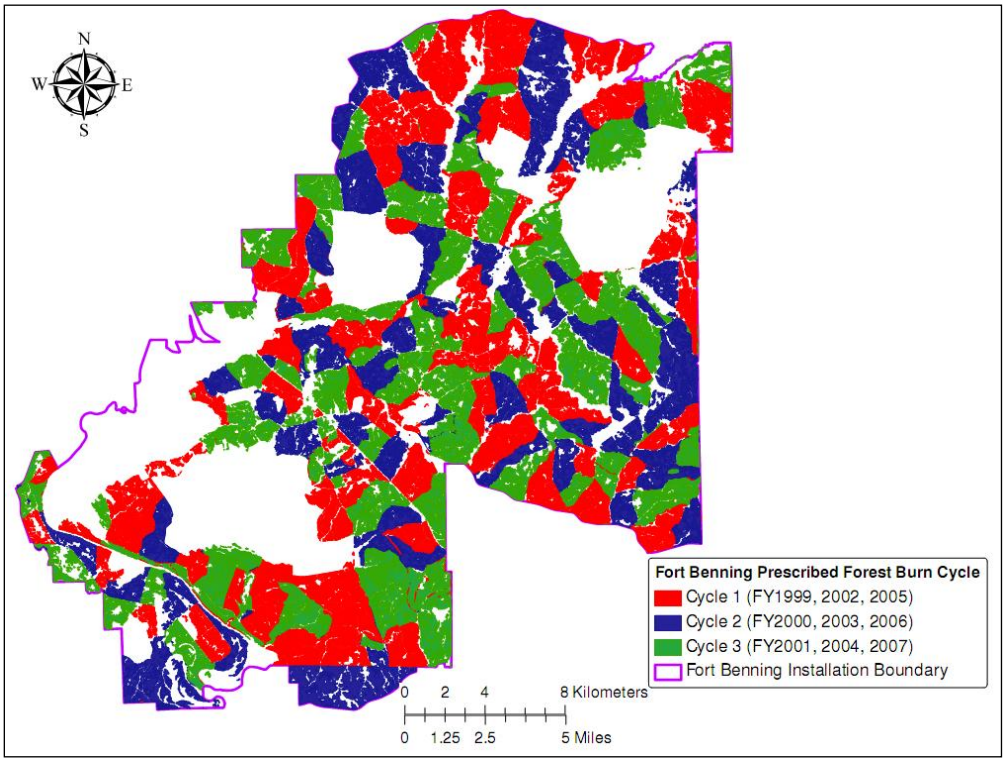

Figure 3.12 Fort Benning Areas that are Burnt Under Different Burn Cycles

The shapefiles of burnt areas also provided the date of each burn. The burn date data was consolidated, and it was observed that majority of the burns take place in the months from January to April of each WY (Table 3.2). Based on patterns of the areas that are burnt each month, we estimated that in each WY, about 20% forests are burnt in January and February, 35% are burnt in March, and 25% in April. These fractions were later used to develop consolidated time series for both interception and canopy cover for each burn cycle.

Table 3.2 Areas Burnt in Each Month for WY 1999-2007

	Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
WY 1999	Area (ac.)	0	0	0	5836	2401	7799	8892	2677	3321	2476	2093	446	
	Pct	0	0	0	16.2	6.7	21.7	24.7	7.4	9.2	6.9	5.8	1.2	35941
WY 2000	Area (ac.)	2	0	0	4381	9140	7614	6245	2599	0	0	46	6	
	Pct	0	0	0	14.6	30.4	25.4	20.8	8.7	0	0	0.2	0	30033
WY 2001	Area (ac.)	18	131	76	4187	4171	8341	8633	7877	184	1134	30	250	
	Pct	0.1	0.4	0.2	12	11.9	23.8	24.6	22.5	0.5	3.2	0.1	0.7	35032
WY 2002	Area (ac.)	272	291	1117	1885	10793	10146	8640	2170	1276	0	0	0	
	Pct	0.7	0.8	3.1	5.2	29.5	27.7	23.6	5.9	3.5	0	0	0	36590
WY 2003	Area (ac.)	0	0	1284	7558	5505	7750	10462	578	0	0	0	0	
	Pct	0	0	3.9	22.8	16.6	23.4	31.6	1.7	0	0	0	0	33137
WY 2004	Area (ac.)	0	52	1325	10799	5408	17732	3418	650	0	381	348	0	
	Pct	0	0.1	3.3	26.9	13.5	44.2	8.5	1.6	0	0.9	0.9	0	40113
WY 2005	Area (ac.)	0	8	2831	8536	6530	14208	6982	0	0	0	0	0	
	Pct	0	0	7.2	21.8	16.7	36.3	17.9	0	0	0	0	0	39095
WY 2006	Area (ac.)	0	0	0	3994	1905	12548	5062.1	0	0	0	0	0	
	Pct	0	0	0	17	8.1	53.4	21.5	0	0	0	0	0	23509
WY 2007	Area (ac.)	0	573	5167	6637	13279	10813	7798	1315	0	150	0	0	
	Pct	0	1.3	11.3	14.5	29	23.6	17.1	2.9	0	0.3	0	0	45732
	Mean of Pct.	0.1	0.3	3.2	16.8	18.0	31.1	21.1	5.6	1.5	1.3	0.8	0.2	

As discussed earlier, it is the understory that is burnt in each burn cycle, and the understory in all the forests are mostly deciduous (USACE, 2007) irrespective of the forest type. The approximate pattern of canopy cover change over the year for a deciduous forest was adopted from Bhat (2005). It was further assumed that the forests were burnt on the 10th of their burn month and canopy cover reduces to 10% immediately and stays like that for three weeks. Using these assumptions, a time series was developed that showed how a deciduous forest recovered following a burn in each of the four burn months of January, February, March and April. Figure 3.13 illustrates the change in canopy cover of a deciduous understory followed by prescribed burn in the WY 2000. The burns could be conducted in one of the four months. The same cycle is repeated in WY 2003. Using these four time series, a consolidated time series was developed to represent burn and recovery of deciduous understory (Figure 3.14) based on percentages for each of the four burn months noted above, and derived from Table 3.2. Once the change in fraction of cover was obtained, it was multiplied by maximum understory cover (0.064 in) to obtain the interception storage capacity due to understory.

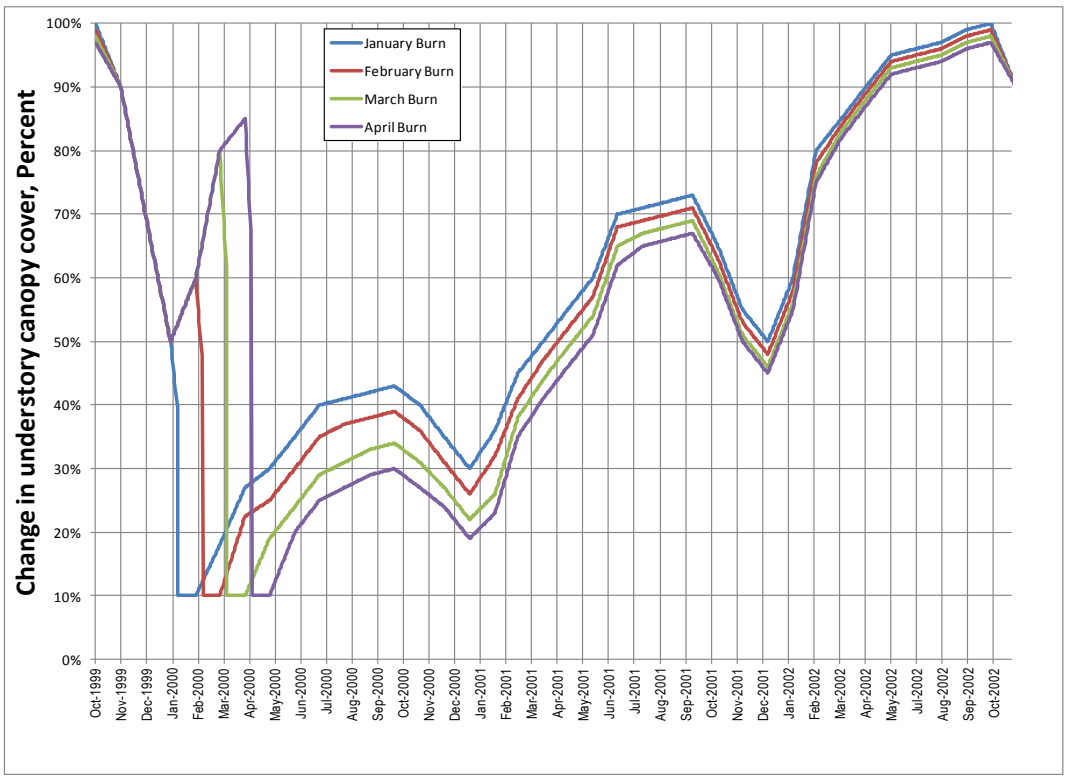

Figure 3.13 Time Series Representing the Recovery of Deciduous Understory under Prescribed Burning

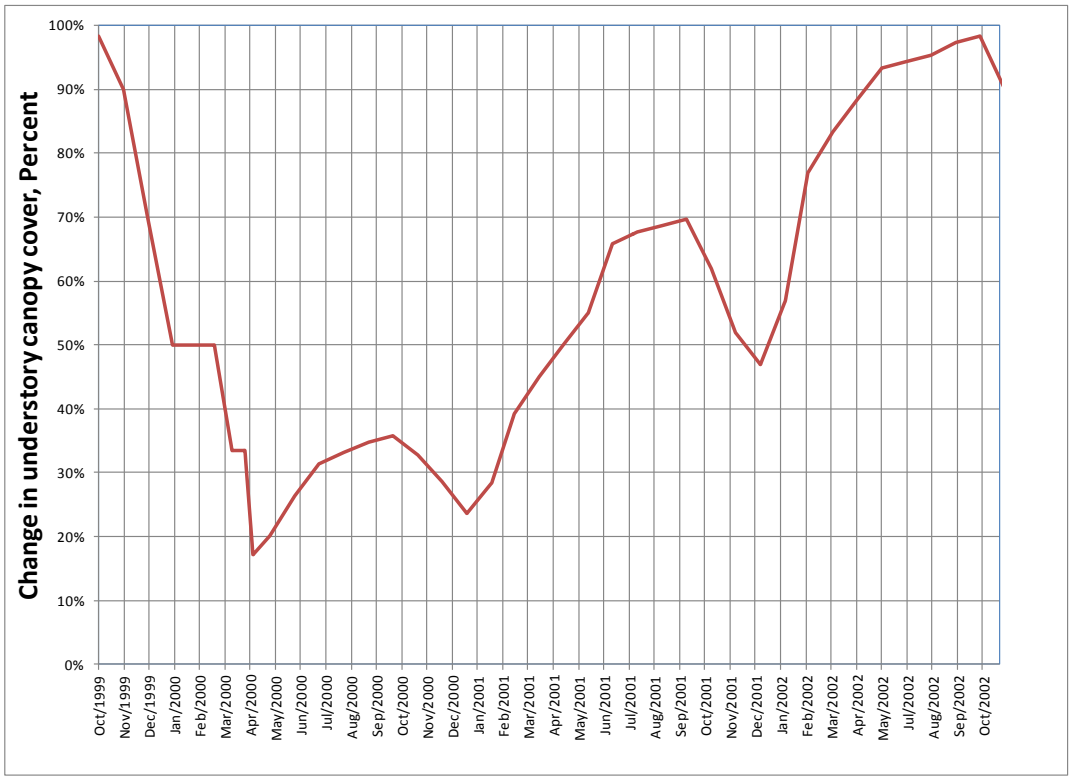

Figure 3.14 Time Series Showing Change in Canopy Cover in Percent for Understory after Consolidating the Time Series for January, February, March, and April Burns

Index to Infiltration Capacity

The index to infiltration capacity (INFILT parameter in HSPF) of forested areas also changes due to prescribed burning. Excessive temperatures during burning cause reduction in infiltration (Shakesby and Doerr, 2006; Shakesby et al., 2007). Partially based on these studies, it was assumed that infiltration capacity would be reduced by 30% (from 0.1 to 0.07 in/hr) after each prescribed burning, and it will recover in three years (the usual prescribed burning cycle) (Figure 3.15). Furthermore, based on the Fort Benning burn data it was assumed that prescribed burning takes place in the month of February, which is generally the middle of the burning season.

Figure 3.15 Change in Infiltration Storage Capacity after Prescribed Burning

Methodology for Representation of Prescribed Burning Impacts on Sediment Erosion

The cover factor for sediment simulation determines how much precipitation can reach the surface and cause detachment of fine sediment particles for subsequent erosion, e.g. a cover factor of 0.92 suggests that only 8% of precipitation can reach the soil surface and cause erosion. The maximum cover factor obtained by parameter guidance and prior experience in the baseline model was 0.92 for evergreen forest, 0.95 for deciduous forest, and 0.935 for mixed forest. These cover factors vary monthly and were provided as a monthly table in the baseline model.

In the enhanced baseline model where the multi-level canopy was implemented, sixty percent of cover was assumed to be provided by overstory, and forty percent by understory; therefore, for evergreen forest, the maximum cover factor for the overstory was 0.823 and maximum cover factor of understory was 0.549. In other words, 17.7% of precipitation can pass from overstory and then 45.1% of 17.7% or about 8% of original precipitation can reach the soil surface and cause erosion, making the effective cover factor 0.92. The overstory cover factor time series

was calculated as sixty percent of cover factor values from the baseline model (Figure 3.16). The understory cover factor time series was calculated by multiplying the canopy fraction time series Figure 3.14 with the maximum cover factor for understory. Similar procedures were used to calculate the maximum cover factor for overstory and understory for the other forest types, deciduous and mixed forest.

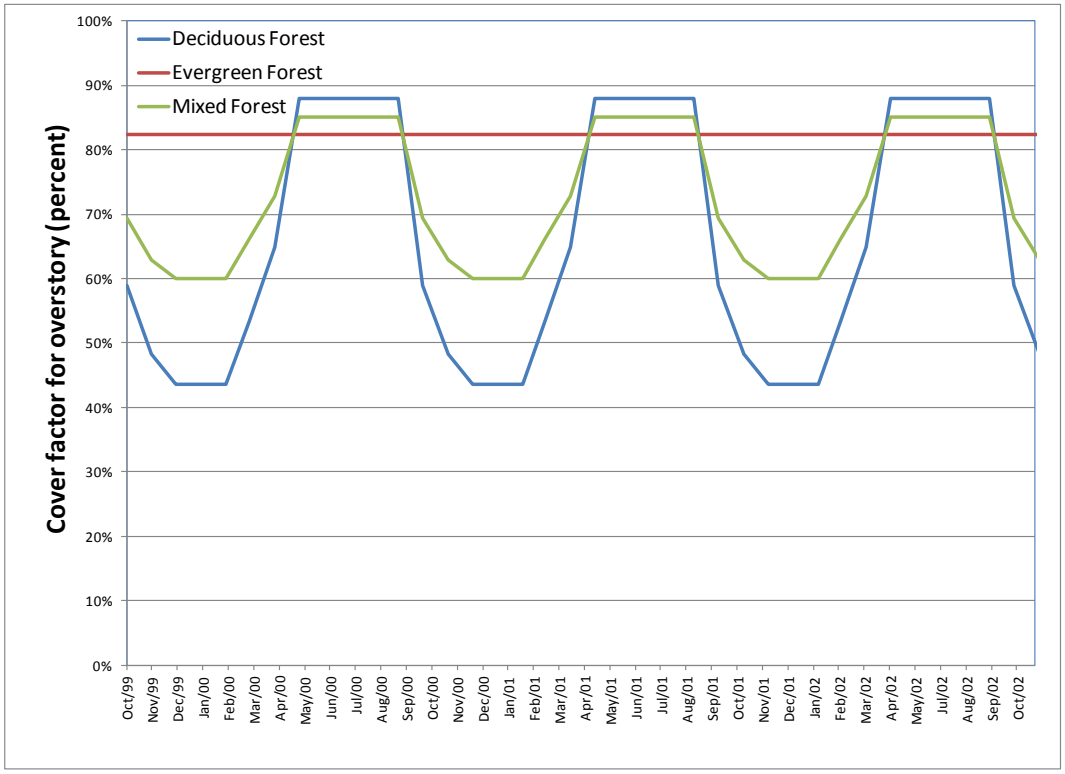

Figure 3.16 Change in Cover Factor for Overstory for Different Kinds of Forest due to Change in Seasons

Further discussion of the multi-level plant canopy enhancement and model results is provided in Section 4.3.

3.2.4 Channel Sediment – EFDC/SEDZLJ 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 and others (2006) concluded that:

> …..disturbance from land use at Fort Benning Military Installation alters particle size distributions in the stream bed, apparently from a combination of erosional (i.e., a disproportionate terrestrial input of fines) and hydrologic (i.e., increased bank erosion from high flashiness) influences, resulting in disproportionately high input of fine particles in disturbed catchments.

Wet weather bank erosion can occur due to several water-driven phenomena on top of or within the bank materials (e.g., rotational or planar failure) or within the stream channel (e.g., scour of the bank toe). Dry weather bank/gully destabilization can occur due to tracked vehicular travel during training activities. When the sediment loads from landscape and bank erosion are

introduced into Fort Benning's stream channels as a result of high flow events, increased sediment carrying capacity, associated with the high flows, often results in transport of not only terrestrial loadings but additional loadings from bed scour. The erodibility and scour of bed sediments is determined by bed sorting (by particle size), coarsening and armoring processes that change constantly in response to the varying flow and sediment loading conditions that occur in a channel.

The research investigation and resulting enhancements to the Fort Benning modeling system that are described in this section address the integration of more robust models for channel flow and channel sediment transport into the Fort Benning Watershed Model and the capability to represent channel bank erosion using an empirical bank erosion algorithm. Further details regarding the channel sediment and bank erosion enhancement are provided in Appendix C.

3.2.4.1 Need

Improvements to three aspects of the baseline model will provide significant benefit to model applications at Fort Benning and at other installations. These enhancements relate to simulation methods for instream flow, instream sediment transport, and bank erosion.

To improve the flow simulation, a hydrodynamic model needs to be added. A hydrodynamic model offers potential for 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 currently used hydraulics-based, flow routing routine. Appropriate representation of high flow events is particularly critical to sediment transport simulations. Improved flow modeling capabilities provide the starting point for satisfying a second need for improvement: the ability to better represent channel scour and deposition by incorporating more detailed bed sediment process algorithms.

One of the important benefits of using improved formulations is to enable the modeling of multiple size classes of non-cohesive sediment, a capability that the baseline Fort Benning model lacked. Adding this capability enables the simulation of bed armoring of both cohesive and non-cohesive dominated sediment beds. The ability to represent bed coarsening and subsequent armoring is crucial in simulating sediment transport during high flow events. If the simulated sediment bed is not capable of armoring, then excessive (i.e., unrealistic) scour may be predicted.

Currently the HSPF watershed model, like all other commonly applied watershed models, lacks a method for representing the generation of sediment loads due to events of bank erosion/failure. This is an extremely important mechanism that needs to be represented, especially in incised streams and rivers that are prevalent in Piedmont physiographic regions where eroding/failing banks are often significant nonpoint sources of sediment to these waters (Simon et al., 1999). In the absence of a means to represent and estimate the contributions to channel sediment load that result from bank erosion/failure, these loads can mistakenly be attributed to landscape disturbances that occur on an installation (e.g., training activities).

3.2.4.2 Research Approach

Our investigation approach for meeting this research need has been previously reported (AQUA TERRA Consultants, 2009). Addressing the three needs (dynamic flow model, detailed channel sediment transport model, bank erosion model) that were identified and elaborated during the investigation required an approach that assured conceptual and practical compatibility among the three improvements, as well as compatibility with related HSPF formulations that would remain intact.

ACOE's Environmental Laboratory (EL) and AQUA TERRA jointly investigated candidate flow and sediment transport models that were both compatible with HSPF and offered the desired enhancements to process representation. A recent and thorough comparison of flow and sediment transport models (Imhoff et al., 2003) was leveraged to evaluate and select among the enhanced flow and sediment transport models available. EL investigated the availability of methodologies for estimating bank erosion and their compatibility with the continuous simulation approach used by HSPF (as well as all the candidate enhanced flow and sediment transport models).

This section describes the modeling system enhancements that resulted from this investigation and were integrated into the "Enhanced Baseline Model" for Fort Benning (see Section 4).

Approach to Enhancing Channel Flow and Sediment Transport Modeling

The Project Team chose to link the three-dimensional (3D) hydrodynamic model EFDC and sediment transport model SEDZLJ into the Fort Benning Enhanced Baseline Model. EFDC (Environmental Fluid Dynamics Code) is a multi-dimensional hydrodynamic model that is capable of simulating both uni-directional and oscillatory open channel flow (Hamrick 2007a, 2007b, and 2007c). EFDC is a public domain surface water modeling system that contains dynamically linked hydrodynamic and sediment transport modules. SEDZLJ (Jones and Lick, 2000, 2001) embodies state-of-the-science equations that have been developed in the past 20 years that allow simulation of the following sediment transport processes: bedload transport of non-cohesive sediment; resuspension of both cohesive and non-cohesive sediments, both calculated as a function of the local bed shear stress; deposition of cohesive sediments calculated as a function of the bed shear stress; and water column transport of all sediment sizes.

Approach to Representing Bank Erosion

The approach chosen by the Project Team was to customize an already-existing empirically-based bank erosion model for integration into the enhanced flow/sediment transport model such that the estimated sediment mass from the eroding bank is added to the sediment bed in the channel modeling spatial unit(s) (i.e., stream cells in EFDC) where the eroding bank is located. Specifically, the empirical bank erosion model that was developed by Ikeda et al. (1981) was chosen to be incorporated into the modeling system.

3.2.4.3 Implementation Methodology

Figure 3.17 summarizes the models and capabilities that comprise the channel component of the Fort Benning Enhanced Model. In addition, model setup procedures and information are provided for the Fort Benning model demonstration described below.

Incorporating Enhanced Channel Flow and Sediment Transport Capabilities

As an element of the Fort Benning Watershed Model Enhancement Plan (AQUA TERRA Consultants, 2009) careful consideration was given to the candidate schemes for incorporating EFDC/SEDZLJ capabilities into the modeling system. At the time that the Enhancement Plan was written a 'tighter' linkage between HSPF and EFDC/SEDZLJ was envisioned than the one that was eventually implemented. Concerns over the long run times (5 hours per simulation year) that are required for EFDC/SEDZLJ played a major factor in the linkage decision. Consequently, a 'loose' linkage was selected and developed whereby the models could be run sequentially, and the channel simulation could be performed in a stand-alone manner using results that had been generated by previous HSPF simulations, as part of the input boundary conditions required by EFDC/SEDZLJ.

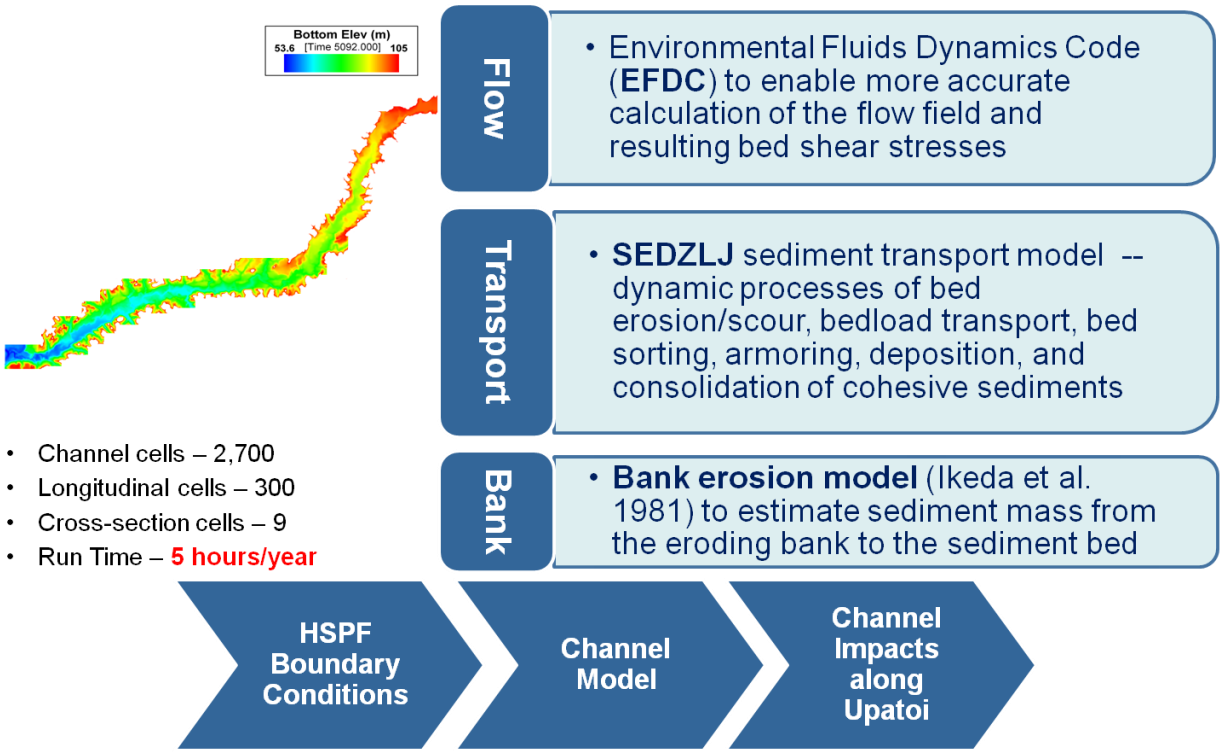

Figure 3.17 Channel Modeling Methodology Implemented in the Fort Benning Enhanced Baseline Modeling System

Developing a Bank Erosion Capability

The empirical model that was implemented calculates the lateral bank erosion rate (in units of 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. An empirical erosion constant, which is estimated from measurements of bank erosion rate and adjusted during model calibration, relates the bank erosion rate to the difference in these velocities. The volume of bank that is eroded per unit length of the bank is obtained by multiplying the lateral bank erosion rate by the average bank height. The bank's height is assumed to be constant in this approach, but the amount of possible erosion that can occur is limited because the width of the bank (taken to be the horizontal distance from the bank face to a hard, i.e., non-erodible, surface at the back of the bank) is a user specified input parameter.

Linkage of HSPF to EFDC/SEDZLJ

Figure 3.18 depicts the linkage that was established between the HSPF model which generated the watershed sediment loadings and the EFDC/SEDZLJ channel flow and sediment transport model(s). Note that the bank erosion formulations were integrated into EFDC/SEDZLJ.

As a watershed model, HSPF generates flow and sediment (and contaminants) from both the watershed landscape and the tributary streams. When HSPF is linked with a more spatially detailed channel (waterbody) model like EFDC/SEDZLJ, these two sources must both be included in the linkage procedures. Consequently, in Figure 3.18, two separate fluxes are shown emanating from HSPF as input to EFDC/SEDZLJ; one source is directly from the land areas (designated as LD or Local Drainage in the figure), and the other source is from the tributaries (designated as T)). The map insert in Figure 3.18 shows the LD areas as land adjacent to the mainstem of the Upatoi, and drains directly to it, and the T subareas that are tributaries that are confluent to the mainstem.

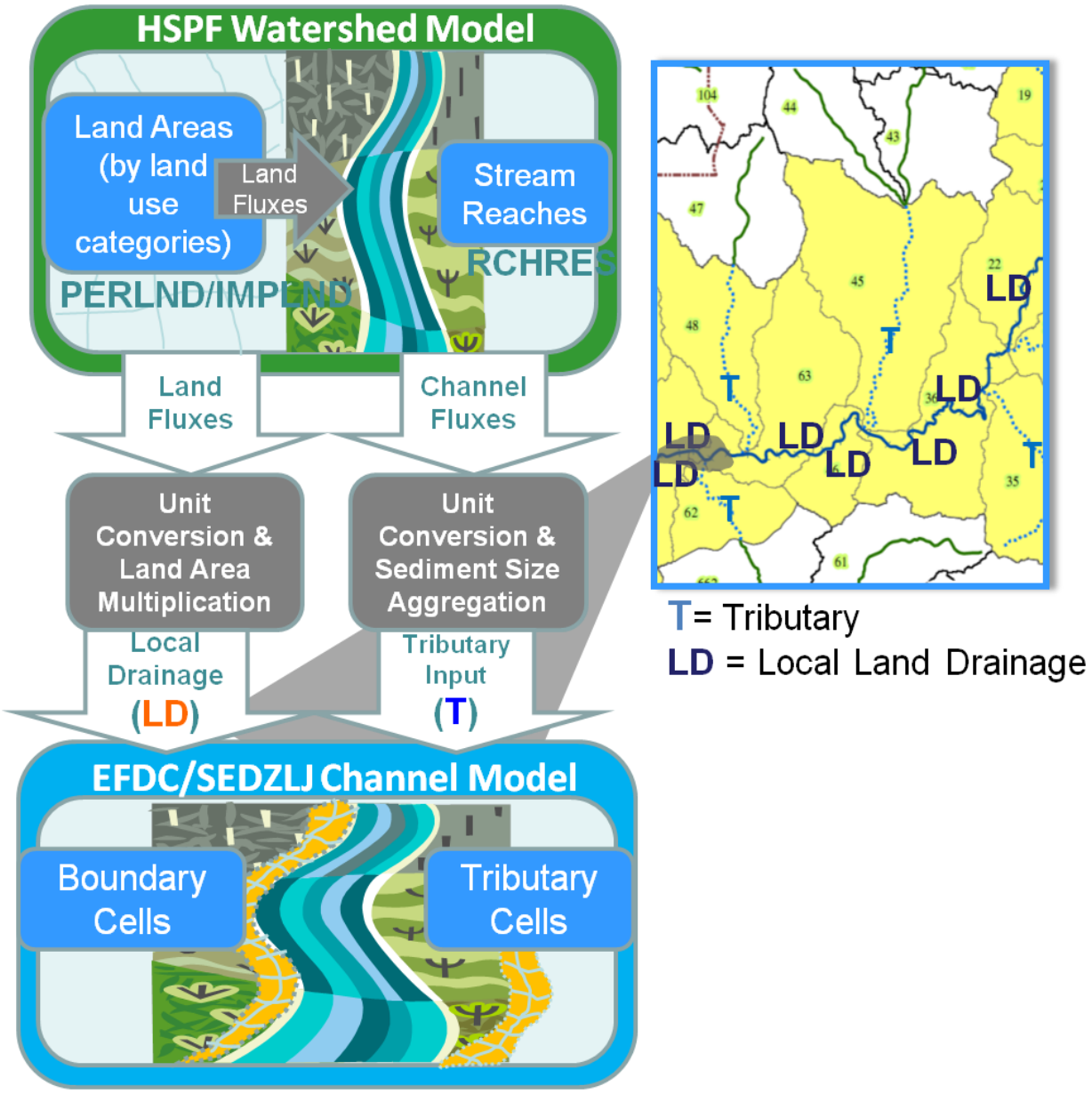

Figure 3.18 Linkage of HSPF to EFDC/SEDZLJ to Perform Sediment Transport Modeling

Each source undergoes unit conversions and different transformations. The LD source must be multiplied by the land area (i.e. acres of land) for each land use category, and then the resultant total load is distributed into cohesive/non-cohesive fractions for EFDC/SEDZLJ. The load from the T source undergoes unit conversions and then the silt/clay components are combined into the cohesive component for input, along with the non-cohesives, to EFDC/SEDZLJ.

The computational steps of the linkage are as follows:

- Boundary data for flow (overland/subsurface) and sediment concentrations (cohesive/non-cohesive) are supplied as PLTGEN files from the HSPF model for local drainage areas and tributaries.

- Code was developed to convert HSPF-supplied flows and concentrations into formats (and units) in which they are directly usable to define EFDC's input for boundary conditions.
- EFDC simulation run(s) are performed for the desired simulation period, and ASCII-format output is created at specified locations.
- Output from EFDC simulations is aggregated (and flow-weighted) using all cells across channel transects, and the result is then imported to the WDM file for further analysis and display.

EFDC/SEDZLJ Model Setup and Calibration

An orthogonal-curvilinear grid was developed to represent the chosen model domain for Upatoi Creek. Two views of portions of this grid are shown in Figure 3.19. As described above, HSPF calculated tributary flows (including the upstream boundary condition for EFDC) and land drainage were provided as time series that were used to drive the hydrodynamic model in EFDC. Time series of clay, silt and sand size sediment were also calculated by HSPF and used as tributary and land drainage boundary conditions by the sediment transport model in EFDC. The concentration time series of clay and silt calculated by HSPF were added together and used for the one cohesive size class represented in the SEDZLJ model. The concentration time series of sand calculated by HSPF was assigned to the finest non-cohesive sediment size class used in the SEDZLJ bed model.

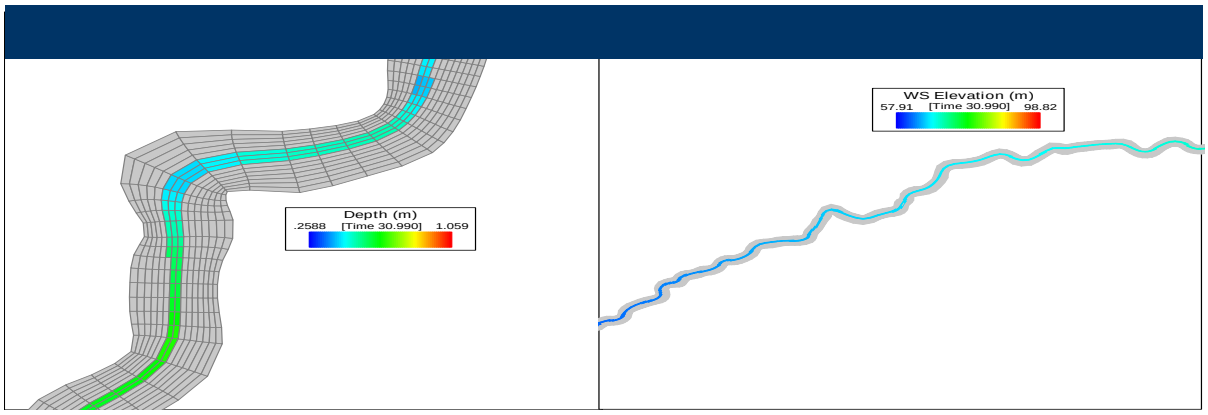

Figure 3.19 a) Zoomed in View of a Short Reach of the Curvilinear-Orthogonal Grid, and b) View of a Longer Reach of the Upatoi Creek Grid

The downstream boundary condition for the hydrodynamic model was the water surface elevation at the confluence of the Upatoi Creek and Chattahoochee River, whereas a zero gradient downstream boundary condition – in which sediment being transport either as bedload or in suspension in the downstream most grid cells were allowed to pass out of the model domain - was used for the sediment transport model.

Calibration of the hydrodynamic model was perform by comparison with measured water surface elevations at McBride Bridge The calibration parameter used to achieve the optimum agreement between the measured and simulated water surface elevations at this location was the effective bottom roughness. The calibration yielded a value of 5 cm for the bottom roughness parameter.

The SEDZLJ sediment bed model was setup using the available (but extremely limited) grain size distribution. Five sediment size classes were used in the bed model – one cohesive class and four non-cohesive classes. The D50 values of the four non-cohesive sediment classes were 375, 750, 1020, and 2000 µm. The sediment bed in the grid cells that represented the Upatoi were initially composed of spatially constant fractions of the four non-cohesive size classes. These fractions were 0.4, 0.4, 0.18 and 0.02 for the 375, 750, 1020, and 2000 µm size classes, respectively. All five bed layers in every grid cell were assumed to be composed of the same initial composition of the sediment size classes.

During the model simulations described below, SEDZLJ was run in morphological mode, which means that changes in bed elevation due to erosion/deposition in the grid cells were used in calculating the new flow field at the next timestep. Extremely limited data prevented complete calibration or validation of the sediment transport model. The limited calibration effort is described in Section 4.4.

SECTION 4.0
RESULTS AND DISCUSSION

4.1 MILITARY TRAINING INTENSITY REPRESENTATION

The development of a methodology to represent military training intensity was successful in that it established a linkage between training intensity and the resulting land condition changes that determine sediment washoff. However, application of the methodology to Fort Benning yielded a somewhat unexpected outcome and path forward for establishing the model parameter values for the Installation's HMAs for modeling scenarios that reflect different (typically increasing) vehicular training loads.

The Army's estimate for total MIMs that occurred at Fort Benning during 2004 is 219,224. The off road vehicular training was almost wholly restricted to the approximately 2300 acres that are classified as HMAs in the watershed model. Assuming a uniform distribution of MIMs over all HMA acres, each HMA acre was subjected to approximately 95 MIMs, or 48 tank passes during 2004. This amount of training clearly results in a condition of minimum infiltration rate and minimum vegetative cover – in fact the literature and field data suggest that less than 10 tank passes result in conditions of minimum infiltration rate and ground cover.

Given that the approach (i.e., calibration to target washoff values/ranges) that was used in the baseline model for simulating sediment already made use of what are perceived by modelers as minimum realistic values for these parameters (i.e., INFILT = .05, COVER = .01), the combination of the relatively large amount of vehicular training and the small amount of HMA acreage at Fort Benning invariably leads to representing land conditions with minimum values for both infiltration rate and vegetative cover. As a result of BRAC 2005, the HMA acreage at Fort Benning is increasing, but not to a level where the assumption of minimum values for infiltration rate and vegetative cover fails.

4.2 HYBRID MODELING AND WEPP DEMONSTRATION

Results related to developing a generalized hybrid modeling capability and modeling sediment erosion from unpaved roads are presented and discussed in this section below.

4.2.1 Results Related to Developing a Generalized Hybrid Modeling Capability

The investigation and effort to develop a generalized hybrid modeling capability had a number of positive outcomes:

1. Small-scale models with potential utility for military applications were identified (AQUA TERRA Consultants, 2009).
2. A proof of concept and demonstration of hybrid modeling was achieved and reported in detail (see Appendix A).
3. The shared code (EXTMOD) needed to enable communication between HSPF and any small-scale model was developed and tested.

In carrying out the implementation effort numerous lessons were learned that clarified both the potential and limitations of hybrid modeling as a practical and reliable evaluation technique. Among these are the following:

1. The successful implementation of a hybrid modeling framework is VERY dependent on the compatibility of the two models that are targeted for use. Compatibility

considerations include both those of model purpose and modeling paradigms. Although at the onset of the demonstration effort the HSPF and WEPP:Road models appeared compatible, incompatibilities became evident for all three of these consideration categories.

2. Combining a deterministic model (HSPF) with a design model (WEPP:Road) introduces significant challenges. As a design model, the WEPP application techniques allowed less opportunity to effectively use historical weather data combined with calibration as a means to fine-tune sediment response to weather. Rather, the WEPP:Road approach was to provide reasonably indicative simulation results using a relatively 'black box' approach that discouraged adjusting the WEPP model parameter values. Considerable effort was required to understand the appropriateness of various instances where the WEPP:Road authors had 'hard-wired' parameter values with the intent of providing *sets* of parameter values for unpaved road features/options/settings that they believed led to appropriate runoff/erosion responses for various types of roads in various regions of the United States. As the effort to use WEPP in conjunction with HSPF progressed, it became more and more necessary to find ways to circumvent a number of these features in order to achieve the modeling results that we believed were appropriate for the Fort Benning application and compatible with the historical weather data that we were using for the HSPF application (See Appendix A for further details).
3. As the demonstration implementation proceeded it became apparent that there were fundamental differences in how the two models estimated runoff and sediment erosion response, and that these differences created additional challenges to using WEPP results as a direct input to HSPF. HSPF simulation features continuous update of hourly soil moisture condition (as well as other water sources and sinks), and by doing so has the necessary information to estimate the runoff response of each new hour's precipitation. WEPP does not keep a running account of soil moisture condition. In situations where sub-daily precipitation data is used as input to WEPP, the model uses the approach of calculating and accumulating runoff 'intensity' values that are used to estimate maximum instantaneous runoff intensity. In turn, this value is used to estimate a storm sediment erosion value. Thus, while the role of WEPP in the hybrid modeling was to provide hourly sediment washoff (and perhaps runoff) values for unpaved roads to the HSPF model, doing so created unexpected challenges.

4.2.2 Results Related to Modeling Sediment Erosion from Unpaved Roads

The final calibration of WEPP:Road sediment washoff met its objective. Simulated unit area sediment washoff for the 14 meteorological segments for WEPP road segments (road plus fillslope) ranged from 1.3 to 2.9 tons/ac/yr. For the modeled meteorological segments, differences in simulated unit area sediment washoff between HSPF and WEPP:Road varied from minus 6 percent to plus 15 percent. Table 4.1 provides the unit area sediment washoff results that were achieved using HSPF and WEPP:Road. Appendix A provides corresponding information regarding the WEPP parameter values that were used to generate the final results.

Table 4.1 Comparison of Sediment Erosion Model Results for HSPF and WEPP:Road

Fort Benning Model Region	Road Area (acres)	Unit Area Erosion Estimates From Road & Fillslope (tons/ac/yr)		
		HSPF	WEPP:Road	% Difference
Hastings Range	1	2.68	2.74	2.2
Hastings Range - Military	1051	2.57	2.87	11.7
Carmouche	2808.3	1.97	2.01	2.1
Malone	860	1.63	1.81	11.1
McKenna	1797	1.11	1.27	14.0
Cactus	1508	2.12	2.37	11.8
Natural Resources	736	1.83	1.93	5.5
Lawson	22	1.71	1.65	-3.3
Pre-Ranger (non-Upatoi)	888	2.46	2.74	11.3
Griswold (non-Upatoi)	902	2.30	2.20	-3.8
Lawson (non-Upatoi)	523	1.71	1.60	-6.4
Natural Resources (non-Upatoi)	187	1.89	1.92	1.6
Alabama (non-Upatoi)	127	1.70	1.84	8.3
Malone (non-Upatoi)	241	2.01	1.99	1.1

4.3 MULTI-LEVEL PLANT CANOPY IN HSPF

The implementation and evaluation of the canopy enhancements within the HSPF code, and the resulting application to the Fort Benning watersheds, provide the following general assessment:

a. The multi-level canopy provides a much improve conceptual representation of the plant compartment by incorporating individual processes associated with the forest overstory, understory, and potentially the forest floor and litter layer. It provides a highly flexible capability for a wide range of canopy conditions and impacts from anthropogenic activities.

b. The approach for allowing a user-defined time series approach to parameterizing the plant canopy layers provides improved operational procedures for representing dynamic changing canopy processes. However, it imposes demands on the user, to accurately assess canopy parameters, through a very flexible mechanism for simulating a wide range of canopy conditions.

c. The impact of the enhanced canopy representation was evaluated by comparing Baseline hydrology and sediment results with comparable results with the enhancements implemented as part of the Enhanced Baseline. The Baseline model represented the prescribed burn cycles with three separate model land categories, each with constant (but seasonally variable) canopy conditions reflecting each year of the three-year burn cycle. Whereas the multi-level canopy enhancements were included with the Enhanced Baseline model and it allowed separate land segments each with its own three-year cycle of prescribe burns and subsequent regrowth, as described in this chapter. Generally, the differences in storm flows and sediment concentrations were minimal, and often indistinguishable when compared at the storm event level. However, the flow error statistics shown in Table 4.2 demonstrate a small, but positive impact of the multi-level canopy enhancements on selected error terms that cover flow volumes and the range of flows from the flow-duration curve. These small flow differences did not translate into any noticeable change or improvement in the sediment results, possibly due to scale of the assessment and lack of available data at the field scale.

Table 4.2 Error Statistics for Flow Results for Baseline Compared to Enhanced Baseline with Multi-level Canopy Changes

	Baseline	With Canopy Changes
Error in total volume (%) =	9.30	8.58
Error in 25% highest flows (%) =	2.39	2.06
Error in 50% lowest flows (%) =	17.20	15.57
Error in 25% lowest flows (%) =	10.09	8.02
Error in 10% lowest flows (%) =	3.57	1.35
Error in average storm peak (%) =	-5.41	-5.60

4.3.1 Discussion

The multi-layer canopy capability that has been implemented in HSPF will enable better characterization of the impacts of changes in vegetation cover (seasonally and from management actions such as prescribed burning) on hydrology and sediment loss.

The approach that has been enabled allows maximum flexibility in the representation and modeling evaluation of forest land perturbations. Values for interception, cover, and selected soil parameters (e.g., infiltration) can be expressed as constant, monthly variable, or a user-defined time series. In conjunction with the HSPF SPECIAL ACTIONS capability, the time series input option can be used to assess the impacts of fire events (or other vegetative perturbations) as well as subsequent regrowth/return to baseline conditions, and provides the potential for evaluating a wide range of anthropogenic disturbances (e.g., construction, crop rotations, mining/forestry practices).

4.3.2 Bottomland Hardwoods and Prescribed Burning

A portion of the forest areas that are included in prescribed burning areas for Fort Benning are actually Bottomland Hardwoods (BH) which do not burn. It was investigated whether these areas may need to be excluded from those forested areas designated as under prescribed burning, in order to accurately reflect impacts. To estimate these areas, a vegetation shapefile was obtained from Fort Benning that classified the vegetation for different ecological groups, formations and associations. Personal communications with Hugh Westbury at Benning, and Michele Elmore (TNC Forest Ecologist at Fort Benning) suggested that the combination of two ecological groups — 'Stream Floodplains,' and 'River Floodplains and Cypress-Tupelo Swamps' — should be considered as the category of BH areas. GIS analysis indicates that the resulting Bottomland Hardwood coverage comprises about 17,500 acres, out of the total forest area of about 121,500 acres, or about 14% at Fort Benning, and about 9% of the total forest area (189, 965 acres) for the Upatoi watershed as a whole.

Once we extracted the BH coverage, we overlaid it with the areas that are classified as under prescribed burning, delineated by training compartment. The resulting areas common to both coverages are shown in Figure 4.1 and they amount to about 7,500 acres. This area is mostly in the floodplains of many of the stream reaches on the base. This area is also about uniformly divided into the three-year prescribed burn cycles, and therefore about 2,500 acres of these BH is subject to prescribed burning each year in our current model.

On average, the total area that is burnt each year on the base is about 35,000 acres; the annual numbers vary between 24,000 and 45,000 acres each year. In other words, about 7% of the land area in the model that is under a prescribed burning cycle is not likely to be burnt.

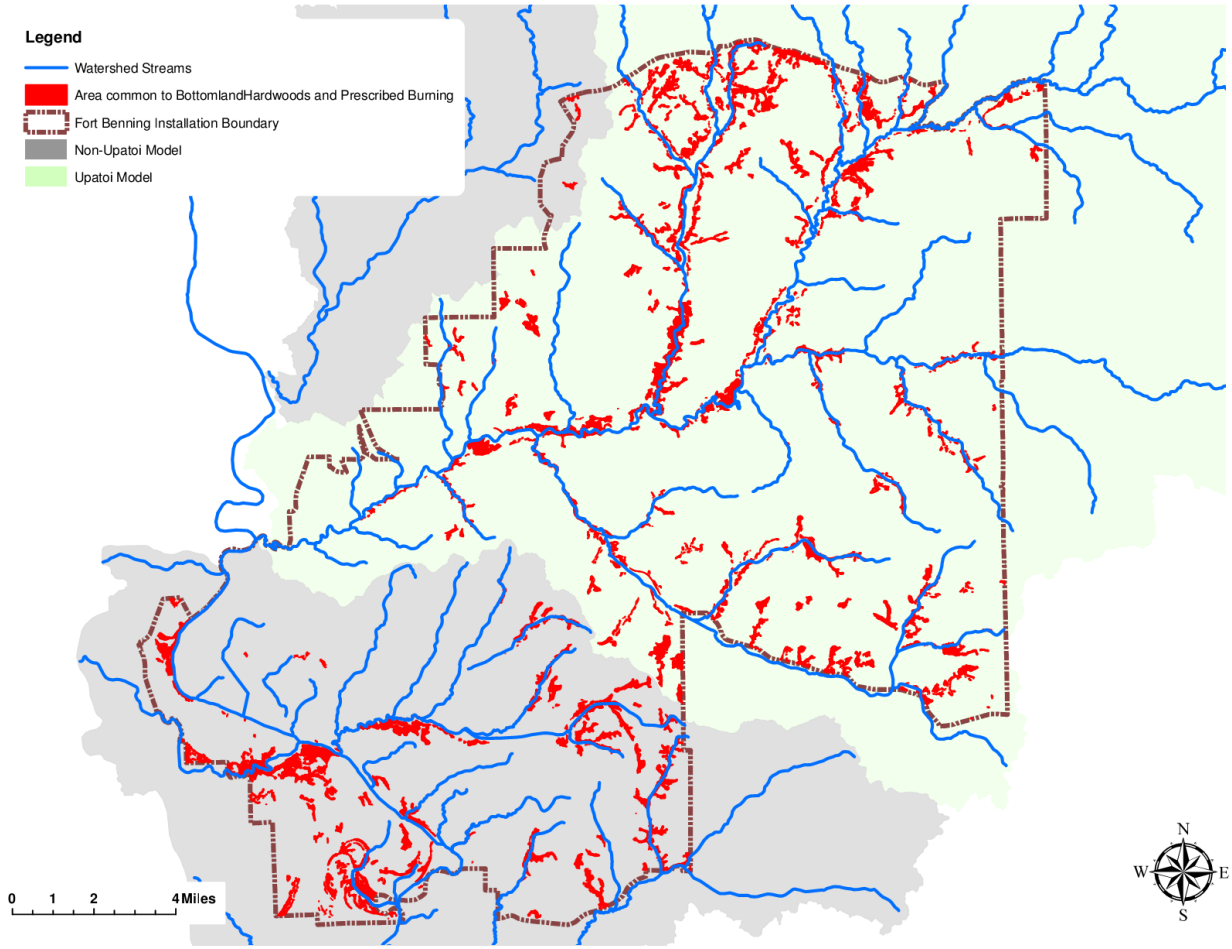

Figure 4.1 Areas of Bottomland Hardwoods Classified as Under Prescribed Burning at Fort Benning

However, even in the forest areas where prescribed burning is practiced, only the understory (underbrush) is affected by the prescribed burning practices with no impact on the overstory canopy. The difference in ET (evapotranspiration) between the burnt and unburnt deciduous forest categories is about 2.1 inches each year; the unburnt forest experiences about 29.5 inches ET and the burnt categories experience about 27.4 inches.

Therefore the model may include an over-estimation of ET of about 2.1 inches on 7% of the burnt area, which represents a difference of about 0.15 inches over the entire burnt area each year (i.e., 7% of 2.1 inches). This small difference will have a negligible impact on the water balance and the hydrology simulation as it represents less than 1% of either Total ET or Total Precipitation (about 44 inches).

With respect to impacts on land cover in the model, overstory is assumed to represent 60% of total forest land cover and understory about 40%. For deciduous forests, the maximum difference in understory land cover between the burnt and unburnt areas is represented in the model as about 65%, allowing for leaf fall and regrowth in the spring. This maximum difference in cover of 65% occurs just after a burn, and is subsequently reduced due to understory regrowth. The maximum difference of 65% for 7% of the burnt area (BH portion) corresponds to about a 4% difference in 'effective' cover over the entire burnt area, due to inclusion of the BH within the prescribed burn areas. And, and as noted this maximum difference will be ephemeral

with subsequent cover increases due to regrowth of the understory following a burn. It is not expected that this maximum difference of 4% in cover, for limited time periods, will lead to a noticeable change in sediment loads due to inclusion of the BH. Moreover, sediment loading rates from the forests are 10-20 times less than Heavy Maneuver Areas and croplands, so the 4% cover difference is likely to have a negligible impact.

However, scale is also a **major** issue related to the potential impacts of the BH, both the scale at which the runoff/sediment processes occur and the scale at which the model represents, or approximates, these processes. Within each subbasin, the model represents multiple land use categories, including multiple forest categories, and assumes that each is connected to the stream channel (represented as a stream reach in the model) by a single, uniform overland flow plane. Studies have shown that that virtually all upland areas in watersheds are connected to permanent streams via channels that become gullies when uncontrolled; thus, sediment increases are more a function of bare vegetation impacted by rainfall rather than concentrated flow in an understory. In other words, these observations indicate that concentrated flow is initiated over relatively short distances (Steichen et al., 2008), and this is consistent with the model assumptions. In the model, this concentrated flow corresponds to the overland flow plane that the model represents. It likely drains both upland and lowland areas, and so the model really represents the net contributions and impacts of both areas as the resulting runoff and sediment load to the stream.

However, if one believes that 'sheet flow' dominates the watershed response, and that runoff occurs uniformly over all the land area, then the overland flow plane is not uniform; the upland areas would contribute runoff/sediment and then these might be filtered by lowland areas (again because the flow is not concentrated) which might act as a buffer, reducing the runoff/sediment before it reaches the stream channel.

In reality, both phenomenon probably occur to varying degrees across the watershed, but the 'scale' of the model (and most lumped parameter watershed models) represents these processes in a lumped fashion, so that the net contribution of runoff/sediment from forested areas includes both the generation from the upland areas and the subsequent buffering from the lowland areas, so that the resulting loading to the stream reflects the net impacts of both areas. This is one reason the forest loading rates are so small, in the range of 0.07 to 0.12 tons/ac/yr, as compared to agriculture and military uses (e.g., maneuver areas) which are in the range of 1.5 to 2.5 tons/ac/yr.

Although our analysis indicates that the impact of including the BH in the prescribed burn areas (which amounted to only 7% of the burned area) was negligible when viewed and analyzed at the overall watershed scale, there might be more significant impacts at smaller scales, and especially where higher concentrations of the BH exist, such as possibly in Randall and Upper Randall Creek (north-central portion of Installation, as shown in Figure 4.1). However, the changes in sediment load would be so small, considering the small magnitudes of the forest loading rates, that any reduction due to exclusion of the BH would quickly dissipate within a short distance, and in our opinion, would not be noticeable downstream either in the mainstem of the Upatoi or at the watershed outlet.

Therefore, based on the above analyses and discussion, we conclude that reclassifying these BH, and subsequent transfer to the unburnt forest categories, will have minimal effect on the overall watershed-scale hydrology and sediment simulations. The reclassification of land uses would require efforts in revising the land use GIS files, updating the land use distribution in the model, running all the different scenarios, re-processing the model output, and updating the reports. A pilot study, and sensitivity analyses, could be designed with the uplands and BH

areas represented as separate and coincident model segments (i.e., upland burnt areas draining to lowland BH areas as buffers) to evaluate this issue further, if needed.

4.4 CHANNEL SEDIMENT ENHANCEMENTS – EFDC/SEDZLJ

Model runs with both HSPF and EFDC/SEDZLJ were performed for the entire calibration period extending from 1999 through 2008, with the HSPF results for the mainstem tributaries and local inputs of both flow and sediment providing the boundary conditions for the EFDC/SEDZLJ simulations. The biggest limitation for this assessment was the lack of reliable and consistent flow and sediment data for which model calibration and comparisons could be performed. The sediment calibration relied primarily on a few selected storms in May 2006 and April 2007 which provided reasonable data for comparison purposes. Figure 4.2 shows the daily flow duration curve for both HSPF and EFDC at McBride Bridge, while Figure 4.3 shows the daily flow and sediment results for the October 2005 through April 2007 period that included the two major storm events. Figure 4.4 and Figure 4.5 show simulations for the two major storm events, in May 2005 and April 2007, comparing the HSPF and EFDC/SEDZLJ results.

The flow duration curves in Figure 4.2 show the percent chance (or percent of time) that the corresponding daily flows are exceeded, for both HSPF and EFDC, along with the observed flow at McBride Bridge. Flow duration curves are essentially cumulative frequency displays of the probability, or percent chance, that a certain flow level will be exceeded. They are widely used in watershed and modeling assessments as they provide a single comprehensive picture of the watershed hydrologic regime, including high flows, low flows and median conditions. Flow duration curves and their uses are further discussed in Section 4.6.

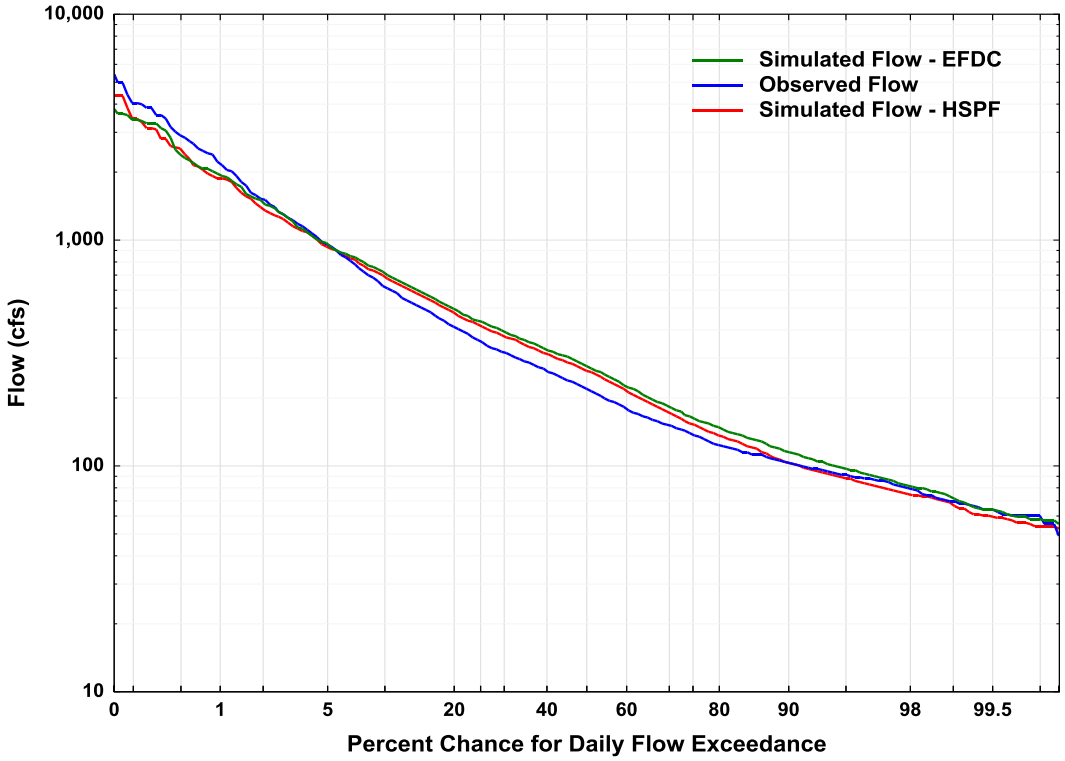

Figure 4.2 Comparison of HSPF and EFDC Flow Duration Curves at McBride Bridge

The HSPF and EFDC flow duration results in Figure 4.2 track each other quite well, as they should since EFDC model results are produced with the HSPF simulated inputs. Both curves are also a good representation of the observed flow duration curve, with some deviations. Both models under-simulate the peak flows occurring less than about 2% of the time, and both tend to slightly over-simulate the mid-range flows, from about 10% to 85% of the time. However, the overall agreement is good.

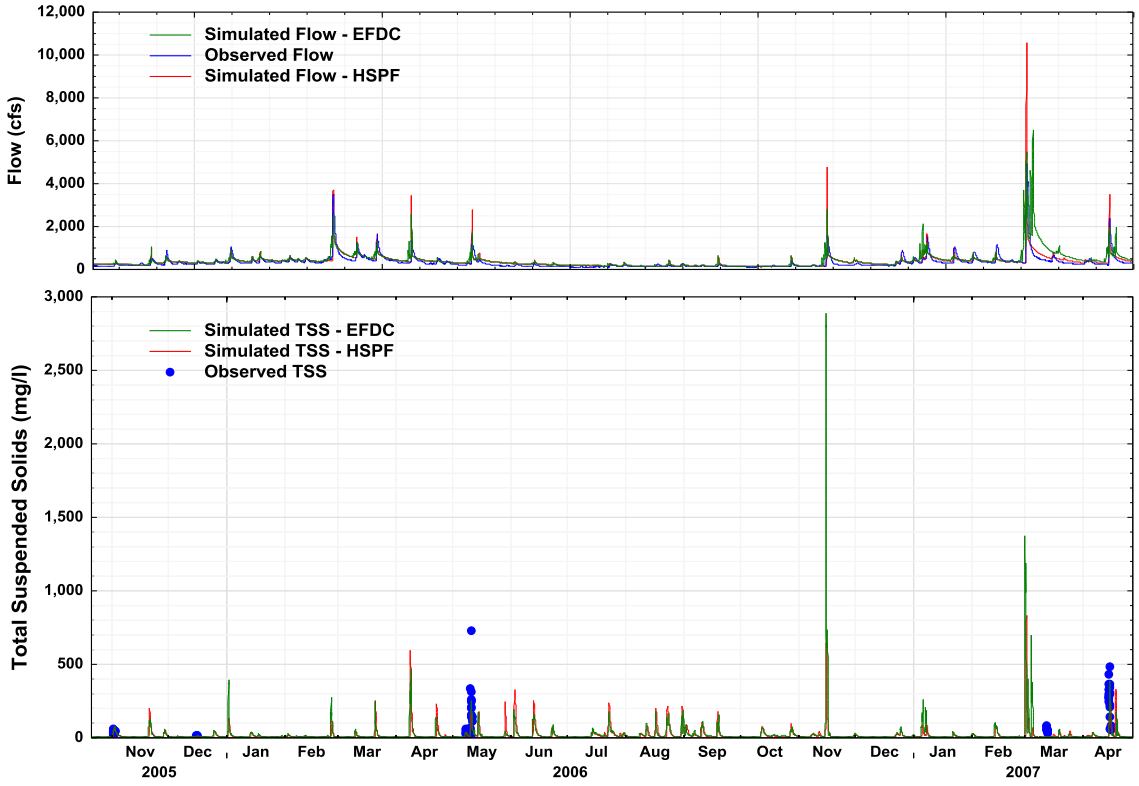

Figure 4.3 Comparison of HSPF and EFDC/SEDZLJ Flow and Sediment Simulation Results at McBride Bridge, October 2005 – April 2007

Review of the daily flow and sediment results in Figure 4.3, and the storm simulations in Figure 4.4 and Figure 4.5 indicate the following:

a. HSPF daily flows tend to over-simulate the observed values for peak flows, whereas the EFDC flows tend to be lower, and generally closer to the observed. This is also shown in the upper portions of the storm graphs in Figure 4.4 and Figure 4.5.

b. With limited data, the daily results in Figure 4.3, especially for sediment, are difficult to interpret due to the sparse data coverage. The storm results in Figure 4.4 and Figure 4.5 show that EFDC does a somewhat better job of simulating the observed flow and sediment data. HSPF tends to over-simulate the flow peaks and under-simulate the sediment concentrations, but both models are in the general range of the observations. Overall, EFDC tends to show more consistency between the flow and sediment simulations than HSPF.

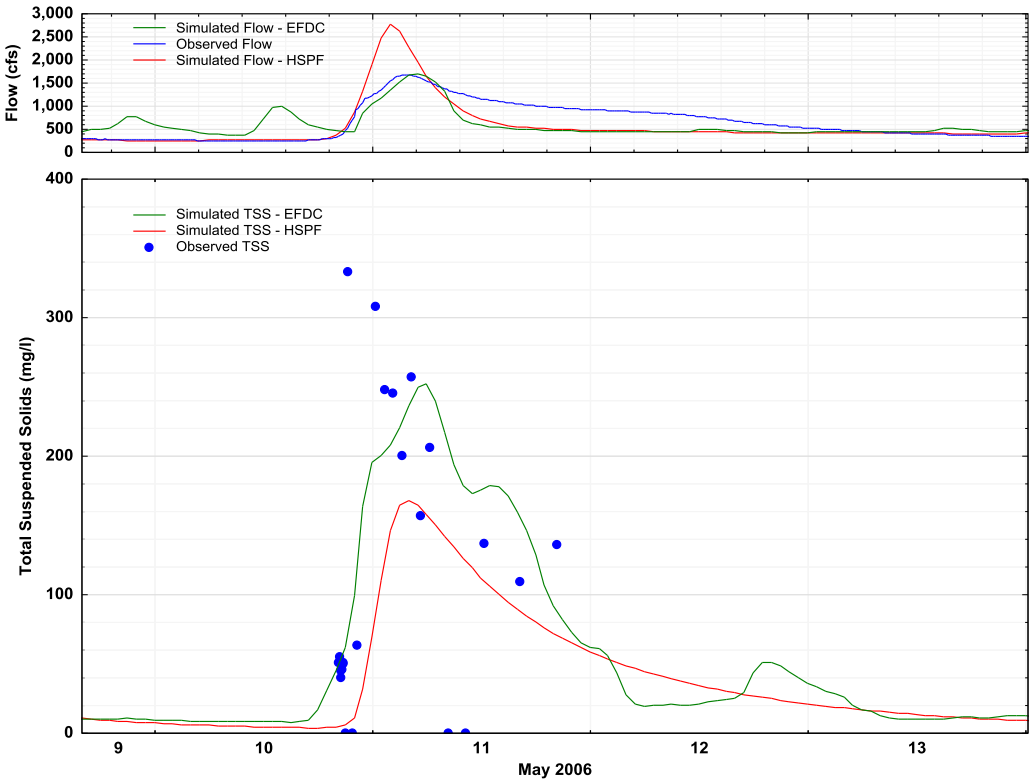

Figure 4.4 HSPF and EFDC Simulation Results for Storm of May 10-11, 2006 at McBride Bridge

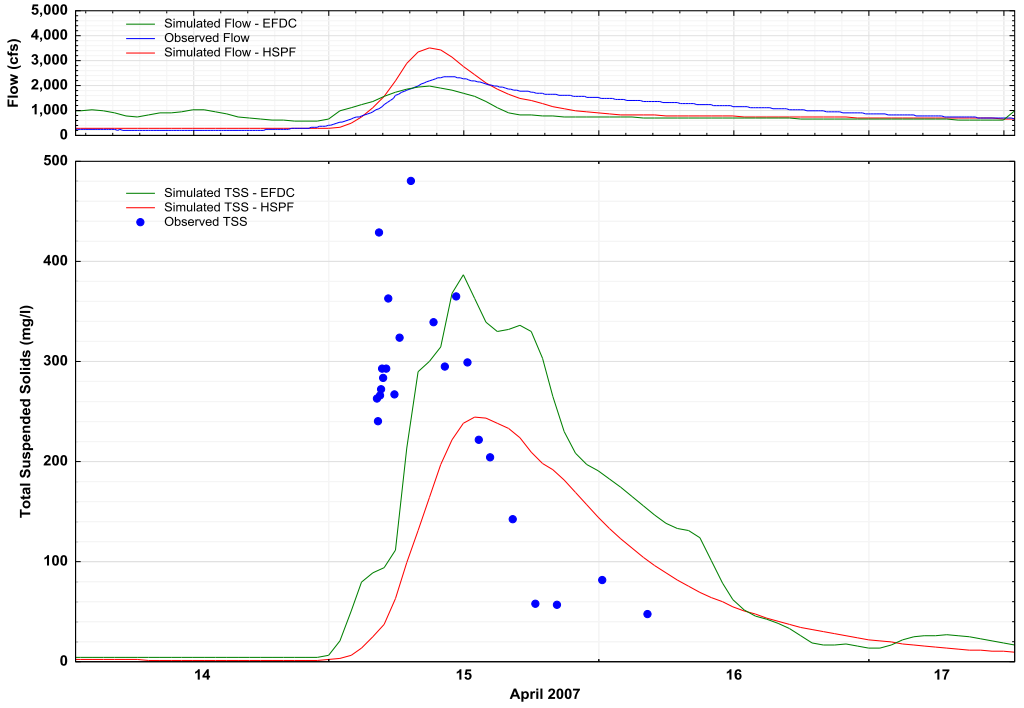

Figure 4.5 HSPF and EFDC Simulation Results for Storm of April 15, 2007 at McBride Bridge

c. It should be noted that sediment simulation results are often depicted on a **log scale**, due to the difficulty of accurately matching individual sediment samples. However, the results in these figures are shown on an **arithmetic scale** to more accurately display the model results.

d. Although the EFDC flows appear to provide a better match to the storm peaks in Figure 4.4 and Figure 4.5, there are also unexplained smaller peaks prior to the event in Figure 4.4 and higher baseflows in Figure 4.5. Both of these conditions are inconsistent with both the HSPF simulations and the observed flows, and require further investigation.

e. Timing differences between HSPF, EFDC, and the observed data shown in the storm simulations are not a major factor in the model comparisons as long as the timeframes are comparable. Often differences in timing are due to with equipment clock errors for either precipitation or flow monitoring.

f. Table 4.3 shows error statistics for both the HSPF and EFDC simulations for selected flow metrics for the entire period of 1999–2008, similar to the error statistics included in Appendix C. All of these metrics show HSPF providing a somewhat better simulation of the observed data than EFDC, although a few of the differences are relatively small. The biggest difference is in the storm event peaks, with EFDC under-simulating peaks by -25%, compared to the -6% for HSPF. A bigger concern is the volume difference; since EFDC takes its inflows from HSPF, the fact that it simulates a higher overall volume indicates a possible mass-balance problem that should be further investigated.

g. Results for both models could be improved with additional observed data, and with additional calibration efforts with the existing data.

Table 4.3 Comparison of Error Statistics for HSPF EBM and EFDC

	HSPF Enhanced Baseline	EFDC Simulation
Error in Total Volume (%)	7.5	11.1
Error in 25% highest flows (%)	1.6	3.2
Error in 50% lowest flows (%)	12.9	20.3
Error in 25% lowest flows (%)	4.3	13.7
Error in 10% lowest flows (%)	-2.8	7.2
Error in average Storm Peak	-6.3	-25.4

4.5 COMPLEMENTARY USGS MONITORING PROGRAM

The original proposal for RC-1547 identified the lack of rating curves for the ECMI monitoring sites as a significant potential limitation that could hinder full use of the available ECMI stage data at many sites within Fort Benning. During the initial data review effort, it quickly became clear that the model calibration would be somewhat limited if the USGS McBride Bridge gaging site was the only site with flow data and a streamflow rating curve. With multiple tributaries, including ones that cross Installation boundaries at multiple sites, additional flow data and rating curves strategically located would greatly assist in and support the model calibration.

Recognizing this need, SERDP funded the USGS to install five (5) additional automated-recording stream stage gages, and perform velocity measurements for selected storm events at each of these sites. The sites selected for the new gaging stations are listed below and their locations are shown in Figure 4.6; the new USGS sites are the **RED** flower symbols:

- Pine Knot Creek Near Eelbeeck, GA (Station No. 02341725)
- Upatoi Creek Below Baker Creek Near Upatoi, GA (Station No. 02341665)
- Ochillee Creek at Ochillee, GA (Station No. 02341910)
- Randall Creek Near Upatoi, GA (Station No. 02341750)
- Upatoi Creek at GA 357 at Fort Benning (Station No. 02342070) (Water Treatment Plant)

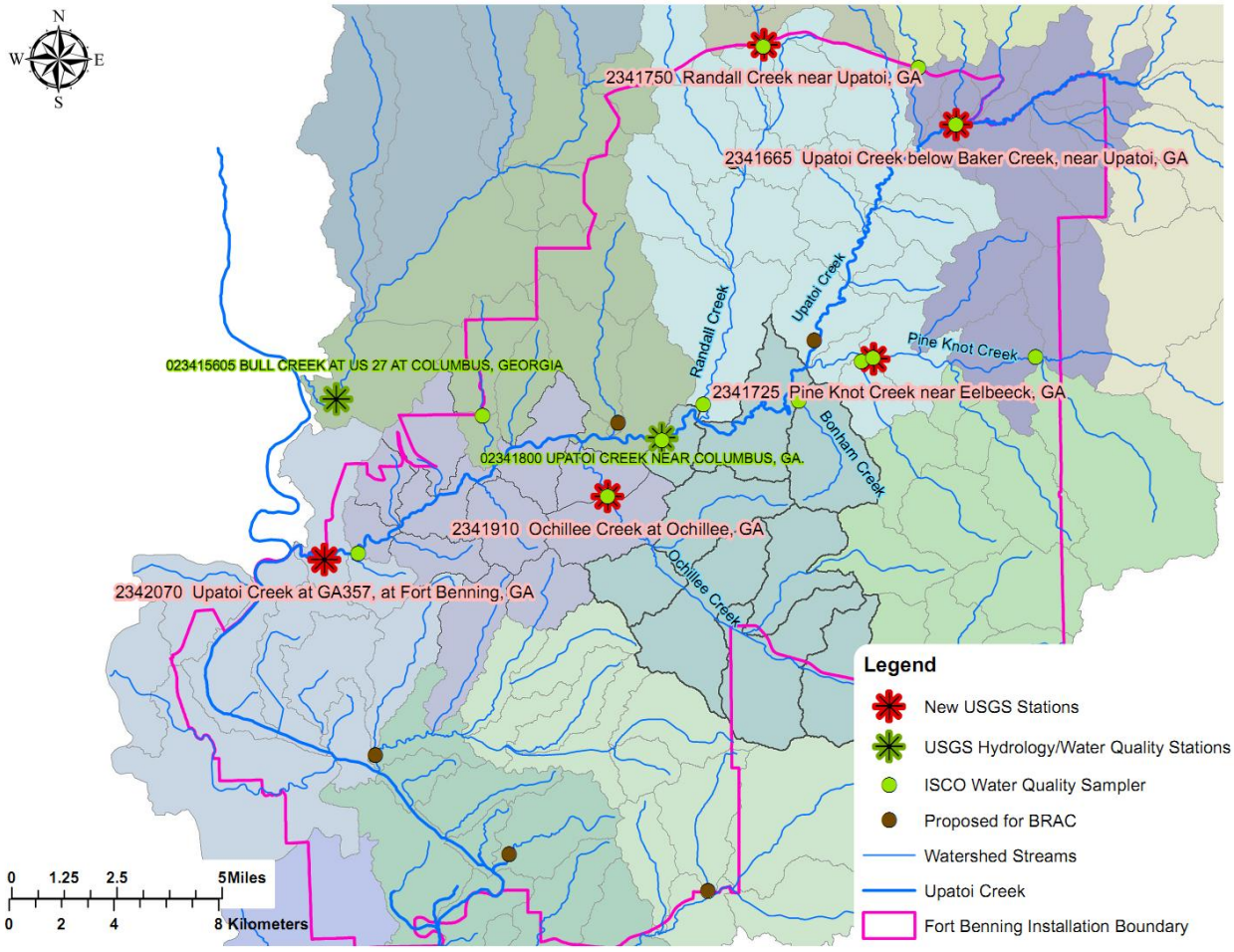

Figure 4.6 Five Supplemental USGS Monitoring Sites on Fort Benning

The USGS monitoring program extended for three years from October 2008 through September 2011 for all five sites, and another year was added for the Pine Knot Creek gage (USGS 02341725) as part of another SERDP project. Each site included a continuous stage recorder, with tie-ins to local benchmark (elevation) monuments, and numerous events at each site (from 4 to 25 separate storms) were monitored to develop paired stage-discharge values for use in developing rating curves. By the end of the 3-year program, rating curves were developed and available for all five USGS monitoring sites. The rating curves for the five sites are shown in Figure 4.7.

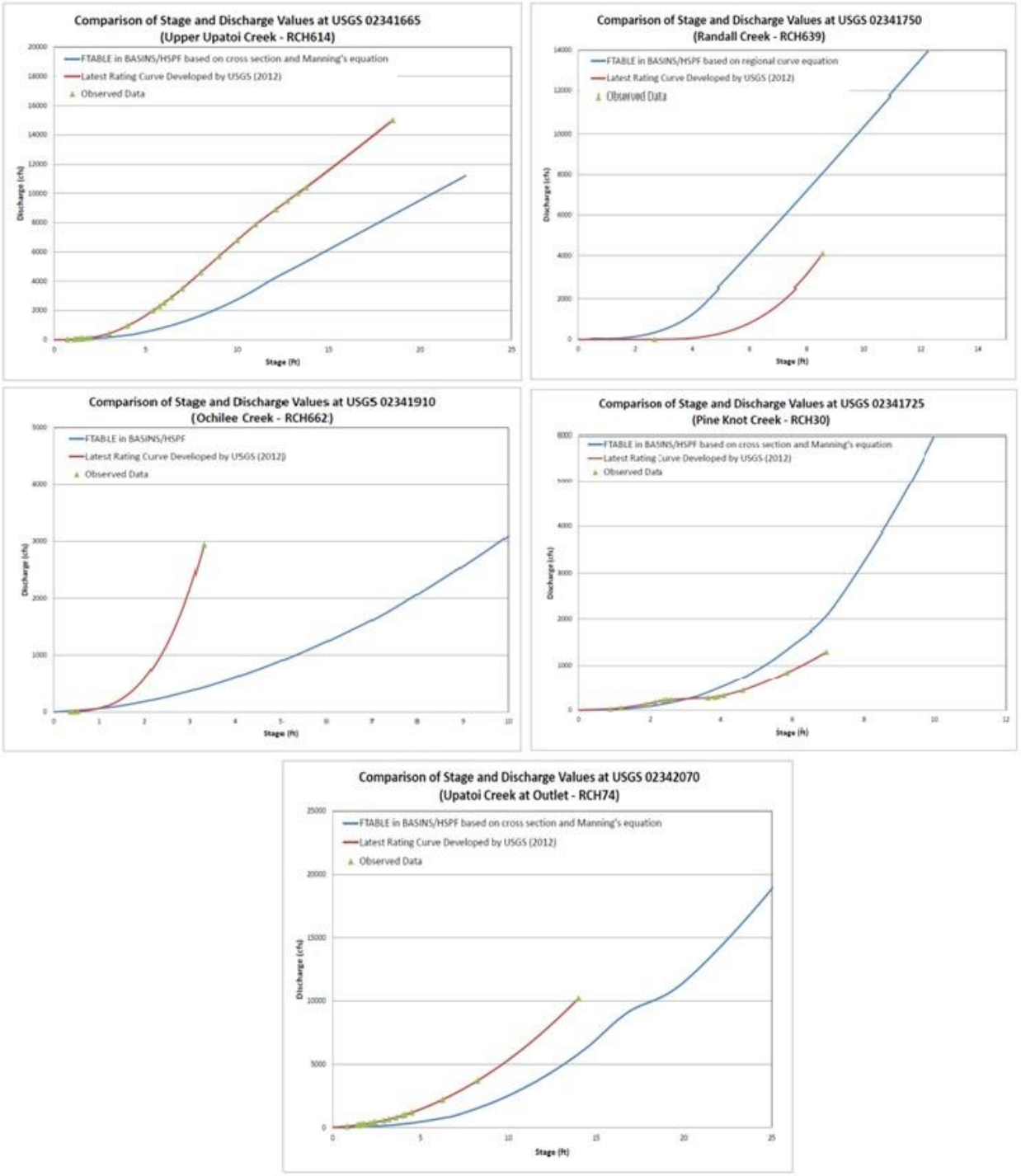

Figure 4.7 USGS Rating Curves for Supplemental Gage Sites on Fort Benning

The benefits of the USGS monitoring program to the SERDP RC-1547 study were expected to be substantial and numerous, as follows:

1. Improved stage-discharge functions (i.e., FTABLES in HSPF) with both cross-section and rating curve data would be available to improve the hydraulic information for the model setup and modeling effort.

2. Additional calibration sites and data, up to five sites, which would be co-located with ECMI and SEMP sites so that previously collected stage data (for various sites and periods) from 1999 to 2008 could be used to generate observed flows for model calibration at multiple sites.
3. In conjunction with 2 (above), additional observed flow data (for 2008 – 2011) at monitoring sites would be strategically located to support future calibration efforts, and to improve model performance spatially (at different sites) throughout the Upatoi Creek Watershed.
4. Selection of monitoring locations near Installation boundaries would provide data and better model performance at sites used to quantify off-base contributions of flow, sediment, and contaminants.

Unfortunately, not all of these benefits came to fruition. This section discusses the benefits that were obtained from the monitoring program, the data issues that limited full use of the three-years of new flow data, the opportunities the data provide for future refinements, and the implications of this experience for monitoring programs and watershed assessments at other installations.

4.5.1 Use of Rating Curves to Improve FTABLES

The Fort Benning HSPF model setup includes approximately 120 stream reaches, each of which require specification of a Function Table (called an FTABLE). The FTABLE for each reach is essentially a rating curve, i.e. stage-discharge paired values, in addition to reach volume and surface area, which is used to perform the hydraulic routing of inflows from upstream and local drainage areas. Since there was only a single useable rating curve for the entire watershed, for the USGS gage on Upatoi Creek mainstem (McBride Bridge), the Baseline HSPF model had been set up with 'estimated' stage-discharge relationships derived from DEM coverage, estimated roughness (Manning's' n) values, and cross-section information at selected, mostly mainstem sites; this was supplemented with regional geomorphic relationships (i.e. channel width and depth as a function of drainage area) that are included in the BASINS functionality. For a few locations, the regional curve method didn't give reasonable FTABLEs. For these locations, we used LIDAR data to obtain a detailed cross-section at selected points within a stream reach (such as in Figure 4.8), and then used EPA developed stage-storage-discharge tools available from the EPA web site to obtain the FTABLE in the proper format for input to the model (http://www.epa.gov/athens/research/modeling/HSPFWebTools/index.html). This use of LiDAR data is a growing movement within the modeling community, and is an option that other installations should consider for developing channel geometric data needed for modeling.

With the additional 'measured' rating curves for the new USGS sites, the FTABLES that corresponded to those sites were revised, along with adjacent stream reaches (upstream and downstream). Thus, the FTABLES for approximately 15 stream reaches were updated and improved as a result of the new rating curves at the five sites. Figure 4.7 shows the new rating curves, compared to the stage-discharge curve previously used in the model prior to the updating. Small green triangles also show the actual discharge measurements taken by the USGS to derive the new rating curves.

Note that at two of the sites, Upper Upatoi Creek and Ochillee Creek, the new rating curve is higher than the FTABLE estimate, while the reverse is true for the other three sites. Although the curves in Figure 4.7 sometimes show dramatic differences between the rating curves and the previously estimated stage-discharge relationships, it is important to recognize that the biggest differences are always at the highest flows, but the vast majority of the flows are usually

less than 1,000 cfs, and are more commonly in the 100-500 cfs range. In this flow range, which occurs more than 70-80% of the time (from the McBride flow duration curve) the magnitude of the differences between the curves is much smaller. However, differences at the higher flows, especially those commonly referred to as 'bank-full' flows, have a much bigger impact on channel scour/deposition and formation, and are important in sediment transport simulation.

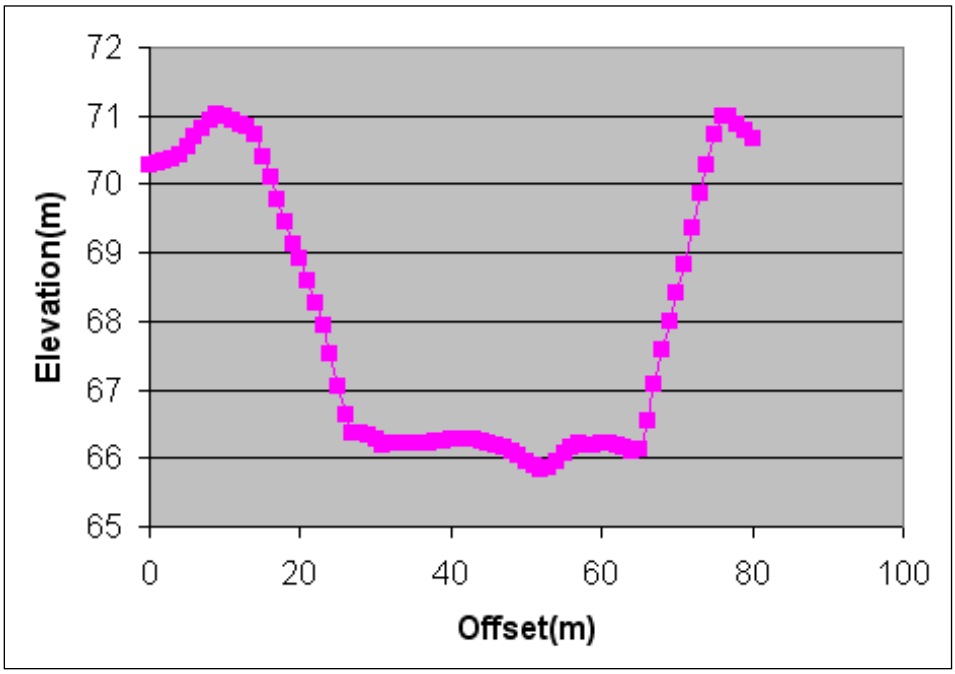

Figure 4.8 Example Cross Section Determined from LiDAR Data for Development of FTABLES

4.5.2 Sensitivity of Model Results to FTABLE Differences

The general magnitude of the differences between the curves shown in Figure 4.7 would seem to indicate that these differences should produce significant differences in the model simulations. However, the extent of the change depends on the specific model output and/or metric of interest. Figure 4.9 shows the impact of the FTABLE refinement on the flow results for a single event on 11 July 2005, at an hourly time step, at the Upper Upatoi Creek site (Reach 614). Note that the FTABLE refinement resulted in somewhat higher flow peaks, and a faster flow recession than the model results with the 'estimated' FTABLE from the Baseline run. This is consistent with the differences shown in the rating curves for the Upper Upatoi site in Figure 4.7 (top left plot in the figure); the new rating curve shows higher flows at the same stage compared to the 'estimated' curve.

However, at the USGS gage at McBride Bridge, approximately 15 miles downstream, the daily flows (Figure 4.10) show very little difference between the two plots for the different rating curves; note that the green line for the new rating curve shows slightly higher daily peaks, as reflected in the new rating curve. Additional metrics of the differences due to the new rating curve are listed in Table 4.4, which compares error statistics for the two model runs. The differences shown are so small as to indicate no significant change at the daily time step and further downstream at the larger scale of the watershed at McBride Bridge. In HSPF, the FTABLE has no significant impact on flow volumes, only the flow rates, so the lack of change in the volume difference is expected. Also, the slight differences in the metrics for the high and

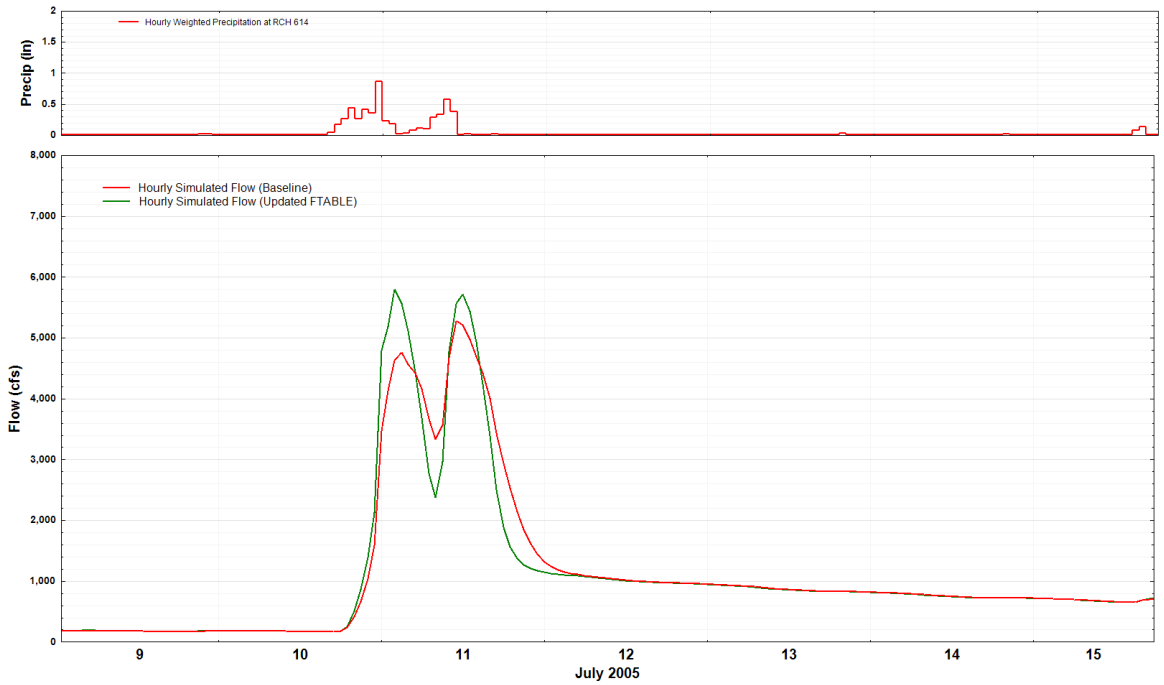

Figure 4.9 Impact of FTABLE Refinements on the Storm of July 5 2005 at Upper Upatoi Creek (Reach 614)

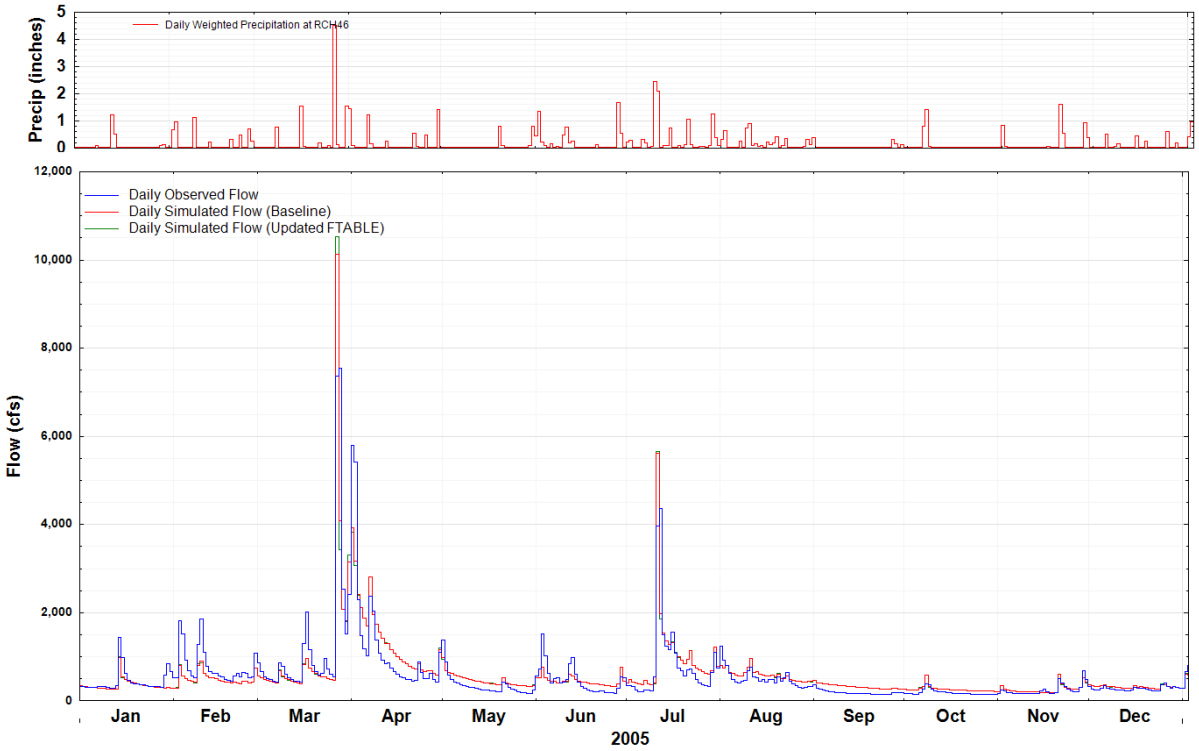

Figure 4.10 Daily Flow Simulations for 2005 at McBride Bridge for Baseline and FTABLE Refinements

Table 4.4 Error Statistics at McBride Bridge for Baseline and FTABLE Refinements

	Baseline	With FTABLE Refinements
Error in Total Volume (%)	8.3	8.2
Error in 25% highest flows (%)	2.0	1.9
Error in 50% lowest flows (%)	14.6	14.6
Error in 25% lowest flows (%)	6.8	6.5
Error in 10% lowest flows (%)	-0.0	-0.5
Error in average Storm Peak	-8.5	-8.8

low flows, and the storm peak flow difference, are likely due to both the impact of the errors being calculated on a daily time step, and the fact that FTABLE refinements were made at three sites (Upper Upatoi, Randall, Pine Knot) plus adjacent reaches, in addition to the distance downstream. Moreover, the new rating curves for Randall and Pine Knot produced lower flows (compared to the estimated curves), and this may have offset the higher flows from the Upper Upatoi site.

Although the daily flow statistics show very little impact of the FTABLE refinements, the impacts on hourly storm flows and peaks, as shown in Figure 4.9, provide an improved flow simulation as an improved basis for the sediment fate/transport simulation. Figure 4.11 demonstrates the impacts of the FTABLE refinements on the sediment simulation at McBride Bridge for a storm in November 2005. Although the comparison with the observed data is still problematic, the increased sediment concentrations are closer to the limited observations. Thus, both increased baseflows and high flows help to improve the overall model simulations for sediment as shown in Figure 4.11.

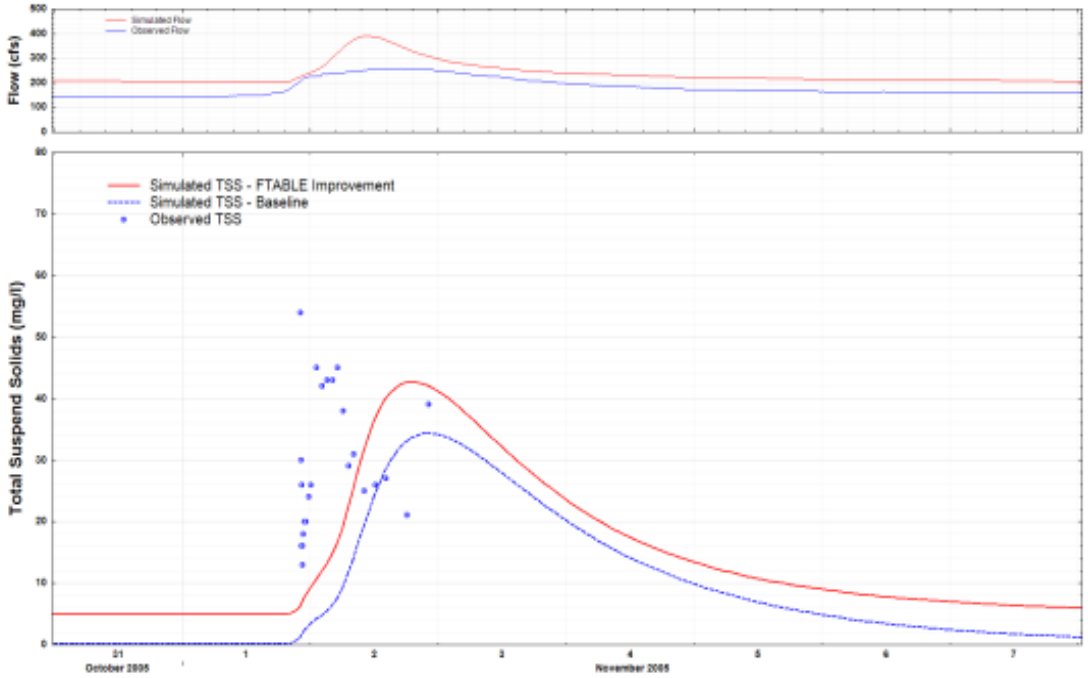

Figure 4.11 Impact of FTABLE Refinements on TSS Concentrations at McBride Bridge

In summary, the new rating curves developed by the USGS produced a better model representation of the stream channel and its simulation through refined FTABLES in the HSPF Fort Benning model. The model subsequently showed the impacts of the refined FTABLES on storm event simulations, but with very little change to daily and downstream flow metrics.

It is important to emphasize that the primary benefit of the monitoring was expected to be the ability to use historic stage data converted to flow rates, to allow additional calibration efforts at multiple gage sites, and thus improve the spatial representation of the model for the entire watershed. Below we discuss the data situation/issue that precluded further calibration efforts. However, this analysis shows that if daily metrics are acceptable for impact assessment at the scale of interest, such as on the Upatoi mainstem and the watershed outlet, then methods for estimation of FTABLEs may be acceptable because we saw very little difference at these larger scales and time steps.

4.5.3 Lack of Benchmarks Limits Utility of USGS Monitoring Efforts for this Study

As noted in the introduction to this section, the two primary objectives of the USGS monitoring was to develop rating curves at the additional gage sites, **and** to allow use of those rating curves to convert historical stage data, at these same sites, within the time frame of 1999 to 2008, to continuous flow data for subsequent model calibration. Unfortunately, key information needed to tie in the USGS stage data with the historical stage data was missing, or never measured. That piece of key information is the **benchmark elevations** for each historical gage site in order to relate those historical stage values to the USGS rating curve stage values. In other words, a reference elevation is needed to ensure that the historical stage data were consistent with, and could be used in conjunction with, the rating curves to generate reliable historical flow data, for model calibration.

A number of alternative procedures and analyses were performed to attempt to resolve this issue. We contacted the CERL Principal Investigator (Dr. Muhammad Sharif, Agricultural Engineer, CERL Point of Contact) to see if those data were available or if they could be obtained from field site measurements, with no success. In addition, Fort Benning staff (Mr. Hugh Westbury, Fort Benning Environmental Management Division, Watershed Program Manager) measured a potential invert elevation at one of the gage sites. Adjustments were made to the measured elevation, i.e., constant differences (plus and minus), to determine if the adjusted elevation data would produce reasonable flow data, when applied to the rating curve and historic stage data. However realistic adjustments did not produce flow rates within a reasonable range.

The inability to convert and use the historical stage data was a significant limitation, and one of the biggest disappointments of this study, because it precluded calibration at upstream and tributary sites with sediment and water quality data. This additional calibration would have provided an improved model for impact assessment of military activities, and especially for isolating contributions from off-base activities and urbanization in adjacent areas. In spite of this limitation, the USGS monitoring data (three years at four sites and four years at an additional site) provide an opportunity for future model improvements and calibration efforts if resources become available. The simulation period would need to be extended through 2012 to cover the monitoring data period of 2008 to 2012; this would involve extending the precipitation and meteorologic data time series through 2012. Calibration could be performed for the additional five sites, plus the McBride Bridge site to develop a more robust model with improved spatial representation, detail, and overall model performance. In addition, these supplemental calibration efforts could be performed successively at each of the five additional USGS gages so that the resulting changes, and presumably improvements, in model metrics can be

documented. This additional effort is highly recommended for continued use of the model as a watershed assessment and management tool for Fort Benning.

4.5.4 Study Implications for Monitoring at Other Potential Application Sites

To assist in determining recommendations for how the final model could be transferred and implemented at installations beyond Fort Benning, a comparison of model performance relative to the increased costs of additional site-specific calibration requirements were investigated as represented by:

i. use of all USGS rating curve data at Fort Benning;

ii. use of successively less rating curve data by reducing the number of streams from which data are considered;

iii. use of only stream cross-sectional data; and

iv. no USGS data input.

Item i in the above list corresponds to the version of the Enhanced Baseline Model (discussed in this section) showing the improvements with the refined FTABLES. Items iii and iv correspond closely, but not exactly, to the original Baseline Model (Task 2 Report, AQUA TERRA Consultants, 2010a), because the only USGS data used in the model was the McBride Bridge data and rating curve.

A central issue is embodied in item ii – how much data are needed for model application, and how does model performance change, or improve, with increasing data collection, and associated costs? OR, are the costs of additional data collection worth the resulting 'expected' improvement in model performance? Although universal answers to these questions do not exist for all watersheds, development of an analysis is possible that has the potential to inform decision-making on these issues. Table 4.5 lists the six gage sites in the Fort Benning Upatoi Creek watershed (See Figure 4.6): the five new USGS sites, plus the McBride Bridge gage site. Also, shown for each gage site is the area of the watershed that is being monitored, the percentage that this area represents of the entire watershed (i.e., at the outlet to the Chattahoochee), and the percentage of the watershed at McBride Bridge.

Table 4.5 USGS Gages and Associated Areas within the Fort Benning Upatoi Creek Watershed

USGS Gage	Reach Number	Description	Area of the watershed (sq.mi.)	Percent of Watershed at McBride	Percent of Watershed at Outlet
02341665	614	Upatoi Creek below Baker Creek, near Upatoi, GA	155.2	46%	34%
02341725	30	Pine Knot Creek near Eelbeeck, GA	65.9	19%	15%
02341750	639	Randall Creek near Upatoi, GA	18.6	5%	4%
02341910	662	Ochillee Creek at Ochillee, GA	63.9	NA	14%
02341800	46	Upatoi Creek Near Columbus, GA (McBride Bridge)	339.7	100%	75%
02342070	74	Upatoi Creek at GA357, at Fort Benning, GA (Outlet)	452.0	NA	100%

Consider the following:

1. The potential for improved model performance increases as a direct function of the percent of the watershed that is monitored, and thus subject to calibration.

2. Table 4.5 shows that the three new USGS gages above McBride Bridge comprise 70% of the watershed at that gage; this includes Upper Upatoi Creek (below Baker Cr.), Pine Knot Creek, and Randall Creek.
3. The current calibration at McBride Bridge relied on just that gage data for calibration since no other flow data were available for the calibration period. One metric of the calibration is the range in errors in the annual flow volumes; from Appendix C, Table 1.3, that range is about 30%, from -8.2% to +20.9%.
4. If we assume, for the current calibration, that the 30% error also applies at the three USGS gage sites above McBride Bridge, the question becomes 'How much can we reduce that error, and subsequent errors downstream, with additional monitoring?' However, it is likely that model errors will increase as the watershed size decreases, unless a more dense coverage of forcing functions is available; that is, the meteorologic inputs of precipitation and temperature will need to be estimated from farther away, and thus can introduce more errors in the model inputs for the smaller sites. Added monitoring of flow will allow a decrease in the errors, and if precipitation is also measured, further error reduction is possible. If we assume at least a 50% reduction in the errors for the new sites and monitored areas, then the 70% of the watershed monitored would demonstrate only 15% error (i.e., 50% of the 30% error), and the resulting error at McBride Bridge would be reduced to about 20%. If we can assume a 70% reduction in error at the tributary sites, then the error at McBride Bridge could see a 50% reduction to about 15%.
5. Similar analyses could be performed for other metrics, such as correlation coefficients, monthly volume errors, uncertainty bounds, etc., and at various sites within the watershed including the Upatoi Creek outlet. Note that Table 4.5 shows that with the McBride Bridge and Ochillee gages, about 89% of the watershed is monitored, including the multiple gages above McBride Bridge.

This type of analysis can be performed at other installations that are considering monitoring in support of watershed modeling applications, as a means of assessing the extent and number of sites they might need to fund. However, any such analysis needs to be site-specific and include considerations such as installation location within the watershed, mainstem versus tributary sites, land uses, training and disturbed areas, contaminant source areas, off-installation conditions and contributions, etc. The percent of the area monitored factors into how big an impact the additional monitoring data might have on model performance, but the monitoring program will need to consider the multiple considerations noted above in its design.

The costs for the USGS monitoring effort at Fort Benning was in the range of $400K. This included installation for five sites, a three-year maintenance and monitoring effort at all sites, and an additional year at one site under a different SERDP study. The costs per site were approximately $23,000 for installation and $13,600 for annual operation and maintenance. These costs are likely to be representative of comparable costs at other installations, especially if the USGS is involved.

As general guidance, based on our experience with other watershed sites and monitoring efforts, we would recommend that installations attempt to develop monitoring programs with sites located so that 40% to 70% of the watershed, or of the specific sites of concern within the watershed, would be monitored by the installed gages. We would suggest that the lower end of 40% (± 10%) be considered a minimum level of monitoring to provide a sound basis for model calibration and application for scenario analyses and watershed management.

4.5.5 Discussion

Recognizing the need for additional rating curves and monitoring data for the Fort Benning watershed modeling effort, SERDP funded the USGS to install five (5) automated-recording stream stage gages, and perform velocity measurements for selected storm events at each of these sites, as part of the rating curve development effort. The sites were co-located with prior ECMI and CERL monitoring sites so that the resulting rating curve could be used with the historic stage data to provide flow time series for expanded calibration efforts beyond the existing USGS gage at McBride Bridge, and thus provide a more robust model with an improved spatial representation of the watershed hydrologic response. Unfortunately, the lack of benchmark elevations at the ECMI/CERL sites for the historic stage data precluded the desired expanded calibration effort, and limited the use of the new data to refining the model stage-discharge relationships (HSPF FTABLES).

The inability to convert and use the historical stage data was a significant limitation, because it precluded hydrologic calibration at both upstream and tributary sites for which historic sediment and water quality data had been collected. This additional calibration would have improved the spatial representation of the model and its ability for use in impact assessment of military activities, and especially for isolating contributions from off-base activities and urbanization in adjacent areas. In spite of this limitation, the USGS monitoring data provide an opportunity for future model improvements and calibration efforts if resources become available. Our recommendations for future use of the USGS data and future monitoring efforts are as follows:

a. Extend the model simulation period through 2012 to allow further calibration with the newly acquired USGS flow data at multiple sites.

b. Perform calibration at all the new USGS sites in a successive manner, and at McBride Bridge, for the extended period, in order to document model performance improvements resulting from the additional monitoring data.

c. Continue monitoring at a selected subset of the USGS sites, depending on the Installation's plans and assessment needs.

d. Consider adding sediment and water quality sampling at the continued sites

4.6 BRAC SIMULATIONS AND RESULTS

The Enhanced Baseline Model for the Fort Benning watersheds includes the combined results of the model enhancements and application refinements discussed in Section 3. This section discusses the evolution of the Enhanced Baseline Model as the foundation for the management alternatives analyses, the model representation of 2005 BRAC implementation conditions on the Installation, the procedures for evaluating impacts of management alternatives through scenario simulations, and a brief discussion of future management simulations that build on the proof-of-principle BRAC management alternative evaluations.

Figure 4.12 provides an overview of the evolutionary process for the transformation of the original Fort Benning Baseline watershed model to the Enhanced Baseline Model and its subsequent use for assessing impacts of potential management alternatives and scenarios. The original application of BASINS/HSPF to the Fort Benning watersheds produced the Baseline Model as described in the Task 2 report (AQUA TERRA Consultants, 2010a). This model was used to help identify watershed model research topics and associated enhancements, as part of the dual-pathway approach described in Section 2, that were subsequently pursued to improve the model's ability to represent the military activities and natural resource management practices of interest to Fort Benning. The resulting Enhanced Baseline Model (EBM) includes WEPP/WEPP:Road, multi-level canopy, military training intensity methodology, and new flow

data enhancements; note that the EBM does not include the EFDC channel modeling, as discussed further below and in Section 4.4.

Figure 4.12 also shows the possible scenarios under each Management Alternative; the highlighted scenarios were the ones selected for evaluation. The remainder of this section discusses use of the EBM to assess the potential impacts of BRAC on sediment loss and contributions throughout the Installation, while Section 4.8 focuses on the Good Hope Mechanized Training Area (GHMTA) of the Installation, and assesses BRAC alternatives and potential BMP impacts.

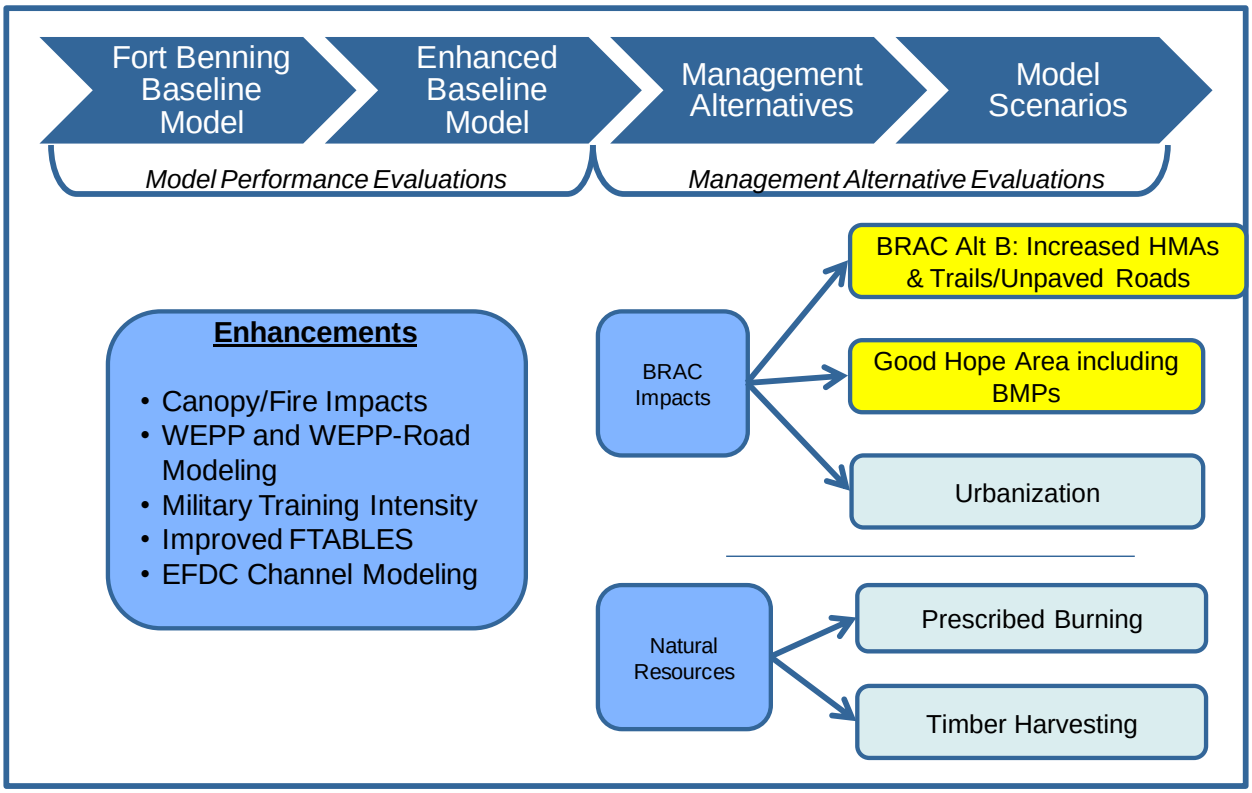

Figure 4.12 Fort Benning Watershed Model Enhancements and Management Scenarios

The EBM provides the foundation, as a 'baseline' or current condition, to which potential future conditions, management practices, and watershed changes can be represented and their impacts assessed. The process is as follows:

a. The EBM is run for the simulation period of 1999-2008 and model results are generated at various points of interest within the Fort Benning watersheds. These results may include flow rates and volumes, sediment concentrations and loads, or other water quality constituents and loads. Since sediment is a major contaminant of concern at Fort Benning, that has been the focus of our current efforts.

b. As noted above, Figure 4.12 shows two primary Management Alternatives, or issues, of interest – BRAC and Natural Resources. Many other categories have been identified and discussed, such as Regulatory Compliance relating to TMDL analyses, stormwater regulation (e.g., Section 438 mandates), etc., as the potential focus of future proof-of-principal alternatives evaluation.

c. Under each Management Alternative, model scenarios are identified, defined in terms of changes/adjustments to the model, and then the model scenario is run (for the same

1999-2008 time period) and model output is generated and analyzed as noted above in step a.

d. The final step is to compare the results from the EBM for the Baseline Condition to the scenario results by identifying and evaluating the differences between the Baseline and each scenario to estimate the impact associated with a proposed scenario.

Thus, a scenario corresponds to a single model run with conditions (e.g., military land use, off-installation land use, BMPs, prescribed burn cycle, etc.) that are either representative of the baseline condition or an alternative future condition to be assessed. The evaluation effort involves comparing the model results between two or more scenarios, usually with one being the Baseline Condition (often an estimate of 'current' conditions), with the differences in model results representing the scenario impacts.

4.6.1 Enhanced Baseline MODEL (EBM) and Conditions

Appendix C provides a complete detailed discussion of the EBM, including the model results as an update from the Task 2 report (AQUA TERRA Consultants, 2010a) which described the model setup and original results from the initial application of BASINS/HSPF to the Fort Benning watersheds, referred to as the Baseline Model. As noted above, the differences between the Baseline Model and the EBM include the most of the model enhancements discussed in Section 3. In addition, the simulation period for the EBM was extended through 2008 to provide opportunity for further model calibration to sediment data collected for a few additional storms in the 2007-08 period.

The EBM differed from the Baseline Model in the following model enhancement areas discussed in Section 3:

1. Military Training Intensity: The model parameterization for two military land use categories – heavy maneuver areas, tank trails – was unchanged between the Baseline and EBM; the unpaved roads category is addressed in item 2 below. The results of further investigation into the literature and the military intensity data for Fort Benning showed that the impacts on land cover and infiltration developed for the Baseline Model as part of the model calibration was also appropriate for the EBM as discussed in Section 3.2.1.
2. Unpaved roads representation: For the EBM, the WEPP and its interface WEPP:Road model was employed to generate the improved sediment loads from unpaved roads. As part of the hybrid modeling linkage, these loads were used to replace the HSPF-generated loads for unpaved roads used in the Baseline Model (see Section 3.2.2).
3. Plant canopy and prescribed burning: For the EBM, model refinements were used to represent changes in forest plant canopy, both overstory and understory, through a time series of values replicating a 3-year prescribed burn cycle. Time series were developed to mimic the burn removal of understory vegetation and subsequent regrowth through the impacts on land cover and infiltration during the 3-year cycle. This approach replaced the static representation in the Baseline Model that approximated these dynamic processes with three different land segments, each representing one year of the cycle (see Section 3.2.3).
4. Channel sediment and bank erosion: As discussed in Section 3.2.4, EFDC/SEDZLJ and an added bank erosion capability was applied for the mainstem of Upatoi Creek and linked to HSPF. This research investigation showed that the additional effort and time/resources for the EFDC/SEDZLJ application was significant and possibly excessive, including the inordinate execution time required for long-term model runs

(i.e., 2-3 days on a supercomputer for a 10-year run). In addition, comparisons of model results between HSPF and EFDC/SEDZLJ show an improvement with the more detailed EFDC simulations, but the extent of the improvement was not judged sufficient to offset the added complications and cost of its use. Although EFDC/SEDZLJ has an established history that demonstrates its merit and purpose for evaluations that require in-depth, multi-dimensional channel modeling, the level of effort and computational burden needed to run these models may be inconsistent with the level of need for such analyses on most installations. Additionally, the expertise and resources needed are judged to be beyond the means and capability of most Installations and the available staff. Consequently, flow and channel modeling by HSPF was deemed sufficient for this investigation and was used for the EBM management alternative evaluations; thus, the **EBM model results shown here are based entirely on BASINS/HSPF simulations** (see Appendix C).

5. Refinements from USGS data: As noted in Section 4.5, the rating curve data obtained from the USGS monitoring program was used to refine the HSPF FTABLES at those sites, along with adjacent upstream and downstream reaches. These improvements, although having marginal impact on the model results, were included in the EBM, as they improved the overall hydraulic representation for the areas near, and downstream of the monitoring sites associated with the new rating curve data.

4.6.2 BRAC Simulations and Results

Figure 4.13 shows the land use coverage for both the EBM (same as Baseline) and the BRAC (Alternative B) scenario; a summary of the differences between the two scenarios is also shown for the three military land uses of HMA, tank trails, and unpaved roads. The Alternative B scenario represents the expected footprint of the three military land uses as presented in the

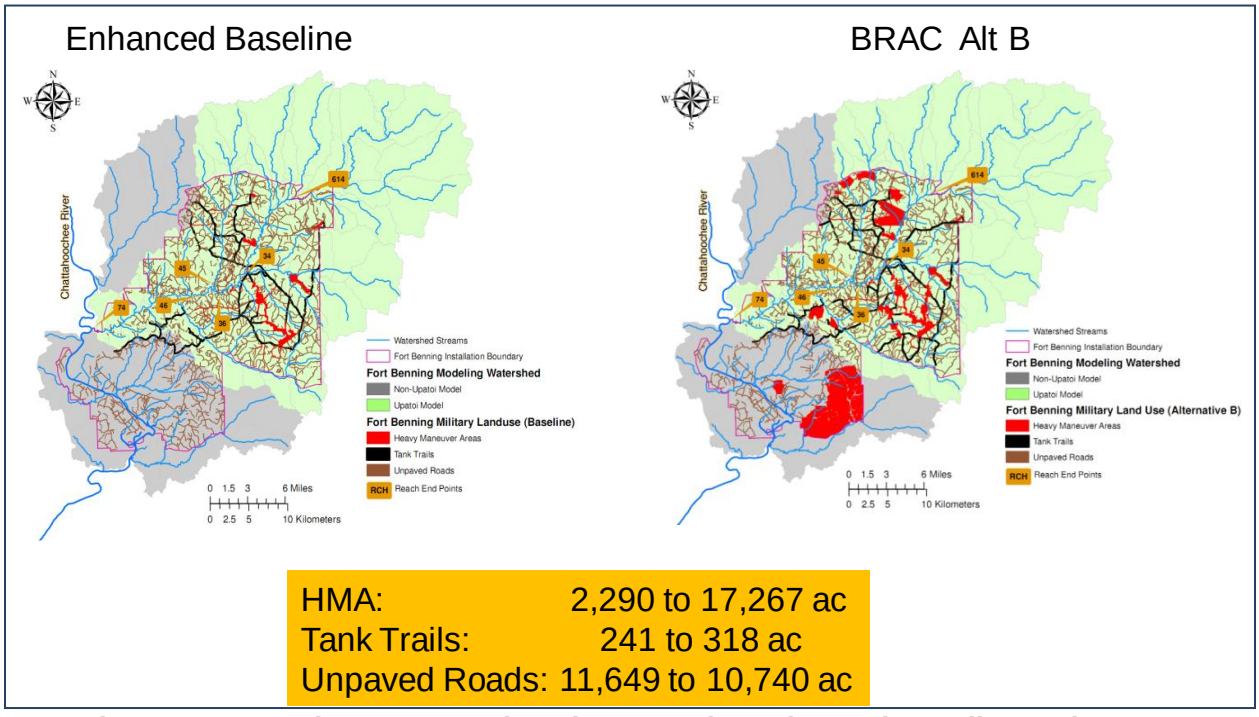

Figure 4.13 Land Use Comparison between the Enhanced Baseline and BRAC Conditions

2007 Draft Environmental Impact Statement that addressed the 2005 BRAC Recommendations (US Army COE, 2007). The actual footprint of the military land uses that currently exists on the Installation is significantly different than the proposed Alternative B footprint, and there have been subsequent revisions to the EIS Plan. The **RED** colored areas are the HMAs, and they show the largest increase, from 2,290 acres under the Enhanced Baseline (current) condition to 17, 267 acres under BRAC, reflecting the transfer of the Armor School to Fort Benning under BRAC. The largest area of **RED** is the Good Hope Mechanized Training Area (GHMTA), which is the focus of separate analyses, discussed in Section 4.8.

Table 4.6 shows the results of three model scenario runs for the Baseline, Enhanced Baseline, and BRAC Alternative B, with sediment loads and percent military contribution at four sites along the mainstem of the Upatoi; the sites are labeled in Figure 4.14. The sediment load is the total average annual loads at each site in tons/year, while the percent military contribution identifies the portion of that load derived from the three military land uses.

Table 4.6 Impacts of the Baseline, Enhanced Baseline, and BRAC Conditions on Sediment Loads in Upatoi Creek Corresponding to the Reporting Locations

	R:614 North Upatoi Creek		R:34 Pine Knot Creek		R:46 Upatoi Creek at McBride Bridge		R:74 Upatoi Creek at Outlet	
	Sediment Loading (t/yr)	Military Contribution (%)	Sediment Loading (t/yr)	Military Contribution (%)	Sediment Loading (t/yr)	Military Contribution (%)	Sediment Loading (t/yr)	Military Contribution (%)
Baseline	9306	7.5	5672	42.3	22352	29.1	28903	34.5
Enhanced Baseline	10169	7.5	5878	41.8	23433	29.1	30912	34.4
Alternative B	10173	7.5	6661	48.7	27852	40.2	36401	44.6

At the upper end of the Installation, at Reach 614, the military contribution is about 7.5% of the total sediment load of about 10,000 tons/year. The annual load increases very slightly between the Enhanced Baseline and the BRAC scenarios at that site, so the percent contribution stays the same. Although this is very near the upper boundary of the Installation, there is still some Installation area that drains to the site where the 614 reach ends. Note that a separate analysis is performed to assess the contributions of land outside of and within the Installation boundary, and this is discussed further below.

Table 4.6 also shows that the contribution from the military land uses increases between the Enhanced Baseline and the BRAC scenarios due to the increased HMA areas and to a lesser extent, the tank trails. The contribution increases about 10 percentage points at McBride Bridge (Reach 46) and at the watershed outlet (Reach 74). At those two sites, and at the Pine Knot Creek site (Reach 34), the military land uses represent between 40% and 50% of the total load, even though those land uses combined are about 3% and 6% of the watershed under the Enhanced Baseline and BRAC land coverages, respectively. As expressed earlier, but worth reiterating, the BRAC management alternative evaluation was confined to the Upatoi Creek drainage area. Another management alternative evaluation, as presented in Section 4.8, focuses on a single training area within the Oswichee and Hichitee drainages (i.e., GHMTA) which is outside of the Upatoi Creek drainage.

Another method to analyze the differences in the model predictions for the Enhanced Baseline and BRAC alternatives is to compare the frequency behavior of the sediment (or TSS) concentrations for each condition. In Section 4.4, we presented the differences in the flow duration curves for the HSPF simulated and observed data at McBride Bridge to demonstrate how this standard hydrologic analysis procedure is used to evaluate model performance. As noted in that section, the flow duration curve is essentially a cumulative frequency plot of the

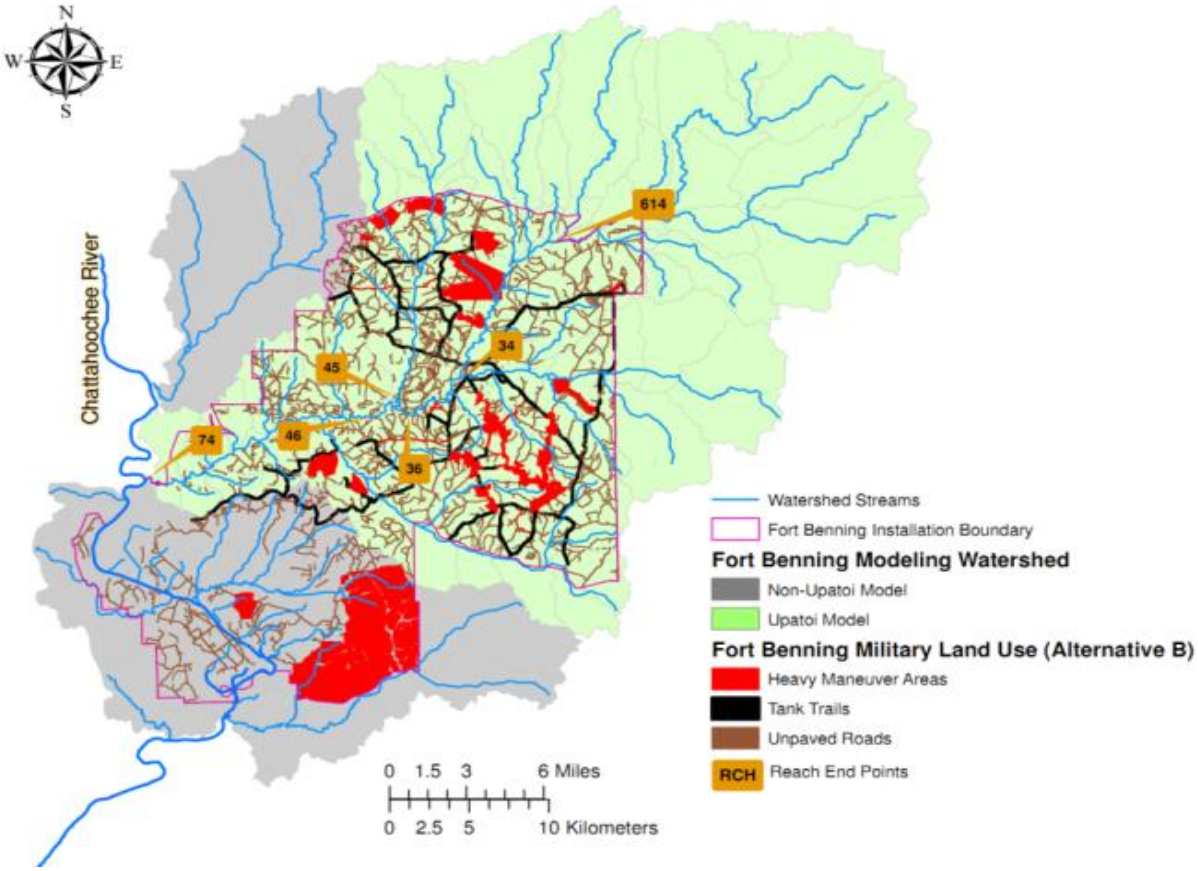

Figure 4.14 Fort Benning Watershed with Mainstem Upatoi Sites

percent chance (calculated as percent of time) that the flow value on the vertical axis is exceeded. This single plot displays and characterizes the entire hydrologic regime of the watershed ranging from extreme low flows, frequently exceeded up to 98% or 99.5% of the time, or greater, to the extreme high flows, which are only occasionally exceeded in the range of 1% of the time, or less, The exceedance frequencies for mid-range flows are also shown indicating 50% exceedance, or the median flow value.

Similar analyses can be performed for sediment (or TSS) concentrations to assess how alternative conditions on the watershed compare based on comparison of the full range of sediment concentrations produced by the model simulations. Figure 4.15 shows the TSS concentration exceedance curves for Enhanced Baseline and BRAC conditions; the Baseline and Enhanced Baseline conditions are similar enough that they would show no real difference in the curves. Comparison of the two curves shows that there is very little difference between the curves for the very low TSS concentrations of 10 mg/l or less, that occur, more than 75% to 80% of the time. However, at the higher concentrations from 50 mg/l to 500 mg/l the differences are significant. In this range, the model results indicate a 10% to 20% increase in TSS concentrations, consistent with the load increases noted above. It is likely that for smaller subwatersheds with higher percentages of HMA and Tank Trail areas, the concentration increase would be greater reflecting the higher intensity of training. Such an analysis would help to identify sediment 'hot spots' with the Installation for further analysis and potential BMP implementation activities.

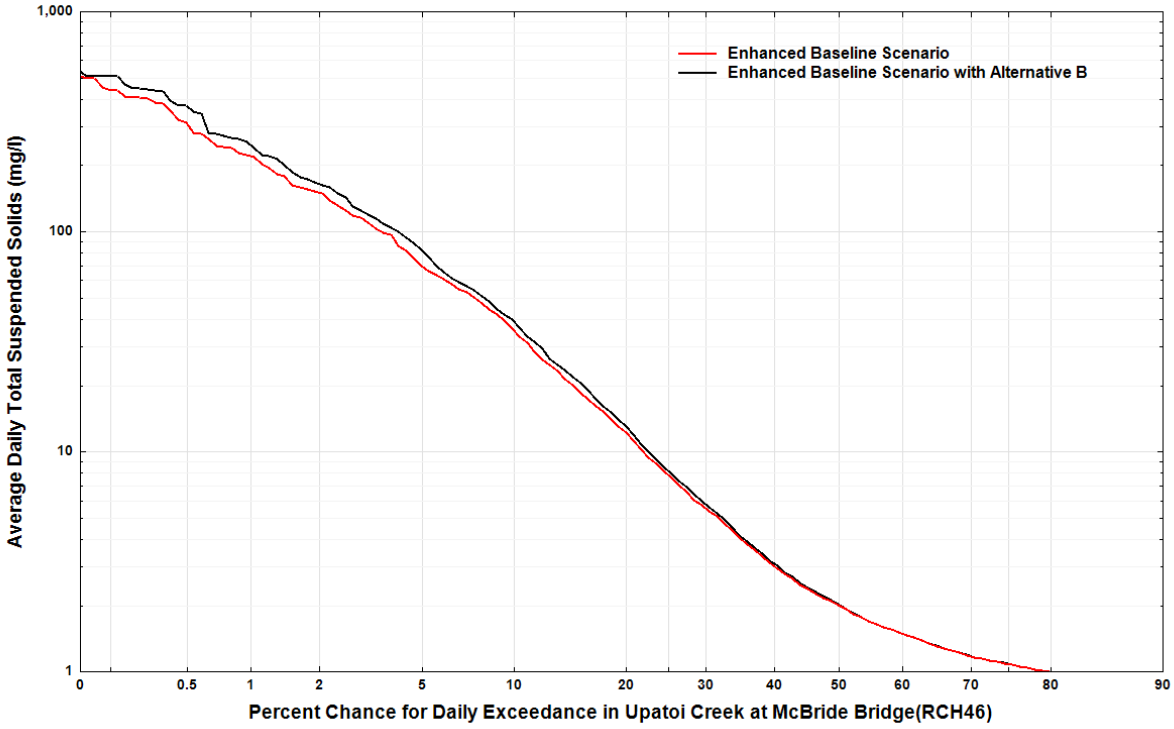

Figure 4.15 TSS Concentration Exceedance Curves for Enhanced Baseline and BRAC Conditions at McBride Bridge

In Section 4.8.4, we discuss the use of the sediment cumulative frequency curves to assess impacts of alternative conditions and BMPs in the Good Hope Maneuver Training Area. When water quality standards are available, EPA has proposed the joint application of flow duration analyses along with established water quality criteria to generate load duration curves for use in developing Total Maximum Daily Loads (TMDLs) (U.S. EPA, 2007b). Although the technique is considered more of a screening procedure, it does provide useful analyses that directly consider the critical importance of the watershed flow regime and its relation to water quality impairments.

4.6.3 Sediment Contributions from Inside and Outside Fort Benning

One of the concerns of the Installation management relates to how much sediment is generated from within the Installation boundary versus how much enters the Installation from lands outside its boundary. The split of sediment loading between external and internal sources determines the extent to which the Installation is responsible for control and mediation of sediment loads that may lead to aquatic impacts and impairments within its borders.

As shown in Figure 4.14, a number of streams traverse the Installation boundary, including the major streams of Randall, Juniper, Pine Knot, Ochillee, and a number of smaller streams. Each carries sediment loads that may originate from outside the Installation boundary, and thus from non-military lands. Systematically calculating the sediment load exiting from each reach that crosses the Installation boundary, and summing up those loads and dividing by the total load from the watershed outlet allows us to partition the contributions from within the Installation versus those from outside the Installation. Table 4.7 shows the Installation's contribution for various tributaries, at McBride Bridge, at the Upatoi Creek watershed outlet, and at Hichitee Creek. This analysis shows that for the sediment load at the Upatoi outlet about 49% originates

from within the Installation and 51% from outside; whereas at McBride Bridge, about 62% originates from outside the Installation with the balance of 38% from within. Also, about 19% of the sediment load of Hichitee Creek that directly flows into the Chattahoochee River (as shown in the Non-Upatoi model) is contributed by land areas inside the Installation, since a significant portion of that watershed area drains outside lands.

Table 4.7 Sediment Loading per Year and Percent Contribution of Eroded Sediment from Inside Base versus Outside the Base

	R:45 (Randall Creek)	R:34 (Pine Knot Creek)	R:46 (Upatoi Creek at McBride Bridge)	R:74 (Upatoi Creek at Outlet)	R:206 (Hichitee Creek)
Total Sediment Load (t/yr)	2,600	5,053	18,983	25,368	1.924
Percent Contribution from the Installation	73.3	55.3	38.0	48.7	19.3
Percent Contribution from outside the Installation	26.7	44.7	62.0	51.3	80.7

4.6.4 Potential Future Alternative Simulations

This proof-of-principle application of the BASINS/HSPF model to the Fort Benning watersheds has demonstrated how watershed modeling can be applied to evaluate potential impacts of land management and military training conditions on the watershed hydrology and water quality. As shown in Figure 4.12, a number of additional alternative management scenarios were identified as being of interest to land managers at Fort Benning, but could not be considered due to resource limitations. Procedures and approaches for addressing these alternatives, along with other possible management options, are discussed below. Future efforts for demonstration and validation of the watershed modeling procedures, directed at military installations, should consider some of the following scenarios:

1. BRAC with and without Urbanization: Evaluate the impact of urbanization outside of the Installation's boundaries on Fort Benning's streams by assuming a percent increase in urban land use coverages and a corresponding decrease in pasture, agricultural, and/or forest land use for the areas outside of the Installation's boundaries. Sensitivity to alternative levels of urbanization can be assessed with scenarios corresponding to different levels of future increases in urban lands.
2. Prescribed Burning: Evaluate impacts of alternative prescribed burn cycles for Fort Benning watersheds by varying the burn cycle from the current 3-year cycle, to alternatives such as 1-year, 2-year, and 5-year cycles.
3. Timber Harvesting: Assess the impact of timber harvesting on the watershed by simulation of alternative conditions, such as: 1) a worst-case scenario of clear cutting of an entire subwatershed; 2) alternative levels of timber harvesting at sites throughout the Installation; 3) multiple analyses of near-site, tributary, and downstream impacts; 4) assess impacts of potential mitigation procedures for runoff and sediment loss.
4. Regulatory Compliance: Alternative analyses in support of TMDLs at identified sites across the Installation, and stormwater requirements (i.e., EISA Section 438) for proposed development areas.

Watershed modeling is an appropriate and cost-effective tool for addressing these and other management needs at a watershed scale while considering land management and regulatory issues of concern to military land managers.

4.7 AQUATOX: MODELING RESPONSE OF AQUATIC ECOSYSTEM

4.7.1 Introduction to AQUATOX

AQUATOX, a mechanistic and dynamic fate and effects model, simulates the significant physical, chemical, and biological processes affecting aquatic biota in streams (including runs, riffles, and pools), rivers, ponds, lakes, reservoirs, and estuaries (Park et al. 2008). The model has been developed with funding from the U.S. Environmental Protection Agency and is well documented (U.S. Environmental Protection Agency 2000b, c, d, a, 2001b, a; Park and Clough 2004a, b). AQUATOX can model multiple species of periphyton, phytoplankton, macrophytes, aquatic insects, mollusks, and fish as well as nutrients, sediments, and toxic organics. The same parameterization has been used to simulate the nutrient-rich, turbid Blue Earth River and the nutrient-poor, clear Crow Wing River in MN. The model has also provided a good fit to data from the nutrient-rich, sporadically turbid Cahaba River in AL and Boise River in ID with minimal changes in parameters. Of particular interest in modeling Fort Benning and other military bases, AQUATOX is capable of assessing the impacts of suspended and bedded sediments on stream communities. It can represent and predict compositional shifts for periphyton, phytoplankton, invertebrates, and fish with changes in N, P, and sediment loadings. The model is a part of the BASINS system and can be linked with HSPF to determine impacts on aquatic ecosystems.

AQUATOX provides a wide range of potential applications to water management issues and programs, including water quality criteria and standards, TMDLs (Total Maximum Daily Loads), and ecological risk assessments of aquatic systems. AQUATOX can be used to predict ecological responses to the pollutant loadings that are likely to result from proposed management alternatives. The model may also help to determine the most important of several environmental stressors, e.g. where there are both nutrients and toxic pollutants.

AQUATOX provides a critical tool when land managers need to understand the processes relating the chemical and physical environment with the biological community in order to meet regulatory requirements. Because the health of a biological system is a direct measure of environmental stress, biological monitoring is often preferred over chemical monitoring for assessing environmental health. Biological monitoring measures the biological health of fish, plant, or macroinvertebrate communities. Monitoring data are used to conduct a bioassessment, which is an examination of attributes such as community composition, reproductive function, tolerance to human disturbance, abundance, and condition. Quantifying these attributes results in a score called an Index of Biological Integrity (IBI). Streams or wetlands with IBI scores less than a certain value are considered impaired for Aquatic Life and placed on the U.S. Environmental Protection Agency (EPA) 303(d) List of Impaired Waters.

A biologically-impaired stream or wetland must be restored to a specific assemblage of fish, macroinvertebrates, or plants through the Total Maximum Daily Load (TMDL) process. During development of a TMDL, detailed analyses are conducted to determine reductions in pollutant loading needed to restore a stream to its intended use. Since the TMDL represents a quantity of pollutant, a surrogate chemical must be found for the biological impairment. For biological impairments, the pollutant may not be known. For example, a stream may not support a healthy fish assemblage because of elevated temperature, nutrients or sediment. Suspended sediment is the most common surrogate for biotic impairments, although others, such as phosphorus, may be used.

TMDLs for biological impairments are written in terms of the surrogate chemical. A model such as AQUATOX can be used in conjunction with a watershed model to estimate the daily pollutant loads that can be discharged to a river or stream without resulting in an unacceptable level of biological impairment.

4.7.2 Linkage to HSPF

Originally, watershed output could be exclusively linked through the BASINS WinHSPF-to-AQUATOX linkage (Clough 2004). This required that the user work with WinHSPF (i.e., the HSPF interface contained in BASINS) and then have WinHSPF produce special time series used for the linkage. For this project, a new procedure was developed that allows a user to import HSPF simulation results that are stored in "WDM files" into AQUATOX. In-stream Concentrations (ammonia, phosphate, oxygen, nitrate, TOC/CBOD, and TSS), flow and water temperature values that are simulated by the HSPF channel module RCHRES are imported instead of the boundary-condition calculations passed in the original linkage. The updated linkage is described in Appendix E.

There was some concern that HSPF and AQUATOX would both be calculating the same in-stream processes so there could be double counting. However, when passing average daily loadings into short reaches with low retention times, the HSPF in-stream concentrations and the AQUATOX in-stream concentrations will be dominated by the inflow loadings rather than in-stream processes. Our testing has indicated that linking HSPF in-stream concentrations as AQUATOX inflow loadings for such short reaches introduces negligible differences.

Additionally, one can design a study such that the AQUATOX boundary condition is represented by the end of, or outflow from, the HSPF reach being linked. This approach would eliminate any potential error from double-calculation of in-stream processes. The assumption would simply be that the well-mixed HSPF reach feeds directly into the AQUATOX reach being modeled downstream.

4.7.3 State Variables for Fort Benning Application

Biotic groups and parameterizations from the Cahaba River, Alabama, implementation were used as starting points for implementation of the model for Fort Benning. However, there are differences in physical habitat in the Coastal Plain streams, which are dominated by sandy substrates, and there are fish species present at Fort Benning that were not simulated in the Cahaba River. Furthermore, most of the streams have low pH, excluding most mollusks. Therefore, the state variables were changed accordingly (Figure 4.16). Of particular interest is the diatom *Eunotia*, which lives on sandy substrates and dominates the Upatoi Creek and other sites (Mulholland et al. 2007). There are two indicator fish species that occur in Fort Benning streams, and they have opposite responses to watershed disturbance (Mulholland et al. 2007). Broadstripe shiners decline with increasing disturbance, and Dixie chubs increase in abundance with disturbance. The general literature does not provide enough information to parameterize the bioenergetics of these differently; therefore, they were calibrated to respond differentially to sediment deposition based on information gathered at Fort Benning (Maloney et al. 2006) and on the Internet. According to Outdooralabama.com:

"The Dixie chub prefers headwater streams with riffles and flowing pools over sandy or soft substrates.... The Dixie chub is an omnivore, consuming a variety of animal and plant foods, including insects, worms, fishes, mollusks, crayfishes, and plant material." and:

"The Broadstripe shiner is typically found in small, clear streams (sometimes in blackwater streams) and is commonly associated with log snags or aquatic vegetation over substrates of sand, clay, silt, or exposed bedrock…. It is presumably a drift feeder, consuming adult and larval insects and detritus."

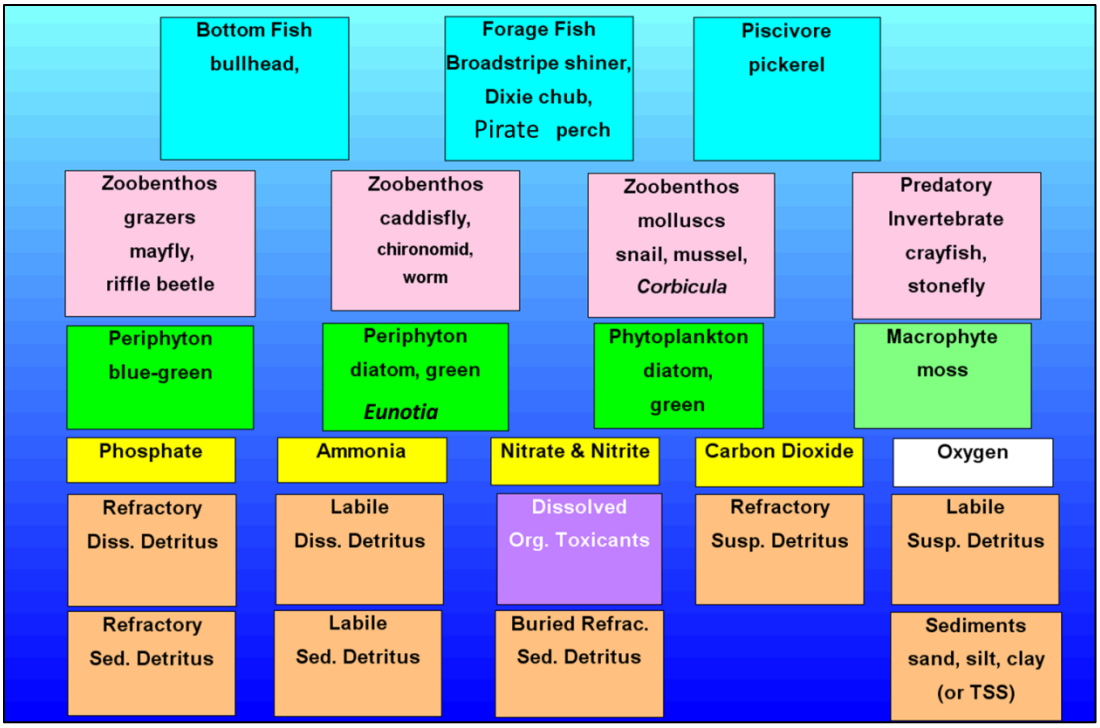

Figure 4.16 State Variables Used in Implementation of AQUATOX for Fort Benning, Georgia

4.7.4 Endpoints

Beyond the state variables that represent a simplified foodweb, there are also output variables (endpoints) that are especially important because they measure the "health" and sustainability of the aquatic ecosystem.

Several aquatic species of concern are found on Fort Benning, as listed in Table 4.8. In many cases these species can serve as useful indicators for system-level conservation targets. A draft plan by the Nature Conservancy is under development for monitoring these species, either by direct or indirect methods, to track their occurrence or in some cases their population trends over time. At this time we have chosen to model the rare Broadstripe shiner (described in the above section); it is known to occur, at least within the recent past, in the watersheds of interest. As mentioned above, it is replaced by the tolerant Dixie chub in streams draining disturbed watersheds (Mulholland et al. 2007).

A biotic metric is a numerical value that represents a quantitative community parameter, such as gross primary production, or percent of an indicator taxon (such as % chironomids). Biotic metrics have been widely used for several decades, stimulated in part by inclusion in rapid bioassessment protocols (RBP) by the US EPA (Plafkin et al. 1989) and by State agencies including Georgia (Hughes et al. 2010). Most are applicable to streams and wadeable rivers (Barbour et al. 1999). However, there are limitations in the application of many such metrics in a modeling framework, limitations that reflect the differing capabilities of simulation models as opposed to field studies. Models can predict continuing complex responses to changing conditions with limited taxonomic resolution, while field measurements usually represent snapshots of existing conditions based on detailed taxonomic identifications and involve counting the numbers of individual organisms per sample. Therefore, only a subset of possible metrics can be implemented with AQUATOX; although, given the biologic realism of the model, the list is much more extensive than for other models. Metrics can be calculated for algae, which

indicate short-term impacts; macroinvertebrates, which integrate short-term impacts on localized areas; and fish, which are indicators of long-term impacts, often over broad reaches (Barbour et al. 1999).

Table 4.8 Aquatic Species of Concern on Fort Benning

Scientific Name	Common Name	System-level Conservation Target	Federal Status	GA Status	AL Status	Global Ranking	State Ranking (GA/AL)
Ameiurus serracanthus	Spotted bullhead	Fall Line Streams and Bottoms		R		G3	S2/S2
Cyprinella callitaenia	Bluestripe shiner	Fall Line Streams and Bottoms		R		G2	S2/S1 S2
Etheostoma parvipinne	Goldstripe darter	Fall Line Streams and Bottoms		R		G4/G5	S2 S3
Hamiota subangulata	Shinyrayed pocketbook	Fall Line Streams and Bottoms	LE	E	E	G1	S2/S1
Pteronotopis euryzonus	Broadstripe shiner	Fall Line Streams and Bottoms		R		G3	S2/S2

Status and Ranking Definitions:

LE = Listed as endangered under the Federal Endangered Species Act.
R = Listed as rare by State.
E = Listed as endangered by the State.
G1 = Critically imperiled globally because of extreme rarity.
G2 = Imperiled globally because of rarity.
G3 = Either very rare and local throughout its range or found locally in a restricted range.
G4 = Widespread, abundant, and apparently secure globally, though it may be quite rare in parts of its range.
G5 = demonstrably widespread, abundant, and secure globally, though it may be quite rare in parts of its range, especially at the periphery.
S1 = critically imperiled in the state because of extreme rarity.
S2 = Imperiled in the state because of rarity.
S3 = Rare or uncommon in the state.

Given the discrimination efficiency of most of the metrics for Subecoregion 65d (Hughes et al. 2010), only a few metrics should be used in this application for regulatory purposes. Based on Hughes' recommendation (George Williams, personal communication, March, 2010), two invertebrate compositional metrics were chosen for each of the two dominant subecoregions (Table 4.9). Furthermore, in anticipation of AQUATOX being used in a weight-of-evidence approach, algal and fish endpoints were used in addition to the invertebrate metrics. Both algal and fish endpoints have their basis in research on disturbance impacts conducted at Fort Benning (Maloney et al. 2006, Mulholland et al. 2007). Several other widely used metrics are computed by AQUATOX and these are available for application on other military bases as warranted.

Table 4.9 Biotic Metrics for Determining Impaired Conditions at Fort Benning Georgia

Sand Hills 65c	Reference	Response to perturbation	DE
% Trichoptera	(Hughes et al. 2010)	decrease	0.7
% Plecoptera	(Hughes et al. 2010)	decrease	0.6
Southern Hilly Gulf 65d			
% Chironomidae	(Hughes et al. 2010)	increase	0.7
% Trichoptera	(Hughes et al. 2010)	decrease	0.7
Both Ecoregions			
% Eunotia	(Mulholland et al. 2007)	decrease	
Broadstripe shiner/Dixie chub	(Maloney et al. 2006)	decrease	

DE = discrimination efficiency between reference and impaired conditions

4.7.5 Calibration and Verification with Available Data

Unlike hydrologic models, aquatic ecosystem models cannot be parameterized on first principles, but rather require at least limited verification and oftentimes fine-tuning of key parameters for application to dissimilar watersheds. Initial calibration in advance of results from watershed modeling in this project utilized available data from several sites at Fort Benning (Figure 4.17).

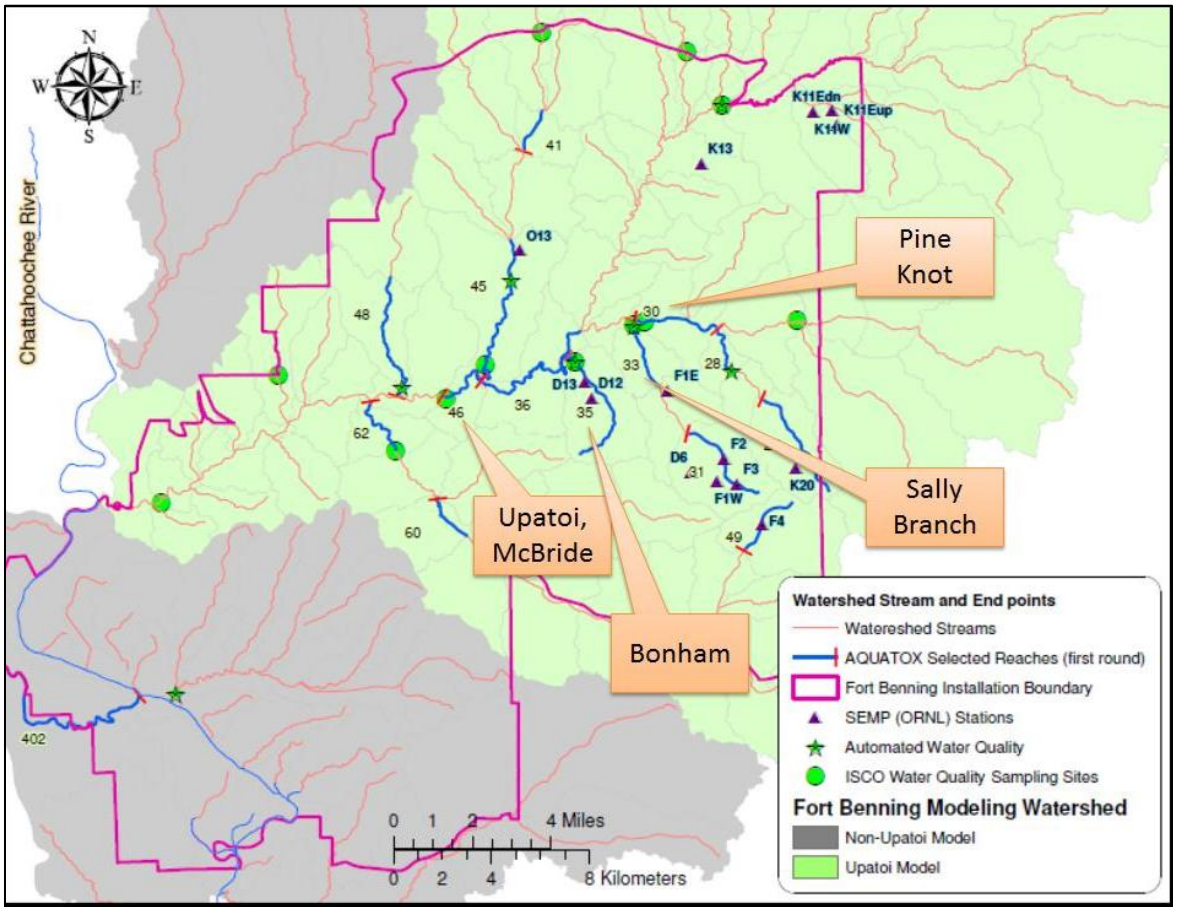

Figure 4.17 Locations of Stream Reaches and Sample Sites Chosen for Possible Application of AQUATOX

McBride Bridge at Upatoi Creek was chosen as the first calibration site (Figure 4.18) because physical and biological data were available from several sources, and the model could be implemented in advance of HSPF simulation results. This was Station Upat 02 of the macroinvertebrate study; and mean and maximum depths, width, and pH were taken from RBP_Report Data-Graphs.xls. Discharge and water quality data were downloaded from the USGS National Water Information System (USGS 02341800). TSS, NTU, and velocity data were obtained from Woodall and Flowlink.xls (Dr. M. Sharif, CERL, personal communication).

Figure 4.18 McBride Bridge, Upatoi Creek site. Note Abundant Sand Bars.

Calibration of the biotic variables was primarily an exercise in changing food preferences for animals to obtain reasonable seasonal dynamics and better fits to sparse data. *Eunotia* susceptibility to scour was calibrated considering that the diatom lives primarily on sand. Periphytic greens were represented by the genus *Stigeoclonum,* which was first calibrated for a Tennessee stream. Following the initial calibration, data from other Fort Benning sites were used in cross-site calibration.

At a later date HSPF simulation results were available and were used as boundary conditions for the studies. AQUATOX was driven by flow, chemistry, and suspended sediment loadings predicted by HSPF – more recently by the enhanced watershed model. The final calibration of AQUATOX for Fort Benning streams depended primarily on Upatoi Creek data, but was checked against data from Sally Branch. The simulated periphyton were dominated by *Eunotia* and the fluctuations are reasonable for a low-nutrient stream with an unstable substrate (Figure 4.19).

The invertebrates are dominated by chironomids in the initial simulation. Predicted percent chironomids exhibits a range of values similar to observed (Figure 4.20). A plot of chironomid rates (Figure 4.21) indicates that emergence is important, as is periodic scour and entrainment. Predation does not appear to be an important factor in chironomid biomass predictions.

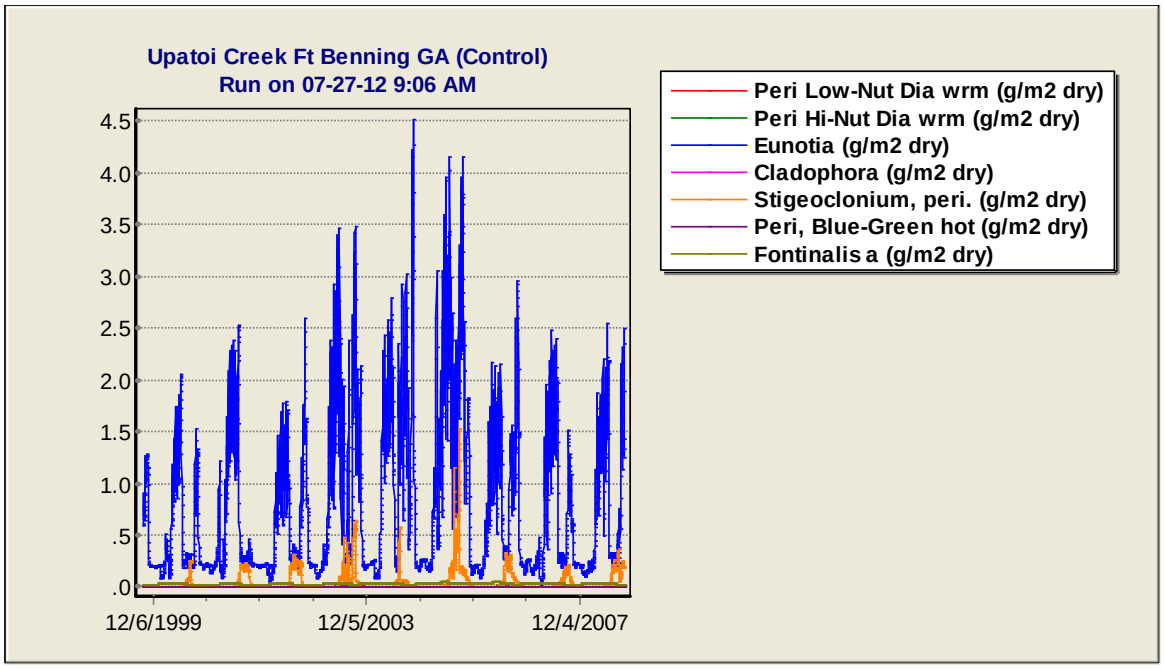

Figure 4.19 Simulated Benthic Algae and Moss in Upatoi Creek, Fort Benning, Georgia

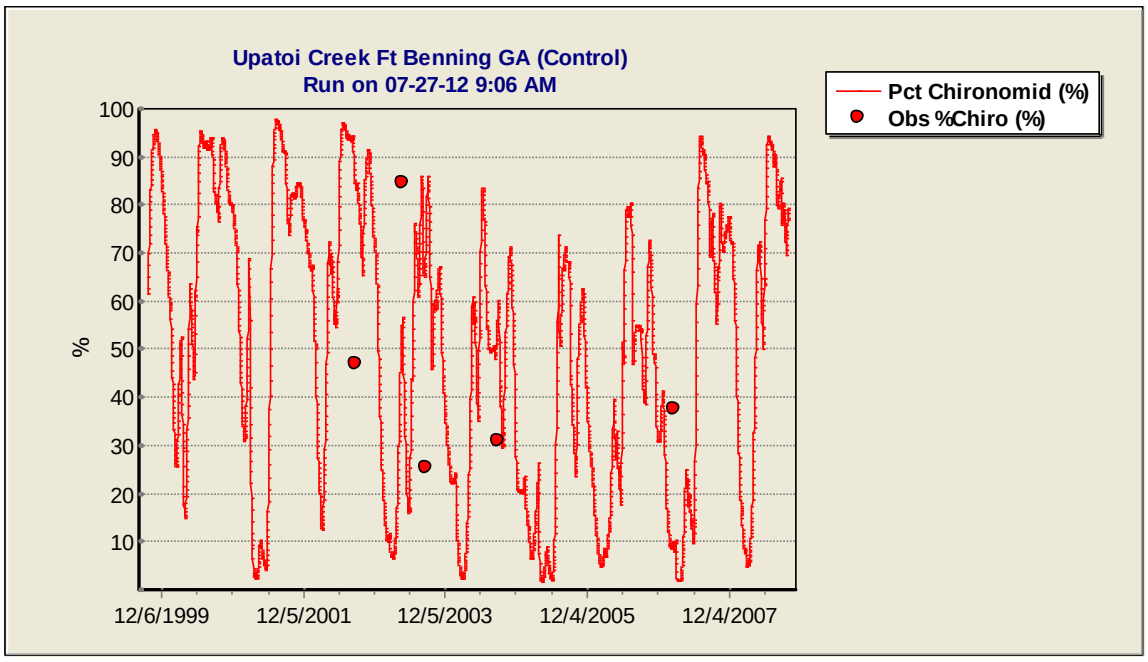

Figure 4.20 Predicted and Observed Percent Chironomids in Upatoi Creek, Georgia

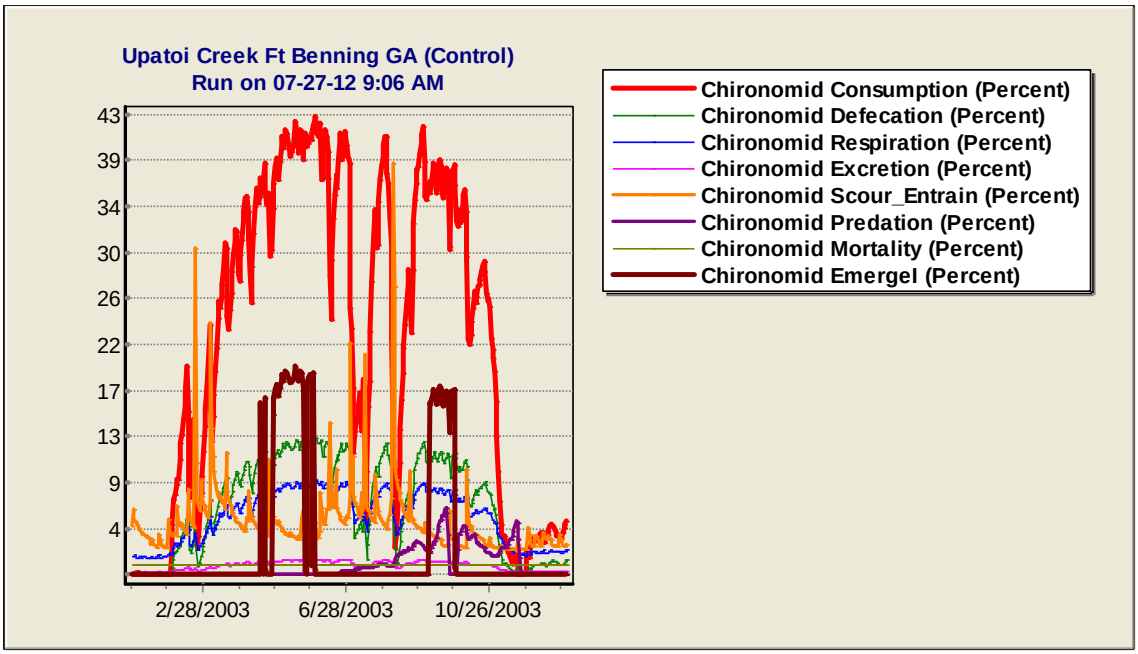

Figure 4.21 Predicted Process Rates for Chironomids in Upatoi Creek, Fort Benning, Georgia

Gross primary productivity (GPP) is a metric that represents overall primary productivity (expressed as oxygen production) at a site and can be summarized over time by calculating the mean and standard deviation (Figure 4.22). Of course, the predicted and observed statistics should be calculated for the same period. Data from a tributary on Upper Sally Branch (Mulholland et al. 2005) were used as limited verification.

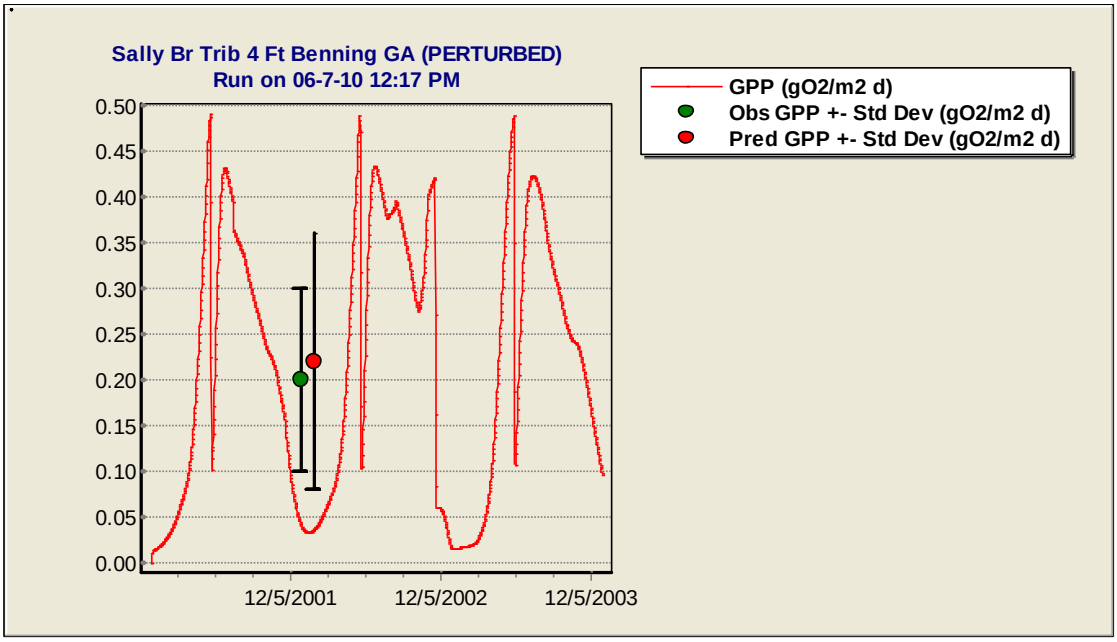

Figure 4.22 Predicted and Observed Gross Primary Productivity (GPP) in Sally Branch Tributary 4, Fort Benning GA. Statistics (mean ± 1 standard deviation) are for the entire three-year period, and therefore their position on the horizontal axis is arbitrary.

Although there are a few data on benthic chlorophyll a in Fort Benning streams, the units appear to be in error and the data were not used. Benthic and sestonic chlorophyll *a* simulations were verified by comparisons with results from the DSAMMt model, which is built into the current version of HSPF. The AQUATOX benthic results tend to be lower than those from DSAMMt (Figure 4.23); however, AQUATOX simulates loss processes such as herbivory and sloughing.

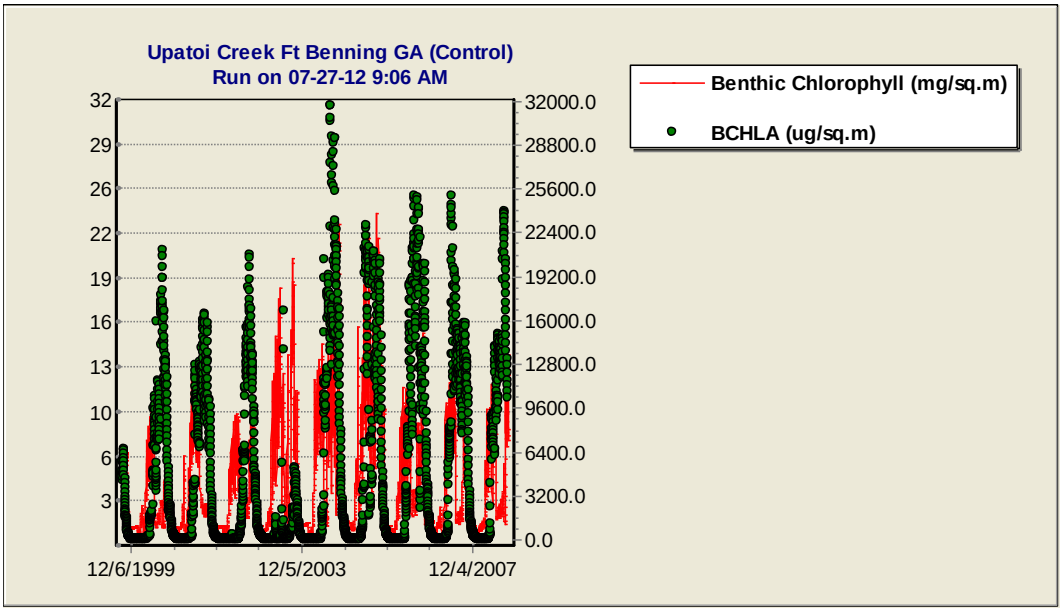

Figure 4.23 Benthic Chlorophyll a Simulated by AQUATOX and DSAMMt Incorporated in HSPF

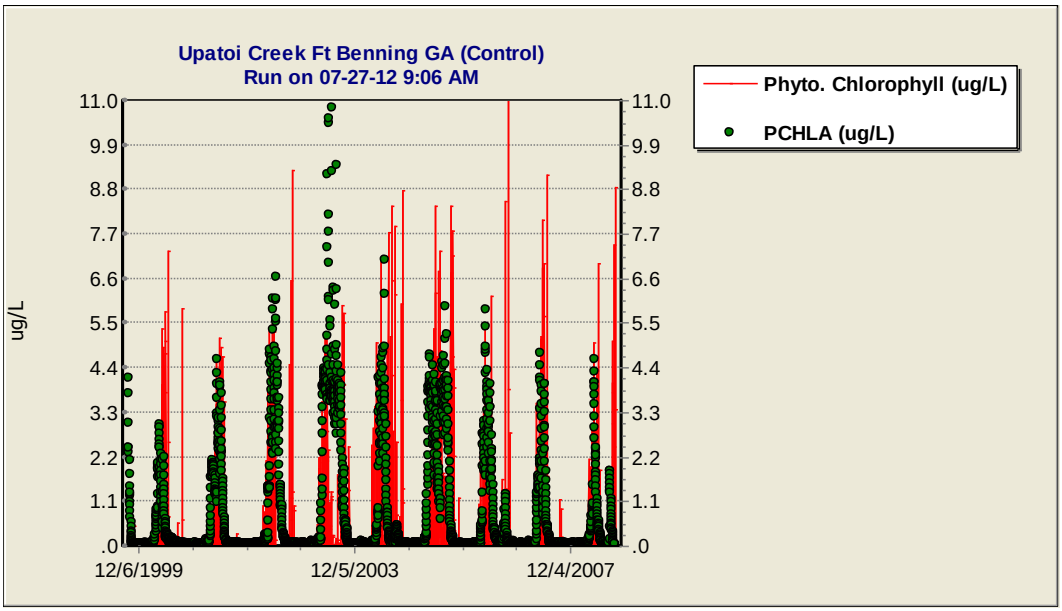

Figure 4.24 Sestonic Chlorophyll *a* Simulated by AQUATOX and HSPF

Likewise, the sestonic chlorophyll *a* results from AQUATOX are higher (Figure 4.24) because they are strongly influenced by sloughing periphyton. This is confirmed by plotting the *Eunotia* rates, which indicate considerable sloughing, as well as herbivory (Figure 4.25).

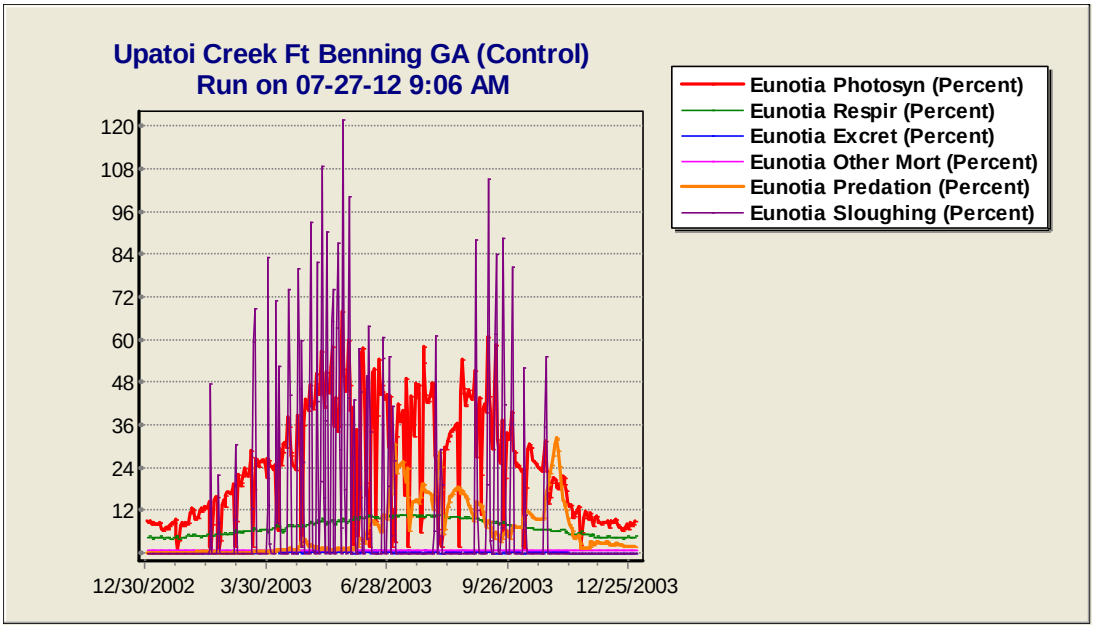

Figure 4.25 Simulated Rates for *Eunotia* at Upatoi Creek; note Prevalence of Sloughing and Importance of Predation (herbivory)

Although it is not a particularly useful metric for representing environmental responses in the Sand Hills Subecoregion, data are available for percent "EPT" (Ephemeroptera, Trichoptera, and Placoptera), and so they are plotted to help in verification. Unfortunately, seasonal fluctuations mask any close correspondence between observation and simulation (Figure 4.26).

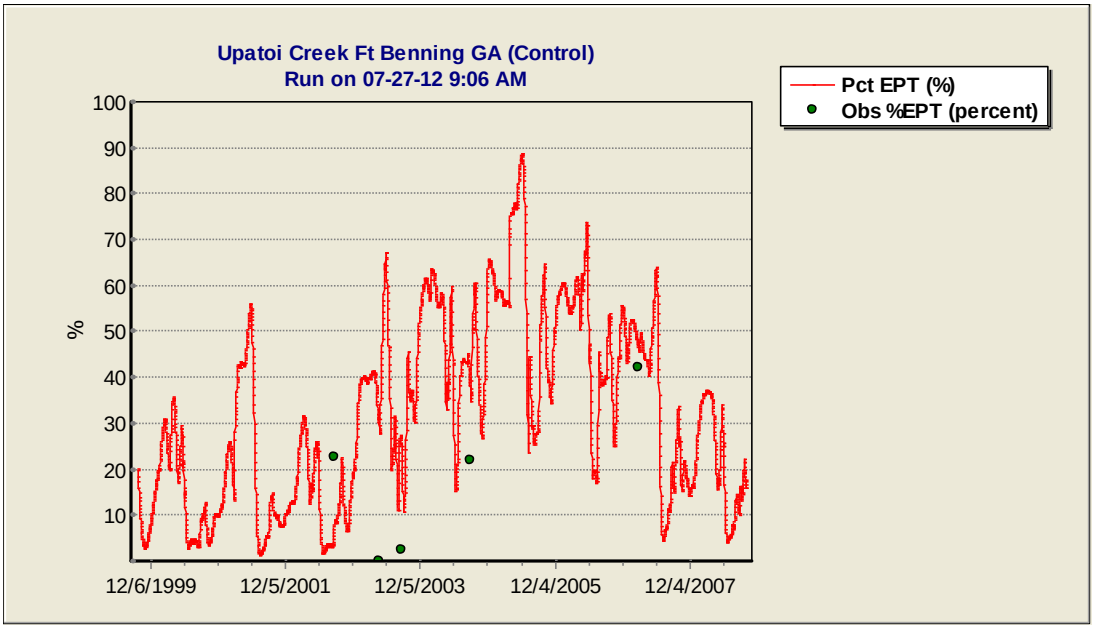

Figure 4.26 Predicted and Observed Percent EPT in Upatoi Creek

Figure 4.27 plots the percentages of each of the "EPT" taxa; the Ephemeroptera (mayflies) that occur in this Subecoregion are tolerant of sedimentation, while the other two groups are intolerant. A plot of all simulated benthic invertebrates shows that chironomids completely

dominate the simulation (Figure 4.28). Perhaps one reason they are so numerous is that they are not affected by high deposition rates, denoted by percent embeddedness.

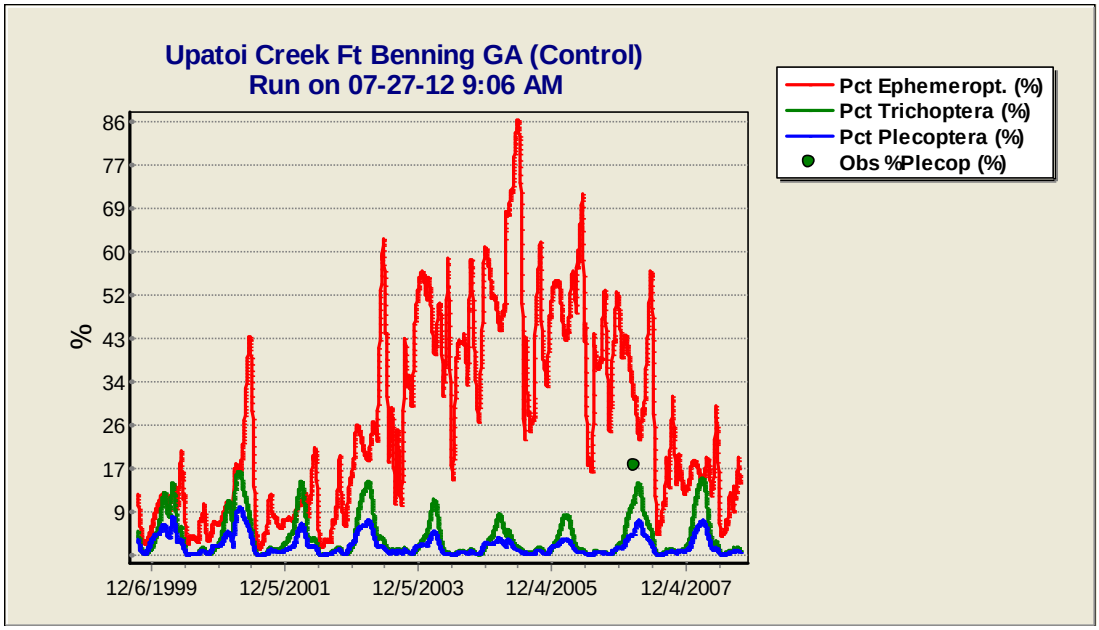

Figure 4.27 Percent of Each of the "EPT" Taxonomic Groups. Percent Plecoptera and Trichoptera are Sensitive to Disturbance in the Sand Hills Subecoregion.

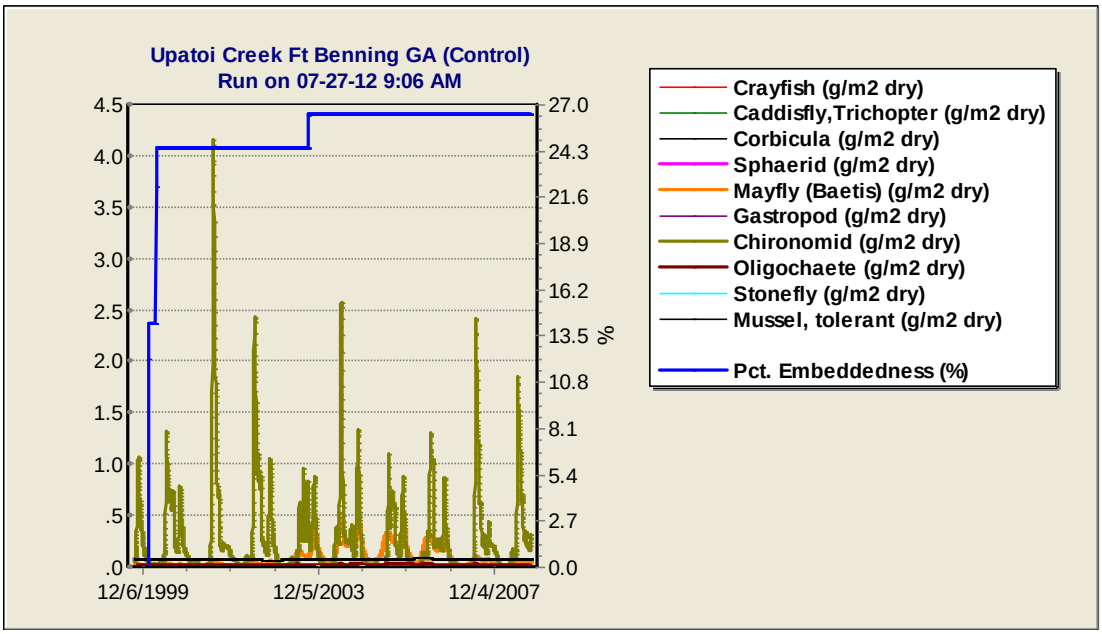

Figure 4.28 Simulated Benthic Invertebrates; note Preponderance of Chironomids. Percent Embeddedness is also Plotted.

The fish (Figure 4.29) reflect the dynamics of the invertebrates—primarily chironomids, which in turn reflect the fluctuations in biomass of algae. Given the TSS levels, which are converted roughly to sedimentation rates and percent embeddedness by the model, Broadstripe shiners are quickly excluded in these particular simulations.

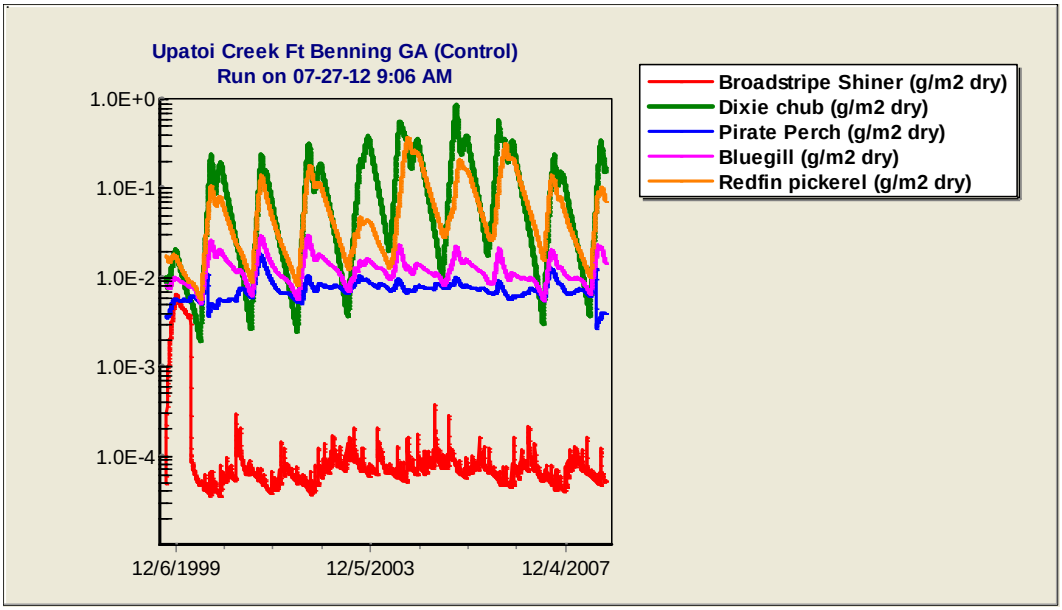

Figure 4.29 Biomass of the Five Fish Species in Baseline Simulation of Upatoi Creek; note Decline of Broadstripe Shiner and Seasonal Dominance of Dixie chub

4.7.6 Sensitivity Analysis

Having calibrated the model for baseline conditions in Upatoi Creek, nominal range and statistical sensitivity analyses were performed as another check on the generality of the calibration. Tornado diagrams provide an intuitive graphical means of interpreting the results of a sensitivity analysis. The parameters and loadings that cause the greatest response in an endpoint are displayed, sorted in decreasing order of sensitivity. Red bars plot results in which the parameter has been reduced by the given percent and blue bars plot results in which the parameter has been increased. The black vertical line in the middle of the blue and red bars represents the baseline model result.

The statistic shown in front of the parameter names is the "sensitivity" statistic which is a normalized average sensitivity for that parameter. If a given parameter was varied by 10% in each direction and the output result also varied by 10% (on average) the "sensitivity" for that parameter/output pairing would be calculated as 100%. Periphytic chlorophyll *a* is seen to increase the most in response to a 10% decrease in temperature (Figure 4.30), suggesting that the dominant algae are experiencing temperatures above their optimum for at least part of the growing season.

A user can also set up an alternative tornado diagram in which the effects of a single parameter change on all tracked outputs can be examined. This was done with TSS; Broadstripe shiner biomass is known to be far more sensitive than any other endpoint so it was excluded. The effects of a +- 10% change in TSS are seen at all trophic levels (Figure 4.31).

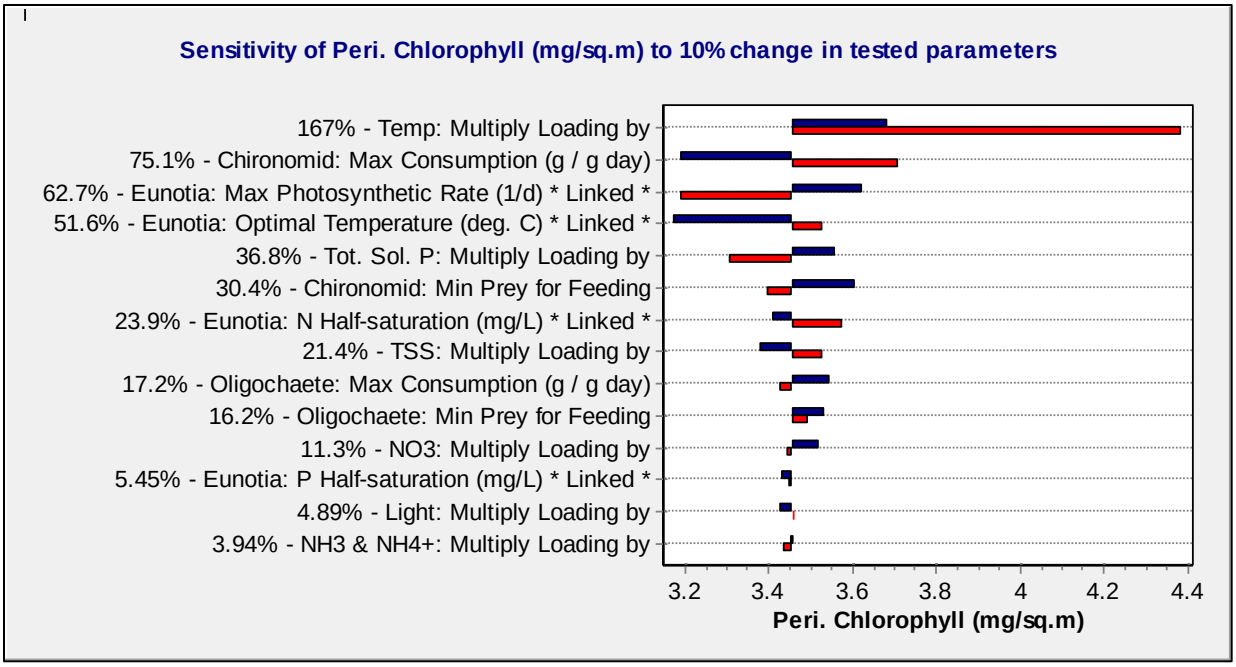

Figure 4.30 Nominal Range Sensitivity Analysis of Periphytic Chlorophyll *a*

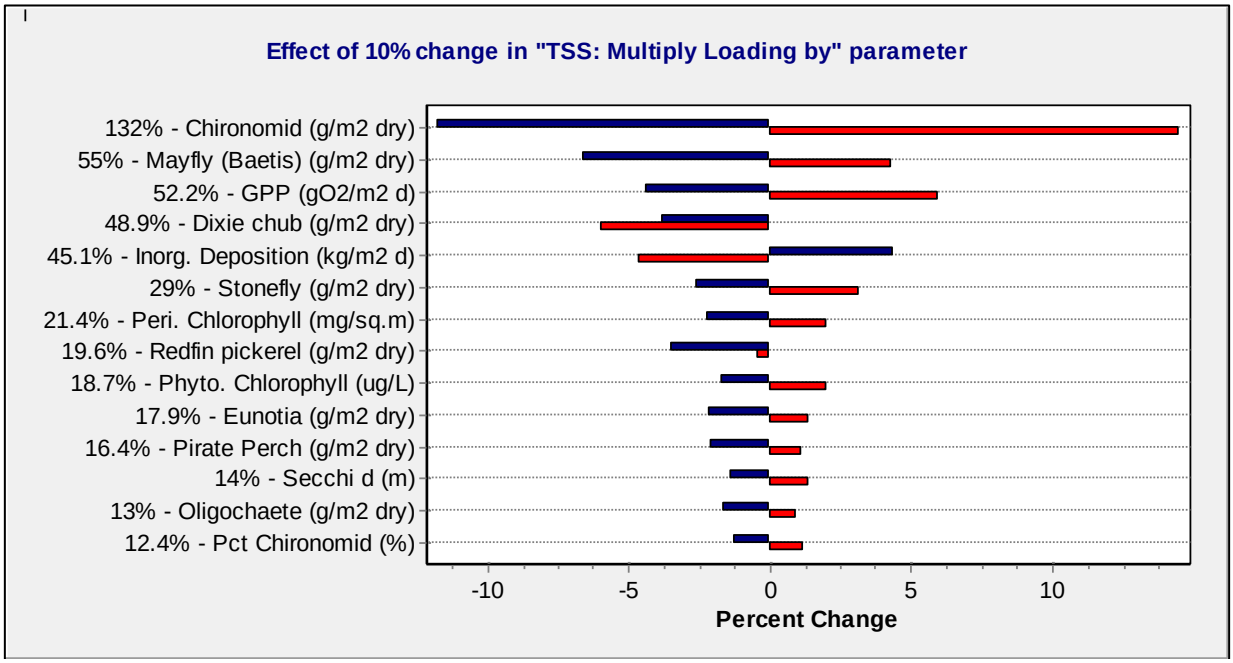

Figure 4.31 A Reverse Tornado Diagram Showing the Effects of Changing TSS on Endpoints Representing all Trophic Levels

Because of the nominal range sensitivities displayed by TSS, statistical sensitivity was also applied. A normal distribution of the TSS loading multiplier was set up (Figure 4.32). The impact of this distribution on *Eunotia* biomass is shown in Figure 4.33.

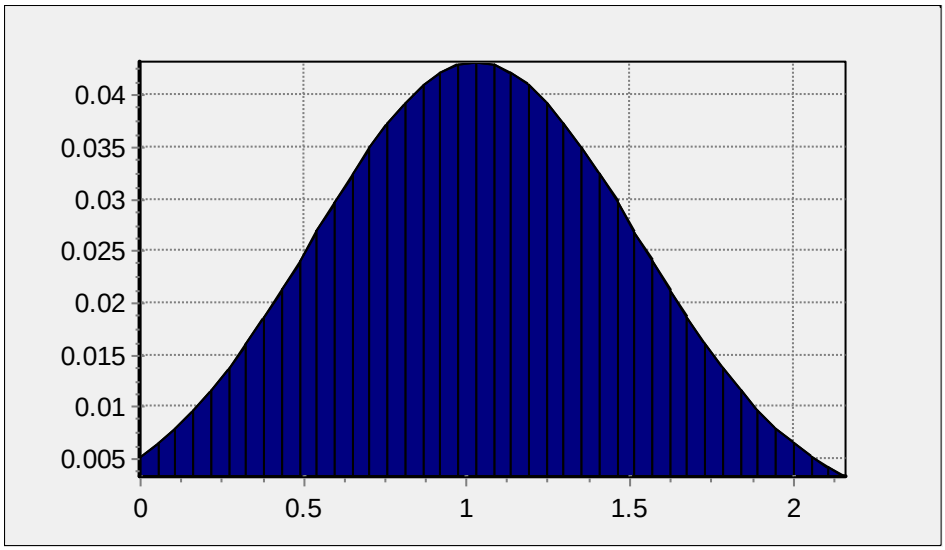

Figure 4.32 TSS Loading Multiplier; mean = 1.0 and std. dev. = 0.5

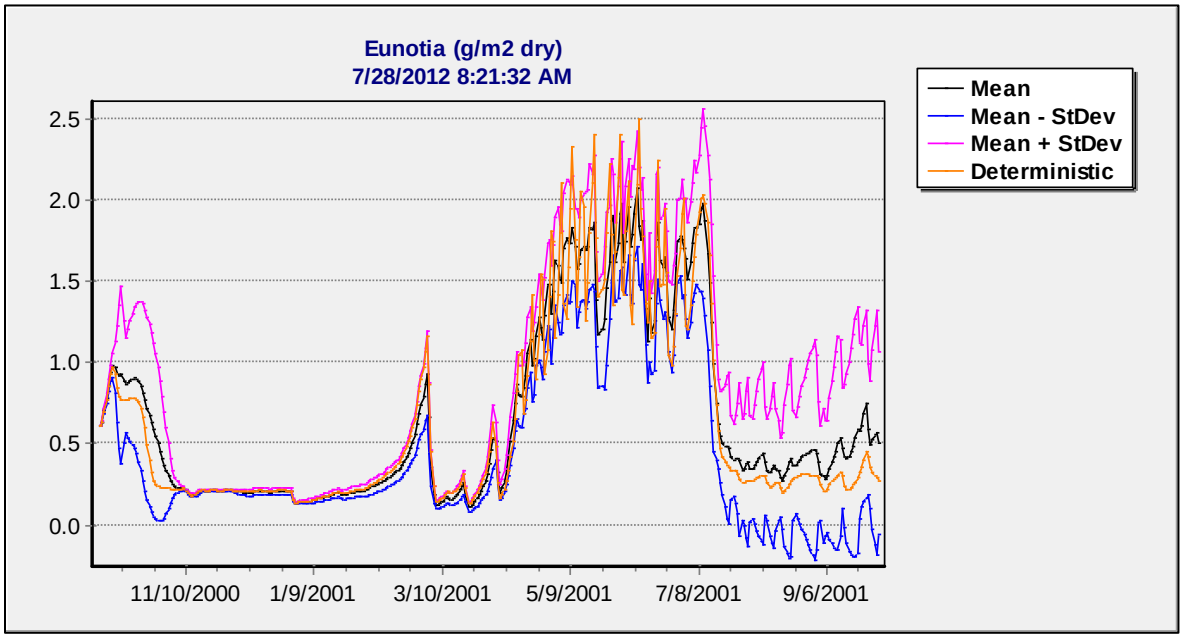

Figure 4.33 Response of *Eunotia* to a Normal Distribution of TSS Loadings

Based on inspection of several tornado and reverse tornado diagrams and several statistical sensitivity diagrams (not shown), the calibration was accepted for application at Fort Benning in conjunction with the enhanced watershed model.

4.7.7 Impact of BRAC Scenario on Aquatic Biota

4.7.7.1 Upatoi Creek

The predicted impact of BRAC land-use scenarios, with increasing acreage of disturbed military areas in the Upatoi Creek watershed is subtle; for instance, it is primarily the short-lived peak concentrations of total suspended solids (TSS) that are affected at McBride Bridge (Figure

4.34). This is not surprising given that, while there is an increase of 3,493 acres of tank trails, heavy maneuver areas, and unpaved roads in the watershed, it is only a 1.6% increase out of 217,420 total acres.

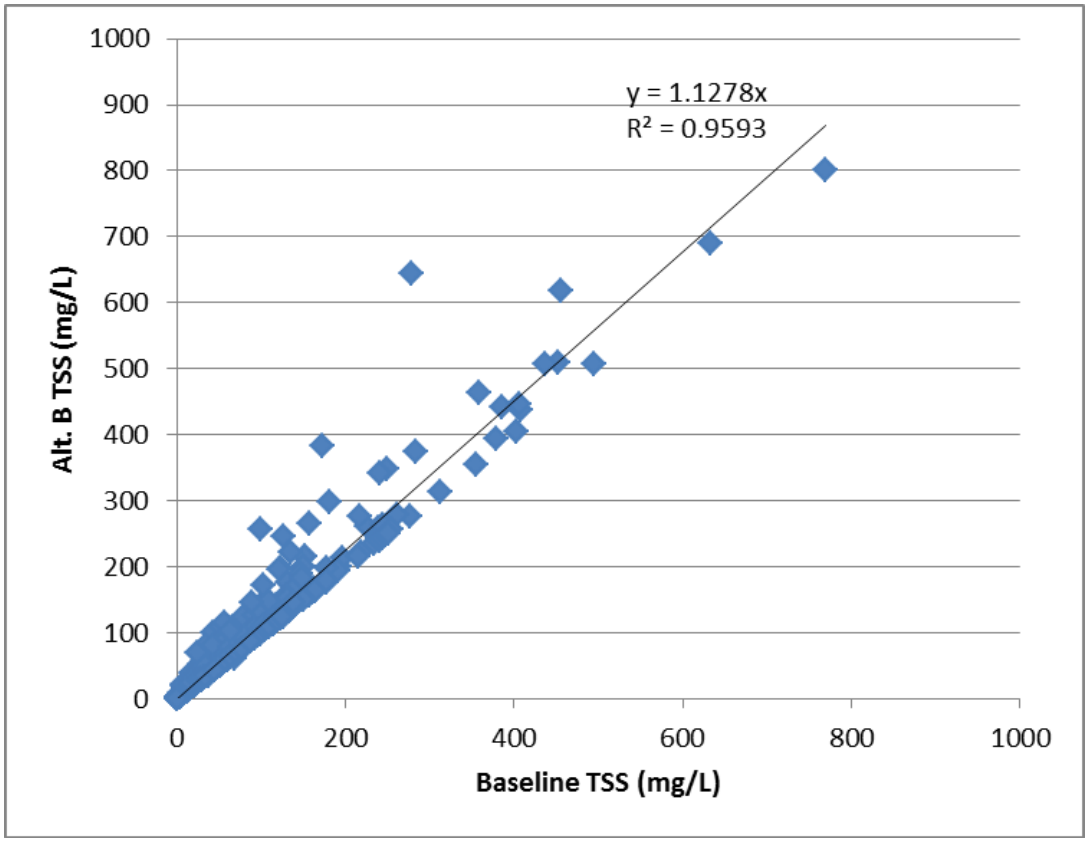

Figure 4.34 Comparison of Total Suspended Solids (TSS) Loading in Baseline Simulation with those in BRAC Scenario, McBride Bridge, Upatoi Creek

The small changes in TSS are reflected in the simulations of the minimal effects of BRAC land-use changes on the aquatic biota. The benthic algae show little change between baseline and perturbed (Figure 4.35) simulations of chlorophyll a. The simulated rates for the dominant alga *Eunotia* are similar for baseline and perturbed conditions (Figure 4.25 and Figure 4.36); although difficult to see, both photosynthesis and predation decline slightly in the perturbed simulation. Likewise, the benthic invertebrates respond similarly in the baseline (Figure 4.28) and perturbed (Figure 4.37) simulations; in the latter, embeddedness increases more quickly and chironomid biomass is less. With only small changes in the forage base, the Dixie chub only exhibit a large difference between baseline and perturbed (BRAC) simulations in one year (Figure 4.38).

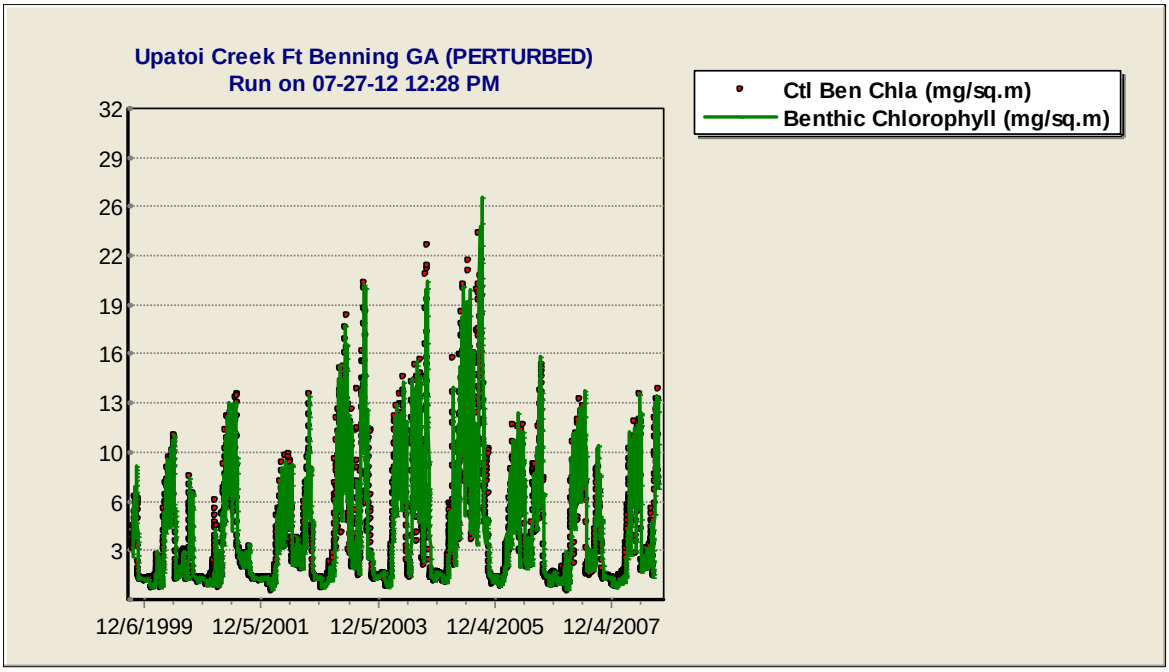

Figure 4.35 Simulated Benthic Chlorophyll *a* in Upatoi Creek with BRAC Land-use Scenario Compared to Baseline (Control) Simulation

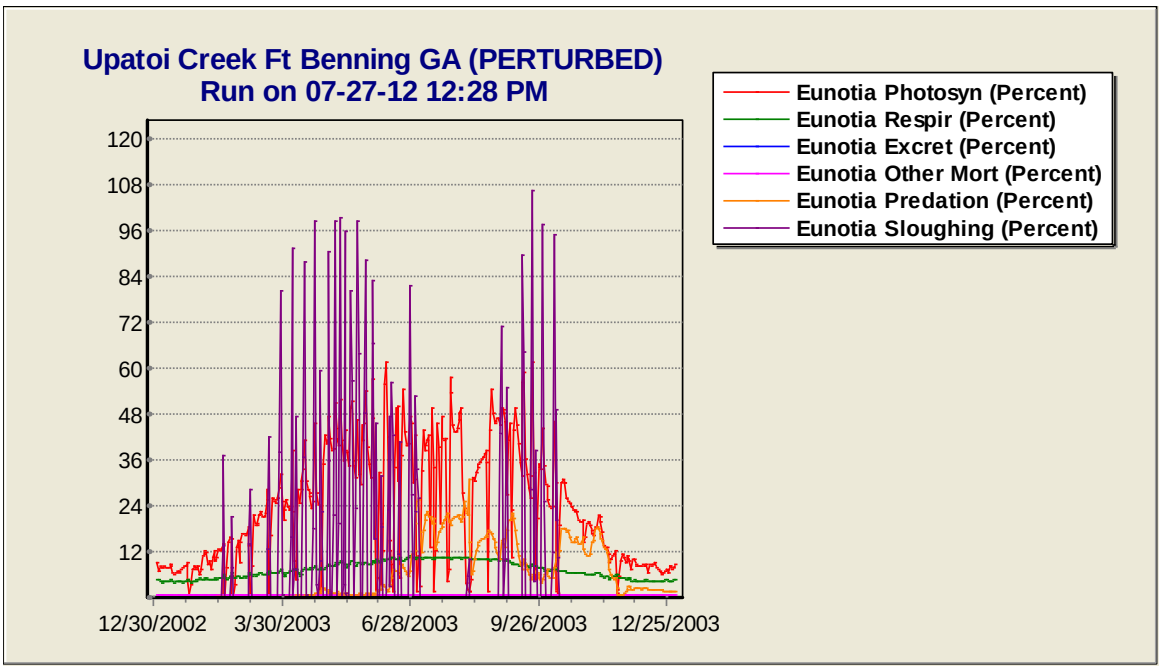

Figure 4.36 Simulated Rates for *Eunotia* at Upatoi Creek with BRAC Land-use Scenario; Compare to Figure 4.25 (Baseline)

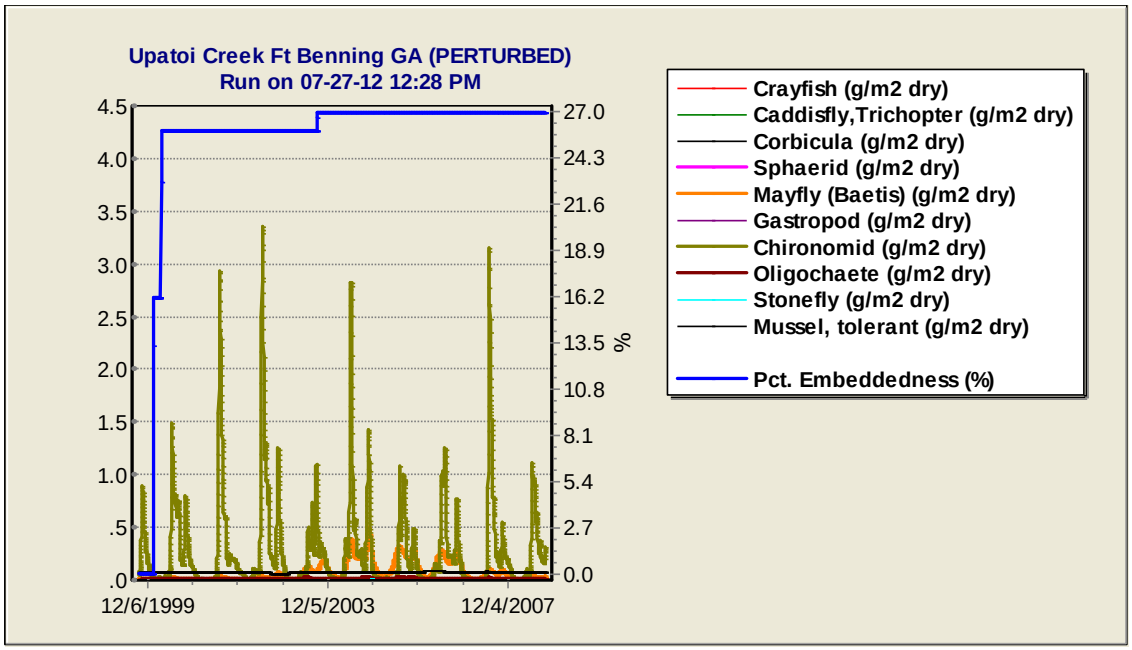

Figure 4.37 Simulated Benthic Invertebrates at Upatoi Creek with BRAC Land-use Scenario; Compare to Figure 4.27 (Baseline)

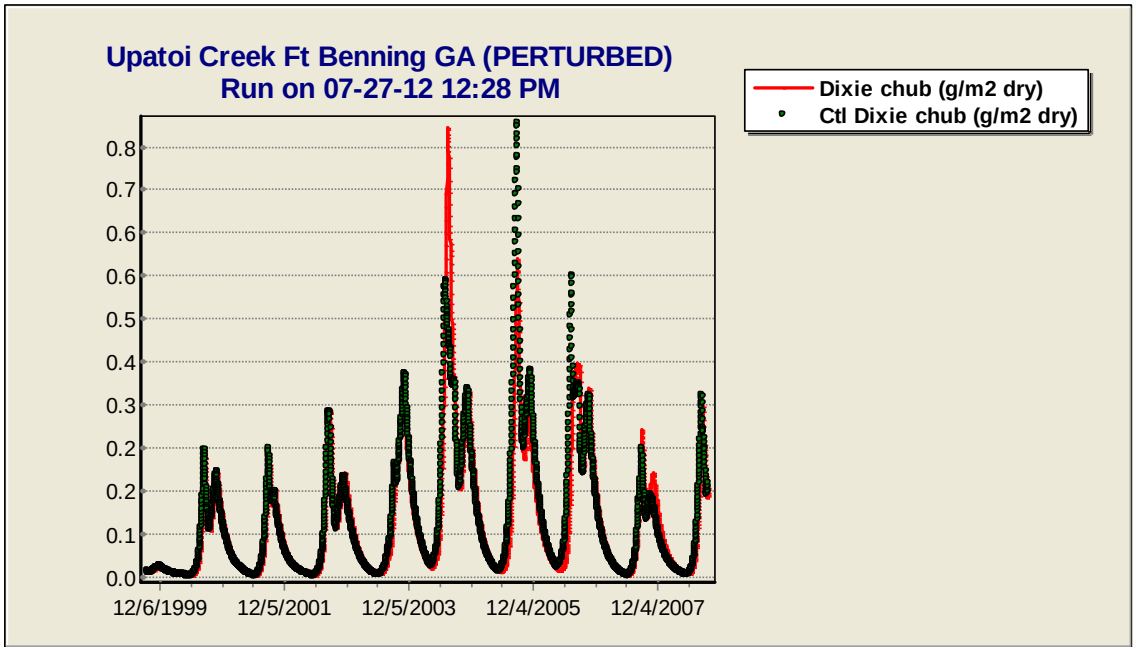

Figure 4.38 Simulated Biomass for Dixie Chub at Upatoi Creek with BRAC Land-use Scenario Compared to Baseline (Control) Simulation

4.7.7.2 Sally Branch

The predicted impact of increasing acreage of disturbed military areas in the Sally Branch watershed is far greater than that predicted for Upatoi Creek at McBride Bridge. At Sally Branch

500 additional acres are affected by the increased military presence (Figure 4.39); that is 8% of the total 6,276 acres.

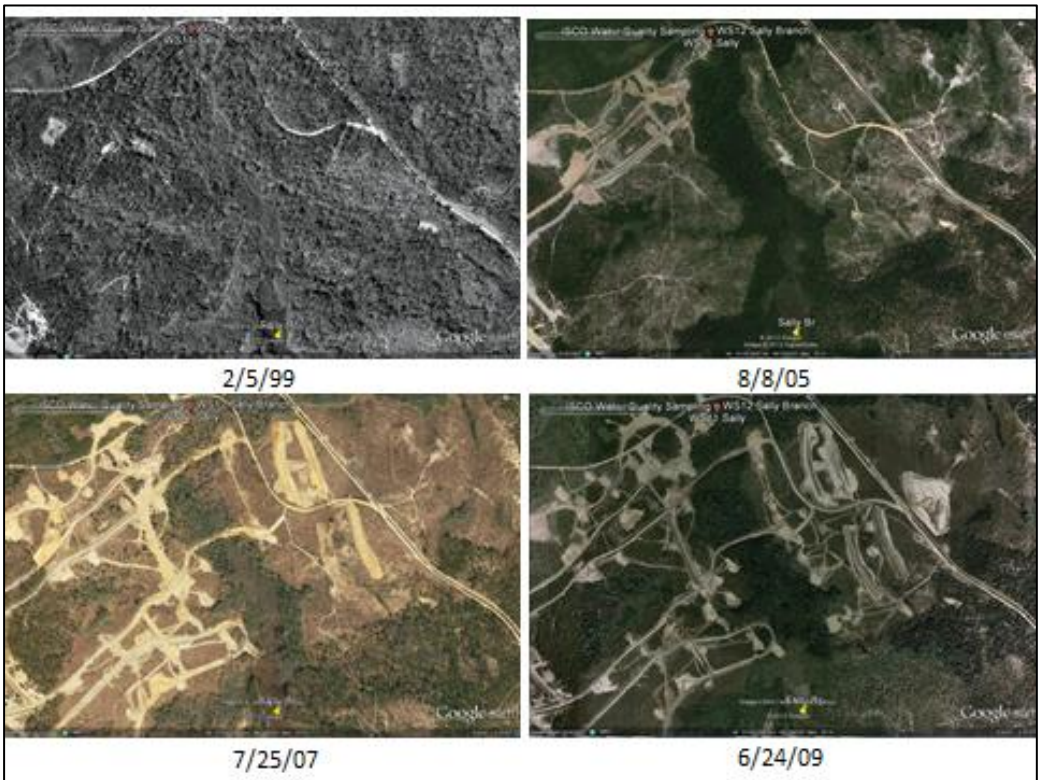

Figure 4.39 Change in Development in Lower Sally Branch Vicinity, Fort Benning, GA (Images taken from Google Earth)

TSS and especially total phosphorus (TP) are affected (Figure 4.40), and those stimulate periphyton growth (Figure 4.41). Field studies led to the same conclusion (Mulholland et al. 2009).

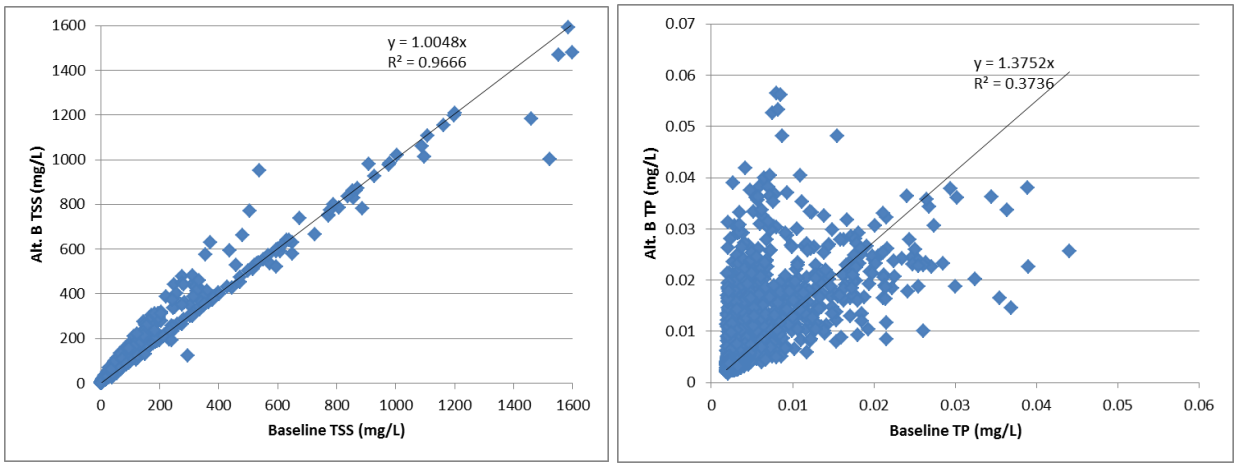

Figure 4.40 Baseline and BRAC Scenario Loadings of TSS and TP in Sally Branch

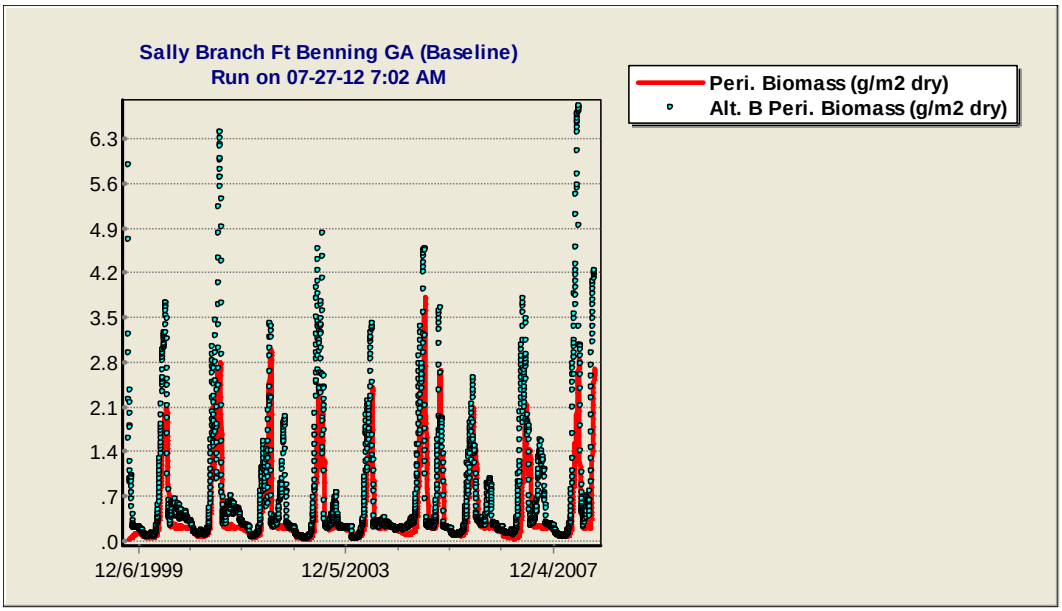

Figure 4.41 Comparison of Baseline and BRAC Simulations of Periphytic Biomass in Lower Sally Branch

The simulations indicate that *Eunotia* was still the dominant alga with increased disturbance, and that too coincides with field results (Mulholland et al. 2009). Simulations also suggest that benthic invertebrates would increase with increased disturbance in the Sally Branch watershed (Figure 4.42), as found in field studies (Mulholland et al. 2009).

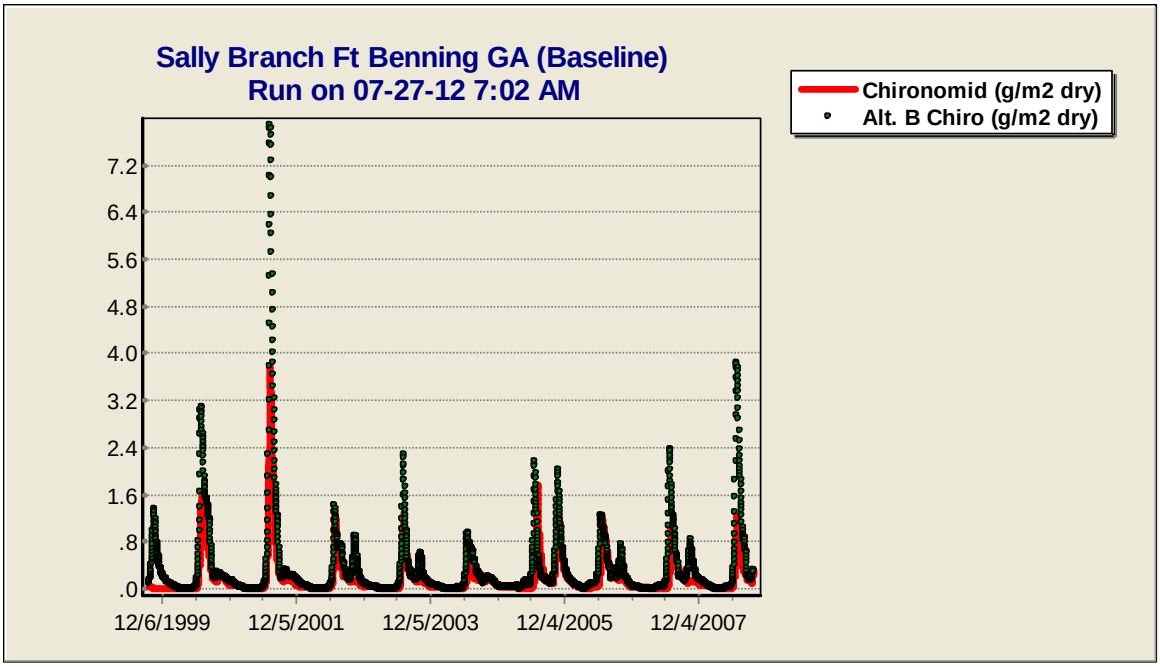

Figure 4.42 Comparison of Baseline and BRAC Simulations of Chironomid Biomass in Lower Sally Branch

As a consequence of the predicted high primary and secondary productivity, the fish biomass is predicted to increase considerably in the Alternative B simulation compared to the baseline

(Figure 4.43). Plecoptera, and to a lesser extent Trichoptera, are predicted to be sensitive to disturbance in the Sally Branch watershed (Figure 4.44).

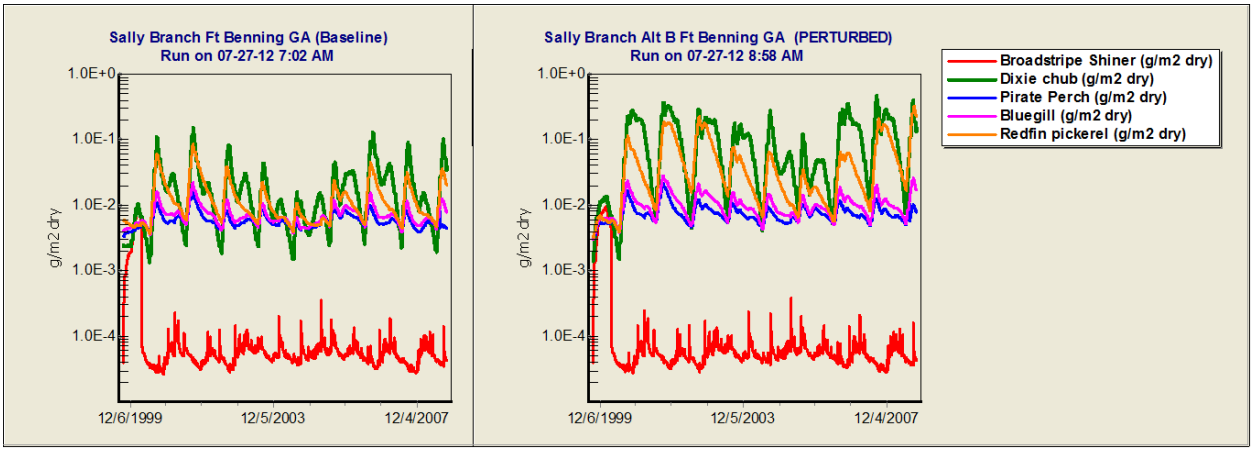

Figure 4.43 Comparison of Baseline and BRAC Simulations of Fish Biomass in Lower Sally Branch

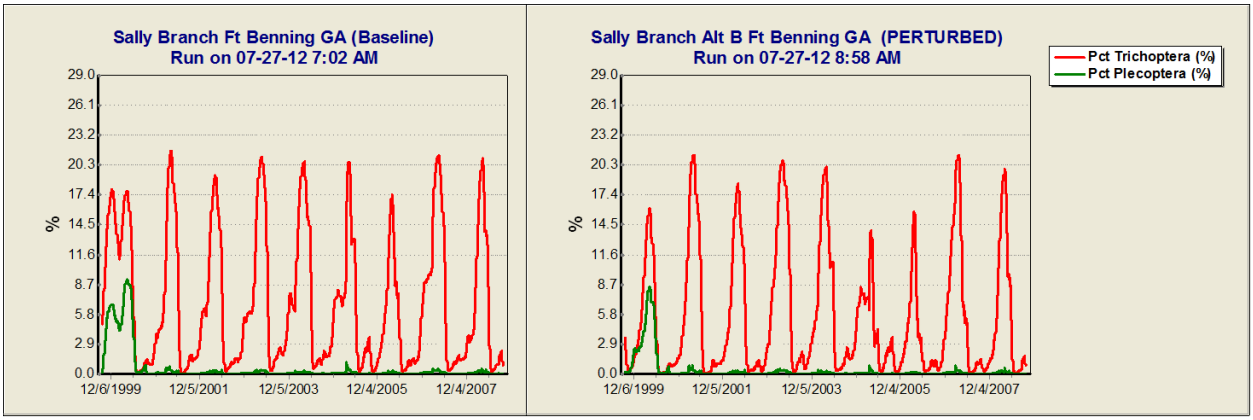

Figure 4.44 Comparison of Baseline and BRAC Simulations of Percent Trichoptera and Plecoptera in Lower Sally Branch

4.7.8 Discussion

AQUATOX was used to analyze the responses of two dissimilar streams to watershed disturbances at Fort Benning, Georgia. The McBride Bridge site on Upatoi Creek drains a large watershed and demonstrated only small changes in the aquatic ecosystem as a result of increased tank trails, heavy maneuver areas, and unpaved roads upstream. Sally Branch, with land-use changes in the immediate watershed, exhibits significant predicted changes in the ecosystem. However, these simulated changes are counterintuitive: one would expect increased sedimentation to decrease productivity. But increased runoff of nutrients stimulates algal growth in the simulation, and this was observed in field studies conducted concurrent with watershed modifications (Mulholland et al. 2009). On the other hand, the large increases in fish biomass under perturbed conditions are not likely and suggest that the fish responses should be calibrated across several stream sites.

This application is intended as a demonstration of the applicability of AQUATOX, including enhanced linkages to the watershed model and the use of endpoints developed specifically for representing watershed disturbances. AQUATOX is an integral part of the BASINS-derived watershed modeling system developed for Fort Benning.

With little additional effort the application of the model to Fort Benning could be improved by calibrating across the other stream reaches where there are biotic field data. The model could also be applied to other military bases—in some cases with minimal changes to existing general calibrations, based on experience in modeling streams in Alabama, Minnesota, and Idaho with the same parameter set.

4.8 GOOD HOPE MANEUVER TRAINING AREA EVALUATION RESULTS

As part of the 2005 BRAC recommendations, a significant portion of the Good Hope Area in the southern portion of the Installation, as shown in Figure 4.45, is now set aside for mechanized training exercises. Fort Benning resource management staff and its contractors conducted an initial evaluation prior to commencement of training exercises within the Good Hope Maneuver Training Area (GHMTA) in an effort to proactively control erosion and sedimentation from the designated training corridors. The study provided conceptual recommendations and a cost estimate to implement best management practices (Parsons, 2012). However, Fort Benning needs a rigorous method to estimate the potential sediment loads to streams to support the

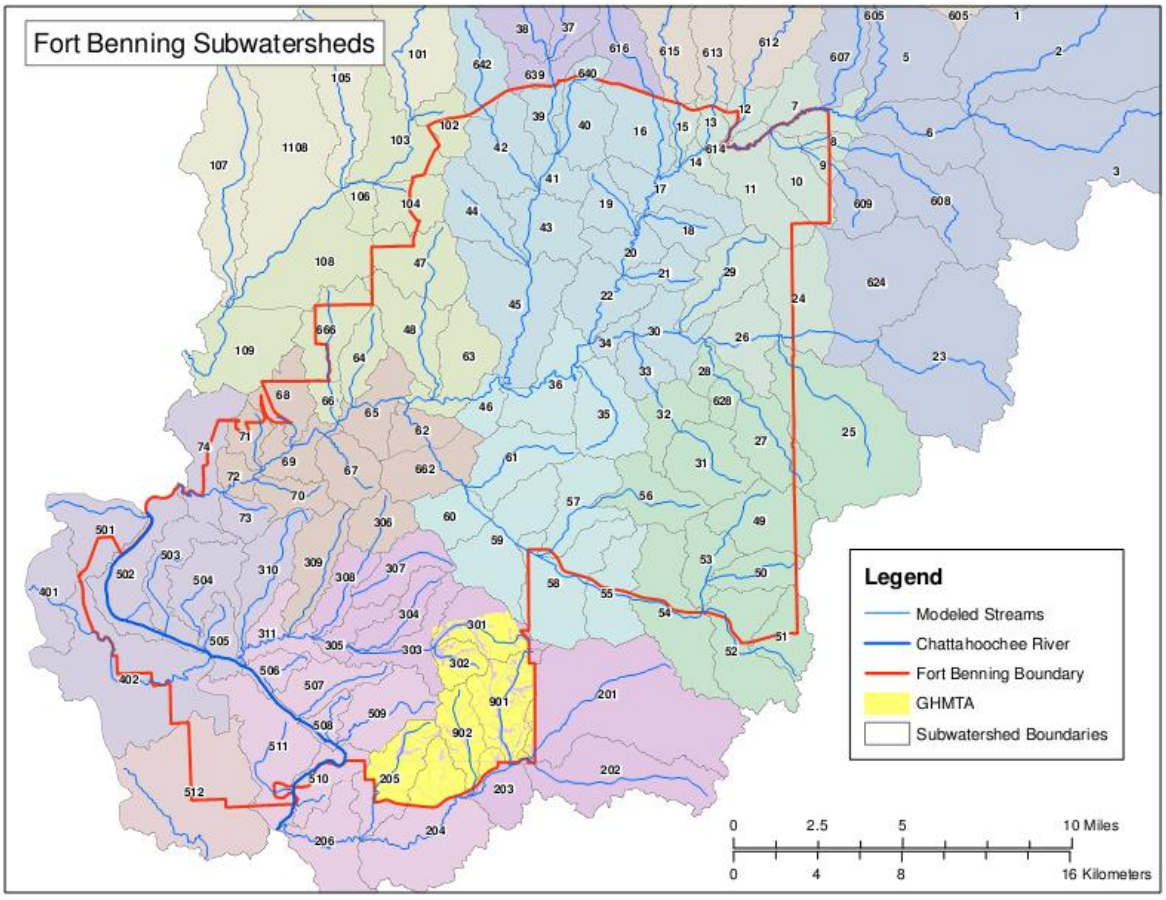

Figure 4.45 Location of Good Hope Maneuver Training Area (GHMTA) within the Domain of the Fort Benning Watershed Model

recommended BMPs and their associated cost. Thus, Fort Benning requested that our project focus on the GHMTA as one of our management alternative evaluations to demonstrate how the FB Enhanced model can be applied to and support a specific management decision process, in this case, to estimate sediments loads from GHMTA without and with BMPs. This section

describes the modeling approach applied, the specific model scenarios developed, the modeling results and potential next steps to further refine and develop the management alternative evaluation.

4.8.1 Overview of Good Hope Area and BRAC Plans

The total GHMTA encompasses 11,200 acres and is considered highly erosive compared to the other areas of the installation because of the occurrence of steep ridges and slopes. Approximately 315 acres outside of the designated wetland and stream buffers are composed of slopes greater than 20 percent. Based upon the GIS information, elevations range from 268 feet mean sea level (MSL) to 524 feet MSL within GHMTA. Slopes less than 20 percent are viewed as highly desirable training areas (Parsons, 2012).

Surface water and runoff within the GHMTA eventually flows to the Chattahoochee River to the west. Approximately 115 acres of the GHMTA consists of wetlands. These wetlands are primarily stream floodplains, small stream swamps, and wooded seepage bogs. Approximately 24 miles of streams are located within the GHMTA. Of the total stream length, approximately 2 miles are perennial, 16 miles are intermittent, and 6 miles are ephemeral. The majority of the project area drains off post into Hichitee Creek, ultimately discharging into the Chattahoochee River with the exception of small portion that drains to the river via Oswichee Creek. The Georgia Environmental Protection Division has assigned a Total Maximum Daily Load (pollutant load limitation) for Hichitee Creek (Parsons, 2012).

Within the maneuver corridors, there are 65 miles of hardened surface trails used to navigate the area. Dirt trails are located off the hardened surface trails leading to the recently constructed low water crossings. Approximately half of the area is forested. The remaining area is open land with some vegetation.

Vehicular training within the GHMTA includes 10 classes per year comprised of 72 students per class in the field for 200 days, traveling 20 to 30 miles per day by way of HUMV, Striker, and M1 Tanks. These training exercises produce a substantial reduction in vegetative cover (Parsons, 2012). Given the high potential for significant sediment transport to local streams and wetlands, the Installation needs an estimate of sediment loads with and without BMPs to justify the costs associated with implementing BMPs.

4.8.2 Modeling Approach

As shown in Figure 4.46, a surface water divide separates subwatersheds that drain to the north into Oswichee Creek and those that drain south into Hichitee Creek. With only a small portion of the maneuver corridors impacting the north-draining subwatersheds, Fort Benning staff recommended that the modeling analyses be restricted to only the subwatersheds that drain south into Hichitee Creek (email from Hugh Westbury dated July 3, 2012). Notice that the stream segments (all perennial) that were modeled are depicted in blue for Figure 4.46.

4.8.2.1 Model Scenarios

While maintaining the original segmentation of the FB Enhanced Model (for land segments and stream reaches), four model scenarios were developed to compare with the Enhanced Baseline Model scenario. These scenarios represented different land use designations and/or the use of BMPs as summarized in Table 4.10. The full description of the Enhanced Baseline model scenario and Alternative B model scenario are presented in the Section 4.0.

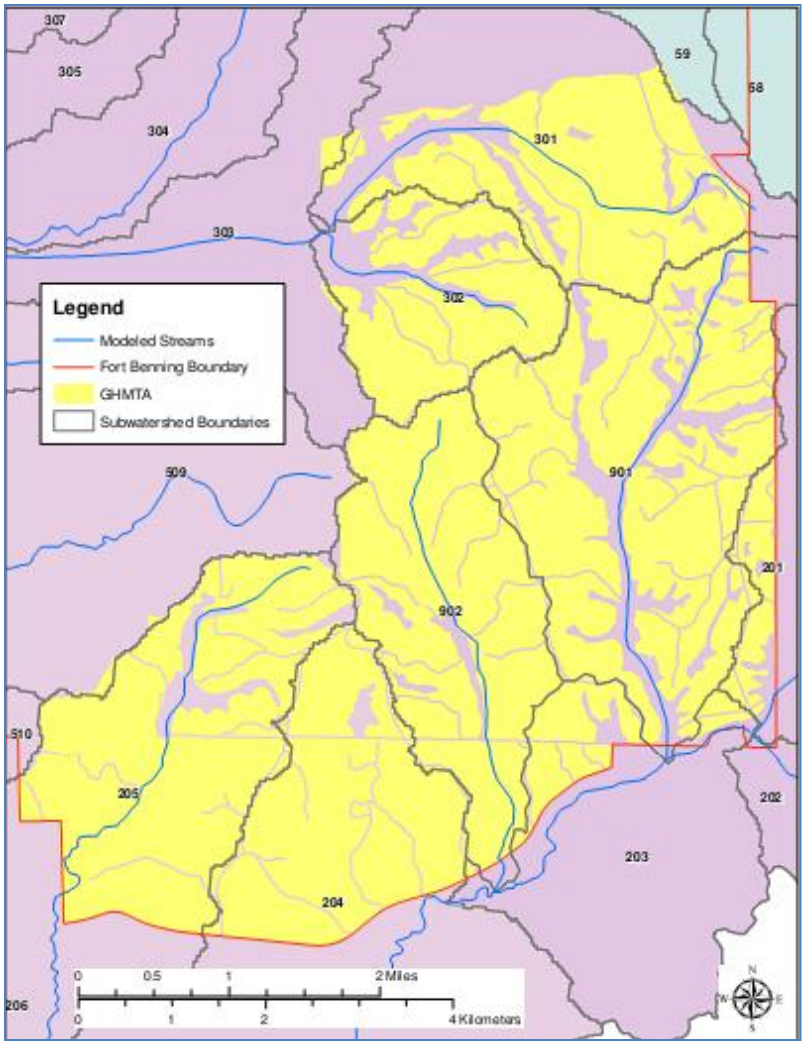

Figure 4.46 Surface Drainage Map of GHMTA with Modeled Stream Reach Segments Shown in Blue

Table 4.10 Summary of Model Scenarios

Scenario	Changes from the Enhanced Baseline Model Scenario
Enhanced Baseline	See Section 4.6 for full description.
Alternative B	Expanded footprint for heavy maneuver areas due to planned 2005 BRAC implementation. Alternative B refers to the alternative presented in the draft EIS (US Army COE, 2007).
Alternative B with BMPs	Alternative B model scenario assuming 75% sediment removal by BMPs associated with the heavy maneuver areas
Current GHMTA	Actual footprint of maneuver corridors as of March 2012 and includes MCoE roads, tank trails, and voluntary buffer areas (GIS files received from Hugh Westbury, March 2012).
Current GHMTA with BMPs	Current GHMTA model scenario assuming 75% sediment removal by BMPs associated with the heavy maneuver areas

4.8.2.2 Land Use Changes

In the Enhanced Baseline model, the GHMTA has unpaved roads as the only designated military land use; the roads comprise approximately 580 acres. Alternative B and Current GHMTA scenarios increased the military land use in the GHMTA to 7,626 acres and 2,138 acres[1], respectively. The land surface in these military land use designations are expected to be denuded after several months of training exercises including areas that were planted for long leaf pine. Below is a description of the land use designations that differentiate the model scenarios. Table 4.11 summarizes the acreage of land use types by model scenario.

Voluntary Buffer - The Georgia Erosion and Sedimentation Act requires that all "state waters" have a 25-foot buffer from the where vegetation has been wrested by normal stream flow. Removal of trees or vegetation from this regulated buffer area is prohibited unless a stream buffer variance is received. A *voluntary buffer*, also known as the training boundary, is a more extensive buffer around sensitive water resources beyond what is required by Georgia law. These voluntary buffers are essentially BMPs themselves and are typically located a minimum of 50 feet from streams and 100 feet from other wetlands. The actual buffer distances vary in the field based on site-specific factors (e.g., steep slopes, sensitive areas).

MCoE Roads/Tank Trails - MCoE roads are tank trails that have been improved with hardened surfaces. They are 25' feet wide with 10' shoulders on each side. There is a surface of 12-18" compacted crusher run stone over an engineered, compacted base. Intersections are concrete. The surface is essentially impervious and the shoulders are covered with grass. For this initial management alternative evaluation MCoE Roads are parameterized similar to tank trails (i.e., without improvements).

Heavy Maneuver Areas (or NEPA Removal Areas) - The original footprint for heavy maneuver areas included the roads and the voluntary buffer areas, which amounted to 3015 acres (Parsons, 2012). A new shapefile was created with roads and voluntary buffer areas removed, to more accurately show the areas of GHMTA that are subject to heavy maneuver training exercises which reduced the NEPA Removal Area footprint to approximately 2000 acres (not including the north-draining area of the GHMTA).

Table 4.11 Acreage of Land Use Types by Model Scenario

Scenario	Unpaved Roads	MCoE Roads/Tank Trails	Heavy Maneuver Areas
Enhanced Baseline	579	0	0
Alternative B	316	0	7,310
Current GHMTA	317	268	1,553

4.8.2.3 BMPs

In the study by Parsons (2012), a wide range of sediment BMPs were recommended, including the following types: sediment basins, berm and swale features, rip-rap lined channels, compost filter socks, rock filter dams, cabled concrete block matting, vegetative cover with surface roughening to protect existing vegetation. In addition, as noted above, the Fort Benning DPW Environmental Division developed a voluntary buffer, or training boundary, around sensitive water resources. These buffers are typically located a minimum of 50 feet from streams and 100 feet from other wetlands (Parsons, 2012).

[1] This acreage does not include the small portion of maneuver corridors in subwatersheds that drain to Oswichee Creek.

To represent an 'effective' mix of BMPs as a model scenario, without refining the model segmentation to model each one explicitly, a **removal efficiency of 75% was assumed** for sediment load reductions from each of the HMAs within the GHMTA. This value of 75% represents a **conservative** reduction level for relatively long buffers and sediment basins, derived from a few recent reviews of buffer performance (e.g., Mankin et al., 2007). In addition, this value is about the mid-to-low range of TSS reduction factors included within the BMP database contained within BASINS/HSPF.

The BMP modeling scenario for the GHMTA was developed by applying the 75% reduction factor to all loads from the HMAs, and the model was run to compare the results with the corresponding results from the EBM run. The reduction factor was **not** applied to the unpaved roads and tank trails on the assumption that different BMPs would likely be applied to those types, and spatial distribution, of sources. (See Section 5.7 for recommendations to consider a finer detailed analysis of the GHMTA area).

4.8.3 Discussion

The resulting land use maps for BRAC Alternative B and the Current GHMTA scenarios are presented as Figure 4.47 and Figure 4.48. The 'blow-up' of the South Maneuver Area in Figure 4.48 shows the finer detail developed by Parsons for locations of the buffers and sediment basins.

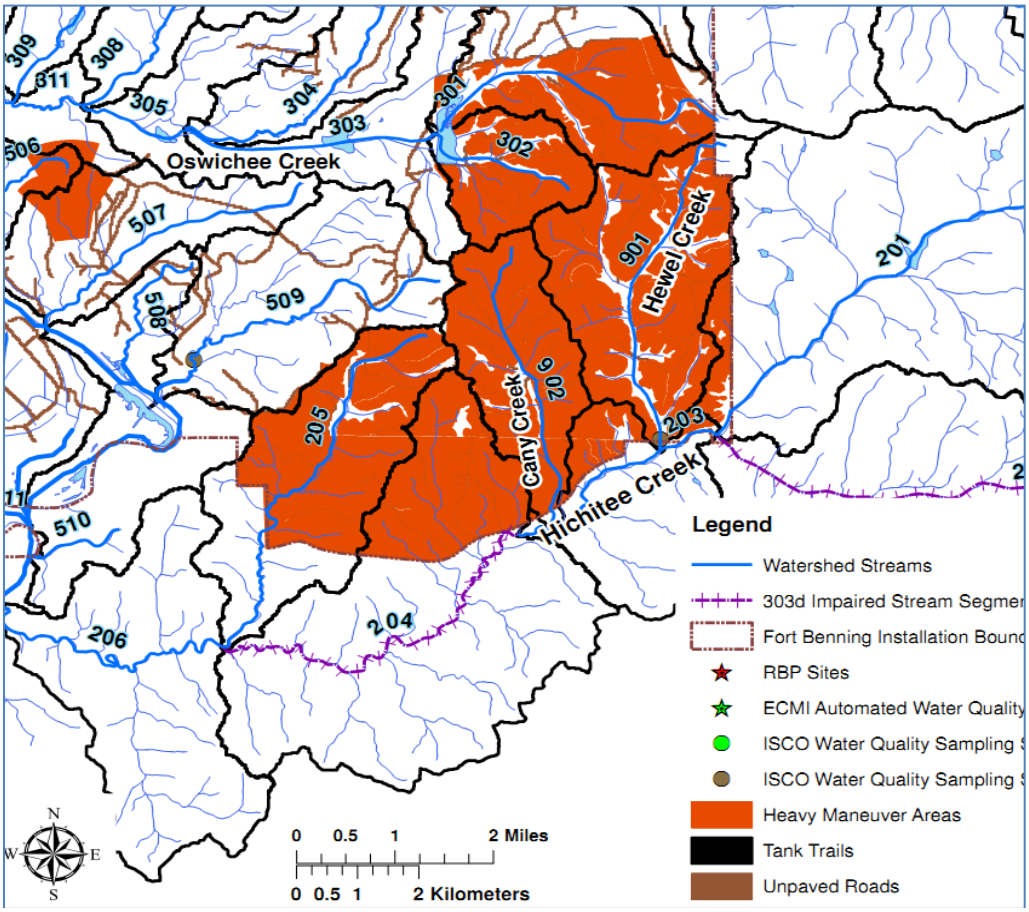

Figure 4.47 Land Use Map for BRAC Alternative B Scenario

Table 4.12 provides the model results for sediment loadings and the percent of those loads from military land use contributions for each of the model scenarios at the reporting locations depicted in Figure 4.48. As noted above, the 'Military Contribution' shown in Table 4.12 represents the sediment load from the three military land uses of HMAs, tank trails, and unpaved roads.

These modeling scenario results clearly indicate the extend of sediment load increases that the BRAC (Alt B) would produce, and the subsequent lower levels that would result from the current GHMTA plan, along with the potential BMP impacts. Review of these results indicates the following:

a. Sediment loads dramatically increase under BRAC (Alt B) but are then also dramatically decreased by the GHMTA restricted NEPA removal areas, indicating the benefits of restricting the extent of the HMAs.

b. Although BMPs show a significant reduction, when the entire area is HMA as under the BRAC (Alt B), the sediment load is still dominated by the military use, representing 92% to 99% for the individual subwatersheds, and 64% at the Hichitee Creek outlet to the Chattahoochee River.

c. At the Hichitee Creek outlet to the Chattahoochee, the GHMTA with BMPS comes close to the original Baseline Condition loads (i.e., 2288 tons/yr versus 1924 tons/yr), indicating that BMPs can help to offset the military impacts.

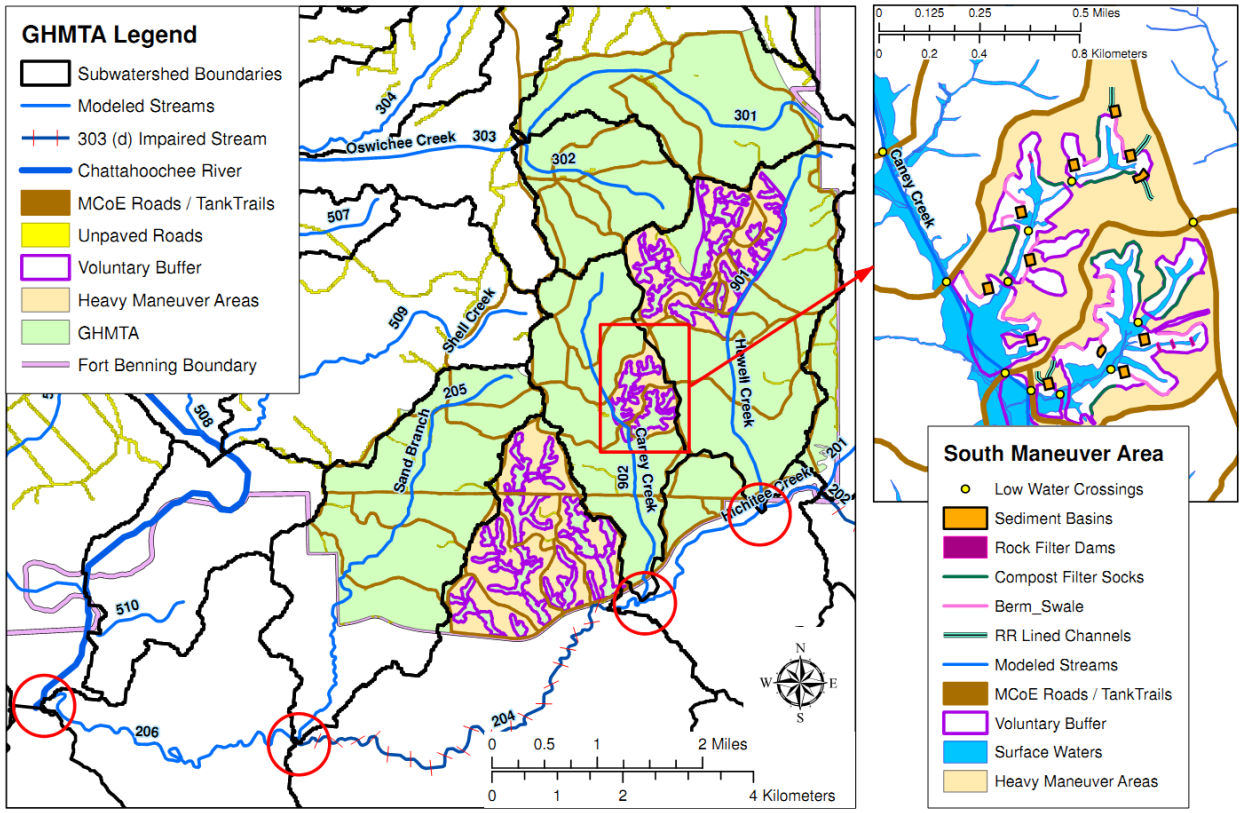

Figure 4.48 Land Use Map for Current GHMTA Scenario with Reporting Locations for Model Results, and Blow-Up of South Maneuver Area

Table 4.12 Total Sediment Loadings per Model Scenario and Percent of Load from Military Land Use Contributions

	R-901 Hewel Creek		R-902 Caney Creek		R: 205 Sand Branch		R:206 Hichitee Creek	
	Sediment Loading (t/yr)	Miltary Contribution (%)	Sediment Loading (t/yr)	Miltary Contribution (%)	Sediment Loading (t/yr)	Miltary Contribution (%)	Sediment Loading (t/yr)	Miltary Contribution (%)
Enhanced Baseline	284	65	183	61	286	37	1924	24
Alternative B	2571	99	1877	100	2177	98	7625	86
AtIternative B with BMPs	743	97	530	99	708	92	3124	64
GHMTA	845	89	349	82	322	49	3183	59
GHMTA with BMPs	444	78	234	72	313	48	2288	39

d. Although Sand Branch (Reach 205), shows very little HMAs in Figure 4.48, it shows a significant military contribution because the loads are derived mostly from unpaved roads and tank trails.

e. The locations of the HMA boxes also impact the numbers in Table 4.12. For Hewell Creek (Reach 901) and Caney Creek (Reach 902), the maneuver boxes are located midway or higher in the subwatershed; thus their loads must travel some distance before reaching the outlets where the loads are tabulated. This allows for deposition of some of the load, and subsequent dilution of concentrations, and thereby their impacts may be reduced compared to the edge of the maneuver box. Thus, one of our recommendations for further analyses is to perform a finer discretization of the stream reaches and their local drainage areas for a more detailed and resolute analysis. Furthermore, the largest maneuver box drains to Reach 204, but in our analysis that load only shows up in the results for the Hichitee Creek outlet. The impacts of sediment loads from that maneuver box are likely greater in Reach 204, and should be analyzed in that reach.

Sediment/TSS concentrations are more commonly used to supplement sediment loads for analyses of aquatic impacts. Shown in Figure 4.49 for the reporting location on Reach 901, the Installation's easternmost confluence with Hichitee Creek, are simulated concentrations of total suspended solids (TSS) over the calibration period for the Alternative B Scenario with and without BMPs. The hydrograph is shown in the upper (auxiliary) scale for comparison. Mean peak TSS without BMPs is 487 mg/l and with BMPs is 187 mg/l, accounting for a 62% reduction of TSS.

The recommended water quality criteria (National Academy of Sciences and National Academy of Engineering for the EPA, 1972), establish the following guidelines for maximum TSS concentration values that assure subjective levels of protection for aquatic communities:

- High level of protection: 25 mg/l
- Moderate protection: 80 mg/l
- Low level of protection: 400 mg/l
- Very low level of protection over 400 mg/l

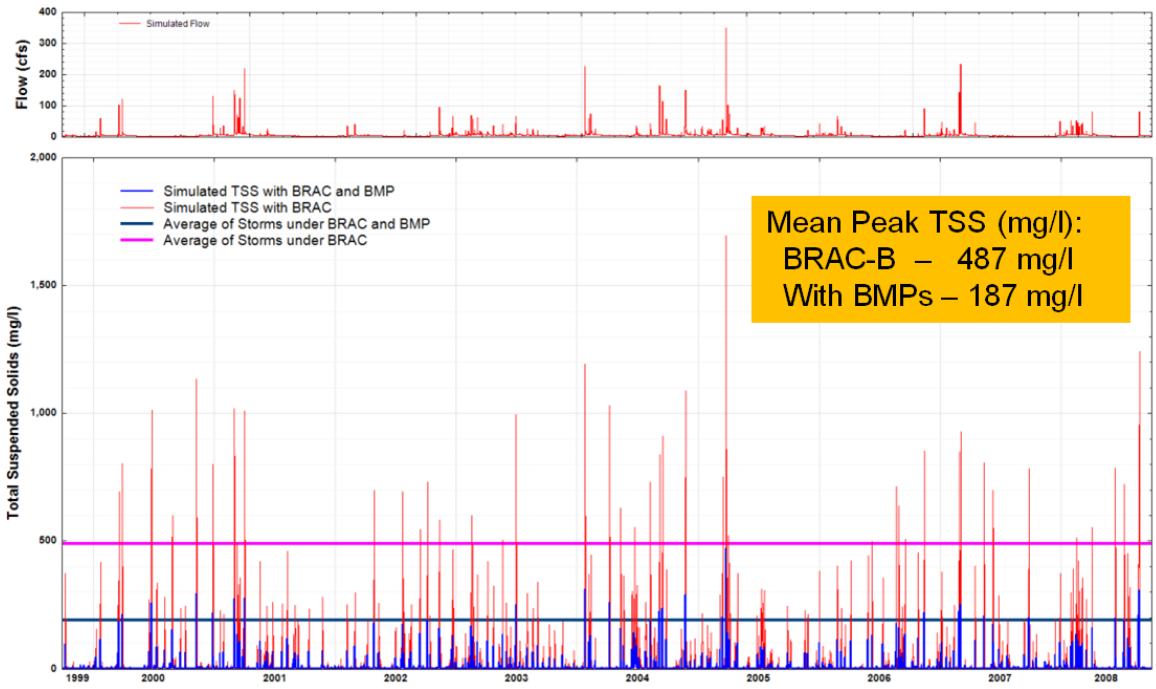

Figure 4.49 Alternative B BMP Impacts on TSS Concentrations (Reach 901)

These TSS guidelines for protection of aquatic communities provide a relative framework for interpreting the TSS concentrations resulting from the model simulations. The mean peak TSS concentration with BMPs corresponds closest to a moderate, and not quite a low, level of protection for aquatic communities in Hichitee Creek. A more in-depth analysis using AQUATOX and the full range and occurrence of TSS concentrations could provide added definition to these potential impacts.

Figure 4.50 and Figure 4.51 present simulated TSS concentrations for the Current GHMTA Scenario at Reaches 901 and 206. These reporting locations provide a representative range of mean peak TSS concentrations across the drainage area from east to west. The mean peak TSS concentrations for the Current GHMTA without BMPs range from 250 mg/l at the reporting location for Reach 901 to 199 mg/l at the reporting location for Reach 206. With BMPs, mean peak TSS concentrations ranges from 198 mg/l to 146 mg/l between Reaches 901 and 206. The percent reduction between mean peak concentrations with and without BMPs varies at these two reporting locations from 62% and 111%.

To fully examine the variation in the reduction of the mean peak TSS also requires a finer discretization of the streams segments than what was used for this proof-of-principle management alternative evaluation. Increasing discretization allows for a more in-depth understanding of the dynamics of sediment loads and concentrations along the length of Hichitee Creek, thus giving more definition to suggest potential causes and effects.

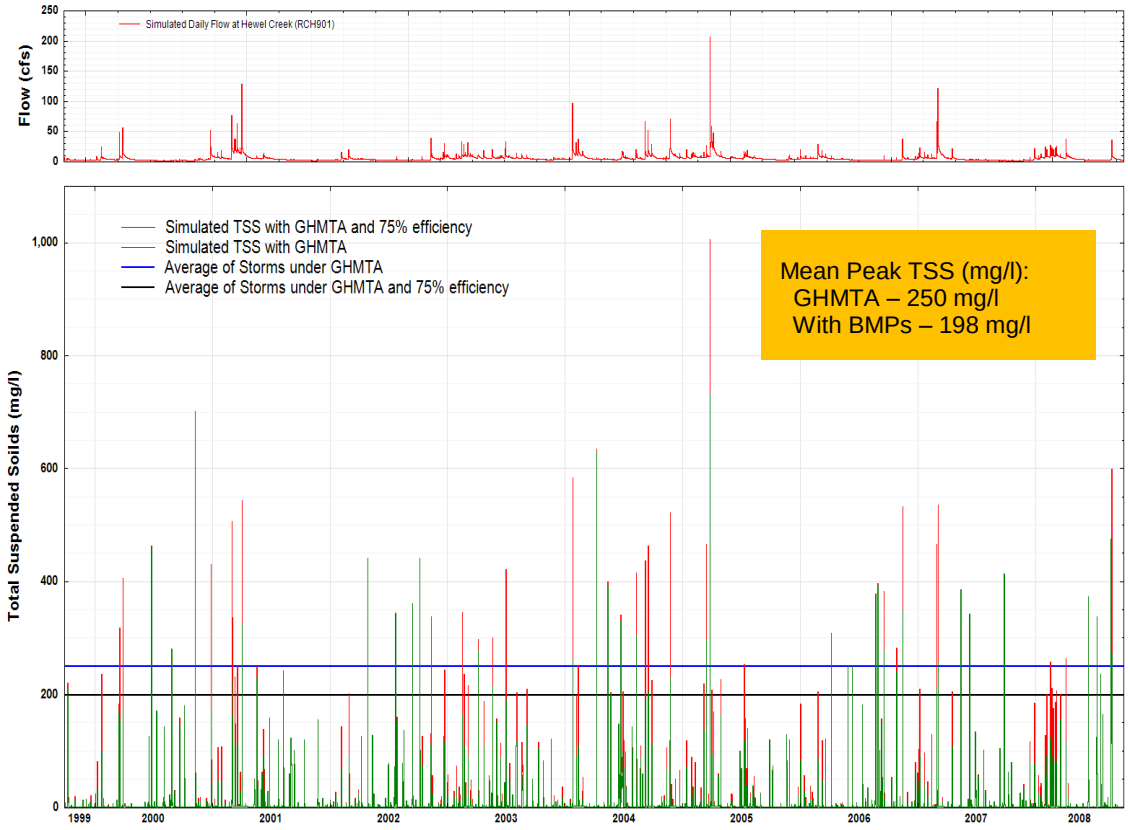

Figure 4.50 Current GHMTA BMP Impacts on TSS Concentrations (Reach 901)

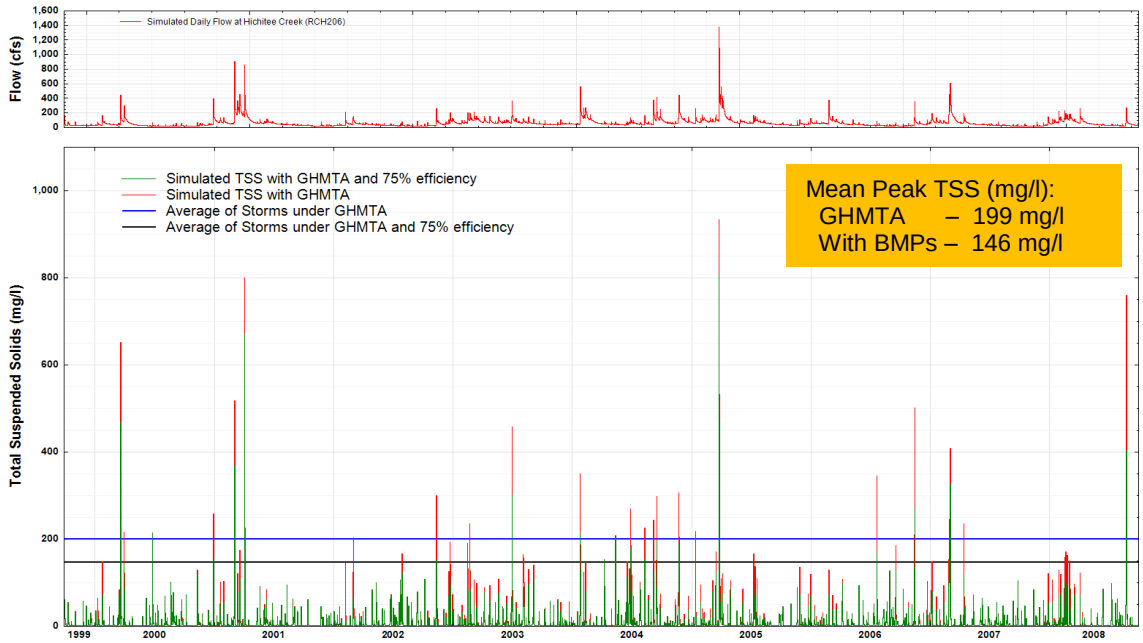

Figure 4.51 Current GHMTA BMP Impacts on TSS Concentrations (Reach 206)

4.8.4 Sensitivity Analyses of Land Use/Management Scenarios

An assessment of the Good Hope Mechanized Training Area (GHMTA) was conducted to evaluate the potential impacts of implementation of best management practices (BMPs) to reduce the expected sediment loads from an expansion of the heavy maneuver areas (HMAs). As part of the 2005 BRAC recommendations, a significant portion of the Good Hope Area in the southern portion of the Installation, shown earlier in Figure 4.47, is now set aside for mechanized training exercises. A study by Parsons (2012) produced a BMP plan to offset the expected increase in sediment loads but the Installation was in need of an analysis to help quantify the performance of the plan. Figure 4.48 showed the map of the Parsons plan for buffer areas and sediment basins to mitigate the HMA training impacts; for convenience that map is also shown as Figure 4.52.

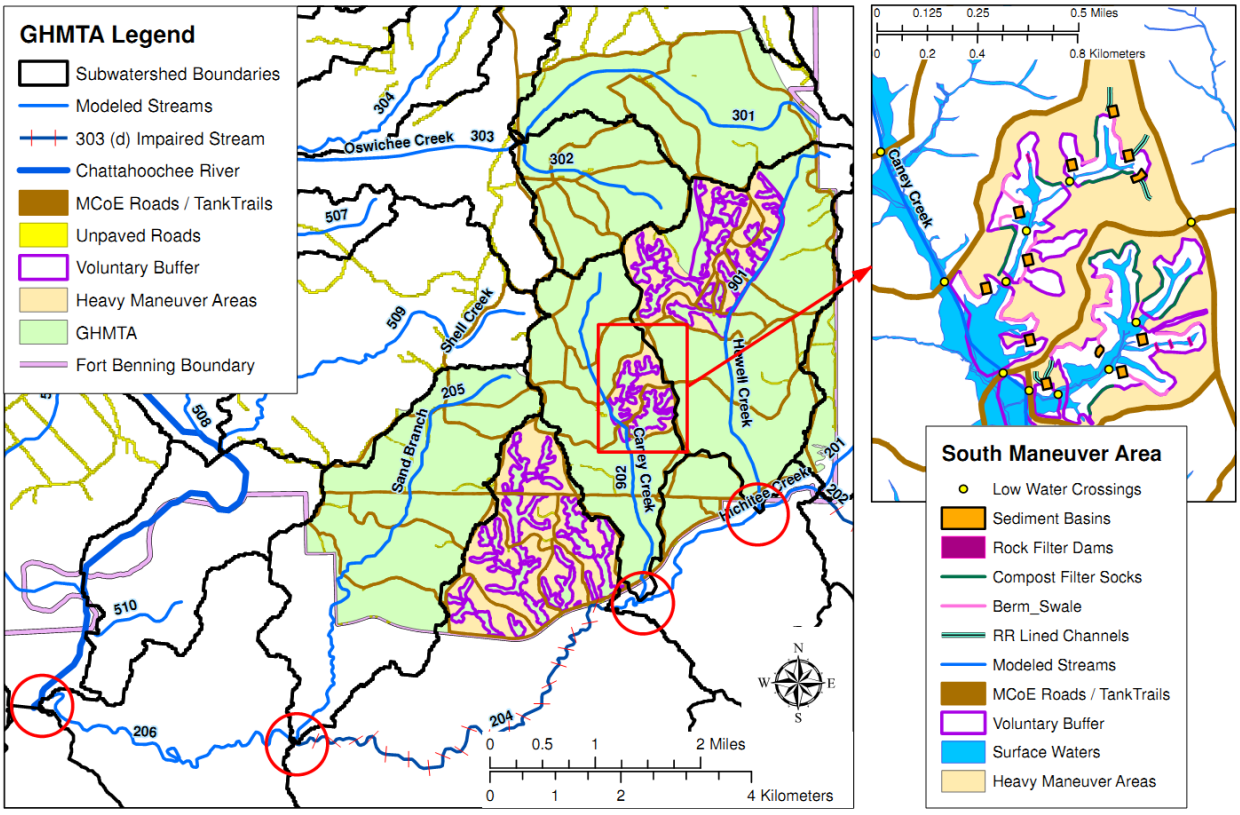

Figure 4.52 Land Use Map for Current GHMTA Scenario with Reporting Locations for Model Results, and Blow-Up of South Maneuver Area

Sensitivity analyses were conducted by running the GHMTA BMP scenario with an increased removal efficiency to evaluate the impacts of the higher removal on the sediment loads and concentrations from the GHMTA. In Section 5 we assumed a relatively conservative removal efficiency of 75% for the 50 feet to 100 feet buffers, whereas in this analysis we increased the removal efficiency to 95%, which is relatively high but not an unreasonable value for long forested/grass/shrub buffer strips. Table 4.13 shows the results for the previous scenarios along with the 95% removal efficiency scenario.

Table 4.13 GHMTA Sediment Loadings by Model Scenario Including 75% and 95% BMP Removal Efficiencies

	R:901 Hewel Creek		R:902 Caney Creek		R:205 Sand Branch		R:206 Hichitee Creek	
	Sediment Loading (t/yr)	Military Contribution (%)	Sediment Loading (t/yr)	Military Contribution (%)	Sediment Loading (t/yr)	Military Contribution (%)	Sediment Loading (t/yr)	Military Contribution (%)
Enhanced Baseline	284	65	183	61	286	37	1924	24
Alternative B	2571	99	1877	100	2177	98	7625	86
Atlternative B _BMP	743	97	530	99	708	92	3124	64
GHMTA	845	89	349	82	322	49	3183	59
GHMTA_BMP_75	444	78	234	72	313	48	2288	39
GHMTA_BMP_95	295	70	192	66	310	47	1917	29

The conclusions stated in previous section also apply here, but the higher removal efficiency produces sediment loads that are closer to the Enhanced Baseline scenario; that scenario represents the pre-construction/pre-BRAC/pre-development condition, i.e., prior to the increased training in the GHMTA area. Note that both the total sediment loadings, and the percent military contributions, are very close to the Enhanced Baseline condition, indicating that a well-designed and well-sited BMP plan can successfully mitigate much, if not most, of the sediment load predicted to be generated by the increased training regimen expected under BRAC in the GHMTA. For example, the total sediment load for Hichitee Creek under Enhanced Baseline is estimated at 1,924 tons/acre/year whereas the corresponding load with 95% removal BMPs is actually slightly less, at 1,917 tons/acre/year. These numbers are actually equivalent with respect to the expected accuracy of the modeling effort. At the other sites, the numbers show a slight increase of the 95% scenario versus the Enhanced Baseline, but the impacts are essentially comparable and reinforce the conclusion that the BMP might be able to offset the expected increased sediment loads.

The scenario and sensitivity results can also be assessed in terms of changes in sediment concentrations under the increased 95% removal scenario. Figure 4.53 shows the nine-year simulation of daily flow and sediment concentrations at Hewell Creek (Reach 901) under each of the three GHMTA scenarios. The red lines represent the GHMTA with the increased HMAs, the green line imposes the 75% BMP scenario, and the blue line represents the 95% removal scenario. For many days (i.e., storm events), the blue (95% removal) line is on top of the other lines, all of which have essentially the same values, i.e., no significant impact, and so the blue line is more evident than the others. However, the mean concentrations for each scenario are also listed in the legend, and shows that the mean sediment concentrations are reduced from 241 mg/l to 202 mg/l to 190 mg/l, for the three scenarios, from the GHMTA scenario to the 75% removal, and then the 95% removal scenario.

Figure 4.54 shows the lines more clearly as it is a blow-up for the 2005 year. For the major storm in March 2005, the highest concentrations are for the GHMTA at about 1,000 mg/l; this is reduced to about 750 mg/l, or 25%, for the 75% removal scenario, and then to about 600 mg/l, or almost 40%, for the 955 removal scenario. These results clearly show both the relative and absolute results for the scenario runs, from this analysis of the sensitivity of the model results to the BMP assumptions and removal efficiencies. The spatial scales in this analysis range from the subwatershed level where the HMAs have the largest impacts, when they occupy a large percentage of the subwatershed area, to the watershed scale at the size of Hichitee Creek, which drains directly to the Chattahoochee River. As recommended in Section 5, a further refinement of the model segmentation, with smaller stream reaches with endpoints adjacent to the HMAs would allow for a more detailed analysis and assessment of more local scale impacts.

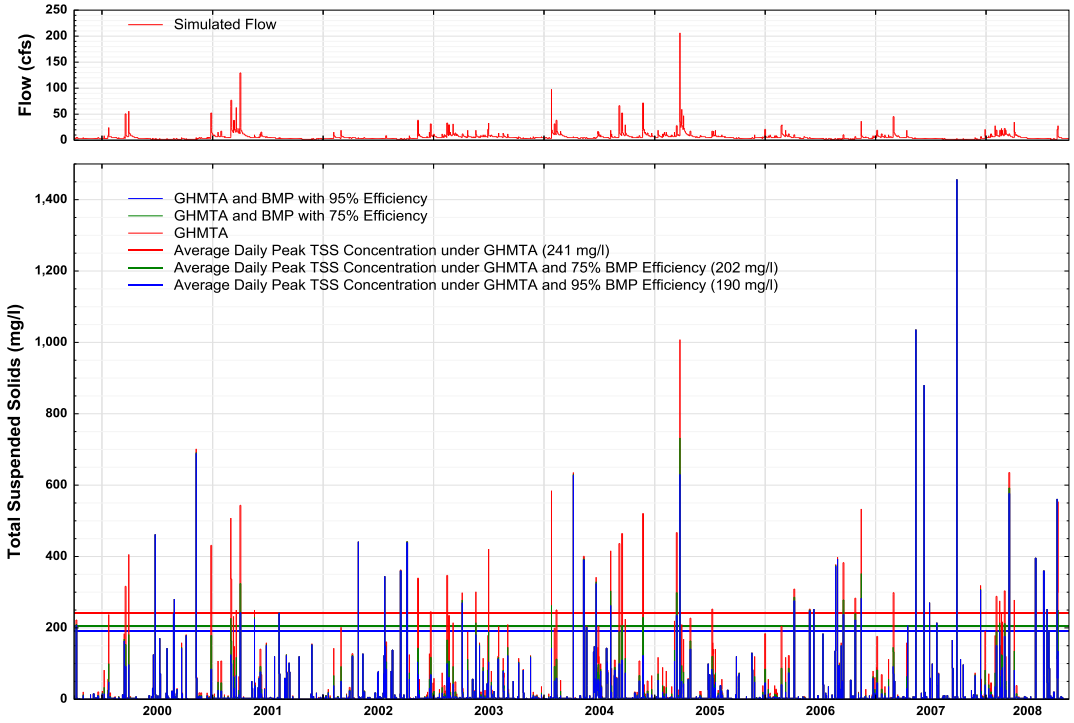

Figure 4.53 Daily Sediment/TSS Concentrations for Hewell Creek (Reach 901) for 1999-2008 under Three GHMTA Scenarios

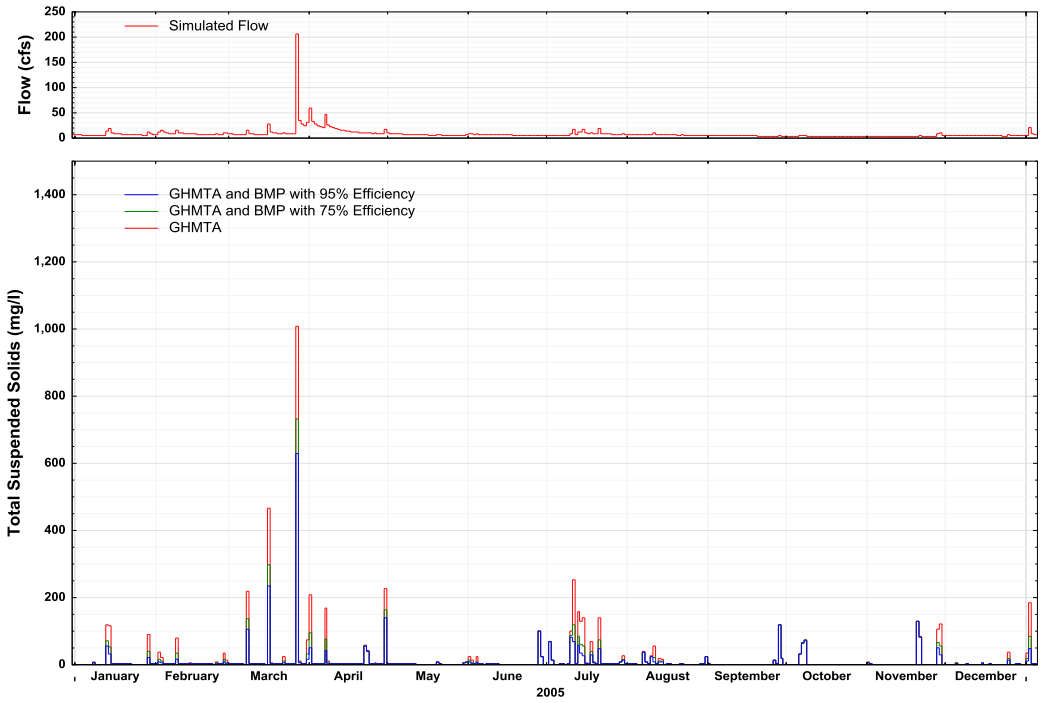

Figure 4.54 Daily Sediment/TSS Concentrations for Hewell Creek (Reach 901) Under Three GHMTA Scenarios for 2005

Analysis of the cumulative frequency results for the GHMTA model runs is shown in the next three figures; Figure 4.55 shows the flow duration curves for three sites within the GHMTA, while Figure 4.56 and Figure 4.57 show the sediment concentration cumulative frequency curves for Hewell Creek (Reach 901) and Hichitee Creek (Reach 206), respectively.

The flow duration curves in Figure 4.55 show that all three sites demonstrate similar behavior as the shape of the curves are essentially the same, and parallel, with the differences due to the drainage area differences. For the smaller sites, Reaches 901 (Hewell Creek) and 902 (Caney Creek), flow values less than about 1 cfs can be considered essentially zero, as these are ephemeral streams and most flow gages have difficulty with accurate low flow readings in this range, Reach 206 which is the outlet of Hichitee Creek to the Chattahoochee River, appears to be a perennial stream with low flows about 10 cfs. These flow duration cures are displayed as a basis for evaluating the sediment concentration cumulative frequency curves at these locations, shown in Figure 4.56 and Figure 4.57, respectively. In reviewing these curves, note the following:

a. The horizontal scales do not extend to about 100% as do the scales for the flow duration curves. For Hewell Creek (Reach 901) the maximum value is about 25%, whereas for Hichitee Creek the maximum value is about 37%. This is essentially indicating that a zero value of TSS is represented in the model for the remainder of the time. These are likely to be extreme low flow conditions, or zero flow for ephemeral streams, and they are represented in the model as zero concentrations.

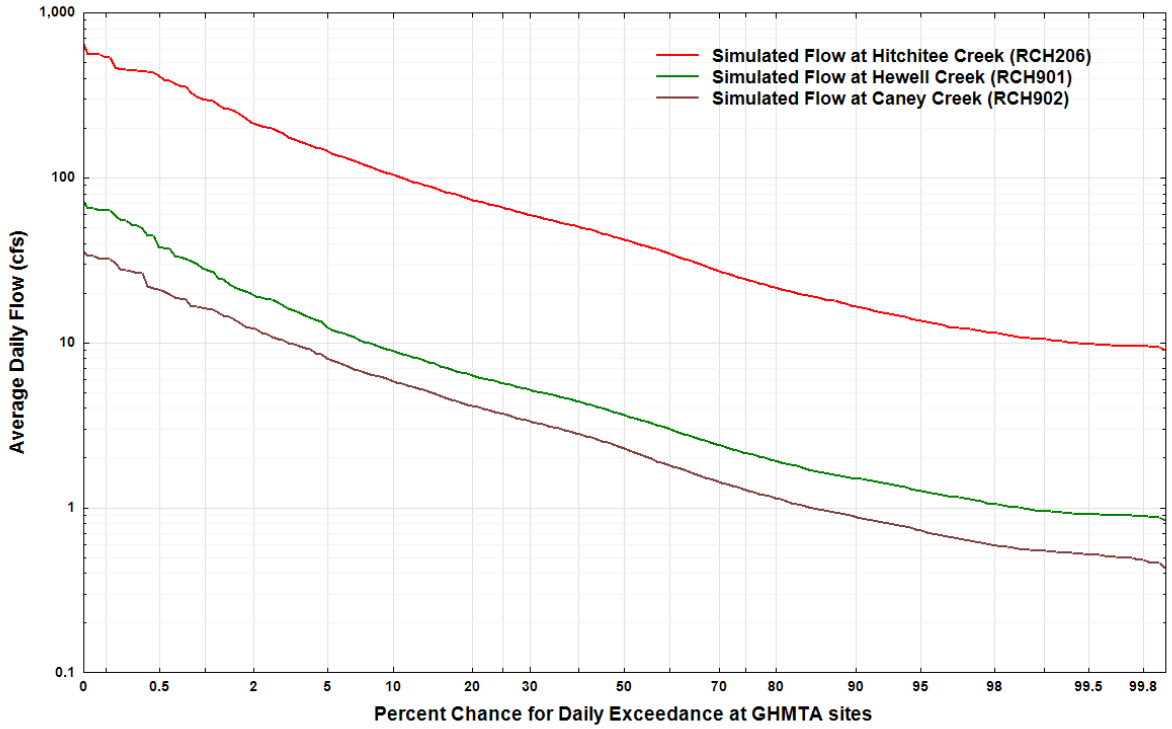

Figure 4.55 Flow Duration at Three GHMTA Sites

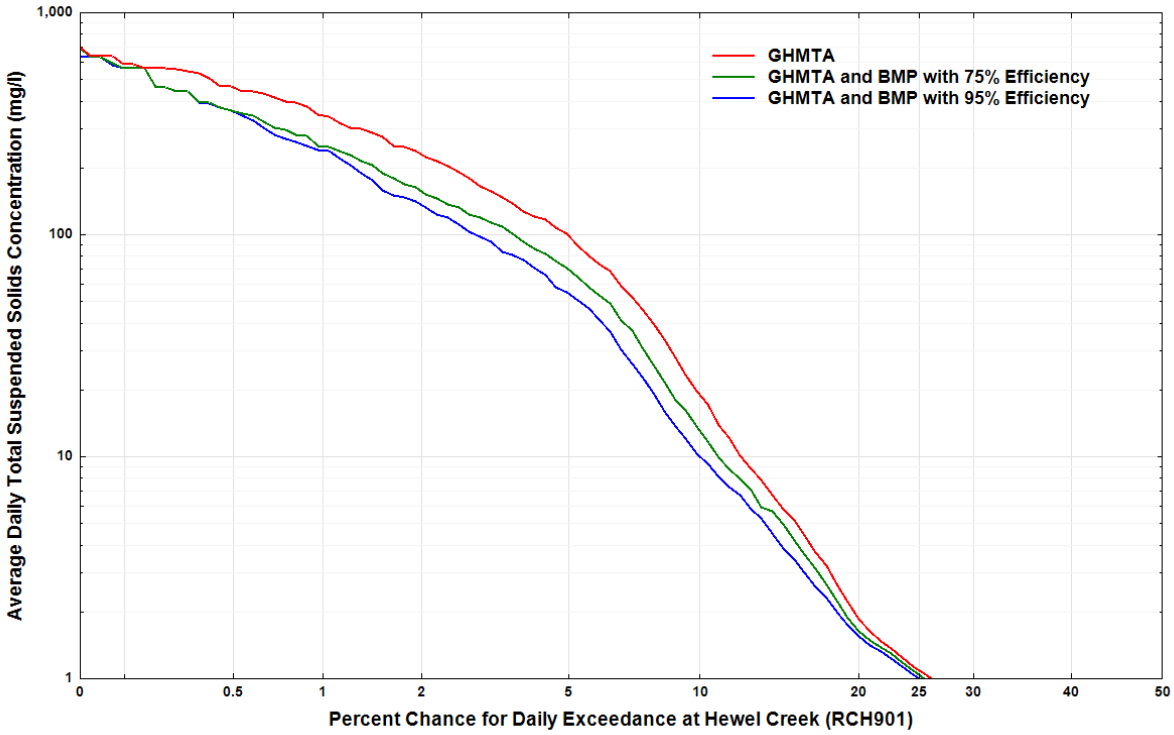

Figure 4.56 Cumulative Sediment Concentration Exceedance Frequency for Hewell Creek for 75% and 95% BMP Removal Efficiencies

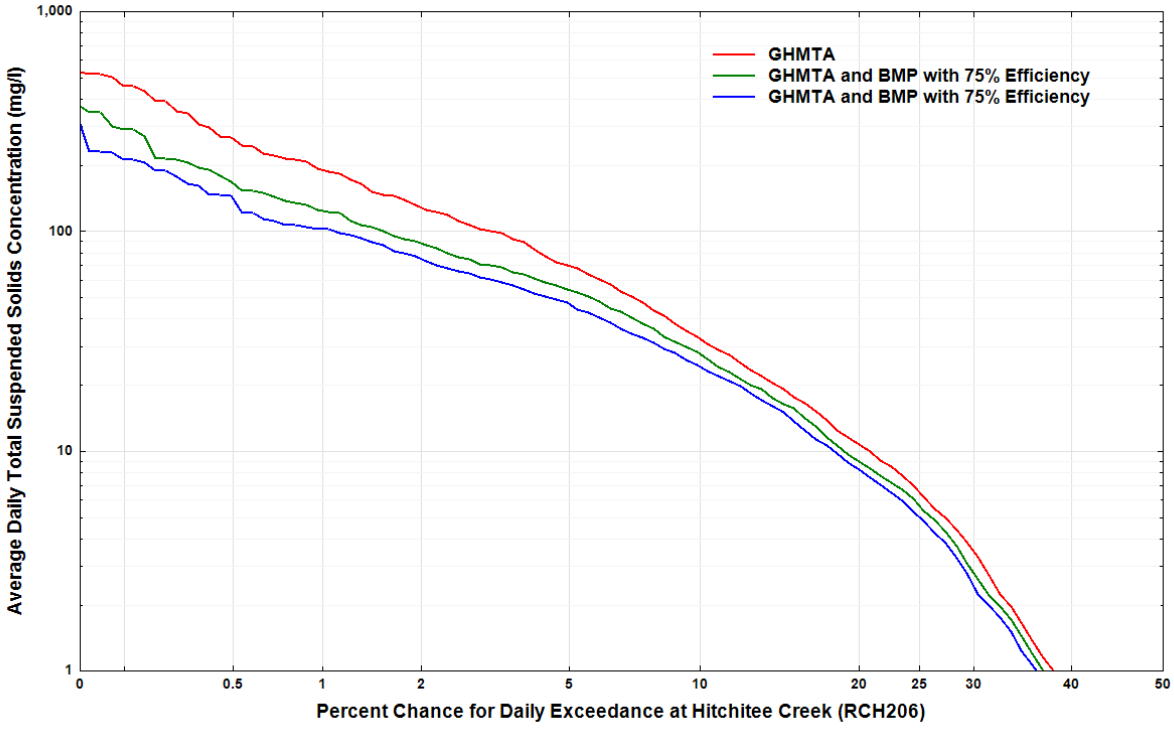

Figure 4.57 Cumulative Sediment Concentration Exceedance Frequency for Hichitee Creek for 75% and 95% BMP Removal Efficiencies

b. Both plots show significant differences between the three curves for the GHMTA condition and the two BMP runs with 75% and 95% removal efficiencies. However, for Hewell Creek (Reach 901) the biggest differences between the curves is in the range of about 0.2% to 20% exceedance, with essentially no difference for the most extreme concentrations with concentrations 500 mg/l or greater. This likely indicates that the removal efficiency has little impact on the extreme flow events, and for those events, the dominant source of sediment may be bed scour and/or bank erosion, which Is not impacted by the BMP removal efficiency.

c. Also, note that for Hewell Creek, the curves for 75% and 95% removal are identical above the 0.5% level, also indicating that the removal efficiency has a lesser impact at the high flow events, possibly due to the availability of sediment to washoff the HMAs for these events.

d. For Hichitee Creek, the differences between the curves appear to increase as the events become bigger, possibly indicating that the longer stream reaches, and associated drainage areas, provide a much larger source of sediment material for erosion and washoff during the extreme events. However, the peak concentrations are higher for the smaller Hewell Creek with values of 600-700 mg/l, whereas the peak values for Hichitee are about 500 mg/l.

e. Analysis of the differences between the 75% and 95% removal efficiency curves indicates that sediment concentrations for the 95% removal curves are reduced by about another 10% compared to the 75% removal curves. Thus, a 20% increase in the removal efficiency yielded about a 10% additional decrease in sediment concentrations.

In addition to these analyses, the cumulative frequency curves can be used directly to assess how often the TSS criteria for aquatic communities are exceeded, and comparing alternative levels of BMP implementation provides a means for assessing the potential benefits of such implementation compared to the associated costs.

SECTION 5.0
CONCLUSIONS AND IMPLICATIONS FOR FUTURE RESEARCH/IMPLEMENTATION

In this section we start by discuss our conclusions related to each of the model enhancement and application topics as described in detail in Section 3. We then explore recommended activities and support for Technology Transfer efforts moving forward, and finish with an interpretation of our efforts in terms of implications for future research and implementation.

5.1 MILITARY TRAINING INTENSITY REPRESENTATION

We believe that the weakest link in using training intensity data for impact assessment that utilizes watershed modeling is the training data itself. Keane and Balbach (2008) drew the following conclusions after their effort to translate current RFMSS data into a format that supports watershed models:

"There are many areas which need to be improved if this process is to be totally adequate from a technical point of view. First, the project needs to have better access to RFMSS datasets for other years, including the more recent years where water quality monitoring has been established. Second, the type of data provided should contain some of the other fields theoretically available within RFMSS, but withheld from the summary provided. Some of these fields are: number of vehicles, number of personnel, and METL (Mission Essential Task List) task accomplished/implemented. All of these elements would provide much more sensitivity to the proposed model implementation, and their acquisition should be vigorously pursued."

For simulation of historical conditions, improvements in RFMSS data support have the potential to enable model representation of actual distribution of training load among an Installation's HMAs, rather than using a fallback assumption of uniform distribution. For simulation of alternative future conditions, the need will still exist to develop rationales that support non-uniform distribution.

Our preliminary investigation into opportunities for improving the modeling methodologies for military training areas led us to conclude that at this point in time improving model process formulations is not likely to significantly improve watershed model simulation capabilities and results related to assessing training impacts (AQUA TERRA Consultants, 2009). We believe that additional effort is warranted in both characterizing training activity and 'firming up' the relationships between training and physical impacts before more detailed process formulation can be utilized effectively. When more progress has been achieved in those areas, it may be advantageous to develop the improved process formulations within the context of a small-scale model that would take advantage of the generalized hybrid modeling capability that has been developed and implemented within HSPF (Section 3.2.1).

5.2 HYBRID MODELING AND WEPP DEMONSTRATIONS

The research and implementation effort that was devoted to hybrid modeling in this project stopped short of developing a 'wrapper' that included code for all operations that were required to express SSM results in the manner that the watershed model needed them for input. (Note that a customized wrapper is required for any SSM used in conjunction with a larger-scale model.) As noted above, the justification for creating a single-code wrapper depends on whether multiple users and multiple applications are envisioned at Installations. To the extent that this is the case, development of a single-code wrapper for the WEPP/HSPF hybrid modeling framework would be justified.

Alternatively, a next step in advancing the use of hybrid modeling could be development of a second framework that included HSPF and a SSM that represents one of the other land use types that were identified (in AQUA TERRA Consultants, 2009) as most relevant to military settings and concerns: e.g., natural and constructed wetlands, detention basins and military training areas. Note that to our knowledge a SSM for the latter land use does not exist and would need to be developed as a follow-on to existing, and perhaps new, research.

Potential next steps for advancing unpaved road simulation methods include the following activities:

1. Isolate and compare estimates in Fort Benning's combined instream sediment loadings that are attributable using WEPP:Road to model unpaved roads.
2. Simulate one or more unpaved road management scenarios to evaluate their impact on sediment loadings. Stand-alone applications of WEPP could be used to estimate changes to unit area sediment washoff, or hybrid modeling applications could be performed to estimate changes to instream sediment concentration at points of interest within the Installations' stream network.
3. Enhance the WEPP/HSPF wrapper and perform a parallel application that utilizes the HSPF EXTMOD module. This effort would enhance the effectiveness and likelihood of additional applications of the hybrid modeling framework at Fort Benning and/or at other Installations.

5.3 MULTI-LEVEL PLANT CANOPY IN HSPF

The multi-layer canopy capability that has been implemented in HSPF will enable better characterization of the impacts of changes in vegetation cover (seasonally and from management actions such as prescribed burning) on hydrology and sediment loss.

The approach that has been enabled allows maximum flexibility in the representation and modeling evaluation of forest land perturbations. Values for interception, cover, and selected soil parameters (e.g., infiltration) can be expressed as constant, monthly variable, or a user-defined time series. In conjunction with the HSPF SPECIAL ACTIONS capability, the time series input option can be used to assess the impacts of fire events (or other vegetative perturbations) as well as subsequent regrowth/return to baseline conditions, and provides the potential for evaluating a wide range of anthropogenic disturbances (e.g., construction, crop rotations, mining/forestry practices).

Even with the implementation of the multi-layer canopy capability, the current version of HSPF does not have explicit representation of any plant community or plant growth processes. Instead, the model captures the main components of a virtual plant community in terms of interactions with the major hydrologic, soil and nutrient processes (i.e., rainfall interception, ET, water and nutrient uptake, litter falls). Incorporation of a dynamic plant growth model would greatly expand the process capabilities and potential applications for watershed impact assessment. HSPF does include a relatively detailed soil nutrient simulation capability. Any integration of plant growth models, and/or refinements of the current algorithms would need to consider how best to incorporate those capabilities into the current nutrient cycling framework.

5.4 CHANNEL SEDIMENT ENHANCEMENT EFDC/SEDZLJ AND BANK EROSION

In summary, the comparisons of HSPF and EFDC model results indicate that both models provide a reasonable representation of the limited observed sediment data, while the EFDC model tends to produce a somewhat more accurate flow simulation for storm event flows. Error

statistics for the entire simulation period indicate HSPF provides a better overall hydrologic simulation for the watershed for most flow metrics. Specific conclusions related to the simulations results and the overall EFDC/SEDZLJ effort are provided below.

Conclusions Related to Simulation Results

1. **EFDC/SEDZLJ shows improved modeling of sediment peaks.** Based on the storm events we analyzed, the EFDC concentrations were consistently higher than the HSPF sediment concentrations, and thereby appeared to be better predictors of the observed values.
2. **EFDC/SEDZLJ shows more consistency between flow and sediment results**. The EFDC/SEDZLJ results showed flow peaks and corresponding sediment concentrations that were more consistent with the observed data than the HSPF results. For Example, in Figure 4.4 the EFDC simulated peak flow is close to the observed and the sediment results are in the middle of the observations, whereas HSPF over-simulates the peak flow and under-simulates the sediment.
3. **Timing differences are not critical in the model assessment.** Timing differences of a few hours are not important metrics for assessing model accuracy as much of this depends on timing of storm patterns and whether or not the monitoring equipment clocks for both rainfall and flow are accurate. However, some disturbing timing differences, of many days, between HSPF and EFDC simulation results has raised some concerns about potential errors in the linkage procedures that should be addressed and resolved.
4. **Extreme TSS concentrations of 2,000 to 3,000 mg/l are not unexpected.** Historical sediment data at McBride Bridge show peak concentrations in the range of 1,500 to 2,000 mg/l for selected events, so the EFDC predicted peaks approaching 3,000 mg/l or more are not unreasonable.
5. **Model differences are clear, but not conclusive.** The model results show clear differences between HSPF and EFDC/SEDZLJ predicted values, but the differences are not of sufficient magnitude and the EFDC results are not sufficiently better (i.e. closer to observations) to support a conclusive assessment that the additional effort, resources, and time to apply EFDC is worth the investment.

Conclusions Related to Utility of Research Effort and Demonstrated Linkage

1. Data limitations, especially for bank erosion, but also for sediment water column concentrations and bed composition/profiles limited the effectiveness of the EFDC/SEDZLJ simulation. These more spatially resolute model(s) are best applied in a data-rich setting, and consequently this same limitation may exist at many Installation sites for which sediment transport modeling might be considered.
2. Large run time requirements (e.g., 2-3 days on a super-computer for a 10 year run) for even a somewhat spatially coarse EFDC/SEDZLJ application are a deterrent to applying the model for evaluations for all but the most challenging and environmentally sensitive planning evaluations.
3. The resource and expertise requirements for an EFDC/SEDZLJ application are likely to exceed those that are available for many Installation investigations.
4. HSPF, with or without enhancements (e.g. adding bank erosion) may be adequate for evaluating many watershed-scale sediment issues and assessments that are important to Installations. A major impetus for pursuing the channel modeling improvements was SERDP's expressed interest in advancing the state-of-the-art of watershed modeling.

Our analysis suggested that in many cases the costs of applying state-of the-art modeling tools can outweigh the benefits.

5. Since HSPF hydraulics are currently being improved under an ongoing investigation for EPA-ORD, by adding a dynamic, full-equations routing capability, consideration should be given to pursuing a refinement of the sediment transport algorithms and a dynamic multi-layer bed simulation. Such improvements would upgrade the HSPF sediment capabilities for application to Installations with sediment issues comparable to Fort Benning.
6. The methodology for representing and simulating bank erosion that was identified in the research investigation and implemented for the demonstration appears to offer promise as a component to the watershed modeling system.

   Given the perceived benefit to watershed models that the bank erosion formulation has, there are three 'next steps' that we believe are warranted:

   a. Collect data from various sources that enable a more detailed characterization of Fort Benning's stream banks in terms of either potential or observed vulnerability to erosion/failure.

   b. Integrate the Ikeda methodology into the existing HSPF channel module (RCHRES). We believe that there is considerable value to also having this formulation as an enhancement to the HSPF channel formulations. RCHRES offers sufficient detail in sediment simulation capabilities to evaluate the relative impacts of landscape sediment loadings as compared to bank erosion loadings.

   c. Validate the utility of the bank erosion methodology within the context of HSPF channel simulation, through further simulations at Fort Benning, and possibly other installations.

5.5 BRAC SIMULATIONS

This proof-of-principle application of the BASINS/HSPF model to the Fort Benning watersheds has demonstrated how watershed modeling can be applied to evaluate potential impacts of land management and military training conditions on the watershed hydrology and water quality.

As shown in Figure 4.12, a number of additional alternative management scenarios were identified as being of interest to land managers at Fort Benning, but could not be considered due to resource limitations. Procedures and approaches for addressing these alternatives, along with other possible management options, are discussed below. Future efforts for demonstration and validation of the watershed modeling procedures, directed at military installations, should consider some of the following scenarios:

1. BRAC with and without Urbanization – Evaluate the impact of urbanization outside of the Installation's boundaries on Fort Benning's streams by assuming a percent increase in urban land use coverages and a corresponding decrease in pasture, agricultural, and/or forest land use for the areas outside of the Installation's boundaries. Sensitivity to alternative levels of urbanization can be assessed with scenarios corresponding to different levels of future increases in urban lands.
2. Prescribed Burning – Evaluate impacts of alternative prescribed burn cycles for Fort Benning watersheds by varying the burn cycle from the current 3-year cycle, to alternatives such as 1-year, 2-year, and 5-year cycles.

3. Timber Harvesting – Assess the impact of timber harvesting on the watershed by simulation of alternative conditions, such as: 1) a worst-case scenario of clear cutting of an entire subwatershed; 2) alternative levels of timber harvesting at sites throughout the Installation; 3) multiple analyses of near-site, tributary, and downstream impacts; 4) assess impacts of potential mitigation procedures for runoff and sediment loss.
4. Regulatory Compliance – Alternative analyses in support of TMDLs at identified sites across the Installation, and stormwater requirements (i.e., EISA Section 438) for proposed development areas.

Watershed modeling is an appropriate and cost-effective tool for addressing these and other management needs at a watershed scale while considering land management and regulatory issues of concern to military land managers.

5.6 AQUATOX APPLICATIONS

AQUATOX was used to analyze the responses of two dissimilar streams to watershed disturbances at Fort Benning, Georgia. The McBride Bridge site on Upatoi Creek drains a large watershed and demonstrated only small changes in the aquatic ecosystem as a result of increased tank trails, heavy maneuver areas, and unpaved roads upstream. Sally Branch, with land-use changes in the immediate watershed, exhibits significant predicted changes in the ecosystem. However, these simulated changes are counterintuitive: one would expect increased sedimentation to decrease productivity. But increased runoff of nutrients stimulates algal growth in the simulation, and this was observed in field studies conducted concurrent with watershed modifications (Mulholland et al. 2009). On the other hand, the large increases in fish biomass under perturbed conditions are not likely and suggest that the fish responses should be calibrated across several stream sites.

This application is intended as a demonstration of the applicability of AQUATOX, including enhanced linkages to the watershed model and the use of endpoints developed specifically for representing watershed disturbances. AQUATOX is an integral part of the BASINS-derived watershed modeling system developed for Fort Benning.

With little additional effort the application of the model to Fort Benning could be improved by calibrating across the other stream reaches where there are biotic field data. The model could also be applied to other military bases—in some cases with minimal changes to existing general calibrations, based on experience in modeling streams in Alabama, Minnesota, and Idaho with the same parameter set.

AQUATOX has a myriad of potential applications to DoD's water management issues and requirements, including those related to water quality criteria and standards, TMDLs (Total Maximum Daily Loads), and ecological risk assessments of aquatic systems. AQUATOX can be used to predict ecological responses to the pollutant loadings that are likely to result from proposed management alternatives. The model may also help to determine the most important of several environmental stressors, e.g. where there are both nutrients and toxic pollutants.

AQUATOX provides a critical tool when land managers need to understand the processes relating the chemical and physical environment with the biological community in order to meet regulatory requirements. A biologically-impaired stream or wetland must be restored to a specific assemblage of fish, macroinvertebrates, or plants through the Total Maximum Daily Load (TMDL) process. During development of a TMDL, detailed analyses are conducted to determine reductions in pollutant loading needed to restore a stream to its intended use. Since the TMDL represents a quantity of pollutant, a surrogate chemical must be found for the biological impairment. TMDLs for biological impairments are written in terms of the surrogate

chemical. A model such as AQUATOX can be used in conjunction with a watershed model to estimate the daily pollutant loads that can be discharged to a river or stream without resulting in an unacceptable level of biological impairment.

5.7 GOOD HOPE TRAINING AREA APPLICATION

Based on the results of the GHMTA management alternative evaluation, Fort Benning has a reasonable initial estimate of sediment loadings to reinforce the request for an estimated $30 Million (Parsons, 2012) to implement BMPs in the Good Hope Area, and the recommended flow and sediment monitoring to measure the effectiveness of the BMPs that are installed.

The management alternative evaluation for the GHMTA could be refined and/or expanded for a more scientifically robust calculation of the spatially variable sediment loads, and for a more extensive demonstration of model capabilities. These refinements and/or expansion of scope could include:

- Increased discretization and associated parameterization for a more detailed and in-depth analysis of impacts related to MCoE Roads, the number and placement of BMPs, and low flow stream crossings.
- Refinement of BMP TSS reduction factors specifically selected for the types (and sizes) of BMPs for the different sediment/TSS sources.
- Linkage with AQUATOX to define the impact of TSS concentrations on aquatic biota.
- Comparison of post- and pre-construction (as represented in the Baseline model) hydrologic conditions of temperature, rate, volume, and duration of storm water flow.
- Investigation of low impact development (LID) alternatives for BMP options.
- Assessment of TMDL for Hichitee Creek with considerations for legacy sediment using multiple loading scenarios (including existing loading conditions, baseline loading conditions and TMDL loading conditions).
- Further validation of the Fort Benning Enhanced model and the GHMTA model results using newly acquired monitoring data from the GHMTA. Figure 5.1 depicts the monitoring site locations as proposed by Fort Benning. Monitoring is expected to commence in October of 2012.

5.8 TECHNOLOGY TRANSFER

DoD resource managers, who are responsible for 30 million acres of land that are used for testing and training, need assessment tools to quantify the hydrology and water quality impacts of military activities on these lands especially related to soil erosion and runoff. Use of continuous simulation computer techniques for evaluation of watershed hydrology and water quality offers much promise as a system-level assessment tool. However, this technology has been slow to be transferred to DoD Installations due in part to a variety of perceived and real shortcomings such as: 1) accurate characterization of military unique impacts, 2) uncertainty about costs related to site-specific data needs, 3) expertise needed to apply the modeling system, 4) the disparity between the scale of the assessment need and the scale of the model's resolution, and 5) a lack of knowledge of the versatility and relevance of the technology to address compliance-specific management issues pertinent to installations.

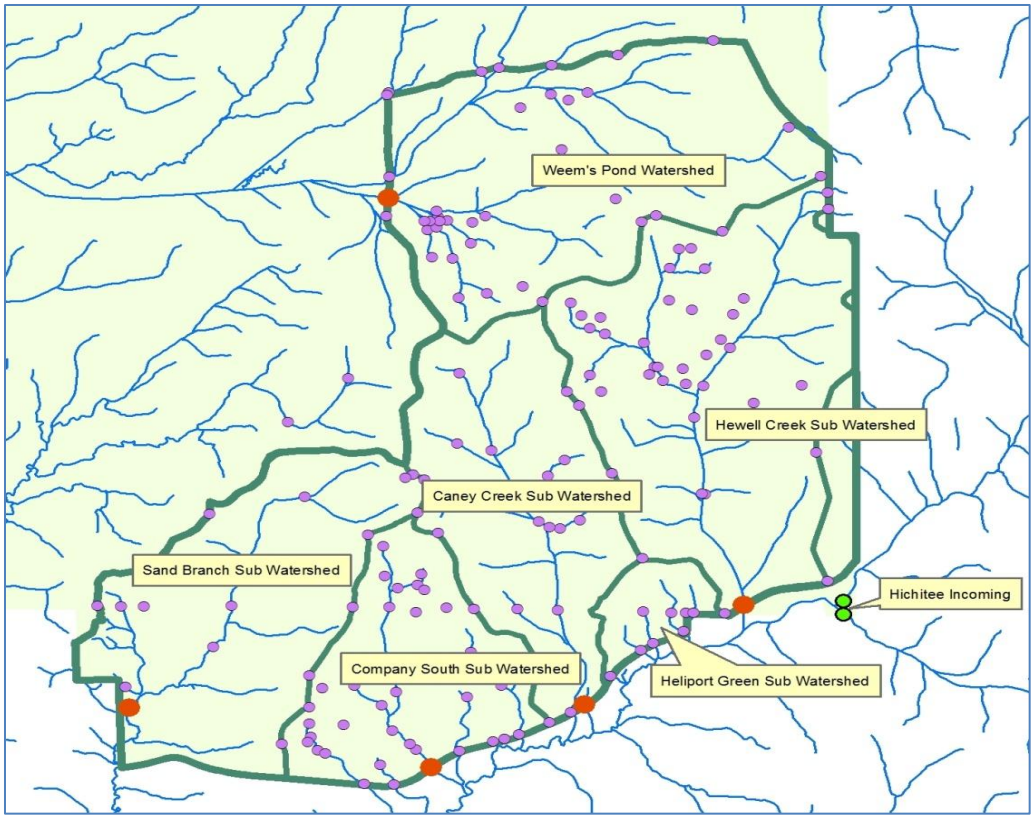

Figure 5.1 Good Hope Monitoring Site Locations

Purple dots = photo recon at stream crossings
Red dots = primary hydrologic monitoring sites (discharge, sediment, biology, WQ)
Green dots = quarterly TMDL monitoring sites (sediment, biology, WQ)

Some of these shortcomings have been addressed as part of our SERDP project. However, further demonstration and validation of the military-enhanced BASINS modeling system (BASINS.MIL) is required before the technology is transitioned across DoD. With this ultimate aim, our technology transfer efforts for our SERDP project have been focused on transitioning the technology to the greater scientific/engineering community through documentation of technological advancements and to the resources managers on Fort Benning through proof-of-principle demonstrations. Based on these key end user groups associated with the evolutionary progression of the technology development, this section summarizes the technology transfer objectives and activities conducted as part of our SERDP project. Additionally, the next steps needed to fully transition the technology to meet the needs of resource manager across DoD, as stated above, are articulated.

5.8.1 Our SERDP Products

Our SERDP project involved substantial efforts devoted to understanding and representing military impacts, as well as improving the state of science for watershed modeling. The result was a military enhancement of the BASINS modeling system or BASINS.MIL and its proof-of-principle applications on Fort Benning. Based on domain knowledge of the military mission, specifically with respect to military readiness activities, environmental compliance and resource protection, datasets were identified and methodologies designed to support watershed impact

assessments related to the leading stressors on military installations, i.e., military training, unpaved roads, prescribed burning, timber harvesting and urban encroachment. Software refinements were developed to (1) improve HSPF simulation of the plant canopy compartment to accommodate disturbance impacts on soil and runoff processes and model parameters, (2) include complex channel modeling beyond what is available in HSPF (i.e., EFDC/SEDZLJ), and (3) allow for linkages to other models (i.e., AQUATOX, WEPP and WEPP:Road). The products of the Fort Benning project, in essence, provide the BASINS/HSPF user with options for building a military-enhanced HSPF model as shown conceptually in Figure 5.2.

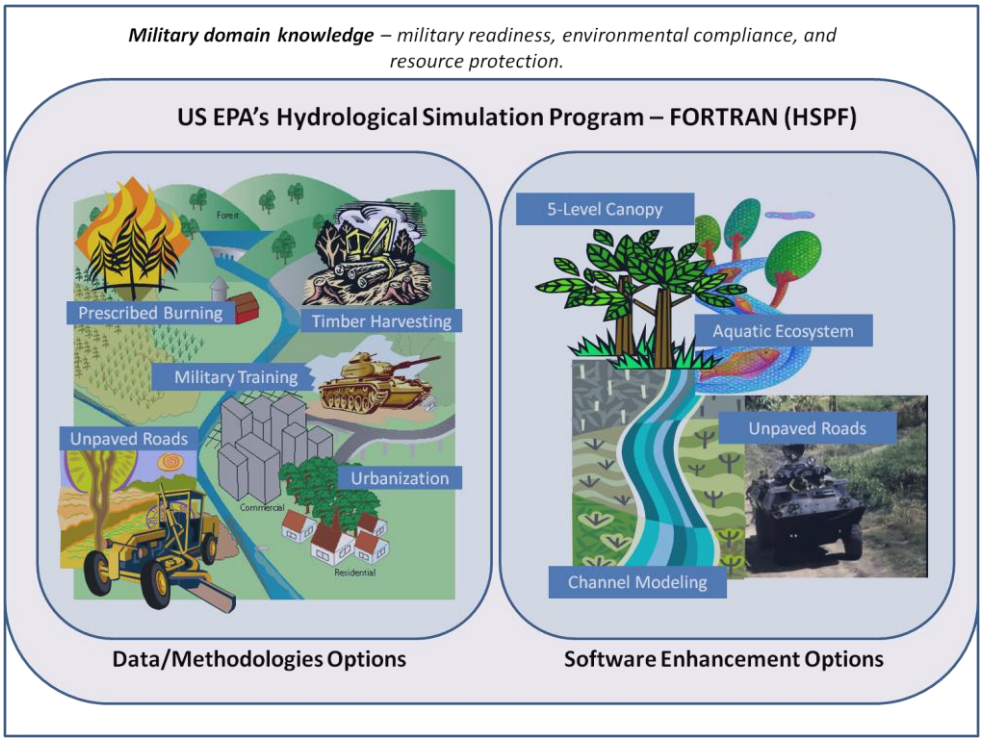

Figure 5.2 Conceptual Illustration of BASINS.MIL

5.8.2 End User Needs and Technology Transfer Objectives

Our technology transfer objectives have targeted three types of end users based on the technological development of BASINS.MIL.

1. to communicate to the greater scientific/engineering community the advances in watershed modeling in general, and the BASINS modeling system, specifically;
2. to transition the technology and the proof of principle of the technology to Fort Benning resource managers; and
3. to articulate the next steps to transition the BASINS.MIL across DoD.

The progression of the BASINS.MIL and the associated targeted end users are conceptually illustrated in Figure 5.3. The BASINS model enhancements, which include data/methodologies and software refinements, involved mostly model process and application developments and are most appreciated by the greater scientific/engineering community interested in technological advancement of watershed modeling in general and BASINS, specifically. The BASINS model enhancements as applied through the Fort Benning model and its applications for several management alternatives provide proof-of-principle of the model enhancements on a military installation. This phase of the technology evolution targeted the resource managers on Fort

Benning who are interested in acquiring a tool to facilitate their watershed management program under the Installation's Environmental Division. The resource managers at Fort Benning need a means to quantify the accumulative and individual impact of military training, construction, natural resource management activities, and other disturbances to support decisions regarding monitoring and adaptive management, and to meet compliance objectives.

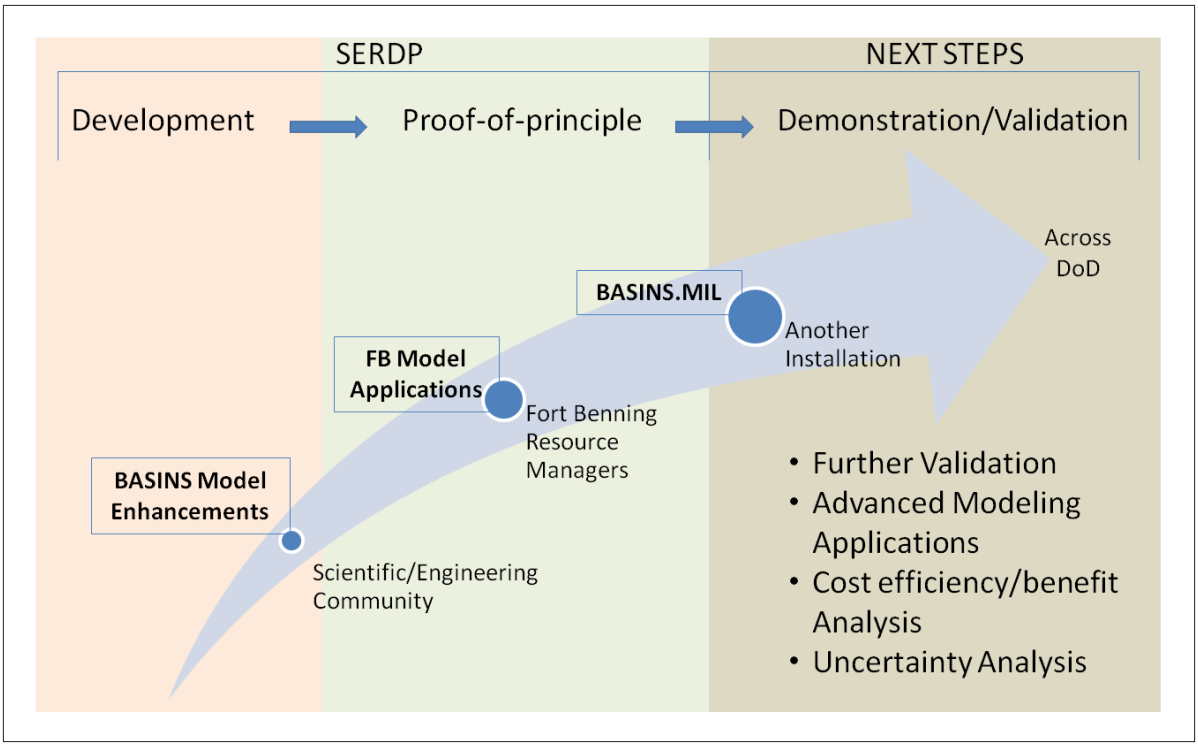

Figure 5.3 Conceptual Process of Technology Transfer

Advancing the modeling applications initiated on Fort Benning, either on Fort Benning or within geographical proximity of Fort Benning offers the advantage of leveraging components of the Fort Benning model, such as, model parameters and adjustments for military training practices and conditions, and demonstrating more extensive applications of the BASINS.MIL. Transitioning BASINS.MIL to another installation to demonstrate a cost-efficient development of a watershed model is necessary before the full utility and benefit of the technology can be embraced across DoD.

5.8.3 Approach, Activities, and Accomplishments

All of our activities related to technology transfer have incorporated the existing features of the BASINS modeling system. Integral to BASINS.MIL transferability is the national extent of BASINS supporting data bases, and the system's development philosophy that produces/uses tools and models that can be applied to very different locations. This is implemented via selection of local time series and model parameter values that allow customizing each model application to fit its specific setting (climate, topography, soils, vegetation, ecohabitats).

Communicating to the greater scientific/engineering community the advances in watershed modeling, in general, and the BASINS modeling system, specifically; was fulfilled through publications of reports and presentations to various science and engineering audiences. A complete list of these communications is provided in Appendix G. In addition to the publication/presentations, concurrence with domain experts of models being linked or

incorporated into BASINS.MIL was maintained throughout the development process. This included US Forest Service personnel with expertise in WEPP and WEPP:Road, US Army Corps staff with expertise in channel modeling, and Dr. Richard Parks, the developer of AQUATOX. This close collaboration offered immediate transition of the technology to the domain experts and its users.

The Fort Benning Model and its proof-of-principle applications were transitioned to Fort Benning resource managers through an on-site meeting to kick off the project, bimonthly telephone calls, technical memoranda regarding selection of management alternatives and road design/maintenance issues, field visits, progress meetings, teleconferences, a webinar, a list of data requirements by category, and a one-day presentation and training workshop on Fort Benning (to be scheduled). The first apparent repercussion of these efforts should be evident by Fort Benning resource managers using the model results from the Good Hope Mechanized Training Area (GHMTA) to justify approximately 30 million dollar budgetary request for implementing and monitoring best management practices in this area.

Based on the specific end user need, Table 5.1 provides a comprehensive list of technology transfer activities that were accomplished across all of these groups. Articulation of the next steps needed to build upon these activities to further transition the BASINS.MIL across DoD follows in the next discussion.

Table 5.1 Summary of End User Needs and Transfer Activities Accomplished

End User Need	Transfer Activity Accomplished
Understanding of technical developments in watershed modeling and the BASINS modeling system	Documentation
Data requirements	List of data requirement by category
Cost to apply technology	Initial comparison of reducing statistical error in F-tables and cost of gathering additional data
Expertise needed to apply technology	Webinar and 1-day training on Fort Benning
Applying model to compliance issues	Proof-of-principle model application at FB
Applying model to master planning	Proof-of-principle model application at FB
Full acceptance of model's accuracy and uncertainty in modeling results	Sensitivity analyses Comparison of model results with literature values FB Model calibration and validation performance
Easily interpretable modeling results	Results presented in terms of military-specific disturbances and distinction of on-site/off-site percent contributions
User friendly navigation of modeling options	User navigational guide

5.8.4 Next Steps

The products of our SERDP project must be advanced to transition the technology to meet the full expectations of military resource managers. The next technology transfer activities require demonstrating and validating the BASINS.MIL's full utility, performance and associated costs, further documentation, training, and resolution of BASINS.MIL software access within military installations' intranet systems. The steps needed to implement these technology transfer activities are listed in Table 5.2.

Table 5.2 List of Next Steps for Technology Transfer

• Further testing of software enhancements and methodologies
• Cost efficiency/benefit analysis of incorporating more data relative to increased model performance
• Cost efficiency/benefit analysis of building and applying BASINS.MIL (assuming no additional cost associated with data collection)
• Advanced model applications to demonstrate fully utility of technology
• Further validation of the model using observed data
• Guidance Manual for implementing BASINS.MIL on an installation
• Document for Regulators (State and Federal) on the use of BASINS.MIL to meet TMDL requirements on military installations
• Capability to download/access BASINS.MIL software within a military installation intranet system.
• DoD-wide workshop after dem/val of technology

The degree of transferability of the Fort Benning Model and its application is greatest in the local area surrounding Fort Benning and will decrease as the similarity of the Fort Benning setting to other military installation watersheds decreases. Figure 5.4 reflects the natural geographic flow of technology transfer from the Fort Benning project to other installations. The most efficient approach to transitioning the proof-of-principle applications of the Fort Benning Model to the next level of advancement is to leverage the existing modeling efforts on Fort Benning.

Building on the modeling work completed on Fort Benning affords a cost-efficient platform to advance the proof-of-principle applications by conducting more in-depth modeling evaluations on Fort Benning to demonstrate the full utility of BASINS.MIL. These advanced modeling applications can be designed to demonstrate the effectiveness of the technology to address compliance-specific management issues at the scale that is relevant to Fort Benning and other installations. Additionally, the acquisition of new flow and sediment data in the GHMTA on Fort Benning (to be commenced in October 2012) allows for further validation of the Fort Benning model.

Although building on the work completed on Fort Benning is a practical next step, transitioning BASINS.MIL to another installation is needed to conduct comprehensive cost efficiency/benefit and uncertainty analyses. Based on the project team's best account, a formal cost/benefit analysis using standardized economic metrics has not been conducted for a watershed modeling application due to the difficulty in normalizing benefits for cost correlations. A creative and innovative approach that incorporates both quantitative and qualitative metrics is needed.

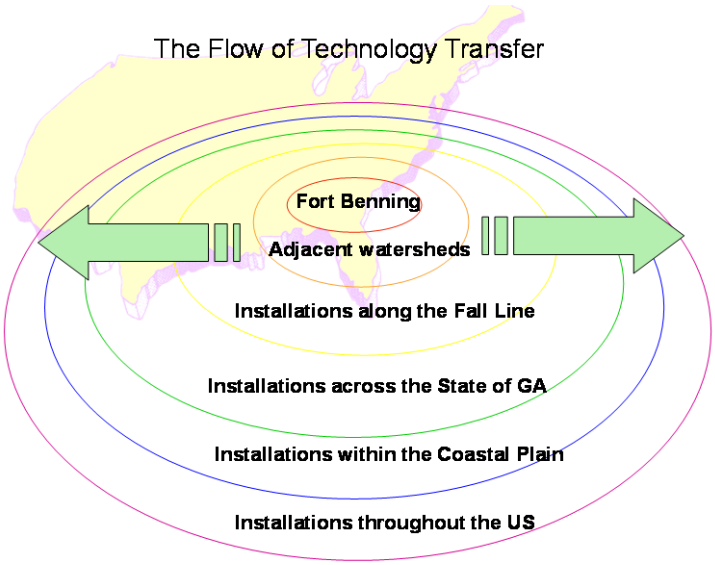

Figure 5.4 Building on the Development Work on Fort Benning

An alternative to a formal cost/benefit analysis is a comparison of approaches for characterizing hydrology and water quality for an installation. For example, an installation located within the Chesapeake Bay offers an idea situation to compare modeling approaches designed to address Total Maximum Daily Loads since a Regional Chesapeake Bay model (Phase 5.3) exists for such purposes. A BASINS.MIL application at an installation scale could be compared to the existing Regional HSPF Chesapeake Bay Modeling approach and results, and to the existing set of pilot studies, using a spreadsheet model approach, conducted by the Army for a handful of installations within the Chesapeake Bay Basin. A comparison of the relative cost efficiencies associated with data requirements; expertise and level of effort to build and apply the models; scientific rigor; regulators' acceptance; and overall utility of each approach affords a relative demarcation of the cost and benefits to build and apply the BASINS.MIL. In combination with an uncertainty analysis, the cost efficiency/benefit analysis of the BASINS.MIL could advance the transition of the technology by demonstrating its performance and practicality.

Guidance documents, training and several software-related development efforts will promote the transfer of BASINS.MIL across DoD. Two types of guidance documents are needed to address the needs of our targeted end users. One geared toward State and Federal Regulators of TMDLs and another towards DoD resource managers who have some expertise in watershed management (i.e., engineer/hydrologist).

BASINS and HSPF are used by resource managers around the globe for watershed management assessments. Training to build and run the model appropriately often are requested and/or required. For the past 10-15 years, BASINS/HSPF training workshops have been routinely funded by EPA, and AQUA TERRA's experience is that attendees to the workshops, with little to no initial modeling experience, leave the 5-day workshop with a comfort level and a significant jump on the learning curve so that they are able to initiate and perform model setup and calibration when they return to their offices.

A customized DoD user training workshop would focus on two key needs: (1) how BASINS.MIL can be used to evaluate management alternatives, and (2) the process for manipulating an existing HSPF model to evaluate alternative model scenarios. The inherent assumption is that most DoD users will likely opt to fund a contractor to build the initial HSPF model of their installation (i.e., involving model set up and calibration), and then using an existing model an

installation will prefer to have in-house capability (i.e., installation staff) to generate and evaluated different management scenarios over time. Thus, the expertise required by the DoD user is concentrated on model scenario generation and evaluation rather than model set up and calibration.

Based on our team's experience on Fort Benning, the difficulty of downloading software on an internal server within the standard firewalls of a military installation may or may not be surmountable. A range of possible alternatives for accessing the BASINS.MIL software will need to be investigated, and if necessary, a workaround established such as a secure external host server.

In order to communicate model outputs and uncertainties to DoD end users and decision makers in a manner that improves interpretability and shows direct correlation to management actions and their effects, the current output interpretation and presentation capabilities within BASINS.MIL can be advanced. A navigation guide, as presented in Figure 5.5, can be further developed to help the DoD user navigate the various options available to build a military-enhanced BASINS model. The user selects the compliance requirements (e.g., TMDL), identifies the major impact on the streams (e.g., sediment), links the requirement and stream impact to a land stressor (e.g., unpaved roads), considers the BMP(s) that could reduce the impact (e.g., road improvements), and then determines the appropriate software option that best fits the combination of the above (e.g., road model).

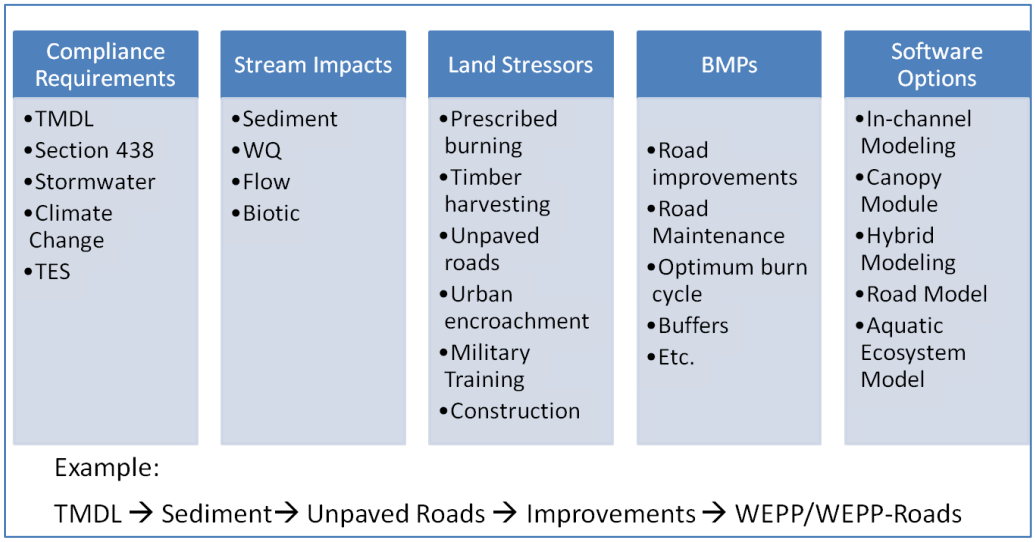

Figure 5.5 Navigation Guide for BASINS.MIL Users

5.9 IMPLICATIONS FOR FUTURE RESEARCH/IMPLEMENTATION

The sub-sections that follow provide focused discussions of a variety of implications for potential future research or implementation activities that have at least partially resulted from the Fort Benning Watershed Model project. The first three sub-sections describe model- and modeling-centric implications. Section 5.9.1 identifies significant benefits that we believe can be achieved by further testing the enhanced modeling capabilities that have been developed, and Section 5.9.2 suggests several supplemental model applications that warrant consideration. Section 5.9.3 focuses on the modeling system (BASINS.MIL) that was the primary product of this project and recommends supplemental efforts that should be pursued in order to build greater familiarity and confidence for planned utilization of the existing version of BASINS.MIL at installations. Section 5.9.4 identifies and discusses a list of “missing pieces” that we believe can

greatly expand the utility of BASINS.MIL and its applications for Fort Benning and other DoD installations. Viewed from a different vantage point, the list identifies field and process knowledge and information resources (and modeling capabilities that depend on them) that we do and do not have, and by doing so it provides useful feedback to field and process research interests. Finally, in Section 5.9.5 relevance of the project findings and accomplishments to military policy issues is discussed.

5.9.1 Model Enhancements

Significant benefits to military interests can be realized by extending the investigation and testing of the FB Enhanced Model beyond our current accomplishments. We believe that the topical areas described below offer the greatest opportunity. Note that the focus of discussion in this section is on the capabilities that have already been implemented as a result of this project. Opportunities that would result from further extending current modeling capabilities are discussed in Section 5.9.4.

Hybrid Modeling and Unpaved Road Simulation. Prior to this project's effort to use the hillslope-scale WEPP model (a USDA product) in tandem with the watershed-scale HSPF model (an EPA/USGS product), the only well-documented hybrid modeling effort of this type involved two models that were both developed by the same group (USDA). This project's effort to 'marry' models that were developed by two different groups clarified the opportunities, the challenges and the limitations that are likely to be involved in developing most hybrid applications. Nonetheless the development of the External Models (EXTMOD) code enhancement to HSPF offers a tool that has potential value to many modelers (Section 3.2.2).

Given the widespread significance to installations of sediment erosion from unpaved roads, taking advantage of a more detailed (spatial and process) hillslope-scale model is warranted. However, the contribution of the smaller scale model to the overall planning process may center on providing better informed input to the watershed-scale model (Section 3.2.2).

A modeling issue that became clear during the project was the inconsistency of WEPP:Road's assumption of a steady state condition for the road surface with the dynamic situation that is imposed by maintenance actions such as grading. From a modeling perspective, a grading event creates a significantly increased storage of erodible sediments, which are subsequently reduced over time by compaction and runoff events. The HSPF 'SPECIAL ACTIONS' capability offers a means of more effectively representing a grading event and simulating both the 'spike(s)' in potential sediment erosion for significant runoff events that follow directly after grading, in turn followed by reduced sediment erosion potential until another grading event occurs.

Recognizing the modeling challenges associated with evaluating maintenance activities, an advantage is realized by taking the approach of using WEPP and WEPP:Road to estimate "design" impacts of managed roads, and then using WEPP/WEPP:Road estimates of erosion rates for specific design/maintenance conditions to inform the appropriate selection of HSPF parameters that best simulate those estimates. Within the HSPF modeling framework the SPECIAL ACTIONS capability can be used to further refine the dynamic nature of changing road surface characteristics.

A future effort should be made to demonstrate the use of WEPP:Road to represent and simulate construction and maintenance alternatives in a standalone 'design' mode. These results should then be re-expressed in the watershed model in a manner that is meaningful for making planning decisions.

Multi-Compartment Canopy Applications. Various uses of the new model formulations for simulating forest management scenarios should be demonstrated and tested:

- Represent, simulate and evaluate the hydrologic and cover impacts of understory re-growth under alternative prescribed burning cycles.
- Represent, simulate and evaluate timber harvesting.
- Explore the use of a forest litter layer as impacted by forest management practices.
- Consider application of the time-varying, multi-level canopy capabilities for investigation of wildfire impacts on watershed hydrology and sediment.

Military Training Intensity Methodology. In the absence of measured data for actual training event impacts on the landscape, it was necessary to develop a methodology for transforming available information on the intensity of military training into estimates of impacts on model parameter values that determine infiltration and vegetative cover. The weakest link in using training intensity data for impact assessment that utilizes watershed modeling is the training data itself (Section 3.2.1). Additional work is warranted in both characterizing training activity and confirming the relationships between training and physical impacts before more detailed process formulation can be utilized effectively.

Channel Modeling. This effort has value to the modeling community in that it clarified requirements and challenges involved in applying and linking complex models for watershed scale assessments (Section 3.2.4).

Channel modeling using EFDC is challenging, extremely data-intensive, and may be impractical for many installations. Moreover, the resulting resolution and scientific rigor may not be needed for the level of characterization required for an installation. We concluded that using a 2-D or 3-D version of EFDC/SEDZLJ at Fort Benning is not warranted (Section 3.4). Consequently, we have no recommendations for additional investigation or testing of EFDC/SEDZLJ unless issues related to evaluating the impact of legacy sediments (see Section 5.9.4, item #9) become a priority concern at Fort Benning or another installation.

The model enhancements provided somewhat improved simulation results pertinent to military training impacts but the more compelling outcome was the improved foundation for representing the types of military and natural resource management activities of concern at installations like Fort Benning (Section 4.3).

5.9.2 Model Applications

The FB Model needs to be further validated with observed sediment and flow data – especially from heavy maneuver areas. In addition, addressing the issue of gullies on the FB Installation and their contributions to the overall sediment load would be an area of fruitful and extremely relevant investigation from a modeling standpoint

It would be beneficial to demonstrate the full versatility of the model for a wider range of management alternatives (i.e., advanced model applications), including stormwater facilities and practices, site-specific BMPs and their design (as opposed to a removal factor), increased urbanization over different planning horizons, climate change impacts on facilities, etc.

Relevant to recommendations that will be made in Section 5.9.4 (Items #1 and #2) regarding improvements to the HSPF channel modeling algorithms, demonstrating the effectiveness of HSPF to meet channel flow and sediment transport needs at Fort Benning or another installation would be beneficial. HSPF, with or without enhancements may be adequate for

evaluating many watershed-scale sediment issues and assessments that are important to installations.

It would be beneficial to further explore the counterintuitive AQUATOX results for fish simulation reported in Section 4.7. This could be accomplished by calibrating fish response across several additional stream sites. As explained in Section 4.7.1, AQUATOX can potentially play a significant role in supporting investigations and solutions to regulatory issues, and accordingly further demonstration of the model in a military setting is warranted.

5.9.3 BASINS.MIL

In order to build greater familiarity and confidence for planned utilization of BASINS.MIL at installations, the following efforts should be pursued to support and better understand the existing capabilities.

- **Perform uncertainty analysis.** A need exists to quantify the uncertainty of modeling results achieved using BASINS.MIL. This analysis should determine the range of uncertainty associated with important model outputs, and compare that uncertainty to accepted levels within the modeling community. Critical model input and parameters for a BASINS.MIL application would be identified and reasonable percent perturbations from the calibration values, increases and decreases, for each would be established. Results of model sensitivity runs would be used to calculate the percent change in model output divided by the percent change in input/parameter value. Model input and parameters would be ranked by sensitivity metric to establish those with the greatest impact on model results for sediment and nutrient loadings.

  Using a Monte Carlo approach, an uncertainty analysis would be performed. This would involve execution of a large number of model runs (e.g., 500-1000) with selected model parameters (i.e., those showing high sensitivity factors in the sensitivity analysis) being randomly chosen from assigned probability distributions (e.g., normal, log normal, uniform). The model results would then be processed for the same output variables and locations as used in the sensitivity analysis to analyze and quantify the expected uncertainty in the model predictions. Uncertainty would be expressed by calculating the 5th and 95th percentiles of the ranked output, representing the range for 90 percent of the model results. The differences between the mean value and the 5th and 95th percentiles values would be calculated, divided by the mean and expressed as percentages, and averaged to express uncertainty as the percent deviation from the mean.

- **Investigate and resolve software installation issues.** Based on our team's experience on Fort Benning, the difficulty of downloading software on an internal server within the standard firewalls of a military installation may or may not be surmountable. A range of possible alternatives for accessing the BASINS.MIL software need to be investigated, and if necessary, a workaround established such as a secure external host server.

- **It would be beneficial to develop a navigation guide** (as described above) to help the DoD user navigate the various options available to build a military-enhanced BASINS model. The approach implemented in the guide would support the user in selecting the compliance requirements (e.g., TMDL), identifying the major impact on the streams (e.g., sediment), linking the requirement and stream impact to a land stressor (e.g., unpaved roads), considering the BMP(s) that could reduce the impact (e.g., road improvements), and then determining the appropriate software option that best fits the combination of the above (e.g., road model).

- **Perform cost/benefit analysis**. Based on the Project Team's best account, a formal cost/benefit analysis using standardized economic metrics has not been previously conducted for a watershed modeling application due to the difficulty in normalizing benefits for cost correlations. A creative and innovative approach that incorporates both quantitative and qualitative metrics is needed.

5.9.4 Other Related Needs and Opportunities

BASINS.MIL (military-enhanced BASINS modeling system) is a platform that already provides substantial potential to address a multitude of management considerations, and the potential can be significantly expanded through further customization and enhancements. Below is a list of potential model enhancements that merit consideration. These include incorporation of new datasets, methodologies, code refinements, applications and linkages. The list addresses field and process research-oriented issues and activities as well as model or modeling system development. Viewed from a different vantage point, the list identifies field and process knowledge and information resources (and modeling capabilities that depend on them) that we do and do not have, and by doing so it provides useful feedback to field and process research interests.

One need that is shared in common by numerous of the topics that are listed below is further investigation of field-scale processes and their impacts at the watershed scale. Many unanswered questions still exist regarding the delivery of sediment and pollutants from field scale, to the stream network, and eventually to the watershed outlet. As a first step to understanding these relationships, continued small-scale research is warranted that will establish how the flow and transport processes occurring in diverse areas (e.g., training areas, timber harvest areas, bottomland hardwood areas) actually work and can be mitigated.

With limited effort (in most cases), addressing the “missing pieces” that are identified below can greatly expand the utility of BASINS.MIL and its applications for Fort Benning and other DoD installations.

- **Integration of bank erosion methodology (Ikeda) into HSPF:** For the SERDP project the bank erosion formulation was integrated into EFDC/SEDZLJ. Since future watershed simulation at Fort Benning will likely not utilize EFDC/SEDZLJ, it is advantageous to integrate the same bank erosion formulation into HSPF. This approach is likely to be sufficient to characterize channel erosion and sedimentation. However, a remaining obstacle to effective use of the bank erosion formulation will be obtaining field data to provide both the location and potential magnitude of erosion for vulnerable channel areas.
- **Generalized and expanded 1-D hydrodynamic model:** AQUA TERRA is currently under contract to EPA Office of Research and Development to extend the flow routing capabilities in HSPF by implementing the full dynamic wave flow routing method. The changes will allow users the option to use either the existing routing method or the dynamic wave option. The initial focus of the code enhancement is to support modeling of small urban watersheds. Expanding the capability to address larger open channel reaches would be advantageous to support a broader range of military and non-military applications, including advanced sediment fate/transport formulations comparable to EFDC/SEDZLJ.
- **Integration of a simplified plant growth model into HSPF:** The multi-compartment plant canopy enhancement that has been integrated into HSPF for this project offers substantial opportunities for representing and evaluating a number of resource management practices. A parallel capability to simulate monoculture (single or dominant plant type) plant growth would further expand the ability of HSPF to simulate natural forest processes. Monoculture process formulations are available in two USDA models (SWAT, WEPP) that could be

integrated into the already enhanced HSPF model. These formulations represent light interception of the canopy by utilizing the basic Beer's Law equation that uses leaf area index as a predefined, species specific parameter. Other plant processes such as root growth, nutrient uptake, and yield harvest are also explicitly represented.

- **Impact of stream crossings:** Stream crossings can cause tremendous degradation to the streams through disruption of stream bed and banks, and generation of excessive amounts of sediment that can potentially exceed Total Maximum Daily Load (TMDL) limits for water quality downstream. Concern related to the potential impacts of stream crossings is especially high in the Good Hope Area of Fort Benning where a high density of stream crossing have been proposed and located.

  Some data on stream crossings and suspended sediment concentrations are available for Fort Benning. In 2006, as part of a SERDP-funded study (RC-1339) the effectiveness of an engineered hardened surface at a stream crossing to reduce soil erosion was investigated at Fort Benning. An articulated roadbed system (cabled concrete) was constructed on the banks of the Upatoi. Prototype optical sediment sensors (4 different designs), developed and fabricated at Kansas State University, were installed to monitor changes in suspended sediment concentrations before, during, and after the construction. Results of total suspended solids (TSS) before and after construction showed an obvious decreasing trend in TSS and indicated the effectiveness of the construction in reducing soil erosion at the crossing.

  Subsequent to this study, an ESTCP-funded project (RC-817) continued demonstration of the optical sediment sensors and a wireless sensor network which were installed on several military installations including Fort Benning. The wireless sensor network is a web-based, installation-wide, remote monitoring of suspended sediment flux and sediment loads. The project team hopes to make the data from the Fort Benning sensors available soon.

  These data and others are critical in determining a modeling approach to evaluate the effects of stream crossings on hydrology and water quality of Fort Benning streams. Figure 5.6 is a conceptual diagram that illustrates the components of a model simulation for a stream crossing. These components include: sediment sources (composition and concentrations), disturbance intensities (number of tanks and passes) and bank/bed geomorphology. Ideally, these components should be characterized both spatially and temporally. Without sufficient data, assumptions and averaging must be utilized in the modeling approach.

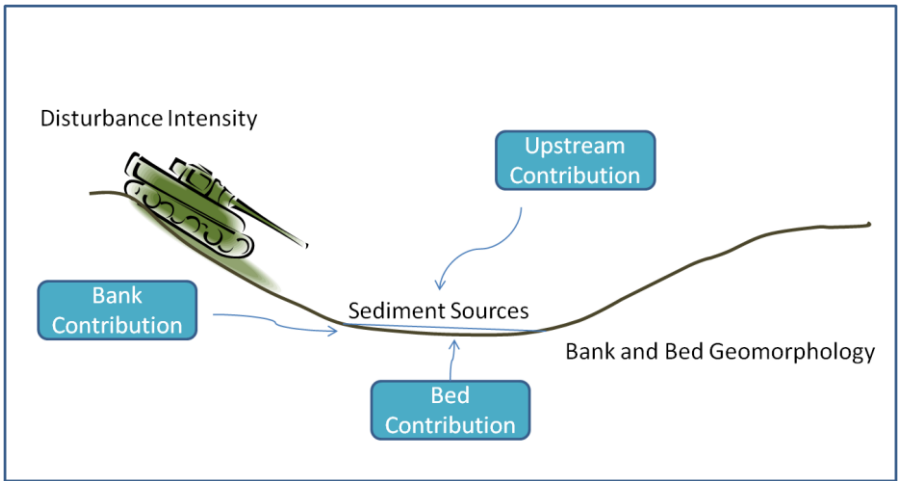

Figure 5.6 Conceptual Diagram of Stream Crossing

- **Refinement of HSPF EXTMOD:** EXTMOD needs user and system documentation, standard test runs and incorporation into an official HSPF release in order to extend the usability of the hybrid modeling concept and capability. The wrapper that ties WEPP and HSPF together should be enhanced to write EXTMOD input blocks in an existing UCI file in addition to writing HSPF WDM timeseries. This would allow incorporation of WEPP results into standard HSPF summary reports developed for SERDP. Additionally, HSPF could be enhanced to directly read HSPF binary formatted output files. Further, EXTMOD could be enhanced to include the ability to execute an external model during a HSPF run and process the external model's results (incorporation of the wrapper into HSPF).
- **Supplemental investigation of canopy issues related to prescribed burning:** While the ability to represent a multi-layer canopy has been implemented, the process knowledge that is necessary to most effectively use it is still lacking. The impacts of canopy changes (whether they are fire-induced or not) on infiltration, soil moisture, sediment erosion, organic matter content and many other state variables and processes require additional investigation.
- **Energy Independence and Security Act of 2007 (EISA) Section 438:** DoD Memorandum: Implementation of Storm Water Requirements under Section 438 of the EISA (DUSD(I&E), 2010) directs all DoD construction projects and redevelopment projects with a footprint of greater than 5,000 gross square feet to "maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the property with regard to the temperature, rate, volume, and duration of flow." Consistent with the intent of Section 438, DoD defines "predevelopment hydrology" as "the pre-project hydrologic conditions of temperature, rate, volume, and duration of storm water flow from the project site."

  Site designers must design, construct, and maintain storm water management practices to preserve or restore the hydrology at the site during the development or redevelopment process in compliance with Section 438. Site designers have two options to meet this standard: Option 1 provides a process to design, construct, and maintain storm water management practices that manage rainfall on-site, and prevent the off-site discharge of storm water from all rainfall events less than or equal to the 95th percentile rainfall event. Option 2 allows the site designers to design, construct, and maintain storm water management practices using a site-specific hydrologic analysis to determine pre-development runoff conditions instead of using the estimated volume approach of Option 1.

  Under Option 2, pre-development hydrology is determined based on site-specific conditions and local meteorology by using continuous simulation modeling techniques and tools such as BASINS.MIL. Option 2 has the advantage of reducing overall costs by more accurately identifying the optimal design parameters related to changes in hydrologic conditions.
- **Additional Sediment Data:** Fort Benning is commencing a monitoring program in October 2012 for the Good Hope Mechanized Training Area (GHMTA) to measure impact of BMPs on flow and sediment concentrations. Newly acquired flow and sediment monitoring data provide an opportunity to validate a portion of the FB Enhanced HSPF Model to determine how closely simulated results compare to observed data. This would involve extending the simulation period of the FB Model using extended weather records and the recently-collected USGS data and rating curves. The success of the validation of the FB Model within the Good Hope Area will be the implementation of a rigorous comparison between simulated results and observed data.
- **Legacy sediment:** Throughout the Eastern United States, large amounts of sediment associated with careless agricultural practices during the 19th and early 20th centuries have

been eroded from upland areas and deposited at lower elevations, often in the floodplains of the region's stream networks. These sediments, commonly known as 'legacy sediments', have resulted in significant change to stream morphology through burial of surrounding wetlands and incising channels that result in unstable stream banks (Thornton, 2009).

The potential for legacy sediments to contribute to total stream loads has raised questions about the relative impacts of current and historical land use activities that have resulted in elevated suspended sediment concentrations, a frequent and critical environmental concern. Recent research (Lockaby, 2008) documents that Fort Benning's streams are actively incising the legacy sediments that have accumulated in their beds and channels as well as the adjacent floodplains, supporting the premise that at least some degree of stream sediment impairment is due to transport of legacy sediments.

Effective planning to protect Fort Benning's streams, sustain the quality of the Installation's uplands, and possibly achieve a degree of restoration to the intermediate wetland and riparian areas, requires a better understanding than currently exists of the relative role of legacy sediments in effecting stream impairments. The addition of EFDC/SEDZLJ to the FB Baseline Model provides a means to approach investigation of legacy sources of sediment.

- **Climate change:** Climate change is expected to impose further changes to Fort Benning's future hydrologic and sediment erosion regime. According to the Intergovernmental Panel on Climate Change projections (Christensen et al., 2007), change in the State of Georgia is expected to result in warmer temperatures, more severe droughts and floods, and sea level rise. Projected climate impacts may amplify certain development-induced impacts, while reducing others.

  To reduce the likelihood of expanding the future restrictions to testing and training activities on installations, installations must be able to assess potential risks and opportunities from climate change and where appropriate, implement practices and strategies to adapt to future climatic conditions. Climate change assessments on Fort Benning's watersheds can be made by using the Fort Benning models in conjunction with the US EPA's Climate Assessment Tool (CAT) which creates climate change scenarios allowing the user to quickly assess a wide range of "what if" questions about how weather and climate could affect their system.

  CAT incorporates climate change scenarios by selecting and modifying an arbitrary base period of historical temperature and precipitation data from HSPF meteorological input data to reflect any desired future change or changes. After selecting a period of historical data to be modified (e.g., from an NCDC weather station used as meteorological input to a watershed model), CAT facilitates the application of one or more operations, or adjustments to that baseline time series. As a post-processing capability, CAT allows users to calculate hydrologic and water quality endpoints based on any variable or flux simulated and output by the HSPF model. CAT is not a stand-alone model. Rather, CAT is seamlessly integrated into the BASINS system through a series of graphical user interfaces. Application of CAT requires a pre-existing, calibrated HSPF application, such as the current FB Enhanced HSPF Model.

- **Urbanization:** Current and projected population pressures on natural lands are a growing concern in many regions of the United States, particularly in the South. In many rapidly expanding cities, development trends are outpacing population growth. As a result, forested land in this region is converted to human-modified urban uses at astonishing rates. Continual increasing populations will only expand the conversion of land from rural to urban uses, posing a major threat to the sustainability of Southern forests. Daily loss of forest land and wildlife habitat to urbanization renders the health of those forests that remain more

critical. As such, studies that quantify forest health conditions and assess correlations to land-use changes in surrounding areas are strongly needed (Deal, B. and J. Westervelt, 2007).

5.9.5 Policy Implications

In this section the relevance of the project findings and accomplishments to military policy issues is discussed. A starting point for doing so is recognizing that the EBM applications that were performed for the project were *proof-of-principle applications*. The simulation results from the proof-of-principal model applications indicate that the FB Enhanced Model performed within an acceptable/reasonable range; it is judged to be a reliable tool to account for cumulative impacts across the entire installation and to distinguish between off-site and on-site contributions. The proof-of-principle application for the GHMTA demonstrated that the model can be used to address specific management decisions regarding BMPs and has the scientific rigor to support budget analyses and requests for BMP implementation. The proof-of-principle application involving AQUATOX demonstrated a means for generating biotic endpoint information that can support regulatory compliance regarding aquatic species of concern.

Having successfully achieved these demonstrations, the stage has been set for using BASINS.MIL in more detailed applications to assess direct effects of policy decisions. Many of the recommended applications (Section 5.9.2) and extensions (Section 5.9.4) that have been identified are directed toward supporting internal policy decisions and/or establishing management practices. Included among these are the following:

- Prescribed burning analysis to identify optimal burning frequency
- Timber harvest impact analysis to more fully assess positive and negative consequences
- Vehicular stream crossing impact analysis to provide a basis for weighing the training benefits against the environmental consequences
- Relative effectiveness of alternative BMPs for mitigating sediment washoff associated with training activities
- Analysis of sediment loading allocations to satisfy TMDL requirements
- Training location impact analysis with respect to sensitive aquatic species
- Analysis of alternative LID strategies (and subsequent design) to satisfy EISA requirements
- Estimation of climate change impacts as a first step to establishing adaptation strategies and policies

SECTION 6.0
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A Watershed Modeling System for Fort Benning, GA Using the US EPA BASINS Framework

Final Report

APPENDICES

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A Watershed Modeling System for Fort Benning, GA Using the US EPA BASINS Framework

SERDP PROJECT SI-1547

REFINEMENT OF UNPAVED ROAD SIMULATION WITHIN THE FORT BENNING HSPF WATERSHED MODEL: A HYBRID APPROACH USING WEPP:ROAD

Final Report
Appendix A

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EXECUTIVE SUMMARY

The 2005 Base Realignment and Closure (BRAC05) decisions realigned thousands of additional troops and hundreds of military vehicles to Fort Benning GA 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.

For SERDP funded project (SI-1547) a comprehensive watershed management model for Fort Benning has been developed over the last three years using the EPA's Hydrological Simulation Program – FORTRAN (HSPF) watershed model (Bicknell et al., 2005). A baseline Fort Benning Watershed Model has been developed and applied to current watershed conditions (AQUA TERRA Consultants, 2010). The model addresses impacts on watershed hydrology, water quality and related ecosystems resulting from military activities and natural resources management. The entire watershed area containing the Installation (682 square miles) and 24 different land uses are represented.

An incremental objective of the SERDP project is to enhance the baseline Fort Benning HSPF watershed model that was developed during the first three project years to better reflect impacts from military training activities. To meet this objective, advantageous science enhancements to HSPF have been identified (AQUA TERRA Consultants, 2009), and the following three enhancements have been undertaken:

- Implementation of a generalized 'hybrid modeling' capability that enables use of HSPF in parallel with smaller-scale, more detailed models for specific land use disturbance
- Integration of more robust models for channel flow (EFDC) (Hamrick, 2007) and channel sediment transport (SEDZLJ) (Jones and Lick, 2001), as well as the capability to represent channel bank erosion (Ikeda et al., 1981)
- Development of a multi-compartment plant canopy module within HSPF useful for better representing land cover dynamics in Fort Benning's predominantly forested watershed

This report describes a hybrid modeling exercise that has been performed by taking advantage of the first of these improved modeling capabilities. The effort entails the development of a demonstration study focused on improving the capabilities that are used for representing and evaluating the unpaved road network at Fort Benning. Road erosion is commonly the largest contributor to sediment production within forest watersheds such as the one that encompasses Fort Benning, and the increases in vehicular travel associated with BRAC05 will impose additional construction and maintenance burdens on the Installation's roads, the majority of which are unpaved. Design, construction and management of unpaved roads at Fort Benning require methods and models for estimating road erosion that provide a level of detail that surpasses the capabilities currently provided by HSPF and similar watershed models. Nonetheless, the full impact of road management practices ultimately needs to be evaluated within the holistic watershed context.

A generalized capability has been developed within HSPF that enables performing hybrid model applications in which HSPF can be used for modeling catchment-scale phenomena, while one or more field- or hillslope-scale models are run in parallel to HSPF. These smaller-scale models (SSMs) can offer more detailed process formulations for specific activities, sources, or land uses. Using this hybrid modeling capability, the SSMs provide time series flow and loadings for localized areas with disproportionately large runoff or water quality impacts. These results are

introduced into HSPF as point sources, the impact of which can then be evaluated in a watershed context.

HSPF model applications utilize 'watershed segmentation', whereby the study area is divided into individual land (PERLND) and channel (RCHRES) segments, or pieces, that are assumed to demonstrate relatively homogenous hydrologic/hydraulic and water quality behavior. One criterion for establishing PERLNDs is land use type, and unpaved roads are one of 24 unique land segment types in the model. For the HSPF model the watershed was divided into 14 different weather regimes, and generalized characteristics (e.g., overland flow length, overland flow slope) for unpaved roads in each of the meteorological areas were developed. Unit area erosion from each segment was simulated, and applied to the total road area contained in each of the 131 localized sub-watersheds that are associated with the model's stream segments to estimate sediment loadings. A target sediment loading value for the road segments was determined based on literature. The fraction of the computed sediment washoff (i.e., delivery ratio) from the road that was delivered to the active channel was estimated using empirical data related to the size of watershed being modeled (USDA-NRCS, 1983). The literature value was reduced by the delivery ratio to establish the target value (5 tons/ac/yr) used to calibrate sediment simulation parameters. Sediment loadings resulting from PERLND simulation were introduced directly into the appropriate reaches represented within the modeled stream network (Figure E.1).

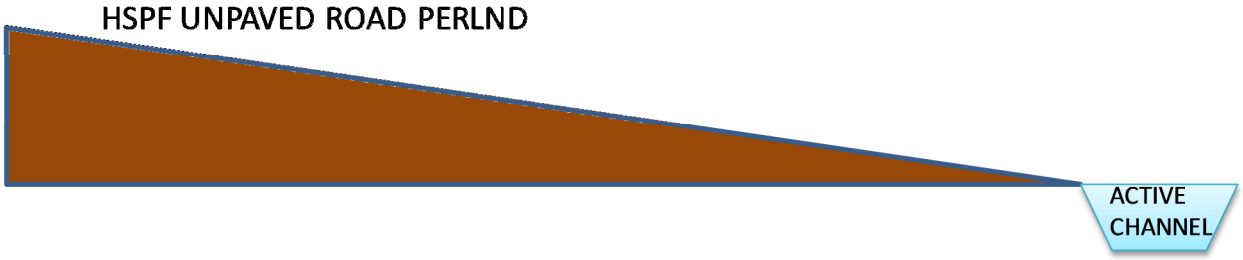

Figure E.1 Schematic for HSPF Characterization of Overland Flow Path for an Unpaved Road Segment (Direct Connectivity from Eroding Surface of HSPF Pervious Land Segment (Road + Fillslope) to Active Stream Channel

To make available a more robust set of formulations for simulating sediment washoff from Fort Benning's unpaved forest roads, a hillslope-scale runoff/erosion model (WEPP:Road) was subsequently applied to representative unpaved road segments in each of the 14 meteorological segments of the Fort Benning Watershed Model. The USFS WEPP:Road interface (Elliot et al., 1999) translates user input describing road and road setting characteristics into model parameters describing water balance and sediment transport processes modeled in the USDA Water Erosion Prediction Project (WEPP) Model (Flanagan and Nearing, 1995). In the WEPP model sediment is eroded by precipitation (interrill erosion) and scoured by runoff (rill erosion) along an overland path comprised of three overland flow elements (OFEs): road surface, fillslope, and forest buffer (Figure E.2). The estimated erosion/deposition along the overland flow path corresponds directly to the predicted physical transport of sediment across the flow path of the three OFEs. Hence, determination of a delivery ratio based on literature values is not necessary; instead, the delivery ratio is achieved by means of the modeled re-deposition of sediments in the buffer OFE. The net sediment export from the combined road and fillslope erosion/deposition phenomena enters the forest buffer OFE where additional erosion can occur at the beginning of the overland flow path through the buffer, typically followed by deposition that either partially or wholly diminishes the sediment load produced by upgradient erosion that eventually enters the active channel system.

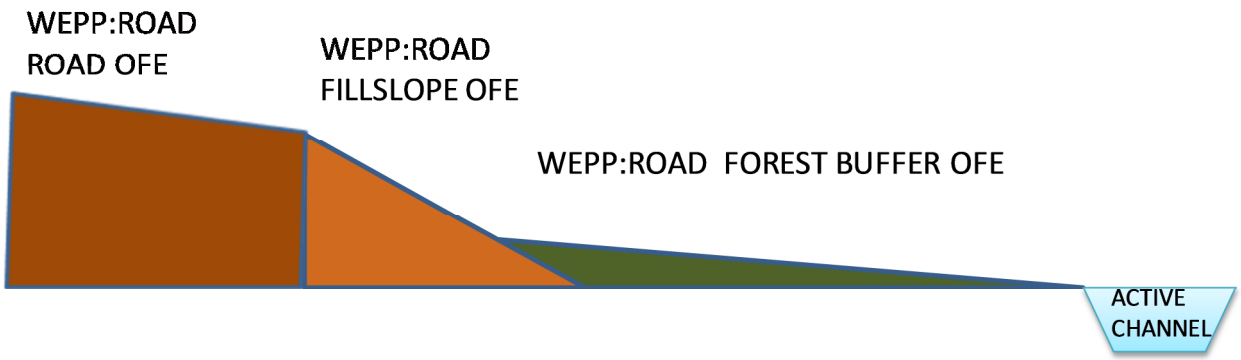

Figure E.2 Schematic for WEPP:Road Characterization of Overland Flow Path for an Unpaved Road Segment (Erosion/Deposition Modeled Along Overland Flow Path Comprised of Three Sequential Overland Flow Elements (Road, Fillslope, Forest Buffer)

Figure E.3 provides a flowchart of the application components and sequencing required for the Fort Benning application of WEPP:Road. The approach featured the following requirements and/or assumptions:

1. In a parallel manner to the watershed-scale HSPF simulation scheme for unpaved roads (and other land use types), a 'representative' road segment was selected for each of the 14 different weather segments into which the watershed model is divided. Net unit area erosion delivered to the stream system by travel across the flow path (road surface, fill slope, forest buffer) for each of the representative road segments was simulated.
2. For both model applications the unpaved road area estimates for each of the sub-watershed areas were assumed to include both the road surface and fill slope. For the PERLNDs modeled in HSPF the road and fillslope areas were combined into a single PERLND, while WEPP:Road modeled the two areas using separate OFEs. Thus, the forest buffer OFE associated with each road segment was not considered to be a component of the road area for purposes of computing unit area sediment delivery to the stream system.
3. The WEPP:Road interface typically utilizes regionalized, synthetically generated *daily* weather data, whereas the Fort Benning Watershed Model utilizes 14 much more localized historical *hourly* weather datasets to represent the sub-areas of the Installation. In the context of the Fort Benning hybrid modeling exercise the localized weather data were reformatted (using a "wrapper") into a breakpoint file, which enabled WEPP to perform its simulations using the same hourly data that drives the HSPF model.
4. After de-coupling the weather data that are typically provided by the WEPP:Road Interface to the WEPP Model, it was still necessary to provide to WEPP:Road input parameter values that define the road characteristics and physical settings for each of the 14 representative road segments, so that the interface could generate the contents of three input files (Soils, Slope, Management) that provide values for the remainder of the input required by the WEPP Model. Our approach was to maintain as much consistency between the physical meaning implied/imposed by parameters/values that were originally used for modeling unpaved roads using HSPF and the parameters/values subsequently required for modeling the same unpaved roads using WEPP:Road.
5. Additional WEPP input requirements are provided using regional parameter values that have been pre-established and included in the files that WEPP:Road provides to the

WEPP model once the geographic location of the model application has been established. To take advantage of the values most representative of the Fort Benning watershed, those established in the WEPP:Road interface that are closest in proximity to the Installation (Opelika, Alabama) were adopted and used for the Fort Benning modeling.

6. The input provided to WEPP:Road for all representative road segments at Fort Benning characterized the roads as outsloped; comprised of native materials and lacking addition of gravel or rock; and subject to heavy traffic.

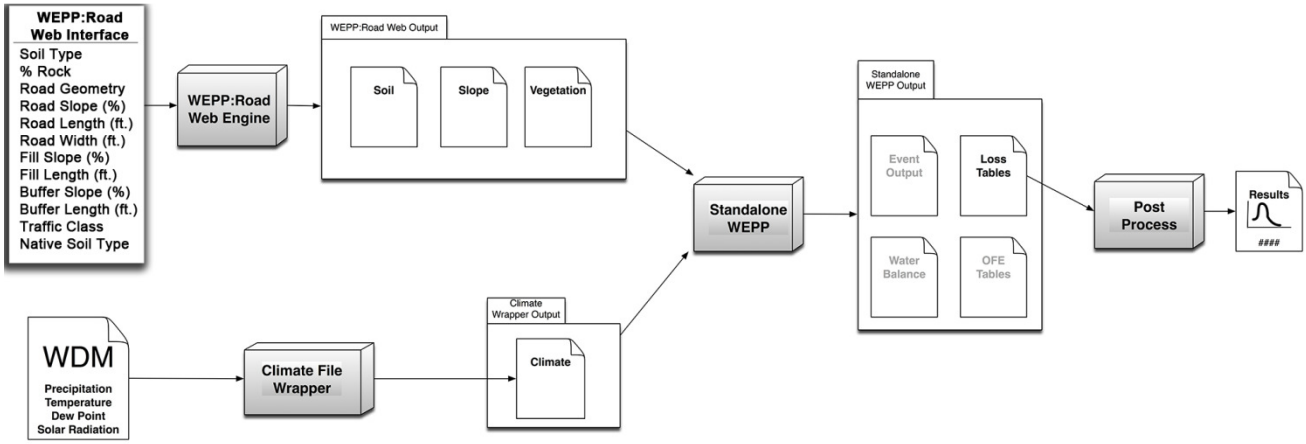

Figure E.3 Flowchart for Application of WEPP:Road to Estimate Sediment Loadings from Fort Benning's Unpaved Roads

The current WEPP:Road results have been achieved using the model in a stand-alone manner to estimate unit area erosion for the erosional OFEs (road and fillslope). Results for the 14 representative road segments fall in a similar range (1.3 – 2.9 tons/ac/yr) to those generated in the HSPF watershed baseline simulation (1.1 – 2.7 tons/ac/yr).

Using automated procedures available for WEPP:Road it is possible to evaluate the sensitivity of road erosion at Fort Benning to road segment length and slope (top) and 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.) This capability has been utilized to provide better understanding of the potential benefits of road siting, design, and maintenance practices that might be employed by the Installation. By integrating WEPP:Road into the Fort Benning Watershed Model, the resulting hybrid model will enable representation and evaluation of (1) siting decisions such as increased buffer widths, (2) alternative road design such as slope constraints or road width limits, and (3) management actions such as gravel additions.

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Dr. John Hall is the Sustainable Infrastructure (SI) Program Manager with SERDP, and Mr. John Thigpen of HydroGeologic is his Assistant. Ms. Carrie Wood and Ms. Kristen Lau of HydroGeologic also assist Dr. Hall and Mr. Thigpen in administering this contract.

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The Principal Investigator (PI) for this project is Mr. Anthony Donigian, Jr. with AQUA TERRA Consultants, and Dr. Patrick N. Deliman serves as the Co-PI for ERDC. Direct contributors to the report included Mr. John Imhoff, Mr. Brandon Gonzales, and Mr. Anthony Donigian, Jr. at AQUA TERRA; and Dr. Patrick Deliman at ERDC.

SECTION 1
PROJECT BACKGROUND

Watershed models are used to assess and evaluate activity impacts, pollutant sources, and management practices at a variety of spatial scales. When activities with limited areal extent do not result in disproportionately large impacts, the smaller scale activities can either be ignored or blended with surrounding activities for the purposes of watershed modeling and associated planning carried out using a lumped-parameter model, such as HSPF. However, there are numerous small-scale activities that potentially impose a significant impact on the overall fluxes of water, sediment and/or water quality constituents. For example, scientific literature and practical experience suggest that the relatively small area of land that comprises unpaved roads through a forest-dominated watershed such as Fort Benning's can generate the largest contribution of sediment washoff from an entire watershed (Jha et al., 2007; Elliot et al., 1999; Brent, 2007).

Not surprisingly, localized activities that have the potential to impose large runoff or pollutant washoff impacts are primary targets for developing and implementing best management practices. Given that a fundamental function of watershed modeling is to assess the effectiveness of management practices, it is clear that the formulations used to represent such critical localized activities/conditions also provide the basis for assessing the effectiveness of alternative siting, design and management practices.

Shoemaker et al. (2005) conclude that the spatial detail required for simulation of Best Management Practices (BMPs), especially stormwater and nonpoint source management techniques, place particular challenges on the development of practical model applications. Most applications use simplified estimates of BMP adoption and benefit to evaluate the potential for load reduction. Land use-based management is often represented by a simple loading reduction. For example, a change in crop practice could be estimated by a reduction in cropland loading expressed as a percentage of the total load. In more detailed simulations, individual BMPs can be explicitly modeled and their effects on water quality can be simulated directly. For example, in an urban watershed, specific stormwater management ponds can be simulated as a hydrologic unit and the trapping of runoff and pollutants simulated for each pond. Although simulation of individual BMPs can be achieved using existing modeling systems, the effort for data collection, representation, and detailed modeling for numerous BMPs for watershed-wide applications is often high.

The traditional mechanism for representing significant flow/pollutant sources generated by small spatial scale activities within lumped-parameter watershed models is to include them as 'effective' point sources. That is to say, a time series of water, chemicals, and/or sediment are added to a specified target area (e.g., a HSPF land segment or channel reach segment) to represent such contributions. The most common use of point sources is in representing the contributions of municipal and industrial wastewaters. Government reporting requirements (e.g., those related to NPDES permitting) for municipal and industrial wastewater treatment (WWT) facilities often expedite the characterization of source water and chemicals discharged from WWT contributors. Monitoring data can be used to develop the timeseries values of flow and chemical loads from each discharger, and discharges can be linked to appropriate receiving water reaches in the model channel network.

Representing other activities with small spatial scale that have the potential to contribute (or eliminate) significant fluxes of runoff, sediment or chemical pollutants has always been a challenge in the context of watershed models. Typically, significant simplifying assumptions have been made. For example, animal feedlots, which are recognized as a significant

contributor of nutrients to the streams of the Chesapeake Bay watershed, were represented in EPA's Chesapeake Bay Phase 4 Watershed Model as impervious land segments with a constant concentration of nutrients in the washoff produced by storm events. The size of the feedlot areas within each modeling segment was adjusted to reflect relative density of animals within existing feedlots (Donigian et al., 1991).

In reality, appropriate representation of the fluxes generated by certain small-scale activities/conditions requires the use of modeling formulations and consideration of factors that are unique and more complex than the more generalized formulations that are applied to estimate fluxes from the surrounding lands. In addition to the forest roads and animal feedlots mentioned above, other examples of localized activities/conditions that most likely warrant specialized model formulations include:

- Heavy maneuver military training areas
- Stream crossing areas for armored vehicles
- Wetlands
- Low impact development (LID) clusters
- Urban drainages
- Detention ponds

In recent years model developers have begun to tackle the challenge of merging more detailed formulations for localized activities with holistic, and more generalized analysis of larger scale watersheds. For example, Weintraub et al. (2003) have incorporated a biozone module into the Watershed Analysis Risk Management Framework (WARMF) model that represents the treatment processes taking place within the biologically active soil layer that develops in a soil receiving septic tank effluent from onsite wastewater systems (OWS). The modeling approach requires specifying the number of OWS in each watershed modeling segment as well as effluent volumes and chemical characteristics. Processes modeled in the localized biozones include changes to porosity, field capacity, infiltration rate, as well as nitrification and decay of fecal coliforms and BOD.

To address multi-scale watershed modeling requirements within agricultural watersheds, Saleh et al. (2000), Osei et al. (2000), and Gassman et al. (2001) report on studies that have taken advantage of the capabilities of the combined SWAT (Neitsch et al., 2002) and APEX (Steglich and Williams, 2008) models by simulating an environmental baseline and agricultural BMPs such as crop rotation and filter strips at the field level using the APEX model, and routing the results from APEX and the remaining land uses within a watershed using the SWAT model. The edge-of-field results generated by APEX are input as point-source time series to the SWAT subbasin outlet that contains each localized area modeled using APEX. Subsequently Saleh and Gallego (2007) have developed an automated program referred to as SWAPP to convert SWAT files to and from APEX format and simulate SWAT and APEX simultaneously.

These integrated uses of watershed and small-scale models have come to be known as a 'hybrid modeling' approach. The hybrid applications, such as those described above, for rural onsite wastewater systems and field scale agricultural BMPs, not only enable a better representation of the runoff and pollutant washoff contributions from significant localized activities/conditions, but also enable more realistic and robust assessment of alternative management practices. For example, WARMF has been used to compare the combined effects of all the OWS in a catchment versus the anticipated impacts of replacing them with a centralized wastewater disposal system. While modeling the specific activities (rural OWS, agricultural BMPs) for which hybrid modeling techniques have already been developed and used may not be pertinent to most military settings, the hybrid modeling approach itself offers parallel opportunities for modeling a variety of small-scale activities that are more relevant to

military land use, including heavy maneuver vehicular training areas, tank crossings, forest roads, timber harvesting, wetlands, and others.

Figure 1.1 demonstrates how a lumped-parameter model such as HSPF might be integrated with small-scale models to produce a hybrid modeling system. Small-scale models can be applied to localized sources – training areas, unpaved roads, urban drainage systems, wetlands – and the timeseries output from these models can in turn be introduced into the overarching watershed model system at whatever point the actual local sources enter the stream or watershed domain. This system retains the efficiency of the lumped-parameter models for long-term model runs, while at the same time enabling the detailed representation of the individual small-scale sources.

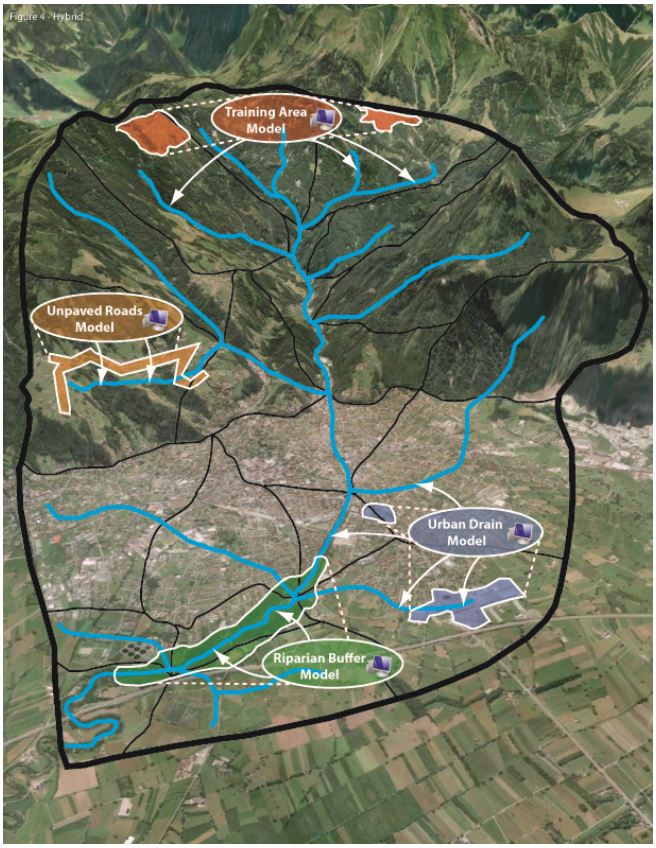

Figure 1.1 Hybrid Modeling Schematic with Local Source Representation

The 2005 Base Realignment and Closure (BRAC05) decisions realigned thousands of additional troops and hundreds of military vehicles to Fort Benning GA 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.

For SERDP funded project (SI-1547) a comprehensive watershed management model for Fort Benning has been developed over the last three years using the EPA's Hydrological Simulation Program – FORTRAN (HSPF) watershed model (Bicknell et al., 2005). A baseline Fort Benning Watershed Model has been developed and applied to current watershed conditions (AQUA TERRA Consultants, 2010). The model addresses impacts on watershed hydrology, water quality and related ecosystems resulting from military activities and natural resources management. The entire watershed area containing the Installation (682 square miles) and 24 different land uses are represented.

An incremental objective of the SERDP project is to enhance the baseline Fort Benning HSPF watershed model that was developed during the first three project years to better reflect impacts from military training activities. To meet this objective, advantageous enhancements to HSPF have been identified (AQUA TERRA Consultants, 2009), and the following three enhancements have been undertaken:

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

- Integration of more robust models for channel flow (EFDC) (Hamrick, 2007) and channel sediment transport (SEDZLJ) (Jones and Lick, 2001), as well as the capability to represent channel bank erosion (Ikeda et al., 1981)
- Development of a multi-compartment plant canopy module within HSPF useful for better representing land cover dynamics in Fort Benning's predominantly forested watershed

This report describes the first application of the generalized capability that has been developed within the HSPF model that enables performing hybrid model applications. The effort entails the development of a demonstration study focused on improving the capabilities within the watershed model that are used for representing and evaluating runoff and sediment erosion from the unpaved road network at Fort Benning. To do so, WEPP:Road (Elliot et al., 1999), a hillslope-scale model and model interface for unpaved forest roads has been used as the modeling 'partner' to the HSPF model in a hybrid model demonstration. As previously noted, road erosion is commonly the largest contributor to sediment production within forest watersheds such as the one that encompasses Fort Benning, and the increases in vehicular travel associated with BRAC05 will impose additional design, construction and maintenance challenges related to the Installation's road network, the majority of which is unpaved. Meeting these challenges requires evaluation methods and models for estimating road erosion that provide a level of detail that surpasses the capabilities currently provided by HSPF and similar watershed models. Nonetheless, the full impact of road management measures ultimately needs to be evaluated within the holistic watershed context.

SECTION 2
PROJECT OBJECTIVES

The overall objectives for the component of the SERDP Project SI-1547 that is described in this report are as follows:

1. **Refine the evaluation of runoff and sediment erosion achieved by the baseline, watershed-scale simulation of Fort Benning's unpaved road network.** The baseline watershed model estimates runoff and erosion phenomena for the unpaved roads using generalized formulations. Efforts devoted to developing methods for adjusting HSPF parameter values to represent washoff processes on forest roads may be of little value in refining the evaluation. There is an apparent mismatch in modeling requirements between those needed for simulating road erosion (i.e., detailed, process-based formulations representing a variety of road setting and design conditions) and those needed for simulating sediment erosion from more generalized watershed segments (i.e., lumped consideration of more generalized or typical settings and land conditions by using formulations dependent on calibration).
2. **Provide a modeling tool within the overarching watershed model that enables evaluation of road siting, design, and management alternatives.** It is unlikely, regardless of the reasonableness of model parameter values that might be established, that the current HSPF formulations could represent the factors/phenomena that are critical to road erosion sufficiently well to enable the evaluation of construction alternatives at the scale appropriate for unpaved roads. In certain forest watershed settings field monitoring studies have demonstrated reductions in sediment erosion by as much as 70% as a result of implementing alternative road construction practices (Elliot et al., 1999). In order for the Fort Benning Watershed Model to provide the capability to evaluate the impacts of specific siting, design and management practices on runoff and erosion, it was necessary to integrate and use a more detailed model to evaluate the unpaved road network. The model must be capable of effectively representing critical factors such as stream buffer widths, gravel additions, and alternative slope/grade requirements.
3. **Demonstrate the HSPF 'hybrid modeling' capability developed for Fort Benning Watershed Model.** Development of a generalized hybrid modeling capability is a component of the Enhancement Plan for the overarching Fort Benning Watershed modeling project. This capability will enable the combined use of HSPF and a variety of smaller-scale models that provide process-based formulations for specific activities/conditions; a hybrid modeling approach is clearly advantageous for accommodating the more detailed simulation of forest roads in conjunction with the more generalized, coarser scale land use types/conditions that the watershed model will simulate.

SECTION 3
PROJECT APPROACH

The Model Enhancement Report (AQUA TERRA Consultants, 2009) for the overarching SERDP project set the groundwork for a hybrid model application utilizing the HSPF model (Bicknell et al., 2005) for watershed-scale simulation of all land use types within the Fort Benning watershed, with the exception of the unpaved road network. USDA's hillslope-scale model WEPP (Flanagan and Nearing, 1995) used in conjunction with the USFS's model interface WEPP:Road (Elliot et al. 1999) was selected for application to the unpaved roads. Figure 3.1 summarizes the project approach for accomplishing the hybrid model application. Corresponding sections of this report that provide details for each component effort are indicated in the figure boxes, and a brief explanation of each element of the effort is provided directly following the figure.

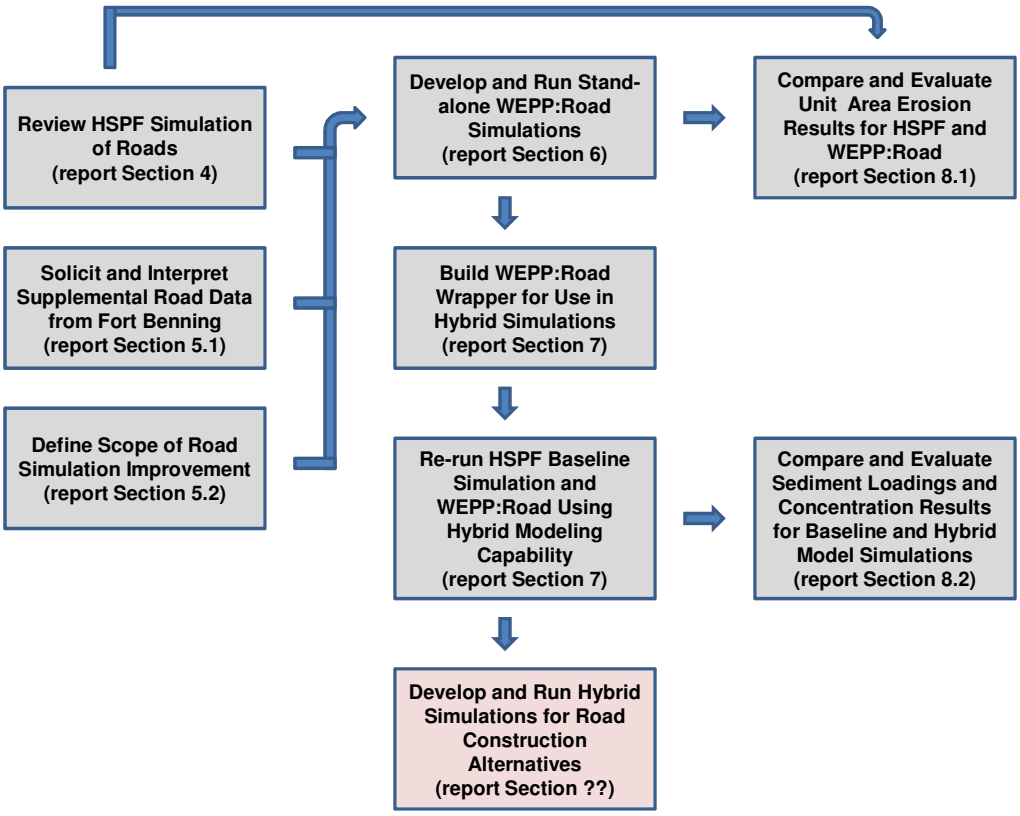

Figure 3.1 Flow Chart Depicting Project Approach

1. Review watershed model (HSPF) representation of roads. The HSPF simulation of runoff and sediment erosion from unpaved roads in the baseline watershed model utilized generalized process algorithms to represent all segments, including the unpaved roads. Unique target sediment loading targets were established for each land use type and then used to calibrate the model parameters that drive sediment erosion. An essential first step to 'improving' the simulation of unpaved roads was a review of the methods and values used in the baseline simulation.

2. Solicit and interpret additional road information from Fort Benning. The WEPP:Road application accommodates a more detailed representation of roads that could benefit from obtaining and using data that were not directly relevant to parameterizing the HSPF model.
3. Define scope of road simulation 'improvement'. HSPF and WEPP:Road results can be integrated using various strategies. For example, the unit area runoff/erosion estimates generated by HSPF could be replaced by estimates for the same erosional areas (road surface and fillslope) generated by WEPP:Road, followed by application of the same stream delivery ratio used in the original HSPF simulation to determine edge-of-stream loadings. Alternatively the WEPP:Road estimates for runoff/erosion computed by WEPP:Road for the erosional surfaces could be introduced into the forest buffer and further modeled by WEPP:Road to estimate the edge-of stream delivery, thereby eliminating the need to apply a delivery ratio.
4. Develop and run stand-alone WEPP:Road simulations. This effort entails establishing the method of representing/implementing improvements using WEPP:Road input options; building and populating a wrapper to enable automated simulation of representative reaches for all model segments; and investigating the sensitivity of key WEPP:Road input parameters.
5. Compare and evaluate unit area erosion results for HSPF and WEPP:Road. This effort provides a basis for understanding the differences that are achieved by using hill-slope scale process modeling to replace watershed-scale process modeling.
6. Build WEPP:Road wrapper for use in hybrid simulations. The wrapper provides and formats all input needed by WEPP:Road, executes the model, reads results produced by the model and formats them into a HSPF-compatible format.
7. Re-run HSPF baseline and WEPP:Road simulations using hybrid modeling capability. This effort enables evaluation of *watershed-scale impacts* of road runoff/erosion simulated at a hillslope scale.
8. Compare and evaluate total sediment loadings to stream segments and concentration results for baseline and hybrid model simulations. This effort provides a basis for understanding differences in model results achieved by the two modeling strategies within localized stream segments and from a whole-watershed perspective.
9. Develop and run hybrid simulations for road construction alternatives. Project objectives emphasize developing a methodology that enables evaluation of road siting, design and maintenance alternatives. This final step entails adjusting WEPP:Road input to represent alternatives and re-running the hybrid model to provide a basis for evaluating impacts.

3.1 LIMITATIONS OF MODELING APPROACH

The following phenomena are not considered/represented by either the HSPF or the WEPP:Road simulations performed for this study:

1. Gully erosion. HSPF has a generalized capability to represent gully erosion (see Appendix B). However, gully erosion occurs outside of the defined HSPF unpaved road segment areas, and hence is not accommodated in the baseline simulation. If gully erosion were to be represented in an improved simulation of unpaved road impacts using HSPF, the area of the unpaved road segments would likely need to be expanded to include gully areas and/or 'special actions' might need to be represented to mimic gully behavior.

While the WEPP model is also capable of representing gully erosion, the capability is disabled by the instructions passed to WEPP by the WEPP:Road Interface. To represent gully erosion in the WEPP simulations, the pre-assigned values for certain critical input parameters for the hillslope and buffer would need to be modified.

2. Impacts of road/ditch maintenance (i.e., grading). Grading procedures and frequency are identified in the literature as one of the four most important determinants of the magnitude of sediment erosion; these maintenance activities are not represented in either the baseline HSPF simulation or the subsequent WEPP:Road simulations. While grading could be represented in HSPF by using the Special Actions capability to alter key parameters representing road surface condition at points in time corresponding to a maintenance schedule (e.g., semi-annually), the most promising approach to evaluation a grading scenario using WEPP:Road would likely be to develop an alternative 'snapshot' for a road that results from the grading frequency/techniques that need to be evaluated.

SECTION 4
REVIEW OF APPROACH AND RESULTS FOR WATERSHED-SCALE (HSPF) UNPAVED ROAD SIMULATION

4.1 MODEL ASSUMPTIONS AND PROCEDURES

The process of sediment simulation in watershed models such as HSPF is preceded by developing a calibrated hydrology model for surface runoff and instream flow. When this has been achieved, sediment simulation involves numerous steps in estimating model parameters and then determining appropriate adjustments needed to ensure a reasonable simulation of the sediment sources, delivery and transport behavior within the channel system (Donigian and Love, 2003). These steps include:

1. Estimating target (or expected) sediment loading rates from the landscape, often as a function of topography, soils, land use, and management practices.
2. Establishing reasonable initial values for the parameters used in HSPF land surface sediment washoff formulations, and then calibrating the model by adjusting these parameters to gain agreement between computed loading rates and established target rates. This procedure is performed for individual land use segments and collectively for subwatersheds and the entire watershed.
3. Adjusting scour, deposition and transport parameters for the stream channel to mimic expected behavior of the streams/waterbodies.
4. Analyzing overall sediment budgets for the land and stream contributions, along with stream aggrading and degrading behavior throughout the stream network.
5. Comparing simulated and observed sediment concentrations, including particle size distribution information, and load information where available.
6. Repeating steps 1 through 5 as needed to develop a reasonable overall representation of sediment sources, delivery, and transport throughout the watershed system.

The HSPF land surface sediment washoff formulations are included in their entirety in Appendix B to support this summary discussion.

HSPF model applications utilize ‘watershed segmentation’, whereby the study area is divided into individual land (PERLND) and channel (RCHRES) segments, or pieces, that are assumed to demonstrate relatively homogenous hydrologic/hydraulic and water quality behavior. One criterion for establishing PERLNDs is land use type, and unpaved roads are one of 24 unique land segment types in the model. For the HSPF model the watershed was divided into 14 different weather regimes, and generalized characteristics (e.g., overland flow length, overland flow slope) for unpaved roads in each of the meteorological areas were developed. Unit area erosion from each segment was simulated, and applied to the road area contained in the localized sub-watersheds associated with model’s 131 model stream segments to estimate sediment loadings.

Obstacles to flow/transport result in re-deposition of a fraction of the sediment eroded by rainfall and scoured by runoff. HSPF assumes that the re-deposited soil remains in the unpaved road area and is available for transport by subsequent storm/runoff events. An additional assumption is made that the travel time in between the exit point from the HSPF unpaved road PERLND areas and the entry point to the active channel is small, and hence the opportunity for significant changes in scour/deposition is also small.

A target sediment loading value for the road segments was determined based on literature. Literature values commonly fell in the range of 2 to 20 tons/acre/year (AQUA TERRA Consultants, 2009). The fraction of the computed sediment washoff (i.e., delivery ratio) from the road that was delivered to the active channel was estimated using empirical data related to the size of watershed being modeled (USDA-NRCS, 1983). The high-end literature value was reduced by the delivery ratio to establish the target value (5 tons/ac/yr) used to calibrate sediment simulation parameters. Sediment loadings resulting from PERLND simulation were introduced directly into the appropriate reaches represented within the modeled stream network (Figure 4.1).

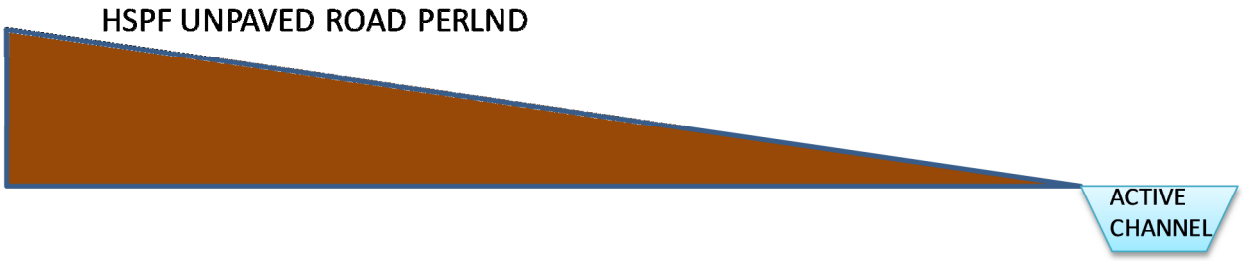

Figure 4.1 Schematic for HSPF Characterization of Overland Flow Path for an Unpaved Road Segment (Direct Connectivity from Eroding Surface of HSPF Pervious Land Segment (Road + Fillslope) to Active Stream Channel.

4.2 WEATHER DATA

As noted above, the purpose of segmenting the watershed is to divide the study area into individual land segments that are assumed to produce a homogenous hydrologic and water quality response. The segmentation then allows the user to assign identical model parameter values to those parts of the watershed that are expected to produce the same unit response of runoff and sediment washoff for a uniform set of meteorological conditions. Where the weather patterns vary across a watershed, it is necessary to also divide the land segments by meteorology to accurately reflect spatial meteorological variability and its effect on the hydrology and water quality of the watershed.

A full hydrology and water quality modeling exercise using HSPF requires the following types of weather data:

1. precipitation
2. air temperature
3. dewpoint temperature
4. windspeed
5. solar radiation
6. potential evapotranspiration

For the HSPF model development and application Thiessen network boundaries were developed using the location of meteorological stations in and around Fort Benning; a Thiessen analysis is a standard hydrologic technique to define the polygons about each gage to define the area represented by the meteorological data recorded at each gage. Results of the analysis led to defining 14 meteorological segments (Figure 4.2) within the Fort Benning watershed(s). Continuous timeseries of hourly values for all six of the weather data types were developed as input for the Fort Benning application by methods described by AQUA TERRA Consultants (2010). The HSPF and WEPP:Road simulations that are compared in this report utilized a seven-year period of the weather data (October 1999 to September 2006) that corresponds to the calibration period for the baseline HSPF model.

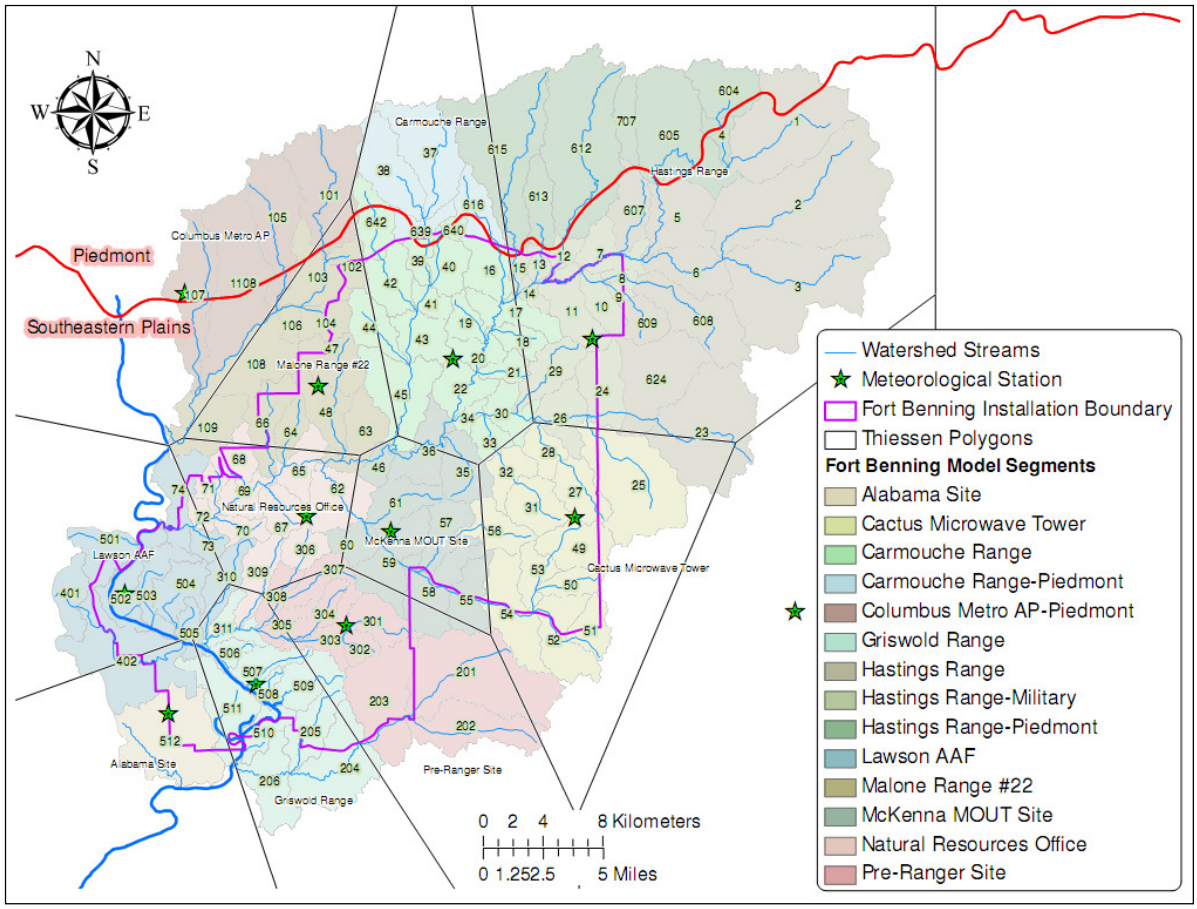

Figure 4.2 Fort Benning Watershed Model Segmentation

The watershed's subbasins were assigned to each meteorological station based on their location and the polygon area derived from the Thiessen network. During the modeling, precipitation from each meteorological station (indicated as green stars in Figure 4.2) is applied to the neighboring subbasins based on the Thiessen analysis.

It should be noted that the period (1999-2006) for which sediment erosion estimates generated by HSPF and WEPP:Road are being compared was a fairly dry one. Whereas average annual precipitation across the Fort Benning watershed ranges between 50 and 52 inches, the averages for the seven-year period for the meteorological stations used for this study ranged from 32.5 inches to 47.5 inches (AQUA TERRA Consultants, 2010).

4.3 HSPF PARAMETER DEVELOPMENT AND CALIBRATION

The baseline simulation performed using HSPF encompassed characterization and calibration of unique PERLNDs for 24 land use types as represented in 14 meteorological segments. Within this model development context, a comparable level of detail and effort was devoted to nearly all of the land use types. The exception, however, was the considerable effort that was expended to perform a search of literature reporting sediment erosion data for unpaved forest roads (AQUA TERRA Consultants, 2009).

Of the numerous parameters that are used in HSPF to characterize runoff and sediment washoff from pervious land segments (PERLNDs), those most significant in differentiating the unpaved road areas from other land use types include the following:

4.3.1 Hydrology Parameters

Slope of overland flow plane (SLSUR): For the HSPF unpaved road segments a single composite slope was computed for all roads in each of the HSPF meteorological segments using an ESRI GIS tool that estimates the X-Y-Z slopes for all grid cells classified as unpaved road; the slope estimates are computed based on elevational information for the cell of interest and the 48 surrounding cells of closest proximity. Using this methodology, the overland flow slopes (SLSUR values) assigned to the unpaved road segments for the HSPF meteorological segments range from 0.034 to 0.086 ft/ft (see Table 4.1 and Figure 4.3). The DEM data used for this analysis had a 10 meter by 10 meter grid dimension.

Length of overland flow plane (LSUR): LSUR values are assigned based on known relationships to SLSUR: the higher the SLSUR value, the lower the LSUR value and vice-versa. For the range of slopes estimated for the Fort Benning meteorological segments, the resulting range of LSUR values is small, with the lowest value being 250 feet and the highest value being 300 feet (see Table 4.1 and Figure 4.3).

Index to mean soil infiltration rate (INFILT): A uniform value of 0.05 in/hr was established through calibration for all unpaved road segments at Fort Benning. This value is the lowest that was established for any land use among the 24 that were represented in the Fort Benning Watershed Model PERLNDs. Elliot (personal communication, 2010) observes that this value is close to the observed hydraulic conductivity values for roads, and contends that in forests, the management of the soil has a greater effect on the soil runoff and erosion response than does the texture. In USFS rainfall/runoff studies on roads, Elliot found that the hydraulic conductivity of a sandy loam road soil was about 3 mm/hr (0.12 in/hr). Elliot and his colleagues suggest that when roads are constructed, they are often constructed in, or with, material from the C horizon, which may have very different properties than an A horizon soil and typically contain a greater fraction of clay, which significantly reduces the infiltration capacity.

For the sake of comparison, INFILT values for wetlands were set to 0.245 in/hr (high end), and a typical value for the PERLNDs representing most other land use types was about 0.095. INFILT is primarily a function of soil characteristics, and value ranges have been related to SCS hydrologic soil groups (Donigian and Davis, 1978). For the sandy loams (SCS hydrologic soil group A) that predominate Fort Benning, low runoff and a significantly larger INFILT value in the range of 0.4 to 1.0 in/hr would be characteristic; however, road construction practices (noted in previous paragraph), and compaction by vehicular traffic are expected to reduce infiltration capacity and increase runoff and erosion.

Subsurface (lower zone) nominal water storage (LZSN): A uniform value of 3.5 inches was established through calibration for all unpaved road segments at Fort Benning. As was the case with INFILT values, the unpaved roads have the lowest values that were established for any land use among those that were represented in the Fort Benning watershed PERLNDs. For comparison, LZSN values for wetlands were set to 10 in. (high end), and a typical value for the PERLNDs representing most other land uses was about 4.5 inches.

4.3.2 Sediment Parameters

Coefficient for transport of detached sediment (KSER): This parameter is used to calculate the capacity of runoff to transport detached sediment off the road PERLNDs. Parameter values were calibrated to meet the overall target loadings reported in the literature as well as at the

outlet of streams used for instream sediment calibration. The KSER values established through calibration for the unpaved road segments for the HSPF meteorological segments range from 3.0 to 6.2 (Table 4.1). These values represent unpaved roads as among the most erodible PERLND types represented in the watershed model. Compared to PERLNDs that represent non-military land uses considered as a group, the average KSER values established for unpaved roads result in about two and a half times as much sediment transport capacity as do the non-military land use PERLNDs for an equal amount of surface runoff capacity. Compared to the KSER values established for unpaved roads, those established for the other two military land use PERLNDs (heavy maneuver areas, tank trails) are higher than those for unpaved roads and result on the average in two and a half and one and a half times as much sediment transport capacity, respectively.

Detached sediment storage (DETS): HSPF includes a dynamic storage term for detached sediment available for transport by runoff (DETS). The value of DETS is increased by rainfall impact and decreased by sediment washoff transported by runoff waters. Additional increments to DETS corresponding to traffic disturbance were represented in the HSPF model by re-setting the value of DETS at the beginning of each month (using the model's Special Actions capability) to ensure that an increased level of detached sediment was available for transport by runoff during storm events. The DETS monthly re-set values for 14 meteorological segments ranged from 7.0 to 8.5 tons/ac (Table 4.1). The availability of detached sediment is not impacted by traffic disturbance on PERLNDS that represent non-military uses, and consequently the DETS values are not re-set by Special Actions. Compared to PERLNDs that represent non-military land uses considered as a group, the average initial DETS values established for unpaved roads result in about five times as much detached sediment storage as that established for the non-military land use PERLNDs. Compared to the DETS values for unpaved roads, those established (and also re-set on a monthly basis) for the other two military land use PERLNDs (heavy maneuver areas, tank trails) are comparable (8.0 tons/ac for heavy maneuver areas, 6.0 tons/ac for tank trails).

Fraction of land protected from erosion (COVER): The fraction of a PERLND that is subject to erosion is determined as 1.0 minus the value of COVER. A value of 0.03 was assigned uniformly to the COVER factor for all unpaved road PERLNDs throughout the Fort Benning watershed, corresponding to nearly complete lack of vegetative cover.

Low (2 tons/ac/yr) and high (20 tons/ac/yr) target sediment loading values for the unpaved road segments were determined based on literature (AQUA TERRA Consultants, 2009), and the high value was selected as the calibration target for the HSPF simulation of current watershed conditions. The fraction of the computed sediment washoff (i.e., delivery ratio) from the road that was delivered to the active channel was estimated as 0.25 by using empirical data related to the size of watershed being modeled (USDA-NRCS, 1983). The high-end literature value was reduced by the delivery ratio to establish the target value (5 tons/ac/yr) used to calibrate sediment simulation parameters. A summary of the values for the key hydrology and sediment parameters described above is presented in Table 4.1. It should be noted that the road coverage information used for the baseline simulation did not indicate the existence of unpaved roads in two of the model's meteorological segments (Hastings Range Piedmont, Carmouche Piedmont), and consequently this land use type was not parameterized or simulated in those segments.

Table 4.1 Key HSPF Parameter Values for Unpaved Road Segments

meterological segment name	Gradient (SLSUR) (% slope)	Length (LSUR) (ft.)	COVER (fraction)	Infiltration (INFILT) (in/hr)	Lower Zone Nominal Storage (LZSN) (in.)	Cofficient to Sediment Washoff Equation (KSER)	Monthly Re-set of Storage of Detached Sediment (DETS) (tons/ac)
Hastings Range	0.05	300	0.03	0.05	3.5	3.0	8.0
Hastings Range - Military	0.05	300	0.03	0.05	3.5	3.0	7.0
Carmouche	0.06	300	0.03	0.05	3.5	5.5	8.5
McKenna	0.06	300	0.03	0.05	3.5	5.5	8.5
Cactus	0.08	250	0.03	0.05	3.5	3.9	8.5
Natural Resources	0.08	250	0.03	0.05	3.5	6.2	8.5
Lawson	0.04	300	0.03	0.05	3.5	6.2	8.5
Malone	0.06	300	0.03	0.05	3.5	4.8	8.0
Pre Ranger	0.06	300	0.03	0.05	3.5	3.0	8.0
Griswold	0.06	300	0.03	0.05	3.5	3.0	7.0
Alabama	0.05	300	0.03	0.05	3.5	4.5	7.0
Columbus	0.09	250	0.03	0.05	3.5	5.5	8.5

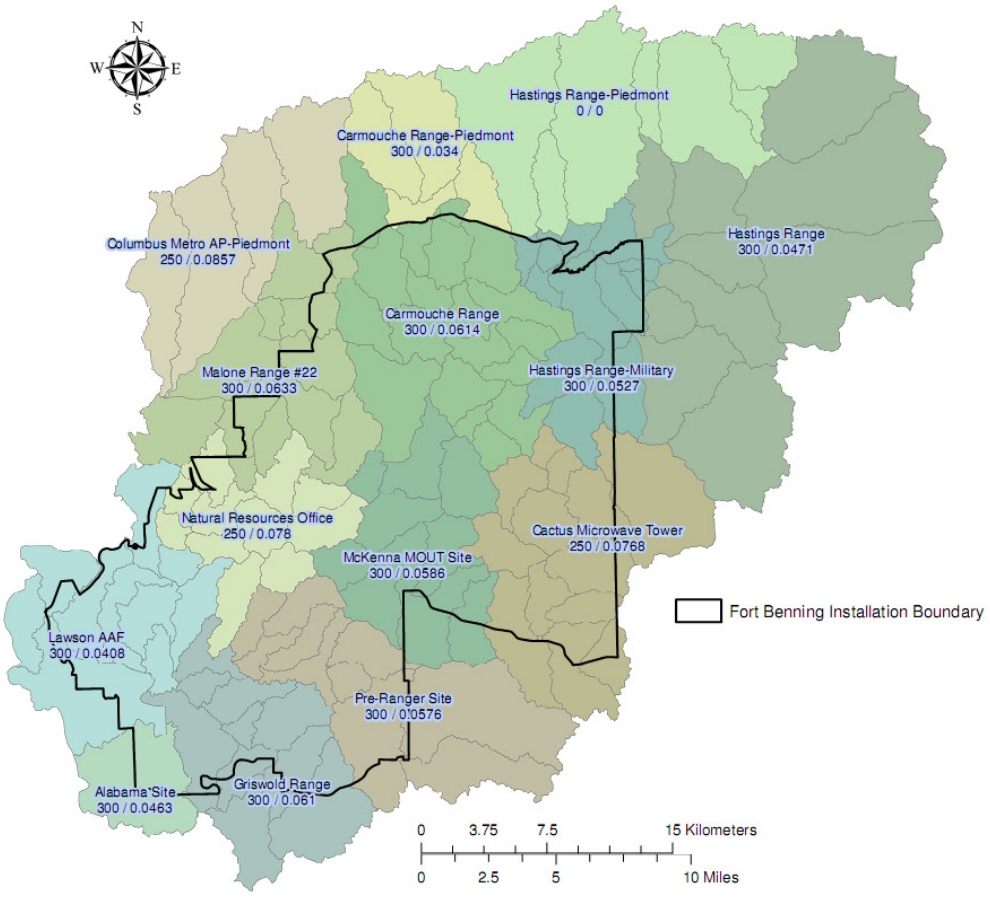

Figure 4.3 HSPF Meteorological Segments and the Assumed Values for Average Overland Flow Length and Slope in their Unpaved Roads

4.4 HSPF EROSION RESULTS

Table 4.2 presents the HSPF simulation results for unit area edge-of-road loadings. (The erosion area represented includes both the road surface and the fillslope.) For the sake of subsequent comparison, the unit area results have been multiplied by the road area estimates that were developed and discussed (Section 7.3) to support the WEPP:Road application, thus providing estimates of total channel loadings for each of the model's meteorological segments. The parallel estimates for erosion that WEPP:Road predicts are presented in Section 6.5, and the results from the two models are compared and discussed in Section 8.1.

Table 4.2 Simulation Results for Unit Area Erosion (tons/ac/yr) and Total Sediment Loadings (tons/yr) for the Meteorological Segments of the Fort Benning HSPF Model

	Baseline Estimate of Unit Area Erosion (tons/ac/yr)	Road Surface and Fillslope Area (acres)	Baseline Estimate of Sediment Loadings (tons/yr)
Hastings Range	2.68	0.6	1.6
Hastings Range - Military	2.57	1050.9	2700.8
Carmouche	1.97	2808.5	5532.7
Malone	1.63	859.5	1401.0
McKenna	1.11	1796.6	1994.2
Cactus	2.12	1508.0	3197.0
Natural Resources	1.83	736.0	1346.9
Lawson	1.17	522.7	611.6
Pre Ranger (non-Upatoi)	2.46	887.6	2183.5
Griswold (non-Upatoi)	2.30	902.4	2075.5
Lawson (non-Upatoi)	1.71	22.3	38.1
Natural Resources (non-Upatoi)	1.89	186.5	352.5
Alabama (non-Upatoi)	1.70	126.6	215.2
Malone (non-Upatoi)	2.01	241.1	484.6

Table 4.2 reports mean annual unit area erosion results for Fort Benning's unpaved roads ranging from 1.1 tons/ac/yr in the McKenna modeling segment to 2.7 tons/ac/yr in the Hastings modeling segment. As described in Section 4.1 these results were achieved by calibrating the HSPF model to target sediment loading rates that were 'pre-adjusted' to account for an expected stream delivery ratio of 0.25. Hence the actual estimates of eroded (but not delivered) sediment range from 4.1 to 10.8 tons/ac/yr. In a personal communication the WEPP:Road author Bill Elliot deemed these results reasonable and noted that his experience with forest roads is that their erosion rates typically fall in the range of 2 to 20 tons/ac/yr and are comparable to those for nearby agricultural areas.

SECTION 5
IMPROVEMENT STRATEGY FOR UNPAVED ROAD SIMULATION

The core of the improvement strategy entailed replacement of the watershed-scale HSPF simulation of Fort Benning's unpaved road network described in the previous section with a hillslope-scale simulation performed using the Watershed Erosion Prediction Project (WEPP) model (Flanagan and Nearing, 1995). Advantages were perceived to applying the WEPP model within the framework of an interface named WEPP:Road (Elliot et al., 1999). This interface customizes WEPP model applications to simulate overland flow and erosion from unpaved forest roads. Since WEPP:Road requires different and more road-specific input than that used in the generalized characterization of unpaved road PERLNDs in the HSPF simulation, the Project Team made supplemental contact with Fort Benning personnel that are responsible for road design and maintenance. As a result, three supporting actions were achieved:

1. Fort Benning substantiated the reasonableness of selected input parameter values (e.g., overland flow length, slope of overland flow surface) used in the baseline HSPF simulation for unpaved road PERLNDs.
2. Fort Benning provided new information (e.g., road drainage design, gravel addition, predominant soil type) needed as input for WEPP:Road simulations.
3. Fort Benning provided a more current and comprehensive vector data set of the Installation's road network.

The end product WEPP:Road application entailed using a 'hybrid modeling' capability implemented with the SERDP project to run HSPF and WEPP in tandem, integrating the results simulated for unpaved roads by WEPP with the results simulated by HSPF for the other 23 land use types included in the watershed model. Achieving this end product required three component efforts:

1. Developing the improvement strategy
2. Applying WEPP:Road in a stand-alone environment to evaluate unit area results
3. Integrating WEPP:Road into the hybrid modeling framework to evaluate holistic watershed-scale results.

These three component efforts are described sequentially in this section and Sections 6 and 7.

5.1 OPPORTUNITIES AND CHALLENGES PRESENTED BY USING WEPP:ROAD

WEPP:Road Opportunities

- Automatic translation of road setting/design conditions into WEPP input parameter values that characterize runoff and erosion conditions
- More detailed, hillslope-scale flow and erosion computations
- Potential to represent processes along the full overland flow path for sediment, hence replacing the delivery ratio approximation used at the watershed scale

WEPP:Road Challenges

- Not a storage-based approach
- Hard-wired assumptions and parameter values
    - Heavy traffic = rutted road conditions

- All three overland flow elements (road fill surface, buffer) have the same soil type

- Resets water content at midnight each day

5.2 IMPROVEMENT STRATEGY

The simply-stated objective of the component of the Fort Benning Watershed Model Enhancement Plan (AQUA TERRA Consultants, 2009) described in this document was to "improve" the sediment erosion simulation for Fort Benning's unpaved roads. Desirable elements of improvement included the following:

- Simulating unpaved roads using a smaller spatial-scale model (WEPP) that potentially offers a better match between process algorithms and the area(s) that needed to be modeled.
- Capability to investigate and evaluate the replacement of the watershed-scale delivery ratio approach for estimating sediment loadings to the stream network with loadings developed by simulating flow and sediment processes in the buffer area between the road and the stream.
- Taking advantage of an existing model interface (WEPP:Road) that translates input describing road and road setting characteristics into model parameters describing hydrologic and sediment washoff processes and simulating expected responses.
- Inherited capability to effectively define and evaluate road design and maintenance alternatives using this same interface and small-scale model.
- Capability to use newly-developed HSPF 'hybrid modeling' capability to run WEPP and HSPF in tandem and to integrate WEPP results into the Fort Benning Watershed Model and evaluate the results in a watershed context.

A project goal was to parameterize the WEPP:Road model in a manner that maintains a characterization of Fort Benning's roads and road settings that is consistent with the previous HSPF simulation for unpaved roads, and one that can be reconciled with both localized and literature data. For example, both models should use the same weather data and the same general soil and topography characterizations. Any variances in the two model's view of the modeling problem should occur either (1) because of WEPP:Road's ability to simulate overland flow and erosion using a more precise characterization of roads and road setting or (2) because the modeling problem originally defined in the HSPF simulation(s) has been refined to address a necessary target for improvement. The models use different parameters and process formulations, but the physical meaning imposed by the parameters values that are provided to WEPP:Road should not result in conflicting representations to those modeled using HSPF.

The approach featured the following requirements and/or assumptions:

1. In a parallel manner to the watershed-scale HSPF simulation scheme for unpaved roads (and other land use types), a 'representative' road segment was selected for all of the 14 different weather segments into which the watershed model is divided. Net unit area erosion delivered to the stream system by travel across the flow path (road surface, fill slope, forest buffer) for each of the representative road segments was simulated.
2. For the purpose of mapping WEPP:Road results to the previous HSPF results, the unpaved road area estimates for each of the 14 sub-areas were assumed to include both the road surface and fill slope OFEs represented in the WEPP:Road modeling scheme. Thus, the forest buffer OFE associated with each road segment was not

considered to be a component of the road area for purposes of computing unit area sediment delivery to the stream system.

3. The WEPP:Road interface typically utilizes regionalized *daily* weather data, whereas the Fort Benning Watershed Model utilizes 14 much more localized *hourly* weather datasets to represent the sub-areas of the Installation. In the context of the Fort Benning hybrid modeling exercise the localized weather data were reformatted (using a "wrapper") into a breakpoint file, which enabled WEPP to perform its simulations using the same hourly data that drives the HSPF model.
4. After de-coupling the weather data that are typically provided by the WEPP:Road Interface to the WEPP Model, it was still necessary to provide to WEPP:Road input parameter values that define the road characteristics and physical settings for each of the 14 representative road segments, so that the Interface could translate and generate the contents of three input files (Soils, Slope, Vegetation) that provide values for all the rest of the input required by the WEPP Model. Our approach was to maintain as much consistency between the physical meaning implied/imposed by parameters/values that were originally used for modeling unpaved roads using HSPF and the parameters/values subsequently required for modeling the same unpaved roads using WEPP:Road.
5. Additional WEPP input requirements are provided using regional parameter values that have been pre-established and included in the files that WEPP:Road feeds to the WEPP model once the geographic location of the model application has been established. To take advantage of the values most representative of the Fort Benning watershed, those established in the WEPP:Road interface that are closest in proximity to the Installation (Opelika, Alabama) were adopted and used for the Fort Benning modeling.
6. The input provided to WEPP:Road for all representative road segments at Fort Benning characterized the roads as outsloped; comprised of native materials and lacking addition of gravel or rock; and subject to heavy traffic.

SECTION 6
HILLSLOPE-SCALE (WEPP:ROAD) APPROACH AND RESULTS

To make available a more robust set of formulations for simulating sediment washoff from Fort Benning's unpaved forest roads, a WEPP:Road application was developed as a component of the Fort Benning Watershed Model. The USFS WEPP:Road interface (Elliot et al., 1999) translates user input describing road and road setting characteristics into model parameters describing water balance and sediment transport processes modeled in the USDA Water Erosion Prediction Project (WEPP) Model (Flanagan and Nearing, 1995). The WEPP model version used for this study was WEPP V.2010.100.

WEPP:Road allows the user to specify the characteristics of the road in terms of the following:

- climate
- soil and gravel addition
- local topography
- road design and surface condition
- drain spacing (if any)
- ditch condition (if any)

6.1 MODEL ASSUMPTIONS AND PROCEDURES

In WEPP sediment is eroded by precipitation (interrill erosion) and scoured by runoff (rill erosion) along an overland path comprised of three overland flow elements (OFEs): road surface, fillslope, and forest buffer. The estimated erosion/deposition along the overland flow path corresponds directly to the predicted physical transport of sediment across the flow path of the three OFEs. Hence, the delivery ratio is achieved by means of the modeled re-deposition of sediments in the buffer OFE. All the sediment eroded from the road surface OFE leaves the road surface and enters either (1) the drainage ditch of an insloped road or (2) directly to the fillslope OFE for an outsloped road, the latter being the case for Fort Benning's roads. Depending on the physical characteristics of the fillslope, additional erosion often occurs in the fillslope OFE. The net sediment export from the combined road and fillslope erosion/deposition phenomena enters the forest buffer OFE. Additional erosion can occur at the beginning of the overland flow path through the buffer, typically followed by deposition that either partially or wholly diminishes the sediment load produced by upgradient erosion that eventually enters the active channel system (Figure 6.1).

The WEPP:Road model was built on extensive soil parameter and forest road research . Important model assumptions are listed below:

- Soil properties are based on research findings.
- The road is assumed to be free of vegetation.
- The fillslope is assumed to be covered with sufficient vegetation to give about 50 percent ground cover.
- The buffer surface is assumed to be covered with litter from a 20-year old forest, generally 100 percent.

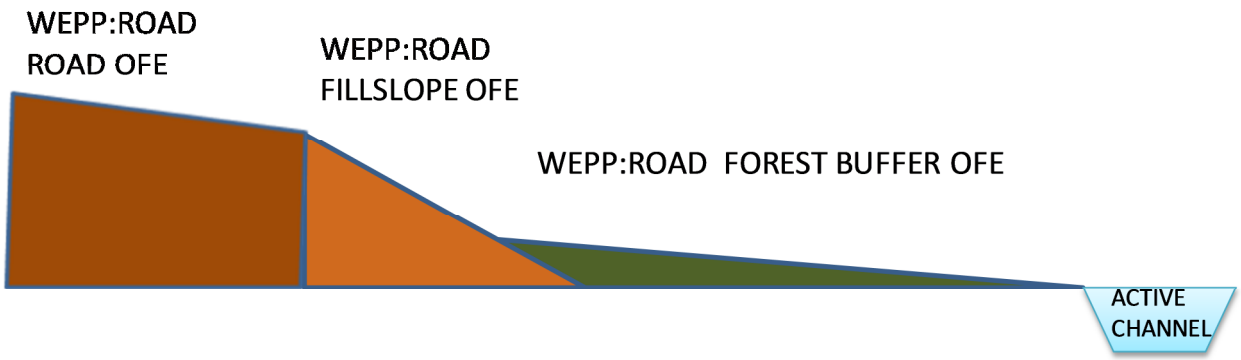

Figure 6.1 Schematic for WEPP:Road Characterization of Overland Flow Path for an Unpaved Road Segment (Erosion/Deposition Modeled Along Overland Flow Path Comprised of Three Sequential Overland Flow Elements (Road, Fillslope, Forest Buffer).

As the requirements of performing the WEPP application at Fort Benning have matured, it has been necessary to refine our semantics regarding the nature of the model application that is being performed. At the onset of the model application, we stated that our strategy was to perform the application(s) of the WEPP model within the framework of the USFS WEPP:Road interface. As the application has evolved, a more appropriate statement is that we are applying the WEPP model itself, but taking advantage of capabilities in the WEPP:Road interface to expedite the generation of certain input values required by the WEPP model.

To understand the need for re-phrasing the description of our model application, it is necessary to understand the basic attributes and constraints of WEPP:Road:

1. WEPP:Road is a web-based application. As such, it cannot be used directly in a hybrid model application that requires performance of WEPP simulations in tandem with HSPF simulations.
2. WEPP:Road enables users to specify the characteristics of a road in terms of climate, soil and gravel addition, local topography, drain spacing, road design and surface condition, and ditch condition (if ditches are present). User input is limited to selection of weather data and specification of values for **12** keystone input parameters.
3. WEPP:Road provides four data files named the weather, slope, soils, and management files to the WEPP model to perform the road simulation. The user selects one of many synthetic daily weather records generated by CLIGEN. WEPP:Road modifies and completes the 'start up' information contained in the other three files (slope, soils, management) by translating interface input parameter information into *process parameter values* used by WEPP. (Example: If the user specifies an outsloping road design, the interface computes an effective flow length for the road surface that crosses the road diagonally rather than flowing across the full length of the road segment that has been specified in the interface input.) Additional process input values required by WEPP are embedded in these three input files based on domain knowledge and professional judgment and are not impacted by the input information provided by the user. (Example: The forest buffer overland flow element is assigned a vegetative cover factor value of '1.0' in the management file.)
4. In certain situations the domain knowledge expressed in the WEPP:Road interface overrides the *combination* of specifications that a user might make in the interface input.

a. Example 1. If a user specifies that an outsloping road is both 'heavy traffic' and 'unrutted', the interface automatically overrides the 'unrutted' specification and designates the road as 'rutted'. Professional judgment is that at the typical level of road maintenance within Forest Service lands heavy traffic makes a rutted condition inevitable.

b. Example 2. If a user specifies that an outsloping road is 'heavy traffic' and has no gravel addition, the interface automatically overrides the specification of 'no gravel' and designates gravel addition as an element of the road characterization. Again, professional judgment provides the basis for this override.

While the professional judgment embedded in the WEPP:Road interface provides significant advantages in translating the characteristics of the three overland flow elements (road surface, fill, forest buffer) into process parameter values that are in turn used by the WEPP model to estimate overland flow and sediment delivery to streams, the 'hard-wiring' of these professional judgments presents challenges both (1) for using WEPP:Road within the context of the Fort Benning HSPF application and (2) for providing specifications to the WEPP model necessary to define and evaluate road maintenance alternatives. Two of the most significant are:

1. The *synthetic* weather data used exclusively by WEPP:Road cannot be used for the unpaved road simulations for Fort Benning. The hybrid modeling exercise requires that the same *observed* weather records that are used for the other 23 land use types in the HSPF watershed model be used as the forcing function for the WEPP simulations of Fort Benning's unpaved roads. Otherwise, integration of the results from the two models is impossible.
2. Although the Fort Benning watershed is a forested watershed, the nature of road construction, road maintenance and traffic conditions differs significantly at Fort Benning from practices and conditions that prevail in Forest Service watersheds. The differences in some cases contradict logic that is embedded in the interface. For example, outsloping roads that are maintained almost consistently in an unrutted condition prevail at Fort Benning (personal communication, Mr. James Benefield), but are not allowed by the interface logic.

To address these needs and challenges, the WEPP and WEPP:Road authors provided 'work-arounds' that have enabled us to proceed with the hybrid model application:

1. To enable the use of Fort Benning's observed weather records, the WEPP authors provided a batch version of WEPP that enabled us to replace the mandatory use of a synthetic weather record with Fort Benning's observed weather values expressed as breakpoint data. We took advantage of the capability of WEPP:Road to generate the remainder of the input data values required by WEPP by selecting the nearest weather station (Opelika, AL) available to WEPP:Road; providing appropriate values to define each of the road and road setting scenarios that we simulated for Fort Benning, and executing the web-based simulation. The goal of doing this was to invoke WEPP:Road to create and save the slope, soils and management files. These files were then transferred to the batch WEPP simulations and used in conjunction with the Fort Benning observed weather data.
2. To enable the simulation of roads at Fort Benning that were at the same time outsloping and unrutted, the WEPP:Road author instructed us to generate a replacement version of each slope file that corresponded to specifying a 'low traffic' condition with all other input

unchanged. This replacement file was used in conjunction with the soils and management files that WEPP:Road produced by specifying a 'high traffic' condition.

Having implemented these work-arounds, we can no longer describe our application as a WEPP application performed within the framework of WEPP:Road. The ensuing discussions will suggest that defining and simulating road maintenance alternatives may require additional divergences from the WEPP:Road approach (i.e., there is a need for direct changes to WEPP model parameter values that differ from those generated by WEPP:Road).

The WEPP model accepts and uses weather data by either of two methods:

1. Data generated by CLIGEN.
2. Breakpoint data. WEPP will use whatever information is provided in the breakpoint input climate file to predict overland flow through time and a hydrograph (which may have multiple peaks through time). However, in terms of the soil erosion predictions, the model determines the peak overland flow rate from the hydrograph, preserves the total volume of flow, and calculates an effective flow duration from those two numbers. This changes a hydrograph that is variable in shape (perhaps with multiple peaks) into a rectangular one, with its height being the peak overland flow rate, and its duration being the 'effective duration'.

Modeling Procedures

- Instantaneous flow and corresponding sediment transport are computed for 100 points along the flow path for each of the three OFEs.
- Text and graphical summaries provide import/ export estimates at boundaries of all three OFEs.

Unpaved forest road modeling options

Representing High and Low Traffic Conditions

WEPP:Road represents the difference between high traffic and low traffic roads is by reducing the rill (Kr variable) and interrill (Ki variable) by 75 percent for low traffic conditions. The runoff from the two roads is the same. Some field data indicate erosion rates could be reduced as much as 80 percent on low traffic roads because the road surface runs out of fines that can be eroded in the absence of traffic, and the surface generally becomes either hard with no fines to detach, or is covered in coarse gravel in the absence of traffic. This means that in the absence of any buffer effects, a high traffic road would generate about 3 times as much sediment as a low traffic road. This difference reduces when a buffer is introduced, in that a greater fraction of the sediment from a high traffic road is likely to be deposited on the buffer, so the delivery at the bottom of the buffer will not be quite so different. Generally, sediment detachment is limiting on the road surface, but sediment transport becomes limiting on a buffer (Elliot, personal communication).

Figure 6.2 provides a flowchart of the application components and sequencing required for the Fort Benning application of WEPP:Road. The approach featured the following requirements and/or assumptions:

1. In a parallel manner to the watershed-scale HSPF simulation scheme for unpaved roads (and other land use types), a 'representative' road segment was selected for all of the 14 different weather segments into which the watershed model is divided. Net unit area erosion delivered to the stream system by travel across the flow path (road surface, fill slope, forest buffer) for each of the representative road segments was simulated.

2. For the purpose of mapping WEPP:Road results to the previous HSPF results, the unpaved road area estimates for each of the 14 sub-areas were assumed to include both the road surface and fill slope OFEs represented in the WEPP:Road modeling scheme. Thus, the forest buffer OFE associated with each road segment was not considered to be a component of the road area for purposes of computing unit area sediment delivery to the stream system.
3. The WEPP:Road interface typically utilizes regionalized *daily* weather data, whereas the Fort Benning Watershed Model utilizes 14 much more localized *hourly* weather datasets to represent the sub-areas of the Installation. In the context of the Fort Benning hybrid modeling exercise the localized weather data were reformatted (using a "wrapper") into a breakpoint file, which enabled WEPP to perform its simulations using the same hourly data that drives the HSPF model.
4. After de-coupling the weather data that are typically provided by the WEPP:Road Interface to the WEPP Model, it was still necessary to provide to WEPP:Road input parameter values that define the road characteristics and physical settings for each of the 14 representative road segments, so that the Interface could translate and generate the contents of three input files (Soils, Slope, Vegetation) that provide values for all the rest of the input required by the WEPP Model. Our approach was to maintain as much consistency between the physical meaning implied/imposed by parameters/values that were originally used for modeling unpaved roads using HSPF and the parameters/values subsequently required for modeling the same unpaved roads using WEPP:Road.
5. Additional WEPP input requirements are provided using regional parameter values that have been pre-established and included in the files that WEPP:Road feeds to the WEPP model once the geographic location of the model application has been established. To take advantage of the values most representative of the Fort Benning watershed, those established in the WEPP:Road interface that are closest in proximity to the Installation (Opelika, Alabama) were adopted and used for the Fort Benning modeling.
6. The input provided to WEPP:Road for all representative road segments at Fort Benning characterized the roads as outsloped; comprised of native materials and lacking addition of gravel or rock; and subject to heavy traffic.

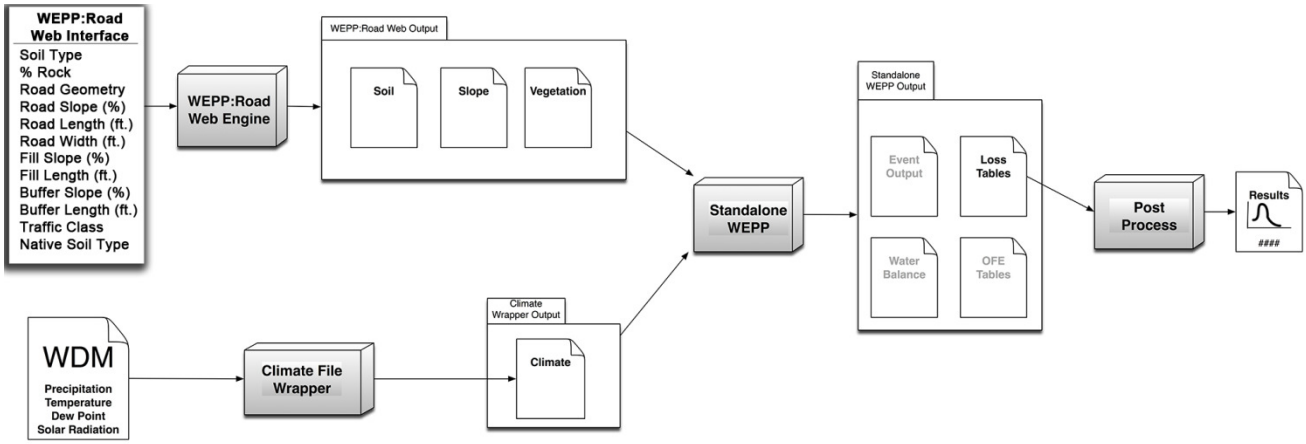

Figure 6.2 Flowchart for Application of WEPP:Road to Estimate Sediment Loadings from Fort Benning's Unpaved Roads

6.2 WEATHER DATA PREPARATION

Perhaps the most critical issue for applying the WEPP model using breakpoint rainfall data is proper representation of the intensity of rainfall, since WEPP directly computes sediment erosion amounts in relation to the *instantaneous peak overland flow values* for storm events. Instantaneous values of rainfall intensity in natural storm events can exceed 10 inches per hour for a period of 2 to 5 minutes. However, the rainfall amount for the hour that includes this intense shorter period of rainfall may only total two inches. For this example using an hourly data value, WEPP would assume a peak rainfall intensity of 2 inches per hour. Peak overland flow rate computed using this lower value of rainfall intensity would in turn be used to compute a lower flow shear stress value for use in rill erosion calculations in the steady-state erosion model. Underestimation of shear stress can result in low or no predictions of rill detachment. In some cases the averaged hourly rainfall rate may be so low that runoff is not predicted because infiltration rate is not exceeded by the hourly value, and there would be no overland flow or sediment erosion for those storms (Flanagan, personal communication, 4/6/10).

Hence, using hourly rainfall data for WEPP storm breakpoint input is likely too coarse to accurately represent overland flow and erosion processes. Use of finer observed breakpoint rainfall data, when they are available, is encouraged. Two methods of intensifying observed hourly rainfall values are available:

- CLIGEN allows input of observed hourly values which are used to generate a synthetic record of daily values. At the same time CLIGEN computes peak overland flow intensities and durations for rainfall events using a double exponential distribution function.
- Disaggregation of hourly rainfall data using a non-uniform distribution scheme.

For our application the former method is not viable, because the result is synthetic, not observed data, and the rainfall events would not coincide with the observed data used for all the other land use type in the watershed model. Consequently, use of the second method is warranted.

As part of its input, Standalone WEPP requires as input, a single file (called the climate file) which contains precipitation (PRCP), air temperature (ATEM), solar radiation (SOLR), wind speed (WIND) and wind direction (WDIR). WEPP accepts this input in two forms, (1) A single file generated by the CLIGEN○R software package (see [3] for more detail), or (2) A text format breakpoint climate file in a timeseries format. Because we had existing timeseries climate data collected at Ft. Benning, we had to translate this data into the breakpoint format. As outlined in [3] (pp. 18-20).

6.2.1 The WDM File

For this project, we were comparing sediment delivery results between HSPF and WEPP, so we needed to use the same weather data passed to HSPF, which was in a binary timeseries format commonly used in the Watershed Data Management (WDM) system [5] (we shall refer to this file as the WDM file).

The WDM file format is a binary file and cannot be opened using a standard text editor. Extracting the data within a WDM file was performed using the atcWDM.atcDataSourceWDM VB.net class freely available for download at http://svn.mapwindow.org/svnroot/BASINS40/atcWDM/. Additional capabilities to open, view, export and perform summary statistics are included in the U.S. BASINS 4.0 program available for free download at http://www.epa.gov/waterscience/basins/.

6.2.2 WEPP Wrapper

The need to perform statistical analysis on several years of data motivated our decision to generate the breakpoint file programmatically. In the VB.net language, we wrote the WeppWrapper method which translates raw WDM file data into breakpoint format. We will attempt to succinctly outline the WeppWrapper method.

Before executing the WeppWrapper, several variables need to be set. There are two ways to set these variables (1) Directly in the WeppWrapper.vb code or (2) by using the GUI in MultiWepp. The variables listed below must all be set.

Using the atcWDM.atcDataSourceWDM class, the single WDM file is imported.

List of variables in WEPP Wrapper

- lWDMFilePath (String): The full path of the source WDM file
- lOutputFilePath (String): The full path of the breakpoint file that is to be created.
- lLogFilePath (String): The full path of text log file (messages, statistics and debugging).
- lTempUnits (Integer): The units of the lATEM timeseries are specified with the integer assignment of (1) Celsius, (2) Fahrenheit, (3) Kelvin.
- lDsnPREC (Integer): The DSN number of the data set corresponding to precipitation.
- lDsnATEM (Integer): The DSN number of the data set corresponding to air temperature.
- lDsnDEWP (Integer): The DSN number of the data set corresponding to dew point temperature.
- lDsnWIND (Integer): The DSN number of the data set corresponding to wind velocities.
- lDsnSOLR (Integer): The DSN number of the data set corresponding to solar radiation.
- lElevation (String): The elevation of the weather station [Meters].
- lRawTsFlag (Boolean): A boolean flag which when true exports the precipitation timeseries in text format to the lRawTsFilePath path.
- lRawTsFilePath (String): The full path of the exported raw timeseries (only necessary when lRawTsFlag = True).
- lStrModelBegin(), lStrModelEnd() (Integer Array): The start and end date for the model to begin and end, respectively. Must be in the format (yyyy, mm,dd,hh,mm,ss), e.g. Assigning a beginning date of 1 October, 1999 at midnight (the instance October 1 begins), would be set with the following line:

  Dim lStrModelBegin() As Integer = {1999, 10, 1, 0, 0, 0}

  Note: It is highly recommended to set a model period in full year intervals. Any other interval will likely yield incomplete and skewed annual average statistics. Currently WEPP allows the model simulation period to be set in number of years, which is set in the in.run (the run file, see section on running Standalone WEPP). The code uses the modTimeseriesMath.SubsetByDate function which will extract a subset from a WDM and interpolate if there are missing values in the WDM timeseries.
- lPreInterpolatorRawTsFlag (Boolean): A boolean flag, which when true exports the precipitation timeseries before interpolation (used to check for holes in the timeseries and verify any interpolation).

- lPreInterpolatorRawTsFilePath (String): The full path of the exported pre-interpolation raw timeseries (only necessary when lPreInterpolatorRawTsFlag = True).

6.2.3 The Breakpoint File Line-by-Line

As outlined in the WEPP User's Guide [3], the breakpoint file that WeppWrapper generates follows the convention shown in Figure 6.3 and Figure 6.4. Note: calculated results are shown in Red while header text is shown in Black - Inserted comments (which do not appear in the generated climate file) are colored Gray. Line numbers are the first two places in the left margin in Gray.

```
 1  0.0
 2  1   1   1
 3  Station - RunID: ID
 4  Latitude Longitude Elevation (m) Obs.  Years Beginning year Years simulated
 5    Latitude    Longitude    Elevation    Y0    1    Y1
 6  Observed monthly ave max temperature (C)
 7    T1s,max    T2s,max    T3s,max    T4s,max    T5s,max    T6s,max    T7s,max    T8s,max    T9s,max    T10s,max    T11s,max    T12s,max
 8  Observed monthly ave min temperature (C)
 9    T1s,min    T2s,min    T3s,min    T4s,min    T5s,min    T6s,min    T7s,min    T8s,min    T9s,min    T10s,min    T11s,min    T12s,min
10  Observed monthly ave solar radiation (Langleys/day)
11    S1s    S2s    S3s    S4s    S5s    S6s    S7s    S8s    S9s    S10s    S11s    S12s
12  Observed monthly ave precipitation (mm)
13    P1s    P2s    P3s    P4s    P5s    P6s    P7s    P8s    P9s    P10s    P11s    P12s
14  da mo year bpts tmax tmin rad w-vl w-dir tdew
15              (#) (C) (C) (1/d) (m/s) (Deg) (C)
16   D1d D1m D1y    24    T1d,max    T1d,min    S1d    V1d    W1d    Dew1d      ← Start Day 1, Year 1
17   1 p1
18   2 p2
19   3 p3
20   4 p4
21   5 p5
22   6 p6
23   7 p7
24   8 p8
25   9 p9
26  10 p10
27  11 p11
28  12 p12
29  13 p13
30  14 p14
31  15 p15
32  16 p16
33  17 p17
34  18 p18
35  19 p19
36  20 p20
37  21 p21
38  22 p22
39  23 p23
40  24 p24
41   D2d D2m D2y    24    T2d,max    T2d,min    S2d    V2d    W2d    Dew2d      ← Start Day 2, Year 1
42   1 p25
43   2 p26
44   3 p27
45   4 p28
↓ continued ↓
```

Figure 6.3 A Schematic for the WeppWrapper Breakpoint Climate File

```
 0.0
1   1   1
OBSERVED CARMOUCH PRECIP - RunID: 4
Latitude Longitude Elevation (m) Obs.  Years Beginning year Years simulated
       32.5161 -84.9422 150 7 1 7
Observed monthly ave max temperature (C)
       14.5   16.4   20.8   24.8   28.7   31.2   33.1   32.4   29.3   25.1   20.6   14.3
Observed monthly ave min temperature (C)
       2.12   4.48   8.15   12.4   16.6   21.2   22.5   22.6   19.7   13.9   8.92   2.94
Observed monthly ave solar radiation (Langleys/day)
       298.   372.   486.   598.   662.   648.   652.   600.   503.   418.   329.   280.
Observed monthly ave precipitation (mm)
       78.8   87.5   149.   74.   56.3   104.   101.   100.   83.   39.8   95.   65.9
da mo year bpts tmax tmin rad w-vl w-dir tdew
            (#) (C) (C) (1/d) (m/s) (Deg) (C)
 1 10 1   24   25.   10.   541.   2.   0.   7.8      ← Start October 1, Year 1
 1 0.
 2 0.
 3 0.
 4 0.
 5 0.
 6 0.
 7 0.
 8 0.
 9 0.
10 0.
11 0.
12 0.2
13 0.5
14 0.9
15 2.3
16 2.7
17 2.7
18 2.7
19 2.7
20 2.7
21 3.
22 4.6
23 5.1
24 5.1
 2 10 1   24   27.8   13.3   527.   2.23   0.   13.3      ← Start October 2, Year 1
 1 0.
 2 0.
 3 0.
 4 0.
↓ continued ↓
```

Figure 6.4 A Sample Output for the Ft. Benning Climate File in.cli

6.2.4 Climate File Metadata

Most WDM files contain Metadata (i.e. data about data). Metadata extracted from the WDM (when available) and included in the breakpoint climate file is listed in the below table

Description

Station Name Run Number Latitude Longitude Station Elevation

Note that all metadata taken from the WDM originate from the precipitation timeseries (ITSPREC). In line (5), the number of years and beginning year are calculated as:

Y0 □ Y1 □ lStrModelEnd(0) - lStrModelBegin(0),

which is the beginning year specified in the preamble subtracted from the end year (as mentioned above, this is why it is imperative to model full years when using WeppWrapper). Both Y0 and Y1 are the same number by default because the timeseries subset (internal to the routine) created by modTimeseriesMath.SubsetByDate is both simulated and observed.

6.2.5 Summary Statistics and Hourly Data

By design WeppWrapper handles hourly WDM timeseries. The modTimeseriesMath.SubsetByDate function generates a value for every constituent for every hour in the simulation period. Missing observations are interpolated. This permits every hour of every day in the simulation period to be accounted for (perhaps in a future revision, the length of the breakpoint file could be shortened by omitting multiple hour lines where there was no change in precipitation). Calculations for the daily and hourly breakpoint lines (line numbers ¡ 15) are shown below. Refer to Figure 6.3 to find where each breakpoint file variable is used and respective variable names.

After the interpolated subset timeseries are generated with modTimeseriesMath.SubsetByDate, the total number of hours is calculated by which the primary hourly loop (commented in the code as Loop1) is iterated. For our calculations in this paper, the number of hours in the entire simulation period given as,

Nh □ lTSPREC.Values.Length (2.1)

is taken from the number of elements in the precipitation timeseries. Within Loop1 an If-statement checks the current hour iteration in the loop to check if it is midnight (00:00 or 24:00). The first iteration (midnight) of the loop is excepted. The idea is to trigger the statistics calculations after a full day (24 hours) has passed. The hour set in lStrModelBegin(3) and lStrModelBegin(3) must be set to "0" for the loop calculations to function as designed.

Once a midnight hour is detected in Loop1 the day summary calculations start and added to that day's summary line (e.g. lines 16, 41 in Figures 6.3 & 6.4).

WeppWrapper calculates summary statistics required by WEPP as outlined in [3] automatically. Before we present the algorithm for WeppWrapper a description of variables for calculated values found in Figure 6.3 and used in the algorithm are listed below.

Variable	Description
$T_m^{s,max}$	Maximum temperature for the mth month ($m = 1$ for January, $m = 2$ for February, etc) for the entire simulation period (s for simulation period).
$T_m^{s,min}$	Minimum temperature for the mth month ($m = 1$ for January, $m = 2$ for February, etc) for the entire simulation period (s for simulation period).
S_m^s	Average daily solar radiation for the mth month ($m = 1$ for January, $m = 2$ for February, etc) cumulative within a day and inclusive of the entire simulation period (s for simulation period).
P_m^s	Average monthly precipitation for the mth month ($m = 1$ for January, $m = 2$ for February, etc) cumulative within a month and inclusive of entire simulation period (s for simulation period).
D^h	Current hour in 24-hour format (this variable is used in this document in the pseudo-code and not a variable in `WeppWrapper`.
D_n^d	Day of the month for day n, where (n is an integer used to track the day in the simulation. It is not an actual variable in `WeppWrapper`.). Possible values: $D_n^d \in \mathbb{N} \ \wedge \ D_n^y \in [1, 31]$
D_n^m	Month integer for day n, where. (n is an integer used to track the day in the simulation. It is not an actual variable in `WeppWrapper`.). Possible values: $D_n^m \in \mathbb{N} \ \wedge \ D_n^y \in [1, 12]$
D_n^y	Year integer for day n, where. (n is an integer used to track the day in the simulation. It is not an actual variable in `WeppWrapper`.). Possible values: $D_n^y \in \mathbb{N} \ \wedge \ D_n^y \in [1, Y_1]$
$T_n^{d,max}$	The maximum temperature that was recorded during day n. (n is an integer used to track the day in the simulation. It is not an actual variable in `WeppWrapper`.). Possible values: $D_n^y \in \mathbb{R}$
$T_n^{d,min}$	The minimum temperature that was recorded during day n. (n is an integer used to track the day in the simulation. It is not an actual variable in `WeppWrapper`.). Possible values: $D_n^y \in \mathbb{R}$
S_n^d	The total accumulated solar radiation during day n. (n is an integer used to track the day in the simulation. It is not an actual variable in `WeppWrapper`.). Possible values: $D_n^y \in \mathbb{R} \ \wedge \ S_n^d \geqslant 0$
V_n^d	The mean velocity for wind during day n. (n is an integer used to track the day in the simulation. It is not an actual variable in `WeppWrapper`.). Possible values: $D_n^y \in \mathbb{R} \ \wedge \ V_n^d \geqslant 0$
W_n^d	The mean wind direction during day n. (n is an integer used to track the day in the simulation. It is not an actual variable in `WeppWrapper`.) *Note: This is not currently calculated in the code as of version 1.0.* Possible values: $D_n^y \in \mathbb{R} \ \wedge \ W_n^d \in [0, 359]$
Dew_n^d	The mean dewpoint temperature during day n. (n is an integer used to track the day in the simulation. It is not an actual variable in `WeppWrapper`.). Possible values: $Dew_n^y \in \mathbb{R}$
p_j	The accumulated precipitation for the hour in the time interval $[j-1, j)$. Possible values: $p_j \in \mathbb{R} \ \wedge \ p_j \geqslant 0$
t_j	The observed temperature for the jth hour. Possible values: $t_j \in \mathbb{R}$
s_j	The observed solar radiation for the jth hour. Possible values: $s_j \in \mathbb{R} \ \wedge \ s_j \geqslant 0$
N_h	The total number of hours in the simulation period. Set in VB.net as the number of values in the precipitation timeseries with `lTSPREC.Values.Length`. Possible values: $N_h \in \mathbb{N}$
A_m	A matrix used to hold the monthly mean running calculation for values of max. temperature, min. temperature, solar radiation, precipitation. The mean of all four constituent vectors are calculated at the end of `Loop1`. In VB.net this array is the collection `lYearCollection()`
M_{temp}	A temporary matrix used to hold daily values of max. temperature, min. temperature, solar radiation, precipitation. The mean of all four constituent vectors are calculated at the end of the month. In VB.net this array is the collection `lTempCurrentMonthStats()`

6.3 WEPP:ROAD PARAMETER DEVELOPMENT

In a parallel manner to the watershed-scale HSPF simulation scheme for unpaved roads (and other land use types), a 'representative' road segment was selected for each of the 14 different weather segments into which the watershed model is divided.

There are 12 input parameters for WEPP:Road, which the Interface subsequently uses to determine values for related physical parameters for the WEPP model. Additional WEPP input requirements are provided using regional values that have been included in more robust data files that WEPP:Road feeds to WEPP once the geographic location of the model application has been established. The input parameters and the method that we used to provide their values are described below.

Soil Texture: The model authors believe that erosion potential of a given soil depends more on the vegetative cover than on the soil texture (Elliot et al., 1999) and therefore require only a coarse distinction of soil texture for each model application from among four choices (clay loam, silt loam, sandy loam, loam).

For the Fort Benning application we designated all roads as located in clay loams. Communications with Fort Benning (personal communication with Mr. James Benefield, 2009) indicated that about 90 percent of the unpaved roads were comprised of clayey sand materials remaining after the surface layer was scraped away during construction. Mr. Benefield also indicated that in cases where road fill was required that the Installation used stockpiles of similar clayey sand materials.

Representing the forest buffer areas of the Installation as clay loams was supported by information provided by Casarim (2010). Whereas the Installation lands viewed as a whole are predominantly characterized by sandy loam soils (AQUA TERRA Consultants, 2010), the surface materials of the forest buffer areas often originate from either legacy sediments deposited during the Cotton Era or sediments that have been deposited as a result of more current land use activities. Casarim reports an average bulk density value for surface legacy sediments in the Bonham Creek sub-watershed of 1.34 g/cm^3 and in the Sally Branch sub-watershed of 1.33 g/cm^3. The Soil Bulk Density Calculator provided by Pedosphere (http://www.pedosphere.com/resources/bulkdensity/triangle.cfm) was used to relate these reported bulk density values to soil textural classes. As Figure 6.5 indicates, the bulk density value of 1.33 measured at Fort Benning corresponds directly to sandy clay, the same material designation that Mr. Benefield indicated for the roads and road fill. Of the four soil texture selections available for selection in the WEPP:Road interface, the measured bulk density values most closely correspond to the clay loam class (Figure 6.6).

%Rock Additive: All Fort Benning simulations were set for *zero* rock additive to the unpaved road segments. This was consistent with the information provided by Mr. Benefield, gravel has been applied to only a very small fraction of the unpaved roads, typically those that are located in swampy areas.

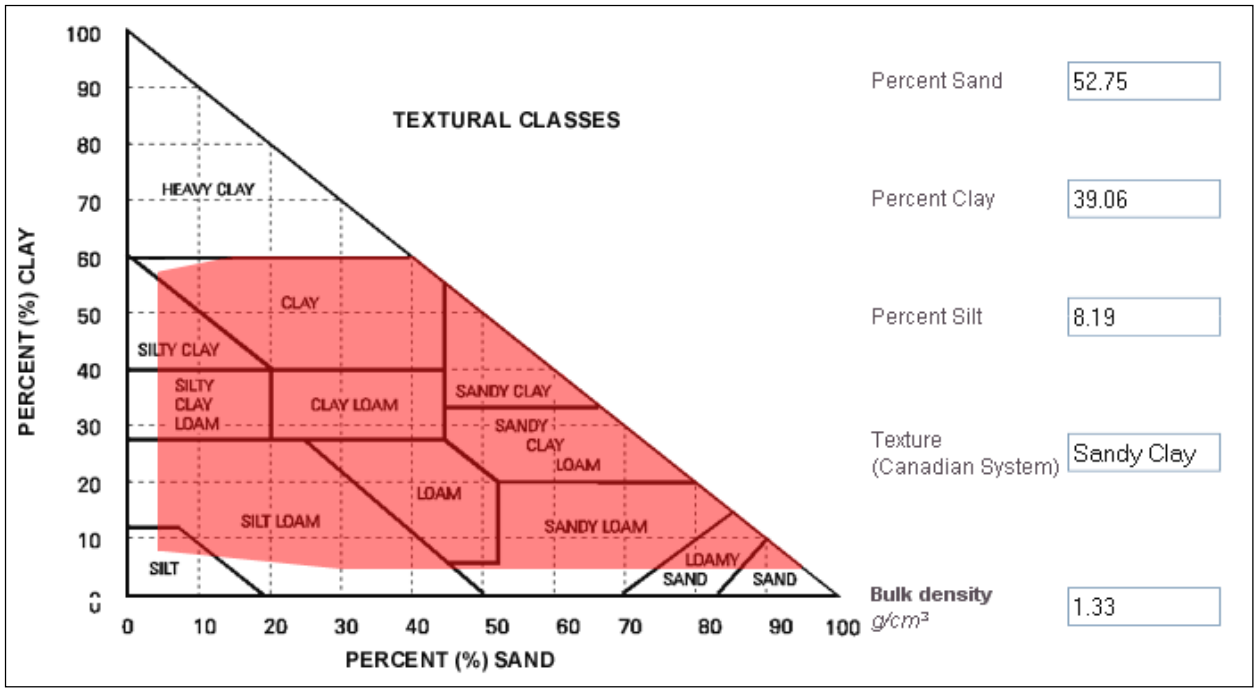

Figure 6.5 Correlation of Measured Bulk Density Values for Legacy Sediment at Fort Benning with Soil Texture Class (Bulk density value of 1.33 = sandy clay)

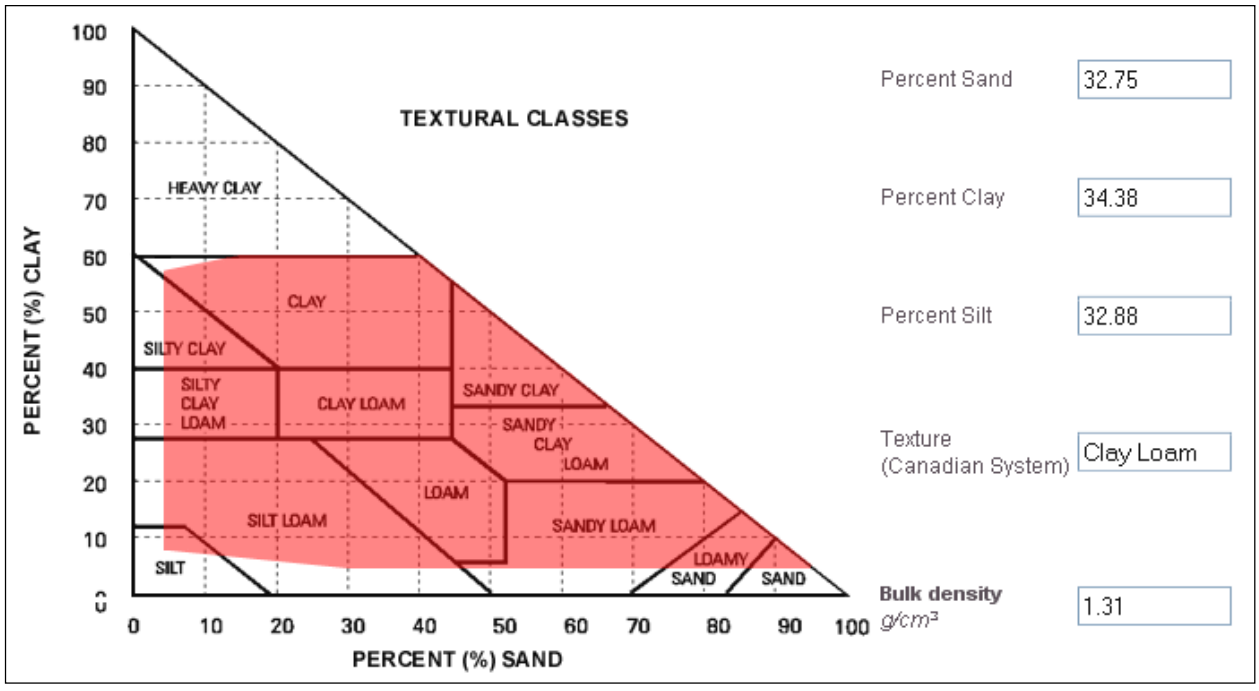

Figure 6.6 Correlation of Measured Bulk Density Values for Legacy Sediment at Fort Benning with Soil Texture Class (Bulk density value of 1.31 = clay loam)

Road Design: The interface requires selection of one of the four road designs illustrated in Figure 6.7 to characterize each road segment that is simulated. Mr. Benefield indicated that 90-95% of the Installation's unpaved roads are sloped for outward drainage with a slight crest. Road maintenance practices at Fort Benning preclude conditions of chronic rutting. Accordingly, all road segments simulated for the Fort Benning model were represented as *outsloped* and *unrutted*.

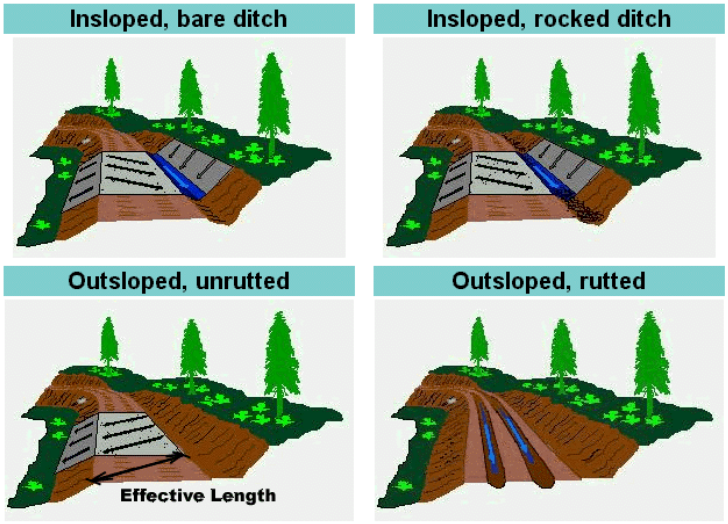

Figure 6.7 WEPP Road Designs. Source: Elliot et al. (1999).

Road Surface: The interface requires selection of one of three surfaces: native, graveled, paved. Our application WEPP:Road is focused only on unpaved roads, and as indicated above, the Installation's unpaved roads are not graveled. Accordingly, all road segments simulated for Fort Benning were represented as *native*.

Road Gradient: For each representative road segment that was simulated, WEPP:Road required a value for gradient expressed as a percentage. These values correspond to the values for slope of overland flow surface (SLSUR) that were established for the HSPF simulation of unpaved road PERLNDs (see Section 4.3). Accordingly, the SLSUR values which are expressed as fractions were converted to percentages and used as input to WEPP:Road. The gradient values ranged from 3.4% to 8.6%

Road Length: WEPP:Road requires a value for road segment length for each of the 14 representative road segments that were simulated. To meet this need the values established for the length of overland flow (LSUR) that were established the simulation of unpaved road PERLNDs (Section 4.3) were adopted for the corresponding representative road segments modeled using WEPP:Road. It should be noted that the road length designated for WEPP:Road simulations does not correspond directly to the length of flow across which overland flow travels across the road surface.

Road Width: WEPP:Road also requires a value for road segment width for each of the 14 representative road segments that were simulated. A uniform estimate of average road width was established based on one anecdotal and one analytical source. Mr. James Benefield, Fort Benning's liaison to our project regarding road information, characterized the range of road widths at Fort Benning as between 12 and 24 feet. In addition, vector coverages of Fort Benning's road network (see Section 7.3) were overlaid on Google Earth imagery, and the line

measurement tool in Google Earth was used to estimate road widths, with maximum zoom implemented. A weighted average value of 22 feet was estimated.

Fill Length: For roads in a similar terrain to Fort Benning in South Central Alabama, Grace and Elliot (2008) measured and reported fill lengths of 16 road sections with a range of 3 to 10 feet. Visual inspection of Fort Benning's road using Google Earth also suggests short fill lengths. A value of 10 feet was used for all 14 representative road segments used in the Fort Benning simulations.

Fill Grade: A value of 6 percent was used for the fill for Fort Benning road segments. Fill gradients measured in Grace and Elliots' Alabama for 16 road sections ranged from 1 to 10 percent, with an average value of 4 percent.

Buffer Grade: A value of 6 percent was used for the buffer between Fort Benning road segments and the stream channels. Buffer gradients measured in Grace and Elliots' Alabama for 16 road sections ranged from 1 to 10 percent, with an average value of 4 percent.

Buffer Length: A buffer length of 30 feet was assigned to all 14 representative road segments for the Fort Benning simulation.

Traffic level: The interface requires selection of one of three traffic levels: high, low, none. As a yardstick for assigning an appropriate traffic level for Fort Benning's roads, WEPP:Road author Bill Elliot defines a high level of traffic for a Forest Service road as 50-60 annual round trips by a logging truck (personal communication). Roads kept free of vegetative growth by either activity or maintenance are considered to be high-traffic roads. For the purposes of WEPP:Road simulation Fort Benning's unpaved roads were designated as high traffic.

Table 6.1 provides a summary of the WEPP:Road input values assigned to the 14 representative road segments for the Fort Benning simulation.

Table 6.1 WEPP:Road Parameter Values for the Representative Road Segments

				Road			Fillslope		Buffer			
	Soil Texture	Rock (ratio)	Road Design	Gradient (% slope)	Length (ft.)	Width (ft.)	Gradient (% slope)	Length (ft.)	Gradient (% slope)	Length (ft.)	Road Surface	Traffic Level
Hastings Range	SL	0	Out, Unrut	0.05	300	28	0.05	10	0.06	131	Native	High
Hastings Range - Military	SL	0	Out, Unrut	0.05	300	28	0.05	10	0.06	131	Native	High
Hastings Range - Piedmont	SL	0	Out, Unrut									
Carmouche	SL	0	Out, Unrut	0.06	300	28	0.05	10	0.06	131	Native	High
Malone	SL	0	Out, Unrut	0.06	300	28	0.05	10	0.06	131	Native	High
McKenna	SL	0	Out, Unrut	0.06	300	28	0.05	10	0.06	131	Native	High
Cactus	SL	0	Out, Unrut	0.08	250	28	0.05	10	0.06	131	Native	High
Natural Resources	SL	0	Out, Unrut	0.08	250	28	0.05	10	0.06	131	Native	High
Lawson	SL	0	Out, Unrut	0.04	300	28	0.05	10	0.06	131	Native	High
Pre Ranger	SL	0	Out, Unrut	0.06	300	28	0.05	10	0.06	131	Native	High
Griswold	SL	0	Out, Unrut	0.06	300	28	0.05	10	0.06	131	Native	High
Lawson	SL	0	Out, Unrut	0.04	300	28	0.05	10	0.06	131	Native	High
Natural Resources	SL	0	Out, Unrut	0.08	250	28	0.05	10	0.06	131	Native	High
Alabama	SL	0	Out, Unrut	0.05	300	28	0.05	10	0.06	131	Native	High
Malone	SL	0	Out, Unrut	0.06	300	28	0.05	10	0.06	131	Native	High
Columbus	SL	0	Out, Unrut	0.09	250	28	0.05	10	0.06	131	Native	High

SL = Sandy Loam Soil
Out, Unrut = Outsloped, Unrutted
Shaded rows indicate met. segments that are not contained in the Upatoi Creek drainage.

6.4 WEPP CALIBRATION

Refinements of the HSPF sediment washoff calibration for all land use types progressed to a point where confidence was gained in the estimates that the model generates for unit area sediment washoff. When this had been accomplished, it was justifiable to use the HSPF annual unit area sediment washoff results (expressed as tons/ac/yr) that were estimated for unpaved roads using HSPF as calibration targets for the parallel WEPP:Road simulations. (Recall that the primary objective of introducing WEPP:Road into the Fort Benning modeling framework was not expectation of more accurate estimates of sediment washoff for unpaved roads, but rather having available its greater level of detail in characterizing a variety of road types, and therefore its potential utility in supporting the representation and evaluation of a variety of alternative road management practices.)

A list and description of the model parameters for which a WEPP:Road user may supply input values, and hence to some extent calibrate model runoff/erosion response is provided in Appendix A. The WEPP:Road software package provides graphical tools that enable visualization of model sensitivity for two of these user-defined parameters: road slope and flow length. (Road length estimates correspond to the average length of run for a road before it reverses slope direction.) We used these graphical tools to evaluate sensitivity for these two parameters within the Fort Benning setting and determined that adjustment of values for these two parameters would not be effective in a calibration effort (see Appendix A). Consideration of the remaining input parameters allowed by WEPP:Road led us to conclude that they also could not provide the doorway to WEPP's process formulations that we needed to effectively represent the runoff/erosion response of the Installation's unpaved roads using observed hour precipitation records as the driver. As a result, we identified the need to circumvent the parameterization scheme of WEPP:Road and interact directly with WEPP to establish value for three key WEPP parameters. Calibration of the WEPP:Road simulations for the 14 meteorological segments focused on adjustment of parameter values for the interrill erodibility coefficient, the rill erodibility coefficient and the baseline shear coefficient . The calibration goal was to reproduce the annual unit area sediment washoff estimated by the baseline HSPF model for unpaved roads in each of the 14 meteorological segments within plus or minus 15 percent (Table 6.2).

Table 6.2 Final Parameter Values after Calibration Process

1 Hastings Range	Road	Fill
Number of Layers	1	1
Albedo of the base dry surface soil	0.6	0.12
Initial Saturation level (m/m)	0.5	0.45
Baseline Interrill Erodibility (kg*s/m^4)	1000000	1000000
Baseline Rill Erodibility (s/m)	0.0003	0.0003
Baseline Critical Shear (N/m^2)	5.7	5.7
Effective Hydraulic Conduc (mm/h)	0.1	6.3
Depth from Soil to Bottom (mm)	200	300
Percent Sand (%)	60	60
Percent Clay (%)	30	30
Percent Organic Matter (%)	0.01	4
Cation Exchange Capacity (meq/100 g soil)	24	26
Percent Rock Fragments (%)	0	0
WEPP Result		2.74
HSPF Recalibration		2.680
WEPP Result vs. HSPF Result		+ 2.24 %

2	Hastings Range - Military	Road	Fill
	Number of Layers	1	1
	Albedo of the base dry surface soil	0.6	0.12
	Initial Saturation level (m/m)	0.5	0.45
	Baseline Interrill Erodibility (kg*s/m^4)	1000000	1000000
	Baseline Rill Erodibility (s/m)	0.0003	0.0003
	Baseline Critical Shear (N/m^2)	5.5	5.5
	Effective Hydraulic Conduc (mm/h)	0.1	6.3
	Depth from Soil to Bottom (mm)	200	300
	Percent Sand (%)	60	60
	Percent Clay (%)	30	30
	Percent Organic Matter (%)	0.01	4
	Cation Exchange Capacity (meq/100 g soil)	24	26
	Percent Rock Fragments (%)	0	0
	WEPP Result		2.87
	HSPF Recalibration		2.570
	WEPP Result vs. HSPF Result		+ 11.67 %

4	Carmouche	Road	Fill
	Number of Layers	1	1
	Albedo of the base dry surface soil	0.6	0.12
	Initial Saturation level (m/m)	0.5	0.45
	Baseline Interrill Erodibility (kg*s/m^4)	150000	150000
	Baseline Rill Erodibility (s/m)	0.0002	0.0002
	Baseline Critical Shear (N/m^2)	5.2	5.2
	Effective Hydraulic Conduc (mm/h)	0.1	6.3
	Depth from Soil to Bottom (mm)	200	300
	Percent Sand (%)	60	60
	Percent Clay (%)	30	30
	Percent Organic Matter (%)	0.01	4
	Cation Exchange Capacity (meq/100 g soil)	24	26
	Percent Rock Fragments (%)	0	0
	WEPP Result		2.011
	HSPF Recalibration		1.970
	WEPP Result vs. HSPF Result		+ 2.08 %

5	Malone	Road	Fill
	Number of Layers	1	1
	Albedo of the base dry surface soil	0.6	0.12
	Initial Saturation level (m/m)	0.5	0.45
	Baseline Interrill Erodibility (kg*s/m^4)	150000	150000
	Baseline Rill Erodibility (s/m)	0.0002	0.0002
	Baseline Critical Shear (N/m^2)	5.7	5.7
	Effective Hydraulic Conduc (mm/h)	0.1	6.3
	Depth from Soil to Bottom (mm)	200	300
	Percent Sand (%)	60	60
	Percent Clay (%)	30	30
	Percent Organic Matter (%)	0.01	4
	Cation Exchange Capacity (meq/100 g soil)	24	26
	Percent Rock Fragments (%)	0	0
	WEPP Result		1.810
	HSPF Recalibration		1.629
	WEPP Result vs. HSPF Result		+ 11.11 %

6	McKenna	Road	Fill
	Number of Layers	1	1
	Albedo of the base dry surface soil	0.6	0.12
	Initial Saturation level (m/m)	0.5	0.45
	Baseline Interrill Erodibility (kg*s/m^4)	150000	150000
	Baseline Rill Erodibility (s/m)	0.0003	0.0003
	Baseline Critical Shear (N/m^2)	5.7	5.7
	Effective Hydraulic Conduc (mm/h)	0.1	6.3
	Depth from Soil to Bottom (mm)	200	300
	Percent Sand (%)	60	60
	Percent Clay (%)	30	30
	Percent Organic Matter (%)	0.01	4
	Cation Exchange Capacity (meq/100 g soil)	24	26
	Percent Rock Fragments (%)	0	0
	WEPP Result		1.270
	HSPF Recalibration		1.114
	WEPP Result vs. HSPF Result		+ 14.0 %

7	Cactus	Road	Fill
	Number of Layers	1	1
	Albedo of the base dry surface soil	0.6	0.12
	Initial Saturation level (m/m)	0.5	0.45
	Baseline Interrill Erodibility (kg*s/m^4)	125000	125000
	Baseline Rill Erodibility (s/m)	0.0002	0.0002
	Baseline Critical Shear (N/m^2)	5.6	5.6
	Effective Hydraulic Conduc (mm/h)	0.1	6.3
	Depth from Soil to Bottom (mm)	200	300
	Percent Sand (%)	60	60
	Percent Clay (%)	30	30
	Percent Organic Matter (%)	0.01	4
	Cation Exchange Capacity (meq/100 g soil)	24	26
	Percent Rock Fragments (%)	0	0
	WEPP Result		2.368
	HSPF Recalibration		2.118
	WEPP Result vs. HSPF Result		+ 11.8 %

8	Natural Resources	Road	Fill
	Number of Layers	1	1
	Albedo of the base dry surface soil	0.6	0.12
	Initial Saturation level (m/m)	0.5	0.45
	Baseline Interrill Erodibility (kg*s/m^4)	125000	125000
	Baseline Rill Erodibility (s/m)	0.0002	0.0002
	Baseline Critical Shear (N/m^2)	5.5	5.5
	Effective Hydraulic Conduc (mm/h)	0.1	6.3
	Depth from Soil to Bottom (mm)	200	300
	Percent Sand (%)	60	60
	Percent Clay (%)	30	30
	Percent Organic Matter (%)	0.01	4
	Cation Exchange Capacity (meq/100 g soil)	24	26
	Percent Rock Fragments (%)	0	0
	WEPP Result		1.931
	HSPF Recalibration		1.830
	WEPP Result vs. HSPF Result		+ 5.52 %

9	Lawson	Road	Fill
	Number of Layers	1	1
	Albedo of the base dry surface soil	0.6	0.12
	Initial Saturation level (m/m)	0.5	0.45
	Baseline Interrill Erodibility (kg*s/m^4)	1500000	1500000
	Baseline Rill Erodibility (s/m)	0.0003	0.0003
	Baseline Critical Shear (N/m^2)	5.1	5.1
	Effective Hydraulic Conduc (mm/h)	0.1	6.3
	Depth from Soil to Bottom (mm)	200	300
	Percent Sand (%)	60	60
	Percent Clay (%)	30	30
	Percent Organic Matter (%)	0.01	4
	Cation Exchange Capacity (meq/100 g soil)	24	26
	Percent Rock Fragments (%)	0	0
	WEPP Result		1.654
	HSPF Recalibration		1.710
	WEPP Result vs. HSPF Result		- 3.27 %

10	Pre-Ranger (Non Upatoi)	Road	Fill
	Number of Layers	1	1
	Albedo of the base dry surface soil	0.6	0.12
	Initial Saturation level (m/m)	0.5	0.45
	Baseline Interrill Erodibility (kg*s/m^4)	150000	150000
	Baseline Rill Erodibility (s/m)	0.0003	0.0003
	Baseline Critical Shear (N/m^2)	5.5	5.5
	Effective Hydraulic Conduc (mm/h)	0.1	6.3
	Depth from Soil to Bottom (mm)	200	300
	Percent Sand (%)	60	60
	Percent Clay (%)	30	30
	Percent Organic Matter (%)	0.01	4
	Cation Exchange Capacity (meq/100 g soil)	24	26
	Percent Rock Fragments (%)	0	0
	WEPP Result		2.741
	HSPF Recalibration		2.462
	WEPP Result vs. HSPF Result		+ 11.33 %

11	Griswold (Non Upatoi)	Road	Fill
	Number of Layers	1	1
	Albedo of the base dry surface soil	0.6	0.12
	Initial Saturation level (m/m)	0.5	0.45
	Baseline Interrill Erodibility (kg*s/m^4)	1000000	1000000
	Baseline Rill Erodibility (s/m)	0.0004	0.0004
	Baseline Critical Shear (N/m^2)	5.2	5.2
	Effective Hydraulic Conduc (mm/h)	0.1	6.3
	Depth from Soil to Bottom (mm)	200	300
	Percent Sand (%)	60	60
	Percent Clay (%)	30	30
	Percent Organic Matter (%)	0.01	4
	Cation Exchange Capacity (meq/100 g soil)	24	26
	Percent Rock Fragments (%)	0	0
	WEPP Result		2.209
	HSPF Recalibration		2.295
	WEPP Result vs. HSPF Result		- 3.75 %

12	Lawson (Non Upatoi)	Road	Fill
	Number of Layers	1	1
	Albedo of the base dry surface soil	0.6	0.12
	Initial Saturation level (m/m)	0.5	0.45
	Baseline Interrill Erodibility (kg*s/m^4)	1000000	1000000
	Baseline Rill Erodibility (s/m)	0.0004	0.0004
	Baseline Critical Shear (N/m^2)	5.2	5.2
	Effective Hydraulic Conduc (mm/h)	0.1	6.3
	Depth from Soil to Bottom (mm)	200	300
	Percent Sand (%)	60	60
	Percent Clay (%)	30	30
	Percent Organic Matter (%)	0.01	4
	Cation Exchange Capacity (meq/100 g soil)	24	26
	Percent Rock Fragments (%)	0	0
	WEPP Result		1.603
	HSPF Recalibration		1.713
	WEPP Result vs. HSPF Result		- 6.42 %

13	Natural Resources (Non Upatoi)	Road	Fill
	Number of Layers	1	1
	Albedo of the base dry surface soil	0.6	0.12
	Initial Saturation level (m/m)	0.5	0.45
	Baseline Interrill Erodibility (kg*s/m^4)	100000	100000
	Baseline Rill Erodibility (s/m)	0.00015	0.00015
	Baseline Critical Shear (N/m^2)	5.9	5.9
	Effective Hydraulic Conduc (mm/h)	0.1	6.3
	Depth from Soil to Bottom (mm)	200	300
	Percent Sand (%)	60	60
	Percent Clay (%)	30	30
	Percent Organic Matter (%)	0.01	4
	Cation Exchange Capacity (meq/100 g soil)	24	26
	Percent Rock Fragments (%)	0	0
	WEPP Result		1.922
	HSPF Recalibration		1.891
	WEPP Result vs. HSPF Result		+ 1.64 %

14	Alabama (Non Upatoi)	Road	Fill
	Number of Layers	1	1
	Albedo of the base dry surface soil	0.6	0.12
	Initial Saturation level (m/m)	0.5	0.45
	Baseline Interrill Erodibility (kg*s/m^4)	1000000	1000000
	Baseline Rill Erodibility (s/m)	0.0003	0.0003
	Baseline Critical Shear (N/m^2)	5.2	5.2
	Effective Hydraulic Conduc (mm/h)	0.1	6.3
	Depth from Soil to Bottom (mm)	200	300
	Percent Sand (%)	60	60
	Percent Clay (%)	30	30
	Percent Organic Matter (%)	0.01	4
	Cation Exchange Capacity (meq/100 g soil)	24	26
	Percent Rock Fragments (%)	0	0
	WEPP Result		1.836
	HSPF Recalibration		1.695
	WEPP Result vs. HSPF Result		+ 8.32 %

15	Malone (Non Upatoi)	Road	Fill
	Number of Layers	1	1
	Albedo of the base dry surface soil	0.6	0.12
	Initial Saturation level (m/m)	0.5	0.45
	Baseline Interrill Erodibility (kg*s/m^4)	150000	150000
	Baseline Rill Erodibility (s/m)	0.0002	0.0002
	Baseline Critical Shear (N/m^2)	5.5	5.5
	Effective Hydraulic Conduc (mm/h)	0.1	6.3
	Depth from Soil to Bottom (mm)	200	300
	Percent Sand (%)	60	60
	Percent Clay (%)	30	30
	Percent Organic Matter (%)	0.01	4
	Cation Exchange Capacity (meq/100 g soil)	24	26
	Percent Rock Fragments (%)	0	0
	WEPP Result		1.987
	HSPF Recalibration		2.009
	WEPP Result vs. HSPF Result		- 1.1 %

6.5 RESULTS

The current WEPP:Road results have been achieved using the model in a stand-alone manner to estimate unit area erosion for the erosional OFEs (road and fillslope). Results for the modeling segments fall in a similar range (1.27 – 2.87 tons/ac/yr) to those generated using the in the HSPF watershed baseline simulation (1.11 – 2.68 tons/ac/yr), as shown in Table 6.3.

Table 6.3 Comparison of Model Results for Unit Area Sediment Erosion Model Simulated by HSPF and WEPP:Road (tons/acre/year)

Fort Benning Model Region	Road Area (acres)	Unit Area Erosion Estimates From Road & Fillslope (tons/ac/yr)		
		HSPF	WEPP:Road	% Difference
Hastings Range	1	2.68	2.74	2.2
Hastings Range - Military	1051	2.57	2.87	11.7
Carmouche	2808.3	1.97	2.01	2.1
Malone	860	1.63	1.81	11.1
McKenna	1797	1.11	1.27	14.0
Cactus	1508	2.12	2.37	11.8
Natural Resources	736	1.83	1.93	5.5
Lawson	22	1.71	1.65	-3.3
Pre-Ranger (non-Upatoi)	888	2.46	2.74	11.3
Griswold (non-Upatoi)	902	2.30	2.20	-3.8
Lawson (non-Upatoi)	523	1.71	1.60	-6.4
Natural Resources (non-Upatoi)	187	1.89	1.92	1.6
Alabama (non-Upatoi)	127	1.70	1.84	8.3
Malone (non-Upatoi)	241	2.01	1.99	1.1

Given the differences in model approaches and assumptions, achieving similar results from both models for edge-of-fillslope unit erosion would not necessarily be a good and desirable outcome. The HSPF erosion values for road and fillslope areas are calibrated to target values

that are already adjusted to include the expected delivery ratio to streams: HSPF assumes that 75% of the sediment that is eroded from the surface of any land use type (including an unpaved road) that is represented in the Fort Benning Model will re-deposit on the same contributing area from which it was eroded. (The delivery ratio that is applied is dependent on watershed size, and the assumption that the re-deposition occurs in the same segment as that in which the erosion occurred becomes a better assumption as the watershed scale and segment sizes increase.) In parallel with this assumption, the amount of sediment that leaves the HSPF unpaved road segment (road surface plus fillslope surface) is wholly introduced into the connected stream network.

Alternatively, using WEPP:Road the amount of sediment leaving the fillslope OFE continues its flow path through the forest buffer to the edge of the stream. Inherent in this approach is the assumption that the bulk of deposition does not occur in the same area (road plus fillslope) as that on which the erosion occurs, but rather it occurs along the flow path that connects the eroding surface to the edge of the stream channel. This appears to be a more appropriate assumption given the geometry (long and thin) and scale of roads. Also inherent in this modeling approach is the assumption that the deposition that occurs in the forest buffer determines the sediment delivery to the stream, and hence this approach eliminates the need for applying a delivery ratio.

The considerations discussed in the previous two paragraphs would lead to an expectation that the edge-of-fillslope sediment erosion estimated by WEPP:Road should be of greater magnitude than that estimated by HSPF, perhaps by as much as a factor of 4.

6.6 SENSITIVITY ANALYSES

Using automated procedures available for WEPP:Road it is possible to evaluate the sensitivity of road erosion at Fort Benning to road segment length and slope and 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.) This capability has been utilized to provide better understanding of the potential benefits of road construction and maintenance practices that might be employed by the Installation. By integrating WEPP:Road into the Fort Benning Watershed Model, the resulting hybrid model will enable representation and evaluation of management decisions such as increased buffer widths, alternative road design (e.g., reduction of road slopes) and gravel additions.

Figure 6.8 and Figure 6.9 illustrate the sensitivity of road erosion at Fort Benning to road segment length and slope (top) and 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.) The model enables representation and evaluation of management decisions such as increased buffers, alternative road design and gravel additions.

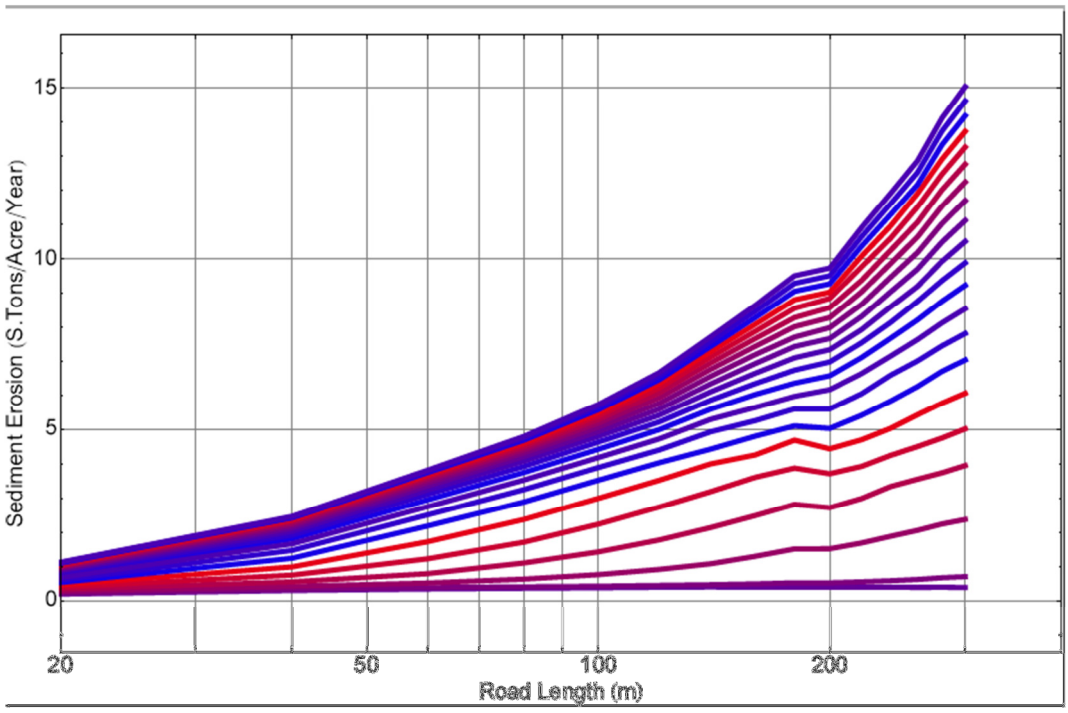

Figure 6.8 Sensitivity of WEPP:Road Erosion Estimates to Road Segment Length and Slope

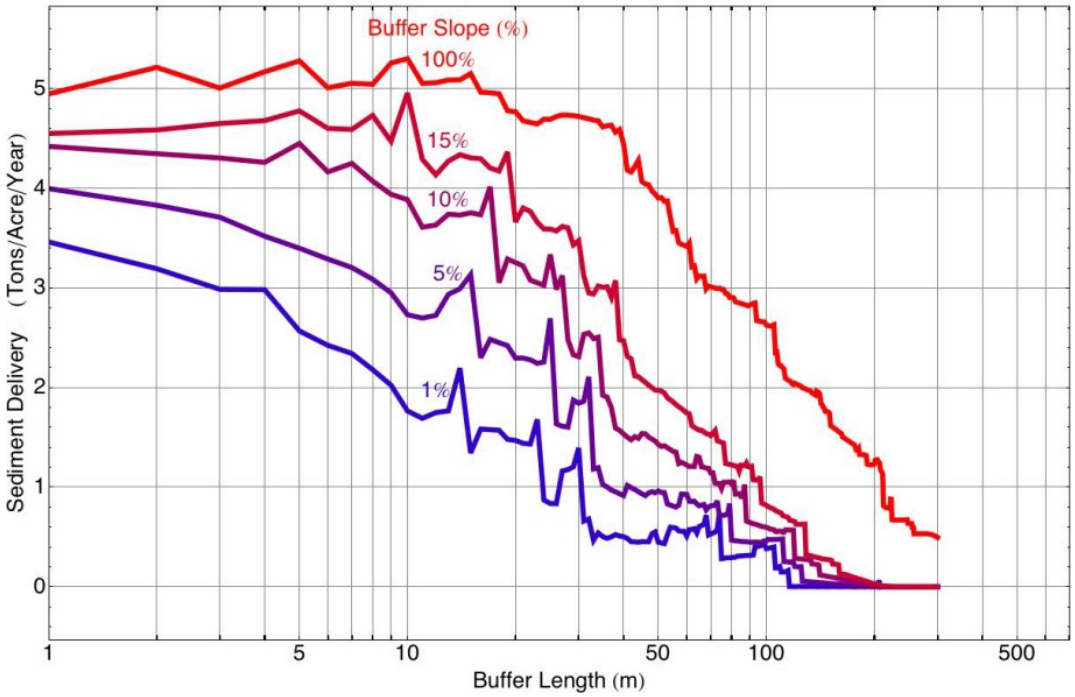

Figure 6.9 Sensitivity of WEPP:Road Sediment Delivery Estimates to Forest Buffer Flow Length and Slope

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SENSITIVITY ANALYSIS OF THE WEPP HILLSLOPE PROFILE EROSION MODEL

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ABSTRACT

Sensitivity analysis was performed on the hillslope profile erosion model developed by the USDA-Water Erosion Prediction Project. The erosion model calculates soil loss and sediment yield caused by rill and interrill erosion on complex shaped hillslope profiles. Sensitivity analysis of a physically based simulation model is used for assessing the rationality of the model, to provide insight into the overall physical system which the simulation model represents, and to help identify research needs. Changes in predicted soil erosion and sediment yield as a function of changes in soil, plant residue and canopy, hillslope topography, and hydrologic input variables were assessed. Dominant factors related to model response were precipitation, rill erodibility, rill residue cover, and rill hydraulic friction factors. Saturated hydraulic conductivity and interrill erodibility were moderately sensitive parameters. Other factors which had less influence on output were canopy height, interrill cover, soil bulk density, antecedent moisture, peak rainfall intensity, time to peak rainfall intensity, rill width and spacing, and sediment characteristics. Slope length, gradient, and slope shape effects on soil loss and sediment delivery were also discussed.

INTRODUCTION

The USDA-Water Erosion Prediction Project (WEPP) was initiated in 1985 to develop new generation soil erosion prediction technology for use in soil and water conservation planning and assessment (Foster and Lane, 1987). The hillslope profile version of the technology was designed to estimate rill and interrill soil losses and sediment yields from a complex shaped slope profile. The WEPP hillslope model is based on fundamentals of hydrologic and erosion science and is process-based and computer-driven. The purpose of this study was to perform a detailed sensitivity analysis of the WEPP hillslope model to assess the overall influence of input parameters to the predicted soil loss estimates provided by the model. This analysis also provides insight into the factors which are most important to assess and ultimately control soil erosion under various environmental conditions.

Development of a physically based model requires two general steps: 1) development of the model equations, algorithms, and structure from existing theories and basic principles; and 2) evaluation of the model (Beck, 1983). The evaluation process includes at least three steps: 1) validation of the model by comparison of results to measured data; 2) sensitivity analysis of the model response to input parameters; and 3) evaluation of confidence limits for the model predictions. Sensitivity analysis is an evaluation of the relative magnitudes of changes in the model response as a function of relative changes in the values of model input parameters. A detailed evaluation of a model's response can yield a great deal of insight into the nature of the model. Also, to the degree that the model accurately represents the physical system which it simulates, sensitivity analysis can provide insight into the factors which influence the response of the physical system. As pointed out by McCuen and Snyder (1983), sensitivity analysis provides a method for examining the response of a model in a way that eliminates the influence of error related to natural variation of the model input parameters. The rationality of the model and the influence of input error can thus be evaluated in detail.

The purpose of this study was to evaluate the response of the WEPP hillslope profile erosion model relative to changes in input parameters. Sensitivity analysis was conducted on soil, plant, hydrologic, and slope profile parameters of the model. The approach was to use an average linear sensitivity coefficient for the change in model response relative to the values of input parameters which represent the extremes in the physical conditions. These are generally the cases of most interest (McCuen and Snyder, 1983). Two forms of the model were used: the single storm version of the WEPP hillslope model which includes both the hydrology and erosion models; and the erosion model from the WEPP hillslope model independent from the hydrology model. The use of both forms of the model helped to better delineate the factors which influenced the erosion model from those which influenced the overall hydrology and erosion computations. A detailed description of the WEPP erosion model was given by Nearing et al. (1989) and the single storm model is described in Lane and Nearing (1989).

It should be noted that validation of the WEPP models is not complete. This sensitivity analysis was not performed on the final version of WEPP. The results

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Contribution of the USDA-Agricultural Research Service, National Soil Erosion Research Laboratory, West Lafayette, IN and the Agricultural Engineering Dept., University of Georgia, Athens.

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SECTION 7
HYBRID MODEL SIMULATION

After the unit area erosion estimates for each of the 14 watershed segments had been computed and evaluated using WEPP:Road, the subsequent step was to transfer these results into the watershed model using the generalized capability for hybrid modeling described in Section 7.1 below. The potential benefits of the hybrid model application over the original baseline model in which unpaved roads were simulated using the generalized HSPF watershed-scale process formulations include:

1. More detailed process algorithms for estimating unpaved road and fillslope runoff and erosion phenomena, and
2. Enhanced capabilities to represent management

The integration of the WEPP:Road results into the Fort Benning Watershed Model enables the evaluation of impact that the sediment erosion from unpaved roads has at all points in the Installation's stream network.

The need for, and benefits of evaluating the unit area sediment washoff that is computed using either the HSPF PERLND module or WEPP:Road *in a watershed context* is illustrated jointly by Table 7.1 and Figure 7.1. By combining simulated unit area erosion contributions from all land use types; sub-basin areas for the land uses; land-stream and stream-stream segment connectivity; and channel sediment transport computations, the watershed model provides a much more robust depiction of the actual impact of erosion phenomena throughout the watershed.

Table 7.1 provides a comparison of the unit area sediment washoff versus the resulting percent contribution of total sediment drainage washoff for aggregated and uses at three locations in the Fort Benning watershed. The Fort Benning Watershed Model is comprised of 131 local sub-basins, each of which drains into a unique reach segment of the stream network. The table reports the sediment washoff contributions (simulated by HSPF) from aggregate land use categories at three different reaches in the network. North Upatoi Creek is located in the upper northeastern portion of the watershed (see yellow circle in Figure 7.1) in an area of low road density and military training activity with a predominant land use of agriculture/other. Pine Knot Creek is located in the central portion of the watershed (see red circle in Figure 7.1) and is an area of high road density and heavy military training activity. The third location is the outlet for the entire Upatoi Creek drainage. As the table indicates, the simulated unit area sediment washoff from military activities (i.e., unpaved roads, tank trails and heavy maneuver areas) at each of three locations is comparable in magnitude, ranging from 5.2 to 6.0 tons/ac/yr. However, the relative contribution of sediment from military activities at the three locations is drastically different. Model results suggest that sediment washoff from military activities contributes only 7 percent of the loading to the North Upatoi Creek, as opposed to 44 percent of the loading to Pine Knot Creek and 34 percent of the total sediment loading to the Upatoi Creek drainage.

Table 7.1 Comparison of Unit Area Sediment Washoff versus % Contribution of Total Sediment Drainage Washoff for Aggregated Land Uses at Three Locations in the Fort Benning Watershed.

Aggregated Land Use	R:14 (North Upatoi Creek)		R:34 (Pine Knot Creek)		R:74 (Outlet Upatoi Creek)	
	t/ac/yr	%	t/ac/yr	%	t/ac/yr	%
Urban	0.3	1.3	0.28	0.9	0.24	1.7
Forest	0.11	14.8	0.13	14.5	0.13	16.6
Shrub/Scrub	0.23	1.2	0.2	1.2	0.2	0.8
Grass/Herb	0.27	4.7	0.22	4.9	0.22	3.7
Ag/Other	3.3	70.7	3.05	33.7	3.09	38.1
Paved Roads	0.23	0.2	0.24	0.1	0.22	0.2
Military Uses	5.29	6.8	6.01	44.7	5.18	38.8
Water/ Wetlands	0.01	0.2	0.01	0.1	0.01	0.1

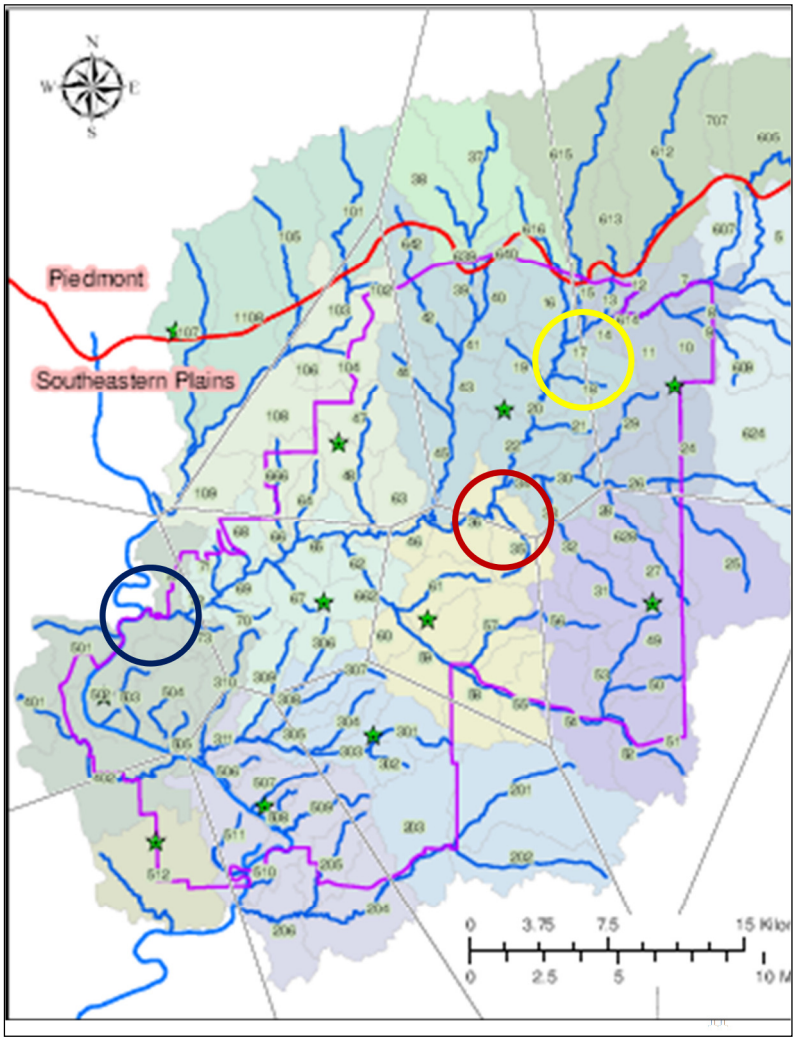

Figure 7.1 Locations of Sediment Data Featured in Table 7.1

The process of implementing the hybrid simulation entails building a wrapper and re-running WEPP:Road in the context of the hybrid modeling module of HSPF, thereby (1) associating roads with watershed met segments and (2) transforming results into point sources; (3) multiplying unit erosion by areas in each met segments; (4) introducing loadings into linked stream channel segments; and (5) evaluating impact at locations of interest.

7.1 WEPP:ROAD WRAPPER DEVELOPMENT

Integration of a SSM into a HSPF model requires a 'wrapper'. The wrapper has three functions:

1. write all input needed by the SSM based on input provided by HSPF or in external files,
2. execute the SSM, and
3. read results produced by the SSM and format them into a HSPF compatible format.

Figure 7.2 depicts the logistical linkage that was established for demonstrating a hybrid modeling methodology using the WEPP model to provide unit area sediment washoff data for the HSPF watershed model. The EXTMOD module was not used for this demonstration; instead the approach was taken to suppress the sediment washoff loadings that the HSPF model was estimating and to introduce as their replacement the sediment washoff loadings that were generated by the WEPP model. Both loading estimates relied on the simulated HSPF flow values. The mechanics of this process were as follows:

- Output from 14 WEPP simulations was processed to get daily loads (kg/m^2) at the edge of the fill slope overland flow element (OLE).
- Daily loads were imported to the watershed data management (WDM) file and units were converted from kg/m^2 to tons/acre.
- Daily loads were distributed to hourly intervals using according to the hourly input precipitation pattern, with an initial set aside of 0.2 inch to accommodate for depression storage.
- Hourly unit area loads were multiplied by unpaved area acreages and used as input to each HSPF stream reach.

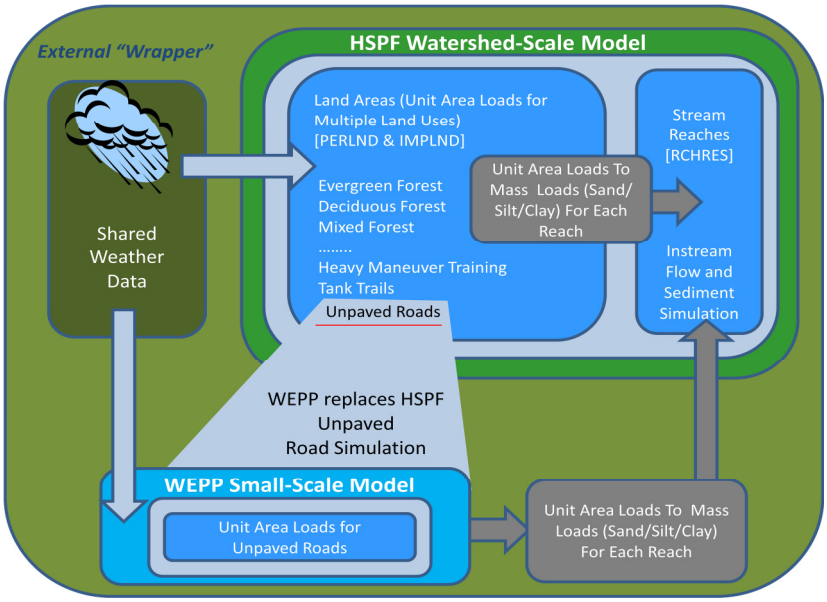

Figure 7.2 HSPF/WEPP Linkage for Performing Hybrid Modeling

7.2 HSPF EXTMOD SIMULATION CAPABILITY

The newly developed HSPF EXTMOD module allows hybrid model applications utilizing the catchment-scale capabilities found in HSPF and the field- or hillslope- scale capabilities found in smaller-scale models (SSM) like WEPP:Road. EXTMOD was designed to allow for the SSM to be used 'natively' - without changes to its input or output. This allows the SSM developer to be comfortable with the implementation of their model in parallel with HSPF, as there are no changes needed to the small-scale model.

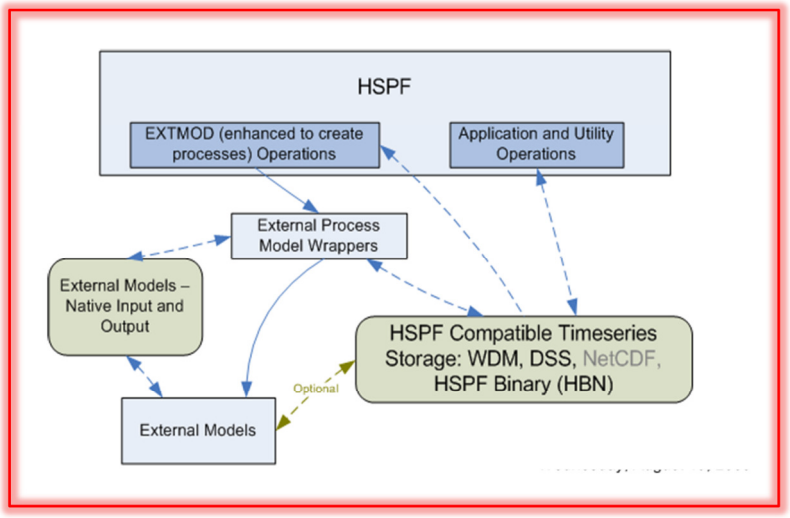

Figure 7.3 Communication Structure between the HSPF Watershed Model and Smaller-Scale Models

HSPF EXTMOD provides 'accounting' services following HSPF conventions to keep track of fluxes and mass balances for the portion of the watershed being modeled by the SSM. An EXTMOD operation (Figure 7.3) reads timeseries data created by a SSM wrapper along with any associated metadata and stores them internally in the HSPF operation status vector, accumulates fluxes to user specified reporting intervals, following the conventions used in other HSPF modules, and reports accumulated fluxes and state variables to text and binary files as requested by the user. Timeseries data defined in an EXTMOD operation are available for use in any other operation present in the HSPF run. This allows some portions of a catchment to be modeled by a SSM and other portions to be modeled by the existing HSPF code.

7.3 ROAD AREA ESTIMATES

Understanding the impact of erosion from Fort Benning's unpaved roads in a watershed context requires that the unit-area erosion results estimated by either or both models (HSPF, WEPP:Road) be combined with estimates of road/hillslope *surface area* and expressed as sediment loadings to the appropriate channel segments to which roads drain.

To support more detailed modeling of the Installation's unpaved roads, Mr. Hugh Westbury at Fort Benning researched the available GIS road coverages that reside in the Fort Benning holdings, and identified the most recent and complete coverage that exists. The selected GIS layer was used to establish the estimates of road surface areas that were subsequently used in both the HSPF and WEPP:Road model applications. The GIS layer identifies approximately 1600 miles of unpaved roads and trails in the watersheds that contain the Installation. Mr. Westbury was unable to attribute an exact date to the layer that he provided, but he indicated that it would be this coverage that the Installation would use for any current needs they might have for road coverage information.

Three categories of unpaved roads are represented in the coverage, and they are described as unpaved 'highways', roads and trails. Mr. Westbury describes unpaved highways as 'major administrative dirt roads'. Such roads would likely be absent from many non-military forest watersheds. Google Earth was utilized to gain a visual understanding of the differences between the three road categories by superimposing the road vectors on photo imagery.

Two of the three road categories represented on the coverage, unpaved highways and unpaved roads, are clearly components of the composite unpaved road category/area that needs to be modeled. By superimposing the third category, the unpaved vehicular trails, on Google Earth photography, it was possible to establish that the unpaved trails were also a necessary component of the composite unpaved road category/area.

In the subsequent estimation of road areas the distinction between the three categories has been preserved, since this distinction could potentially be represented in future WEPP:Road simulations that require finer resolution than the current application. Road lengths were measured using both the MapWindow (www.mapwindow.org) and ArcGIS software packages, using two different line measurement tools, and the analyses were performed by two different individuals to provide a QA/QC check on results. Limitations presently inherent in the MapWindow software made it impossible to estimate the full set of three road categories in all 14 meteorological segments, but in the 19 instances (an instance being defined as estimation of cumulative road length for a single road type in a single met segment) where MapWindow successfully computed estimates, the estimates were identical for ArcGIS and MapWindow. We have a high level of confidence in the estimates of road length that have been derived from the Fort Benning vector layer.

Estimates of road widths were developed based on one anecdotal and one analytical source. Mr. James Benefield, Fort Benning's liaison to our project regarding road information, characterized the range of road widths at Fort Benning as between 12 and 24 feet. In addition, the line measurement tool in Google Earth was used to estimate road widths, with maximum zoom implemented. The method was capable of making estimates of road width at the required level of detail.

For each of the three unpaved road categories (highway, road, trail) the line measurement tool was applied to three different cross-sections for each of three randomly selected road segments (9 total width measurements). Results corroborated that the widths of trails are consistently less than those of roads, which in turn are less than those of highways. Measured widths for trails were clustered closely to a value of **3 meters**; those for roads were clustered closely to a value **6 meters**. Widths for the three randomly selected unpaved highways were more variable, and the sample size was expanded to gather additional measurements; the widths of three additional highways (6 total samples, 18 total width measurements) were measured before determining a representative width of **12 meters**. Width estimates for trails and roads coincide well with the anecdotal information from Mr. Benefield. Although the average width for unpaved highways falls outside of the range that Mr. Benefield's suggested, the imagery convincingly supports the selection of this value as representative of the unpaved highway category.

At full zoom the Google Earth imagery is adequate to perform a visual search for evidence of fillslopes along the side of roads that might be of sufficient size (width, length) to contribute significant erosion. Visual inspection suggests that substantial fillslopes are scare, although some clearly exist. Visual evidence supports (1) minimizing the area represented as fillslope in the WEPP:Road simulations, and (2) assuming that the unpaved road PERLNDs designated in HSPF include both road surface and fillslope areas.

Both the road density and connectivity represented in the Fort Benning road layer (Figure 7.4) appear more poorly developed *outside* the Installations' boundary than that represented *within* Installation boundaries. It is possible that the road coverage in these areas is incomplete.

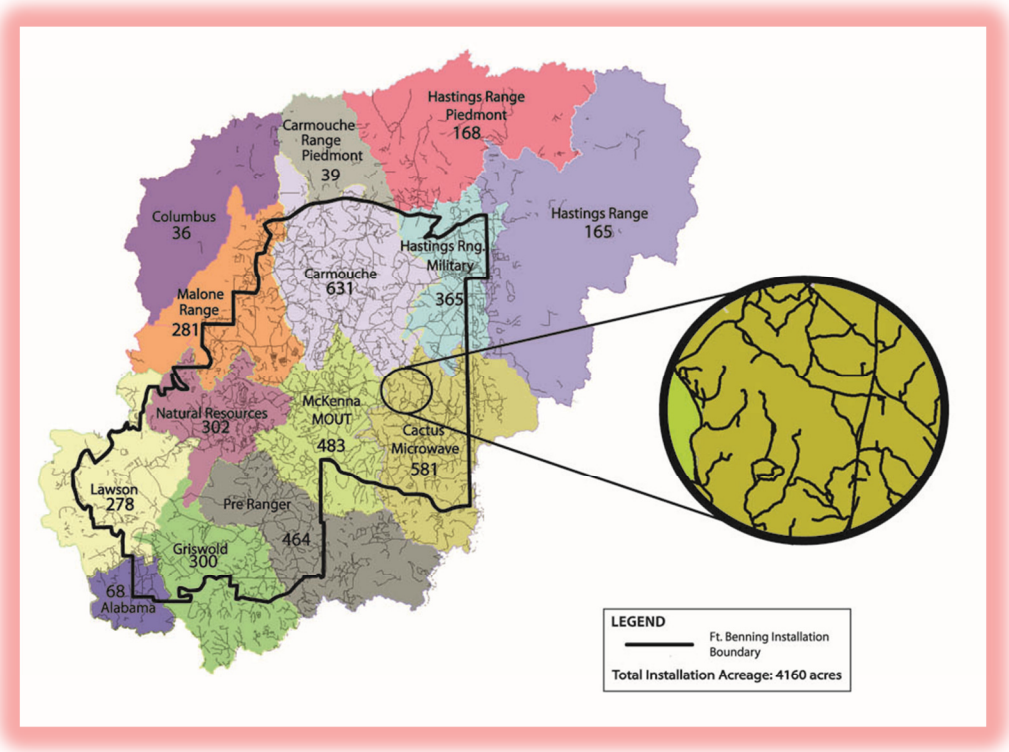

Figure 7.4 Unpaved Road Distribution and Density in Fort Benning's 14 Major Model Segments

Table 7.2 provides road surface area estimates derived from the Fort Benning GIS road layer. For each of 14 HSPF meteorological segments, ArcGIS-based estimates of extent (i.e., cumulative length) for unpaved vehicular trails, roads and highways as well as the total of the three categories are provided. Estimated average widths for each of the three road categories are also indicated, and resulting estimates of road areas are tabulated.

Table 7.2 Estimates of Current Road Surface Area within the Fort Benning Watershed Model's 14 Meteorological Segments

Meteorological Segment	Cumulative Road Length (m)	Average Road Width (m)	Road Surface Area (sq. m)	Surface Area (acres)
Hastings Range				
Unpaved trails	9728	3	29184	7.2
Unpaved roads	13106	6	78636	19.4
Unpaved 'highways'	46725	12	560700	138.5
Total Unpaved	69559		668520	**165.1**
Hastings Range –				
Unpaved trails	107890	3	323670	79.9
Unpaved roads	49072	6	294432	72.7
Unpaved 'highways'	71661	12	859932	212.4
Total Unpaved	228623		1478034	**365.1**
Carmouche Range				
Unpaved trails	180443	3	541329	133.7
Unpaved roads	116317	6	697902	172.4
Unpaved 'highways'	109605	12	1315260	324.9
Total Unpaved	406365		2554491	**631.0**
Carmouche Range –				
Unpaved trails	3685	3	11055	2.7
Unpaved roads	3721	6	22326	5.5
Unpaved 'highways'	10287	12	123444	30.5
Total Unpaved	17693		156825	**38.7**
Hastings-Range -				
Unpaved trails	12385	3	37155	9.2
Unpaved roads	30138	6	180828	44.7
Unpaved 'highways'	38389	12	460668	113.8
Total Unpaved	80912		678651	**167.6**
Malone Range # 22				
Unpaved trails	93914	3	281742	69.6
Unpaved roads	66166	6	396996	98.1
Unpaved 'highways'	38192	12	458304	113.2
Total Unpaved	198272		1137042	**280.8**
McKenna MOUT Site				
Unpaved trails	98345	3	295035	72.9
Unpaved roads	134739	6	808434	199.7
Unpaved 'highways'	71064	12	852768	210.6
Total Unpaved	304148		1956237	**483.2**
Cactus Microwave				
Unpaved trails	115353	3	346059	85.5
Unpaved roads	123627	6	741762	183.2
Unpaved 'highways'	105324	12	1263888	312.2
Total Unpaved	344304		2351709	**580.9**
Natural Resources				
Unpaved trails	63380	3	190140	47.0
Unpaved roads	73179	6	439074	108.5
Unpaved 'highways'	49587	12	595044	147.0
Total Unpaved	186146		1224258	**302.4**
Lawson AAF				
Unpaved trails	35680	3	107040	26.4
Unpaved roads	64542	6	387252	95.7
Unpaved 'highways'	52683	12	632196	156.2
Total Unpaved	152905		1126488	**278.2**
Pre-Ranger Site				
Unpaved trails	70212	3	210636	52.0
Unpaved roads	128759	6	772554	190.8
Unpaved 'highways'	74494	12	893928	220.8
Total Unpaved	273465		1877118	**463.6**
Grisworld Range				
Unpaved trails	73505	3	220515	54.5
Unpaved roads	114718	6	688308	170.0
Unpaved 'highways'	25305	12	303660	75.0
Total Unpaved	213528		1212483	**299.5**
Alabama Site				
Unpaved trails	18074	3	54222	13.4
Unpaved roads	10576	6	63456	15.7
Unpaved 'highways'	13025	12	156300	38.6
Total Unpaved	41675		273978	**67.7**
Columbus Metro AP				
Unpaved trails	1664	3	4992	1.2
Unpaved roads	2291	6	13746	3.4
Unpaved 'highways'	10477	12	125724	31.1
Total Unpaved	14432		144462	**35.7**
All Met Segments				
Unpaved trails	884258	3	2652774	655.2
Unpaved roads	930951	6	5585706	1379.7
Unpaved 'highways'	716818	12	8601816	2124.6
Total Unpaved	2532027		16840296	**4159.6**

7.4 RESULTS

7.4.1 Results Related to Developing a Generalized Hybrid Modeling Capability

The investigation and effort to develop a generalized hybrid modeling capability had a number of positive outcomes:

- Small-scale models with potential utility for military applications were identified (AQUA TERRA Consultants, 2009).
- A proof of concept and demonstration of hybrid modeling was achieved and reported in detail (see Appendix A).
- The shared code (EXTMOD) needed to enable communication between HSPF and any small-scale model was developed and tested.

In carrying out the implementation effort numerous lessons were learned that clarified both the potential and limitations of hybrid modeling as a practical and reliable evaluation technique. Among these are the following:

- The successful implementation of a hybrid modeling framework is VERY dependent on the compatibility of the two models that are targeted for use. Compatibility considerations include both those of model purpose and modeling paradigms. Although at the onset of the demonstration effort the HSPF and WEPP:Road models appeared compatible, incompatibilities became evident for all three of these consideration categories.
- Combining a deterministic model (HSPF) with a design model (WEPP:Road) introduces significant challenges. As a design model, the WEPP application techniques allowed less opportunity to effectively use historical weather data combined with calibration as a means to fine-tune sediment response to weather. Rather, the WEPP:Road approach was to provide reasonably indicative simulation results using a relatively 'black box' approach that discouraged adjusting the WEPP model parameter values. Considerable effort was required to understand the appropriateness of various instances where the WEPP:Road authors had 'hard-wired' parameter values with the intent of providing *sets* of parameter values for unpaved road features/options/settings that they believed led to appropriate runoff/erosion responses for various types of roads in various regions of the United States. As the effort to use WEPP in conjunction with HSPF progressed, it became more and more necessary to find ways to circumvent a number of these features in order achieve the modeling results that we believed were appropriate for the Fort Benning application and compatible with the historical weather data that we were using for the HSPF application.
- As the demonstration implementation proceeded it became apparent that there were fundamental differences in how the two models estimated runoff and sediment erosion response, and that these differences created additional challenges to using WEPP results as a direct input to HSPF. HSPF simulation features continuous update of hourly soil moisture condition (as well as other water sources and sinks), and by doing so has the necessary information to estimate the runoff response of each new hour's precipitation. WEPP does not keep a running account of soil moisture condition. In situations where sub-daily precipitation data is used as input to WEPP, the model uses the approach of calculating and accumulating runoff 'intensity' values that are used to estimate maximum instantaneous runoff intensity. In turn, this value is used to estimate a storm sediment erosion value. Thus, while the role of WEPP in the hybrid modeling

was to provide hourly sediment washoff (and perhaps runoff) values for unpaved roads to the HSPF model, doing so created unexpected challenges.

7.4.2 Results Related to Modeling Sediment Erosion from Unpaved Roads

The final calibration of WEPP:Road sediment washoff met its objective. Simulated unit area sediment washoff for the 14 meteorological segments for WEPP road segments (road plus fillslope) ranged from 1.3 to 2.9 tons/ac/yr. For the modeled meteorological segments, differences in simulated unit area sediment washoff between HSPF and WEPP:Road varied from minus 6 percent to plus 15 percent. Table 2.1 provides the unit area sediment washoff results that were achieved using HSPF and WEPP:Road. Appendix A provides corresponding information regarding the WEPP parameter values that were used to generate the final results.

SECTION 8
CONCLUSIONS

8.1 UNPAVED ROAD SIMULATION

8.1.1 Conclusions Related to Understanding Hybrid Modeling Challenges and Issues

The fundamental conclusions that we drew regarding the hybrid modeling technique are as follows:

- Detailed familiarity (both theoretical and mechanistic) with both models that are intended for use is a necessity.
- If there is a need to gain familiarity with one or both models, that effort may require greater time and resources than the implementation aspects of the hybrid modeling application.
- Of the necessary communication components for a hybrid model application (Figure 2.1.3), development of the wrapper is the most time consuming and the most critical, because it is this component that performs the often complex task of translating the results that are a natural expression of a SSM's paradigm into a format that reflects the larger-scale model's paradigm. The wrapper operations can be performed either as a single code module or as sequential steps that are manually performed by the modeler. Whether or not the development of a single-code wrapper is justified depends on the likelihood of there being multiple users of the hybrid modeling framework. If a single application of the framework is envisioned, the effort is probably not warranted.

While we continue to see potential value in hybrid modeling, we have a heightened appreciation of the challenges and level of effort that may be required for a successful application.

8.1.2 Results Related to Developing a Generalized Hybrid Modeling Capability

The investigation and effort to develop a generalized hybrid modeling capability had a number of positive outcomes:

- Small-scale models with potential utility for military applications were identified (AQUA TERRA Consultants, 2009)
- A proof of concept and demonstration of hybrid modeling was achieved and reported in detail (see Appendix A)
- The shared code (EXTMOD) needed to enable communication between HSPF and any small-scale model was developed and tested.

In carrying out the implementation effort numerous lessons were learned that clarified both the potential and limitations of hybrid modeling as a practical and reliable evaluation technique. Among these are the following:

- The successful implementation of a hybrid modeling framework is VERY dependent on the compatibility of the two models that are targeted for use. Compatibility considerations include both those of model purpose and modeling paradigms. Although at the onset of the demonstration effort the HSPF and WEPP:Road models appeared compatible, incompatibilities became evident for all three of these consideration categories.

- Combining a deterministic model (HSPF) with a design model (WEPP:Road) introduces significant challenges. As a design model, the WEPP application techniques allowed less opportunity to effectively use historical weather data combined with calibration as a means to fine-tune sediment response to weather. Rather, the WEPP:Road approach was to provide reasonably indicative simulation results using a relatively 'black box' approach that discouraged adjusting the WEPP model parameter values. Considerable effort was required to understand the appropriateness of various instances where the WEPP:Road authors had 'hard-wired' parameter values with the intent of providing *sets* of parameter values for unpaved road features/options/settings that they believed led to appropriate runoff/erosion responses for various types of roads in various regions of the United States. As the effort to use WEPP in conjunction with HSPF progressed, it became more and more necessary to find ways to circumvent a number of these features in order achieve the modeling results that we believed were appropriate for the Fort Benning application and compatible with the historical weather data that we were using for the HSPF application.
- As the demonstration implementation proceeded it became apparent that there were fundamental differences in how the two models estimated runoff and sediment erosion response, and that these differences created additional challenges to using WEPP results as a direct input to HSPF. HSPF simulation features continuous update of hourly soil moisture condition (as well as other water sources and sinks), and by doing so has the necessary information to estimate the runoff response of each new hour's precipitation. WEPP does not keep a running account of soil moisture condition. In situations where sub-daily precipitation data is used as input to WEPP, the model uses the approach of calculating and accumulating runoff 'intensity' values that are used to estimate maximum instantaneous runoff intensity. In turn, this value is used to estimate a storm sediment erosion value. Thus, while the role of WEPP in the hybrid modeling was to provide hourly sediment washoff (and perhaps runoff) values for unpaved roads to the HSPF model, doing so created unexpected challenges.

8.1.3 Conclusions Related to Improving Modeling for Runoff and Erosion from Unpaved Roads

Given the significant impact that erosion from unpaved roads may have at Installations, using a small-scale model with more detailed process representation than watershed models can offer is warranted and will likely continue to offer potential benefits to Installation managers.

Although WEPP:Road embodies much information that is useful in translating unpaved road characteristics, settings and management practices into changes in WEPP model parameters, the limitations that the tool places on users in terms of performing calibration preclude its effective use as a management tool.

Potential exists for using the WEPP model itself (without the WEPP:Road interface) to more effectively characterize and evaluate unpaved roads.

<u>Most Promising Road Maintenance Alternatives</u>

The fundamental objectives for maintenance of unpaved, outsloped roads are (1) to prevent concentrated rill/channel erosion and (2) to maintain the outslope. WEPP:Road author Bill Elliot identifies the following list of maintenance actions relevant to outsloped roads:

- Restrict traffic to dry season (not likely a viable action at Fort Benning).
- Regularly grade roads to remove ruts and maintain outsloping. (Bill Elliot contends that grading itself will have about the same affect on road erosion as traffic in making

sediment available for detachment and offsite transport. So if a road is experiencing traffic, then grading won't make it any worse. If a road is not experiencing traffic, then grading does make more sediment available for transport.)

- Reduce tire pressure in vehicles.
- Add surface gravel. The best gravel types are resistant to breakdown; have sufficient fines to stabilize gravel, but nonetheless encourage enhanced infiltration.
- Design and construct unpaved roads with rolling dips to break up the flow path length of ruts that might form in between grading. (We currently have no knowledge whether this technique had been applied at the Installation.)
- Pave roads within 30 feet of stream crossings, and implement armored drainage ditches for the paved areas.

The above list of actions assumes that opportunities *do not* exist for influencing the siting and design of unpaved roads. If such opportunities do exist, the most beneficial actions include the following:

- Increase buffer width between roads and stream channels.
- Decrease road gradients.
- Minimize road segment lengths between points of flow reversal that are induced by topographical relief.

It is our understanding that an additional action under consideration by Fort Benning to control sediment washoff from unpaved roads is construction of sediment collection basins. While this is not technically a road maintenance action, I did discuss it with Bill Elliot. His response: "If roads are outsloped and dispersing the runoff across a wide area, then trying to collect the sediment into a sediment basin is not a wise thing to do. Just because we can design sediment basins doesn't mean we should. Also, sediment basins are an expense that keeps on spending, with annual maintenance programs required, and the nuisance of trying to clean them out without damaging the overflow pipe requires a pretty good operator. If the basins are hard to access, then either manual cleaning, or additional disturbance by machinery in the buffer can make matters worse."

Current Unpaved Road Maintenance Practices at Fort Benning

We have identified two sources of information related to current road maintenance practices at the Installation.

1. Fort Benning referred our questions related to road maintenance to their authority on these issues, Mr. James Benefield. Mr. Benefield said that the Installation has a contractor who grades the major unpaved roads (these roads are categorized by Mr. Westbury as 'administrative' roads) twice a year, and that other unpaved roads on the Installation are only graded when an activity is planned in the area which they serve. Mr. Benefield and Mr. Westbury both indicated that rutting is not a dominating issue at this point in time on the Installation. Mr. Westbury attributes this to the fact that the 3rd BGD has been deployed since 2003. Mr. Westbury reports that maintenance of major unpaved roads has decreased due to sparse funding.
2. The Fort Benning INRMP says that since 1992 a 3-year rotational road maintenance schedule has been implemented on FB unpaved forest roads, which is likely coordinated with the 3 year prescribed burning cycle. Mr. Westbury relates the term 'unpaved forest roads' in the INRMP to a different group of roads referred to as 'vehicular trails' that are

identified as a group in the most current road coverage that Fort Benning has developed. Mr. Westbury reports that the funding for maintaining these roads is related to the prescribed burning schedule – the maintenance is performed to maintain the effectiveness of the roads as firebreaks, and is achieved through RCW funding from the Land Management Branch.

Assumptions Inherent in the 'Current Condition' Simulation

Another useful step before attempting to design one or more model scenarios to represent the impact of road maintenance is clarity on what our 'current condition' WEPP simulations imply about road conditions at Fort Benning. In essence our simulations assume that pre-BRAC05 road conditions and erosion behavior had the following attributes:

- Pre-BRAC05 traffic intensity was already comparable to what would be considered an upper limit for Forest Service roads. Hence the impact of traffic on the erodibility of the road surface was already represented at the upper limit that WEPP:Road allows for the prevalent soil type at Fort Benning. This suggests that further increases in road traffic and surface disturbance caused by implementation of BRAC05 will necessitate higher values for rill and interrill erodibility factors than can be specified using WEPP:Road – parameter adjustments will need to be made in the soils file that is provided to WEPP since there is no method of implementing this change in WEPP:Road.
- Road grading was occurring twice a year on frequently used roads, and only as needed to support specific activities on other roads. By specifying 'heavy traffic' conditions for all 'current condition' roads we have defined all road surfaces as highly erodible, at least within the range experienced in Forest Service lands. Hence, according to Bill Elliot's philosophy, the roads were all designated as highly erodible regardless of grading frequency. (Note: In the recently acquired Fort Benning road database we have the ability to discern between unpaved vehicular trails, unpaved roads, and unpaved highways – this information could be used to specify and model different road conditions for different categories of roads, but it would take some additional effort.)
- Based on information provided by the Installation, we have stipulated that the Installations' unpaved roads as a whole maintain their outsloped orientation and drainage and do not rut, regardless of the surface disturbance by high traffic, and that they do so without gravel addition.

Road Maintenance Modeling Alternatives

Among the list of six maintenance actions identified in Section III, three are either not practicable at Fort Benning, or do not lend themselves to evaluation by means of modeling:

1. Restrict traffic to dry season. Training requirements would likely preclude this action.
2. Reduce tire pressure in vehicles. Representing this action in a modeling framework would be problematic.
3. Pave roads within 30 feet of stream crossings, and implement armored drainage ditches for the paved areas. Representing this action in the modeling framework would require consideration of a more discrete spatial scale than is currently implemented.

The remaining three maintenance actions appear amenable to evaluation using our modeling framework:

1. Add surface gravel.
2. Regularly grade roads to remove ruts and maintain outsloping.

3. Design and construct unpaved roads with rolling dips to break up the flow path length of ruts that form in between grading.

The impact of any of these three actions must either be expressed using changes to input to WEPP:Road or directly to WEPP. It should be noted that regardless of which or these two methods is used to define a maintenance scenario, the result is the specification of a different, steady-state condition for the eroding surface. WEPP is not a storage-based model, and hence does not represent time-varying road conditions or road overland flow response within the period of simulation (an example: the erodibility of the surface in response to a given rainfall/runoff intensity does not change; another example: WEPP resets soil moisture at midnight each day rather than performing soil moisture storage accounting).

Bill Elliot suggests that it is likely that either gravel additions or increased frequency of grading will be required if/when Fort Benning road traffic dramatically increases. He considers the two as complementary, with the primary consideration being offsetting costs of gravel with reduced need for grading. Before addressing these two actions, a brief mention of the third candidate maintenance scenario (rolling dips) is warranted. This scenario could be represented and evaluated using WEPP:Road by simply decreasing the length of the representative road segments that are simulated. However, since all of the representative road segments we are modeling are outsloping, the impact of this modification would only come into play when the length between dips was specified as less than the calculated effective flow lengths that are automatically computed for the outsloping roads. The calculated effective flow lengths for our representative road segments fall in the range of 30 to 50 feet.

The impact of gravel addition is represented in WEPP:Road by (1) increasing the value for hydraulic conductivity and (2) disallowing the creation of a rutted condition and the resulting increased flow/erosion length along the full road segment length. Our 'current condition' simulations already disallow rutting, and consequently specification of gravel addition in the WEPP:Road interface as a road maintenance alternative would equate solely to increased rainfall infiltration into the road surface.

Bill Elliot does not offer authoritative guidance on representing the net impacts on the road surface of changes in grading frequency. He says "There are some complicated ways a set of runs could be done on WEPP windows with different intensities of grading, but I think the risk of making a poor assumption, or in thinking that everything was described exactly right when in fact not everything was are high."

So we are on our own to develop our rationale for adjusting WEPP parameters to produce one or more snapshots of a changed road condition resulting from changed grading frequency. A fundamental decision will be whether we want to preserve the logic currently embedded in WEPP:Road, i.e. that increased traffic conditions detach sediment in a manner and to a degree that mirrors the impact of increased grading frequency. If we choose to preserve this assumption, then the suggestion that I made above that we manually introduce higher values for WEPP's rill and interrill erodibility factors to represent an even higher traffic condition (resulting from BRAC05) than that available in the WEPP:Road interface, may at the same time offer an approximation of the impact of the increased grading frequency that is likely to be required to accommodate increased road traffic at the Installation.

In addition to the three maintenance actions discussed above, it should be noted that all three road siting and design actions (increased buffer widths, decreased road gradients, decreased road segment lengths) identified near the end of Section III can be effectively evaluated using WEPP:Road.

8.2 HYBRID MODELING CAPABILITY

8.2.1 Lessons Learned Regarding Hybrid Modeling

As a smaller-scale model (SSM) moves farther away from behaving similar to a continuously stirred reactor (CSTR), the linkage/wrapper becomes more complex and the accompanying assumptions increase to achieve mass balance and flux definitions (e.g., definition and transfer of water balance components other than runoff from WEPP to HSPF).

We do want to achieve mass balance and doing so presents challenges:

- SSMs that do not explicitly track needed fluxes
- SSMs that do not consider constituents that are modeled in the watershed-scale application (e.g., no nutrient simulation in WEPP)

8.2.2 Note Opportunities Resulting from Implementation of HSPF Hybrid Modeling Capability

Wetlands

Future training impact model

SECTION 9
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A Watershed Modeling System for Fort Benning, GA Using the US EPA BASINS Framework

SERDP PROJECT SI-1547

QUANTIFYING VEHICULAR IMPACTS FROM MILITARY TRAINING

Final Report
Appendix B

CONTENTS

FIGURES

TABLES

NOTE

This appendix provides supplemental information for Section 2.1 of the Final Report. It was authored by Niels Svendsen at USACE CERL. Note that a secondary document by the same author that is related to generating training impact maps is included as an attachment.

SECTION 1
INTRODUCTION

Considerable work has been completed characterizing military impacts on sediment transport related site variables. However using these data and training load measures to predict the results of future training scenarios has been difficult. This section summarizes published information on vehicle based military impacts relevant to sediment transport modeling.

In the 1980's, Engineer Research and Development Center (ERDC) conducted a series of studies that characterized the ecological effects of military vehicle training on the soils, vegetation, and wildlife of a number of military installations [2, 3, 4, 5, 6, 7, 8]. These studies covered a much wider range of ecological communities and military activities. This research consisted of visiting disturbed training areas and measuring soil and vegetation parameters. This research was typically observational in nature and the specific activities creating the impacts were largely unknown in their duration, frequency, extent, and vehicle type. Thus, this research only indirectly linked natural resources impacts with levels of training load. The studies summarized changes in vegetation and soils for historically low and high use areas in terms that can be beneficial to sediment modeling. Results from these studies can be used to parameterize sediment models by selecting values from the studies that are representative of the site to be modeled. However it is difficult to use these values to predict future conditions associated with specific training regimes or vehicles.

More recently, a number of studies have quantified military vehicle impacts through the use of small scale classical experimental plot designs [21, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54,55, 56, 57, 58]. These studies typically assess the impact of a specific vehicle and impact regime under controlled conditions on soil and vegetation resources [21, 31, 32, 33, 34, 36, 38, 39, 41, 42, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 69, 70, and 71]. The vehicle studied is typically either the most damaging vehicle used during training, most common vehicle used in off-road training activities, or a new weapon system being fielded at an installation. The impact regimes vary but typically either include single to multiple passes, straight and/or curved tracking, or alternate impact dates. The advantages of these studies are that impact regimes and site conditions are known, statistical methods can assess cause and effect relationships, and many dependent response variables can simultaneously be assessed. While controlled replicated studies clearly relate specific vehicle impacts to site damage, logistical constraints (i.e. number of plots) limit the range of treatments that can be quantified. In addition, interactions between vehicle static properties (weight, ground pressure), vehicle dynamic properties (velocity, acceleration, turning), and site conditions (soil texture and moisture, vegetation type) are often not captured in such studies. These studies are geographically limited and results must be extrapolated to other installations or vegetation/soil types within an installation. Some regions have been intensively studied (Southwest United States) while others have been largely unstudied (Southeast and Northeast United States).These studies can only document site changes that are small in spatial scale than the study's plots. Another limitation is that many critical sediment modeling variables were not measured in these studies. Many studies only measured relatively simplistic measures of soil and vegetation condition including plant cover, soil compaction, and soil rutting. Despite these limitations, small scale replicated plot studies provide the foundation for driving sediment erosion modeling efforts. Study results relate changes in critical model inputs to specific training loads. This approach has been used in several modeling efforts [78, 81, 82, 89, 117, and 118]. The limit to using this approach is the need to determining 1) the units and events involved in

training, 2) the vehicle mileage associated with the training units and events, and 3) the distribution of training across the landscape being modeled.

Anderson et al. [72] utilized data from existing Army natural resource monitoring programs to assess vehicle impacts to installation resources in a manner similar to replicated plot studies. This was done to make vehicle impact data more readily available to other installations where field studies did not exist and to account for more vegetation/soil types within an installation. In this study, not only plot-level assessments are made but data are also spatially extrapolated to assess impacts at broader spatial scales. This approach of using historical monitoring data to quantify single vehicle pass impacts like the plot studies but also provided a means to account for cumulative vehicle impacts. Results have been used in a number of published studies [2, 43, 64, 65, 74, 75, 76, and 79]. The advantage of using existing monitoring data is that quick assessments of vehicle impacts can be made until more robust data can be obtained. A limitation of using monitoring data for impacts assessment is that the impact regime is inferred rather than known. Another limitation is that impact and recovery processes are often confounded. Monitoring plots are measured at a point in time while vehicle impacts and recovery processes occur concurrently since the previous plot measurement. Use of this data in sediment modeling efforts would be the same as for use of controlled study plot data. The limit to using this approach in sediment models is the need to determine the 1) units and events involved in training, 2) vehicle mileage associated with the training units and events, and 3) distribution of training across the landscape being modeled. However the approach of Anderson et al [72] did document historic spatial and temporal vehicle disturbance patterns. These patterns have been documented in other studies [60, 72,126,127].

Limitations of replicated plot studies of vehicle impacts are that they do not exist for all vehicle types and site conditions that might be needed in a sediment modeling scenario. Modeling approaches used include 1) assuming all vehicles have the same impact [121], 2) assessing only the most severe vehicles [78], and 3) using conversion factors or vehicle models to relate untested vehicles to tested vehicles [82,85]. Models to estimate site impacts based on vehicle properties generally include vehicle static and/or dynamic properties. Vehicle designs have been shown to affect site impacts [59, 85, 86]. Modeling and simulation of vehicle-site interactions have become an integral part of the design, testing, and fielding of the new vehicles [87, 88]. Although such models were not developed to assess natural resources impacts they have been used to extend our understanding of potential vehicle impacts [85, 86]. A number of studies have emphasized the effect of vehicle designs or static vehicle properties on site impacts [85, 89, 90, 91, 92, and 93]. Use of these vehicle impact models have been integrated into land management decision-making models [85, 89]. Vehicle impact models overcome the lack of data for specific vehicles and sites. However they have the same implementation limits of needing to determine the 1) units and events involved in training, 2) vehicle mileage associated with the training units and events, and 3) distribution of training across the landscape being modeled.

Assessing the impact of vehicles on sediment transport requires more than an understanding of the small-scale impacts of vehicle use. To fully assess impacts at the landscape level, one must understand when and where vehicles can potentially be used, where and how vehicles are actually used, and how vehicles may be used in the future. Understanding when, where, and how vehicles are used is critical in impact assessments because sites vary in their susceptibility to damage and the existence of significant site by vehicle use interactions [10,35,38,39,41,59,63,69,70,72,74,80,83]. A number of studies have quantified where vehicle impacts are likely to occur based on whether vehicles can physically access a site [89, 91, 92, 95, 96, 97, and 98]. This approach often uses a vehicle mobility analysis to assess the potential spatial distribution of impacts including seasonal pattern differences. A limitation of all these

approaches is that just because a site is suitable for vehicle use does mean it will actually be used in a predictable fashion.

Other studies have quantified the spatial distribution of actual site usage using a variety of approaches including 1) tracking vehicles, 2) using Army standard monitoring data, 3) using remotely sensing data, and 4) using subject matter experts to estimate disturbance patterns [40,60,62,66,72,99,100,101,102,103,104,105,106,112,113,114]. Vehicle tracking approaches quantify the use patterns of individual vehicles, on and off-road use, and total vehicle mileage. Vehicle tracking approaches are limited by the need to have vehicles available for monitoring. Similarly, using historic use patterns to assess vehicle use patterns requires that vehicle have been using the site of interest and the doctrine of training has not changed. Using subject matter expert opinion requires prior knowledge of future vehicles and doctrine and their interaction with site characteristics. While these approaches provide information on the spatial distribution of mission impacts, their use in sediment transport models is still limited by the need to determine the 1) units and events involved in training and 2) vehicle mileage associated with the training units and events.

To make use of the information known about vehicle impacts from existing studies in sediment transport models, there are two general modeling approaches. First only model current land conditions without trying to assess future conditions or alternative land use scenarios. Data from prior site characterizations impact studies would generally provide sufficient data for model parameterization with possibly some additional data collection for model unique parameters. This approach still implies that some installation spatial data exists to account for current conditions. The second model approach, which is more difficult to implement, is to predict future land condition based on alternative training scenarios. This approach requires all the current condition and model parameterization data required for the first approach in addition to information on the 1) units and events involved in future training, 2) vehicle mileage associated with the training units and events, and 3) distribution of training across the landscape being modeled.

Approaches for estimating units/events that have been used include use of vehicle motor pool records [72,140], measures of main units stationed at an installation [60, 72], Range Facility Management Support System (RFMSS) data [127,129], and Army Range Requirements Model (ARRM) data [210, author's unpublished data]. Vehicle motor pool records were used record daily mileage and/or hours of operation for each vehicle in the motor pool. Conversion factors based on subject matter experts were used to convert hours of operation to miles of operation. Mileage estimates were combined to provide annual training load. Advantages of this data are that actual vehicle usage by vehicle type was available. Limitations of the data are that it was very labor intensive to obtain and little to no information was available on location of impacts. Anderson et al [72] demonstrated that this type of detailed data was correlated with changes in land condition. Anderson et al [72] also showed that much coarser measures of training loads (number of battalions) was just as useful for explaining changes in vegetation cover. These results indicate more easily obtainable data might be more applicable for sediment transport modeling.

RFMSS is a tool used to schedule training areas and record training area usage. The main advantages of using RFMSS data to characterize training load is 1) commonly used by many military installations, 2) provides information on location of training, 3) provides standardized reporting and addition of ad hoc reporting. Limitations of using RFMSS data include 1) input information generally not standardized, 2) scheduling and actual use are not always maintained, 3) only provides training distribution at the training area level. Information scheduled in RFMSS often does not record the type of unit, training event, and number of vehicles in a consistent

manner that allows easy summarization of training load measures that easily relate to site impacts. An effort was conducted as part of the ATTACC program (author's personal experience) to incorporate this type of information into RFMSS. This RFMSS component was called the ITAM component. The RFMSS software update was tested at Fort Carson. It was determined that implementation of the module was too difficult and time consuming for training units. There was not leadership support for implementation like there is for munitions tracking. As a consequence most or all RFMSS data must be interpreted by local personnel to convert unit and event designations to meaningful records of numbers of vehicles. Despite these limitations, Wang et al [127] showed that general training load information from RFMSS (troop-days) could be used to explain changes in vegetation cover over a 13 year period. Davis [128] showed that the same data could explain temporal changes within a year and spatial difference among training areas in vegetation cover. Quist et al [74] showed for the same location that these differences in vegetation were correlated with changes in water quality. Thus, while RFMSS data might be limited, it has potential for use in sediment transport modeling.

ARRM is an Army planning tool for estimating training through put on ranges and lands. ARRM contains 1) all units within Army and NG, 2) where units are stationed and train, and 3) estimates of training load (rounds, MIMs). Advantages of ARRM data is that 1) training load is consistently estimated across all installations, 2) training scenarios can be constructed for alternative assumptions, 3) training load is in useful measures like miles and rounds fired. ARRM includes ATTACC MIM values which have been utilized with erosion models in a number of applications [author's unpublished work]. Limitations of ARRM data include 1) data are based on objective and subjective data, 2) no information on distribution besides which installation.

SECTION 2
APPENDIX BODY

2.1 ATTACC AND USLE

Modified USLE erosion estimates were developed as part of ATTACC for approximately 32 military installations that represent over 75% of Army training lands and 85% of Army training loads. Modified USLE means that RUSLE values were used for all USLE parameters except the C value. USLE C values were used based on an unpublished study conducted by the USDA NRCS that indicated USLE C values predicted erosion loss as well or better than RUSLE C values for rangeland conditions. Installations included in ATTACC erosion estimates include APG, Camp Blanding, Fort Bliss, Fort Bragg, Fort Campbell, Fort Carson, Fort Chaffee, Fort Drum, DPG, Camp Edwards, Camp Gruber, Camp Grayling, Hohenfels, Fort Hood, Fort Huachuca, Fort Irwin, Fort Jackson, Fort Knox, Fort Leonardwood, Fort Lewis, Fort McCoy, OTA, Camp Ripley, Fort Sill, Fort Stewart, Camp Williams, and YTA.

Methods have been developed to make USLE/RUSLE input parameters more appropriate for military applications. Wang et al [169] developed more spatially explicit R factor maps to account for variation in R factor across installations. This was more relevant to very large installations and installations with large elevation changes. A number of studies have used alternative methods for estimating LS factor that account for the complex topography of military installations [145,147,148,149,154, 156,157,158,181,182,183]. Since some of these LS factor approaches account for sediment transport indirectly, these methods may not necessarily be relevant to HSPF. Several studies have examined alternative data sources for K factor including published values and field values [184,185].

Several studies have looked at the relative role of different USLE/RUSLE parameters in determining erosion estimates [170]. R factor is the greatest determinant of erosion rates with LS factor being second. However C factor is the factor most affected by military actions. The K factor is generally considered unaffected by military activity because changes in soil properties are captured in the P factor [personal communications Dr. Foster].

The following table summarizes some typical data sources used for each USLE/RUSLE input value.

Table 2.1 RUSLE Factor Descriptors and Data Sources

RUSLE FACTOR	DESCRIPTION	DATA SOURCES
R	The rainfall and runoff factor or erosivity factor for a specific location.	Published isoerodent maps Local precipitation data
K and T	The soil-erodibility (K) factor is the rate of soil loss per rainfall erosion index unit under standardized conditions. The soil loss tolerance (T) factor denotes the maximum level of soil erosion that will permit a high level of soil productivity to be sustained economically and indefinitely.	NRCS Soil Survey Geographic Data Base (SURGO) NRCS State Soil Geographic Data Base (STATSGO) NRCS National Soil Geographic Data Base (NATSGO) Digitized public NRCS soil survey reports NRCS Map Unit Interpretations Record (MUIR) attribute data base Soil samples from field surveys

RUSLE FACTOR	DESCRIPTION	DATA SOURCES
LS	A quantitative representation of the effect of the local topography on erosion rates. This factor includes both the slope length and steepness.	Elevation (i.e., terrain) data USGS Digital Elevation Models (DEM) National Imagery and Mapping Agency (NIMA) Digital Terrain Elevation Data (DTED) LIDAR imagery Digital imagery Field measurements RTLA/LCTA data Global Positioning System (GPS) data
C	The cover (C) factor reflects the degree of erosion protection provided by vegetative cover.	RTLA/LCTA data Other vegetation survey data National Land Cover data Remotely sensed imagery Installation vegetation maps and published C values
P	The conservation practices (P) factor is a quantitative expression of the mitigating effect that conservation practices have on the erosion process.	Published data Expert opinion

ATTACC went beyond predicting erosion based on current conditions. ATTACC attempted to make predictions of future conditions based on changes in land condition associated with projected training. To predict future conditions, a Delta USLE C value is used to predict cover after a specified amount of military training. Delta USLE C value is the change in USLE C value associated with a single vehicle track. It is derived from RTLA data (formerly called LCTA data) using methods of Kennaway et al [130]. The mean Delta USLE C value calculated for Fort Benning using this method is 0.084 with standard error of 0.015. Anderson published Delta USLE C values for a range of installations [151]. Representative USLE C factors, erosion rates estimated from USLE, and percent disturbed area are available for the same installations with estimates of the amount of disturbance. Figure below is a distribution map generated for Fort Benning. One problem with this approach is that Fort Benning has not continued collection of RTLA data. Alternative methods for calculating USLE/ATTACC data input values are described in Kennaway et al [130].

Military applications for USLE/RUSLE are applicable to HSPF implementation because USLE/RUSLE can be used as a source term for sediment loss at a location. This approach is similar to other applications [190,189,188,187].

2.2 SEDIMENT PRODUCTION FROM HEAVY MANEUVER LANDS FROM NON-ATTACC-BASED USLE ESTIMATES

A number of studies have used USLE to estimate erosion rates for environmental impact statements that assessed impacts of planned training activities [131,132,139,141, 142,143]. Installations included in these studies include Camp Shelby, Fort Carson, Fort Lewis, Yakima Training Center, Fort Polk, several HI installations, several Alaska installations. Diersing et al [78] used USLE soil loss estimates to estimate training land carrying capacity. Carrying capacity was established at a point where predicted soil loss would exceed tolerable soil loss amounts. The use of USLE in this military application is very similar to an approach used to estimate

recreation capacity in national parks [133,134,135]. Several authors have used Army monitoring data to assess land condition with erosion estimates being one of the measures of land condition [75,76,117,136,137,138,146,155,161]. All the approaches to using USLE to estimate soil loss on military lands are very similar. Kennaway et al in proposing alternative methods for implementing USLE within ATTACC attempted to summarize the approaches and relate to available Army data [130].

In addition to using various modification to USLE that are essentially alternative data development approaches, some authors have attempted to modify specific components of USLE to make them more applicable to military use. These modifications usually involve the LS factor and are modified to account for soil transport and deposition [145,147,148,150,154,156,157,158]. Dr. Foster (USDA ARS) who was responsible for development of the RUSLE was taken on a tour of several installations including Fort Hood and Fort Benning. Dr. Foster's conclusion is that RUSLE is appropriate for use on military lands if input data are properly developed to characterize the site.

2.3 FORT BENNING TRAINING AREAS USLE ESTIMATES AND/OR USLE FACTOR VALUES

The following Figures 2.1-2.7 show USLE/RUSLE input values and predicted erosion rates for Fort Benning, GA. The K and T factors are derived from NRCS soil surveys. The C factor is derived from RTLA data and spatially extrapolated using remotely sensed imagery. LS values were derived from a DEM. The R value used is 400 and obtained for RUSLE manuals. Using the input maps, a current RUSLE/USLE erosion map for Fort Benning is provided.

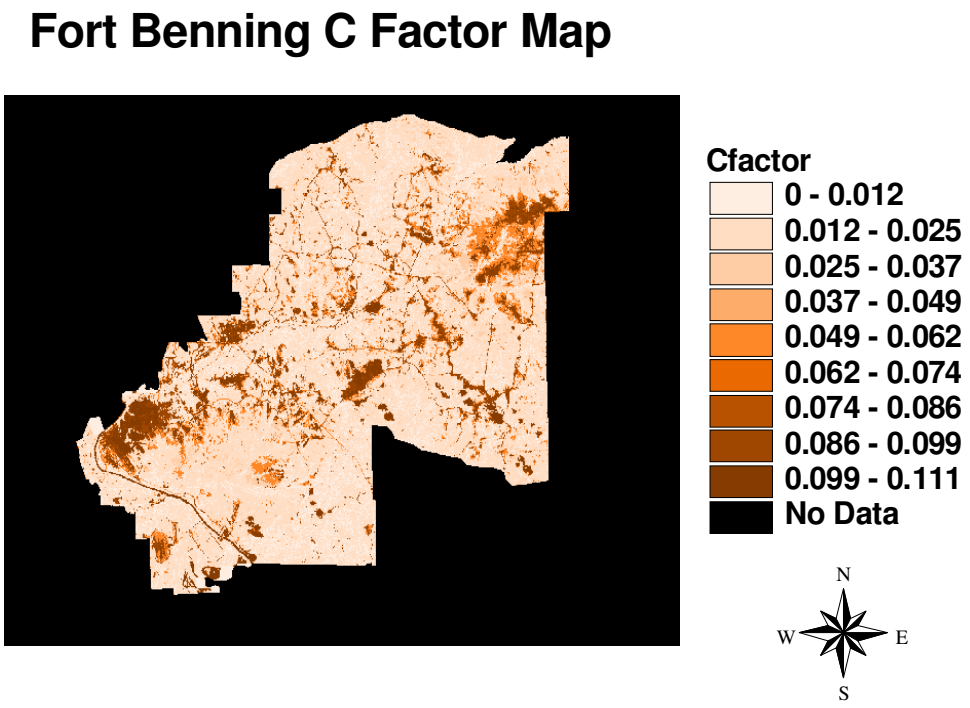


Figure 2.1 Fort Benning USLE C Factor Map Using RTLA Data

Fort Benning K factor Map

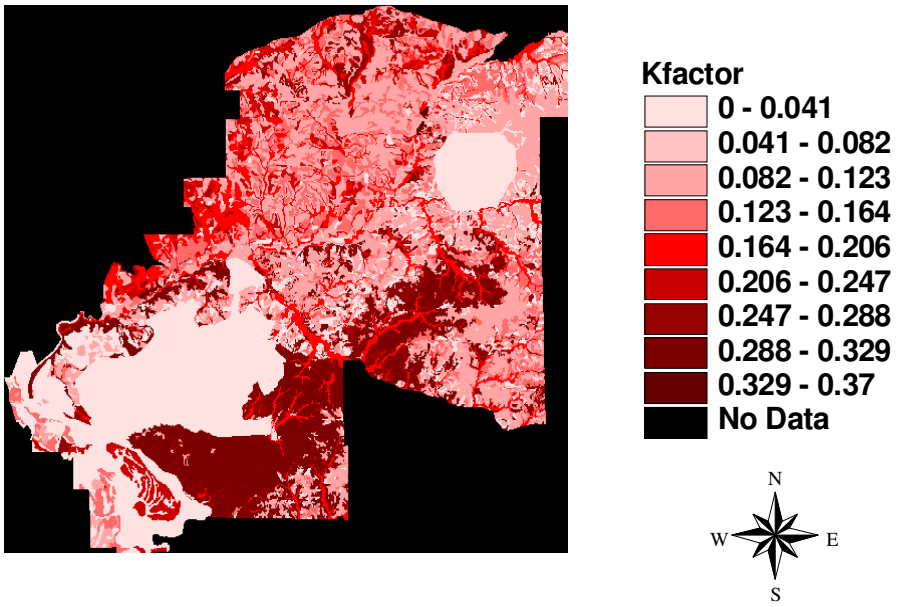


Figure 2.2 Fort Benning K Factor Map

Fort Benning LS factor Map

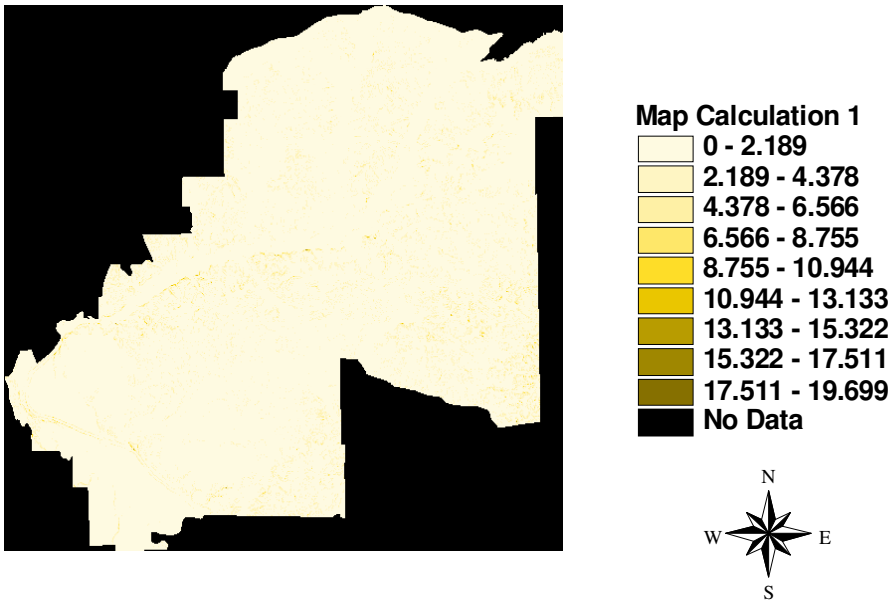


Figure 2.3 Fort Benning LS Factor Map

Fort Benning LS factor Map

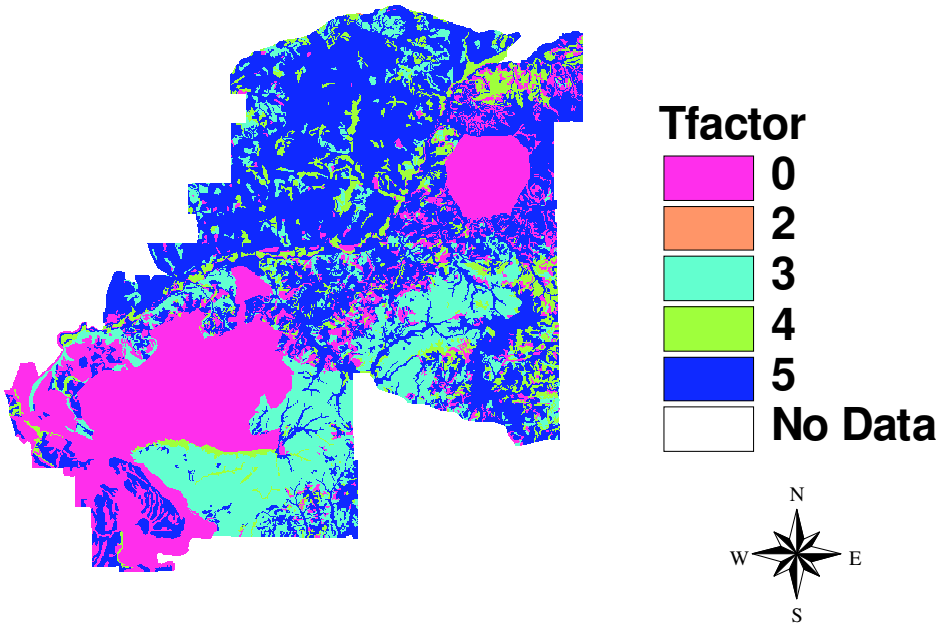


Figure 2.4 Fort Benning T Factor Map

Fort Benning Current Land Condition Map

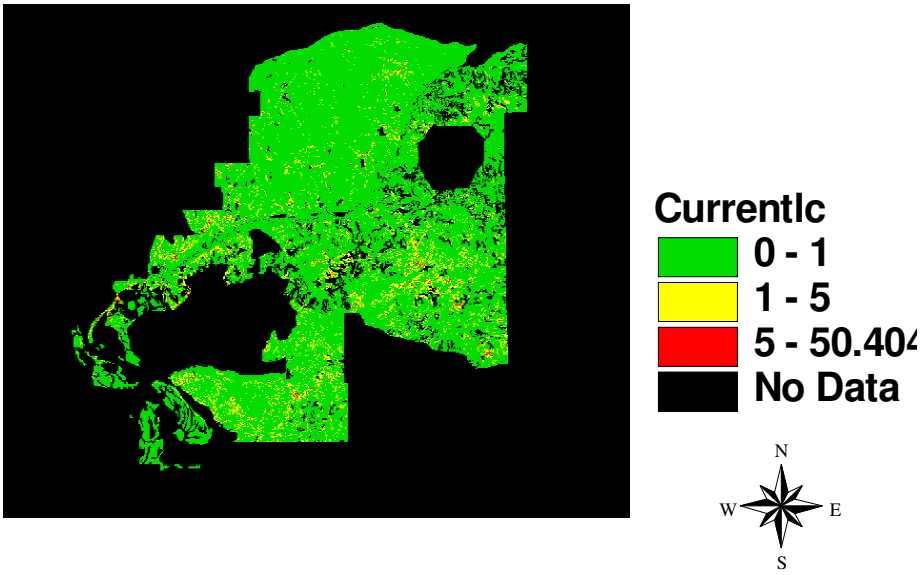


Figure 2.5 Fort Benning Current Land Condition Based on USLE Erosion Status

The following figure shows a training distribution map generated using the methods of Fang et al [60]. The distribution map is combined with an estimate of total vehicle miles and vegetation loss (Delta C Factor value) to predict a future condition.

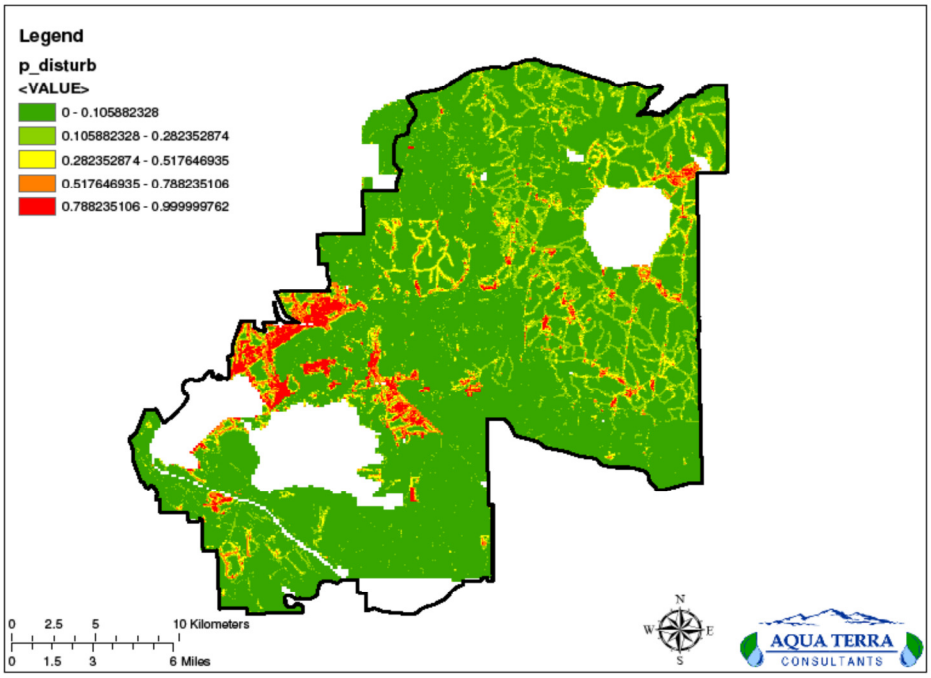


Figure 2.6 Fort Benning Training Distribution Map Using RTLA Data

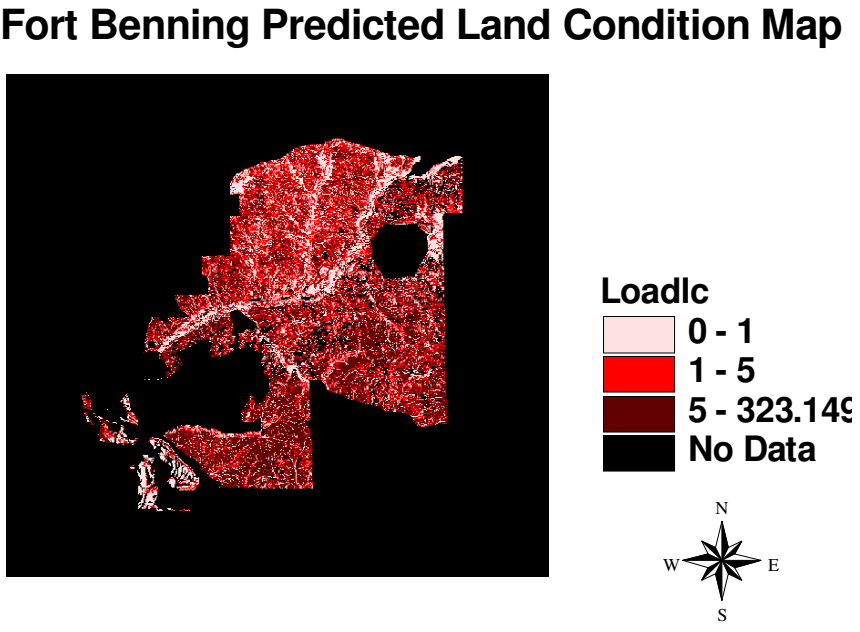


Figure 2.7 Fort Benning Predicted Land Condition Using Current Condition, Training Load, and Distribution

The previous discussion in this section covered USLE/RUSLE estimates specifically made for Fort Benning. This is relevant to HSPF because USLE/RUSLE could be used as a sediment source model. However to parameterize and validate HSPF, one would need sediment transport or water quality data. Lockaby et al [162] indirectly measured rates of sedimentation at Fort Benning over the past 25 years. They reported sedimentation values ranging from 0 in undisturbed reference watersheds to 4.0 cm/yr in disturbed watersheds. Short-term sedimentation rates ranged from slightly negative to 3.2 cm/yr. Bhat et al [163] found that military training land, road density, and the number of roads crossing streams were the three management variables that most impacted storm water responses at Fort Benning. Maloney and Feminella [164] suggest 8–10% of the catchment as bare ground and unpaved road cover as a threshold of disturbance that is meaningful in terms of water quality. This threshold is similar to other land use thresholds like urbanization [164]. Houser et al [166] similarly reported vegetation disturbance had clear effects on suspended sediments, nutrients, and other aspects of stream chemistry. A relatively simple disturbance metric, the proportion of a catchment composed of bare ground on slopes greater than 5% and unpaved roads, explained significant proportions of the variability for a group of stream chemistry parameters. The dominant effect of military training disturbance to upland vegetation and soils on streams was a large increase in inorganic suspended sediment transport. Maloney et al [167] similarly reported that the amount of catchment disturbance causing denuded vegetation and exposed soil is a key terrestrial influence on stream hydrology and a greater determinant of in-stream organic matter conditions than is natural factors. Bhat et al [165] found slightly different results for water chemistry. They reported that military land disturbance extent did not show significant relationships with either total phosphorus or chloride. They did find that road networks used to support military training had significant relationships with both total phosphorus and chloride.

2.4 INFORMATION CHARACTERIZING SITE CONDITIONS OF UNDISTURBED, LIGHTLY DISTURBED, AND HEAVILY DISTURBED AREAS

A number of studies have characterized site conditions of undisturbed and disturbed areas for a broad range of military installations [2,3,4,5,6,7,8]. Information on vegetation cover, exposed soil, compaction, infiltration rates are available for HSPF model parameterization. A number of small scale classical experimental plot design studies have also quantify site conditions after tracking by military vehicle [21,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43, 44,45,46,47,48,49,50, 51,52,53,54,55,56,57,58]. A number of installation surveys that located plots across a gradient of impacts have also characterized site conditions in maneuver areas [2,43,64,65,74,75,76,79]. Use of plot and monitoring studies requires some translation of site conditions into broad modeling classes like light/medium/heavy use.

While many studies provide applicable information for HSPF, the data are 1) not uniformly available for all installations are ecotypes, 2) may not be at a scale relevant to HSPF, and 3) may not include all relevant HSPF input requirements. Research will be required to extrapolate data from know studies to a broader range of environments found at installations likely to implement HSPF.

2.5 INFORMATION DEFINING SPATIAL BOUNDARIES OF UNDISTURBED, LIGHTLY DISTURBED, AND HEAVILY DISTURBED AREAS

A number of studies have proposed methods to identify boundaries of light and heavy use areas. Most methods are based on mapping of bare ground and make the assumption that bare ground is correlated with level of use. This is not an unreasonable assumption since many studies that quantify vehicle impacts show vegetation cover or bare ground as a consistent consequence of training. Even if this assumption is incorrect, bare ground caused by other land

use activities will still be sources of sediment that HSPF will need to account for. While a number of methods have been proposed, most methods consist of statistical techniques to correlate know bare ground locations with remotely sensed images [66, 72, 102, 105, 106, 108, 109, 110, 111, 117, 126, 127, 128, 129, 130, 136, 171, 172, 176, 178, 179, 180]. A recently completed map (or soon to be completed) of recent erosion sites was produced for Fort Benning [personal communications S. Tweddale]. This map was produced by reclassifying remotely sensed imagery with ground control points.

Some installations specifically map disturbed areas as part of their long-term monitoring programs [89]. These programs map high/low use areas as part of the monitoring program plot allocation strategy. These land monitoring units could also be used in HSPF.

Historic land use patterns can be used to estimate current land use patterns. Fang et al [60] showed for some installations that the location of high and low use areas are fairly consistent over time. Wang et al [127] showed for other installations that this assumption is not always correct. In that study areas of high impact tended to vary in location from year to year. Most all studies have shown that relatively few areas are severely impacted and the majority of lands have relatively low impacts [60,127].

As part of the SEMP program at Fort Benning, researchers frequently identified light and heavy use areas differently based on the study metrics. For HSPF, light and heavy use areas will need to be identified in a consistent manner based on the HSPF input parameters of importance.

2.6 PREDICTING FUTURE CONDITION BASED ON SUBJECT MATTER EXPERT APPROACHES TO DELINEATING LOW/MEDIUM/HIGH USE

Herl et al [113] proposed the use of military doctrine to identify use patterns for vehicles. The approach was validated by Warren et al [114] which measured site disturbance after a period of training to see if actual disturbance patterns reflected projected disturbance patterns. The authors concluded the approach reasonably predicted future use patterns for some applications.

A variation of the doctrine approach is the use of a few doctrine and site access variable to predict patterns of use. Mobility and trafficability maps have been used to assess where vehicle can and are likely to go within the landscape [89,192]. These trafficability maps are available as standard Army land use interpretation within the NRCS county level soil surveys.

Military planners often provide maps or templates of proposed changes in training area designs. These proposed changes often must be assessed for environmental impacts before building. These impacts include erosion, sediment transport and water quality. Environmental impact statements often include these alternatives. Balbach et al [131] estimated erosion losses for alternative land clearing activities associated with range development. Estimates were made for several alternative designs of forest conversion to open areas. Army software like the Range Managers Toolkit (RMTK) has GIS templates that delineate standard range designs. These templates are used to locate ranges in a GIS to physically allow room for safety fans. These templates are also used to assess noise affects of range siting. The ATTACC for munitions model used these templates to predict relative locations of vegetation loss due to munitions activities. Munitions loads were also used to estimate vegetation loss [191]. HSPF could use a similar approach of using templates of proposed changes to model sediment transport. The advantage is that these templates are often available. The limitation is that conditions within the templates have to be estimated or extrapolated from other areas. Use can also vary dramatically between similar ranges.

2.7 PREDICT FUTURE CONDITION BASED ON RELATIVE TRAINING LOAD VALUE

Dubois et al mimicked the use of mobility maps by using primary variables like slope maps to summarize land use patterns [132]. In this study, the authors used slope maps and historic information about relative use of various slopes to predict future levels of use based on increased training. Monitoring data was used to relate relative use of various slopes. Essentially, a 25% increase in training loads would increase each slope category use by that amount.

Several researchers have utilized historic use patterns and course measures of training load to predict patterns of disturbance or changes in patterns of USLE/RUSLE C factors [60,72,129,128]. The approaches used historic monitoring program data and training load measures to develop a relationship. That relationship with projected training loads was used to predict future conditions. For several studies, changes in training loads were obtained from the number of units stationed at an installation. For another troop days of scheduled training were used. In these studies, crude measures of training load did account for a meaningful change in vegetation cover, erosion, or disturbance. Advantages of this method are that training load is specifically included in the model process and is tied to land condition. The disadvantages are that 1) historic data is not always available to develop the relationship, 2) there needs to be some change in training load to develop a relationship, 3) pattern of usage across an installations is generally assumed to remain constant. Figure 2.6 shows a distribution map created for Fort Benning.

The use of crude measures of training load is often questioned as having value. Anderson et al [72] showed that crude measures of training load explained changes in land condition almost as well as much more expensive and difficult to obtain metrics. In this study, the number of battalions was as useful as TVE. TVE was total miles per vehicle obtained from the motor pool and adjusted for differences in potential impact of vehicle type (see Figure 2.8).

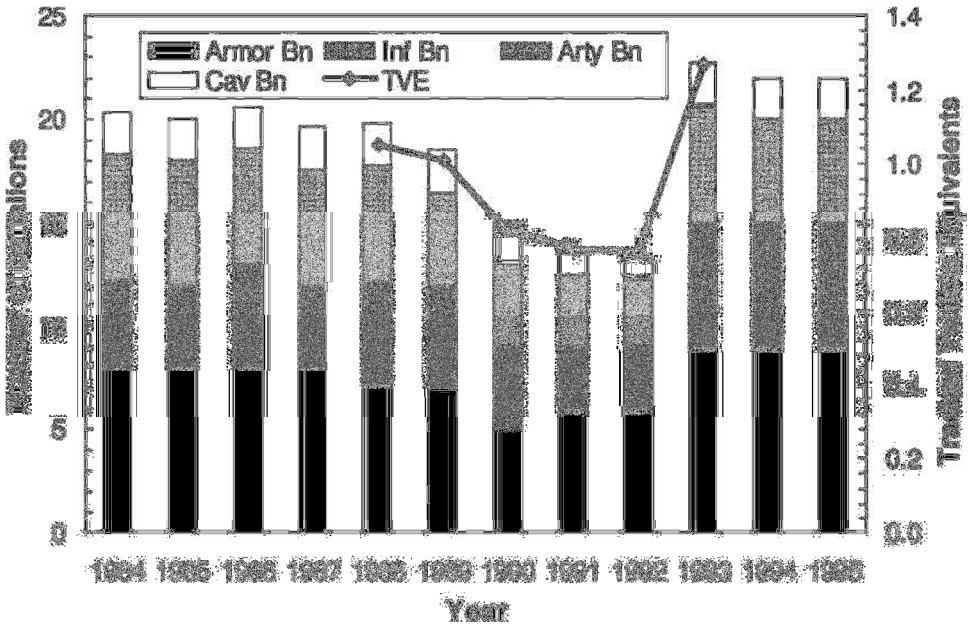


Figure 2.8 Comparison of Battalion vs. Individual Vehicle Training Load Estimates

2.8 RFMSS DATA BASE AS A STARTING POINT FOR CHARACTERIZING DEGREE OF LAND DISTURBANCE

The RFMSS system was developed initially at ERDC-CERL for two purposes. The first was to assist Army installation range management personnel to plan and report on the usage of ranges and training areas by the numerous elements on the installation which required them. The second was to accumulate data which could be used in planning and management of the training lands through acquiring a dataset showing how much usage each of the many areas had sustained for any given period, as well as how much was planned for the near future (normally, only one year's plans and data are active at any one time). Over the years, the first function has been reasonably successful; however the second has not been a total success. Many of the datasets within the RFMSS records are aggregated in such a manner, or truncated, such that their actual application to environmental management has been very infrequent. Some installations do not archive RFMSS records or archive records cannot be obtained for various reasons.

A few studies have used RFMSS data. Davis [128] and Wang et al [127] showed RFMSS data useful for explaining variation in vegetation cover at Fort Riley, KS. Wang et al [127] used annual changes in troop days from RFMSS to explain annual changes in vegetation over a 13 year period. Davis [128] used the same measure to explain changes in cover within a year and between training areas. The relationship was not as good within a year and between training areas as it was over longer time periods and larger areas.

RFMSS data is available for Fort Benning. Information on training area assignments was obtained from training directorate personnel at Fort Benning for the year 2004 (conversation with H. Westbury, 2010). This was provided as an Excel spreadsheet file organized by listing each military training unit and the different training facilities/areas they had scheduled. The scheduling was broken down into number of days scheduled (from a maximum of 365), followed by the number of days the unit had utilized the facility as scheduled (see Table 2.2).

Table 2.2 RFMSS Training Area Utilization at Fort Benning by Unit, 2004

UNIT NAME	FACILITY	NO SHOW	CANCELED	UTILIZED	SCHEDULED	UTILIZATION %
11TH 1ST BN	FARNSWORTH	0	0	3	3	100%
	C03	1	0	2	3	67%
	C04	1	0	2	3	67%
	C05	1	0	2	3	67%
	C06	1	0	2	3	67%
	C07	1	0	2	3	67%
	C08	1	0	2	3	67%
	C09	1	0	2	3	67%
11TH 1ST BN	C10	1	0	2	3	67%
	C11	1	0	2	3	67%
	Q01	6	0	5	11	45%
	Q02	6	0	5	11	45%
	Q03	6	0	5	11	45%
	Q04	6	0	5	11	45%
	Q05	6	0	5	11	45%
	Q06	6	0	5	11	45%
	Q07	6	0	5	11	45%
	ROOSEVELT	0	0	1	1	100%
	SIMPSON	0	0	1	1	100%
	WARE	0	0	4	4	100%
	A09	1	0	10	11	91%
	A12	0	0	25	25	100%
	A13	0	0	5	5	100%
	B01	0	0	20	20	100%
	B02	1	0	10	11	91%
	B03	1	0	10	11	91%

After manipulation of the data, a map of the relative and absolute levels of scheduled training was generated and is illustrated in Figure 2.9. The RFMSS data is very useful in that is represents historic record of use and planned level of use for the near future. However, the data is limited to showing use at the training area level. Use within a training area must be assumed to be uniform or additional information must be used to allocate the training spatially within each training area. This is important because training areas often do not correspond with HSPF modeling units (watersheds, low/high use areas, etc). An additional problem is that days scheduled may not relate to the severity of use in terms of HSPF parameters like vegetation cover Furthermore information on number of vehicles and miles traveled are not available.

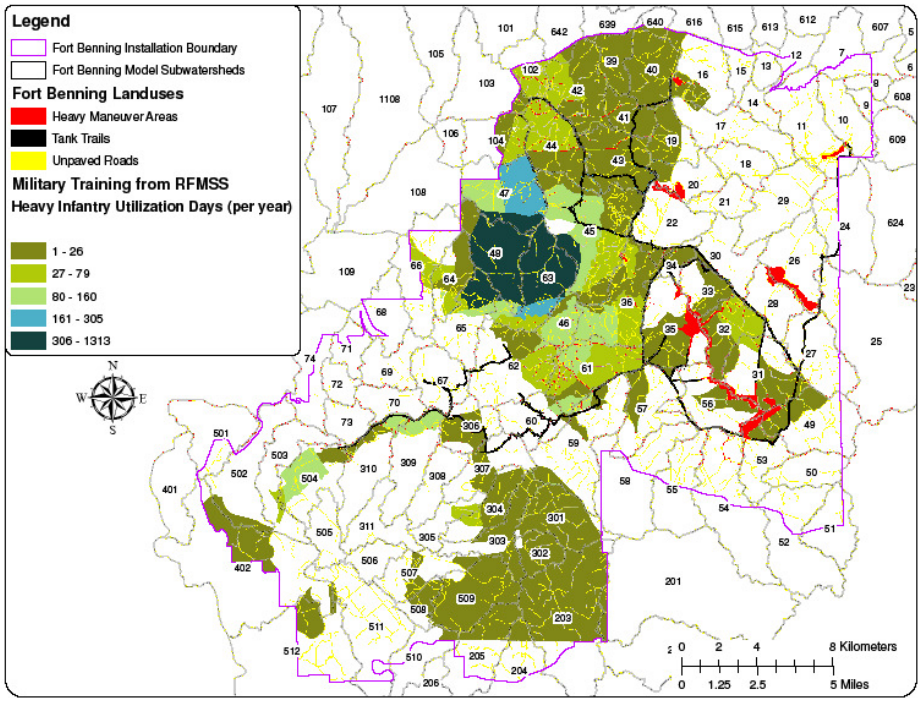


Figure 2.9 Map of Fort Benning Training Area Utilization, 2004

An effort was conducted as part of the ATTACC program (author's personal experience) to incorporate number vehicles, type of vehicles, and mileage estimates into RFMSS. This RFMSS component was called the ITAM component. The RFMSS software update was tested at Fort Carson. It was determined that implementation of the module was too difficult and time consuming for training units and there was not Army Headquarters leadership support for implementation, unlike munitions tracking. As a consequence, most or all RFMSS data must be interpreted by local personnel to convert unit and event designations to meaningful records of numbers of vehicles.

2.9 QUANTIFYING MILITARY LAND MANAGEMENT BEST MANAGEMENT PRACTICES FOR USE WITH HSPF

HSPF is a bulk model. Predicting future condition may involve examining the impact of best management practices to offset military disturbance. We conducted a literature search for LRAM effectiveness values. We included in our search studies that 1) compared soil loss from treated and untreated study plots, 2) compared soil loss before and after treatment, 3) compared soil loss from soil erosion modeling, 4) listed subject matter expert estimates, and 5) provided effectiveness values for LRAM practices for agricultural, construction, rangeland,

forestland, and military lands. There are limitations to these values including 1) values depend on the implementation, 2) effectiveness is affected by site conditions, 3) effectiveness varies over time, 4) effectiveness varies with the measure of land condition, and 5) tendency in the literature to document successful instances of practices.

The following table summarizes our results for several common best management practices. Individual data not provided in this report. ATTACC values are from the ATTACC/ELVS program. Literature values are from a series of independent published journal articles. EPA values are obtained from Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters EPA-840-B-93-001c January 1993 (http://www.epa.gov/OWOW/NPS/MMGI/).Overall, the conclusion is that 1) ATTACC values probably underestimate effectiveness, 2) EPA values correspond closely with published values, 3) EPA corresponds closely with studies on military lands, 4) there is wide variation in effectiveness values for all best management practices, and 5) there is sufficient data to support an implementation of HSPF.

Table 2.3 Comparison of Best Management Practices from Various Sources

Practice	Source	Mean	Min	Max
Seeding	ATTACC	0.68	0.63	0.73
	Literature	0.25	0.01	1.00
	EPA	0.10	0.01	0.50
Ground Cover	ATTACC	0.57	0.50	0.63
	Literature	0.21	0.01	0.64
	EPA	0.30	0.03	0.80
Vegetation Filter Strip	ATTACC	0.59	0.53	0.65
	Literature	0.45	0.01	1.00
	EPA	0.35	0.20	0.80
Sediment Barrier – Fence	ATTACC	0.57	0.53	0.65
	Literature	0.21	0.10	0.32
	EPA	0.30	0.01	0.90
Sediment Barrier - Basin	ATTACC	0.56	0.48	0.68
	Literature	0.20	0.01	0.51
	EPA	0.30	0.01	0.45
Terraces	ATTACC	0.68	0.65	0.70
	Literature	0.41	0.01	1.00
	EPA	0.35	0.30	0.40

Practice	Source	Mean	Min	Max
Grassed Waterways	ATTACC	0.65	0.65	0.65
	Literature	0.40	0.10	0.90
	EPA	0.40	0.01	0.90
Cultivation Practices	ATTACC	0.60	0.58	0.68
	Literature	0.59	0.13	1.00
	EPA	-	-	-

As part of the ITAM program, installations are required to provide 5 year projections of land repair activities for funding requests as part of the Workplan Analysis Module (WAM) process that supports the ITAM Program Objective Memorandum (POM) submission. These plans require information on the type of land repair activity, location, and projected implementation date. A review of the WAM data indicates considerable variation among installations in the level of detail provided in these submissions. WAM data provides a foundation to support HSPF future condition projections or provide potential scenarios for HSPF application.

2.10 ATTACC/ARRM TRAINING LOADS

The ATTACC model consists of three components: training load, environmental characterization, and cost analysis. The cost analysis component is not relevant to our discussion. The land condition component is largely discussed in previous sections. Training load is the term used to describe the collective impact of all military activities that occur on a given parcel of land. ATTACC measures training load in terms of MIM. The MIM value for each mission activity is derived from vehicles type and number, the vehicle miles traveled, and training event type. The mathematical equation for calculating an installation's training load in ATTACC is shown in equation (1) listed. Training load is calculated using Training Impact Factors (TIFs). The TIFs are the Event Severity Factor (ESF), Vehicle Severity Factor (VSF), Vehicle Off-road Factor (VOF), and Vehicle Conversion Factor (VCF). The ESF is a multiplier that represents the relative impact of an event, as compared to the standard event (Armor Battalion FTX). The VSF is a multiplier that represents the relative impact of a vehicle, as compared to the standard vehicle (M1A2 tank). The VOF is a multiplier that represents the percentage of vehicle mileage typically driven off improved roads. The VCF is a multiplier that represents the area impacted by a vehicle, as compared to the area impacted by the standard vehicle.

$$MIMs = \sum_{E=1}^{e}\left[\left(\sum_{V=1}^{v}\left(Number_V * Mileage_V * VSF_V * VOF_V * VCF_V\right)\right) * Duration_E * ESF_E * LCF_E\right] \quad (1)$$

where:

MIM = normalized training load (maneuver impact miles)

E = event (dimensionless)

e = number of events (dimensionless)

V = vehicle type (dimensionless)

v = number of vehicle types (dimensionless)

Mileage = daily mileage for vehicle type V for event type E (miles/day)

Number = number of vehicles of type V (dimensionless)

VSF = vehicle severity factor for vehicle type V (dimensionless)

MIM training load values were developed for all installations within the ITAM program thus making the approach of value because it applies to so many areas. A problem with the approach is that the training load values are fairly static and it is difficult to identify new training load values based on mission changes. ATTACC MIM values were used to assess BRAC restationing associated with Fort Knox and Fort Benning (unpublished studies). However this required military subject matter experts to work with MIM inputs to develop the correct scenarios. This approach was also used in several environmental impact statements [141,142,143]. To address this problem, MIM equations were linked with the Army Range Requirements Model (ARRM).

ARRM is an Army planning tool for estimating training through put on ranges and maneuver lands. ARRM contains 1) all units within Army, Army Reserve and Army National Guard, 2) identifies where units are stationed and train, and 3) estimates of training load for both munitions and maneuvers. Advantages of ARRM data is that 1) training load is consistently estimated across all installations, 2) training scenarios can be constructed within the software for alternative assumptions, 3) training load is in useful measures like miles and rounds fired, and 4) it is used by other Army process and has acceptance. ARRM includes ATTACC MIM values using the same equation listed above which have been utilized with erosion models in a number of applications [author's unpublished work]. Limitations of ARRM data include 1) data are based on objective and subjective data, 2) no information on distribution besides which installation, 3) unit descriptions are not always used by installations within RFMSS, 4) access is limited based on need, 5) it is still evolving so some features/data change or are eliminated, 6) data is not archived.

Because ARRM data only provides data on an annual basis and an installation wide spatial basis, additional methods or assumptions are required to spatially and temporally allocate data. ARRM data is like RFMSS data with regards to its limitations. RFMSS usually only has planned and not actual training. ARRM has required training to meet standards, but does not provide actual training. ARRM does provide a means to identify minimum training due to standard, maximum based on funding, and most commonly used training levels.

An early version of ARRM data was used within the ATTACC for munitions (AFM) [191]. ARRM data may be useful for HSPF in that in provides a means to get relative or absolute changes in training load associated with deployment of specific units, restationing of specific units. The connection between this measure of training load and HSPF could potentially be done through a modification of the approach used within ATTACC. ATTACC could provide a means to relate changes to USLE/RUSLE. Additional research would be required to relate training load to other HSPF model parameters. Another advantage is it provides information on munitions loads that could be used with an AFM like approach within HSPF.

With regards to ATTACC and the usage of MIMs, another way to view the MIM is as an area of disturbance. Since the MIM is based on the M1A2 tank and the vehicle track dimensions and distance traveled are known (1.3 meters x 1609 meters), a MIM is equivalent to 0.2 hectares of disturbance (~0.5 acres). This approach is helpful when using training data to analyze environmental conditions.

2.11 DETAILED RFMSS TRAINING LOADS

Some of the limitations of data obtained from RFMSS include 1) scheduled use as opposed to actual use, 2) limited information of types of vehicles, units and events, 3) inconsistent archiving, and 4) difficult access to data. One solution offered has been input of impact relevant data including number and type of vehicles. An effort was conducted as part of the ATTACC program to incorporate number vehicles, type of vehicles, and mileage estimates into RFMSS. It was determined that implementation was too difficult and time consuming for training units. As a consequence, most or all RFMSS data must be interpreted by local personnel to convert unit and event designations to meaningful records of numbers of vehicles.

Another option with RFMSS is to work with RFMSS developers to obtain standardized reports that are more relevant to HSPF implementation. Data obtained from RFMSS is limited because data must be obtained through authorized sources that use canned reports that were developed for other purposes. Our inability to access more useful data does not mean additional data is not available. A need exists to work not only with local personnel but also RFMSS developers/supporters to identify and access more relevant information. There is a high likelihood that more detailed relevant data is not available.

2.12 VEHICLE TRACKING DATA

Another source of military training load data is through tracking of vehicles during live training [62, 99, 103, 104, and 129]. This approach uses GPS tracking equipment to record vehicle movement and impact models to predict patterns of disturbance in terms of vegetation loss and rutting. This information can be obtained from Army training systems or through installation specific tracking activities. This approach 1) does not provide data for future training load estimates, 2) does not provide data for historic training loads, 3) does not summarize all activities, 4) data is only available for a few installations, 5) and data must be scaled in a manner to relate to bulk input required by HSPF. The advantages of this approach include 1) spatially explicit patterns of use/impact, 2) actual use rather than projected or scheduled. This data could potentially be used by HSPF to develop scaling methods as part of data development of bulk parameters. Knowledge of the spatial patterns of training is useful for defining relevant bulk parameter values associated with single events. Data from tracked events has been used to examine the amount of on-road and off-road vehicular activity. Svendsen et al calculated the amount of activity both on and off-road that occurred during a training exercise at Orchard Training Area, Idaho in 2008. It was found that vehicles spent 15.9% of their time and 5% of the distance off-road [208]. Vehicle tracking studies completed at installations across the country have indicated that frequently, the bulk of military training occurs on roads. A general rule of thumb is that 85-95% of vehicle activity occurs on-road while 5-15% of vehicle activity occurs off-road. The ATTACC model accounts for this off-road activity with the Vehicle Off-road Factor (VOF) during the calculation of the MIM. However, those factors are representative of average conditions for installations across the US as determined by subject matter experts. Individual events or events at an installation may in practice vary from the established VOF. In such instances a Local Condition Factor (LCF) or Event Severity Factor (ESF) may need to be used to represent individual situations. These factors are accounted for in the ATTACC model, but have values set to 1 in ARRM.

2.13 FOOT TRAFFIC EFFECTS ON VEGETATIVE COVER AND BULK DENSITY

Much of the data collected on human foot traffic in natural environments has been focused on recreational sites. Previous studies have shown that high foot traffic increases soil bulk density, decreases water infiltration and causes soil compaction in the near surface soil layer (0-15 cm).

Excessive foot traffic on recreational sites destroys vegetation both above and below ground through trampling and surface soil disturbance [18,195,196,197,198,199,200,201,202,203,204].

The impact of foot traffic from training activities on military training lands is similar to that of recreational sites. Whitecotton et al [205] examined training activity at the U.S. Air Force Academy Jack's Valley Training Area in Colorado to determine if this assertion was true. The researchers determined that bulk density and infiltration from high use and moderate use sites were similar. Furthermore, bulk density increased approximately 25% (undisturbed: 1.04 g/cm^3, high use: 1.37 g/cm^3, moderate use: 1.30 g/cm^3) and infiltration decreased approximately 82% (undisturbed: 3.83 cm/min, high use: 0.67 cm/min, moderate use: 0.63 cm/min) in the disturbed sites as compared to a reference undisturbed site. The distinction between high and moderate use foot traffic should be made as defined by the study. High use implies constant foot traffic from 480 cadets on the site for 16 days, while moderate use implies sporadic foot traffic from the cadets over 16 days. The C factor for estimating erosion using USLE at the study site was calculated as being 0.008 for the undisturbed reference site, 0.08 for the moderate use site, and 0.38 for the heavily used site. McDonald and Glen [206] examined changes in soil bulk density from foot traffic in southern New York and plotted the change in bulk density against the number of passes (foot traffic). They found that foot traffic caused loss of vegetation and ground cover within 400-500 passes which corresponded to a bulk density of 1.10 g/cm^3. Once that vegetative cover layer was removed soil bulk densities increased dramatically.

The calculation of this equivalency to the number of passes it takes an M1A2 tank to denude a site is as follows. 1) Assume that the C-factor for a bare ground site is 0.45 (the theoretical value is 1.0, yet in field conditions the maximum value is often assumed to be approximately 0.45). 2) The change in cover per pass for Fort Benning is $\Delta C = 0.084 \pm 0.015$ (a conservative estimate would be 0.066), 3) Assume a linear degradation of soil conditions for each vehicle pass until the ground is completely removed of vegetation,

$$C = \Delta C \times (\text{number of passes}) = 0.45 = 0.066 \times (\text{number of passes}) \qquad (2)$$

Solving for the number of passes to achieve a bare ground state yields 0.45/0.066 = 6.8 passes for an M1A2 tank. This can be compared to the number of foot passes it takes to achieve a bare ground state (assume conservatively 400 passes). This comparison yields a value of 59 foot passes = 1 M1A2 tank pass.

Using the data from Whitecotton et al [205] study the C-factor for a near bare ground condition is 0.38 and the bulk density is 1.3 g/cm^3 while the undisturbed condition has a C-factor of 0.008 and a bulk density (B.D.) of 1.04 g/cm^3. Using this information plus the information from McDonald and Glen [206], the change in bulk density per pass can be calculated, ΔB.D./pass = (1.3 g/cm^3– 1.04 g/cm^3) /400 passes = 6.5 x 10^{-4} g/cm^3/foot pass. Similar calculations can be performed for any number of correlated physical properties if they are known at one location, but not another.

2.14 INFILTRATION ESTIMATES FOR FORT BENNING USING EGLIN AFB DATA

The assumption for infiltration is that water movement for field conditions are not limited by surface conditions, such as soil surface sealing. Additionally, water movement into the soil is assumed to follow the Green-Ampt infiltration model. The infiltration rate, f, can be found using the following equation,

$\boldsymbol{f(t) = K\left(\frac{\Psi \Delta \theta}{F(t)} + 1\right)}$, where K = hydraulic conductivity, Ψ = Wetting front soil suction head, θ = effective porosity, F = the cumulative depth of water infiltrated.

To determine infiltration capacity (constant head) or hydraulic conductivity (falling head) in the field within rut formations a double ring infiltrometer is recommended. For the study at Eglin AFB in 2010, the falling head method was utilized to approximate field hydraulic conductivity. During a double ring infiltrometer falling head test lateral movement of water is constrained by the outer ring. This constraint approximates 1-Dimensional infiltration and from this water movement into the soil can be determined over a period of time. Data was collected from both inside the vehicle ruts and outside the ruts in the surrounding area away from vehicle impact. For this test, movement of the M2 in a straight track results in a single pass and movement of the HEMMT in a straight track results in 4 passes due to the number of axles. During the tracking event two vehicles were used one tracked (M2) and one wheeled (HEMMT). The vehicle moved at both high and low speeds and performed straight tracking and turn tracking (moderate and sharp). The vehicle characteristics of the HEMMT indicate that the sharper the turn the wider the spread of rut formation. The vehicle characteristics of the M2 are similar to that of any tracked vehicle with sharper turns resulting in more soil shearing and vegetation removal over a widespread area. After the vehicles completed their tracking event in early May 2010, infiltration tests were conducted and the data collected and analyzed.

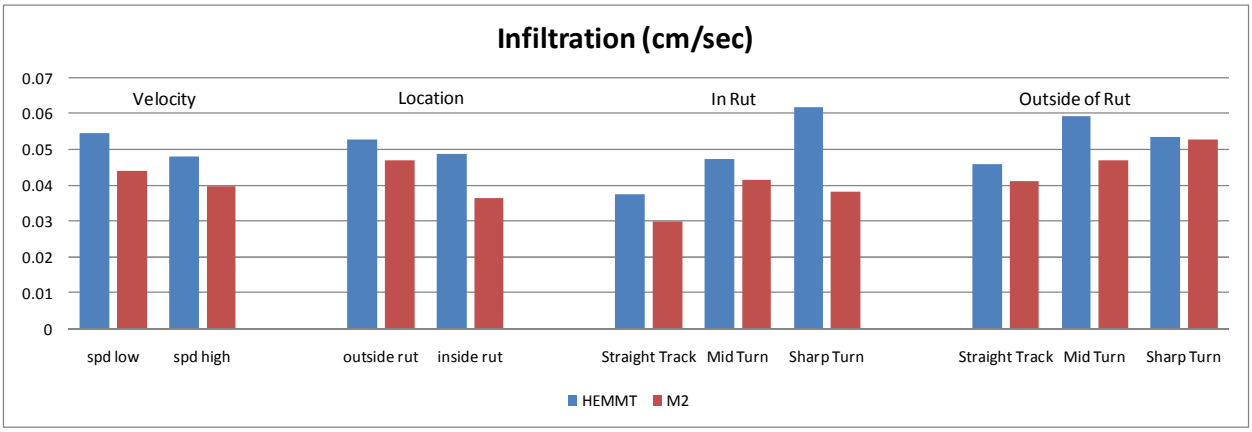


Figure 2.10 Infiltration Rates for M2 and HEMMT Ruts

According to the USDA NRCS WSS the study site soil consists of two types. Type 1 is Lakeland sand while Type 2 is Foxworth sand. These sands are moderately to excessively well drained soils that exhibit a high or very high hydraulic conductivity (K_{sat} = .004 cm/sec – 0.014 cm/sec for Lakeland sand and K_{sat} = 0.014 cm/sec – 0.035 cm/sec for Foxworth sand). Comparing these ranges to the ranges found in the field the data suggests that the soil is primarily Foxworth sand and that the results obtained in the field are not unreasonable. Falling head infiltration tests using smaller double ring infiltration test result in hydraulic conductivity estimation errors of ± 15%. A first look at the data shows several potential trends related to hydraulic conductivity and infiltration with regards to the vehicle tracking study at Eglin AFB. 1) Tracked vehicle hydraulic conductivity is less than the wheeled vehicle hydraulic conductivity. 2) Higher vehicle speeds are associated with lower vehicle hydraulic conductivity. 3) Straighter tracks have lower hydraulic conductivity (multi-pass loading by several wheels such as with the HEMMT). 4) Tracked vehicle hydraulic conductivity is lower during straight tracking, but as the vehicle turns soil shearing by the vehicle results in less compaction (i.e. greater hydraulic conductivity). As the turn becomes more severe particle movement and rearrangement along with void space reduction and biomass destruction results in a soil with a smaller hydraulic conductivity. For both the HEMMT and the M2 additional factors related to turning are needed to explain how vehicle characteristics vary hydraulic conductivity during mobility exercises.

Through examination of the data it was found that for sandy soils hydraulic conductivity from wheeled tracking decreased approximately 20% after 4 passes and tracked vehicle hydraulic conductivity decreased 20% after one pass. This assumption would indicate a linear relationship for both wheeled and tracked vehicles to soil infiltration reductions, where for wheeled vehicles 1 pass decreases hydraulic conductivity approximately 5% and thus 4 passes of a wheeled vehicle is approximately equal to one pass of a tracked vehicle. However, this approach is rather simplistic as it dictates that infiltration would eventually become zero. In reality, infiltration is reduced to a level (not zero) based on the compactive effort (i.e. the weight of the vehicle), soil type, and soil moisture content. A more appropriate approach would be to use a multiplicative process to determine the reduction in infiltration as a result of vehicle passes. Equation 3 illustrates one possible formulation for determining infiltration.

$$f(x) = a^n(x) + b \quad (3)$$

Where a equals a constant as determined by conditions at Fort Benning, n equals the number of vehicle passes and b equals the limiting infiltration value. It is known that Fort Benning has similar soils to Eglin AFB and it is assumed that soil property changes as a result of vehicle disturbance at both locations are similar with respect to one another. A simplified way of looking at Equation (3) is to assume that after each pass infiltration is 80% of the current infiltration value until it reaches some minimum value determined by the operation of an M1A2 tank.

2.15 VEGETATION IMPACTS AND RECOVERY CONSIDERATIONS AT FORT BENNING, GA

As mentioned in a previous section, the average change in vegetative cover per vehicle pass has been determined to be 52.6% with a standard deviation of 43.69. The change in C-factor for each vehicle pass is 0.084 with a standard error of 0.108 and a standard deviation of 0.015 for Fort Benning, Georgia [130]. The implementation of this as with the calculation of infiltration is that for every vehicle pass a new vegetative coverage must be determined before applying each successive vehicle pass. Unlike infiltration however, the change in C-factor is not expressed as a percentage. Therefore, the method of calculating vegetative impact from vehicle traffic depends on which measure of vegetation is being used. The use of data expressed as a percent vegetative cover follows the same format as equation (3). The use of the C-factor as representative of vegetative coverage implies a linear change in the C-factor for each successive vehicle pass. While this may not be truly representative of actual field conditions, no studies have been conducted that have determined the percent change in C-factor with each successive vehicle pass.

It is important to note that vegetative recovery is an important and ongoing process at most installations after vehicle disturbance. However, that vegetative recovery rate is impacted by the level of soil disturbance at a given location. Goldsmith et al examined the balance between soil mechanical stability and plant growth capacity and reported based on findings in published literature that bulk densities should not exceed 1.85 g/cm^3 for sands and 1.6 g/cm^3 for silts to ensure that the growth limiting bulk densities for long term vegetative stability are not exceeded [207]. These published limits on disturbed soils being a suitable medium for vegetative recovery corresponds to an infiltration rate. Information such as this can be helpful in assessing training land recovery on a year to year basis. Garten et al took readings of soil bulk density at undisturbed, lightly disturbed, moderately disturbed, and heavily disturbed areas and found that soil bulk density fell below the values reported by Goldsmith et al [209].

2.16 FORT BENNING TRAINING LOAD ANALYSIS

The Army Training Testing Area Carrying Capacity (ATTACC) methodology measures training load for mission activities in terms of maneuver impact miles (MIM). One MIM has the equivalent impact on soil erosion as an M1A2 tank driving one mile in an Armor battalion (BN) FTX. MIMs were used to compare the relative impact of current training at Fort Benning with several scenarios of increase training load. MIMs are an estimate of off-road impacts to installation resources. Training load estimates are derived from a version of the Army Range Requirements Model (ARRM).

The Installation listed in Table 4 as "Fort Benning – Original" is an estimate of the current annual training load at Fort Benning. The installation listed as "Fort Benning+Armor School" is the current Fort Benning training load increased by the training load associated with the Armor school currently at Fort Knox. The installation listed as "Fort Benning+StrykerCBT" is the current Fort Benning training load increased by a typical Stryker CBT. MIM estimates for the Stryker CBT is an average derived from estimates developed for the Alaska, Hawaii, and Fort Polk environmental impact statements. "Fort Benning+InfantryBCT" was similar to "FortBenning+ArmorSchool".

In Table 2.4, Total Executed MIMs is an estimate of the total training load for an installation. Net Maneuver Acreage is an estimated of lands available for training at an installation. This acreage would be before any land use changes and range reconfiguration associated with restationing of troops. These values vary depending on the source of data used. MIM per Acre is the total training load divided by the number of available training acres. MIM per Acre is a relative measure of the training load intensity for an installation that includes both impact and available lands.

Table 2.4 Training Load Intensity Estimates

Installation	Total Executed MIMs	Net Maneuver Acreage	MIMs Per Acre
Fort Benning+ArmorSchool+StrykerBCT	279,235	71,500	3.91
Fort Benning+Stryker BCT	268,485	71,500	3.76
Fort Benning+Armor School+InfantryBCT	168,315	71,500	2.35
Fort Benning+InfantryBCT	158,315	71,500	2.21
Fort Benning+Armor School	156,485	71,500	2.19
Fort Benning-Original	146,485	71,500	2.05

2.17 ASSUMPTIONS FOR MODELING MILITARY ACTIVITY IN BASINS

2.17.1 What are the Military Training Load Assumptions?

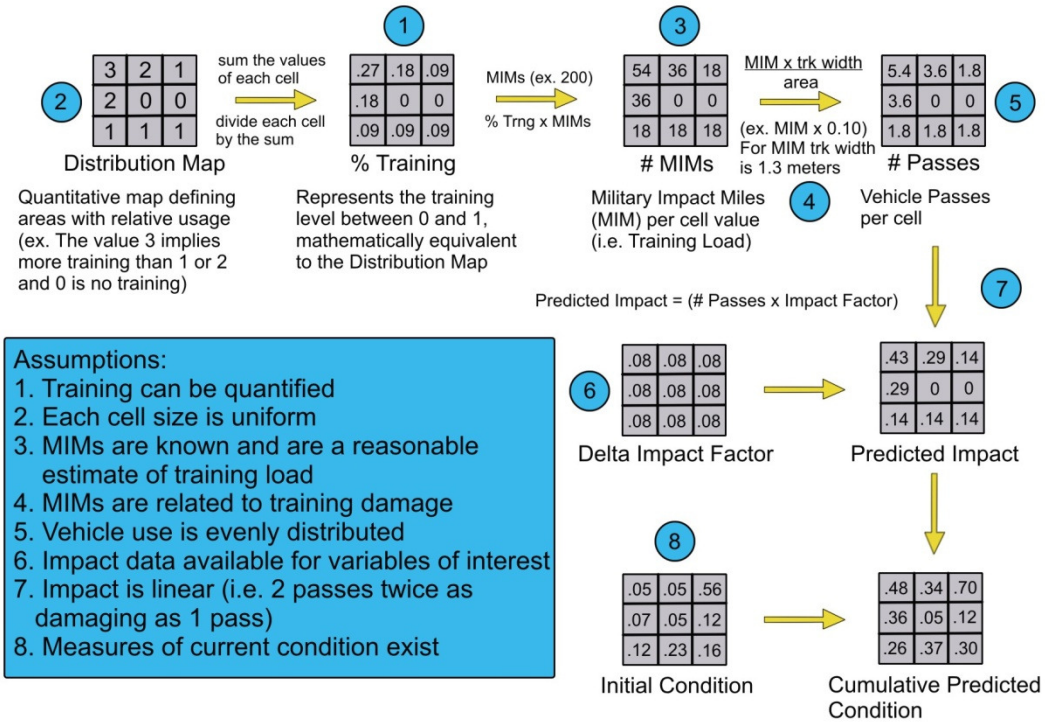
1. The Army Range Requirement Model planning tool (ARRM) is an accurate representation of installation training as required by AR 350-19. We assume that the model correctly identifies the correct number of units, unit training locations, vehicle numbers and the number of miles per vehicle.

   a. Assumption should be reasonable because the Army uses this model as its primary training load estimator for a number of planning situations (use AR350-19 to summarize uses).
   b. Assumption should be reasonable since data source is an official Army database and used for many other planning efforts. Installations have the option in system to modify unit and training to reflect local knowledge or recent changes in actual or planned unit stationing.
   c. Assumption should be reasonable if we are making projections into the future of expected training scenarios. Assumption unreasonable for predicting actual training in any one year or less than one year.
2. The Army Training and Testing Area Carrying Capacity (ATTACC) methodology measures training load using a Maneuver Impact Model (MIM), a MIM represents the soil erosion caused by an M1A2 tank being driven 1 mile and all other military vehicles are related to this value regardless of vehicle characteristics.
   a. Assumption should be reasonable. Studies have been completed to verify these relationships and have been published. (Sullivan and Anderson. 2000)
   b. Assumption should be reasonable based on application of similar approach used in other Army studies and programs (AEC 1999).

2.17.2 Vegetation Loss Associated with Vehicle Traffic for use in BASINS

1. Range and Training Land Assessment (RTLA) data was used to calculate the differences in C factor, ground cover, aerial cover, and minimum drip height between disturbed and undisturbed portions of field transects. Undisturbed portions of transects had no military disturbance. Disturbed portions of transects only had single pass vehicle disturbance. Other disturbance categories were not included in this portion of the analysis. Only single pass portions of transects were used so that differences between disturbed and undisturbed portions of transects would be an estimate of resource damage associated with single pass vehicle tracking events.
2. Delta C-Factor is the change in USLE C-Factor associated with a single pass of a vehicle. Delta C-Factor is unitless value. Delta Ground Cover the change in ground cover associated with a single pass of a vehicle. Delta Ground Cover is in percent with 100 being fully covered and 0 being completely uncovered. Delta Aerial Vegetation Cover the change in vegetation cover associated with a single pass of a vehicle. Delta Vegetation Cover is in percent with 100 being fully covered and 0 being completely uncovered. Delta Minimum Drip Height the change in height of the vegetation closest to the ground surface associated with a single pass of a vehicle. Delta Minimum Drip Height is in meters.
3. Fort Benning Delta USLE C-Factor: 0.084 Mean, 0.108 StdDev
4. Fort Benning Delta Ground Cover: Mean = 52.6, σ = 43.69
5. Fort Benning Delta Aerial Vegetation Cover: Mean = 14.2, σ = 30.17
6. Fort Benning Delta Minimum Drip Height: Mean = 0.08, σ = 2.058

2.17.3 How Can Training Be Distributed over the Landscape for use in BASINS?



2.17.4 What are the Training Distribution Assumptions?

1. Training Load Distribution Maps are correct and vehicle impacts (erosion and vegetation loss) within an area in a Training Load Distribution map are uniform.
    a. Assumption should be reasonable because other data sources are not available.
    b. Distribution is from RFMSS data so it is based on installation data. Assumes the number of personnel is correlated with number of vehicles.
    c. Assumption should be reasonable because approach has been used in other Army studies and programs. (Shaw, Diersing 1989; Diersing, Shaw, Warren, Novak E 1988).
    d. If training load is uniformly distributed at a appropriate level, the model should not be too sensitive to this assumption (Anderson and Sydelko 1999)
2. The Fort Benning Impact Factor is correct as determined by subject matter experts and data.
    a. Assumption should be reasonable because other studies have used impact factors calculated in the same manner using similar data. (Mendoza, Anderson, Gertner 2002a;. Mendoza, Anderson, Gertner 2002b; Anderson, Ayers, Palazzo, Fehmi, Shoop, Sullivan 2005; Shaw Diersing 1989; Shaw, Bern, Schultz, Diersing, Tazik D 1990; Shaw, Diersing 1989; Diersing, Shaw, Warren, Novak E 1988;)
    b. should be reasonable because methods defined in ATTACC implementation guidance (Kennaway, Anderson, Sydelko. 2003).

SECTION 3
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SECTION 4

ATTACHMENT TO APPENDIX B: IMPACT MAP GENERATION

4.1 INTRODUCTION

The purpose of this document is to provide guidance for the development of datasets that can be utilized to produce inputs for the water modeling software package, BASINS. These datasets will provide the necessary input regarding military vehicle impacts and the reduction of infiltration resulting from military vehicle impacts.

The necessary information regarding military impacts will be taken from two sources 1) the Army Range Requirements Model (ARRM) and 2) the Range Facility Management Support System (RFMSS). These two systems function as planning, logistics and reporting tools for deciding how to disperse military units over the landscape such that those units can meet their training requirements and feedback as to how those units were spatially distributed to fulfill those training requirements.

For this document we will be using Fort Benning, located in Southwestern Georgia and Southeastern Alabama to illustrate the concept of introducing military vehicle impacts (i.e. vegetative loss and infiltration reduction) into a modeling framework such as BASINS.

This document is separated into sections that allow the user to perform the basic steps required to make an assessment of military vehicle impacts on training lands. This document is structured to allow the user to further refine the process if over the passage of time better information becomes available that improves vehicle impact assessments on military training landscapes.

4.2 ASSUMPTIONS

Owing to the fact that military vehicle impact data is primarily restricted to a gross scale this guide depicts a methodology that is forced to make several assumptions with regards to military training distribution and vehicle use. However, several studies have been done that found that this type of information is still useful in determining land use impact on military training areas (Anderson et al, 2005; Wang et al, 2007). The following assumptions are assumed to be valid when determining the impact of military vehicles on the landscape.

1. Training is quantifiable
2. Training distribution is known
3. Training load is known
4. Training load is correlated to training damage
5. Vehicle use is evenly distributed over a training area
6. Impact is a linear function
7. Current conditions are known

4.3 CALCULATIONS

In this section, we will examine the basic calculations related to military training that provide the foundation to determine landscape impacts relating to changes in vegetation coverage, soil infiltration, based on the number of vehicles passes over a landscape. To understand the process thoroughly, several terms relating to military unique environments are defined and derived to provide a user a more complete background regarding troop training.

4.3.1 Definition and Derivation: Military Impact Miles

The Maneuver Impact Mile (MIM) has been selected as the quantitative value to represent vehicle impacts on military lands. Over the years numerous studies have been completed to quantify the value of the MIM such as Braunack and Williams (1993), Jones and Bagley (1997), Thurow et al (1995), Prosser et al (2000), Grantham et al (2001), Halvorson et al (2001), Fuch et al (2003), Jones (2003), and Jones and Kunze (2003) to illustrate a few. At its most basic level the MIM is defined as the impact caused by an M1 Abrams tank moving one mile. However, other tactical vehicle impacts have been related to the MIM via a vehicle conversion factor (VCF) and therefore vehicle impact information exists for all tactical vehicles and can be quantified for non-vehicular impacts such as foot traffic (Whitecotton et al, 2000 and McDonald and Glen, 2007). However, for the methodology described here, non-vehicle military impacts will be ignored as comparatively they are observed to cause significantly less damage relative to vehicle military impacts. Through the examination of vehicle mobility parameters and vehicle design characteristics, all vehicles used on military training lands can be related to the area of disturbance of an M1 Abrams tank in terms of MIMs.

The calculation of the MIM is determined using equation (1):

$$\text{MIM} = \sum_{E=1}^{e}[(\sum_{v=1}^{v}(Number_V * Mileage_V * VSF_V * VOF_V * VCF_V)) * Duration_E * ESF_E * LCF_E] \quad \textbf{(1)}$$

where:

MIM = normalized training load (maneuver impact miles)

E = Event (dimensionless)

e = number of events (dimensionless)

V = vehicle type (dimensionless)

v = number of types of vehicles in event E (dimensionless)

Mileage = daily mileage for vehicle type V for event type E (miles

Number = number of vehicles of typed V (dimensionless)

VSF = Vehicle Severity Factor for vehicle type V (dimensionless)

VOF = vehicle off-road factor for vehicle type V (dimensionless)

VCF = vehicle conversion factor for vehicle type V (dimensionless)

LCF = local condition factor for event E ((dimensionless)

Duration = number of day for event type V (days)

ESF = event severity factor for event type V (days)

The ESF, VSF, VOF and LCF values are currently derived using expert opinion. The VCF values are based on published vehicle tire/track widths. Because Training Impact Factors like VSF and LCF are based on subject matter expert opinion, there is an opportunity to improve the accuracy of the ATTACC methodology through improved Training Impact Factors (Sullivan and Anderson, 2000).

4.3.2 Definition and Derivation: Impact Area of a MIM

Based on published vehicle information the track width of one M1 Abrams tank track = 63.0 cm, and since each M1 Abrams tank is built with two tracks the cross-sectional track width of an M1 tank is:

63.0 cm/track x 2 tracks = 126 cm or 1.26 meters = 4.13 feet = 49.6 inches.

Also, 1 mile = 1609 meters = 1.609 km and using the values obtained above the area of disturbance of an M1 Abrams tank moving 1 mile is 1 MIM x 1609 meters/MIM x 1.26 meters = 2027.34 m^2 = Impact Area of 1 MIM. The conversion of the impact area of a MIM from SI units to English units is 2027.34 m^2 x (1 acre/4047 m^2) = 0.5 acres of impact. Thus when the number of MIMs is known the area of disturbance is known as well. Correspondingly, the location of the disturbance is generally not known, but data exists to assign MIMs to general locations.

4.3.3 Definition and Derivation: Changes in Soil Infiltration as a result of Military Training

The change in soil infiltration along with other soil physical properties due to military training is correlated to heavy maneuver training. Heavy maneuver training is reported via RFMSS data using the Military Impact Mile (MIM). Over the years numerous studies have examined the impact this maneuver training has had on various soil properties (e.g. compaction, rut depth formation, soil shear strength, etc.)(Braunack and Williams, 1993; Ayers, 1994; Thurow et al, 1995; Halvorson et al, 2001; Prosser et al, 2000; Fuch et al 2003; Haugen et al, 2003). Of particular interest is the relationship between infiltration, vehicle maneuvering and the number of passes a vehicle makes over a given area. Rut formation studies for wheeled and tracked vehicles on straight paths and turning paths have quantified the phenomenon as a percentage increase in rut formation per pass. For an M1 Abrams tanks this value was determined to be approximately 20% per pass (all military vehicles are normalized to the M1A2 tank). Field studies at Eglin AFB measured the decrease in infiltration after military vehicle passes. The soils at Eglin AFB and Fort Benning are similar and therefore it is reasonable to assume that similar results would be obtained at Fort Benning. The study at Eglin AFB measured decreases in soil infiltration to be 15-20% after the 1st pass (this value will change as general soil type changes, but can be inferred if compaction or bulk density information can be obtained for an area). Rut formation and soil infiltration are related soil parameters via the increase in soil bulk density after a given pass. It is assumed that a multiplicative relationship exists between soil infiltration, f, and the number of vehicles passes. For each pass infiltration is reduced 20% from the current infiltration rate. This relationship can be expressed as $f(x) = a^n(x) + b$, where x = the initial soil infiltration, n = the number of vehicle passes, a = constant, and b = constant. Infiltration does not decrease until it reaches zero, it decreases to a minimum level, b, based on the compactive effort (i.e. the weight of the vehicle), soil type, and soil moisture content after a certain number of passes. Values on the number of vehicle passes to reach this level can be obtained from studies of changes in rut depth and bulk density due to wheeled and tracked vehicles passes but can range from 4 passes for clay soils to 13 passes for sandy soils (Lyasko, 2010). One must take care in interpreting these values as there are two methods for reporting number of passes in the literature, 1) by vehicle and 2) by axle. Additionally, the treatment of wheeled and tracked vehicles is also done separately. The analysis and report by Lyasko, used axles in the reporting method (2010). The change in infiltration on training land areas can be approximated as a percentage impact on original field infiltration value. This is not an unreasonable assumption as Liu et al found similar results in their multi-pass study of wheeled and tracked vehicles (2009).

The change in infiltration can be calculated for any training area, Z, given in square meters, based on RFMSS derived information using the following relationship:

N_{passes} at Training Area Z = (RFMSS MIM Impact Area)/Training Area Z, **(2)**

where N_{passes} = number of vehicle passes and the RFMSS MIM Impact Area is the disturbed area of Training Area Z.

If the RFMSS MIM Impact Area = Z, then the number of passes over the entire training area is 1. Preliminary studies at Elgin AFB have established a value for the change in soil infiltration, $\Delta f_{overall}$ = 20% or 0.2. For this example, the F-factor would be (1.0-0.2) = 0.8. This F-factor has values ranging from 1 to 0 and serves to reduce the original field infiltration value using the following equation,

Field infiltration = $0.8^{Npasses}(x) = 0.8^{[(RFMSS\ MIM\ Impact\ Area)/Z]}(x) = 0.8^{[(2027m^2*MIM)/Z(m^2)]}(x)$ **(3)**

However, using this equation requires information on the minimum infiltration of the soil in question and would require a database of Any training area with a number of vehicle passes greater than 5 would result in an area where infiltration is zero and surface runoff is the predominant mechanism of stormwater transport.

4.3.4 Definition and Derivation: Vegetative Coverage Change

Range and Training Land Assessment (RTLA) data was used to calculate the differences in C factor, ground cover, aerial cover, and minimum drip height between disturbed and undisturbed portions of field transects. Undisturbed portions of transects had no military disturbance. Disturbed portions of transects only had single pass vehicle disturbance. Other disturbance categories were not included in this portion of the analysis. Only single pass portions of transects were used so that differences between disturbed and undisturbed portions of transects would be an estimate of resource damage associated with single pass vehicle tracking events. Additionally, vegetative recovery was not considered in this derivation.

ΔC-Factor is the change in USLE C-Factor associated with a single pass of a vehicle. ΔC-Factor is a unitless value representing a linear decrease in C-factor for each vehicle pass. ΔGround-Cover represents the change in ground cover associated with a single pass of a vehicle. ΔGround-Cover is reported as a percentage with 100% being fully covered and 0% being completely uncovered. ΔAerial-Vegetation-Cover represents the change in vegetation cover associated with a single pass of a vehicle. ΔAerial-Vegetation-Cover is reported in percent with 100% being fully covered and 0% being completely uncovered. ΔMinimum-Drip-Height represents the change in height of the vegetation closest to the ground surface associated with a single pass of a vehicle. ΔMinimum-Drip-Height is reported in meters.

Fort Benning Δ USLE C-Factor: 0.084 Mean, σ = 0.108

Fort Benning Δ Ground Cover: Mean = 52.6, σ = 43.69

Fort Benning Δ Aerial Vegetation Cover: Mean = 14.2, σ = 30.17

Fort Benning Δ Minimum Drip Height: Mean = 0.08, σ = 2.058

When vegetation is expressed as a percentage of remaining ground cover as with Δ Ground Cover and Δ Aerial Vegetation Cover the calculation of a new vegetative coverage follows the same logic as with Equation (3) as illustrated in equations (4) and (5).

Ground Cover = $0.525^{Npasses}(x) = 0.526^{[(RFMSS\ MIM\ Impact\ Area)/Z]}(x) = 0.526^{[(2027m^2*MIM)/Z(m^2)]}(x)$ (4)

Similarly,

Aerial Vegetation Cover = $0.14^{Npasses}(x) = 0.14^{[(RFMSS\ MIM\ Impact\ Area)/Z]}(x) = 0.14^{[(2027m^2*MIM)/Z(m^2)]}(x)$ (5)

4.4 GENERAL SUMMARY

This document is meant to provide guidance in the generation of vehicle impact maps and the subsequent generation of vehicular vegetative impact maps and vehicular infiltration impact maps. Although this approach is constrained by certain assumptions and limitations of the dataset it provides a reasonable estimate of the impact that vehicles have on military training areas and is the accepted Army approach. The approach to generating vehicle impact maps is outlined below:

- Training Distribution Data Acquisition
- Training Distribution Percentage Map Generation
- Training Load Data Acquisition (MIMs via ARRM)
- Training Load Map Generation (MIMs/Acre)
- Vehicle Impact (# of Passes) Map Generation
- Vegetative (C-Factor) Impact Map Generation
- Infiltration (F-Factor) Impact Map Generation

This approach results in the creation of three maps: 1) a vehicle impact map, 2) a vegetative impact map, and 3) an infiltration impact map. Once the vehicle impact maps have been generated for each year of interest, a comparison from year-to-year can be undertaken for to examine landuse changes based on vehicular impacts.

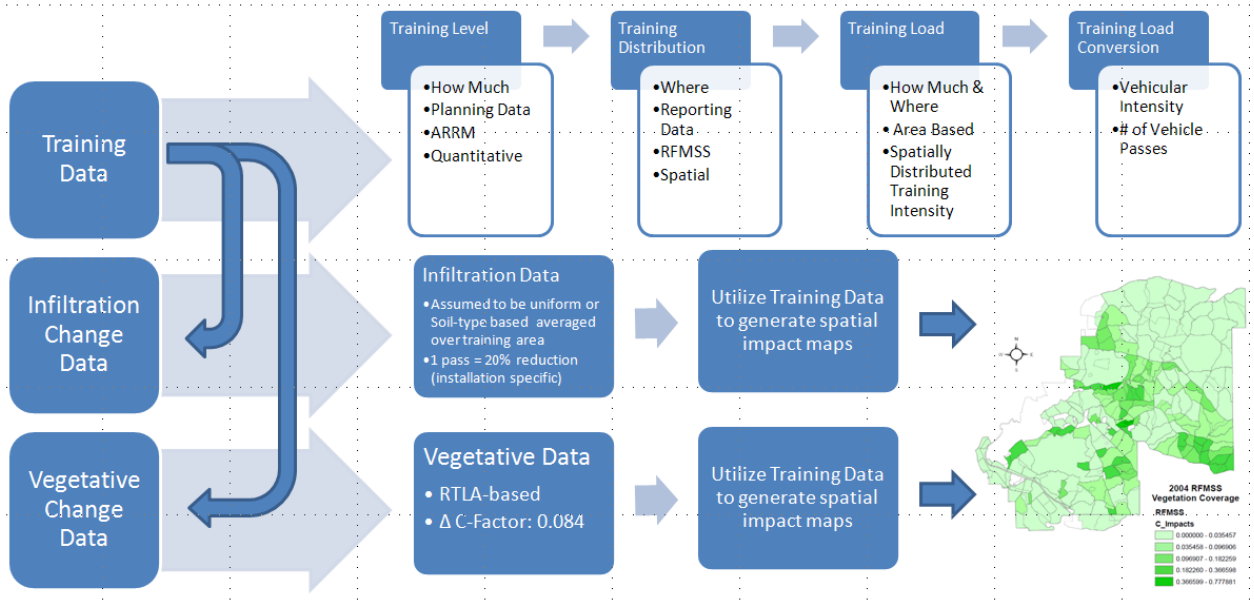

Figure 4.1 Process Overview for Generating Spatial Impact Data

4.5 STEP-BY-STEP INSTRUCTIONS FOR GENERATING IMPACT MAPS

4.5.1 STEP 1 - Training Distribution Dataset/Map Development:

Once information related to training distribution is obtained through the examination and analysis of Army Range Requirement Model/Range Facility Management Support System (ARRM/RFMSS) data for a given year (e.g. 2004) a dataset/map of training distribution can be generated. The ARRM data approximates the level of training that is expected to occur (but may not actually occur) on the installation while the RFMSS data is the reported training record of the gross spatial distribution of training over an installation. The training distribution map can utilize any quantity that purports to represent the spread of training over the landscape. In this document, the selected parameter is range utilization days (RD), which is a value obtained from RFMSS.

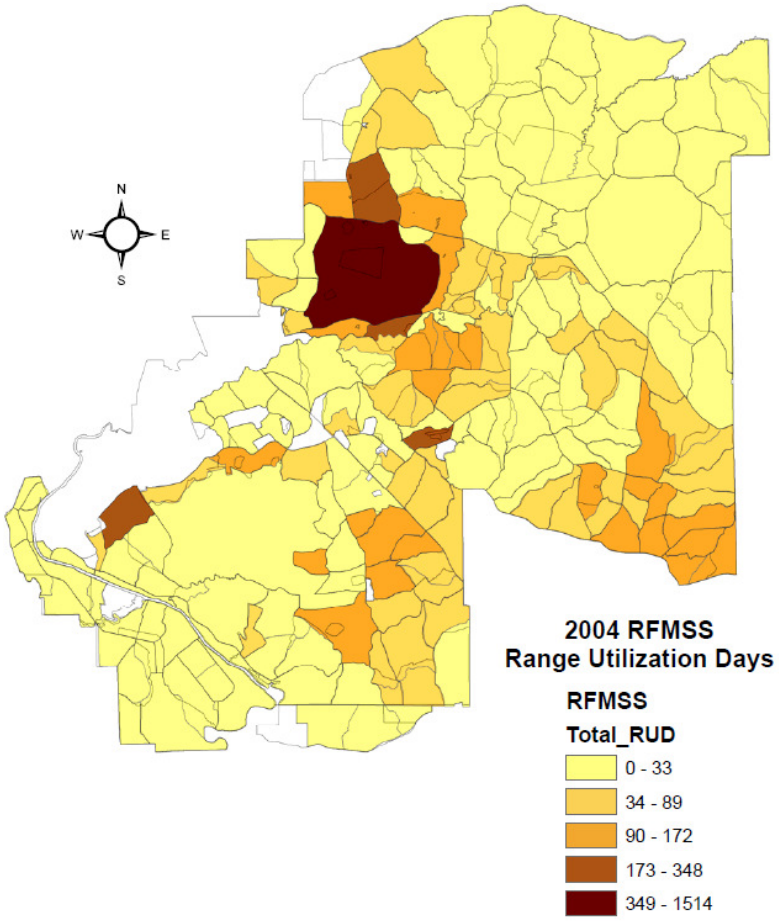

Figure 4.2 Training Distribution Map Based on Utilization (Range Days (RD)) 2004

Figure 4.2 illustrates a map of the training distribution over each range in total range utilization days (RD). It is important to note here that while RFMSS data may be able to be differentiated according to Light or Heavy Maneuver Training, basic MIM data is not broken up into categories of light and heavy training and would require a detailed examination of the ARRM data to make a distinction between MIMs in each category.

4.5.2 STEP 2 - Training Distribution Percentage Dataset/Map Development:

The dataset/map created in this step is very similar to the map developed in Step 1. It is essentially a transform map that is mathematically equivalent to the training distribution map. The mathematical relationship used to derive values for this map is Percent Utilization = [Range Utilization Days (or some training distribution equivalent)/Total Installation Utilization]. During 2004, Fort Benning had a sum total of 10331 Range Utilization Days. As seen below in Figure 4.3, the percent range of utilization over the installation ranged from 0% - 15%.

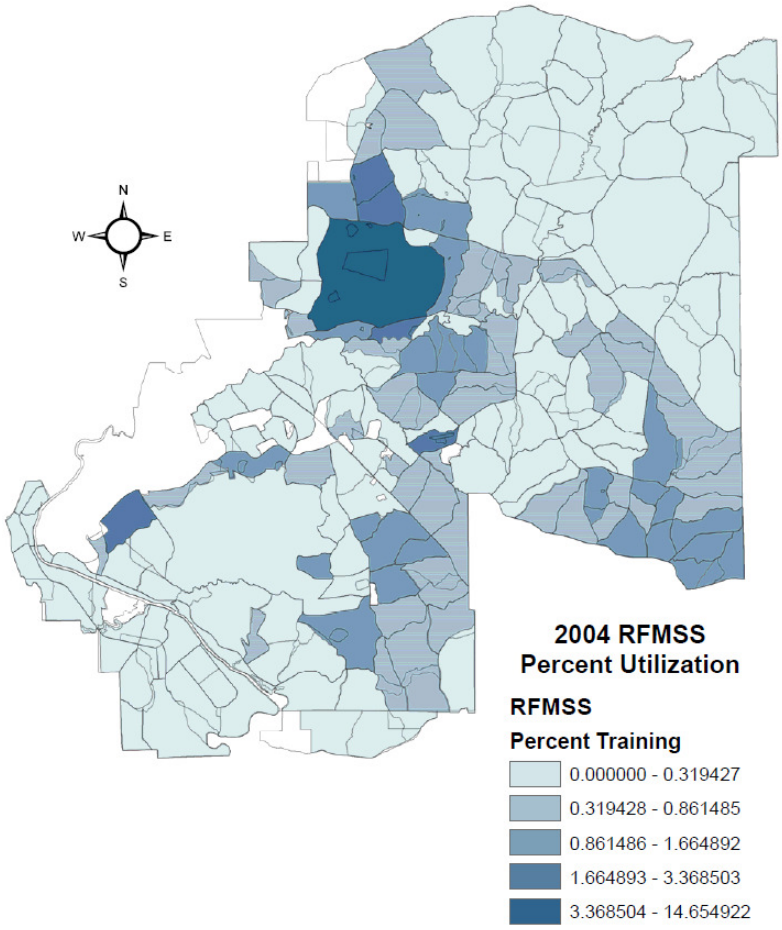

Figure 4.3 Fort Benning Percent Range Utilization Map

4.5.3 STEP 3 - Training Load Dataset/Map Development:

The map and data generated in this step is representative of training load across an installation using MIMs. At its most basic level, this is the combination of the map from Step 2 and the total MIM value for the entire installation in 2004. For example, the 2011 MIM value taken from ARRM is 602,134. ARRM data reports the planned level of training that is required to occur on a military post to maintain troop readiness. The drawback to using ARRM information is that it gives no indication of where this training is to occur or whether or not it actually occurred. That decision is left to an installations training range management team which will decide where the required training is best suited on the installation landscape. Regardless, the value of the MIM does not change; therefore, this value can be applied to the training percentage data (see Figure 3 and Step 2) to create a new dataset that represents training load (MIMs) over the

installation. For this step it is important to select the relevant training load information such that MIM values reflect training impact across the installation in the correct location (see Table 1 for an example of MIM derived training information). It is assumed that for our purposes RFMSS data is the best representation of training distribution over the landscape. The total reported RFMSS MIMs for 2004 on Fort Benning was 219,226 (see Table 4.1) as interpreted by Fort Benning range personnel (communication with H. Westbury). Given this information, the map of training load for the various training areas is a scalar of the percentage training map derived in Step 2 and is illustrated in Figure 4.4.

Table 4.1 2004 MIM reporting on Fort Benning training (compiled by Fort Benning Range Personnel)

FORT BENNING TOTAL MILES AND MIMS BY UIC WITH POI & KNOX POI & ONE EOD								
						COMPO	TotMiles	TotMIMs
						TOTAL AC	6,227,647	197,771
						TOTAL NGB	628,426	20,701
						TOTAL USARC	181,615	754
						TOTAL ALL	7,037,688	219,226
FY	UIC	UICDesc	COMPO	BR	SRC	HostInstall	TotMiles	MIMs
2005	WA0GAA	00 0317 BN HVY DIV	AC	EN	05335L000	FORT BENNING	302,270	23,977
2005	WAZQAA	00 0036 HHCGP (EAC)	AC	EN	05412L100	FORT BENNING	46,217	304
2005	WBC3AA	00 0063 CO CBT SPT EQUIP	AC	EN	05423L000	FORT BENNING	166,023	9,503
2005	WARXAA	01 0010 BN 155SP (3X6)	AC	FA	06365A200	FORT BENNING	576,925	8,234
2005	WJBLAA	03 0075 BN RGR (ABN)	AC	IN	07085L000	FORT BENNING	202,828	915
2005	WAR0AA	01 0015 BN MECH (FVS)	AC	IN	07245L400	FORT BENNING	440,613	31,027
2005	WGK6AA	01 0030 BN MECH (FVS)	AC	IN	07245L400	FORT BENNING	440,613	31,027
2005	WDDDAA	00 0075 HHCRGR RGT (ABN)	AC	IN	07302L000	FORT BENNING	58,967	294
2005	WFGHAA	00 0926 DETPREVENTIVE MED	AC	MD	08429A000	FORT BENNING	13,833	32
2005	WBM2AA	00 0498 CO AIR AMB (UH-60)	AC	MD	08443L200	FORT BENNING	69,800	174
2005	WBNXAA	00 0690 CO GROUND AMBULANCE	AC	MD	08453A000	FORT BENNING	81,429	239
2005	WBJTAA	00 0014 HSPCOMBAT SPT (EAC)	AC	MD	08855A000	FORT BENNING	43,651	246
2005	WC46AA	00 0756 DETMINIMAL CARE	AC	MD	08949A000	FORT BENNING	32,722	65
2005	WFK6AA	00 0608 CO HQ MOD AMMO ORD	AC	OD	09408L000	FORT BENNING	221,467	318
2005	WB7EAA	00 0731 CO EOD CO	AC	OD	09447L000	FORT KNOX	63,133	97
2005	WB7PAA	00 0789 CO EOD CO	AC	OD	09447L000	FORT BENNING	63,133	97
2005	WCS3AA	00 0283 BNDARMY	AC	AG	12113L000	FORT BENNING	6,860	17
2005	WAZMAA	00 0010 TRPBDE RECCE TROOP, D	AC	AR	17087F000	FORT BENNING	199,038	6,669
2005	WGM6AA	02 0069 BN TANK BN	AC	AR	17375L100	FORT BENNING	394,812	25,700
2005	WGDKAA	00 0988 CO CBT SPT	AC	MP	19677L000	FORT BENNING	79,919	174
2005	WDBGAA	00 0071 DETMP DET (LAW&ORDER)	AC	MP	19710A000	FORT BENNING	9,516	13
2005	WDBHAA	00 0209 DETMP DET (LAW&ORDER)	AC	MP	19710A000	FORT BENNING	9,516	13
2005	WE0ZAA	00 0086 DET(CID)	AC	MP	19883A000	FORT BENNING	9,516	13
2005	WNC9AA	00 0518 HHD BN	AC	MP	19886A000	FORT BENNING	50,710	135
2005	WE7MAA	00 0598 CO MAINT NON-DIV DS	AC	OD	43209L000	FORT BENNING	63,133	301
2005	WHEJAA	00 0361 DETTLR TRANSFER PT	AC	TC	55540FE00	FORT BENNING	68,205	154
2005	WCN7AA	00 0104 CO MDM TRK CGO CORPS	AC	TC	55728F100	FORT BENNING	319,341	539
2005	WJD2AA	00 0203 BN FSB 1X2 LDXXI 3ID	AC	CS	63005L600	FORT BENNING	807,308	17,248
2005	WCA3AA	00 0013 HHDCORPS SUPPORT BN	AC	CS	63426L000	FORT BENNING	35,572	49
2005	WAR4AA	03 0003 HHCBDE	AC	HQ	87042L400	FORT BENNING	51,641	1,461
2004	SCHOOL	BENNING POI SCHOOL	AC	IN	TOTAL	FORT BENNING	1,036,806	20,000
2004	SCHOOL	KNOX POI SCHOOL	AC	AR	TOTAL	FORT KNOX	262,129	18,738
2005	WQR9AA	265 HHC GP (CORPS)	NGB	EN	05412L200	FORT BENNING	13,865	91
2005	WPDBAA	02 121 BN MECH (FVS)	NGB	IN	07245L4EH	FORT BENNING	220,307	15,513
2005	WPFTAA	111 HHD EOD GROUP	NGB	OD	09627L000	FORT BENNING	6,572	11
2005	WPC3AA	3203 CO MSL SPT (EAC)	NGB	OD	09629L000	FORT BENNING	6,572	11
2005	WXA9AA	151 BND ARMY	NGB	AG	12113L000	FORT BENNING	2,058	5
2005	WVBPAA	348 TRP ARMD CAV, HSB, E	NGB	AR	17483L0EH	FORT BENNING	99,519	3,335
2005	WXBEAA	214 CO CBT SPT	NGB	MP	19677L000	FORT BENNING	23,976	52
2005	WVBJAA	1156 DET CASE	NGB	MP	19883A000	FORT BENNING	2,855	4
2005	WPX8AA	201 BN SUPPLY&SERVICE BN	NGB	QM	42446L000	FORT BENNING	6,572	28
2005	WQVRAA	166 CO MAINT NON-DIV	NGB	OD	43209L000	FORT BENNING	18,940	90
2005	WXBKAA	158 CO MAINT NON DIV	NGB	OD	43209L000	FORT BENNING	18,940	90
2005	WPKUAA	731 HHD BN MAINT DSGS	NGB	OD	43436L000	FORT BENNING	6,572	32
2005	WQE1AA	131 DET MOBILE PUBLIC AFF	NGB	PA	45413L000	FORT BENNING	15,418	49
2005	W780AA	62 TRP CMD	NGB	HQ	51610L000	FORT BENNING	4,216	9
2005	W789AA	78 TRP CMD	NGB	HQ	51610L000	FORT BENNING	4,216	9
2005	W7L7AA	DET CIV SPT TM 46 WMD	NGB	HQ	51610L000	FORT BENNING	4,216	9
2005	W7MTAA	ACT USPFO ACTIVITY AL	NGB	HQ	51610L000	FORT BENNING	4,216	9
2005	W84FAA	CMD 621 TRP CMD	NGB	HQ	51610L000	FORT BENNING	4,216	9
2005	W8ASAA	HQ STARC AL ARNG	NGB	HQ	51610L000	FORT BENNING	4,216	9
2005	W8FKAA	HQ S ARNG LDR TNG BDE	NGB	HQ	51610L000	FORT BENNING	4,216	9
2005	W8FTAA	HQ GA ARNG TNG INST	NGB	HQ	51610L000	FORT BENNING	4,216	9
2005	WV03AA	1177 CO MDM TRK CGO CORPS	NGB	TC	55728L100	FORT BENNING	95,802	164
2005	WQVJAA	110 HHD CORPS SUPPORT BN	NGB	CS	63426L000	FORT BENNING	10,672	15
2005	WTALAA	1103 HHD CORPS SUPPORT BN	NGB	CS	63426L000	FORT BENNING	10,672	15
2005	WVBLAA	48 HHC BDE	NGB	HQ	87102L2EH	FORT BENNING	35,390	1,126
2005	W8KRAA	1207 HSP USA 100B	USARC	MD	08949A000	FORT BENNING	9,817	19
2005	W72GAA	09 108 TRN BN (QM) 108 REG	USARC	QM	10466L000	FORT BENNING	11,397	23
2005	W72EAA	07 108 TRN BN (PS) 108 REG	USARC	AG	12427L000	FORT BENNING	7,035	18
2005	WS8WAA	213 CMD LEGAL SPT ORG	USARC	JA	27522LA00	FORT BENNING	7,035	18
2005	W72HAA	1081 TRN TNG DET (ORD)	USARC	OD	43436L000	FORT BENNING	6,572	32
2005	W7ZAAA	2145 HQ USA GAR (AUG)	USARC	HQ	51610L000	FORT BENNING	4,216	9
2005	W72FAA	08 108 TRN BN (TC) 108 REG	USARC	TC	55506LA00	FORT BENNING	1,041	3
2005	W72DAA	4 TRN BDE(CSS) 108 DIV	USARC	CS	63426L000	FORT BENNING	10,672	15

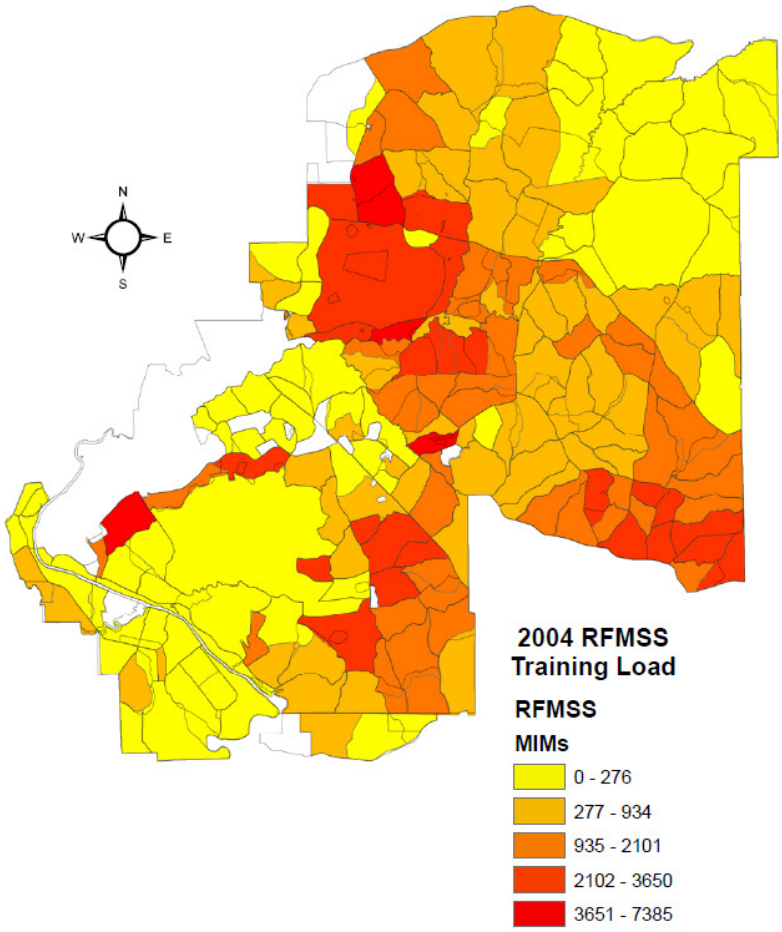

Figure 4.4 Fort Benning 2004 Training Load Map (Reported in MIMS)

To create the data for the map in Step 4 an assumption with regards to training distribution within a training area is necessary. That assumption is that vehicle use is evenly distributed across the landscape of a training area. Although this assumption does not accurately reflect actual conditions on the ground, without better information, this assumption is the best available.

4.5.4 STEP 4 - Vehicle Pass Dataset/Map Development:

This is the final step in the process to create a dataset that allows us to relate training land usage to infiltration and vegetative cover impacts.

Once the dataset representing training load has been developed as described in the previous step, this information can be used to generate more data involving the number of vehicles passes over the training areas. This can be done by taking the derived dataset from the previous step and dividing the obtained MIM values for each training area by the MIM Impact Area value (2027 m^2) to determine the number of vehicles passes within that area. A map of the number of vehicle passes per training area can be observed in Figure 4.5.

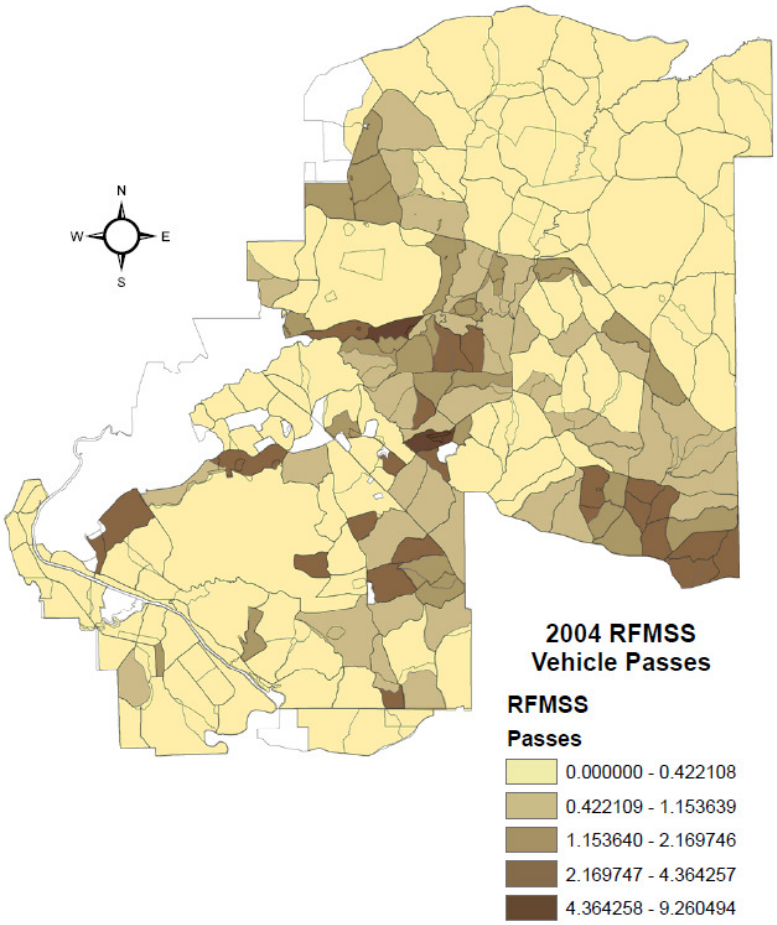

Figure 4.5 Fort Benning 2004 Number of Vehicle Passes per Range Map

The generation of this map and dataset is the desired final product with regards to training land impacts as this information can then be used to relate to changes in soil infiltration and vegetative cover.

4.5.5 STEP 5 - Delta-Impact Factor Dataset/Map Derivation:

Based on the information provided in the calculations section of this document, the impact factor datasets for Delta-C (change in vegetative cover) and Delta-F (change in soil infiltration) are constant values representing uniformity over the installation training (more detailed information on infiltration and vegetative cover can be utilized if that information is available). Delta-C = .084 and Delta-F = 0.8 are the values that alter these parameter based on the number of vehicle passes.

4.5.6 STEP 6 - Predicted Impact Dataset/Map Development for Vegetation and Infiltration:

Once the Delta Impact Factor datasets have been developed a new dataset based on the number of vehicles passes can be integrated with the Delta-Impact Factor dataset to generate a predicted impact dataset and map based on vegetative changes and soil infiltration change as related to training over the year of interest. These dataset can be compared to or combined with the initial condition map to generate a Delta Difference Map or a Cumulative Impact Map depending on the required analysis.

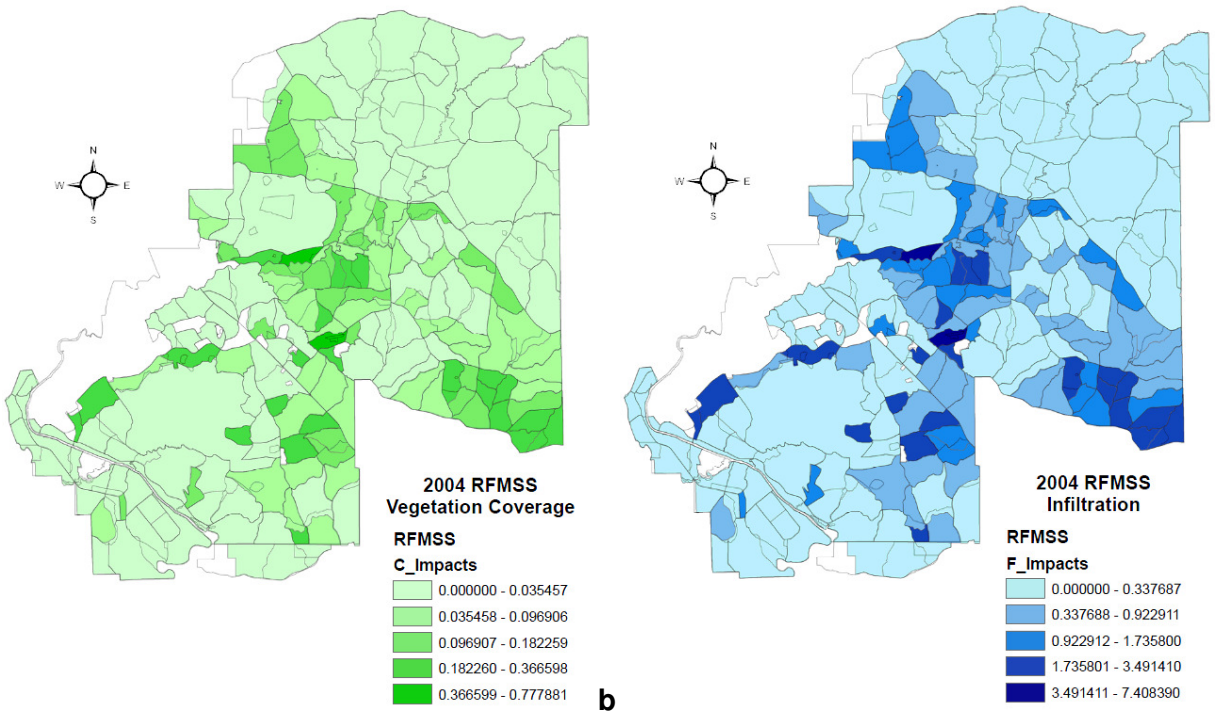

Figure 4.6 Fort Benning 2004 a) Vegetative Cover Impact Map and b) Soil Infiltration Impact Map

As a final note, all map generation noted in these steps can be skipped to obtain only the dataset needed to proceed to the next step. The final datasets can then be used for comparison to other years to map changes in vegetation or infiltration. However, it is often useful to examine the map presented in step 4 to ascertain if the final product agrees with the training distribution map observed in Figure 4.2.

SECTION 5

ATTACHMENT TO APPENDIX B:

RFMSS DATA AND THE USE OF RANGE UTILIZATION DAYS

The use of RFMSS and ARRM as tools to assist with the management of military training lands and the primary data source to calculate training land utilization was established by Army Regulation 350-19, The Sustainable Range Program. Essentially, RFMSS and ARRM are databases that provide Army personnel information on training requirements, training land utilization (throughput) to facilitate Army training scheduling, monitoring and budgetary analysis. Depending on user requirements training distribution datasets/maps can be generated for the majority of training occurring across an installation Figure 5.1a, Figure 5.1b, and Figure 5.2a illustrate the differences between varying training categorical types. RFMSS data can be reported as a total of the range utilization days, or as a subset of those total range utilization days based on training type (i.e. Heavy Mechanized, Light Infantry, Heavy Infantry, etc.). The issue with using training type subsets is that in ARRM there is currently no differentiation between these subcategories as they relate to MIMs. Creating the required subcategories is a labor intensive process that requires looking at individual training units and determining what category they fit into; however, this process could potentially be automated.

The use of RFMSS/ARRM data has several drawbacks:

- ARRM data is primarily a budgeting and planning tool that approximates the level of training on an installation (based on the ATTACC methodology). Actual training on an installation may be different.
- ARRM data systematically overestimates MIM values on installation since it assumes that all required training is carried out at the installation and does not account for changes in schedule.
- ARRM data is only periodically updated so it will not account for training variability or redundancy.
- RFMSS reporting may only capture what is said to occur on the installation training areas, actual training may deviate from the reported information.

Regardless, of the drawbacks in using this information, the use of ARRM and RFMSS data as a tool for determining training requirements and reporting actual training has been accepted by the Army. Currently, with the exception of isolated cases for individual events there is not a better method to calculate training impacts to installation lands.

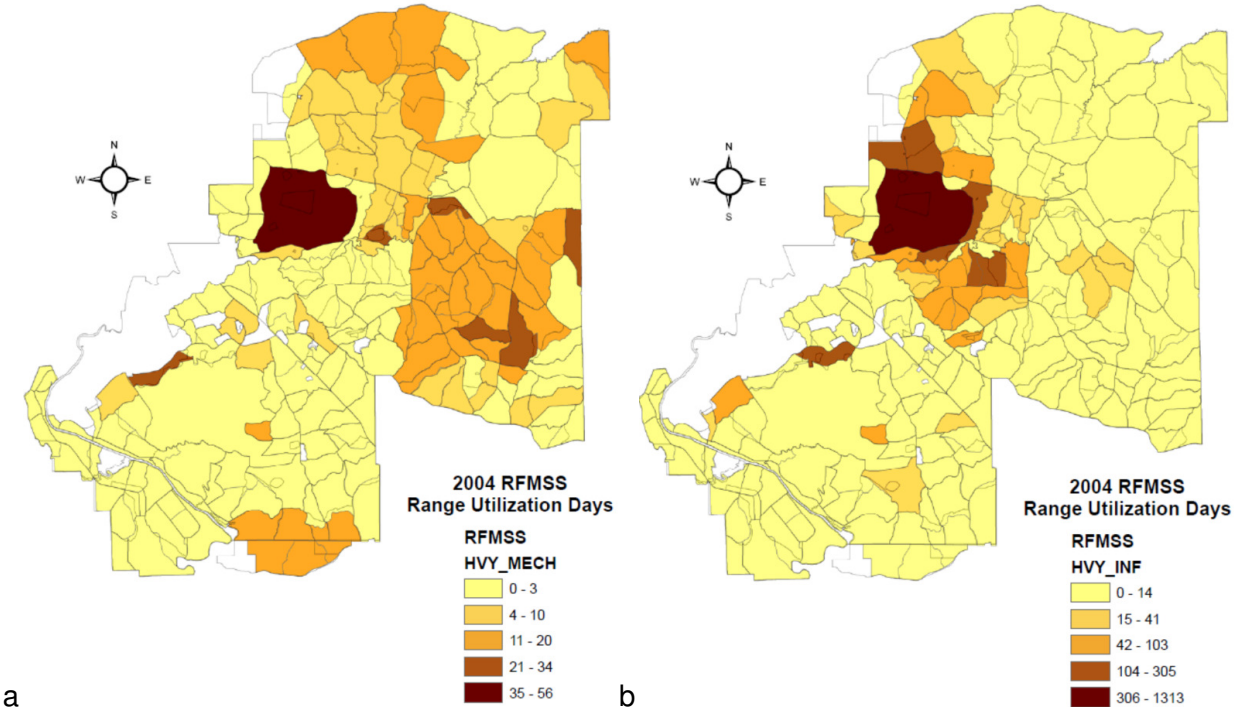

Figure 5.1 Fort Benning 2004 RFMSS a) Heavy Mechanized and b) Heavy Infantry Range Utilization Days

Even with these limitations, in the absence of more accurate land use data, ARRM/RFMSS does provide a reasonable estimate of training load that is accepted and used by the Army.

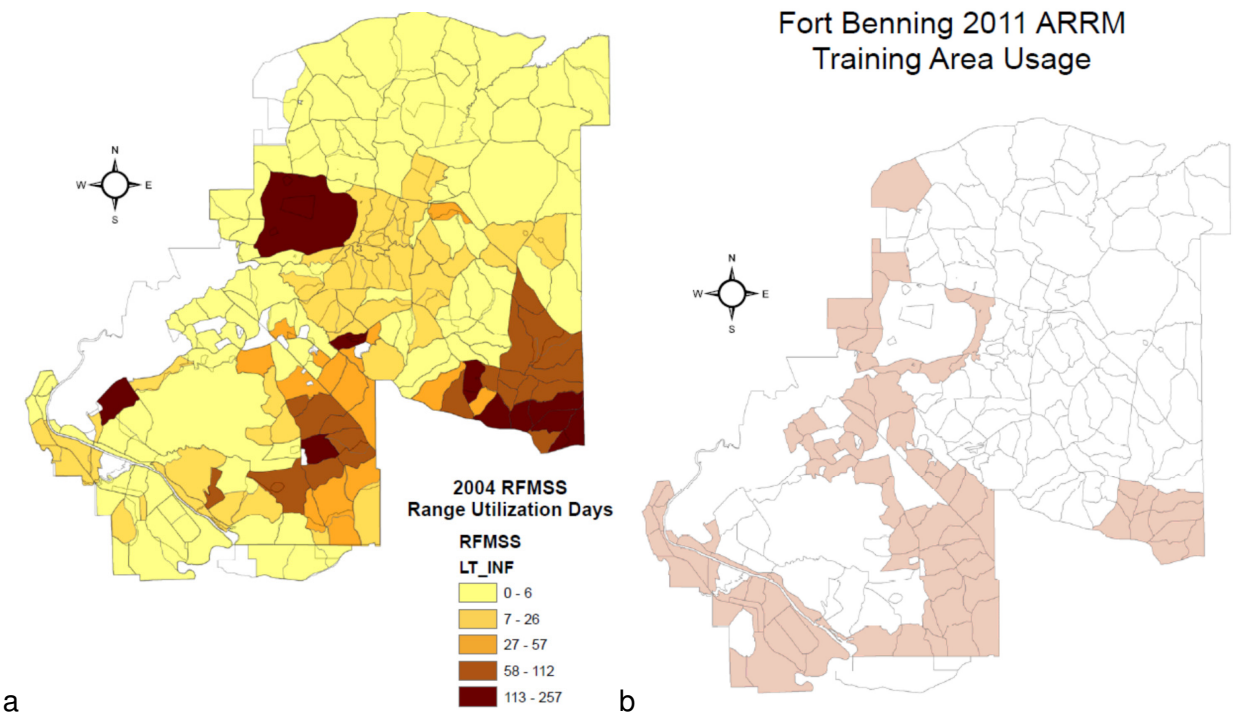

Figure 5.2 Fort Benning 2004 RFMSS Light Infantry Range Utilization Days and 2011 ARRM Range Use

Figure 5.2b is presented as an example of what kind of results are obtained if we look at using ARRM data directly without utilizing RFMSS. It is true that ARRM does place training within an array of training areas. Unfortunately, those areas are not where the units generally end up conducting their training. Those assigned training areas essentially are place holders for the training and it is up to the range managers at each installation to distribute training to the appropriate area.

SECTION 6
CONCLUSION

This documents intent was to present in detail, a stepwise process to determine how to utilize Army Training Area military training data (i.e. ARMM and RFMSS) for the calculation of impacts to infiltration and vegetation. This methodology is applicable to other training area resources if information exists that correlates military training to resource impacts.

SECTION 7
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December 2012

A Watershed Modeling System for Fort Benning, GA Using the US EPA BASINS Framework

SERDP PROJECT SI-1547

ENHANCED BASELINE MODEL RESULTS

Final Report
Appendix C

CONTENTS

FIGURES

TABLES

SECTION 1
INTRODUCTION

This document is an update to the Baseline Model application of the US EPA HSPF model to Fort Benning, GA, as described by AQUA TERRA Consultants (2010), to produce the Enhanced Baseline Model that resulted from subsequent model refinement and re-application efforts during the course of the SERDP Project RC-1547. The original Baseline Model was the result of Task 2 of the overall project flowchart (see Section 1.0 Final Report) which focused on an application of the BASINS/HSPF model using the native model capabilities before the research into needed model refinements, and their implementation within the code, to better represent the impacts of military training and natural resource management activities occurring on the Installation.

As a result of the research in RC-1547, the Enhanced Baseline Model included several improvements as listed below:

- Multiple canopy representation: This was done to better represent the changes in interception and cover due to prescribed burning and seasonal variation of the understory vegetation.
- Improved FTABLE (Function Tables): The additional monitoring by USGS provided improved FTABLE representation (i.e., stage-discharge-volume-surface area) of several reaches in the watershed.
- Hybrid capability: The sediment erosion from unpaved roads was simulated using a finer scale model, WEPP:ROAD to better simulate the erosion processes and resulting sediment loads occurring at a finer spatial scale.

The nature and details of these enhancements are described in Section 2 of the Final Report.

The original Baseline Model Report (AQUA TERRA Consultants, 2010) describes the details of the supporting database and original model setup activities; since these have not changed for the Enhanced Baseline Model they are not repeated here. The reader is referred to the Baseline Model Report for those details. Also, since the model enhancements had little impact on the water quality simulation and constituents, other than sediment, the water quality results were essentially unchanged from the Baseline Report and are also not duplicated here.

A map of the Fort Benning watershed illustrating major modeled watershed, streams, and military land uses is presented in Figure 1.1. Since the vast majority of the observed data was within the Upatoi watershed, the calibration was focused on that watershed which drains the majority of Fort Benning lands.

1.1 CALIBRATION TIME PERIODS

The Fort Benning watershed was simulated for water years 2000-2006 in the Baseline Model simulation (AQUA TERRA Consultants, 2010). For the Enhanced Baseline model, the simulation period was extended for two additional years, through 2008. The precipitation data was available at the stations in the ECMI stations (used in the Baseline Model) for the additional two years, but the data was not continuous and several months of data were missing. To fill the missing precipitation data, available ECMI data was compared with the BASINS stations at Columbus (GA092166) and Buena Vista (GA091372), and a multiplier was obtained that could be used to help estimate the missing data. Other meteorological data for the extended period was obtained from the updated BASINS database.

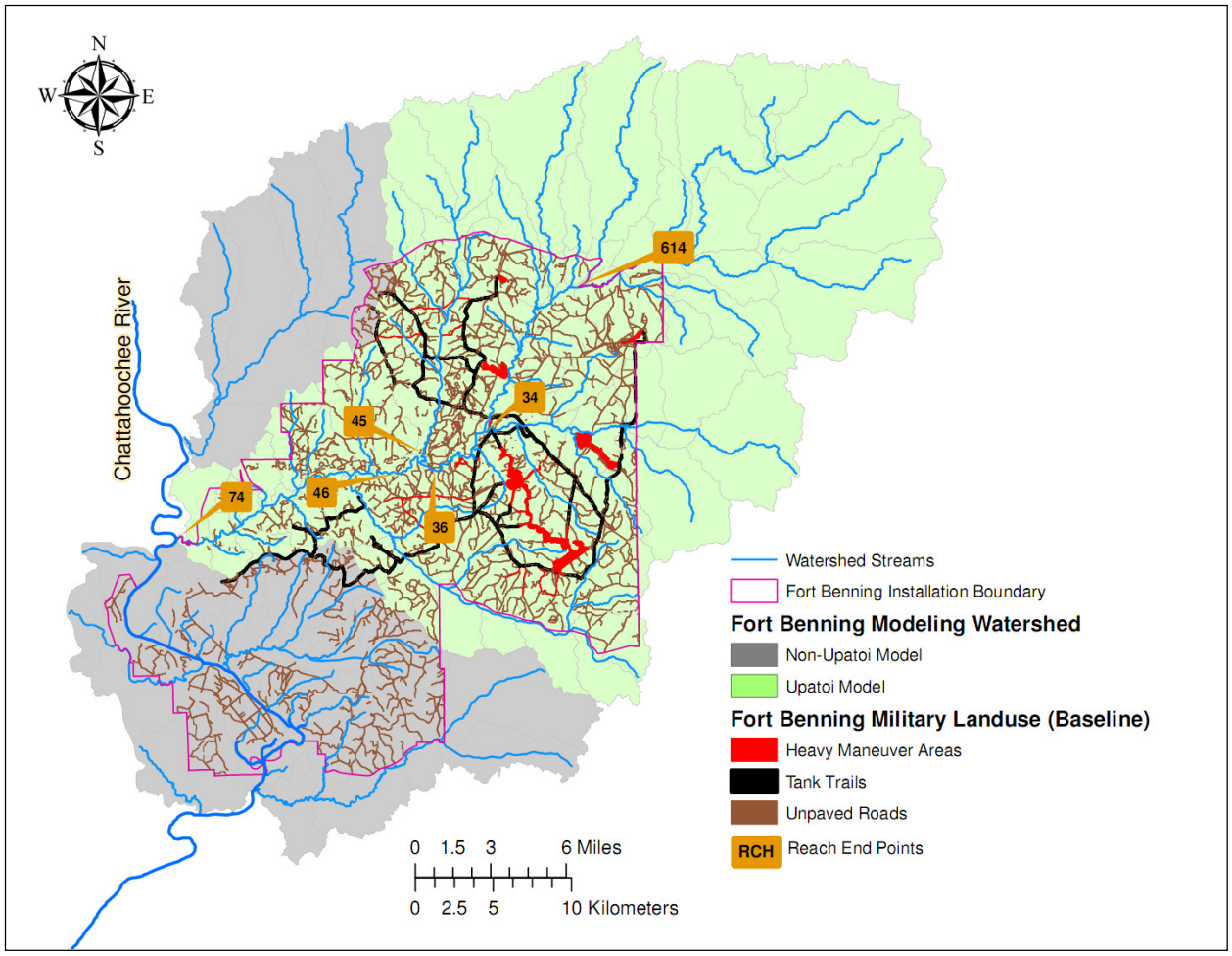

Figure 1.1 Map showing the Modeling Watersheds, Major Streams, and Military Land Uses in the Enhanced Baseline Model for Fort Benning

1.2 HYDROLOGY CALIBRATION RESULTS FOR THE FORT BENNING WATERSHED

As discussed in Task 2 report (AQUA TERRA Consultants, 2010) the Fort Benning watershed was divided into two separate watersheds; Upatoi and Non-Upatoi, to conduct hydrology and water quality calibrations. All the land segments that were flowing into Upatoi Creek were modeled, and designated as the 'Upatoi model', and the remaining area was designated as the 'Non-Upatoi' model. This was done to keep the model input and files at a manageable size. Moreover, only Upatoi creek at McBride Bridge had hydrologic data and most reaches that had other water quality data drained in Upatoi creek. The calibrated hydrologic and water quality parameters from the Upatoi model were used in the Non-Upatoi model. The hydrology calibration for the Fort Benning watersheds primarily focused on the Upatoi creek at McBride Bridge.

The remainder of this section discusses the qualitative and quantitative comparisons of the model results with the observed data, performed for revised calibration period. Only selected graphical comparisons and tables are presented in this section to streamline the discussion.

As mentioned in the Baseline Model Report, the subbasins were assigned a precipitation station based on a Thiessen analysis of the watersheds and gage locations (see Figure 1.2). Three upstream model segments, Hastings Range, Hastings Range-Military, and Hastings Range-

Piedmont were assigned the precipitation from ECMI station Hastings Range, and constituted an area of greater than 200 sq. mi. The precipitation from the Hastings Range gage was assigned multiplication factors of 1.07, 1.03, and 1.05 before applying it on the Hastings Range, Hastings Range-Military, and Hastings Range-Piedmont segments, respectively. This reflected a slight increase in rainfall in the upper watershed based on observed isohyetal patterns, which was not well represented by the ECMI stations.

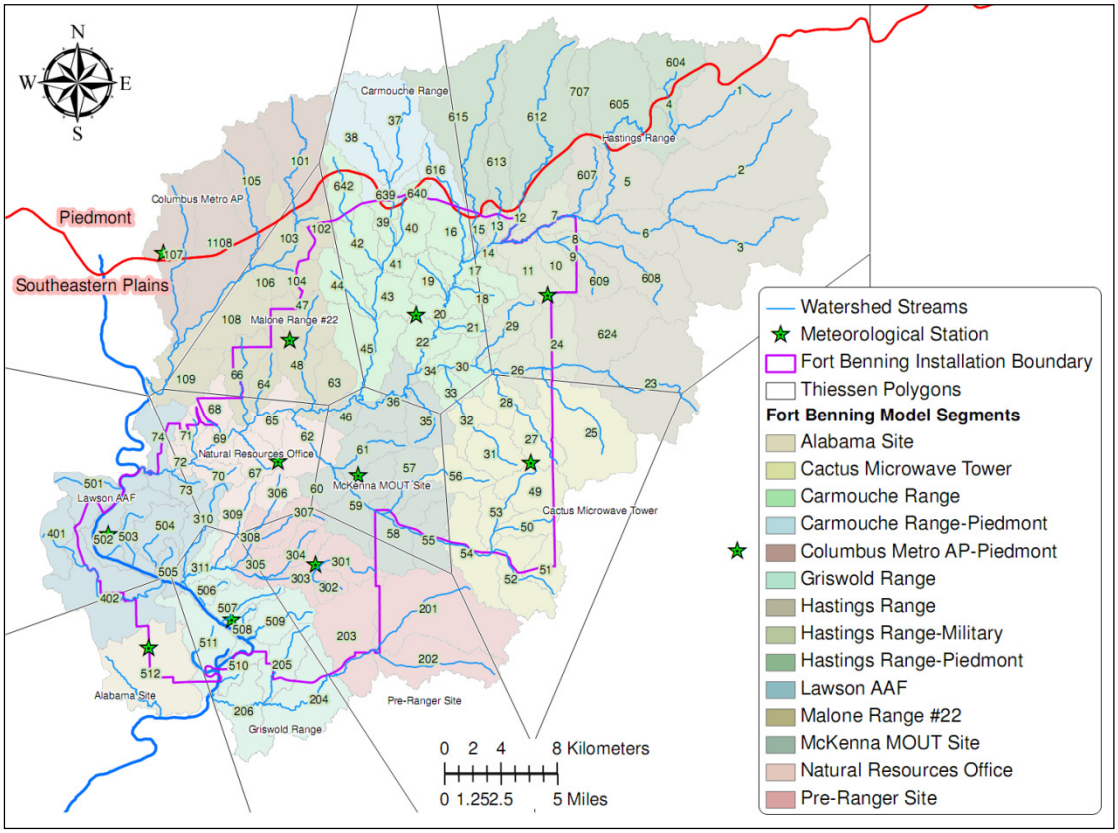

Figure 1.2 Fort Benning Final Segmentation Scheme

As discussed in the Baseline Model Report, the calibration process involves multiple model-data comparisons of observed and simulated flow, usually starting with a daily flow comparison (Figure 1.3), and the daily flow duration curves (Figure 1.4). In the Upatoi watershed, overall the daily simulated flow matched well with observed daily flow. In addition, the seasonal patterns are well represented and the dynamic nature of the daily flow simulation is clearly representing the observed values. However, when we compare high and low flow separately in a flow frequency duration curve, we noticed that the Baseline Model slightly under-simulated very high flows and very low flows. These differences were improved in the Enhanced Baseline Model through the additional calibration efforts. The flow duration comparison in Figure 1.4 is noticeably improved from the Baseline and demonstrates a good calibration; other components of the model performance evaluation are discussed subsequently.

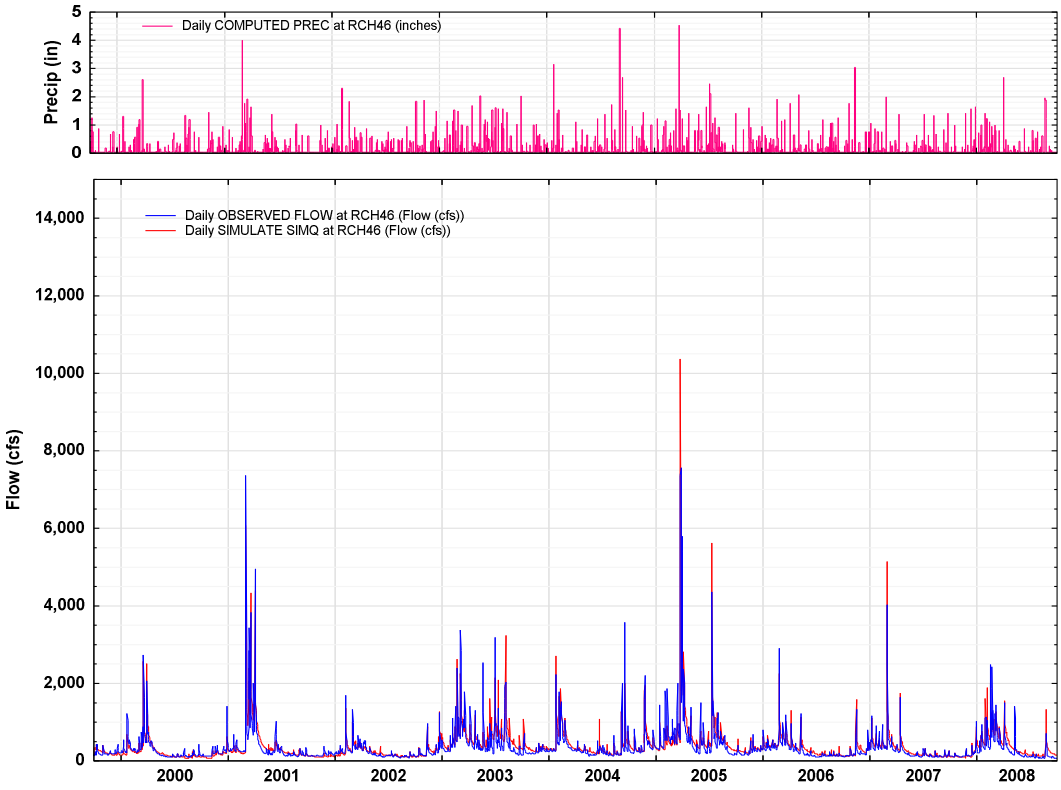

Figure 1.3 Comparison of Observed and Simulated Flow in Upatoi Creek at McBride Bridge for the Complete Calibration Period

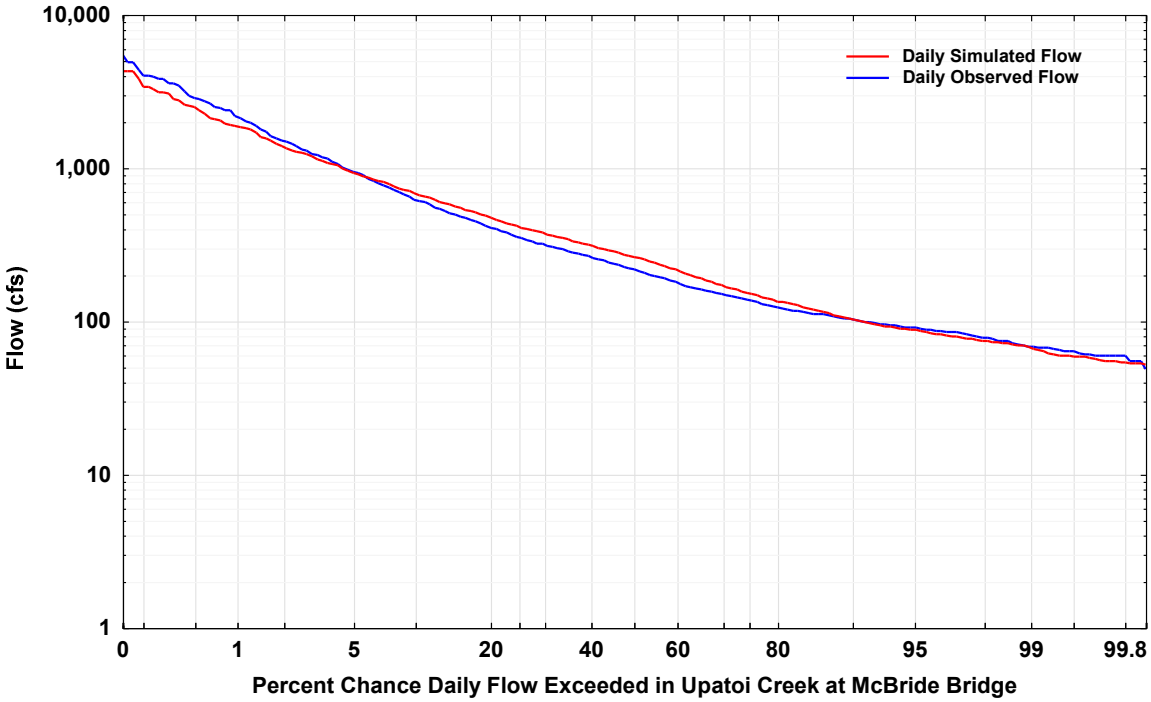

Figure 1.4 Frequency-Duration Curve of Flow in Upatoi Creek at McBride Bridge

To further evaluate the model performance we calculated the annual average statistics of the model (Table 1.1) and different error terms (Table 1.2). The average annual statistics show that the model simulates the flow close to observed flow, and total volume has an error of 7.5%, which is less than the criterion for total flow; however, compared to the 6.2% difference in the Baseline Model, the Enhanced Model showed a slightly larger difference, but not really significant. Most of the errors are within the acceptable limits, except 50% low flow and seasonal volume error. The seasonal volume error could be improved with a denser network of precipitation gages, as the summer storms in Southeastern US are very localized. Also, most of the error terms showed a small improvement of the Enhanced Model compared to the Baseline Model, just the opposite of the volume comparison noted above.

Table 1.1 Annual Average Statistics of Flow in Upatoi Creek at McBride Bridge for the Calibration Period

	Observed Total Runoff	Simulated Total Runoff	Simulated Surface Runoff	Simulated Interflow
total (inches)	13.4	14.4	2.3	4.6
10% high (inches)	5.1	4.8		
25% high (inches)	7.8	8.0		
50% high (inches)	10.6	11.3		
50% low (inches)	2.8	3.2		
25% low (inches)	1.1	1.1		
10% low (inches)	0.4	0.3		
storm volume (inches)	3.0	2.9	1.0	1.3
average storm peak (cfs)	1,381	1,293	954.6	483.1
baseflow recession rate	1.0	1.0		
summer volume (inches)	2.4	2.9		
winter volume (inches)	3.8	3.7		
summer storms (inches)	0.6	0.6	0.2	0.2
winter storms (inches)	0.7	0.6	0.3	0.3

Table 1.2 Error Terms and Criteria for the Annual Average Flow Statistics.

	Current	Criteria	Meets Criteria?
Error in total volume (%)	7.5	10	OK
Error in 10% highest flows (%)	-5.2	15	OK
Error in 25% highest flows (%)	1.6	10	OK
Error in 50% highest flows (%)	6.1	10	OK
Error in 50% lowest flows (%)	12.9	10	Fails
Error in 25% lowest flows (%)	4.3	10	OK
Error in 10% lowest flows (%)	-2.8	10	OK
Error in low-flow recession	-0.01	0.03	OK
Error in storm volumes (%)	-5.6	15	OK
Seasonal volume error (%)	22.7	20	Fails
Error in average storm peak (%)	-6.3	15	OK
Summer volume error (%)	20.0	20	OK
Winter volume error (%)	-2.8	15	OK
Summer storm volume error (%)	-3.8	15	OK
Winter storm volume error (%)	-9.3	15	OK

Comparison of annual flow volumes for each year during the calibration period show that simulated flow volumes are generally greater than observed flow volume (Table 1.3). Similar comparisons were made graphically and the yearly flow comparison for WY2006 is shown in Figure 1.5. The variation in the volume and distribution of rainfall during the calibration period is responsible for this distribution. In five out of nine years, the simulated runoff was greater than observed by more than 10%, but conversely four out of nine are less than 10% different. Also, note that the biggest difference was in the extended period of 2008, and that large difference likely biased the volume error term in the positive direction. The years 2007 and 2008 also required a number of missing data to be filled in, and this can often lead to volume errors in the model comparison. It is likely that those differences in the 2007-08 period had a bigger impact on the error terms than the model enhancements.

Table 1.3 Simulated and Observed Yearly Flow Volume (in) for Calibration Period.

Year	Precipitation	Simulated	Observed	Residual	% Error
2000	31.3	9.1	10.0	-0.8	-8.2
2001	41.1	15.2	15.3	-0.0	-0.2
2002	32.5	7.4	7.9	-0.5	-6.7
2003	58.1	21.4	19.0	2.4	12.4
2004	44.1	14.9	12.9	2.0	15.6
2005	53.5	24.4	23.8	0.6	2.4
2006	37.4	12.6	10.8	1.8	16.3
2007	37.3	11.5	10.1	1.4	14.2
2008	38.8	13.3	11.0	2.3	20.9
Mean	41.6	14.4	13.4	1.0	7.5

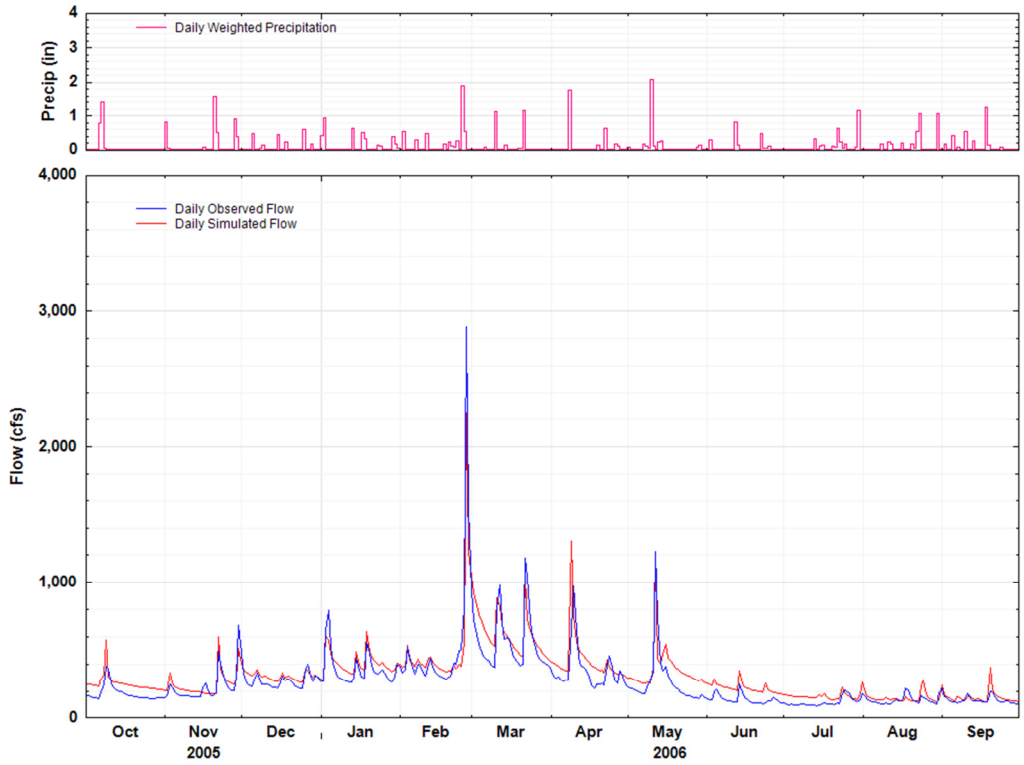

Figure 1.5 Flow in Upatoi Creek at McBride Bridge for the WY 2006.

The monthly flow volumes were also compared (Table 1.4, and Figure 1.6). The percent error in monthly flow volume was as high as 27% for June, and as low as -7% for February. In general, the flow was over-simulated in warmer months compared to colder months. Separate statistics were calculated for comparison of monthly and daily flow volumes (Table 1.5). The statistics improved from daily, to monthly volumes, which underscores the fact that it is difficult to calibrate to daily flow volumes. According to the model performance criteria specified in the Baseline Report, the model performance is good for daily flows and very good for monthly flows.

Table 1.4 Comparison of Simulated and Observed Average Monthly Flow Volume (in)

Month	Simulated	Observed	Residual	% Error
October	0.66	0.56	0.10	18.2
November	0.77	0.75	0.02	2.4
December	0.92	0.90	0.02	2.0
January	1.20	1.20	0.00	-0.4
February	1.60	1.72	-0.12	-6.7
March	2.66	2.65	0.00	0.2
April	1.95	1.69	0.27	15.7
May	1.00	0.85	0.15	18.0
June	0.91	0.72	0.20	27.4
July	1.08	0.93	0.16	16.8
August	0.92	0.79	0.13	16.9
September	0.75	0.67	0.08	12.7
Totals	14.42	13.42	1.01	7.5

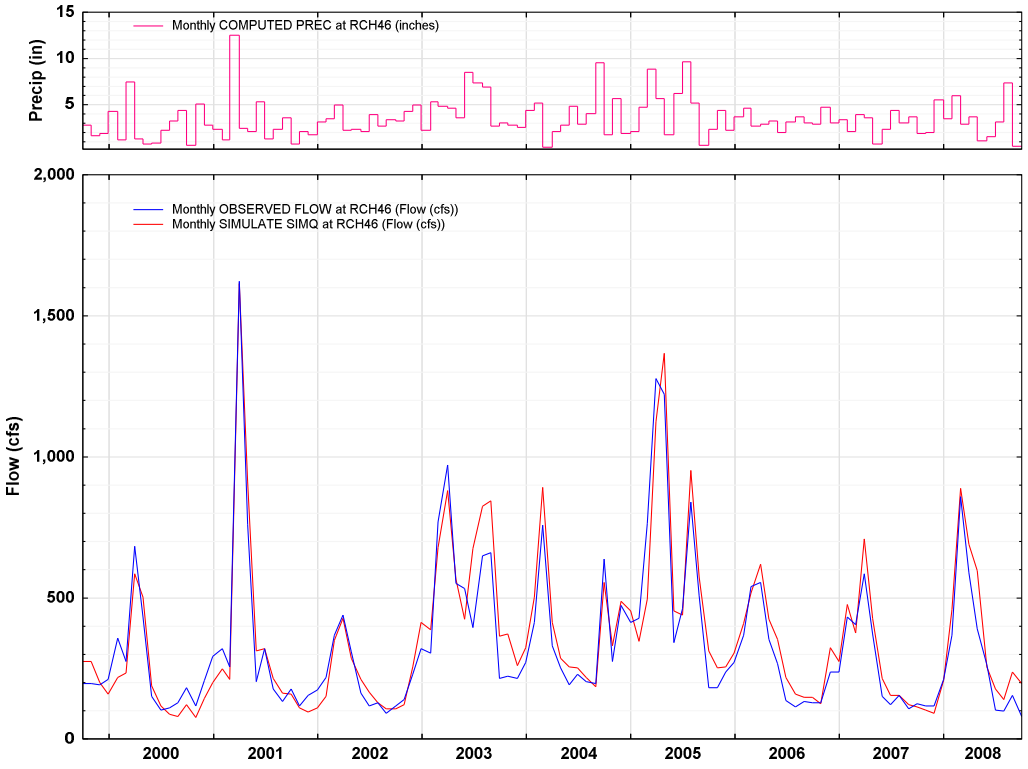

Figure 1.6 Monthly Flow Volume for the Calibration Period

Table 1.5 Monthly, and Daily Statistics of Flow Volume.

Statistics	Monthly	Daily
Correlation Coefficient	0.96	0.89
Coefficient of Determination	0.92	0.79
Mean Error (cfs)	24.9	25.2
Mean Absolute Error (cfs)	64.0	105.4
RMS Error (cfs)	83.5	211.8
Model Fit Efficiency	0.90	0.78

Hydrology calibration also requires comparing individual storm hydrographs. During the process of calibration, a set of well-defined storms is chosen for the entire period of calibration which represent storms in different seasons, and of different magnitudes. For the current calibration task, 66 individual storms were chosen during the calibration period. The expert system calculates several storm statistics, as illustrated in Table 1.1 and Table 1.2. The storm peaks and storm volumes were generally under simulated by smaller percentages; however, they were within the HSPEXP criteria. Each individual storm was plotted after the model run to compare the model performance for each individual storm. Some storms are illustrated in Figure 1.7, Figure 1.8 and Figure 1.9.

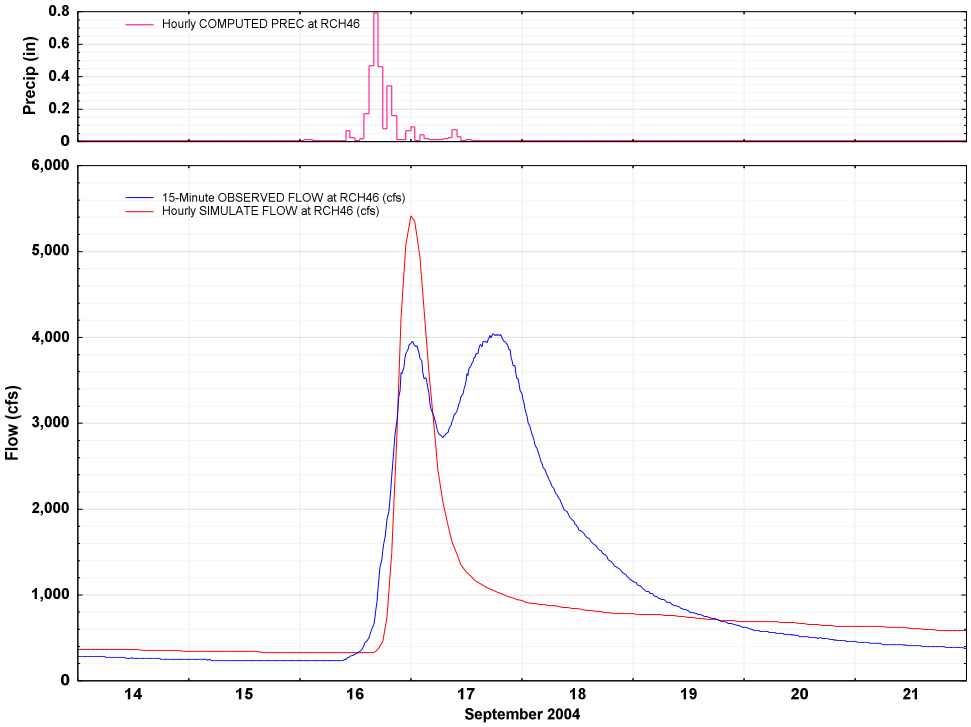

Figure 1.7 Hydrograph for a Storm in September 2004

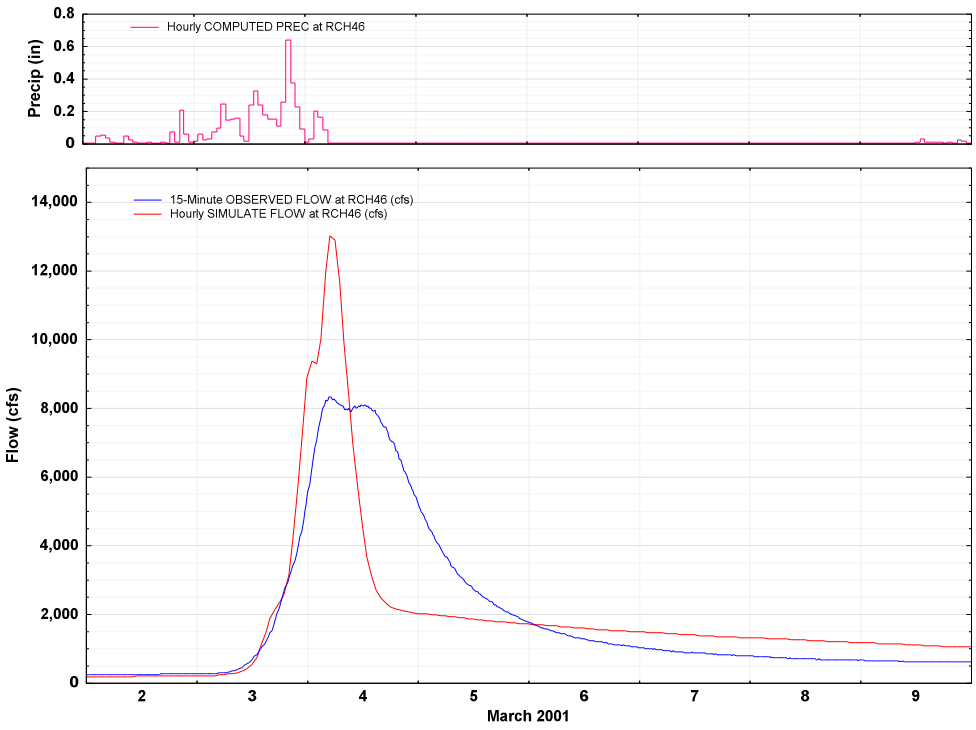

Figure 1.8 Hydrograph for a Storm in March 2001

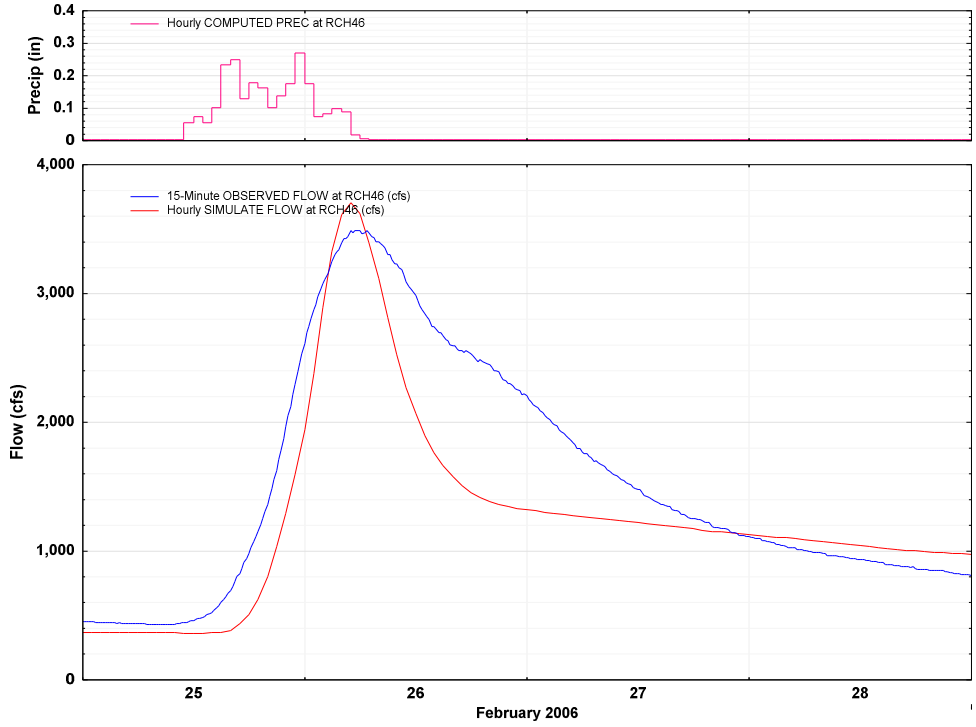

Figure 1.9 Hydrograph for a Storm in February 2006

In addition to all the comparisons conducted above, a comprehensive set of water balance components were reviewed at different locations in the watershed (Table 1.6) and by land use (Table 1.7) across the entire watershed. These values were a separate consistency check to ensure that the model represents a system that is closer to reality. At this stage, the model was considered reasonably calibrated as it performed satisfactorily on different flow statistics. Most HSPEXP criteria were also OK, as listed in Table 1.2. The model also performed reasonably well in different storms that were simulated during the calibration period. The water balance components in different parts of watershed appear to be reasonable and appropriate for the region.

Table 1.6 Water Balance Components at Different Locations in the Watershed

Location	N Upatoi Creek (R:614)		Pine Knot Creek (R:34)		Randall Creek (R:45)		Upatoi Creek at McB Bridge (R:46)		Upatoi Watershed (R:74)	
	in	ac-ft	in	ac-ft	in	ac-ft	in	ac-ft	in	ac-ft
Influx										
Rainfall	44.7	369,910	43.5	177,800	40.4	110,970	43.1	780,870	42.2	1,017,100
Runoff										
Surface-Pervious	0.9	7,712	1.0	4,006	0.7	1,934	0.9	16,354	0.9	20,605
Surface-Impervious	1.1	9,003	0.5	2,001	0.7	1,984	0.8	14,067	0.9	21,812
Interflow	4.1	33,563	3.7	15,082	3.2	8,842	3.7	66,976	3.5	83,522
Base flow	9.4	77,433	9.1	37,147	8.3	22,929	9.0	162,990	8.7	209,200
Total	15.4	127,710	14.3	58,237	13.0	35,690	14.4	260,390	13.9	335,140
GW Inflow										
Deep	0.4	3,352	0.4	1,600	0.4	997	0.4	7,057	0.4	9,063
Active	9.7	80,439	9.4	38,400	8.7	23,925	9.4	169,380	9.0	217,510
Evaporation										
Potential	38.5	318,700	38.5	157,470	38.5	105,900	38.5	697,640	38.5	928,220
Interception Storage	8.4	69,400	8.4	34,055	8.1	22,298	8.3	150,270	8.2	198,220
Upper Zone	10.8	89,540	11.2	45,692	10.6	29,147	10.8	196,270	10.6	256,420
Lower Zone	9.0	74,386	8.9	36,518	7.8	21,539	8.7	157,170	8.5	205,160
Ground Water	0.1	1,002	0.1	389	0.1	387	0.1	2,308	0.1	3,050
Base flow	0.4	3,037	0.4	1,477	0.4	964	0.4	6,531	0.4	8,498
Impervious	0.2	1,998	0.1	459	0.2	500	0.2	3,219	0.2	5,260
Total	28.9	239,250	28.9	118,210	27.0	74,380	28.4	514,330	28.0	673,970

Table 1.7 Water Balance Components by Land Use Category within the Fort Benning Watersheds

Land Use	Open Space	Low Intensity	Medium Intensity	High Intensity	Unburnt	Cycle 1	Cycle 2	Cycle 3	Unburnt	Cycle 1	Cycle 2	Cycle 3	Unburnt	Cycle 1	Cycle 2	Cycle 3	Shrub/ Scrub	Grass/ Herb	Ag/ Other	Paved Roads	Tank Trails	Heavy Maneuver	Unpaved Roads	Water/ Wetlands	Watershed Average
	Urban Cantonment				Evergreen Forest				Deciduous Forest				Mixed Forest							Military					
Influx																									
Rainfall	40.7	39.8	39.4	38.4	43.7	39.9	40.5	39.7	43.3	40.3	40.5	40.3	43.0	39.9	40.3	40.0	42.8	42.7	43.9	41.9	39.8	40.8	40.2	41.8	42.2
Irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Runoff																									
Surface	2.5	2.2	2.0	1.7	0.3	0.3	0.3	0.2	0.3	0.3	0.3	0.2	0.2	0.3	0.2	0.2	1.8	1.8	2.1	3.8	4.8	5.3	5.0	0.7	0.9
Interflow	1.3	1.2	1.1	1.1	4.4	4.6	4.0	3.4	4.4	4.8	4.1	3.7	4.1	4.6	3.5	3.5	2.6	2.7	3.1	1.8	1.5	1.5	1.5	0.8	3.6
Baseflow	8.7	8.7	8.6	8.3	8.8	8.5	8.0	7.3	9.0	8.7	8.2	7.7	8.7	8.6	7.5	7.5	9.1	9.1	9.6	10.5	8.1	8.2	8.1	11.8	8.9
Total	12.4	12.1	11.7	11.1	13.5	13.4	12.3	10.9	13.7	13.8	12.6	11.6	13.1	13.5	11.2	11.2	13.5	13.6	14.9	16.1	14.3	15.0	14.6	13.3	13.4
GW Inflow																									
Deep	0.4	0.4	0.4	0.3	0.4	0.4	0.3	0.3	0.4	0.4	0.4	0.3	0.4	0.4	0.3	0.3	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.6	0.4
Active	8.9	8.6	8.4	8.2	9.2	8.8	8.3	7.6	9.4	8.9	8.4	8.0	9.1	8.9	7.7	7.8	9.2	9.3	9.8	10.3	7.9	8.1	7.9	13.5	9.3
Total	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pumping	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Evaporation																									
Potential	38.5	38.5	38.5	38.5	38.5	38.5	38.5	38.5	38.5	38.5	38.5	38.5	38.5	38.5	38.5	38.5	38.5	38.5	38.5	38.5	38.5	38.5	38.5	38.5	38.5
Interception	7.2	7.1	7.2	7.2	10.0	9.2	9.3	9.2	8.7	8.7	8.6	8.6	9.4	8.8	8.9	8.8	7.9	7.2	6.8	5.4	3.3	3.3	3.3	9.1	8.5
Upper Zone	10.9	10.7	10.5	10.2	9.7	11.6	10.7	9.7	10.6	12.3	11.3	10.6	10.0	12.0	10.4	10.1	11.1	11.5	12.3	14.3	16.2	16.5	16.3	9.1	10.9
Lower Zone	9.6	9.6	9.7	9.8	9.7	5.3	8.0	9.7	9.5	5.1	7.6	9.2	9.8	5.3	9.7	9.6	9.7	9.8	9.2	5.9	5.9	5.8	5.8	7.4	8.7
Grnd Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.1
Baseflow	0.4	0.0	0.0	0.0	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.0	0.0	0.0	0.0	0.4	0.4
Total	28.1	27.5	27.4	27.1	29.9	26.1	27.9	28.6	29.2	26.0	27.6	28.4	29.5	26.0	28.9	28.5	29.1	28.9	28.7	25.6	25.3	25.7	25.5	28.0	28.5

SECTION 2
WATER QUALITY CALIBRATION PROCEDURES AND COMPARISONS

Water quality calibration is an iterative process, and the model predictions are the integrated result of all the assumptions used in developing the model input and in representing the modeled processes. Differences in model predictions and observations require the model user to re-evaluate these assumptions, in terms of both the estimated model input and parameters, and consider the accuracy and uncertainty in the observations. At the current time, water quality calibration is more an art than a science, especially for comprehensive simulations of nonpoint, point, and atmospheric sources, and their impacts on instream water quality.

The following steps were performed at each of the stations where the water quality data were available, following the hydrologic calibration and validation, and after the completion of input development for point source and atmospheric contributions:

1. Estimate all model parameters, including land use specific accumulation and depletion/removal rates, washoff rates, and subsurface concentrations
2. Tabulate, analyze, and compare simulated nonpoint loadings with expected range of nonpoint loadings from each land use and adjust loading parameters when necessary
3. Calibrate instream water temperature
4. Compare simulated and observed instream concentrations at each of the calibration stations
5. Compare annual nonpoint loading rates with expected values presented in available literature
6. Analyze the results of comparisons in steps 3, 4, and 5 to determine appropriate instream and/or nonpoint parameter adjustments

The essence of watershed water quality calibration is to obtain acceptable agreement of observed and simulated concentrations (i.e. within defined criteria or targets), while maintaining the instream water quality parameters within physically realistic bounds, and the nonpoint loading rates within the expected ranges from the literature. The nonpoint loading rates, sometimes referred to as 'export coefficients' are highly variable, with value ranges sometimes up to an order of magnitude, depending on local and site conditions of soils, slopes, topography, climate, etc.

The main goal of water quality calibration is to obtain acceptable agreement of observed and simulated concentrations, while maintaining the instream water quality parameters and processes within physically realistic bounds, and the nonpoint loading rates within the expected ranges from the literature or based on local experience and guidelines. The use of target nonpoint source loading rates is useful because the water quality concentrations measured at a particular location reflect the combined effects of contributions from multiple land uses, point sources, and instream processes. The loading rates of different water quality constituents were compiled before the start of the water quality calibration process; the loading rate for sediment are discussed below, while those for each constituent are included individually in the original Baseline Model Report (AQUA TERRA Consultants, 2010).

2.1 SEDIMENT

Sediment calibration follows hydrology calibration and precedes calibration of other water quality constituents. Calibration of the parameters involved in sediment erosion simulation is more uncertain than hydrology simulation due to less experience with sediment simulation in different regions of the country (Donigian and Love, 2003). Sediment calibration for watershed involves numerous steps in estimating model parameters, then determining appropriate adjustments needed to ensure a reasonable simulation of the sediment sources, delivery, and transport behavior within the channel system. As described in Donigian and Love (2003), these steps are:

1. Estimating target (or expected) sediment loading rates from the landscape, often as a function of topography, land use, and management practices
2. Calibrating the model loading rates to the target rates
3. Adjusting scour, deposition and transport parameters for the stream channel to mimic expected behavior of the streams/waterbodies.
4. Analyzing sediment bed behavior (i.e. bed depths) and transport in each channel reach as compared to field observations
5. Analyzing overall sediment budgets for the land and stream contributions, along with stream aggrading and degrading behavior throughout the stream network
6. Comparing simulated and observed sediment concentrations, including particle size distribution information, and load information where available
7. Repeating steps 1 through 6 as needed to develop a reasonable overall representation of sediment sources, delivery, and transport throughout the watershed system

For the purpose of watershed modeling, sediment loadings to stream channels are estimated by land use category from literature data, local Extension Service sources, or by utilizing procedures such as the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) and adjusted for delivery to the streams with estimated sediment delivery ratios (SDRS). The delivery adjustment is needed because HSPF, like most watershed-scale (lumped parameter) models, represents landscape loadings to the stream channel, which are less than the field-scale estimates from USLE. These loading rates become 'calibration targets' for the watershed model. In Fort Benning, we used a form of the USLE to obtain preliminary sediment calibration targets for different land uses adjusted by the sediment delivery ratio (Table 2.1).

Table 2.1 Sediment Calibration Target (t/ac/yr) for Different Land Uses.

Land Use	Calibration target
Urban/Cantonment Open Space	0.2-0.3
Urban/Cantonment Low Intensity	0.2-0.3
Urban/Cantonment Medium Intensity	0.3-0.4
Urban/Cantonment High Intensity	0.4-0.5
Evergreen Forest	0.10
Deciduous Forest	0.11
Mixed Forest	0.09
Shrub/Scrub	0.17
Grassland/Herbaceous	0.16
Agriculture/Other	1-3
Paved Roads	0.20

Land Use	Calibration target
Tank Trails*	1.25-5.0
Heavy Maneuver Areas*	2.5-7.5
Unpaved Roads*	0.5-5
Water/Wetlands	0.01

*These estimates were obtained by literature review (AQUA TERRA Consultants, 2009), and consider a sediment delivery ratio of 0.25.

The military land uses (Tank Trails, Heavy Maneuver Areas, and Unpaved Roads) were assigned sediment load targets based upon literature reviews (AQUA TERRA Consultants, 2009), and a sediment delivery ratio (SDR) of 0.25. To calculate SDR of these land uses, mean subwatershed area of the watersheds in the Fort Benning installation boundary was used. The mean area of subwatersheds inside Fort Benning is 3.4 sq. mi. which corresponds to a SDR of 0.25, according to the relationship among SDR and drainage area (USDA-NRCS, 1983).

In HSPF, the erosion process on pervious land areas is represented as the net result of detachment of soil particles by raindrop impact on the land surface, and then subsequent transport of these fine particles by overland flow. On impervious surfaces (e.g. parking lots, driveways), soil splash by raindrop impact is neglected and solids washoff is often controlled by the rate of accumulation of solid materials. The primary sediment erosion solids parameters are as follows:

KRER	-	Coefficient in soil detachment equation (pervious areas)
KSER	-	Coefficient in sediment washoff equation (pervious areas)
KEIM	-	Coefficient in impervious area solids washoff equation
ACCSDP	-	Accumulation rate of solids on impervious surfaces

Although a number of additional parameters are involved in sediment erosion and solids simulation, such as those related to vegetal cover, agricultural practices, rainfall and overland flow intensity, etc., KRER and KSER are the primary calibration parameters controlling sediment loading rates. KRER is usually estimated as equal to the erodibility factor, K, in the USLE, and then adjusted in calibration, while KSER is primarily evaluated through calibration and past experience. For impervious surfaces, the rate of washoff is controlled by the KEIM parameter, but the net washoff is most often limited by the accumulation rate, ACCSDP. Sediment erosion calibration is further described in the BASINS Technical Note #8 (USEPA, 2006), the HSPF Application Guide (Donigian et al., 1984), and by Donigian and Love (2003).

Table 2.2 shows the average calibrated washoff (t/ac/yr) for each land use for the Upatoi watershed. As part of the calibration of military and agriculture land uses, the sediment storage in these categories was reset at the start of each month to reflect the conditions of disturbance of the land surface by military activities and agricultural practices. This was needed to provide sufficient sediment fine material produced by these activities, so that enough sediment is available for erosion when runoff occurs. The erosion parameters were adjusted until the average washoff from these land uses matched with the target loads within a reasonable tolerance. The washoff loading rates and percent of total load was also calculated at different locations in the watershed, as shown in Table 2.3. This allowed a calculation of the percent contribution of the total sediment load derived from military sources, and demonstrates how it changes throughout the Upatoi Watershed. As shown in Table 2.3, the highlighted row for 'military land uses' shows that the military contribution increases from about 7% at the upper Upatoi site (R:614) near the upper extremity of the Installation, to about 27% at the McBride

Bridge USGS gage, to about 33% at the outlet. The modeled sediment loading rates are consistent with the available targets, demonstrate a sound variation with land use and spatial variations in watershed characteristics, and provide appropriate ranges for the climate, soils, and land use conditions in the Fort Benning watershed.

Table 2.2 Calibrated Sediment Erosion Rates from Each Land Use and Their Contribution in Overall Sediment Erosion in the Upatoi Watershed

Land Use	Washoff (tons/acre/year)	Percent of Total Load	Aggregated Land Use	Total Percent
Urban /Cantonment Open Space	0.17	2.0		
Urban /Cantonment Low Intensity	0.19	0.8		
Urban /Cantonment Medium Intensity	0.27	0.2		
Urban /Cantonment High Intensity	0.27	0.1	Urban	3.1
Evergreen Forest	0.07	5.2		
Evergreen Forest _Cycle 1	0.09	0.9		
Evergreen Forest _Cycle 2	0.07	0.7		
Evergreen Forest _Cycle 3	0.07	1.0		
Deciduous Forest	0.08	7.0		
Deciduous Forest_Cycle 1	0.10	2.2		
Deciduous Forest_Cycle 2	0.09	1.5		
Deciduous Forest_Cycle 3	0.08	1.2		
Mixed Forest	0.07	1.2		
Mixed Forest_Cycle 1	0.10	1.0		
Mixed Forest_Cycle 2	0.08	0.5		
Mixed Forest_Cycle 3	0.07	0.5	Forests	22.9
Shrub/Scrub	0.14	1.4	Shrub/Scrub	1.4
Grass/Herb	0.17	6.4	Grass/Herb	6.4
Ag/Other	1.07	30.7	Ag/Other	30.7
Paved Roads	0.16	0.3	Paved Roads	0.3
Tank Trails	1.87	0.6		
Heavy Maneuver	2.42	8.6		
Unpaved Roads	1.72	23.5	Military	32.7
Water/Wetlands	0.00	0.0	Water/Wetlands	0.0
Average for Pervious Areas	0.22	97.3		
Impervious Area	0.22	2.7		
Total		100.0		

Table 2.3 Loading Rates and Percent Contribution of Eroded Sediment from Different Aggregated Land Uses at Different Locations in the Watershed

Aggregated Land Use	R:614 (North Upatoi Creek)		R:34 (Pine Knot Creek)		R:36 (Upatoi Creek)		R:45 (Randall Creek)		R:46 (Upatoi Creek at McBride Bridge)		R:74 (Upatoi Creek at Outlet)	
	t/ac/yr	%	t/ac/yr	%	t/ac/yr	%	t/ac/yr	%	t/ac/yr	%	t/ac/yr	%
Urban	0.27	2.4	0.21	1.6	0.24	2.1	0.16	3.5	0.22	2.2	0.18	3.0
Forest	0.09	24.5	0.07	18.6	0.08	21.9	0.05	21.6	0.08	21.9	0.08	22.9
Shrub/Scrub	0.17	1.8	0.14	1.9	0.15	1.6	0.07	0.6	0.14	1.5	0.14	1.4
Grass/Herb	0.20	7.5	0.16	8.1	0.18	7.8	0.11	3.4	0.18	7.3	0.17	6.4
Ag/Other	1.21	53.3	1.12	27.5	0.20	40.5	0.46	13.7	1.11	37.4	1.07	30.7
Paved Roads	0.20	0.4	0.17	0.2	2.07	0.3	0.13	0.3	0.18	0.3	0.16	0.3
Military Uses	2.76	7.3	2.48	41.1	2.10	23.8	1.79	54.1	2.00	27.3	1.87	32.7

Following the calibration of sediment loading rates, the sediment calibration was focused on the channel processes of scour, deposition, and transport in HSPF SEDTRN that determine both the sediment load and the outflow sediment concentrations to be compared with the observations. In practice, instream calibration involves steps 3, 4 and 5 as listed and discussed above; these steps involve both parameterization, to establish initial parameter values, and a subsequent adjustment and calibration process. For HSPF, the initial parameterization tasks include the following:

- Divide input sediment loads into appropriate size fractions
- Estimate initial parameter values and storages for all reaches
- Run HSPF to calculate shear stress in each reach to estimate critical scour and deposition values

Although the sediment load from the land surface is calculated in HSPF as a total input, it must be divided into sand, silt, and clay fractions for simulation of instream processes. Each sediment size fraction is simulated separately, and storages of each size are maintained for both the water column (i.e., suspended sediment) and the bed. The sediment load from the watershed land surface was assumed to consist of 5% sand, 55% silt, and 40% clay, reflecting the enrichment of fine materials (silts and clays) compared to surface soil textures on the watershed, as the coarser sand particles deposit during transport on the overland flow pathway.

The initial sediment parameters in the RCHRES section, such as particle diameter, particle density, settling velocity, bed depth and composition, and beginning calibration parameter values can be initially estimated from local/regional data, past experience, handbook values, etc., (see BASINS Tech Note #8, U.S. EPA, 2006) and then selected values are adjusted based on available data and calibration. Bed composition data are especially important so that the model results can be adjusted to reflect localized aggradations (deposition) or degradation (scour) conditions within the stream system. At Fort Benning, bed composition data were available at selected locations as shown in Table 2.4. This information was extrapolated to all remaining reaches in the watershed. Standard literature values were used for particle diameter (Sand - 0.005 in, Silt – 0.004 in, Clay – 0.001 in), settling velocity (Sand – 0.02 in/s, Silt – 0.0003 in/s, Clay – 0.00001 in/s), and particle density (Sand – 2.5 g/cm^3, Silt – 2.2 g/cm^3, Clay – 2 g/cm^3) for all the reaches. These values were based on previous sediment modeling experience with HSPF and the guidance available from the BASINS Tech Note #8 (U.S. EPA, 2006).

Table 2.4 Bed Composition Data Collected in April 2008 at Several Locations in the Fort Benning Watershed

	Average		
	% Sand	% Silt	% Clay
Bonham Creek	97.6	1.1	1.4
East Pine Knot	94.2	3.4	2.4
McBride Bridge	96.9	2.0	1.1
N Randall	86.2	8.1	5.4
N Upatoi	99.5	0.3	0.2
Ochillee Creek	92.3	3.8	3.9
South Randall	99.6	0.2	0.2
Sally Branch	97.2	1.2	1.6
Tar River	97.3	1.3	1.3
Tiger Creek	97.7	1.2	1.1
West Pine Knot	95.1	3.1	1.8

In HSPF, the transport of the sand (non-cohesive) fraction is commonly calculated as a power function of the average velocity in the channel reach in each timestep. This transport capacity is compared to the available inflow and storage of sand particles; the bed is scoured if there is excess capacity to be satisfied, and sand is deposited if the transport capacity is less than the available sand in suspension within the channel reach.

For the silt and clay (cohesive) fractions, shear stress calculations are performed by the hydraulics (HYDR) module, and then in the SEDTRN module they are compared to user-defined critical, or threshold, values for deposition and scour for each size (shown in Figure 2.1). When the shear stress for a timestep is greater than the critical value for scour, the bed is scoured at a user-defined erodibility rate and transport through the reach occurs; when the shear stress is less than the critical deposition value, the silt or clay fraction deposits at a settling rate input by the user for each size. If the shear stress falls between the critical scour and deposition values, the incoming suspended material is transported through the reach.

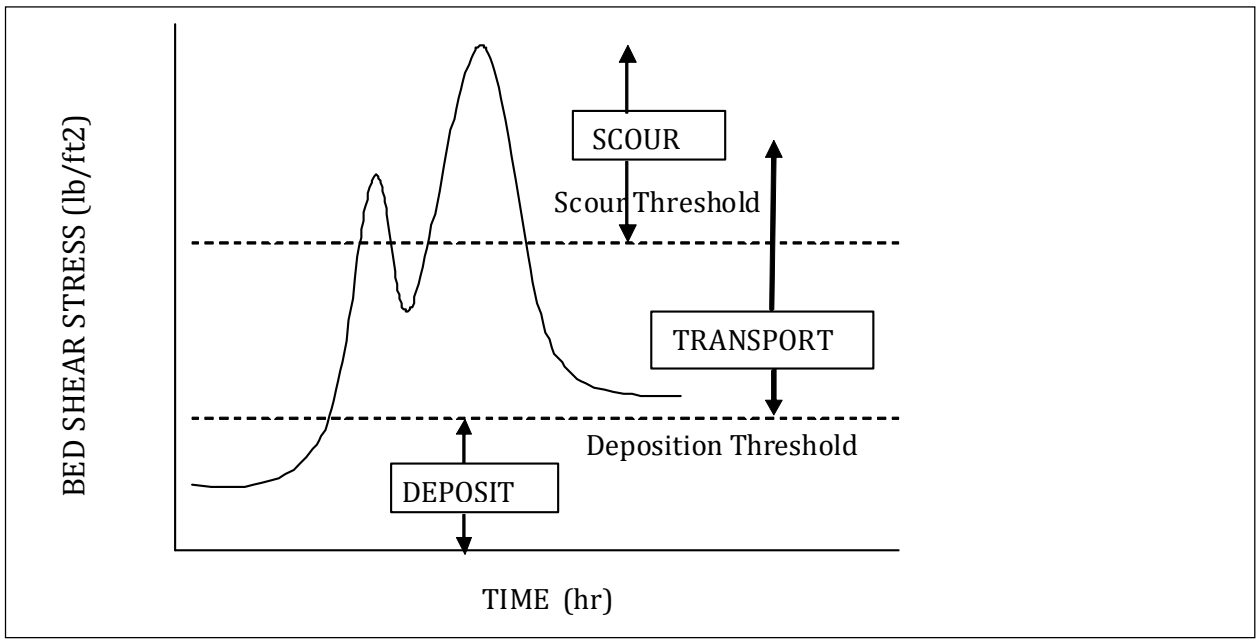

Figure 2.1 Shear Stress Algorithm for Silt and Clay Fractions in HSPF

As part of the sediment parameterization, the model was run with the initial parameter estimates and shear stress values were output for each stream reach. For the silt and clay size particles, the critical shear stress parameters (one for scour and one for deposition) for each size were adjusted so that the model calculates scour during high flow events, deposition and settling during low flow periods, and transport with neither scour nor settling for moderate flow rates. This adjustment process is repeated multiple times to ensure that stream beds are relatively stable for the calibration period. During high flow periods, the amount of scour was adjusted with changes to the bed erodibility factor for each reach that controls the rate of scour whenever the actual shear stress is greater than the critical shear stress value for scour. The sediment balance of selected reaches for the entire calibration period is illustrated in Table 2.5; this information is reviewed for all the reaches to ensure and confirm a reasonable bed and sediment load simulation.

Table 2.5 Sediment Balance of Major Streams in Fort Benning Watersheds (tons/yr)

Reach Segment	Nonpoint	Upstream Input	Outflow	Deposit-Scour	Cumulative Total	Cumulative Trapping (%)	Reach Trapping (%)
R:614 - Upatoi Cr. - Upper	0	8,876	8,747	129	10,148	13.8	1.5
R:34 - Pine Knot Cr.	56	4,648	5,053	-349	5,205	2.9	-7.4
R:36 - Upatoi Cr. - Middle	299	16,535	16,409	426	18,890	13.1	2.5
R:45 - Randall Cr.	576	2,104	2,600	80	2,550	-20.	3
R:46 - Upatoi Cr. - USGS	86	19,010	18,983	114	21,526	11.8	0.6
R:74 - Upatoi Cr.- Outlet	243	24,949	25,368	-176	27,464	7.6	-0.7

Following the calibration of sediment loading rates from all the land uses, and the sediment balance from all the streams, the TSS concentration was matched with the observed data at several locations where the data was available for a limited number of storm events (Figures 2.2 - 2.6). At most of the locations except Upatoi Creek at McBride Bridge (RCH46), flow data was not available severely restricting the calibration process. In fact, the lack of flow data and minimal sediment data for only a few storm events are the major limitations that should be addressed in any future modeling efforts at Fort Benning (see Section 7: Conclusions, Recommendations, and Lessons Learned).

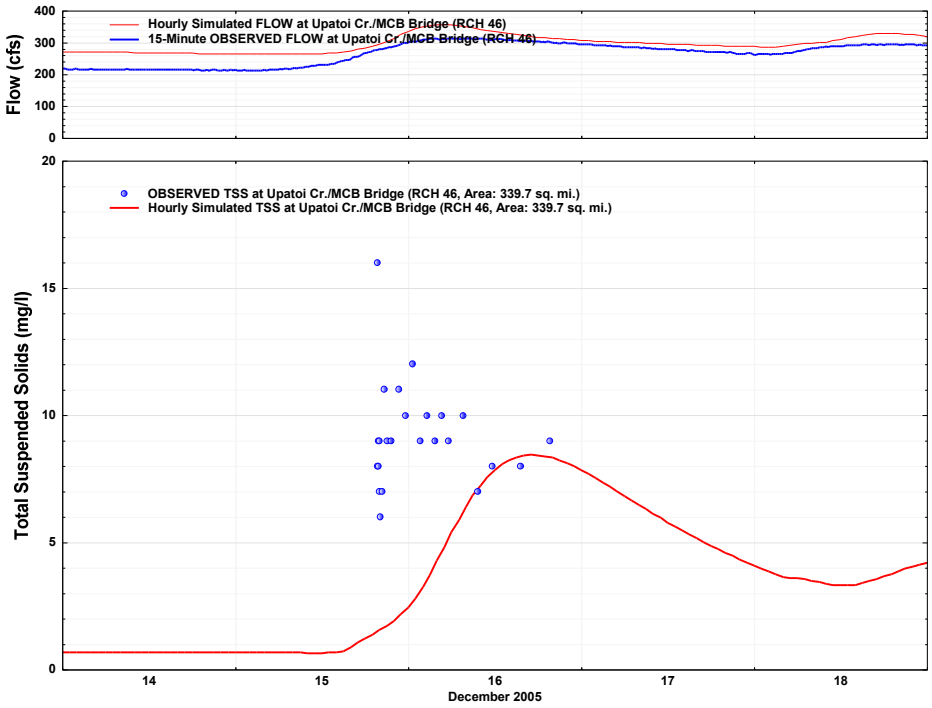

Figure 2.2 Observed and Simulated Total Suspended Solids (mg/l) at Upatoi Creek in December 2005

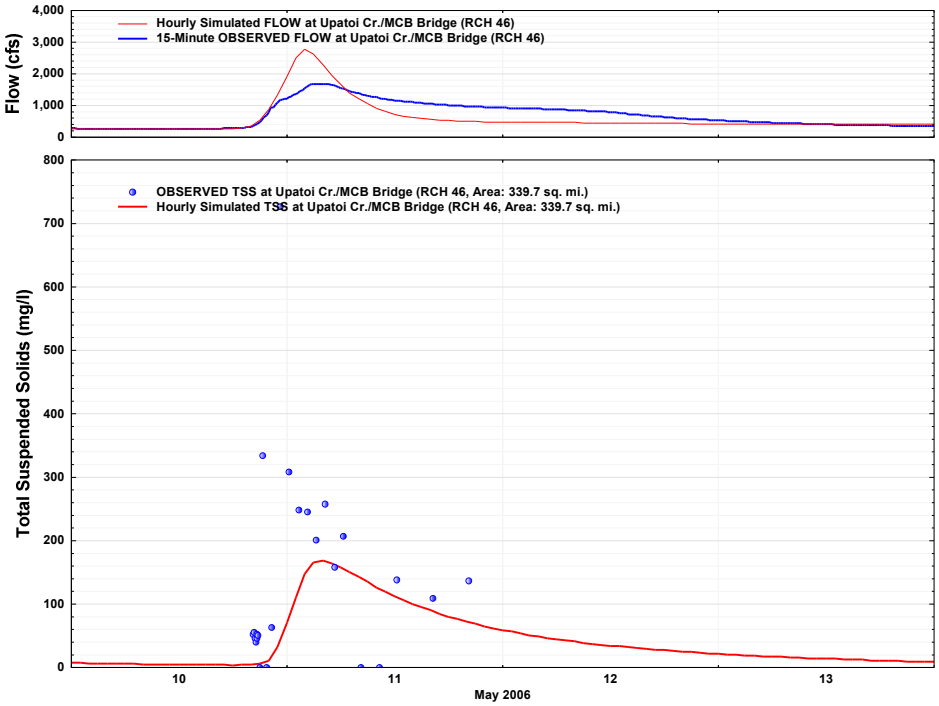

Figure 2.3 Observed and Simulated Total Suspended Solids (mg/l) at Upatoi Creek in May 2006

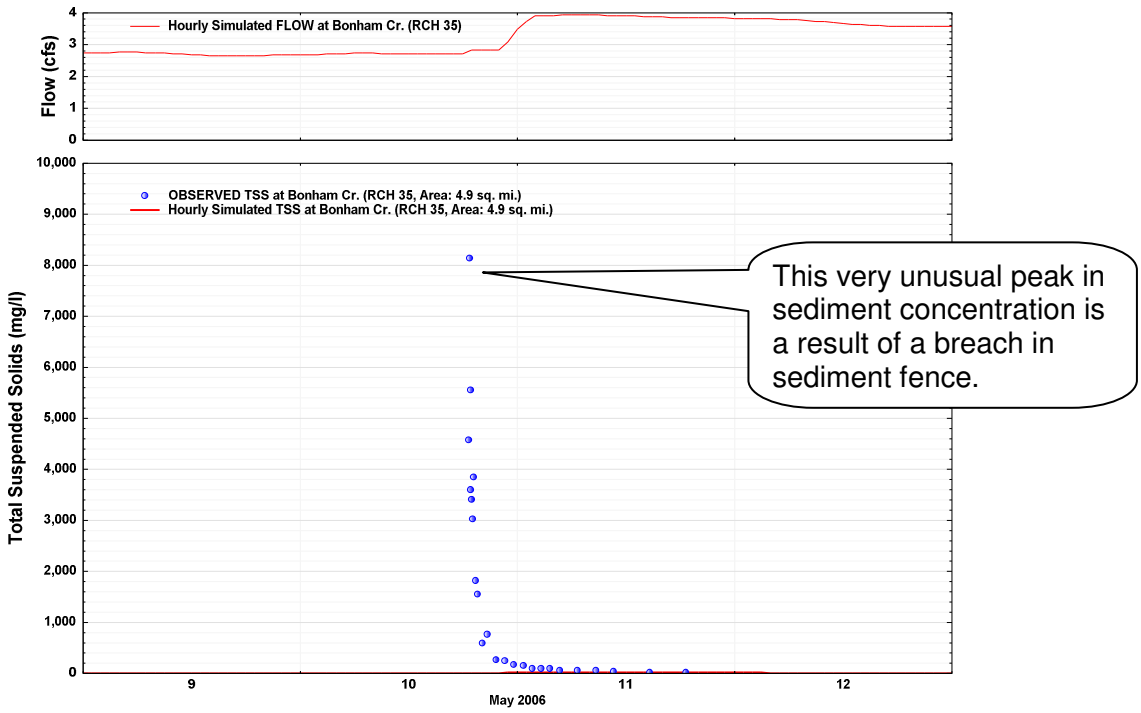

Figure 2.4 Observed and Simulated Total Suspended Solids (mg/l) at Bonham Creek in May 2006

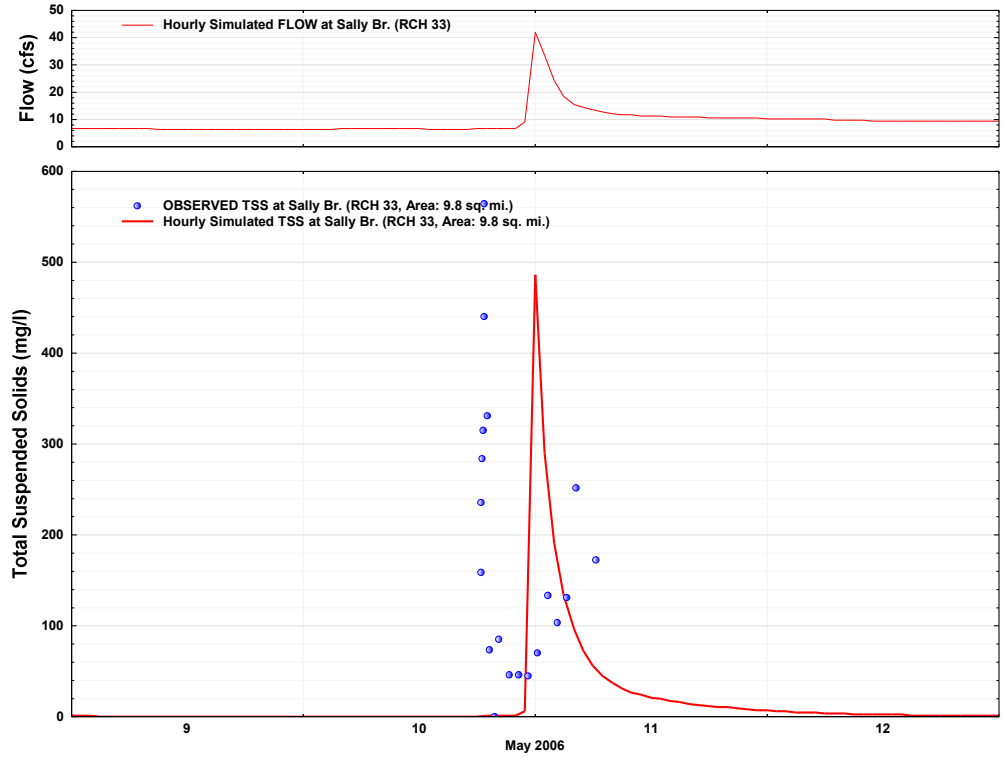

Figure 2.5 Observed and Simulated Total Suspended Solids (mg/l) at Sally Branch in April 2006

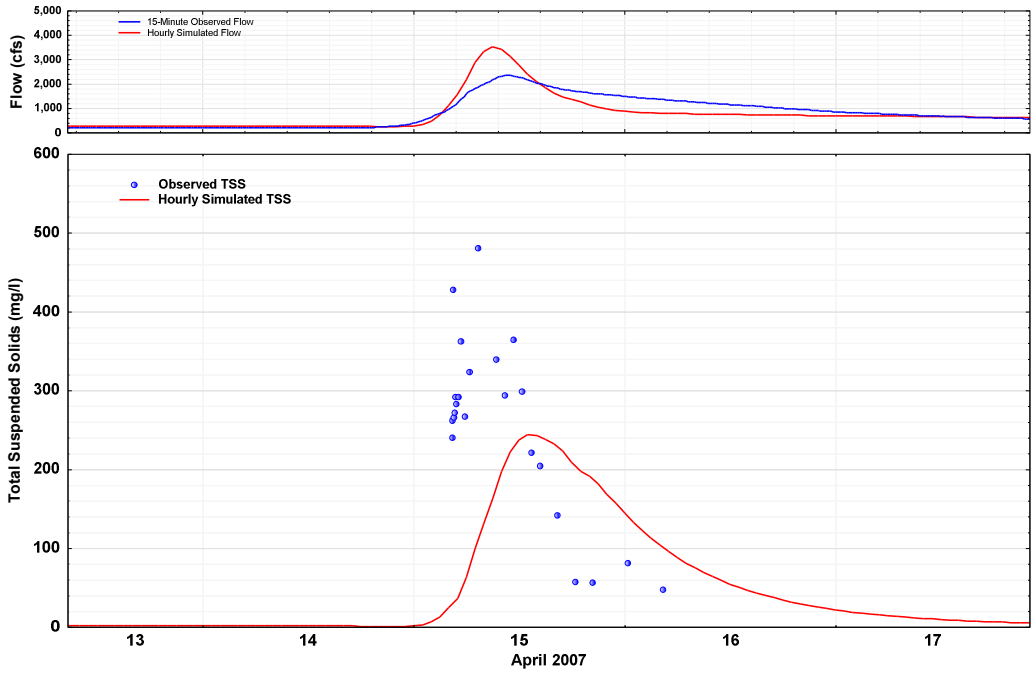

Figure 2.6 Observed and Simulated Total Suspended Solids (mg/l) at Upatoi Creek in April 2007

The simulated sediment concentrations are an adequate representation of the dynamic nature of the observations, but the agreement across both small and large storms is not universally good; improvements are needed. In truth, only a few storms had sufficient data on both flow and sediment/TSS concentrations to provide a sound basis for calibration. Additional data was available at a number of tributary sites, but no flow data was available so there is very little basis on which to assess the accuracy of the sediment simulation at those sites. Some smaller storms showed good agreement, but many larger storms either had no data or the sediment concentrations were under-simulated (e. g. Figures 2.3 and 2.6).

As illustrated in Figures 2.3 and 2.6, the storm flows were also over-simulated during May 2006 and April 2007, and therefore simulated sediment concentration reduced. However, the May 2006 storm is especially interesting at Bonham Creek (see Figure 2.4), where the observed concentrations reached as high as 9000 mg/l, which is exceptionally high, especially for a relatively small runoff event, and this level of sediment concentration is rarely seen in most stream systems. The fact that the flow only had a slight increase of about 1 cfs raised some suspicions about this event. Due to these extreme sediment concentration values, we further investigated this storm event, and the following comment was received from Fort Benning (Personal communication, Mr. George Williams, Watershed Management Program, Fort Benning, GA.)

> *"After an approximate .25 of rainfall this afternoon a flow traveling down Trail 1 was observed carrying sediment into Bonham creek causing it to appear cloudy at the time of inspection. This flow enters Trail 1 near STA 14+00 and appears to originate from ground water which then flows Southward down the East side of Trail 1 before flowing through* ***an opening*** *in the installed SD1-Bb just North of the crossing before entering Bonham Creek. This flow has remained constant since the contractor began grading in this area and is not shown on the original drawings."*
>
> *Note: SD1-Bb refers to a brush barrier. These are essentially piles of logging debris that are used as BMPs to check velocities and trap sediments. These work best when installed parallel to the slope, however, in many cases on the DMPRC they were perpendicular to the slope and had the tendency to concentrate flows and create problems.*

Thus, failure of a sediment BMP appears to be the primary cause for the extreme concentrations observed in Bonham creek for this event.

2.2 SEDIMENT CONTRIBUTIONS FROM INSIDE AND OUTSIDE FORT BENNING

One of the concerns of the Installation management relates to how much sediment is generated from within the Installation boundary versus how much comes onto the Installation from lands outside its boundary. This basically determines the extent to which the Installation is responsible for control and mediation of sediment loads that may lead to aquatic impacts and impairments.

As shown in Figures 1.1 and 1.2 (Section 1), a number of streams traverse the Installation boundary, including the major streams of Randall, Juniper, Pine Knot, Ochillee, and a number of smaller streams. Each carries sediment loads that may originate from outside the Installation boundary, and thus from non-military lands. Systematically calculating the sediment load exiting each reach end points that crosses the boundary, and summing up those loads and dividing by the total load from the watershed outlet allows us to partition the contributions from the Installation versus those from outside the Installation. Table 2.6 shows that the Installation

contribution for various tributaries, at McBride Bridge, at the Upatoi Creek watershed outlet, and at Hichitee Creek. This analysis shows that for the sediment load at the Upatoi outlet about 49% originates from within the Installation and 51% from outside; whereas at McBride Bridge, about 62% originates from outside the Installation with the balance of 38% from within. Also, about 19% of the sediment load of Hichitee Creek that directly flows into the Chattahoochee River (Non-Upatoi model) is contributed by land areas inside the Installation.

Table 2.6 Sediment Loading per Year and Percent Contribution of Eroded Sediment from inside Base versus outside the Base.

	R:45 (Randall Creek)	R:34 (Pine Knot Creek)	R:46 (Upatoi Creek at McBride Bridge)	R:74 (Upatoi Creek at Outlet)	R:206 (Hichitee Creek)
Total Sediment Load (t/yr)	2,600	5,053	18,983	25,368	1.924
Percent Contribution from the Installation	73.3	55.3	38.0	48.7	19.3
Percent Contribution from outside the Installation	26.7	44.7	62.0	51.3	80.7

2.3 CLOSURE ON SEDIMENT SIMULATION

The Enhanced Baseline Model is definitely an improvement over the previous Baseline Model developed as the initial BASINS/HSPF application to the Fort Benning Watersheds. The model results have been improved compared to the Baseline model results, but the improvements have been marginal in terms of detailed simulation results and the comparisons with the limited observed data. The real improvement is in the representation of the processes and the practices on Fort Benning provided by the multi-level canopy representation and its use to mimic the prescribed burning practices, the improvements in the FTABLES with the additional USGS rating curve data, and the refined sediment load estimates provide by the WEPP:Road hybrid modeling component.

In spite of these improvements, the resulting sediment simulation can only be described as an adequate representation of the dynamic sediment behavior on the watersheds, largely due to the very limited, concurrent flow and sediment data available for calibration. Consequently, the primary recommendation from this work is to take full advantage of the additional USGS flow data collected in 2008-2011, extend the simulation for that period, and perform calibration efforts at multiple sites across the watershed to improve the overall model performance. In addition, plans for collecting sediment data in the Good Hope area may also provide an opportunity to extend the calibration efforts to include that data.

SECTION 3
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December 2012

A Watershed Modeling System for Fort Benning, GA Using the US EPA BASINS Framework

SERDP PROJECT SI-1547

CHANNEL SEDIMENT ENHANCEMENTS

Final Report
Appendix D

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SECTION 1
INTRODUCTION

Observations have identified the vulnerability of the stream banks within the portion of the Upatoi Creek watershed within Fort Benning, GA to erosion and failure under both wet and dry weather conditions. Wet weather bank erosion can occur due to several water-driven phenomena on top of or within the bank materials (e.g., rotational or planar failure) or within the stream channel (e.g., scour of the bank toe). Dry weather bank/gully destabilization can occur due to tracked vehicular travel during training activities. Representing the additional stream load caused by these sediment-generating phenomena requires improved algorithms for bank erosion and sloughing, as well as instream sediment erosion and deposition of multiple size classes of sediment. The effectiveness of these enhancements can be heightened by using an enhanced flow model that is linked to HSPF; these enhancements will provide a flow model that is able to more accurately simulate the dynamic nature of flows within the Upatoi Creek watershed during flashy runoff events, including out-of-bank flow events. The enhanced flow model would yield a more accurate calculation of the spatial variation in stream velocities and flow-induced bed shear stresses. The latter are used in predicting 1) the erosion rates of sediment in the surface layer of the sediment bed, and 2) the deposition rates of suspended sediment.

Representing bank erosion in watershed-scale models is at this point in time a research topic, and little exists in terms of methods or useful results. Figure 1.1 shows the four most common modes of bank failure. Even the most advanced bank failure model is not able to represent all four of these failure modes. First generation mechanistic models that represent bank erosion have been developed, for example by Osman and Thorne (1988) and the ARS CONCEPTS/Bank Stability and Toe Erosion Model. The complexity and extensive data requirements of these mechanistic models would seem to preclude their incorporation in the Fort Benning HSPF model. Advantages and disadvantages of both mechanistic and simpler, e.g., empirical, bank erosion models are given in

Table 1.1.

Currently the Fort Benning HSPF watershed model lacks a method for representing the generation of sediment loads due to events of bank erosion/failure. This is an extremely important mechanism that needs to be represented, especially in incised streams and rivers that are prevalent in Piedmont physiographic regions as eroding/failing banks are often significant non-point sources of sediment to these waters (Simon et al., 1999). Further, once the sediment loads from landscape and bank erosion are introduced into the Fort Benning stream channels, the need exists to improve the model's capability to represent sediment transport during both low and high flow events.

Appropriate representation of high flow events is particularly critical to sediment transport simulations. Improved flow modeling capabilities provide the starting point for satisfying a third need for improvement: the ability to better represent channel scour and deposition by incorporating improved algorithms. One of the important benefits of these improved formulations is to enable the modeling of multiple size classes of non-cohesive sediment, a capability that the model currently lacks. Adding this capability will enable the simulation of bed armoring of both cohesive and non-cohesive dominated sediment beds. The ability to represent bed coarsening and subsequent armoring is crucial in simulating sediment transport during high flow events. If the simulated sediment bed is not capable of armoring, then excessive (i.e., unrealistic) scour may be predicted.

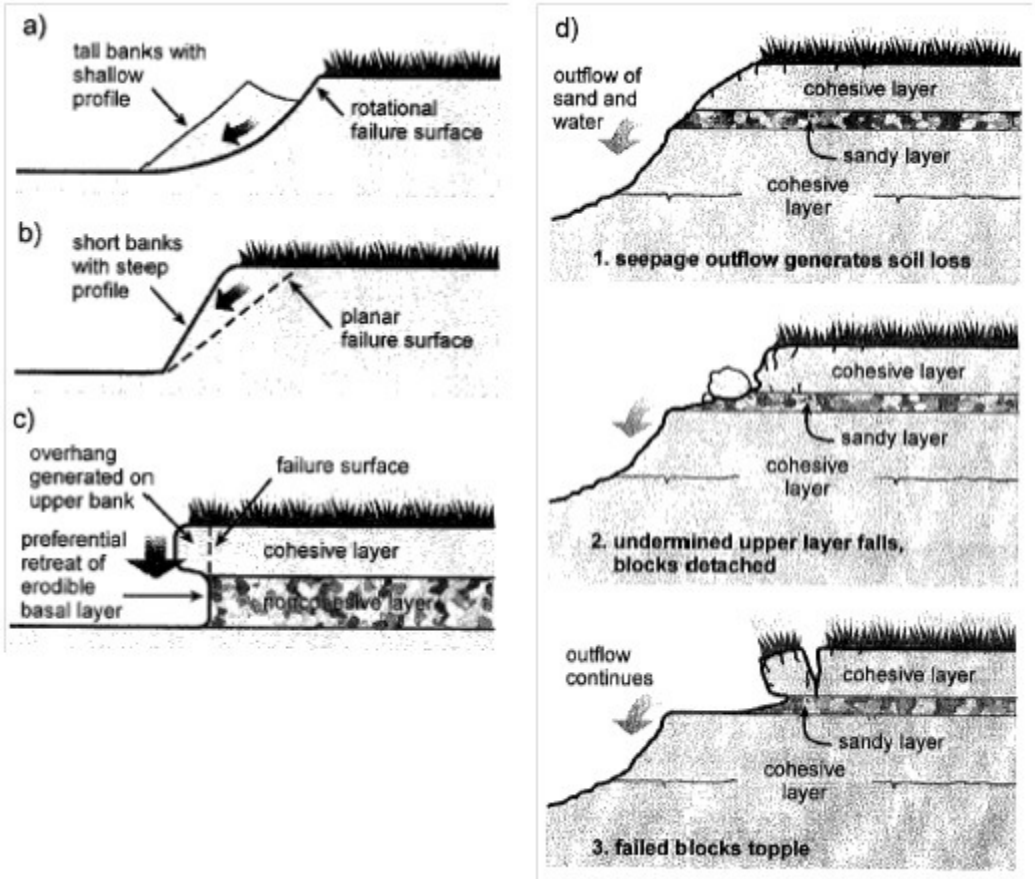

Figure 1.1 Bank Failure Mechanisms

Table 1.1 Advantages and Disadvantages of Bank Erosion Models

	Advantages	Disadvantages
Empirical Bank Erosion Model	Simple model to develop and apply Shown to be a useful model for predicting bank erosion on reach-scale portions of rivers Model is calibrated using site-specific bank erosion data	Non-mechanistic approach • Uncertain reliability outside calibration range Captures reach-scale bank erosion processes • May not adequately represent local-scale erosion processes Dependent on erosion rate data for calibration • Limited data may introduce uncertainty into model results
Mechanistic Bank Erosion Model	Sophisticated model that incorporates various processes such as toe erosion and bank failure (i.e., mass wasting) May be more reliable than an empirical model outside calibration range	Requires relatively large amount of site-specific data Calibration process is unclear Model utility, as demonstrated by predicted-observed comparisons, is unknown

SECTION 2
BACKGROUND

Imhoff et al. (2003) performed an evaluation of contaminated sediment transport models for EPA, and identified the following capabilities of the sediment transport model in BASINS and HSPF (HSPF-RCHRES):

- Ability to simulate the transport of three different sediment classes, i.e., clay, silt, and sand.
- Settling, deposition, and resuspension rates of sediment are computed internally, as opposed to these rates being provided as input parameters.

The identified limitations of HSPF-RCHRES are the following:

- The sediment transport formulations used in HSPF-RCHRES are based on equations given in scientific literature published during the 1960s and 1970s.
- Bedload transport of non-cohesive sediment is not represented.
- The resuspension and deposition rates are not calculated as a function of the bed shear stress.
- A flow routing routine is used in HSPF to simulate stream hydraulics and not a hydrodynamic model that solves the conservation of mass and non-linear linear momentum equations. As such, HSPF is only capable of simulating uni-directional gradually varied open channel flow. In addition, the simulated flows by HSPF are not as accurate as those calculated by a hydrodynamic model that accounts for driving forces (e.g., stream gradient, wind, vertical stratification, etc.), retarding forces (e.g., bottom friction due to skin friction and form drag), and convective and temporal accelerations in the flow field. Convective and temporal flow accelerations can be substantial during high flow events when most sediment is eroded and transported downstream, and as such, the identified limitation of HSPF (and therefore BASINS) should be addressed to improve upon this model's capability of simulating sediment transport during non-baseflow conditions.
- The inability to simulate the critical process of bed coarsening and subsequent armoring in non-cohesive sediment dominated sediment beds using only one size class of sand has previously been discussed.
- HSPF-RCHRES is limited to a single surficial sediment bed to represent the exchange of sediment between the bed and the water column, whereas most advanced sediment transport models typically represent the coupled interaction of sediment deposition and erosion.
- HSPF-RCHRES does not represent primary consolidation of fine-grained, i.e., cohesive, sediment since the HSPF sediment bed is defined only by a surficial bed, i.e., only one layer.
- Over the course of a model simulation HSPF does not account for changes in bed elevations that result from erosion and deposition of sediment from and to a sediment bed, respectively, in predicting changes in the flow field during the next time step. This limitation can lead to over prediction in the amount of erosion and deposition that is simulated to occur due to the hydrodynamic model not accounting for the resulting decrease and increase in bed elevation, respectively, and consequently not accounting for the corresponding change in the flow depths or current velocities.

All of these limitations would need to be addressed to significantly improve the sediment transport capabilities in BASINS and HSPF.

SECTION 3
METHODOLOGY

Addressing the identified model enhancement needs required an approach that assured conceptual and practical compatibility among the improvements, as well as compatibility with related HSPF simulations. The methodology to achieve the following project objective - enhancement of BASINS through the linkage of more robust models for channel flow (EFDC), channel sediment transport (SEDZLJ), and the capability to represent channel bank erosion using an empirical bank erosion model to HSPF - is described in this section.

1. Linkage of EFDC to HSPF: The three-dimensional (3D) hydrodynamic model EFDC was externally linked to HSPF. EFDC (Environmental Fluid Dynamics Code) is a multi-dimensional hydrodynamic model (EFDC) that is capable of simulating both uni-directional and oscillatory open channel flow (Hamrick 2007a, 2007b, and 2007c). EFDC is a public domain surface water modeling system that contains dynamically linked hydrodynamic and sediment transport modules. EFDC can simulate barotropic and baroclinic flow in a water body due to astronomical tides, wind, density gradients, and river inflow. When this substantial enhancement is completed, BASINS will be capable of accurately simulating: a) tide-driven flows in rivers that drain lower coastal plain watersheds; b) rapidly accelerating flows during the rising limb of a flashy runoff hydrograph; c) flows through hydraulic structures such as dams and culverts; and d) flow onto floodplains during the rising limb of an out-of-bank event and flow back into the river during the falling limb of out-of-bank flow events by representing the floodplain using grid cells that are adjacent to the cells that represent the channel, i.e., stream/river, network. Additional capabilities of EFDC and reasons why this model was selected for the hydrodynamic model to be linked to HSPF include the following:

    - EFDC can represent a multi-order stream network with a more general approach than is capable with a one-dimensional (1D) model, e.g., HEC-RAS. For example, EFDC can represent first- and second-order streams using a 1D approach where the stream cross-section is approximated as a rectangle that has the width of the stream and the average depth, whereas third- and higher-order streams can be represented in a two-dimensional, vertically integrated (2D-H) manner in which more than one cell is used to represent the cross-section of the stream/river. This approach would be appropriate to use when vertical density stratification over the flow depth does not occur. If vertical density stratification due to temperature or salinity does occur in higher order streams closer to the outlet of the modeled watershed, then it is possible to represent these streams/rivers using EFDC in either the two-dimensional, laterally integrated (2D-V) or full 3D mode in which the water column can be divided into a model user specified number of vertical layers.
    - EFDC has been in the public domain since its development in the early 1990's and has been applied to hundreds of water bodies.
    - The application history for EFDC includes applications by the U.S. Army Corps of Engineers Engineer Research and Development Center (ERDC) and the U.S. Environmental Protection Agency (EPA).
2. Linkage of SEDZLJ to HSPF: The project team chose to link the SEDZLJ sediment bed model developed by Jones and Lick (2000, 2001) to HSPF. This model was selected for the following reasons:

- State-of-the-science equations that have been developed in the past 20 years are included in SEDZLJ to allow simulation of the following sediment transport processes: bedload transport of non-cohesive sediment; resuspension of both cohesive and non-cohesive sediments, both calculated as a function of the local bed shear stress; deposition of cohesive sediments calculated as a function of the bed shear stress. Figure 3.1 shows the sediment mass balance achieved by SEDZLJ. In this figure, U = near bed flow velocity, δ_{bl} = thickness of layer in which bedload occurs, U_{bl} = average bedload transport velocity, D_{bl} = sediment deposition rate for the sediment being transported as bedload, E_{bl} = sediment erosion rate for the sediment being transported as bedload, E_{sus} = sediment erosion rate for the sediment that is eroded and entrained into suspension, and D_{sus} = sediment deposition rate for suspended sediment.
- Whereas a hydrodynamic model is calibrated to account for the total bed shear stress, which is the sum of the form drag due to bed forms and other large-scale physical features (e.g., boulder size particles) and the skin friction (also called the surface friction), the correct component of the bed shear stress to use in predicting sediment resuspension and deposition is the skin friction. The skin friction is calculated in SEDZLJ as a function of the near-bed current velocity and the effective bed roughness. The latter is specified in SEDZLJ as a linear function of the mean particle diameter in the active layer.

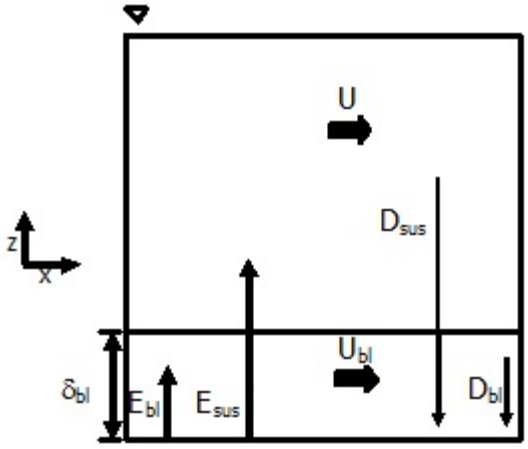

Figure 3.1 Sediment Mass Balance Achieved in SEDZLJ

- Multiple size classes of both fine-grain (i.e., cohesive) and noncohesive sediments can be represented in the sediment bed. As stated previously, this capability is necessary in order to simulate coarsening and subsequent armoring of the surficial sediment bed surface during high flow events.
- To correctly represent the processes of erosion and deposition, the sediment bed in SEDZLJ can be divided into multiple layers, some of which are used to represent the existing sediment bed and others that are used to represent new bed layers that form due to deposition during model simulations. Figure 3.2 shows a schematic diagram of this multiple bed layer structure. The graph on the right hand side of this figure shows the variation in the measured gross erosion rate (in units of cm/s) with depth into the sediment bed as a function of the applied skin friction. SEDFLUME (described below) was used to measure these erosion rates.

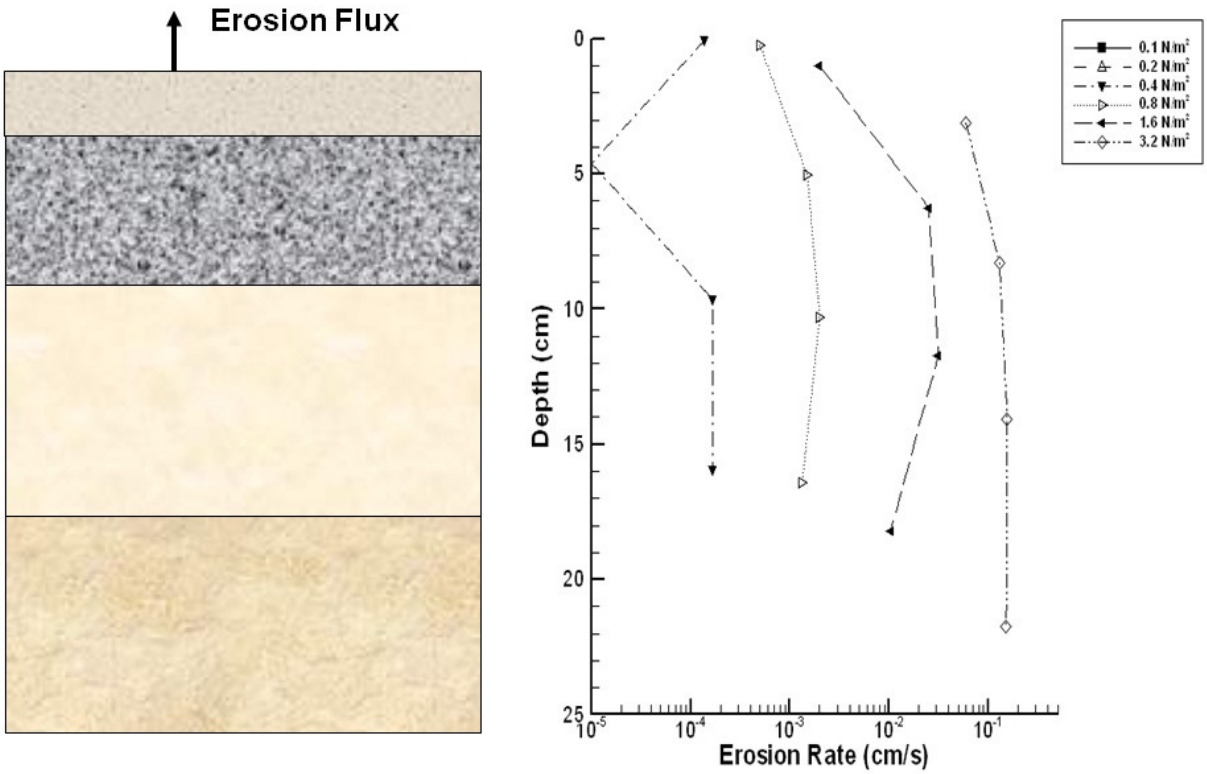

Figure 3.2 Multi-Bed Layer Model Used in SEDZLJ

Erosion from both cohesive and non-cohesive beds is affected by bed armoring, which is a process that limits the amount of bed erosion that occurs during a high-flow event. Bed armoring occurs in a bed that contains a range of particle sizes (e.g., clay, silt, sand). During a high-flow event when erosion is occurring, finer particles (i.e., clay and silt, and fine sand) tend to be eroded at a faster rate than coarser particles (i.e., medium to coarse sand). The differences in erosion rates of the various sediment particle sizes creates a thin layer at the surface of the sediment bed, referred to as the active layer, that is depleted of finer particles and enriched with coarser particles. This depletion-enrichment process can lead to bed armoring, where the active layer is primarily composed of coarse particles that have limited mobility. The multiple bed model in SEDZLJ accounts for the exchange of sediment through and the change in composition of this active layer. The thickness of the active layer is normally calculated as a time varying function of the mean sediment particle diameter in the active layer, the critical shear stress for resuspension corresponding to the mean particle diameter, and the bed shear stress. Figure 3.3 shows a schematic of the active layer at the top of the multi-bed layer model used in SEDZLJ.

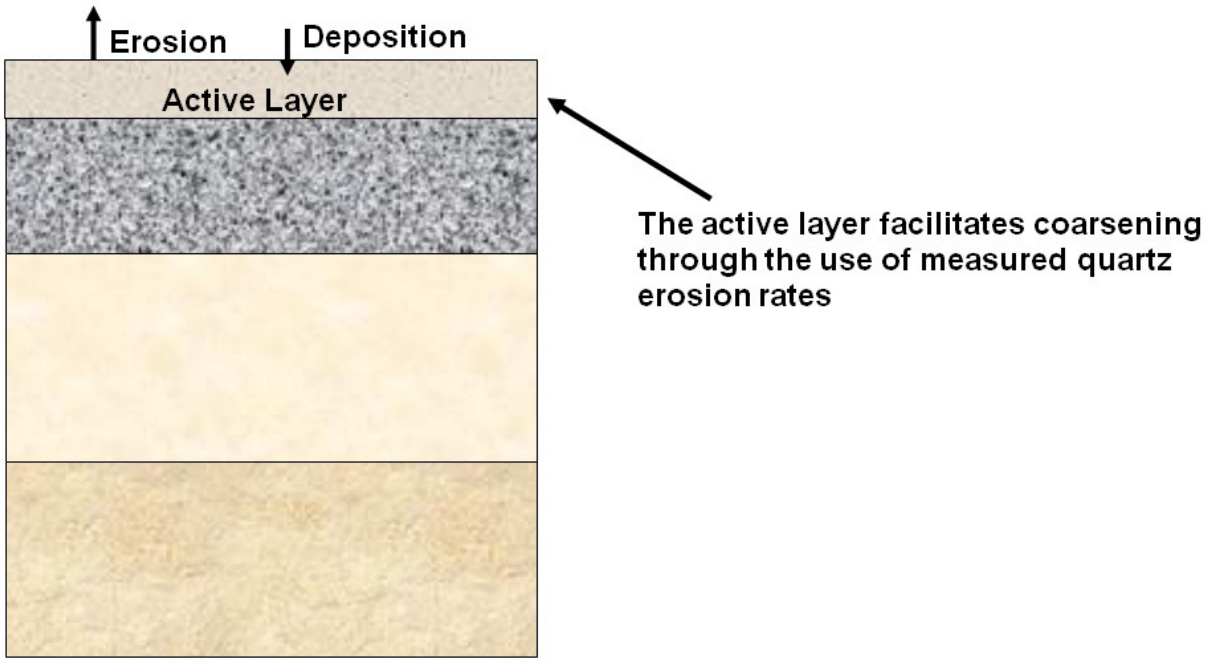

Figure 3.3 Schematic of Active Bed Layer Used in SEDZLJ

- SEDZLJ was designed to use the results obtained with SEDFLUME, which is a straight, closed conduit rectangular cross-section flume in which detailed measurements of critical shear stress of erosion and erosion rate as a function of sediment depth are made using sediment cores dominated by cohesive sediment collected at the site to be modeled (McNeil et al. 1996). However, when SEDFLUME results are not available, it is possible to use a combination of literature values for these parameters as well as the results of SEDFLUME tests performed at other similar sites. In this case, a detailed sensitivity analysis should be performed to assist in quantifying the uncertainty that results from the use of these non-site specific erosion parameters.

  SEDZLJ can simulate overburden-induced consolidation of cohesive sediments. An algorithm that simulates the process of primary consolidation, which is caused by the expulsion of pore water from the sediment, of a fine-grained, i.e., cohesive, dominated sediment bed is included in SEDZLJ. The consolidation algorithm in SEDZLJ accounts for the following changes in two important bed parameters: 1) increase in bed bulk density with time due to the expulsion of pore water, and 2) increase in the bed shear strength (also referred to as the critical shear stress for resuspension) with time. The latter parameter is the minimum value of the bed shear stress at which measurable resuspension of cohesive sediment occurs. As such, the process of consolidation typically results in reduced erosion for a given excess bed shear stress (defined as the difference between the bed shear stress and bed shear strength) due to the increase in the bed shear strength. In addition, the increase in bulk density needs to be represented to accurately account for the mass of sediment (per unit bed area) that resuspends when the bed surface is subjected to a flow-induced excess bed shear stress. Models that represent primary consolidation range from empirical equations that approximate the increases in bed bulk density and critical shear stress for resuspension due to porewater expulsion (Sanford, 2007) to finite difference models that solve the non-linear finite strain consolidation equation that governs primary consolidation in saturated porous media

(e.g., Arega and Hayter, 2008). An empirical-based consolidation algorithm is included in SEDZLJ.

- SEDZLJ is the sediment transport model that is incorporated in the version of EFDC to be externally linked to HSPF.
- As previously discussed, HSPF does not account for changes in bed elevations that result from erosion and deposition of sediment from and to a sediment bed, respectively, in predicting changes in the flow field during the next time step. SEDZLJ contains a morphologic algorithm that, when enabled by the model user, will adjust the bed elevation to account for erosion and deposition of sediment. It is proposed to add an option so that the user can activate this algorithm so that the bed elevations and flow depths are adjusted, when and where necessary, during every time step. The adjusted flow depths would be used during the next time step by the flow routing routine in HSPF to update the flow field.
- In addition to the advantages gained by using the SEDZLJ sediment transport model, the advantages of using the EFDC model to perform the dynamically linked hydrodynamic and sediment transport modeling are the following:
    - More accurate predictions of the sediment transport that occurs during a rainfall induced high-flow runoff event. This increased accuracy will be possible due to the more accurate predictions of the hydrodynamics in the stream network as a result of using a hydrodynamic model to predict the rapidly changing flow depths and current velocities that occur during runoff events.
    - The ability to simulate out-of-bank flows and the resulting transport and possible deposition of sediment onto the floodplains.

3. Linkage of bank erosion model to HSPF: As stated previously: a) simulating bank erosion in watershed-scale models is at present a research topic, and little exists in terms of methods or useful results; and b) currently the Fort Benning HSPF watershed model lacks a method for representing the generation of sediment loads due to events of bank erosion/failure. Therefore, a bank erosion model was linked to HSPF to account for the sediment that is introduced to streams from eroding/failing banks.

The approach chosen by the project team was to integrate an empirical-based bank erosion model into EFDC such that the estimated sediment mass from the eroding bank is added to the sediment bed in the grid cell where the eroding bank is located. The empirical bank erosion model by Ikeda et al. (1981) was chosen to be linked to EFDC. This empirical model calculates the lateral bank erosion rate (normally in units of meters/day) as a linear function of the difference between the near-bank, depth-averaged velocity and the reach-averaged velocity at bank-full flow. An empirical erosion constant, which is estimated from measurements of bank erosion rate and adjusted during model calibration, relates the bank erosion rate to the difference in these velocities. The volume of bank that is eroded per unit length of the bank is obtained by multiplying the lateral bank erosion rate by the average bank height.

SECTION 4
HSPF ENHANCEMENT

This section contains a discussion of the procedures that were used to implement the chosen model enhancements to HSPF.

4.1 FLOW COMPONENT

The specific steps that were used to externally link EFDC to HSPF were the following:

- The EFDC model was externally linked to HSPF such that the model user can choose whether to only use the existing flow routing module in HSPF or run EFDC after HSPF is run using boundary condition time series generated by HSPF. In other words, the linkage between HSPF and EFDC is static, in which simulated watershed and groundwater loading from HSPF is read by EFDC and used to simulate the hydrodynamics and sediment transport.
- If the static linkage is specified, the modified user manual for HSPF would instruct the model user to first run HSPF to generate the binary output file in which the time series of nonpoint loadings from the watershed and groundwater would be written at specified time intervals. With the static linkage specified in the input files, code will be added to EFDC to read the binary output file at specified time intervals and interpolate stream reach loadings to the grid cells in each HSPF reach.
- If the user chose the dynamic linkage option, the EFDC model would be invoked by a call statement that would be added to HSPF. A routine would be written that converts the HSPF calculated nonpoint loadings during a model run to the required format for use in EFDC. Note that this capability was not implemented due to the extreme run time differences between HSPF and EFDC.

4.2 SEDIMENT TRANSPORT COMPONENT

SEDZLJ was dynamically linked to the hydrodynamic model in the version of EFDC that was externally linked to HSPF. This causes the simulated changes in the bed elevations due to erosion and deposition during a particular time step being used by the hydrodynamic model in the next time step to update the flow field in the model domain.

4.3 BANK EROSION COMPONENT

The chosen empirical bank erosion model was dynamically linked to EFDC. The specific steps that were performed as well as the procedure used by this model are the following:

- An algorithm based on the empirical bank erosion model by Ikeda et al. (1981) was developed to calculate the rate per unit length of the bank at which the bank erodes as a function of the water surface elevation in the adjacent stream/river. An empirical erosion constant, which is estimated from measurements of bank erosion rate and adjusted during model calibration, relates the bank erosion rate to the difference in these velocities. The volume of bank that is eroded per unit length of the bank is obtained by multiplying the lateral bank erosion rate by the average bank height. The bank's height is assumed to be constant in this approach, but the amount of possible erosion that can occur is limited because the width of the bank (taken to be the horizontal distance from the bank face to a hard, i.e., non-erodible, surface at the back of the bank) is a user specified input parameter.

- The calculated bank erosion rate is multiplied by the specified number of model time steps (the number will depend on whether an hourly or daily bank erosion rate is calculated) to give the mass of sediment that is eroded per unit length of the bank per specified time interval, i.e., day.
- The mass of sediment eroded will be multiplied by the cell length (or by multiple cell lengths if spatial averaging is specified) to give the mass of sediment that will be added uniformly (i.e., a layer of uniform thickness will be added) to the top of the sediment bed in that cell (or cells) at the end of the current time step. The composition of sediment in the eroding bank will be reflected in the sediment mass added to the top of the sediment bed in the adjacent cell(s).

Data that are required to estimate bank erosion rates and develop the site-specific empirical equations include (at a minimum) the following:

- Spatial distributions along river shorelines of bank height and geometry, areas of active erosion, and empirical bank erosion/bulk properties (e.g., grain size composition of banks).
- Long term erosion rate estimates that can be determined using aerial photographs of the river shoreline taken at two different times, or measurements of bank erosion rates at a few locations along the stream/river to be modeled.

SECTION 5

EFDC-SEDZLJ MODEL SIMULATION

Model Setup and Calibration

An orthogonal-curvilinear grid was developed to represent the chosen model domain for Upatoi Creek. Two views of portions of this grid are shown in Figure 5.1. As described above, HSPF calculated tributary flows (including the upstream boundary condition for EFDC) and land drainage were provided as time series that were used to drive the hydrodynamic model in EFDC. Time series of clay, silt and sand size sediment were also calculated by HSPF and used as tributary and land drainage boundary conditions by the sediment transport model in EFDC. The concentration time series of clay and silt calculated by HSPF were added together and used for the one cohesive size class represented in the SEDZLJ model. The concentration time series of sand calculated by HSPF was assigned to the finest non-cohesive sediment size class used in the SEDZLJ bed model.

The downstream boundary condition for the hydrodynamic model was the water surface elevation at the confluence of the Upatoi Creek and Chattahoochee River, whereas a zero gradient downstream boundary condition – in which sediment being transport either as bedload or in suspension in the downstream most grid cells were allowed to pass out of the model domain - was used for the sediment transport model.

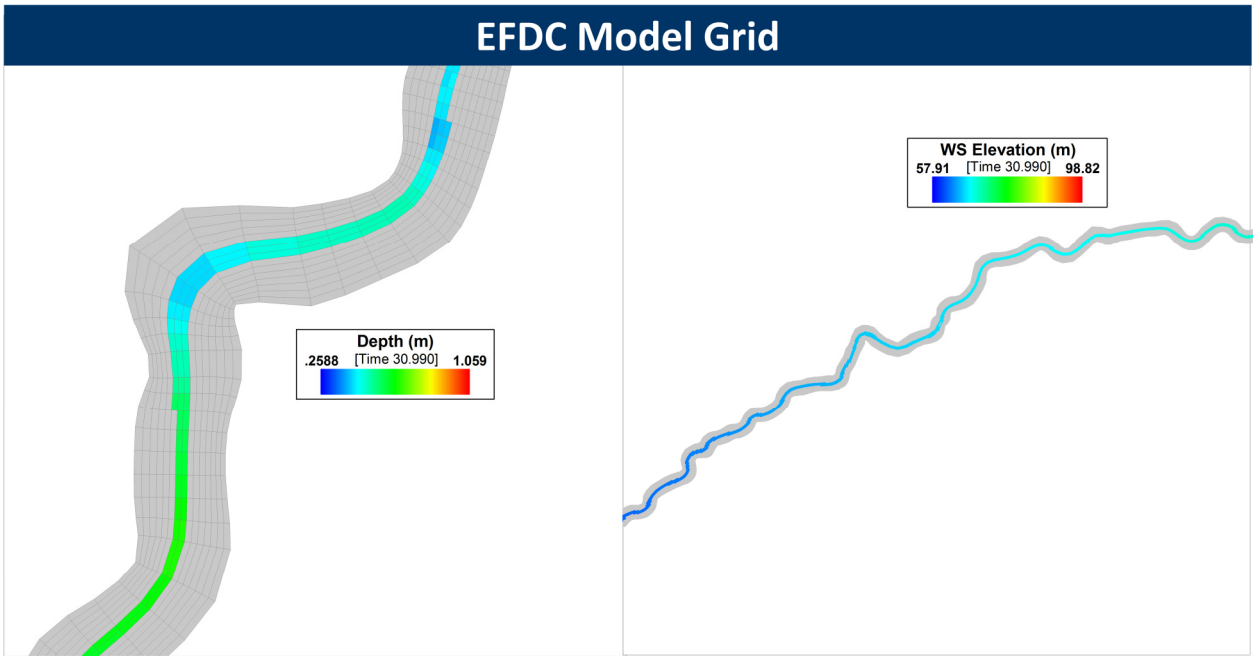

Figure 5.1 a) Zoomed-in View of a Short Reach of the Curvilinear-Orthogonal Grid, and b) View of a Longer Reach of the Upatoi Creek Grid

Calibration of the hydrodynamic model was performed by comparison with measured water surface elevations at McBride Bridge. The calibration parameter used to achieve the optimum agreement between the measured and simulated water surface elevations at this location was the effective bottom roughness. The calibration yielded a value of 5 cm for the bottom roughness parameter.

The SEDZLJ sediment bed model was setup using the available (but extremely limited) grain size distribution. Five sediment size classes were used in the bed model – one cohesive class and four non-cohesive classes. The D50 values of the four non-cohesive sediment classes were 375, 750, 1020, and 2000 *μm*. The sediment bed in the grid cells that represented the Upatoi were initially composed of spatially constant fractions of the four non-cohesive size classes. These fractions were 0.4, 0.4, 0.18 and 0.02 for the 375, 750, 1020, and 2000 *μm* size classes, respectively. All five bed layers in every grid cell were assumed to be composed of the same initial composition of the sediment size classes.

During the model simulations described below, SEDZLJ was run in morphological mode, which means that changes in bed elevation due to erosion/deposition in the grid cells were used in calculating the new flow field at the next time step. Extremely limited data prevented complete calibration or validation of the sediment transport model. A limited calibration effort is described below.

Model runs with both HSPF and EFDC/SEDZLJ were performed for the entire calibration period extending from 1999 through 2008, with the HSPF results for the mainstem tributaries and local inputs of both flow and sediment providing the boundary conditions for the EFDC/SEDZLJ simulations. The biggest limitation for this assessment was the lack of reliable and consistent flow and sediment data for which model calibration and comparisons could be performed. The sediment calibration relied primarily on a few selected storms in May 2006 and April 2007 which provided reasonable data for comparison purposes. Figure 5.2 shows the daily flow duration curve for both HSPF and EFDC at McBride Bridge, while Figure 5.3 shows the daily flow and sediment results for the October 2005 through April 2007 period that included the two major storm events. Figure 5.4 and Figure 5.5 show simulations for the two major storm events, in May 2005 and April 2007, comparing the HSPF and EFDC/SEDZLJ results.

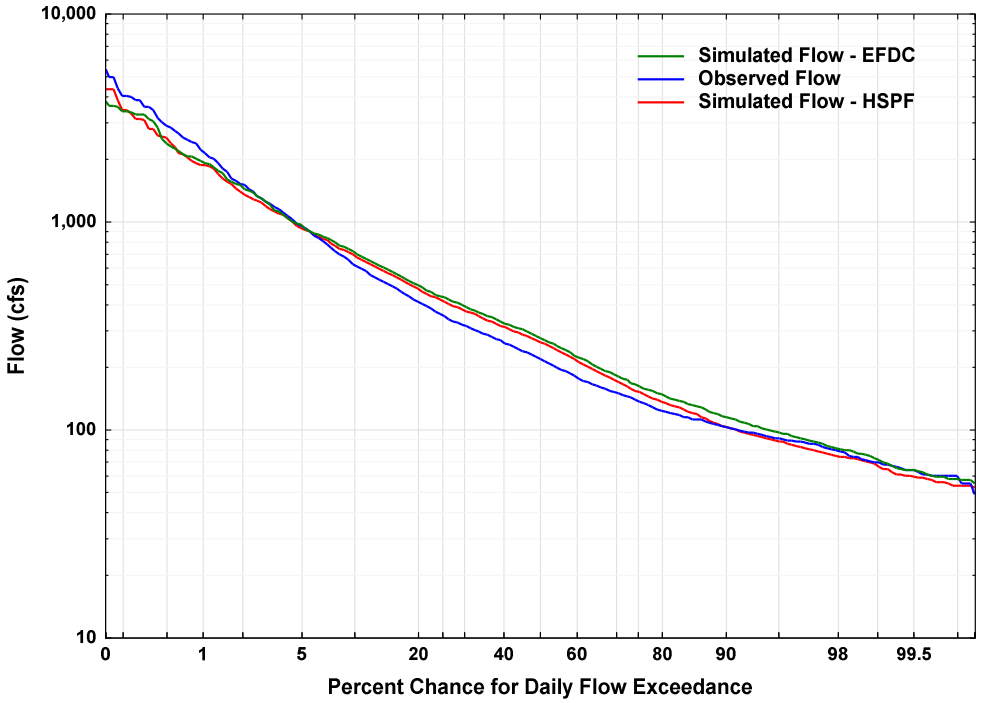

Figure 5.2 Comparison of HSPF and EFDC Flow Duration Curves at McBride Bridge

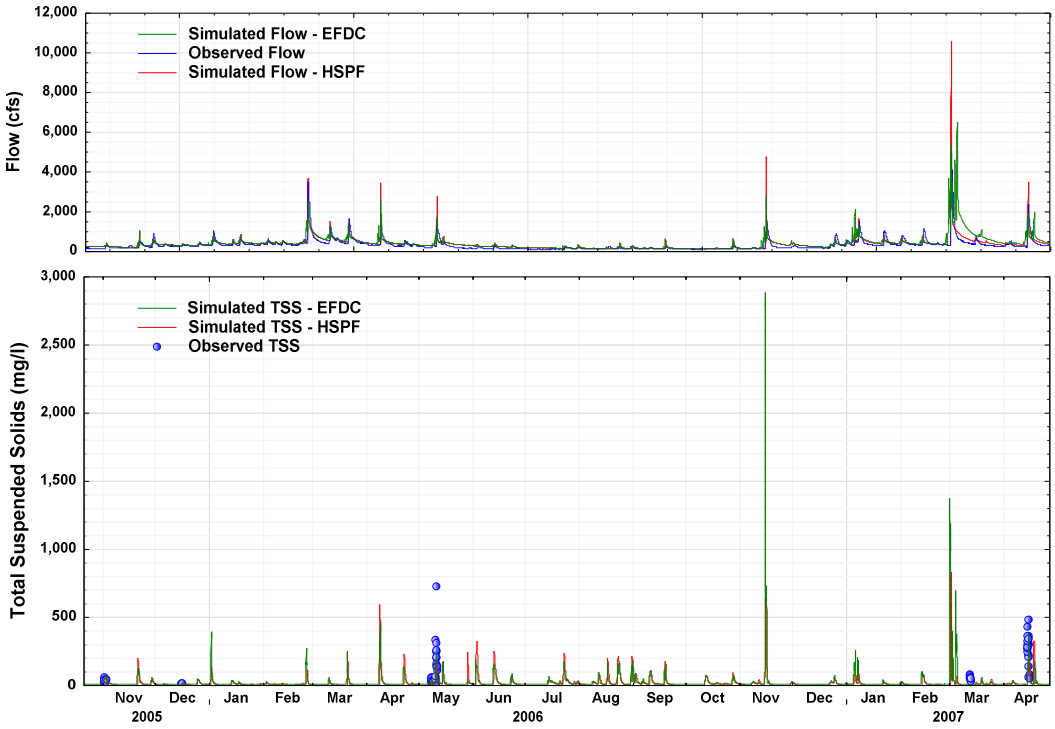

Figure 5.3 HSPF and EFDC Flow and Sediment Simulation Results at McBride Bridge, October 2005 – April 2007

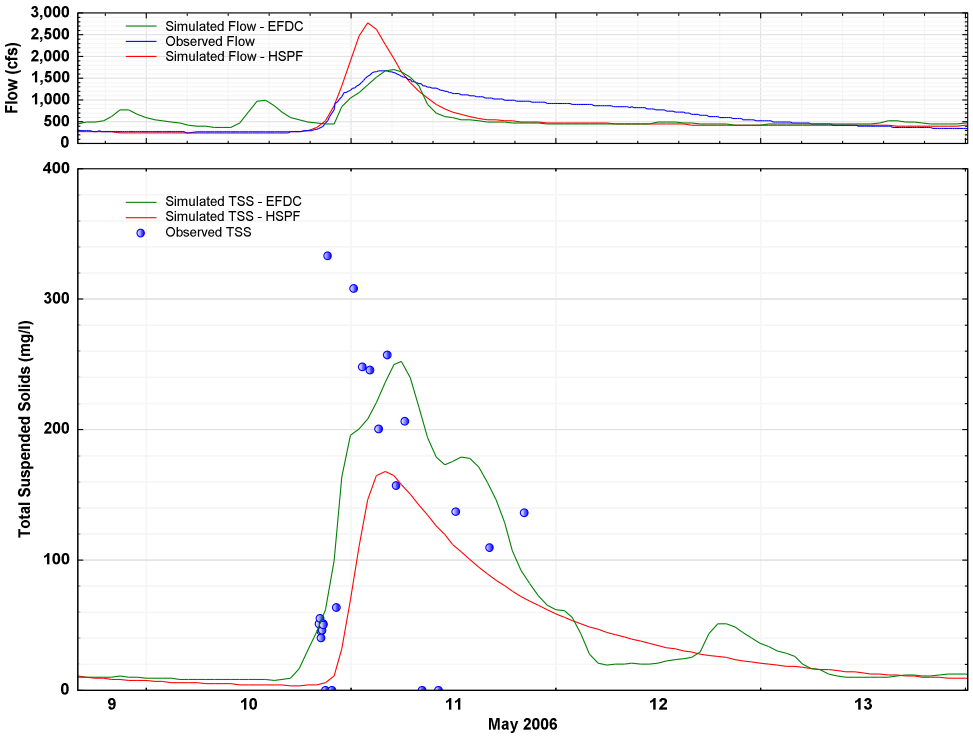

Figure 5.4 HSPF and EFDC Simulation Results for Storm of May 10-11, 2006 at McBride Bridge

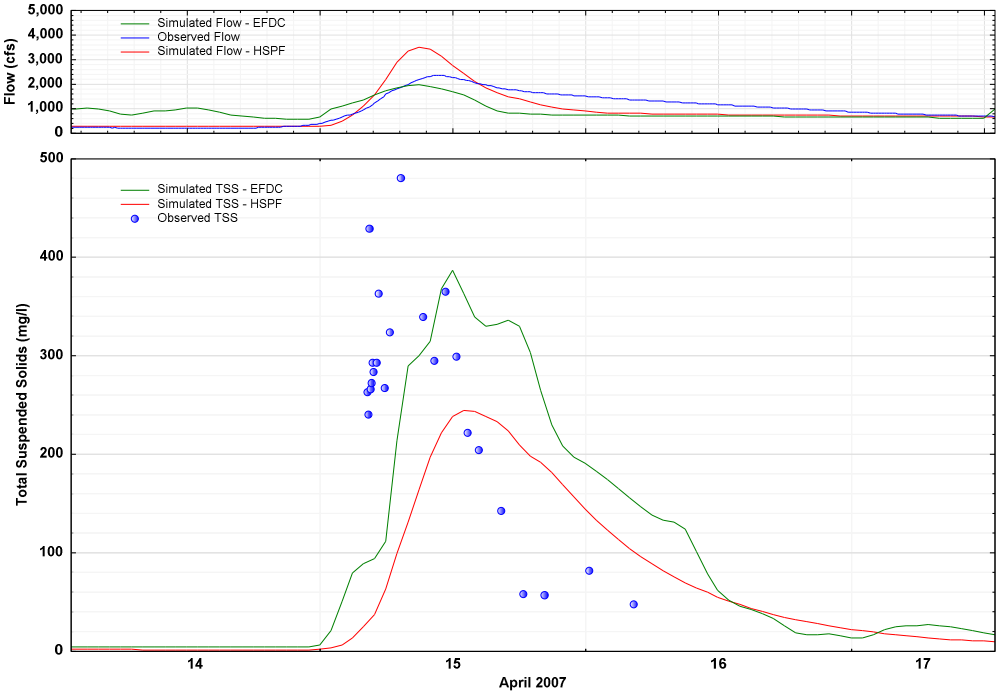

Figure 5.5 HSPF and EFDC Simulation Results for Storm of April 15, 2007 at McBride Bridge

The flow duration curves in Figure 5.2 show the Percent Chance (or Percent of time) the corresponding daily flows are exceeded, for both HSPF and EFDC, along with the observed flow at McBride Bridge. The HSPF and EFDC results track each other quite well, as they should since EFDC model results are produced with the HSPF simulated inputs. They are both also a good representation of the observed flow duration curve, with some deviations. Both models under-simulate the peak flows occurring less than about 2% of the time, and both tend to slightly over-simulate the mid-range flows, from about 10% to 85% of the time. However, the overall agreement is good.

Review of the daily flow and sediment results in Figure 5.3, and the storm simulations in Figures 5.4 and 5.5 indicate the following:

a. HSPF daily flows tend to over-simulate the observed values for peak flows, whereas the EFDC flows tend to be lower, and generally closer to the observed. This is also shown in the upper portions of the storm graphs in Figures 5.4 and 5.5.

b. With limited data, the daily results in Figure 5.3, especially for sediment, are difficult to interpret due to the sparse data coverage. The storm results in Figures 5.4 and 5.5 show that EFDC does a somewhat better job of simulating the observed flow and sediment data. HSPF tends to over-simulate the flow peaks and under-simulate the sediment concentrations, but both models are in the general range of the observations. Overall, EFDC tends to show more consistency between the flow and sediment simulations than HSPF.

c. It should be noted that sediment simulation results are often depicted on a **log scale**, due to the difficulty of accurately matching individual sediment samples. However,

d. The results in these figures are shown on an **arithmetic scale** to more accurately display the model results.

e. Although the EFDC flows appear to provide a better match to the storm peaks in Figures 5.4 and 5.5, there are also unexplained smaller peaks prior to the event in Figure 5.4 and higher baseflows in Figure 5.5. Both of these conditions are inconsistent with both the HSPF simulations and the observed flows, and require further investigation.

f. Timing differences between HSPF, EFDC, and the observed data shown in the storm simulations are not

g. Table 5.1 shows error statistics for both the HSPF and EFDC simulations for selected flow metrics for the entire period of 1999 - 2008, similar to the error statistics included in Appendix C and Section 2 of the Final Report. All of these metrics show HSPF providing a somewhat better simulation of the observed data than EFDC, although a few of the differences are relatively small. The biggest difference is in the storm event peaks, with EFDC under-simulating peaks by -25%, compared to the -6% for HSPF. A bigger concern is the volume difference; since EFDC takes its inflows from HSPF, the fact that it simulates a higher overall volume indicates a possible mass-balance problem that should be further investigated.

h. Results for both models could be improved with additional observed data, and with additional calibration efforts with the existing data.

Table 5.1 Comparison of Error Statistics for HSPF EBM and EFDC

	HSPF Enhanced Baseline	EFDC Simulation
Error in Total Volume (%)	7.5	11.1
Error in 25% highest flows (%)	1.6	3.2
Error in 50% lowest flows (%)	12.9	20.3
Error in 25% lowest flows (%)	4.3	13.7
Error in 10% lowest flows (%)	-2.8	7.2
Error in average Storm Peak	-6.3	-25.4

In summary, the comparisons of HSPF and EFDC model results indicate that both models provide a reasonable representation of the limited observed sediment data, while the EFDC model tends to produce a somewhat more accurate flow simulation for storm event flows. Error statistics for the entire simulation period shown in Table 5.1 indicate HSPF provides a better overall hydrologic simulation for the watershed for most flow metrics.

SECTION 6
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December 2012

A Watershed Modeling System for Fort Benning, GA Using the US EPA BASINS Framework

SERDP PROJECT SI-1547

AQUATOX-HSPF LINKAGE: IMPORT BOUNDARY CONDITIONS INTO AQUATOX FROM HSPF WDM

Final Report
Appendix E

This menu option (in the Study menu) allows a user to pass data from HSPF "WDM files" into AQUATOX. This compliments the existing BASINS HSPF-to-AQUATOX linkage, which required that the user work with WinHSPF (i.e., the HSPF interface contained in BASINS) and then ask WinHSPF to produce special time series used for the linkage. In some recent HSPF-to-AQUATOX linkage applications, the HSPF simulation produced the needed boundary conditions in a form not compatible with the previous WinHSPF-AQUATOX linkage. This required time-consuming manual linkages of time-series, something that this automated linkage attempts to avoid.

This linkage has AQUATOX import, as inflow loadings, "in-stream concentrations" as derived from HSPF as opposed to the boundary condition calculations passed in the original linkage.

There was some concern that HSPF and AQUATOX would both be calculating the same in-stream processes so there could be double counting. However, when passing average-daily loadings into short reaches with low retention times, the HSPF in-stream concentration and the AQUATOX in-stream concentration will be dominated by the inflow loadings rather than in-stream processes. Our testing has indicated that linking HSPF in-stream concentrations as AQUATOX in-flow loadings for such short reaches introduces negligible error.

Additionally, one can design their study such that the AQUATOX boundary condition is represented by the end of, or outflow from, the HSPF reach being linked. This approach would eliminate any potential error from double-calculation of in-stream processes. The assumption would simply be that the well-mixed HSPF reach feeds directly into the AQUATOX reach being modeled below.

Specific Mechanics of the Linkage:

The steps taken by this linkage are summarized below:

1. The HSPF simulation must have been run and nutrients, organic matter and flow outputs must have been satisfactorily calibrated. The results must be in an accessible WDM file.
2. From AQUATOX, the user selects the WDM file, and then the relevant location, and scenario to be linked using the "study" menu (select "Import Data from HSPF WDM").
3. The user selects the date range for the linkage. (Note that this changes the AQUATOX first day and last day of simulation but this can be changed after the linkage is complete.)
4. The user is presented with options for importing phosphate. The following HSPF outputs may be input to maximize flexibility
    a. TOTP -- Total Phosphorus in mg/L (Default is to link this to the AQUATOX Total P compartment, and AQUATOX will estimate Total Soluble P from Tot P)
    b. Any combination of the below three compartments may be summed and imported as TP or TSP.
        i. PO4-P – Ortho P concentration as P in mg/L
        ii. PPO4 -- Adsorbed orthophosphate as P in mg/L
        iii. TORP-- Total Organic Phosphorus in mg/L
5. The following items are loaded (Hourly data are converted to daily except for oxygen, CO2, organic matter, and nutrients.)
    a. FLOW is read as AQUATOX "outflow water," units are checked to be in cubic feet per second (cfs). If units are not specified the user is told that the

assumption is that units are cfs. If different units are specified the user is prompted as to whether to continue or not. Units are converted to AQUATOX m3/d.

b. Average depth is read assuming the units are feet if unknown, converting, and prompting the user as above.
c. Ammonia, Phosphate, Oxygen, Nitrate,TOC/CBOD, and TSS are imported in units of mg/L.
d. CO2 is set to the default value of 0.7 mg/L. This can be changed (or not set) if that is desirable.
e. Temperature is imported and converted to Celsius units (C). if required.
f. For QA/QC, these imports may be examined as compared to the WDM file results.

6. The linkage also imports Chlorophyll a, Benthic Chlorophyll a, and CBOD as "external data" to plot against AQUATOX results (but not to drive the model).

With regards to the units of data being imported, if units are not specified in the WDM file the log-file alerts the user that it assumes they are using a certain type of unit (general HSPF defaults). If units are specified and the linkage finds unexpected units it raises an error.

This new capability can link both BASINS and HSPF, since both simulations read from, and write their data/results to WDM files, which is the primary medium of this linkage.

Following successful linkage a log file describing all imported data and/or any errors encountered can be examined through the AQUATOX interface. A log from linking AQUATOX to the WDM file for Upatoi Creek follows:

HSPF - AQUATOX: BASINS Linkage Log

HSPF File: C:\work\AQUATOX\Documents\SERDP\Upatoi_EB.wdm
HSPF Scenario: SIMULATE
HSPF Location: RCH46
Linkage Time: 7/17/2012 4:32:18 PM

FirstDay of HSPF Loadings Read: 10/1/1999
LastDay of HSPF Loadings Read: 9/30/2008
Loadings will be imported from 10/1/1999 to 9/30/2008
Initial Condition Volume could not be read, no "VOL" data found
OUTFLOW WATER timeseries read into AQUATOX.
Note: Data converted from CFS to m3/d.
SURFACE AREA could not be read, no "SARA" or "SAREA" timeseries found
Average Depth timeseries read into AQUATOX.
Note: "AVDEP" data converted from ft to M
WATER TEMPERATURE timeseries read into AQUATOX.
Note: Hourly data are averaged to get daily data.
Note: "TW" data converted from F to C.
AMMONIA LOADING timeseries read as an inflow loading with units of mg/L of inflow water.
TOTAL PHOSPHATE LOADING timeseries read as an inflow loading with units of mg/L of inflow
water.
OXYGEN LOADING timeseries read as an inflow loading with units of mg/L of inflow water.
CO2 is set to default value of 0.7 mg/L
NITRATE LOADING timeseries read as an inflow loading with units of mg/L of inflow water.
TOC LOADING timeseries read as an inflow loading with units of mg/L of inflow water.
TSS CONCENTRATION timeseries read into AQUATOX.
Note: Hourly data are averaged to get daily data.
Overwrote Observed Data: BOD (mg/l)
Overwrote Observed Data: PCHLA (Unknown)
Overwrote Observed Data: BCHLA (Unknown)

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A Watershed Modeling System for Fort Benning, GA Using the US EPA BASINS Framework

SERDP PROJECT SI-1547

TECHICAL MEMO RE: MANAGEMENT ALTERNATIVES

Final Report
Appendix F

AQUA TERRA CONSULTANTS
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Mountain View, CA 94043-1115
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www.aquaterra.com

MEMORANDUM

To: John Brentand Hugh Westbury — Date: February 16, 2010

From: Eileen Regan, Tony Donigian, and John Imhoff — Client: SERDP SI-1547

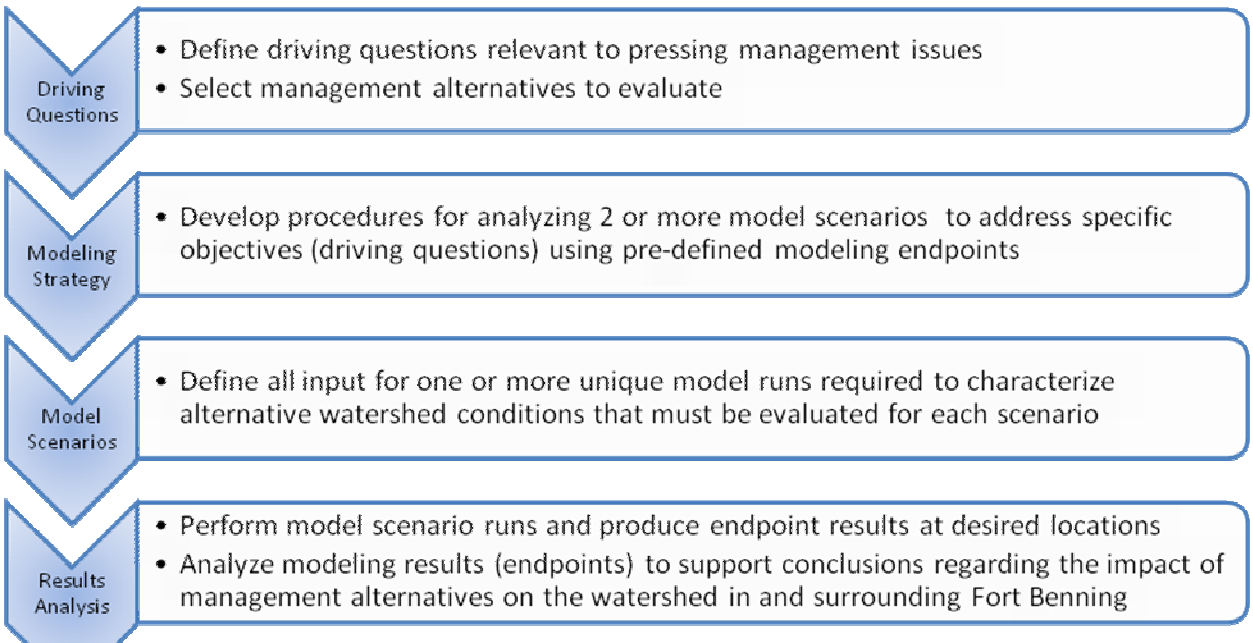
Copies: John Hall and Lee Mulkey — ATC Project No. 20710-01

Subject: Selection of Management Alternatives for Modeling Evaluations at Fort Benning

Our SERDP project, which applies the EPA BASINS Framework to Fort Benning watersheds, currently is developing a strategy report that defines how our military-enhanced model will be applied to assess the impact of selected management alternatives. The report, which is titled: *Fort Benning Military-Enhanced Model Application Strategy Report*, provides the roadmap for performing the actual enhanced-model demonstrations for these assessments.

The flow chart below outlines the process that we propose to follow. Notice that the selection of management alternatives and the driving questions behind each of them are key to the process.

Our strategy report is ideally based on the selection of appropriate management alternatives that Fort Benning land managers agree are most pertinent to the management of the watersheds on and around Fort Benning. We are contacting you at this time to ensure that our modeling strategies and model scenarios are based on appropriate management alternatives and associated driving questions, modeling endpoints, and locations for reporting endpoint results. These are listed below for your review.



Process for Selecting and Performing Enhanced-Model Demonstrations

Actions Required:

1) *Establish Endpoints:* Our modeling endpoints are the metrics we intend to use to characterize the response of the watershed to changed conditions (e.g., use of best management practices or BMPs). Below is a set of endpoints for your consideration. Please review our proposed set to determine if other endpoints should be included.

Category	Endpoint
Flow	Volume (daily, monthly, annual), daily flow duration, high storm peaks and low flow conditions
Sediment	Washoff (tons/acre/yr), total load (tons/yr), TSS concentrations
Water Quality	Water temp, nutrients (N, P) concentrations, DO concentrations
Aquatic Biota	%EPT, broadstripe shiner

2) *Establish Locations for Evaluations:* Are there locations or stream segments within the watershed where it would be particularly helpful to have endpoint information reported? We propose that, at a minimum, endpoint results are determined and evaluated at the following locations:

Model Endpoint Locations	Rationale
Outlet of basin	Important to show the accumulative downstream impact
McBride Bridge	Reference location for calibration and validation
Selective individual tributaries (TBD)	Definition for discriminating impact assessments (e.g., streams draining the Good Hope Area, Northern Maneuver Corridor, and Southern Maneuver Corridor)

3) *Define Management Alternatives:* We currently are considering four categories of management alternatives:
   a. BRAC Future Alternatives – alternatives based on the proposed BRAC land-use designations as described in the Alternative "B" of the BRAC Final EIS.[1]
   b. Natural Resources Management Alternatives – alternatives that capture the set of activities that directly impact natural resources.
   c. Road Alternatives – alternatives that address road locations, miles and design.
   d. Compliance Alternatives – alternatives that explore compliance issues.

   Listed under each of these four categories is our initial set of management alternatives. Budget considerations will limit the number of scenarios analyzed, so prioritization of the management alternatives is critical. Please carefully review the listed management alternatives. Are there variations of these alternatives that you would like us to consider (e.g., construction impacts and increases in maneuver area footprints)? Then, rank the management alternatives according to the Installation's management priorities.

   Please review the set of associated driving questions and provide confirmation or revisions to each. The more specific our driving questions are the greater utility they can have in defining optimal modeling strategies and scenarios. A well-defined driving question addresses location, action or changed condition and endpoints.

1/ US Army COE, Mobile District. 2007. Final Environmental Impact Statement for BRAC 2005 and Transformation Actions at Fort Benning Georgia.

Management Alternative	Associated Driving Question
BRAC Future Alternatives	
BRAC (as defined in the FEIS "B" Alternative) without permanent or long-term BMPs	*Overarching Question* - How will the BRAC Future Alternative *without* BMPs impact endpoints?
	What are the impacts on total annual stream loads/concentrations of sediment in the streams draining the Good Hope Area, Northern Maneuver Corridor, and Southern Maneuver Corridor?
	What impacts will BRAC actions have on impaired stream segments?
BRAC with permanent or long-term BMPs	*Overarching Question* - How will the BRAC Option *with* BMPs improve upon or mitigate the impacts on endpoints?
	What are the impacts on total annual stream loads from projected reduction of sediment loadings by BMPs within military training areas of the Good Hope area and throughout the remainder of the installation?
Natural Resource Management Alternatives	
5 year burn cycle[2]	How does a change in the prescribed burn cycle from 3 years to 5 years impact endpoints?
Timber Harvesting	Does timber harvesting in selected locations have an impact on endpoints?
Aquatic Habitat	How does the location and area of disturbed stream banks impact in-stream sediment loads and concentrations?
Road Alternatives	
Road Development	Does the level of road development in the Good Hope Area cause sediment loads and concentrations to exceed GA EPD TMDLs?[3]
Road Design	What reduction in sediment washoff from newly constructed roads can Fort Benning achieve by limiting road grades to 4% and employing other construction options (e.g., width of forest buffer and rock addition)?

2/ Some observers suggest that the three-year return cycle burn frequency on Ft. Benning may be too short for recovery. "Loblolly pine decline on Ft. Benning: An analysis of potential underlying causes", William J. Otrosina, Hal Balbach, Pauline C. Spaine, and Shi-Jean S. Sung; Forest Health White Paper, Ecological Society of America 2008, Preliminary Draft.

3/ The GA TMDL for Fort Benning impaired stream segments is a narrative water quality standard for aquatic life. The TMDL is based on the hypothesis that an impaired watershed having an annual average sediment loading rate similar to the biological reference watersheds will remain stable and not be biologically impaired due to sediment. The average sediment loads of the reference watersheds in the Piedmont and Southeastern Plains ecoregions within the Chattahoochee Basin is 0.63 tons/acre/yr (ranging from 0.30 to 1.26 tons/acre/yr).

Compliance Alternatives	
Impaired Stream Segments	*Overarching question:* What is needed to address the issue of impaired stream segments?
	Can the 30 mg/L upper limit threshold[4] for the annual mean suspended sediment concentration for piedmont streams be achieved under BRAC without BMPs?
	Do AQUATOX simulations of the aquatic biota support the impaired stream classification?
Sediment Sources	What is the distribution of sediment loads across all sources of sediment for selective stream reaches (e.g., at McBride Bridge and within the Good Hope Area, Northern Maneuver Corridor, and Southern Maneuver Corridor)?
Off-site Sediment Sources	What percent of the total sediment load is from off-site sources?
Increased Urbanization	How does the projected increase in urbanization (i.e., population in surrounding counties is expected to grow by 3.5% per year) surrounding the Installation effect sediment loads and impact endpoints?

To summarize, we are asking you to carefully address the following questions:

- What are the specific questions that drive the assessment of management alternatives?
- What endpoints are needed for the Installation to assess the impact of land uses and management activities on Fort Benning?
- Where in the watershed do you want/need endpoint results reported?
- How would you rank the management alternatives to represent your prioritization for conducting impact assessments, and what variations in these alternatives should be considered?

4/ Between 2000 and 2004, an Interagency, multi-disciplinary working group came together under facilitation of The Georgia Conservancy. This group became known as the Sediment Technical Advisory Group [TAG]. The Sediment TAG's purpose was to establish recommendations for sediment thresholds in Georgia water-bodies since no established water quality threshold for this parameter existed. The TAG identified 30 mg/L as an upper limit threshold for annual mean suspended sediment concentrations for streams in the Piedmont and Blue Ridge ecoregions.

December 2012

A Watershed Modeling System for Fort Benning, GA Using the US EPA BASINS Framework

SERDP PROJECT SI-1547

LIST OF PUBLICATIONS AND PRESENTATIONS

Final Report
Appendix G

Abstract and poster presentation for the 2008 SERDP/ESTCP Symposium, Washington D.C.
Oral presentation presented by Anthony Donigian to American Water Resources Association (AWRA) 2009 Spring Specialty Conference, Anchorage, AK, May 2009; *Modeling Sediment Impacts of Training Activities on Military Installations: Approach and Baseline Model Results*
Donigian, A.S. Jr., J.C. Imhoff, A. Mishra, P.N. Deliman and E.C. Regan. 2009. Modeling Sediment Impacts of Training Activities on Military Installations: Approach and baseline Model Results. Proceedings of AWRA 2009 Spring Specialty Conference. May 4-6, 2009. Anchorage, AK.
Abstract and poster presentation for the 2009 SERDP/ESTCP Symposium, Washington D.C.
Oral presentation by Anthony Donigian at the Total Maximum Daily Loads 2009: Combining Science and Management to Restore Impaired Waters, Minneapolis, MN, August 2009; *A Watershed Modeling Framework for Military Installations: A Preliminary Approach and Baseline Model Results*
Donigian, A.S. Jr., J.C. Imhoff, A. Mishra, P.N. Deliman and E.C. Regan. 2009. *A Watershed Modeling Framework for Military Installations: A Preliminary Approach and Baseline Model Results*. WEF TMDL 2009, August 9 - 12, 2009. Minneapolis, Minnesota.
Oral presentation by Anthony Donigian at 2009 ASA-CSSA-SSSA International Annual Meeting, Pittsburgh, Pennsylvania, Nov. 1-5, 2009; *Characterizing and Assessing Military Activities and Disturbance Impacts: A Conceptual Approach Demonstrated within the Fort Benning Watersheds*
Oral presentation by John Imhoff at 2010 AWRA Spring Specialty Conference: GIS and Water Resources VI. Orlando, FL, March 29-31, 2010; *Development and Demonstration of a Hybrid Modeling Capability within the Fort Benning HSPF Watershed Model: Refinement of Unpaved Road Simulation Using WEPP:Road*
Imhoff, J.C., J.L. Kittle, Jr., B.B. Gonzales, A.S. Donigian, Jr., P.N. Deliman, W.J. Elliot and D.C. Flanagan. 2010. *Development and Demonstration of a Hybrid Modeling Capability within the Fort Benning HSPF Watershed Model: Refinement of Unpaved Road Simulation Using WEPP:Road.* Proceedings of AWRA 2010 Spring Specialty Conference. March 29-31, 2010. Orlando, FL.
Abstract and poster presentation for the 2010 SERDP/ESTCP Symposium, Washington D.C.
Oral presentation by Anthony Donigian and Pat Deliman for a Watershed Management Side Meeting at the 2009 SERDP/ESTCP Symposium, Washington, D.C.
Oral presentation by John Imhoff at the 3rd USGS Modeling Conference, Denver, CO, June 7-9, 2010; *Using U.S. EPA BASINS Modeling System for Linking Hydrologic Models with An Ecological Model for Aquatic Endpoint Impact Assessments*
Oral presentation by John Imhoff at the Joint Interagency Conference on Sedimentation and Hydrologic Modeling, June, 2010 in Las Vegas, NV; *Assessment of the Hydrologic and Sediment Washoff Impacts of Military Management Alternatives*
Oral presentation by Pat Deliman at the Joint Interagency Conference on Sedimentation and Hydrologic Modeling, June, 2010 in Las Vegas, NV; *Enhancing the Sediment Transport Modeling Capability of a Watershed Modeling Framework.*
Donigian, A.S. Jr., J.C. Imhoff, A. Mishra, P.N. Deliman and E.C. Regan. 2010. *A Watershed Modeling Framework for Military Installations: Assessment of the Hydrologic and Sediment Washoff Impacts of Military Management Alternatives.* Proceedings of Joint Interagency Conference on Sedimentation and Hydrologic Modeling (JFIC2010). June 27-July 1, 2010. Las Vegas, NV.

Hayter, E.J., J.L. Kittle Jr. and A.S. Donigian, Jr. 2010. *Enhancing the Sediment Transport Modeling Capability of a Watershed Modeling Framework.* Proceedings of Joint Interagency Conference on Sedimentation and Hydrologic Modeling (JFIC2010). June 27-July 1, 2010. Las Vegas, NV.
Svendsen, Niels G., P.N. Deliman, A.S. Donigian Jr., J.C. Imhoff, E.C. Regan, A. Mishra, 2010. *Military Activities and Disturbance: The Development of a Watershed Modeling System for Fort Benning*, 1st Annual Army Training Support System (TSS) Workshop, Nashville, TN, August 02, 2010.
Abstract and poster presentation for the 2011 SERDP/ESTCP Symposium, Washington D.C.
Imhoff, J.C., A. S. Donigian, Jr., P. N. Deliman, A. Mishra, and E.C. Regan, 2012. *Watershed Modeling for Impact Assessment on U.S. Military Installations Oral Presentation and abstract for the Fifty Years of Watershed Modeling Conference*, Boulder, Colorado, Sept 24-26.