Method Development for Watershed Sediment Budgets to Support the CHIA/PHC Process: A Focus on Sediment Modeling for Estimating Sediment Loads

Photos from New River Basin, Scott County, TN

US Department of Interior, Office of Surface Mining
2007 Applied Science Program

University of Tennessee - Knoxville
Department of Civil and Environmental Engineering

July 2010

Method Development for Watershed Sediment Budgets to Support the CHIA/PHC Process: A Focus on Sediment Modeling for Estimating Sediment Loads

USDoI Office of Surface Mining
Applied Science Program
Grant Control # S07AP12477

Report Submitted to:

U.S. Department of Interior, Office of Surface Mining
Appalachian Region, Knoxville Field Office, Knoxville, Tennessee

KFO Director: Earl D. Brady, Jr.
OSM COR: Richard Mann

Report Prepared by:

University of Tennessee - Knoxville
Department of Civil and Environmental Engineering

Project Investigators:
Dr. John S. Schwartz and Dr. Eric C. Drumm

Graduate Students:
M. Patrick Massey, Daniel Johnson
Patrick White; and William Cantrell

Final Report: Main Document

July 2010
Draft Revisions: February 2010
Original Draft: December 2009

Table of Contents

Page

Table of Contents

Page

List of Figures

Page

List of Figures

Page

List of Figures

Page

List of Tables

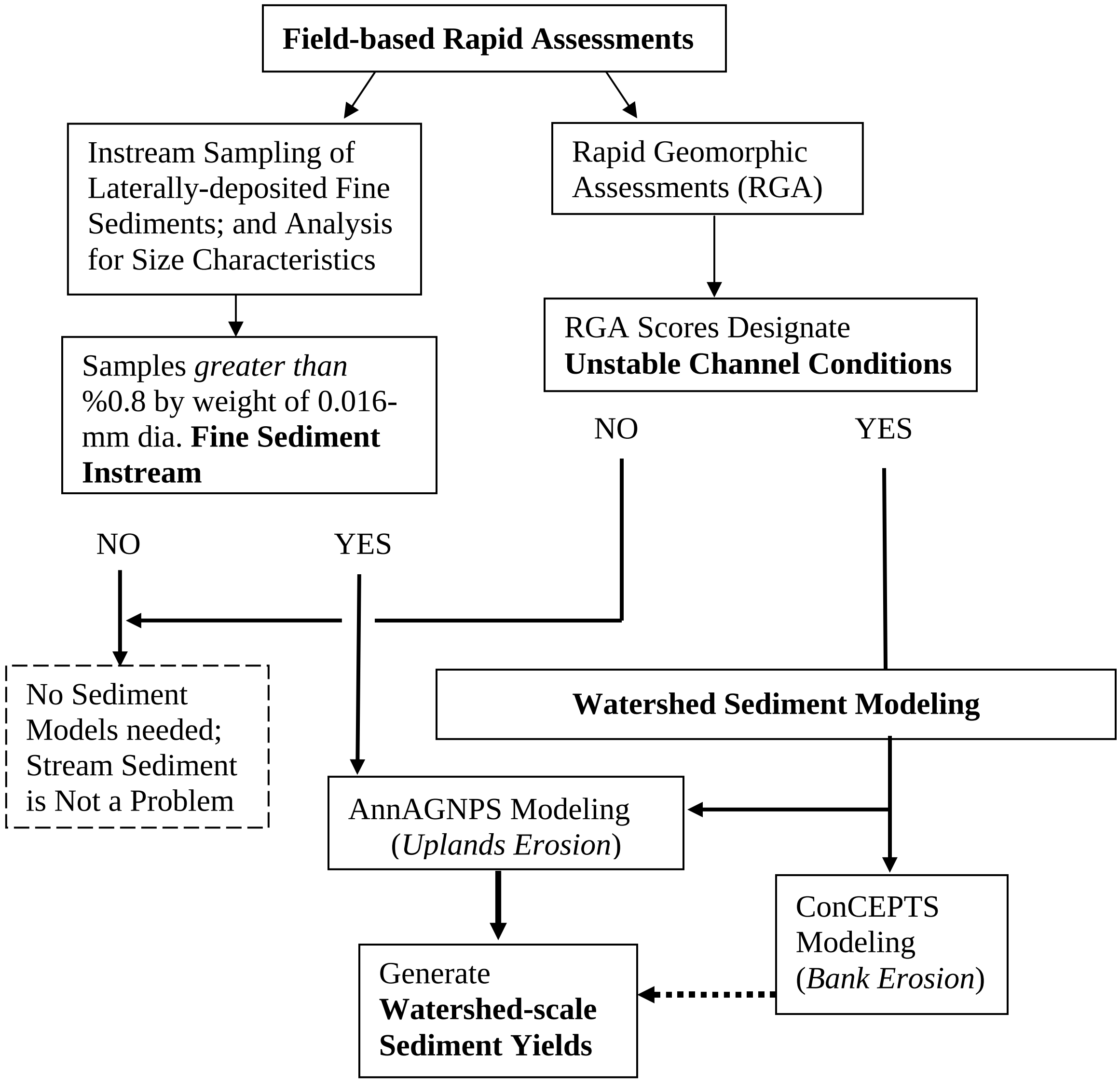
EXECUTIVE SUMMARY

Method Development for Watershed Sediment Budgets to Support the CHIA/PHC Process: A Focus on Sediment Modeling Estimating Sediment Loads

Permitting of coal-mining activities require the completion of a cumulative hydrologic impact assessments (CHIA) to fulfill the federal requirements of 30 CFR 773.16(e). In many designated cumulative impacts areas (CIAs), rivers and streams may be negatively impacted by sediment such that they no longer meet a state's biocriteria standards for the aquatic life designated use. Excessive sediment loads to rivers and streams are generated by many different human-related activities on the landscape, including active surface mining sites, pre-law mine operations (abandoned mine lands), coal-operation haul roads, oil and gas operations and their access roads, timber harvest or logging, dirt roads used by all-terrain vehicles (ATV), agriculture practices, and urban development. Because sediment is a major issue that must be addressed in a CHIA, technical staff with the Office of Surface Mining (OSM) would benefit from better geomorphic assessment and sediment modeling tools that aid in distinguishing sediment load source from different land disturbance types.

Geomorphic assessment and sediment modeling tools, organized as a set of protocols, can be used to develop watershed sediment budgets in which annual total sediment yields are estimated and percentages of the total yield are partitioned by source. Sediment budgets provide the spatially explicit data locating potential sources of excessive sediment erosion, and providing OSM a means to improve permitting with targeted best management practices (BMPs) for source controls. The main goals of this project were to: 1) evaluate a rapid geomorphic assessment (RGA) developed at the USDA National Sedimentation Laboratory (NSL) for application in Appalachian highland streams; 2) apply and evaluate AnnAGNPS and ConCEPTS sediment models; 3) investigate the utility of stream-uplands sampling techniques for sediment source identification, and 4) formulate a set of protocols that can be used in a CHIA's assessment of potential sediment impacts from surface mining. The study was preceded by the Phase I study, which evaluated the utility of the RGA, set-up the AnnAGNPS model for the testing in the New River basin, Tennessee, and evaluated the use of an upland geomorphic assessment. A complete copy of the Phase I Final Report can be downloaded from the OSM National Technology Transfer (NTT) Team, Applied Science Program (ASP) web page under 2006 completed projects: http://www.techtransfer.osmre.gov/ NTTMainSite/appliedscience/AScompleted.shtm.

The final evaluation of field-based geomorphic assessment and sediment modeling tools, from both Phase I and II study efforts found four sediment tools that could be applied in a cost-effective and comprehensive approach supporting CHIAs. As a set of protocols, the four tools included: 1) RGA; 2) fine sediment sampling on the streambed; 3) AnnAGNPS model; and 4) ConCEPTS model. Fine sediment sampling on the streambed is conducted by a unique technique relying on identifying instream depositional areas primarily in lateral point bars or behind large instream structures, i.e., logs and boulders. It is described in detail in this report where particle size distribution are analyzed for samples and an indicator metric is generated from it as '*%0.8 by weight of 0.016 mm diameter fine sediment*'. Recall, the 0.016 mm particle size is between medium and fine-grained silt on the Wenthworh scale. The suggested combined use of field-based rapid geomorphic assessment and sediment modeling tools is shown in a flow chart format that follows on the next page. Geomorphic assessments first identify whether an instream sediment and channel stability problems exist. If no problems are assessed, sediment modeling need not be applied to further characterize a problem and generating a sediment



Flowchart of Field-based Assessment and Sediment Modeling Tools for Proposed Use in Developing Watershed-scale Sediment Budgets

budget. A sediment budget accounts for erosion sources and estimates sediment yields transported out of a CHIA subwatershed. When a sediment model is applied, it spatially defines locations of major sediment sources providing OSM staff with valuable information to better specify BMPs in surface mining permits. The two models evaluated were AnnAGNPS, a GIS-driven model that can generate daily sediment yields in tons, and summarize multiple year simulations estimating an average annual yield for a specified period. AnnAGNPS accounts for uplands sources of sediment from erosion. If the stream channel is not stable, the ConCEPTS model routes sediment generated by AnnAGNPS model output throughout the watersheds, in addition to sediment from bank erosion. ConCEPTS model is necessary to accurately account for the sediment source due to bank erosion.

1.0 INTRODUCTION

Permitting of coal-mining activities require the completion of a cumulative hydrologic impact assessments (CHIA) to fulfill the federal requirements of 30 CFR 773.16(e). In many designated cumulative impacts areas (CIAs), rivers and streams may be negatively impacted by sediment such that they no longer meet a state's biocriteria standards for the aquatic life designated use. Excessive sediment loads to rivers and streams are generated by many different human-related activities on the landscape, including active surface mining sites, pre-law mine operations (abandoned mine lands), coal-operation haul roads, oil and gas operations and their access roads, timber harvest or logging, dirt roads used by all-terrain vehicles (ATV), agriculture practices, and urban development (Reid and Dunne 1996; Montgomery 1999; Jones *et al*. 2000; Nelson and Booth 2002). Because sediment is a major issue that must be addressed in a CHIA, technical staff with the Office of Surface Mining (OSM) would benefit from better geomorphic assessment and sediment modeling tools that aid in distinguishing sediment load source from different land disturbance types (OSM 2005a&b).

Geomorphic assessment and sediment modeling tools, organized as a set of protocols, can be used to develop watershed sediment budgets in which annual total sediment loads are estimated and percentages of the total load partitioned by source. Sediment budgets provide the spatially explicit data to locate potential sediment sources, providing OSM a means to improve permitting with targeted best management practices (BMPs) for source controls. In general, information derived by sediment budgets improves CIA management efforts throughout the Appalachian region. Of particular concern in the Tennessee CIA Area 8 is the New River watershed that drains into the Big South Fork River and National Recreational Area.

The main goals of this project were to: 1) evaluate a rapid geomorphic assessment (RGA) developed at the USDA National Sedimentation Laboratory (NSL) for application in Appalachian highland streams; 2) apply and evaluate AnnAGNPS and ConCEPTS sediment models in the Appalachian region; 3) investigate the utility of stream-uplands sampling techniques for sediment source identification, and 4) formulate a set of protocols that can be used in a CHIA's assessment of potential sediment impacts from surface mining. The RGA has been conducted throughout the United States (Simon 1989; Simon and Darby 1999; Simon *et al*. 2004a; Simon and Klimetz 2008). The AnnAGNPS is a watershed-scale hydrology and pollutant transport model used to predict water and sediment yields for various land management scenarios (USDA 2000). AnnAGNPS was primarily developed for agricultural lands and had not been tested in steep-sloped Appalachian landscapes. ConCEPTS is an one-dimensional instream hydraulic and sediment transport model with a dynamic bank failure module (Langedoen 2000). Reid and Dunne (1996) suggest *uplands-stream sediment sampling techniques* can be used to identify dominant sediment sources to streams and aid in the development of watershed sediment budgets.

After evaluation of these assessment and modeling tools by this study, those tools proved to have utility were merged into a set of protocols for developing sediment budgets with a focus on sediment source identification. The protocols provide OSM with an assessment framework to complete sediment elements of a CHIA. To support any field data collections, recommendations will be made on how field procedures for probable hydrologic consequences (PHCs) can be improved to support the efficient use of sediment assessment and modeling tools proposed in the protocols. In addition, other modeling tools are suggested for use within the overall set of protocols, complementing the tools tested in this study, are referenced in this document's concluding chapter. For example, CCHE2D a two-dimensional instream hydraulics and sediment model can be used for in local reaches with potential aggradation problems (Wu 2001; Zhang 2006; Johnson 2008), and the Bank Stability Toe Erosion Model (BSTEM) used to predict local bank failure based on a non-dynamic approach (Simon *et al*. 2009b).

This project consisted of two phases with this report focused on presenting results on the Phase II study. Phase I primarily supported the evaluation of the RGA (Schwartz *et al*. 2008a). In addition, Phase I set up the AnnAGNPS model with study findings used to guide the final selection of land use types incorporated into the Phase II study AnnAGNPS modeling. Project objectives and proposed outcomes are summarized in Section 2 of this report, followed by study background in Section 3. Section 3 provides brief descriptions on watershed sediment budgets, RGA, streambed and uplands sediment sampling, and AnnAGNPS and ConCEPTS models. Study design, methods, and project results are in Sections 4 through 7. Suggested protocols for sediment source identification and developing watershed sediment budgets are in Section 8.

2.0 PROJECT OBJECTIVES and OUTCOMES

This study investigates the use of sediment field-based assessment and computer-based modeling technologies, in which combined, generates information on sediment sources from uplands disturbed areas and hydrologically impacted stream banks, generating a sediment budget for the CHIA process. The specific objectives for the Phase II study include:

1) Develop and calibrate sediment models in CHIA subbasins in the New River (Tennessee), supporting protocol development for sediment source identification; additional subwatersheds will be added to enhance model development.
2) Test a new field-based approach of sediment source identification using sediment samples from upland disturbed areas and lateral depositional areas in stream channels.
3) Develop protocols for generating sediment budgets for CHIA size subwatersheds, incorporating recommendations for CHIA and PHC data collection.
4) Support organization of a technology transfer workshop on sediment sampling methods, rapid channel/hillslope geomorphic assessments, sediment modeling, and development of watershed sediment budgets for the Appalachian region.

Objectives for the Phase II study complement Phase I study objectives with the overall goal to provide OSM protocols with innovative assessment and modeling tools to develop watershed sediment budgets (Figure 1). Phase I results are in Schwartz *et al*. (2008a). To note, protocols suggested in this report are to be used at the *watershed scale*, and not the local scale of surface mining sites. Objective 4 of the Phase II effort was meant on August 12, 2008, in which a technology transfer workshop was held at the Knoxville Field Office.

3.0 BACKGROUND: GEOMORPHIC ASSESSMENTS AND SEDIMENT MODELS

In this section background information is provided on the importance of assessing instream sediment condition and estimating sediment yields with respect to water quality and biological integrity in rivers and streams located in the Appalachian region. The basic discussion on the development of watershed sediment budgets is provided in this section. Of the key assessment

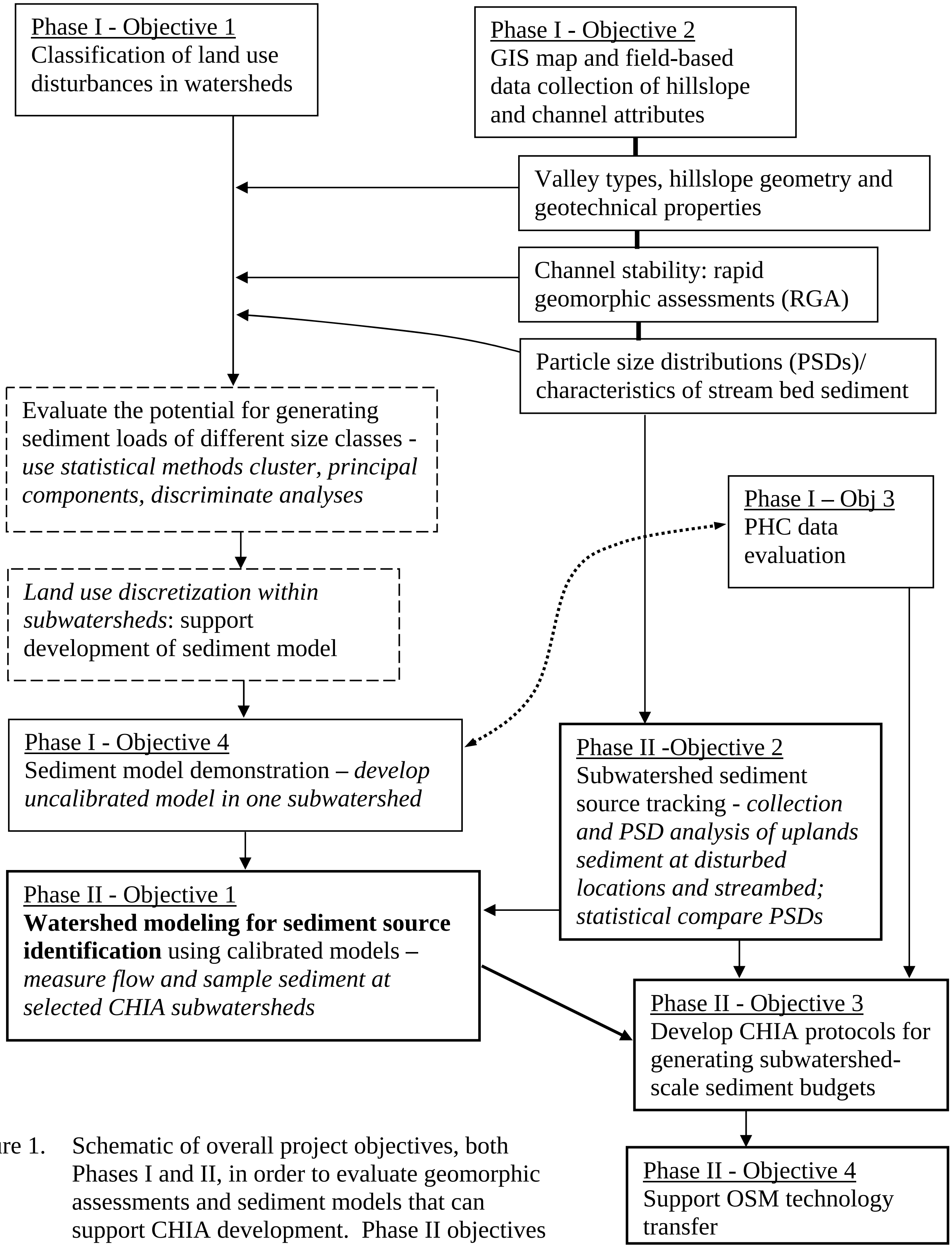


Figure 1. Schematic of overall project objectives, both Phases I and II, in order to evaluate geomorphic assessments and sediment models that can support CHIA development. Phase II objectives in bold text boxes. Note: PSDs = particle size distributions.

and modeling tools evaluated here within, each will be described and support documents referenced in this *Background* section. Tools included: 1) RGA, 2) field-based uplands-stream sediment sampling techniques, 3) AnnAGNPS model, and 4) ConCEPTS model. A summary of the Phase I work will also be provided as background to the Phase II work because together they were used to generate the final set of protocols for watershed investigation of potential water quality impacts due to sediment.

3.1 Impairment to Biological Integrity from Sediment

Of all the potential water quality impacts on stream biota in surface waters, sedimentation or siltation, the excessive erosion, transport, and deposition of sediment, is the most commonly cited reason for water quality impairment in United States [1996 National Water Quality Inventory; Section 305(b) Report to Congress]. As an example in the State of Tennessee, currently 863 stream reaches are designated on the state §303(d) list as water quality impaired, and over 45 percent of those streams are listed because of siltation and habitat alteration. Designated §303(d) streams require regulatory action by setting total maximum daily loads (TMDLs). Sediment impairment is defined by the degradation of aquatic life, whereby aquatic life is defined as the statutory "designated beneficial use" and sediment is the causative ecological stressor. Typically, development of sediment TMDLs have relied on setting a single target based on annual yields of sediment delivery from the universal soil loss equation (USLE), or annual suspended sediment concentration and load from reference watersheds (USEPA 1997, 1999; 2006; Simon *et al*. 2004a; Schwartz *et al*. 2008b; 2010). Once watershed sediment loads can be estimated, TMDL targets can be proposed. It is essential for a TMDL to establish scientifically sound links between sediment dynamics and ecological processes.

In general, aquatic biota is impacted by degradation of habitat quality when channels have rapidly adjusted to a landscape and/or channel disturbance. Excessive sediment suspension and deposition, including changes in particle size characteristics can impair lotic ecosystems by affecting their organism productivity and biodiversity (Wood and Armitage 1997). Abundance and diversity of macroinvertebrate community structure provides a good indicator of stream quality (Freeman 2004; TDEC 2003). Some macroinvertebrates such as the Ephemeroptera, Plecoptera, and Trichoptera taxa are very sensitive to fine sediment (Kaller 2004), while others such as Diptera and Chironomidae are resilient (Maul *et al*. 2004). Benthic macroinvertebrates and their species-specific sensitivities to pollution are commonly used biological integrity assessments (Barbour *et al*. 1999). Mussels and fish are also impacted by sedimentation and have been used as indicators to poor water quality (Bakaletz 1991; Evans 1998; Newcombe 2003). Effective implementation of best management practices (BMP) can improve biological integrity of impaired streams and keep healthy streams from becoming impaired (USEPA 1999).

3.2 Watershed Sediment Budgets

Watershed sediment budgets can provide natural resource managers a means to evaluate changes in erosion and sedimentation from various activities that disturb vegetated land covers (Reid and Dunne 1996; Fargas *et al*. 1997; Walling *et al*. 2002). A major concern is the amount of sediment that enters stream channels, how much sediment is transported from headwater areas to downstream reaches, and how excessive loads may change channel morphology and stream habitat. The ultimate goal is protection of water resources for the designated beneficial users (Section 3.1). Successful watershed management requires a comprehensive knowledge of the sediment budget, and the land and channel geomorphic processes governing instream sediment dynamics.

A sediment budget is an accounting of the sources and disposition of sediment as it travels from it point of origin to its eventual exit from a watershed (Reid and Dunne 1996). Uplands sediment sources typically identified include landslides, sheetwash on exposed non-vegetated land surfaces, gullies, drainage concentration by roads, excavation, stream bank erosion, treethrow, and animal activities (Figure 2). Sheetwash on exposed non-vegetated land surfaces can be from any human activities that expose soil to rainfall, i.e., logging roads, surface mines, and all-terrain vehicles (ATVs) trails. Each of these potential sediment sources in the uplands or hillslope areas vary widely per drainage basin and human activity (Dietrich *et al.* 1993; Whiting and Bradley 1993; Montgomery 1999; Kirby *et al*. 2002). The basic information that is needed for generating a sediment budget includes:

- type and location of the major natural and management-related sources of sediment,
- approximate amount of sediment contributed by each type of source,
- grain-size distribution of sediment contributed from each source,
- approximate sediment volume and grain sizes in storage along the stream channels, and
- approximate sediment transport rates, per sediment size class, that leaves the basin.

Each erosion process produces a characteristic size distribution of sediment (Walling *et al*. 1999; Whiting and King 2003). Sheetwash erosion generally carries off only the finer sediment present on the soil surface, while shallow landslides remove the entire soil column and produces

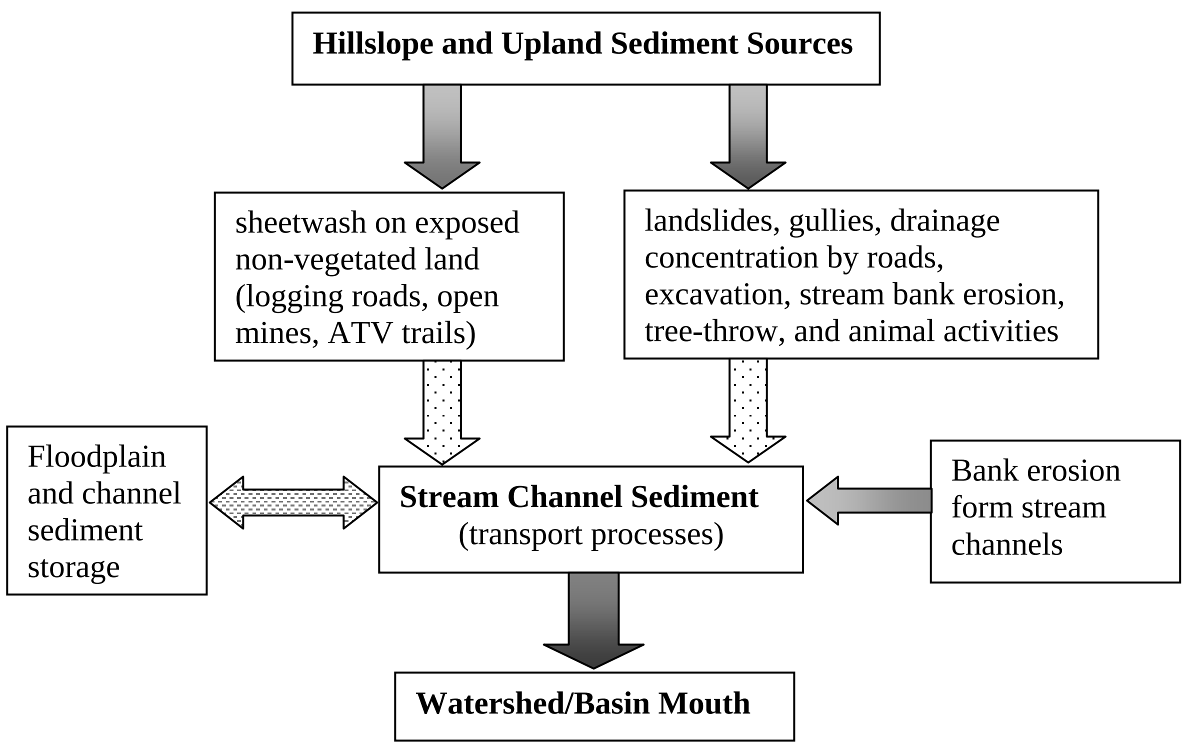


Figure 2. Flow chart of sediment dynamics in a watershed illustrating the components of a sediment budget.

sediment of the same size class distribution as the soil profile. As sediment is transported through the drainage network, hydraulic processes sort sediment sizes from its original source characteristics. However, Fryirs and Brierley (2001) found that size characteristics of sediment deposits in lateral stream channel areas correlated with size characteristics of the sediment sources from land use disturbances in an Australian watershed. Field surveys of bank condition provide a means to evaluate channel stability, and estimate volumes of sediment as a source or in channel storage. An understanding of how geomorphic processes change the nature of the sediment grain size from source origin to basin outlet is important. Characteristics size distribution of streambed sediment will be one useful diagnostic tool, in a suite of several, which support relating process rates to causal factors (Walling and Moorehead 1989; Harvey 2001).

Disturbances to the landscape from mining operations, logging, and agricultural can affect both flow and sediment regimes within the drainage network of a watershed (Knighton 1998; Montgomery 1999; Kirkby *et al*. 2002). Effects from land use changes can increase or decrease flows and sediment loads depending on the type and severity of disturbance (Dietrich *et al*. 1993; Newham *et al*. 2003). For example, clearing a large, steep, well-vegetated slope, and leaving the land exposed for a long period of time, will greatly increase flood flows and sediment load. Also disturbed watersheds with greater prolonged transpiration and reduced infiltration on compacted soils, reducing groundwater storage can lower stream baseflows (Burges *et al*. 1998; Jones *et al*. 2000). Flow and sediment load transported through channel control the morphological character of stream reach (Julien 1998; Knighton 1998). Other factors, including geology and vegetation also control channel morphology. Particularly in the steep mountainous areas of the Cumberland Plateau, geology can play a major play in governing channel morphology and adjustment processes, and must be considered in hydrologic assessments of sediment regime change (Babbit 2005). Typically when changes in flow and sediment regimes occur, channel morphology adjusts to the new regime outside the original equilibrium condition. Overtime as the landscape stabilizes from vegetation re-growth, channel morphology readjusts back to some equilibrium cross-sectional shape.

A geomorphic framework to rapidly assess hillslope erosion and channel stability provides a means to partition watershed areas into land surfaces with unique rates of sediment erosion and yields (Montgomery 1999; Wysocki *et al*. 2000). Methods for the rapid assessment of channel stability and hillslope erosion provide a means to evaluate geology, physiography, vegetation, and disturbances in the watershed with respect to the potential for sediment production. One approach using slope and geomorphic shape of the hillside was evaluated in the Phase I study (Schwartz *et al.* 2008a). Aerial photo imagery and GIS were used to spatially identify disturbed land locations, and designate different contributing area types to be incorporated into the AnnAGNPS model. In addition, an uplands-stream sediment sampling scheme was evaluated to for the tendency of uplands areas to produce sediment (Reid and Dunne 1996). The study examined hillslope land uses and conditions (such the presence of haul roads or the existence of logging operations or landslides) with respect to the potential to produce sediment.

Sediment budgets by land use activity within watersheds are typically derived by the combined use of aerial/satellite imagery, rapid field assessments, field sediment samples and particle size distribution analysis, and sediment yield models. GIS allows for spatially explicit data management, and supports sediment modeling. Sediment models can estimate approximate sediment transport rates, however land use and watershed physiographic data must be properly delineated in order to generate useful sediment budgets for management (Nelson and Booth 2002; Newham *et al*. 2003).

3.3 Study Summary of the Phase I Project

The key objectives of the Phase I study were to: 1) identify the potential land use disturbances in subwatersheds in the New River basin and evaluate a land use classification scheme that can be effectively used in a sediment delivery model, supported by a statistical analysis relating various GIS and field geomorphic measurements to subwatersheds with varying land use characteristics; 2) evaluate the utility of a RGA technique developed by the USDA NSL, to identify unstable stream channels in the Appalachian region caused by land use disturbances, and if applicable in this region, evaluate its usefulness for the CHIA process; 3) evaluate whether the AnnAGNPS sediment delivery model and ConCEPTS sediment transport model can provide useful output to support the CHIA process; and 4) discuss possibilities of improving PHC data collection, to better support the CHIA process utilizing a sediment delivery model (Figure 1). In order to complete these objectives, a study design included collection of GIS- and field-based geomorphic data among multiple stream assessment sites within three reference or undisturbed watersheds (Brimstone Creek, Frozen Head, and Greasy Creek), and four disturbed watersheds (Smokey Creek, Montgomery Fork, Ligias Fork, and Bull Creek).

A land use classification scheme was finalized and included the following types: current disturbed mine lands, abandoned mine lands, logging areas, and unpaved or dirt roads. Oil and gas operations and ATV trails were included into the dirt road classifications. Land cover represented undisturbed lands including: forest, pasture, shrub/scrub, grassland, developed land, pasture, and woody wetlands. Logging areas were classified into 100%, 75%, 50% and 25% vegetative cover. Dirt roads were classified into foot paths, low traffic intensity, and high traffic intensity, in which high traffic intensity represented the coal haul roads. Statistical analysis found that the land use classification scheme distinguished subwatersheds by their use activity. For example, Bull and Smokey creeks were found highly correlated with logging activities, and excessive fine sediment in the stream. The three reference streams did not correlate with attributes of excessive stream sediment, and statistically correlated with forest land cover. It was concluded that the land cover/use scheme developed in the Phase I study is applicable as the GIS land use data layer required as input for the Phase II AnnAGNPS modeling effort.

The RGA field technique provided a key outcome for understanding potential sources of sediment in the New River basin. Most sites surveyed were located in the headwater areas, and they were found to have stable channels, as distinguished by their low RGA scores (less than 10; possible range 0 to 36). Because the study sites used in this analysis were located in headwater streams, geologic controls appeared to be a major factor for the observed channel stability. Therefore, channels do not adjust from land use modifications in headwater areas. The RGA may have limited utility as a geomorphic assessment tool in upper headwater streams. However, utility of RGA is more appropriate in rivers and streams that lie in active floodplains with alluvium (e.g., lower reaches of Smokey Creek and Ligias Fork). Results from the RGA surveys indicated that bank erosion is not likely a major source of sediment delivered to the stream in upper reaches of Appalachian watersheds. In many cases, this indicates that the AnnAGNPS model can be used alone without coupling it with the ConCEPTS model where it is used to predict bank erosion and yields from bank mass failures and routes sediment through the stream channel. RGA surveys in a subwatershed provide OSM the justification whether to use the ConCEPTS model or not, recommendations for use would be if RGA scores are generally found to be above a score of 20. Otherwise, AnnAGNPS alone can be used to predict sediment yields from uplands sources.

As part of our field effort conducting RGA surveys, fine bed sediment was also collected and analyzed for particle size characteristics. Fine bed sediment samples collected in lateral deposition areas of streams appeared to be a useful and cost-effective rapid assessment for identifying streams potentially impacted by uplands land disturbances. Recent work in East Tennessee has found that the particle size near the 0.016-mm diameter (silt) correlated with TDEC's biological impairment indices for an impaired stream condition (Williams 2005). The Phase I study found when a bed sediment sample had greater than 0.8% of its particles less than 0.016 mm diameter size, the stream site occurred in a disturbed subwatershed. The metric '*0.8% finer of 0.016-mm diameter sediment*' has utility as a potential impairment indicator identifying streams impacted by excessive sedimentation.

In the Phase I effort it was determined that the AnnAGNPS model in an Appalachian mountainous watershed, or subwatershed, appeared to provide reasonable estimates of annual sediment yields and could identify sediment sources within a subwatershed. Information on sediment sources from different land use activities is vital information for the OSM. In other words, the model can generate a watershed sediment budget estimating the individual amounts of sediment yield generated from logging, mining, dirt roads, and other land cover/uses. Therefore, Phase II was proposed to further examine its utility with calibrated and verified model simulations, by comparing model output with field measurements.

A review of the PHC requirements was completed to evaluate whether better data could be collected to support the CHIA process, and input data for a sediment delivery model. The following assessments and field data needs were discussed in the Phase I report:

1.) Rapid geomorphic assessments (RGA) in channels;
2.) Fine bed sediment samples (collected in lateral depositions areas); and
3.) Stream flow and suspended sediment data needs for calibration and verification of a watershed-scale sediment delivery (AnnAGNPS model).

A complete copy of the Phase I Final Report can be downloaded from the OSM National Technology Transfer (NTT) Team, Applied Science Program (ASP) web page under 2006 completed projects:

http://www.techtransfer.osmre.gov/NTTMainSite/appliedscience/AScompleted.shtm.

3.4 Rapid Geomorphic Assessment for Stream Channel Stability

The USDA NSL developed a RGA to assess stream channel stability, and based it on the channel evolution model (Simon *et al*. 2004a; Simon and Klimetz 2008). A regular pattern of channel adjustment from equilibrium to non-equilibrium condition occurs when a watershed land surface is disturbed or a channel modified; followed by a return to an equilibrium condition (Simon 1995). Once back in an equilibrium condition, channel morphology is relatively stable, and sediment transport or dynamics is "normal." This regular pattern of channel adjustment from a landscape or channel disturbance has been described as the channel evolution model (Figure 3). The channel evolution model consists of six observed stages. They are described as follow.

I. *Pre-modified* – Stable bank conditions exist in this stage, meaning no mass wasting, and small, low angle bank slopes. Established woody vegetation is also present on the banks, and the bank shape often consists of a convex upper bank and a concave lower bank.

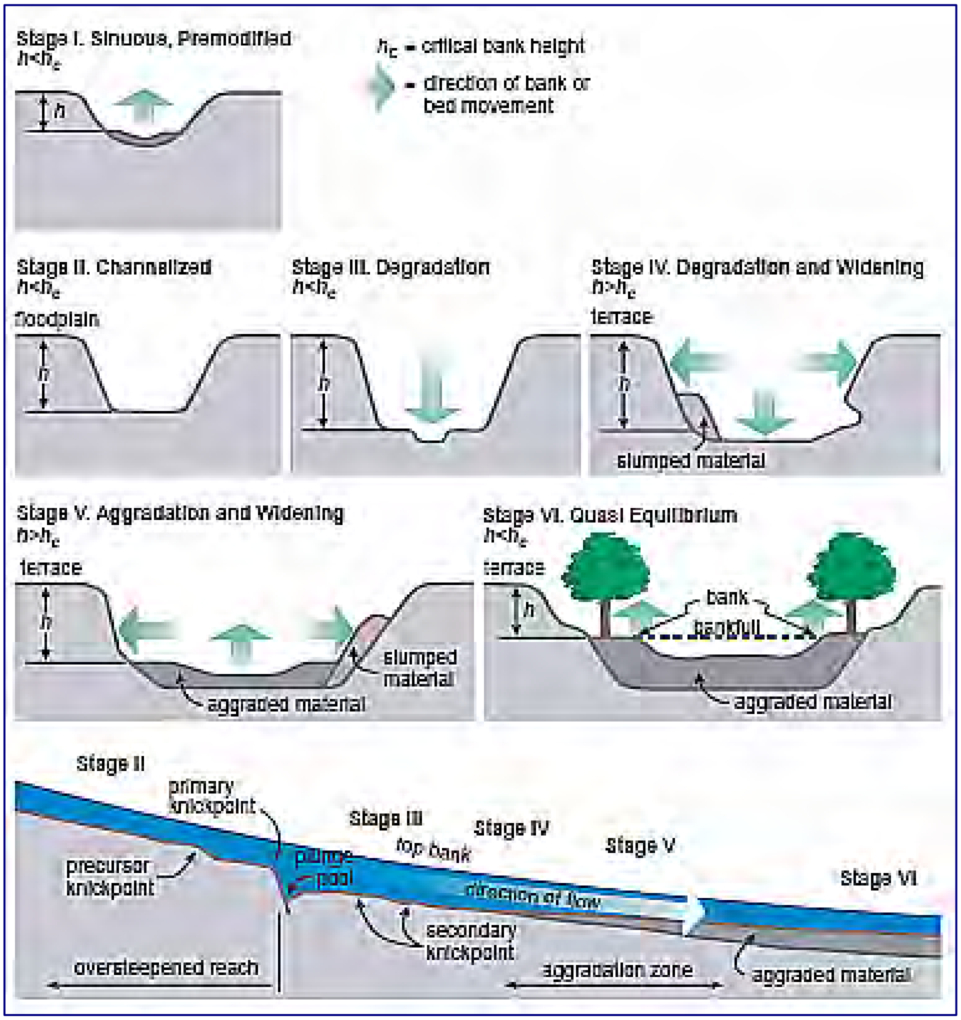


Figure 3. Channel evolution model that conceptually illustrates the changes in channel morphological in succession from unstable to stable conditions (modified from Simon *et al*. 2004a).

II. *Disturbed/Modified* – Artificial reshaping of existing banks has occurred in this stage. Vegetation is often removed and the banks are steepened, heightened, and made linear. It can also include hydromodification, a land use change than causes hydrology to be altered impacting a watershed's geomorphic equilibrium.

III. *Degradation* – The channel bed is lowering and, consequently, there is an increase in bank height. Incision occurs without widening. Bank toe material is often removed causing an increase in bank angle.

IV. *Threshold* – Degradation and basal erosion occurs, which results in incision and active channel widening, as well as mass wasting and extensive undercutting of banks. Due to the bank failures, trees and vegetation tend to lean and fall from the banks. Vertical bank faces may be present.

V. *Aggradation* – Deposition of material, often sand, occurs on the bed. The channel widens due to bank retreat, not incision. The bank profile has a concave shape and filed material is reworked and deposited. Floodplain terracing and channel meandering is also a trait of this stage.

VI. *Restabilization* – Reduction in bank heights and aggradation of the channel bed often occurs. There is also deposition on the upper bank that visibly buries vegetation. The banks have a convex shape, and floodplain terraces may occur.

Stages I and VI are considered the “reference” stream in equilibrium conditions (Simon *et al*. 2004a). The pre-modified stage, or Stage I, is the reference condition in pristine areas where disturbances either have not occurred or are minimal. The restabilization stage is considered the reference stream for reaches once equilibrium has been reestablished after disturbance. Similar geomorphic processes occur between low- and high-gradient systems, but geological and vegetation controls govern stability to a greater extend in high-gradient systems (Hey 1978). The RGA methodology is described in Section 5.1.

3.5 Characterization of Streambed and Uplands Sediments

Characteristics of streambed sediment provide a means to evaluate whether the stream is impacted by uplands disturbance where excessive fines enter the stream channel and cause biological impairment (Henley *et al*. 2000; Sutherland *et al*. 2002; Nietch *et al*. 2005; Yarnell *et al*. 2006). Fine sediment filling pore spaces within gravel-cobble streambed has been termed embeddedness, and it is has been identified as a stressor to some benthic organisms, fish and mussels (Barbour *et al*. 1999). Williams (2005) developed a unique sampling approach for fine sediment collection, where lateral deposition areas were sampled and quantified as an indicator to how much suspended sediment moves during flood events. It was found that % finer than 0.016 mm (silt) from these lateral deposition samples correlated with poor biotic integrity (RPBIII) scores, in addition to a significant correlation with RGA scores. This sampling approach for fine sediment was also used in this study and described in Section 5.2.2.

Traditionally, course streambed sediments are a key metric used to characterize channel morphological features. Wolman (1954) first described and published a field technique to characterize bed sediments. Since this 1954 publication, various researchers have modified the sampling approach although remaining consistent is the unbiased measurement of 100 bed particles (Rosgen 1996; Oslen *et al*. 2005; Garcia 2007; Simon and Klimetz 2008). The minimum number of 100 was determined statistically to provide a reasonable estimate on size distribution. The pebble count conducted on riffles provides an indication of the size of bed sediment transported during floods. This data is necessary for running the ConCEPTS model, or any sediment transport model (Section 3.7).

Uplands sediment sampling was used to evaluate the potential for sediment input to streams from uplands erosion, and certain assumptions were made about the sediment production characteristics of soils (Reid and Dunne 1996). These assumptions were: 1) when particle size distributions of upland and stream samples are similar it indicates upland sources are a dominant contributor to stream sediment; 2) low plasticity clay content of upland soils is an indicator of sediment production because this type of soil particle is not heavy and does not have enough plasticity to resist water run-off gradients; and 3) low shear strength for upland soils is an indicator of sediment production because soil uses its shear strength to overcome the forces of the water run-off gradient (Reid and Dunne 1996; Garcia 2007). Other watershed factors also influence the erosion and transport of fine sediment to stream including slopes of the valley and valley walls, and vegetative cover. The quantity and size of sediment material transported by channel flow are functions of flow velocity and turbulence, both of which increase as the slope steepens and the flow increases. Increased accumulation of flow tends to increase erosion. The larger the eroding material, the greater the velocity and turbulence must be to transport it (Garcia 2007). Physical properties of the soil affect both the detachment and transportation characteristics during erosion. Details on the sampling methodology are in Section 5.3.

3.6 AnnAGNPS Model

3.6.1 AnnAGNPS Model Introduction

The Annualized Agricultural Non-Point Source (AnnAGNPS) pollutant loading model is a dynamic extension of the AGNPS program and it was developed and maintained by the same personnel at the USDA National Sedimentation Laboratory (NSL) in Oxford, Mississippi. Like the AGNPS model, the AnnAGNPS model is written in the ANSI Standard FORTRAN 90 language and was originally developed for management scenarios in agricultural settings to control sediment, nutrient, and pesticide transport to nearby streams. In contrast to the AGNPS program, the AnnAGNPS system is used for long-term analysis of pollutant transport, where AGNPS is made for a single event simulation (USDA 2000). Even though the AnnAGNPS software was developed for analysis of agricultural management scenarios using various BMPs to conserve natural environmental resources, it has been implemented for other land cover disturbances in forested and urbanizing watersheds, and many regions in the country (Simon *et al.* 2002; Ming-Shu & Xiao-Yong 2004; Zhen *et al*. 2004; Thames 2005; Shrestha *et al*. 2006; Sarangi *et al*. 2007).

A model description was provided in the Phase I report and this report can be downloaded from the OSM National Technology Transfer (NTT) Team, Applied Science Program (ASP) web page under 2006 completed projects (*see report* Section 3.3, page 14). In addition, this web page has an AnnAGNPS model user's manual produced by M. Patrick Massey for download. The University of Tennessee MS thesis by Massey (2008) also contains a description of the model and model inputs. Relevant information associated with model input, and field data collection for model calibration and output verification follows.

3.6.2 AnnAGNPS Model Input Requirements

The AnnAGNPS pollutant loading model required a substantial amount of empirical data to correctly predict the hydrological and sediment-based elements occurring within a watershed. A brief summary table (Table 1) is shown to provide the sources of information used for the AnnAGNPS pollutant loading model with this study. The following sections describe the basic information used in the AnnAGNPS model.

Land Use. The land use/land cover data for the AnnAGNPS model was obtained from several sources. Initially, the land use/land cover GIS shape files for the study subwatersheds were obtained from the USGS Seamless Data Distribution System (http://seamless.usgs.gov/), but a noticeable difference from the 2001 USGS land use/land cover and actual conditions from field reconnaissance indicated that more information was required for an accurate analysis. OSM generously provided a recent 2006 USGS Land Cover GIS shape file with recent logging from local Tennessee Wildlife Resource Agency (TWRA) personnel, and surface mining GIS shape files, which defined disturbed areas not found on the USGS land use/land cover maps. OSM also provided aerial photographs taken in years 2005-2007 that were used to better classify current logging and surface mining activities. From the combination of GIS data from USGS, OSM, TWRA, and slight modifications to all of these files to match recent aerial and field maps of the area, the land use/land cover GIS map of the four subwatersheds of interest in the New

Table 1. Summary of data sources used in the AnnAGNPS model.

AnnAGNPS Required Data	Source of Data
Soils	Tabular & Spatial files from USDA-NRCS (Nashville District)
Land Use	General land use base map from USGS - Seamless Data Distribution System
	Updated/Modified with DOI-OSM Active & Abandoned Surface Mining Permitted Areas
	Updated/Modified with TWRA Forest Logging Permitted Areas
	Updated/Modified with USGS, DOI-OSM, & TWRA Haul Roads, Dirt Roads, & Trail Maps
	Updated/Modified with DOI-OSM 2006 Raster Images of the New River Basin
DEM	10-Meter Resolution Quad Maps provided by USGS & DOI-OSM
Climate	Full weather station used at the Big South Fork River & Recreation Area maintained by MesoWest
	Precipitation data for each sub-watershed was modified with 4-NOAA tipping bucket rain gauges maintained by DOI-OSM

River Basin were created for the AnnAGNPS-ArcView Interface. Each cell contained an attribute table that specifically defined the spatial land use/land cover patterns for hydrological computations. Figure 4 presents several polygons appended to the USGS land use GIS files, which represent recent forest logging and surface mining activities in each study subwatershed used in this study. Observed in Figure 4 are different polygons, which represent different severities of logging (25%, 50%, 75%, and 100% logged areas) and surface mining (abandoned and active). Variations of green polygon outlines were the four different classifications of logging while the red polygon outlines are for active and abandoned mining land uses. The numbers found inside each polygon are the different field identifications given to each land use. For areas that have 25%, 50%, 75%, and 100% logged, the associated field identification numbers are 101, 102, 103, and 104 respectively. For example, active mining has a field number of 201 while abandoned surface mined areas have are identified by the field number of 202.

Soils. The soil GIS shape files for the AnnAGNPS pollutant loading model were obtained from the USDA-NRCS Soil Data Mart (http://soildatamart.nrcs.usda.gov/). Once the GIS shape files of the different soil types are placed into the AnnAGNPS-ArcView Interface, a set of two National Soil Information System (NASIS) comma separated value (.csv) files must be loaded into the AnnAGNPS Input Editor to translate the graphical GIS shape files. The numerical soil information for the entire New River Basin was obtained by a state soil scientist with the USDA-NRCS office in Nashville, Tennessee. Initially the single NASIS soil file was sent as a text file (.txt) that contained all the soil information specifically for the use of AGNPS and AnnAGNPS models. The single NASIS soil text file had to be translated into two different comma separated value files to be imported into the AnnAGNPS model. The NASIS text file was sent to the NSL for proper conversion of the data into two distinct comma separated value files for the AnnAGNPS model. The soil files (defined as soil_layer.csv and soil_dat.csv) were imported into the AnnAGNPS Input Editor to correctly match and identify the numerical tables of data

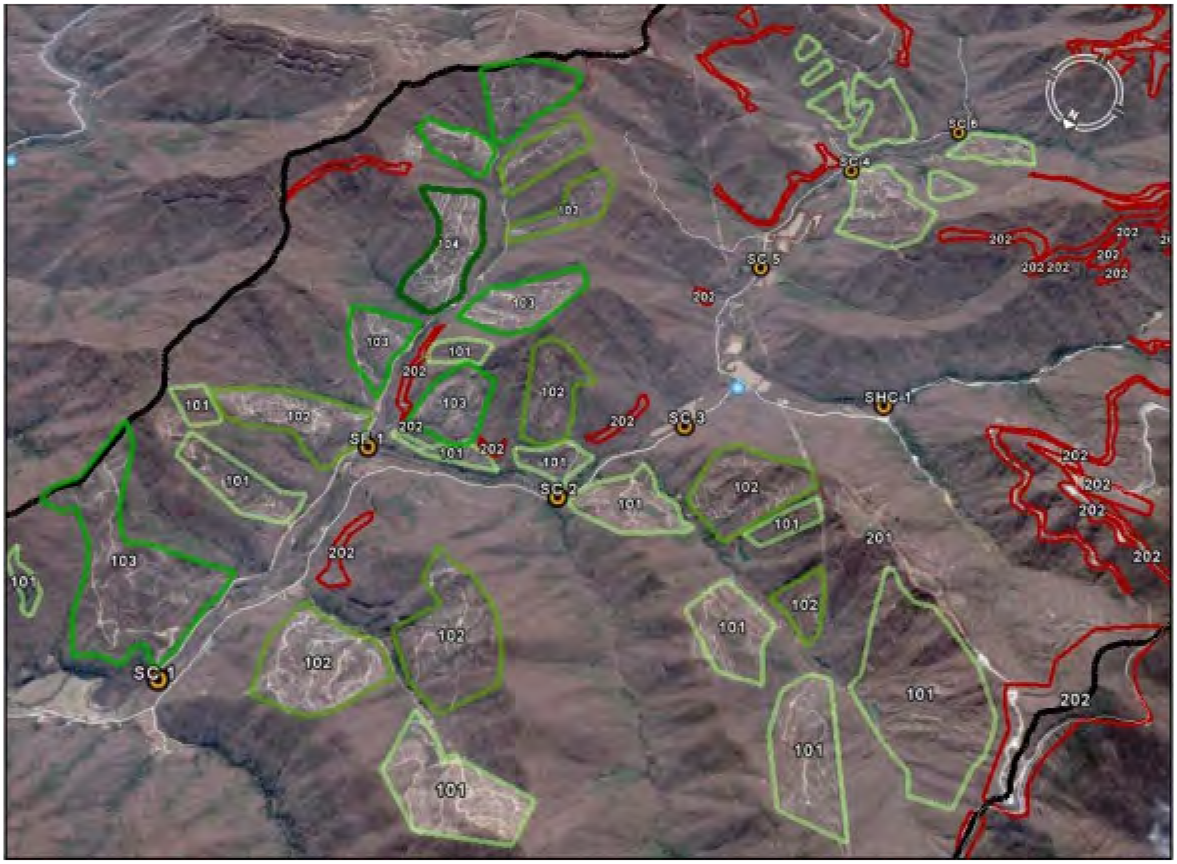


Figure 4. Example of land use polygons created for AnnAGNPS (aerial raster image taken from Google Earth, 2007).

with the polygons in the AnnAGNPS-ArcView GIS interface of USDA-NRCS soils in the four study subwatersheds in the New River Basin (Section 4.1).

Topography. The topography of the study subwatersheds of interest is represented by Digital Elevation Maps (DEMs). DEMs are a digital representation of topography maps and are useful for establishing a defined surface grid for computer simulations. Initially, a set of 30-m resolution DEMs of the entire New River Basin was obtained through the USGS Seamless Data Distribution System. To increase the accuracy of the AnnAGNPS model, a better resolution of the area was suggested. With the help of the local OSM office in Knoxville, Tennessee, a 10-m resolution display of the New River Basin in defined quad maps was provided for the analysis. After merging several 10-m DEMs with the AnnAGNPS-ArcView Interface, a single DEM grid for the area of interest in the New River Basin was created and used for the AnnAGNPS modeling in this study.

Climate. The climate of the study subwatersheds in the New River Basin is represented from the data measured by a weather station found at the Big South Fork River and Recreation Area in Scott County, Tennessee. The location of this weather station lies at an elevation of 440.5 meters and is found at latitude and longitude of 36.4750-N and 84.6542-W, respectively. The local weather station has been collecting data since 2003 through the MesoWest (University of Utah – Mountain Meteorology Group). For proper calibration of the AnnAGNPS model, a simulation period of four years (2005-2008) was selected to establish average annual erosion and sediment yield values for each of the study subwatersheds. Measured weather data for the period 2005-2008 were placed into the AnnAGNPS model. The program was initialized with normal historical climatic observations for the specific location of the New River Basin. The model's results during years 2007 and 2008 were compared with measured runoff and suspended sediment (Section 6.1). From the weather station, maximum temperature, minimum temperature, dew point, wind speed, and solar radiation were summarized in daily values from January 1, 2005 to March 7, 2008. Because precipitation data is one of the most critical sources of information needed for a calibrated AnnAGNPS model, four additional precipitation gauges were used in the surrounding New River Basin to better estimate specific precipitation at each study subwatershed. Additional precipitation gauge information was provided through the Automated Flood Warning System (AFWS) managed by the National Weather Service. These tipping bucket rain gauges are located at Buffalo Mountain, Cross Mountain, Walnut Mountain, and Adkins Mountain. Precipitation volume estimates for each station were weighted with the Big South Fork Weather Station (based on location and elevation) to determine an overall estimate of daily precipitation for each study subwatershed for calibration purposes.

Because of the size and the mountainous terrain of the subwatersheds found in the New River Basin, more climate measuring devices could be strategically placed to optimize the best results produced by AnnAGNPS model. However, because of the short duration of the Phase II study period, climate data used in the AnnAGNPS model was restricted to the closest available weather stations to the study subwatersheds. No new, long-term or temporary monitoring stations were identifies or installed within the any of the subwatersheds.

3.6.3. AnnAGNPS Model Input Parameters for Erosion Calibration

To establish an accurate simulation in the AnnAGNPS program, the watershed storm type, the 2-year 24-hour precipitation amount, the rainfall factor (R-factor), the ten-year frequency storm erosivity value (EI_{10}), and the storm erosivity (EI) distribution zone for the United States must be properly defined for each subwatershed hydrologically simulated. Using the *NRCS TR-55 Urban Hydrology for Small Watersheds* manual (USDA 1986), the study subwatersheds of the New River Basin fall into the Type II Rainfall Distribution. The manual is also used to estimate the 2-year 24-hour precipitation amount of the New River Basin, which is approximately 83 mm (3.25 inches).

Using the isoerodent map of the eastern United States from the *USDA-ARS Agriculture Handbook Number 703 - Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE)*, the R-factor is estimated to be 3,320 MJ-mm / ha-hr-yr (195 ft-tonsf-in / acre-hr-yr), the EI_{10} value is estimated to be 1362 MJ-mm / ha-hr (80 ft-tonsf-in / acre-hr), and an EI distribution zone of 109 for all subwatersheds is found within the New River Basin (Renard *et al*. 1997).

The AnnAGNPS model uses the SCS Runoff Curve Method found the in the *NRCS TR-55 Urban Hydrology for Small Watersheds*. The SCS Runoff Curve Number (CN) calculations are used to estimate the overland and subsurface flow of storm water for different land use/land cover as well as specific soil types. The general SCS runoff equation (USDA 1986) is defined as:

$$Q = \frac{[P - I_a]^2}{[P - I_a] + S}$$

where,

Q = runoff (mm); P = rainfall (mm);
S = potential maximum retention after runoff begins (mm);
I_a = initial abstraction (mm)

The soil retention, or storage variable (S) after runoff begins is largely based on the CN value assigned to a land use and its hydrologic soil group. Largely, the S variable, which defines the amount of the soil's retention ability, is what is used by the AnnAGNPS model to calculate the amount of storm water runoff. As seen in the equation below, S (mm) can be determined by the CN, defined for certain land uses and soils (USDA 1986). The initial abstraction (I_a) variable accounts for the hydrological losses before runoff begins, which includes water retained in surface depressions, interception, evapotranspiration, and infiltration. The I_a variable is determined from the soil's retention value (S) shown in the equation below.

$$S = 254\left(\frac{100}{CN} - 1\right) \qquad I_a = 0.2 \cdot S$$

As seen in the initial abstraction equation above, the I_a is only 20% of the soil's retention value (S). This 20% of the soil's retention value for the initial abstraction comes from a collaboration of many studies in small agricultural watersheds (USDA 1986). For the AnnAGNPS model, there will not be any storm water runoff generated if the daily precipitation value is less than the initial abstraction value.

Within the AnnAGNPS Input Editor, each land use/land cover defined in the subwatersheds contains many hydrological variables to better calculate runoff, erosion, and sediment yield. Initially, the CN for the hydrologic soil groups for each land use found in each subwatershed were selected from the *NRCS TR-55 Urban Hydrology for Small Watersheds* handbook (USDA 1986), suggestions from AGNPS User Manual, and previous AnnAGNPS models used by personnel at the USDA NSL. The CN values were slightly adjusted to better calibrate the AnnAGNPS model's land use activities with runoff and sediment yield. The CN values are not just dependant on land use alone; they are also defined by the hydrologic soil group for the same area for a single land use activity. The hydrologic soil group classifications (A, B, C, and D) are used in conjunction with land use activities to define the natural infiltration rate of the soil, which relates to amount of surface runoff per storm event.

Similar to the rainfall-runoff computations of the NRCS TR-55 model, the AnnAGNPS model uses typical Manning's n values for sheet flow, shallow concentrated flow, and channel flow to account for the roughness and drag of storm water transported throughout different land use environments. The Manning's n values are individually inserted into designated cells and reaches, by the user, within a watershed in the AnnAGNPS model. Typical Manning's n values for sheet flow, based on different land use classifications can be found in USDA (1986). For the AnnAGNPS model, the shallow concentrated flow Manning's n values are provided for either disturbed or non-disturbed areas, which are 0.05 and 0.025 respectively. The Manning's n values for channel flow conditions are defined for the reaches that connect cells of area in a watershed. Each reach can have a specific Manning's n value for open channel flow if desired, but the AnnAGNPS model automatically designates a general 0.04 value to each reach otherwise. For this study, Manning's n values were defined through calibration techniques for sheet, shallow, and concentrated flows within each cell and reach based on the dominant land use determined.

The next set of calibration parameters within the AnnAGNPS model is through the RUSLE (version 1.05) calculations. The RUSLE equation is primarily used for estimating average annual sheet and rill erosion, in terms of mega-grams (Mg), equivalent to a metric ton (t) per unit area. The RUSLE equation can be seen below (Renard *et al.* 1997).

$$A = R\ K\ L\ S\ C\ P$$

where,

A = average annual erosion rate (Mg / ha or t / ha)
R = rainfall-runoff erosivity factor (MJ mm / ha h)
K = soil erodibility factor (t ha h / ha MJ mm)
LS = topography factor (m/m)
C = cover management factor (dimensionless)
P = support practice factor (dimensionless)

Next, the RUSLE R-factor was estimated by use of the isoerodent map of the U.S. from Renard *et al.* (1997). This value is manually typed into the AnnAGNPS Input Editor from the location of the area of interest. The K-factor is an integration of the impacts of rainfall and runoff causing erosion on a plot of soil and is calculated in the AnnAGNPS model based on the soil properties entered for the watershed. The K-factor has historically been estimated by the use of nomographs. The analytical relationship of the nomograph is found in the following equation (Wischimeier *et al.* 1971).

$$K = \frac{(2.1\times10^{-4})(12-OM)(M^{1.14})+3.25(S_1-2)+2.5(P_1-3)}{100}$$

where,

K = soil erodibility factor (t ha h / ha MJ mm)
OM = percentage of organic matter (%)
M = primary particle size fractions (%)
S_1 = soil structure (1-4 based on soil characteristics)
P_1 = soil permeability (1-6 based soil drainage rate)

For the K-factor to be calculated, the primary particle size fraction function (M) is determined based on the percentages of silts (MS), very fine sands (VFS), and clays (CL) in the following equation (Hann *et al.* 1994).

$$M = (MS + VFS) \cdot (100 - CL)$$

Another RUSLE parameter required in the AnnAGNPS program is the LS-factor. The LS-factor is estimated from the topographical elevations defined by the DEM's in the GIS interface for the AnnAGNPS pollutant model for defined cells in the watershed.

One of the RUSLE parameters within the AnnAGNPS model to be used in the calibration process is the relationship of the different land use values with the RUSLE Cover-Management Factor (C-Factor). The C-factor can be broken into several sub-factors: Prior-Land Use (PLU), Canopy-Cover (CC), Surface-Cover (SC), Surface- Roughness (SR), and Surface-Moisture (SM). Using these C sub-factors, a soil loss ratio can be determined using the following equation, *next page* (Renard *et al.* 1997).

$$SLR = PLU \cdot CC \cdot SC \cdot SR \cdot SM$$

From the soil loss ratio and an EI value for a certain period of time, the C-Factor can be computed using the following equation (Renard *et al.* 1997).

$$C = \frac{\left[(SLR_1)(EI_1) + (SLR_2)(EI_2) + ... + (SLR_n)(EI_n)\right]}{EI_t}$$

where,

SLR_i = Soil loss ratio for time period i
EI_i = EI parameter for time period i
EI_t = Sum of the EI percentages for the entire time period

Thus, the program calculates the RUSLE C-Factor by analyzing multiple values seen in the Non-Crop Data Section of the AnnAGNPS Input Editor. The multiple C sub-factors used to calculate the RUSLE C-Factor in AnnAGNPS are the initial annual root mass, cover ratio, rainfall height, and surface residue cover values, which are associated with each land use type. The initial values used for the defined land use classifications within the four subwatersheds were estimated from AnnAGNPS simulations for sediment yield completed by Thames (2005), Simon *et al.* (2002), and Simon *et al.* (2004b). Once the model accurately predicted the daily runoff, the RUSLE C sub-factors were adjusted until the model produced an accurate sediment yield from each subwatershed.

Finally, the last parameter that is to be calibrated by the AnnAGNPS pollutant loading model is the Management Field data defined for each land use. The Management Field data for each land use consists of defining the percent rock cover, RUSLE P-factor, the type of erosion likely, and whether the land use is classified as cropland, urban, forest, pasture, or rangeland. Like that of the RUSLE C-factor values, the Management Field data parameters for each type of land use was initially estimated from AnnAGNPS models from the work of Thames (2005), Simon *et al*. (2002), and Simon *et al*. (2004b). The final Management Field data parameters used in this study are discussed in Section 5.7. To check the initial parameters used for each land use description in the AnnAGNPS model for each of the four study subwatersheds, storm water runoff and sediment yield from the program were matched with the stream discharge and suspended sediment measurements from specific storm events.

Just as the AnnAGNPS model uses the RUSLE equation to estimate the erosion for a defined plot of land, the following HUSLE equation is used to estimate the sediment yield from sheet and rill erosion from Theurer and Clark (1991).

$$S_y = 0.22 Q^{0.68} q_p^{0.95} KLSCP$$

where,

S_y = sediment yield (Mg / ha or t / ha)
Q = surface runoff volume (mm)
q_p = peak rate of surface runoff (mm / s)
K, L, S, C, P = RUSLE factors

Because RUSLE does not assume any deposition from sheet and rill erosion, AnnAGNPS uses HUSLE to create a delivery ratio to determine the deposition amount from erosion and sediment yield for five separate soil particles sizes (clay, silt, sand, small and large aggregates) based on each particle's mass fall velocity (Bingner *et al*. 2003). The sediment delivery ratio is estimated from an initial location in a cell at point "1" (time of concentration equal to zero) to a cell's outlet location at point "2" is shown in the following equation.

$$D_r = \frac{S_{y2}}{S_{y1}} = 0.95\left(\frac{q_{p1}}{q_{p2}}\right)$$

where,

D_r = delivery ratio from location "1" to "2"
S_{y1} = sediment yield at location "1" (Mg / ha or t / ha)
S_{y2} = sediment yield at location "2" (Mg / ha or t / ha)
q_{p1} = peak rate of surface runoff at location "1" (mm/s)
q_{p2} = peak rate of surface runoff at location "2" (mm/s)

3.6.4 Incorporation of Dirt Roads into AnnAGNPS Model

As observed during the Phase I field investigations, dirt roads were determined to be a major contributor of fine sediment into nearby streams. Many studies have reported large amounts of sediment entering streams from heavily used dirt roads in rural regions of the world (Costantini *et al*. 1999; Jones *et al*. 2000; Sidle *et al*. 2004; Shrestha *et al*. 2006; Sarangi *et al*. 2007; Sugden and Woods 2007). For example, Table 2 provides an example of how much sediment dirt roads can contribute in a watershed.

All the dirt and gravel road systems were drawn into the GIS land use shape file used in the AnnAGNPS model to incorporate different land use activities into the flow cells. Because the AnnAGNPS model's grid of flow cells only accept the largest land use activity within the same area of each flow cell, the dirt road were never recognized since their polygons dominated such a small portion of each flow cell. Therefore, it was evident that the program had to recognize the dirt roads into its sediment budget analysis before any further calibration could be completed. AnnAGNPS does not provide a direct point source option for sediment, as it does for many agriculturally-based pollutants, the classical gully function was used to roughly estimate the annual sediment yield generated from dirt roads in the New River (Section 5.7). From field observations, the dirt roads used for travel to logged areas, mined areas, and other locations, often contained drainage ditches and culverts that created gullies down to the local streams. From different storm events, grab samples were taken from a variety of different gullies, culverts, and drainage ditches carrying sediment from dirt roads in each subwatershed. The suspended sediment samples taken from the roads were further analyzed with the hydraulic components of the road drainage ways to estimate the amount of flow and suspended sediment that was required by the classical gully command in AnnAGNPS. Finally, each cell in each subwatershed contained a large percent of dirt roads (5,000 m^2 or 5% of a cell's area) was identified in the classical gully command to better estimate the sediment yield occurring at each subwatershed in the New River Basin (Section 5.7).

3.6.5 Merging AnnAGNPS Model Output with the ConCEPTS Model

Another unique characteristic of the AnnAGNPS pollutant loading model is its compatibility with the Conservational Channel Evolution and Pollutant Transport System (ConCEPTS), which individually models the long-term analysis of erosion and sediment transport processes between land and water (Section 3.7). ConCEPTS models streams within the watershed and their geomorphologic process as a result of runoff and sediment yield into the channels (Merritt *et al.* 2003). The ConCEPTS program was also developed and is continuously updated at the USDA NSL, but it is represented by a different set of scientists from that of the

Table 2. Erosion measurements on roads and paths (Reid and Dunne 1996).

Location	Road use	Gravel Depth (cm)	Slope (%)	Average Rainfall (mm/yr)	Soil Texture[1]	Soil Loss Rate[2] tons/(ha-yr-cm)
Washington	Abandoned	30	9	3500	sd-cl-lm	0.004
North Carolina	Light	0	5	2000	?	0.8
North Carolina	Light	5	8	2000	cl	0.5-1.0
North Carolina	Light	5	10	2000	sd	0.8-1.6
North Carolina	Light	15	5	2000	sd	0.06-0.12
North Carolina	Light	15	6	2000	cl	0.3
Washington	Light	30	9	3500	sd-cl-lm	0.03
Machakos, Kenya	Moderate	0	4	900	?	0.4-0.9
Machakos, Kenya	Moderate	0	14	900	?	1.0-2.8
Shinyanga, Tazania	Moderate	0	?	800	?	0.4-0.9
Shinyanga, Tazania	Moderate	0	1	900	sd-lm	0.8
Shinyanga, Tazania	Moderate	0	3	900	sd	1.1-1.4
Shinyanga, Tazania	Moderate	0	3	800	sd	1
Washington	Moderate	30	9	3500	sd-cl-lm	0.4
North Carolina	Heavy	0	5	2000	?	2.3
North Carolina	Heavy	5	10	2000	sd	1.6
North Carolina	Heavy	5	8	2000	cl	2.4
North Carolina	Heavy	15	5	2000	sd	0.2
North Carolina	Heavy	15	6	2000	cl	1.6
Washington	Heavy	30	9	3500	sd-cl-lm	2.3

Notes:

[1] Soil texture abbreviations: cl = clay, lm = loam, sd = sand

[2] Values for soil loss rate are in tons/(ha-yr) per cm of rainfall

AGNPS or AnnAGNPS model. With the AnnAGNPS and ConCEPTS programs combined together, a complete, continuous simulated analysis of a watershed can be studied for BMPs. When compared to other computer models that simulate the erosion and sediment yield of land surfaces and streams, an advantage of the AnnAGNPS model, a hillslope erosion model, is its ease of compatibility with a powerful channel sediment transport model (the ConCEPTS model) that together can represent the entire hydrological system of a watershed.

3.7 ConCEPTS Channel Sediment Transport Model

3.7.1 ConCEPTS Model Description

ConCEPTS is a one-dimensional hydraulic model capable of computing unsteady flow hydraulics and sediment transport capacity; and it also simulate change in channel morphology from bank erosion (Langendoen, 2000). ConCEPTS model was developed by the USDA NSL. ConCEPTS is composed of three physical-process components: 1) hydro-dynamics for unsteady flow hydraulics, 2) mobile bed dynamics for sediment transport and bed adjustment, and 3) bank erosion and channel widening from fluvial and geotechnical processes. The ConCEPTS modeling system has been designed to accompany the AnnAGNPS sediment delivery modeling system in absorbing the hydraulic contents collected from the cells in a watershed and representing the channel's response to the collected runoff, sediment, and increased flows during a storm event. The ConCEPTS model then predicts certain parameters that deal with channel morphology and open channel hydraulics, which include bank erosion, failures, mass wasting, and bed aggradations and degradations (Simon *et al.* 2002).

After AnnAGNPS cells have cumulatively determined the amount of stormwater and sediment runoff characteristics that enters the main stream channel through upstream reaches, the AnnAGNPS creates a set of output files that are loaded into ConCEPTS that contains the flow, peak discharge, time of concentration, and the sediment by particle sizes of clay, silt, and sand into the main stream (Section 3.6.5). The ConCEPTS model utilizes open channel hydraulics through numerical iterations of the dynamic or diffusion wave equations, including rapidly or gradually varied flow conditions. These equations consist of a continuity equation representing mass conservation of water and a momentum equation representing the conservation of fluid momentum. The model uses the generalized Preissman method of discretization, a forward time finite difference numerical method, to solve for the Saint Venant equations (also referred to as the dynamic wave equation). When the Saint Venant Equations that represent the mass conservation of water and conservation of fluid momentum are simplified, they produce the diffusion wave model (Sturm 2001). The ConCEPTS model switches between these two sets of equations with the use of the generalized Preissman scheme for governance in order to produce accurate and real hydraulic solutions for different stream parameters. Without the combination of two different versions of the Saint Venant Equations, ConCEPTS could calculate invalid results with certain situations.

Sediment transport is directly related to flow hydraulics, bed-material composition, and upstream sediment contribution (Langendoen, 2000). Through iterations with the mass conservation equation, the ConCEPTS is capable of predicting sediment transportation capacity and bed adjustment through sediment scour and aggradation dynamics. A modification of the sediment transport capacity predictor SEDTRA is used to calculate the total sediment transport by size fraction for 17 pre-defined size classes with a suitable transport equation for each size fraction (Table 3).

Langendoen (2000) states in order to model sediment transport in a stream, cross-section of the water's depth must be divided into two layers in order to simulate the movement of suspended bed sediment (wash load) and the particles that travel near the bed surface (bed load transport). In order to efficiently determine the sediment transport within the streams, ConCEPTS combines the bed and wash loads into a total sediment load approach. The calculation of sediment transport analysis begins with the mass conservation of sediment by size fraction with the entrainment and deposition rates computed based on cohesive or cohesionless homogeneous bed material for streams in disequilibrium. The sediment transport load under equilibrium is calculated with a modified sediment transport capacity predictor (SEDTRA) created by Garbrecht *et al.* (1996) that contains a mixture of transport equations for different sediment size fractions. With the program constantly calculating non-cohesive and cohesive streambed sediment concentrations, the ConCEPTS model uses another series of hydraulic equations to simulate over time variations in streambed elevation, and the sediment concentrations for surface and subsurface layers.

Within the ConCEPTS manual, Langendoen (2000) notes that after the sediment transport and streambed's surface adjustments have been calculated, the ConCEPTS model simulates the bank erosions and the corresponding change in the simulated channel's width due to fluvial

Table 3. Sediment size classes used in the ConCEPTS model.

Size Class	Lower Bound (mm)	Upper Bound (mm)	Description	Transport Equation
1	0	0.002	Total Clay	Washload
2	0.002	0.004	Very Fine Silt	Washload
3	0.004	0.008	Fine Silt	Washload
4	0.008	0.016	Medium Silt	Laursen
5	0.016	0.031	Coarse Silt	Laursen
6	0.031	0.063	Very Coarse Silt	Laursen
7	0.063	0.125	Very Fine Sand	Laursen
8	0.125	0.25	Fine Sand	Laursen
9	0.25	0.5	Medium Sand	Yang
10	0.5	1	Coarse Sand	Yang
11	1	2	Very Coarse Sand	Yang
12	2	4	Very Fine Gravel	Meyer-Peter and Mueller
13	4	8	Fine Gravel	Meyer-Peter and Mueller
14	8	16	Medium Gravel	Meyer-Peter and Mueller
15	16	32	Coarse Gravel	Meyer-Peter and Mueller
16	32	64	Very Coarse Gravel	Meyer-Peter and Mueller
17	64	128	Small Cobbles	Meyer-Peter and Mueller

erosion and mass bank failure. The fluvial erosion of stream banks is calculated using an excess shear stress approach for cohesive soils, which is based on the shear stress of the stream flow and the shear strength of the bank's soil. A submerged jet test device, developed by Hanson (1990), is a method used to help estimate the detachment rate for the calculation of fluvial erosions within ConCEPTS model.

When fluvial erosion heightens and erodes the toe of stream channel banks, mass wasting can occur due to the gravitational forces in nature creating enough shear stress to cause banks to fail. Langendoen (2000) states that the two types of bank failures simulated in ConCEPTS are 1) planar failure and 2) cantilever failure for homogeneous cohesive bank materials. They are the most frequent types of mass wasting events observed in the southern and western U.S. regions.

Channel width adjustments are modeled by incorporating the physical processes for bank retreat through fluvial erosion and mass bank failure (Langendoen 2000). The model accounts for cohesionless and cohesive bank material, and uses a multi-layer modeling approach to account for vertical differences in soil properties. Lateral bank erosion by fluvial process is based on the relationship of soil density and critical shear stress for soil entrainment (Mallison 2008). The rate of soil erosion is assumed to be approximately linear with increases in boundary shear stress. Fluvial erosion at the bank toe eventually causes bank instability resulting in mass wasting of the bank material. Bank instability depends on the balance between gravitational forces against the soil mass in a downward direction and the forces of friction and cohesion that resist mass movement. Vegetation on the bank affects the rate of width adjustment and mass failures, where its influence can be both stabilizing or destabilizing. Bank stability analysis is accomplished by limit equilibrium methods, based on static equilibrium of forces and or moments of a failure block. The forces acting on a failure block include (Figure 5):

1. the weight of the failure block, Ws
2. the weight of surface water on the failure block, Ww
3. the hydrostatic force exerted by the surface water on the vertical slip face, Fw
4. the hydrostatic for exerted by water in the tension crack, Ft
5. the seepage force, Fs
6. the shear force at the base of the failure block, S
7. the total normal force at the base of the failure block, N

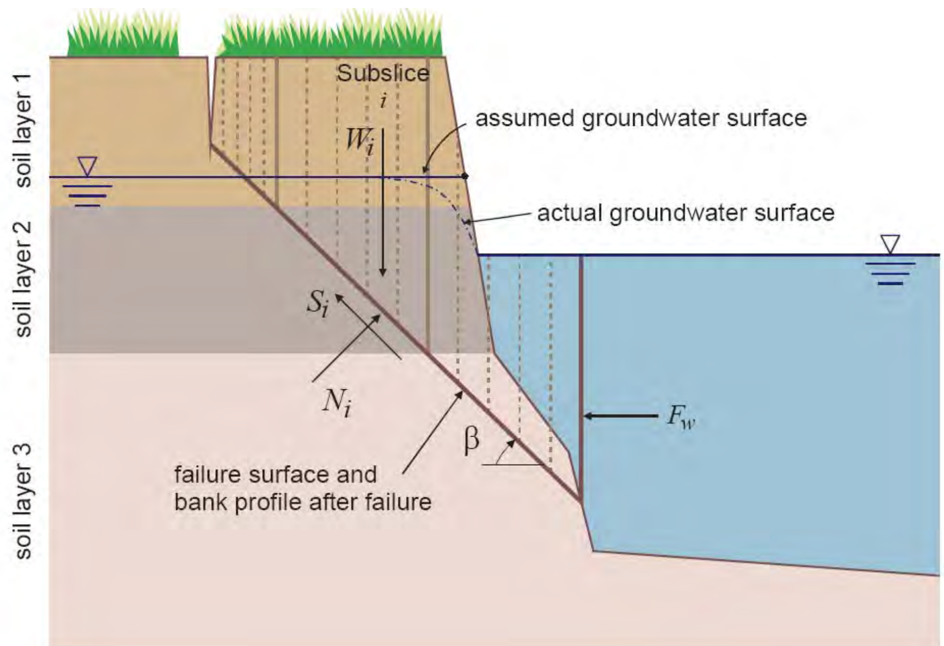


Figure 5. Summary of forces on a failure block used in ConCEPTS bank stability analysis (from Langendoen 2000).

To understand bank failure, Langendoen (2000) thoroughly describes the two types of bank failure simulated in ConCEPTS, planer failure and cantilever failure. The planar failure simulation divides the banks into cross-section slices with an established failure plane and applies all the surrounding natural forces and pressures to each slice in the horizontal and vertical directions. The geometrical and soil properties are then used to determine an adequate Factor of Safety (FS) value based on the shear strength of the bank soils. The calculated FS of the bank for different stages simulated in the channel is compared with a modified quadratic fitting process used in ConCEPTS to estimate the minimum FS, which determines whether planar failure occurs. The cantilever failure simulation also determines a FS value that is based on the weight of the overhanging bank that is based on the weight of the overhanging bank and the shear strength of the bank soil. When the calculated FS is compared to a minimum FS value selected by ConCEPTS model, the failures of the overhanging bank is determined.

Once the threshold for bank failure is surpassed, the bank block failures and the soil mass enters the channel. It is assumed that the soil mass from the block failure completely enters the channel as a lateral flux of sediment. The lateral flux of sediment is partitioned by size class, and added to the sediment mass governed by conservation laws (Section 6.2).

The prediction abilities of ConCEPTS model is very powerful aiding natural resource managers in making long-term decisions to better develop restoration designs and reduce impacts from stream instabilities and excessive sediment transport loads. When ConCEPTS model can be used with a watershed model like AnnAGNPS, a very comprehensive study of erosion and sediment transport can be analyzed for development of sediment budgets. Also, AnnAGNPS and ConCEPTS models combined have the capability to demonstrate channel evolution processes due to the land use/cover changes over long periods of time (Merritt *et al.* 2003).

ConCEPTS model was implemented in this project due to the ability of the model to: interpret output directly from the AnnAGNPS program (Section 3.6.5), compute unsteady flow hydraulics, compute in stream sediment transportation, and estimate channel widening due to bank failure. Input data required by ConCEPTS model includes: run control data, discharge data at the upstream boundary of the modeling reach, and channel geometry (Section 5.9).

3.7.2. ConCEPTS Model Use: Case Studies

ConCEPTS has been applied and validated in both flume studies and natural channels. Five case studies are mentioned in the following paragraphs to illustrate the application of the ConCEPTS model. Four case studies involved the application of the ConCEPTS model in natural channels, including Yalobusha River, Goodwin Creek, Kalamazoo River, and Shade Creek. One case study was concerned with validating the ConCEPTS model by comparing simulated and experimental flume study results.

ConCEPTS was used to simulate the channel morphology of a 42.4 kilometer-long reach of the Yalobusha River upstream of Grenada Lake, North Central Mississippi between 1967 and 1997 (Thomas and Langendoen 2002). The ultimate goal of the project was to determine the channels response to channelization on the Yalobusha River System. The hydraulic boundary conditions (i.e., historical inflows of water at the upstream boundary and tributaries) were provided by the computational hydrological model AnnAGNPS, and based on mean-daily historical rainfall. Simulated long-term statistics agree well with those measured. Simulated peak discharges up to 500 m^3/s are under predicted but flows above this, those that transport the most sediment, are adequately simulated by the combination of AnnAGNPS and ConCEPTS. Comparisons of morphological simulations, observed thalweg profile and channel top widths showed good agreement with r^2 values of 0.976 and 0.838 respectively. The largest discrepancy between observed and predicted values occurs with deposited sediment characteristics; this discrepancy is most notable within areas under the influence of a large channel sediment plug. The authors concluded that the model has limited simulation capability in areas with complex flow patterns (i.e., effects of woody vegetation and channel plugs), but provides reasonably accurate results for planning purposes and is the most applicable approach where historical or current channel conditions are not in equilibrium with existing or predicted sedimentological and hydrological inputs.

ConCEPTS model was implemented on a reach of Goodwin Creek, Mississippi to simulate bank erosion and channel widening (Langendoen *et al*. 2001). Model simulations incorporated data obtained over a five-year period, included eleven major failure episodes, and measured bank retreat up to 4.7 m. Results show ConCEPTS is adequately capable of simulating the undercutting of a stream bank. Due to the complex geomorphic processes involved with channel widening, erosion, and bank failure processes a slight error between measured and simulated results is expected. The retreat of the top of the outside bank, at the apex of the bend, was under predicted by an average of approximately 2 m. The authors concluded that the under predicted bank retreat can be attributed to the difference between simulated and actual shear stress at the toe of the bank. Simulated shear stress at the toe of the bank was most likely under predicted with respect to actual values, resulting in less lateral erosion with respect to simulated and actual site conditions.

Four dams constructed between the mid-1800s and the early 1900s along the Kalamazoo River between Plainwell and Allegan, Michigan have created impoundments that are acting as settling basins, trapping sediment and industrial waste materials from upstream sources (Wells *et al*. 2007). ConCEPTS was implemented to simulate three scenarios: 1) current channel conditions (Dams In), 2) instantaneous removal of two low-head dams (Dams Out), and 3) a design channel without the low head dams (Design) to asses the erosion, transport, and deposition of sediment along the simulated reach. The simulation included an 8.8 km reach of the Kalamazoo River between Plainwell and Otsego, Michigan over a 37-year period. Field data was collected and analyzed to provide geotechnical properties of the boundary sediments; this data provided the resistance of the boundary sediments to erosion. Boundary roughness was calibrated through measured and simulated water-surface elevations. The authors concluded that the bank erosion and bed erosion increased with the instantaneous removal of the two low-head dams. A net deposition resulted in the current channel simulation along the study reach. The design simulation resulted in the least amount of deposition without any erosion. The design case showed a decrease in deposition of 3,840 tons/yr. The 'Dams Out' scenario resulted in a 19,200 tons/yr of erosion at the downstream boundary.

ConCEPTS was implemented on Shades Creek, Alabama to evaluate the effects of urbanization on channel erosion and bed-material gradation and the effects of stream bank stabilization on sediment yield (Simon *et al*. 2004b). Four modeling scenarios were conducted to investigate a range of past, current and potential future conditions in the watershed. The scenarios included: 1) a validation scenario using past land use data, 2) effects of current land use changes on sediment loads and bed-material composition, 3) effects of future land use changes on sediment loads and bed material composition, and 4) effects of generic bank stabilization along actively widening reaches on sediment loads and bed-material composition. Simulated annual runoff for the validation scenario and $Q_{1.5}$ event was 22% less than and within 5% of measured values, respectively. Both runoff and average annual suspended-sediment load showed only minor differences between simulations, except for the future land-use modeling scenario. Increases in sediment load in the future land use modeling scenario can be attributed to the increase in runoff rates caused the replacement of forested lands with urban development. The majority of Shades Creek's sediment emanates from stream bank erosion. Results show that the computational models accurately simulated a reduction in suspended sediment loads with an increase in bank protection. A 40% reduction of suspended load resulted by protecting 11% of the stream length. Results show that ConCEPTS can successfully simulate a reduction in suspended sediment with an increase in bank protection. The authors conclude that the combination of the AnnAGNPS and ConCEPTS models can provide adequately accurate results of suspended sediment loading and transport for planning purposes.

The most recent paper focuses on the validation of ConCEPTS with respect to simulating streamflow hydraulics and the evolution of graded streambeds in incised streams (Langendoen and Alonso 2008). Degradation was validated by comparing simulated results with laboratory experiments conducted by Ashida and Michiue (1971). Flume experiments were conducted to study the degradation of a graded streambed and the development of an armor layer with a clear water inflow. The rate of erosion is under predicted, but the simulated final depth or erosion agrees well with experimental measurements. The simulated sand-sized fraction, particularly between 0.5 and 2 mm are slightly over predicted. However, ConCEPTS predicts both the rate of development and the final grain-size distribution of the armor layer well. The degradation rate is under predicted because the transport capacity computed by SEDTRA in the first few hours of the experiment is too small. Overall the final erosion depths and grain-size distribution of the streambed are accurately simulated by ConCEPTS. Additionally, the capabilities of ConCEPTS to simulate bed profile and surface and subsurface composition of aggrading streams was tested using data based on a study conducted at the Saint Anthony Falls Laboratory, University of Minnesota. Langendoen and Alonso (2008) report the simulated evolution of the bed and final water surface profiles agree well with those observed. In addition, the simulated geometric mean of the grain-size distribution of the deposit and surface layers agrees very well with that of measured data. Both longitudinal and vertical fining of the deposition simulated accurately. The downstream and vertical changes in percent sand were simulated accurately within the deposition, but percent sand is approximately 6% too large in the surface layer.

4.0 STUDY DESIGN

4.1 Study Area: New River Basin

The study area, located in the mountainous Cumberland Plateau region of Tennessee, is within the New River Basin (Figures 6 and 7). The New River Basin has seen a long history of forest harvesting and coal mining since the late 1800's (Gardner 2006). The New River begins near the Frozen Head State Park of Tennessee (which is just north of Oliver Springs, Tennessee and east of Wartburg, Tennessee) and forms the outlet of the basin when it intersects with the Clear Fork stream. At the New River and Clear Fork confluence, the South Fork Cumberland River begins near the 497 km^2 (192 mi^2) Big South Fork National River and Recreation Area. The New River Basin, which is just southeast of the Big South Fork National River and Recreation Area contains a drainage area of 1,026 km^2 (396 mi2) and is completely contained in Anderson, Campbell, Morgan, and Scott counties of Tennessee (Carey 1984). The New River Basin is a subbasin of the SF Cumberland Basin (HUC 05130104). It contains a rugged terrain ranging in elevation from 335 m to 1,006 m (1,100 ft to 3,300 ft) with an average hillslope of 25% (Overton 1980).

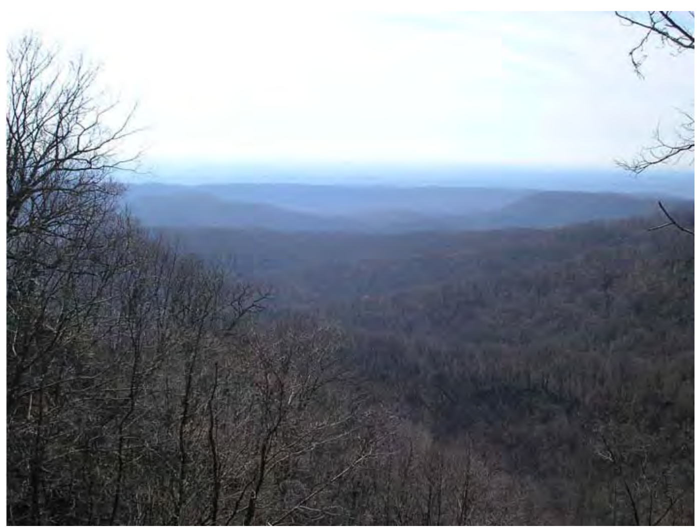


Figure 6. Overlooking the New River basin at Windrock Mountain (2006).

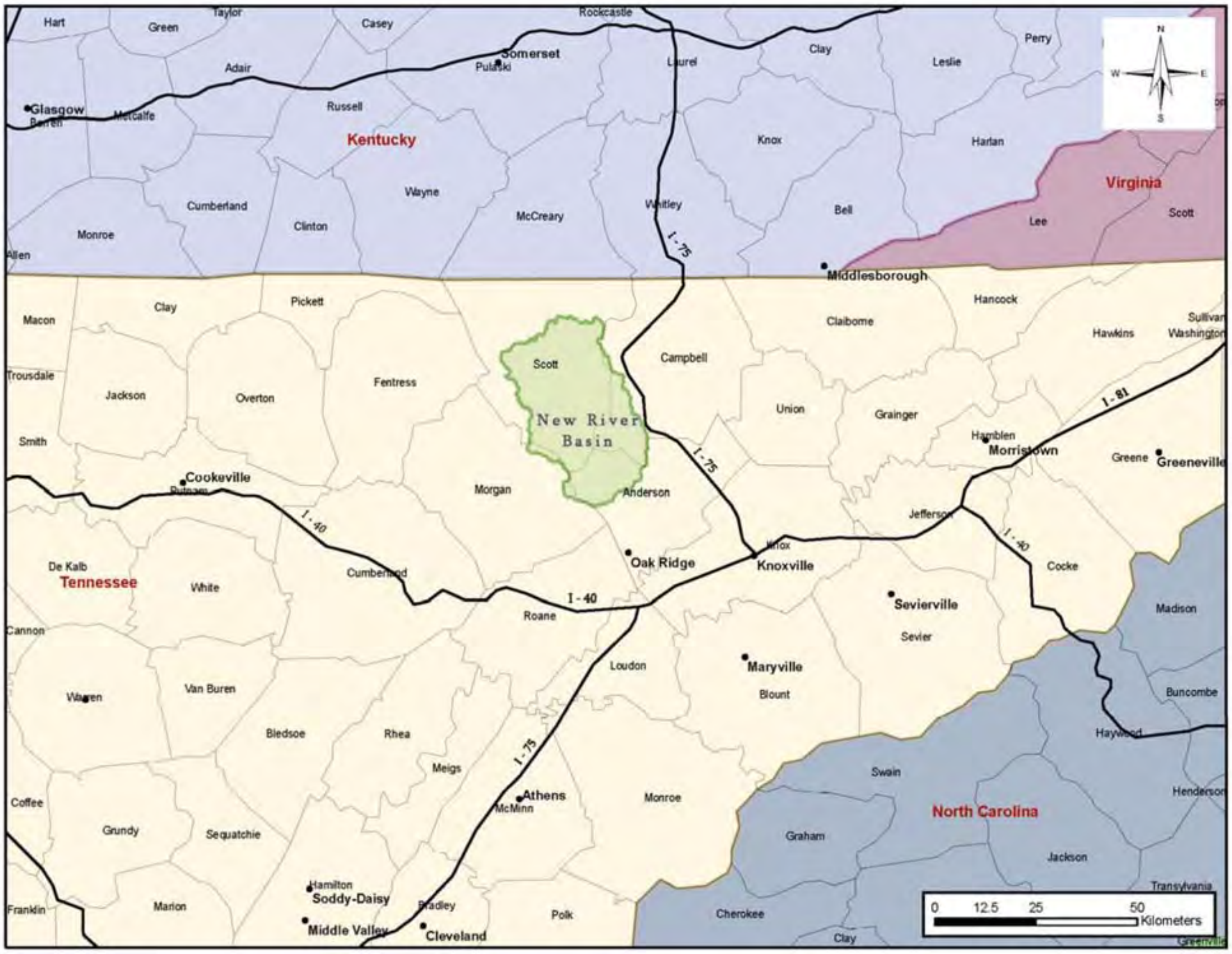


Figure 7. Location map of the New River Basin, Tennessee.

The New River Basin is located in the humid climatic regions and has a moderate average annual temperature of 12.3°C (54.2°F) and an abundant 1,358 mm (53.4 inches) of annual rainfall. The area's climate tends to be the warmest in the month of July, which has an average temperature of 23.3°C (73.9°F), while the coldest time of the year occurs in the month of January with an average temperature of 1.0°C (33.8°F) (NOAA 2002). Therefore, this area observes warm to hot summers and generally mild winters.

In general, this area receives an annual average value of 1,270 mm (50 inches) of rainfall and 432 mm (17 in) of snowfall in the mountains (Overton 1980). Typically in the New River Basin, March appears to receive the highest volumes of rainfall with a value about 133 mm (5 in) but precipitation continues throughout the summer months with monthly volumes about 127 mm (5 in). Autumn season of September through October in this area usually receives the least rainfall at about 76 mm (3 in).

The New River Basin is part of the Appalachian Plateau physiographic region, locally called the Cumberland Plateau in the Kentucky, Tennessee, and Alabama areas (USGS 2003). The geologic formations of the Cumberland Plateau are from the Mississippian (360-320 million years ago) and the Pennsylvanian periods (320-296 million years ago). The sediments that were hardened during these geologic periods created an abundance of coal, shale, sandstone, and limestone within the area (NPS 2007). With a large amount of these rock types in the region, there are a vast amount of caves, karsts, cliffs, waterfalls, and boulders. The soils of the basin are diverse and range from deep loamy and clayey soils on the mountains to well drained, moderately deep clay subsoils and silty clay topsoils on ridge tops, to well drained silty clay loam soils at lower elevations (Overton 1980).

4.2 Study Area: Subwatersheds Defined

Four subwatersheds in the New River Basin were selected for study based on variations of rural land use disturbances observed (Table 4). Of the four subwatersheds, three of them have been impacted by several land use activities: Montgomery Fork, Ligias Fork, and Smokey Creek (Figure 8). The fourth subwatershed was Brimstone Creek subwatershed, and it was selected as the minimally-disturbed or reference subwatershed in order to compare sediment modeling results with disturbed subwatersheds. Figure 8 also shows the locations of the streambed sediment collections (Section 5.2).

Montgomery Fork, Ligias Fork, and Smokey Creek all contain a considerable amount of land use activities including: forest logging, abandoned surface mined areas (reclaimed and un-reclaimed), and dirt road travel (Table 4). The only potential non-point sediment sources found within the reference subwatershed, Brimstone Creek, were small percentages of dirt roads, logging, and abandoned mining areas near the watershed boundaries.

4.3 Study Design

The main objective of this study was to evaluate the performance of the AnnAGNPS model in mountainous, forested watersheds, and assess its applicability as a potential CHIA tool. The four study subwatersheds, as identified in Figure 8, represented a mix of land uses along a continuum of minimally disturbed (Brimstone) to disturbed (Ligias, Montgomery, and Smokey) subwatersheds. Having this range of land use mixes within each subwatershed provided a means to examine sediment yields generated from the AnnAGNPS model. The Phase II effort consisted of collecting field data to calibrate and verify the model output, in contrast to the Phase I effort that consisted of model set up and evaluate what land use categories should be incorporated into the model. Methods on field data collected, and model calibration and verification are described in Section 5.0. The AnnAGNPS model provides the essential application to generate sediment budgets that differentiates yields per source in a subwatershed.

Additional study efforts included development and evaluation of field-based assessment and laboratory analysis approaches to identify streams that are being impacted by uplands sediment erosion. Development of these approaches is important because employing the AnnAGNPS model can be time consuming, and should be used when streams are impacted and a model is needed to test possible management scenarios through BMP implementation. Two approaches were tested in this Phase II effort: 1) examine whether the average annual hillslope sediment yield estimated by the AnnAGNPS model correlated with measured fine particle size characteristics collected at specific streambed deposition points; and 2) examine whether fine particle size characteristics collected at specific streambed deposition points correlated with soil samples collected at uplands disturbed sites. Sediment sampling on the streambed and at uplands sites occurred in the same four subwatersheds as the AnnAGNPS modeling effort. Correlations between uplands soil characteristics and streambed fine sediments would support the development of a sediments-impacts assessment methodology that can be used for CHIA reports.

Table 4: Land use/cover during 2006 defined for the four study subwatersheds in the New River Basin.

Land Use Classification	Watershed Area Occupied Smokey Creek (m^2)	Smokey Creek (%)	Ligias Fork (m^2)	Ligias Fork (%)	Montgomery Fork (m^2)	Montgomery Fork (%)	Brimstone Creek (m^2)	Brimstone Creek (%)
100% Logged	580,098	0.67%	0	0.00%	0	0.00%	0	0.00%
75% Logged	2,886,302	3.33%	4,213	0.01%	743,932	1.30%	0	0.00%
50% Logged	3,177,084	3.66%	707,456	1.33%	1,159,430	2.02%	603,400	1.80%
25% Logged	5,261,740	6.07%	2,176,537	4.10%	4,669,355	8.13%	521,068	1.55%
Abandoned Surface Mining	3,851,843	4.44%	3,624,669	6.83%	1,821,261	3.17%	607,920	1.81%
Active Surface Mining	506,845	0.58%	242,875	0.46%	362,261	0.63%	0	0.00%
Dirt Roads	833,694	0.96%	708,265	1.33%	495,703	0.86%	148,130	0.44%
Developed, Open Space	1,920,556	2.21%	755,674	1.42%	1,286,000	2.24%	533,214	1.59%
Developed, Low Intensity	44,510	0.05%	26,868	0.05%	872	0.00%	4,605	0.01%
Developed, Medium Intensity	0	0.00%	15,903	0.03%	6,630	0.01%	0	0.00%
Barren Land (Rock/Sand/Clay)	16,628	0.02%	17,565	0.03%	2,689	0.00%	0	0.00%
Deciduous Forest	63,678,228	73.40%	40,069,883	75.45%	45,178,748	78.66%	27,998,743	83.40%
Evergreen Forest	3,254	0.00%	13,959	0.03%	38,483	0.07%	105,319	0.31%
Mixed Forest	2,212,644	2.55%	3,298,107	6.21%	1,432,744	2.49%	2,538,730	7.56%
Shrub/Scrub	429,477	0.50%	14,328	0.03%	37,868	0.07%	47,580	0.14%
Grassland/Herbaceous	965,015	1.11%	1,361,588	2.56%	164,453	0.29%	188,390	0.56%
Pasture/Hay	296,366	0.34%	71,824	0.14%	9,568	0.02%	273,577	0.81%
Woody Wetlands	87,401	0.10%	0	0.00%	25,550	0.04%	2,279	0.01%
Total	86,751,582	100.00%	53,104,609	100.00%	57,435,358	100.00%	33,572,998	100.00%

Note: Data used is from a combination of sources (USGS, DOI-OSM, & TWRA) with modifications from 2006 Arial Photography (Raster Images).

The final product, combining the findings from Phase I and II efforts, is a flow chart of tools to be used for sediment impacts assessments, and modeling of sediment yields for the development of subwatershed sediment budgets. The flow chart provides a "road map" of tools and outcomes, and the CHIA developer can choice the level of effort required for CIA-specific needs. This chart also incorporates the use of the ConCEPTS model, evaluated for use in CHIA applications when severe bank erosion and mass failures are a concern.

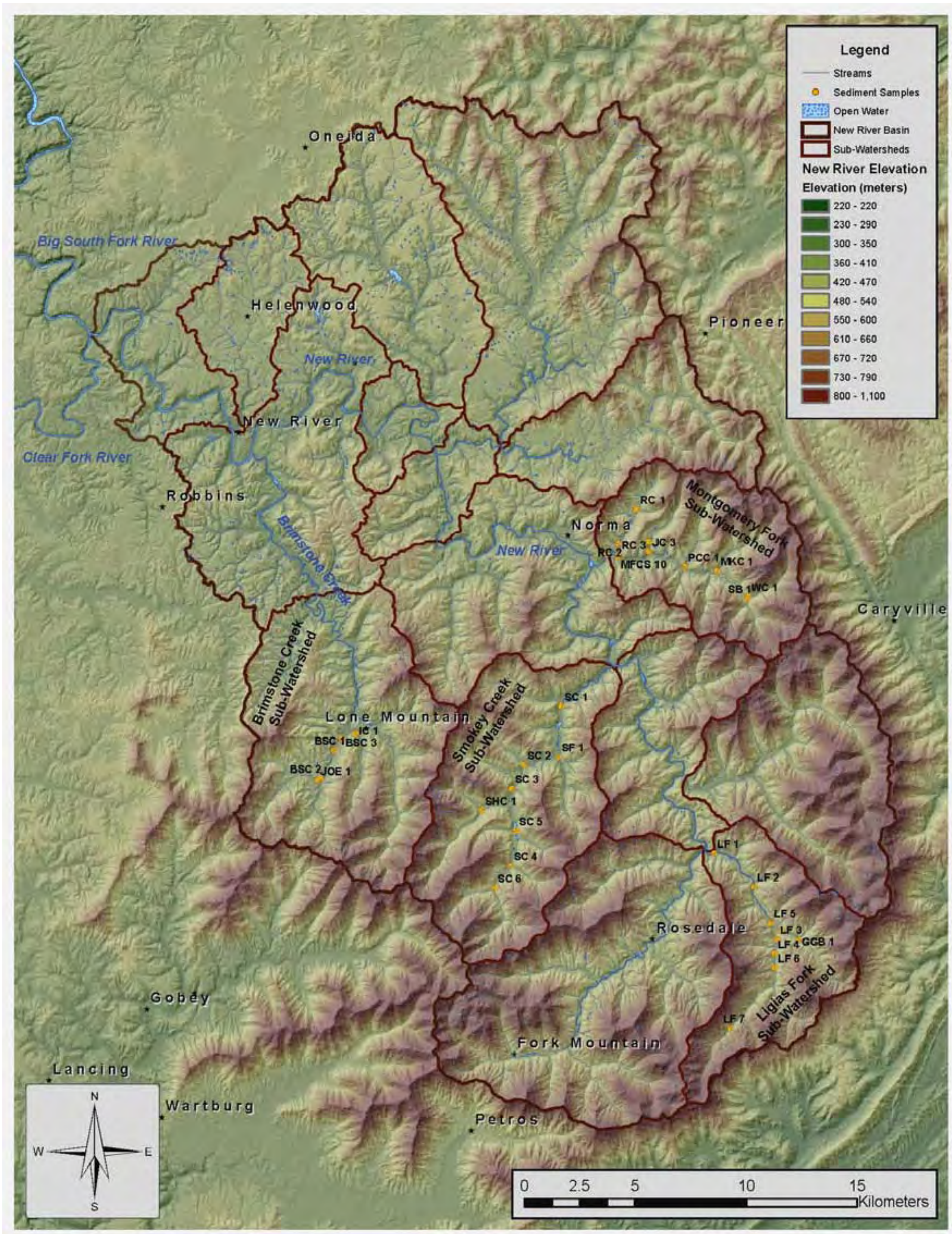


Figure 8: Location map of the four study subwatersheds in the New River Basin. Selected bed sediment sample sites are shown; complete list of sites with NAD83 UTM coordinates are in Table 7.

5.0 STUDY METHODS

5.1 Rapid Geomorphic Assessment for Stream Channel Stability

A RGA is implemented to generate a channel stability index value through a field-based ranking scheme, in which 9 different channel geomorphic conditions are ranked between 0 and 4 (Table 5, Appendix A). The total RGA index score ranges between 0 and 36, in which lower scores represent more stable channels and higher scores represent more unstable channel conditions. RGA scores of 0 or 36 are not possible, but do define the assessment domain. Through NSL experience, a RGA below 10 is considered stable, and above 20 a channel is considered unstable. Channels with scores between 10 and 20, stability is based on the stage of channel evolution, in which Stage I and VI channels would be considered stable, and Stage II, III, IV and V channels would be considered unstable. Overall, this geomorphic assessment of streams evaluates the relative amount of sediment contributed by bank erosion, one of the potential sediment sources for a watershed sediment budget.

The RGA requires several in-field tasks to be conducted in order to characterize a stream reach's stability. The survey length for a stream reach was approximately equal to 6 to 10 channel widths. More than one reach should be surveyed to evaluate the extent of any channel stabilities in an entire CHIA watershed. In general, a reach was identified for a survey, and basic site data are collected as listed in Table 6. Channel slope can be estimated for each reach using a hand level, or an automatic level and stadia rod. Slope is not directly used in the RGA index score. A pebble count was also conducted at a riffle or point bar to characterize the course material that is transported during flood events (Section 5.2.1). While conducting RGAs for each stream site a Garmin™ GPSMap 76 was used to record the coordinates of each site within five meters of accuracy. Photographs were taken for survey documentation. Once the initial site data has been collected, the RGA ranking scheme was conducted, each geomorphic condition ranked, and all of the 9 assessment scores are summed to obtain a single index score that characterizes the stability of a stream. Geomorphic conditions are described next, as follows.

Table 5. Geomorphic conditions used for the RGA.

RGA Geomorphic Condition Parameter	**Description**
Primary bed material	Bed sediment is categorized as bedrock, boulder/cobble, gravel, sand, or silt clay.
Bed/bank protection	Marked if the bed or banks are artificially protected, and whether it is one or both banks that are protected.
Degree of incision	Ratio of water depth in the channel thalweg by the bankfull height.
Degree of constriction	Obstructions are present within the channel making the upstream width differ from the downstream width of the stream.
Stream bank erosion	Surface erosion by fluvial processes or geotechnical mass wasting.
Stream bank instability	Characterizes the percent each bank is failing.
Established riparian woody-vegetative cover	Amount of permanent vegetation growing on the stream banks is estimated by the amount of vegetation with woody stems.
Bank accretion	Percentage of the reach with fluvial deposition of material.
Stage of evolution	Consult Figure 3, determine the channel's stage of evolution channel.

Table 6. Summarized details of the RGA form's required data.

Object	Information Required
River	River or stream name required, as found on Topographical maps
Site Identifier	Site number as given by pre-determined numbering scheme
Date	Month/Day/Year
Crew	Initials of personnel present
Samples Taken	Number of Particle Counts, Particle Size Bulk Sample
Pictures	Upstream, Downstream, & Cross-sectional views
Slope	As calculated using distance/drop of thalweg
Pattern	Label as: Meandering (a stream following a sinuous path), Straight (a stream that has a straight course), or Braided (where the channel splits into a number of different smaller channels with islands separating them)

The *Primary Bed Material* consists of five different bed material categories; they are: bedrock, boulder/cobble, gravel, sand, and silt/clay. As the bed material gets smaller in diameter, the RGA value increases, indicating a channel that has more potential to change geomorphologically during stream high-flow stages. Bedrock bed material can be quite noticeable on a stream reach and is recorded if it is observed as a dominant feature throughout the stream reach. The boulder/cobble bed material category is defined by a majority of aggregates greater than 64.0 mm in diameter. The gravel bed material is defined by a majority of bed particles that contain a median diameter between 64.0 mm and 2.00 mm. The sand bed material is defined by a majority of bed particles that contain a median diameter between 2.00 mm to 0.63 mm. Finally, the silt/clay bed material is defined by a majority of bed particles that contain a median diameter less than 0.63 mm. In developing the particle size distribution, if the sample is greater than 15% sand and silt/clay fractions then a sample of fines are collected for laboratory sieving and resulting fractions are proportionally added to the size distribution.

The *Bed/Bank Protection* is a two-part question that scores the site's stream reach based on artificial protection. To answer this question, first determine whether the bed is protected by artificial modifications such as rip rap or concrete, then note whether there are one or two banks protected by an artificial substance. If there are no artificial protections found in the stream site the total score of the bed/bank protection should be equal to one. If a site had only one bank protected, the bed/bank protection would have a score of 3.0.

The *Degree of Incision* classification scores the stream site on the degree of geomorphic occurrences of channel deepening over time. This question is determined by dividing the depth of water at the deepest point at the cross-section (of the stream site) by the vertical bank height.

The *Degree of Constriction* classification is a score that represents the amount of unnatural changes around the stream's environment have occurred. In other words, the degree of constriction is largely influenced around structures in or adjacent to the stream, which impede its natural course of travel. This category is an approximate percent of the site's stream reach that decreases in top-bank width from up to downstream.

The *Stream Bank Erosion* category is used to characterize the type of current erosion that is taking place on the left and right banks looking upstream. Note that the traditional RGA form suggests looking downstream to classify the left and right banks. This question should answer what type, if any, erosion is relevant for the left and right banks. Fluvial erosion is defined as a slow erosional process at the banks by moving floodwater. Fluvial erosion is commonly seen where there is open soil not shielded by bank vegetation slowly creating undercutting at the bank toe. Mass wasting is the movement of large amounts of material from the bank(s) from a geotechnical failure.

Stream Bank Instablility is an approximate percentage given to each bank to indicate the percentage of stream reach that exhibits mass wasting of the banks. Note that the left and right banks, like that of the Stream Bank Erosion category, are defined by looking upstream.

Established Riparian Woody-Vegetation Cover is an approximate percentage of permanent vegetation (omitting grass) grown on each stream bank, for the entire stream reach analyzed.

Occurrence of Bank Accretion is another approximate percentage of stream reach banks (both left and right banks looking upstream) that contains fluvial deposition (fines, sands, gravels). Depositions include point bars and lateral floodplain sedimentation.

The last condition is the *Stage of Channel Evolution* defines the geomorphological stage of the channel at the present time (Figure 3; Table 1). There are a total of six different stages with Stage I representing pre-disturbed stable bank conditions, Stages III to V indicating unstable channel conditions, and Stage VI representing a post-disturbed, stable channel condition.

Additional information on the RGA methodology can be obtained from the Phase I 2006 Applied Science Report and MS thesis by Massey (2008). Webpage links are as follow:

http://www.techtransfer.osmre.gov/NTTMainSite/appliedscience/AScompleted.shtm.
http://etd.utk.edu/2008/MasseyPatrick.pdf

5.2 Streambed Sediment Characterization

Course and fine streambed sediments were characterized by two separate methods; they were the: 1) modified Wolman pebble count at riffles; and 2) collection of fine bed sediment in uniquely defined depositional areas, respectively. Both methods are described below in detail. The location of sampled streambed sediment in each subwatershed was chosen to best represent the overall stream network for each subwatershed. By taking sediment samples on various stream locations where hillslope sediment yields differ from varying land use disturbances, the study could relate stream sediment characteristics with land use composition (Figure 8). Overall, 33 streambed sediment samples were collected as part of the Phase II study (Table 7). At each sediment collection site for course and fine bed substrates, RGA measurements were also taken.

5.2.1 Course Bed Sediments: Sampling and Analysis

Pebble counts within the stream and at riffles were completed after fine sediment was sampled, so that movement within the stream would not alter lateral deposition areas. A *modified* Wolman pebble count can be used in contrast to the original pebble count method described in Wolman (1954). The original Wolman pebble count uses a 3-ft square box with 10 by 10 grid constructed or wire designating the location to collected particles in the stream. In contrast to the modified pebble count, a stretched 30-m tape across a stream channel is used to collect particles at equal intervals along the tape. Small streams require the tape to be stretched across the channel at several locations. In both field methods 100 particles are collected, measured, and recorded (Section 3.5). By a particle (grain) size distribution frequency analysis, the 100 particle size measurements are used to compute a median streambed diameter (D50), and a streambed diameter that is larger than 84% of the majority of the streambed material (D84).

Table 7. Location and site numbers of streambed collection sites within the four study subwatersheds: Brimstone Creek, Ligias Fork, Montgomery Fork, and Smokey Creek.

GPS Site ID No. (---)	Study Subwatershed (---)	Easting-Northing NAD-83 UTM COORDINATES (meters)	(meters)	Elevation (meters)
BSC 1	Brimstone Creek	724,066	4,014,829	399
BSC 2	Brimstone Creek	723,488	4,013,568	425
BSC 3	Brimstone Creek	724,437	4,015,349	381
IC 1	Brimstone Creek	725,053	4,015,581	404
JOE 1	Brimstone Creek	723,332	4,013,459	409
GGB 1	Ligias Fork	745,010	4,006,255	469
GGB 2	Ligias Fork	744,253	4,006,655	438
LF 1	Ligias Fork	741,210	4,010,193	408
LF 2	Ligias Fork	743,011	4,008,626	374
LF 3	Ligias Fork	744,046	4,006,282	456
LF 4	Ligias Fork	743,938	4,005,627	468
LF 5	Ligias Fork	743,772	4,007,003	436
LF 6	Ligias Fork	743,954	4,004,977	471
LF 7	Ligias Fork	741,900	4,002,280	575
MFCS 1	Montgomery Fork	736,370	4,023,646	367
MFCS 10	Montgomery Fork	736,889	4,023,545	372
RC 1	Montgomery Fork	737,758	4,025,733	455
RC 2	Montgomery Fork	736,918	4,024,137	400
RC 3	Montgomery Fork	736,927	4,023,644	380
JC 1	Montgomery Fork	738,320	4,024,237	421
JC 3	Montgomery Fork	738,304	4,023,789	391
MKC 1	Montgomery Fork	741,339	4,022,921	477
PCC 1	Montgomery Fork	739,890	4,023,088	394
SB 1	Montgomery Fork	742,711	4,021,671	483
WC 1	Montgomery Fork	742,741	4,021,748	476
SC 1	Smokey Creek	734,326	4,016,826	382
SC 2	Smokey Creek	732,652	4,014,181	399
SC 3	Smokey Creek	732,095	4,013,103	410
SC 4	Smokey Creek	732,053	4,009,619	449
SC 5	Smokey Creek	732,287	4,011,204	436
SC 6	Smokey Creek	731,326	4,008,590	451
SF 1	Smokey Creek	734,213	4,014,525	390
SHC 1	Smokey Creek	730,765	4,012,125	438

5.2.2 Fine Bed Sediments: Collection Methods and Assessment

Fine bed sediments were collected at specific locations in the channel where fine sediments tend to settle out during high flow (flood) events. The locations are mostly lateral areas where hydraulic recirculation zones occur in a stream. Common areas include the tail end of a submerged point bar, sidebars, behind large roughness elements (i.e., fallen trees, logs, large boulders), and elevated side channels. This study uses procedure described by Williams (2005) to collect fine bed sediment at these depositional areas, in which a priority is given to the collection of fine bed sediments at point bars, then a side bar. Finally, if a point bar or side bar could not be located for a suitable sediment sample, depositional areas behind large objects (boulders and logs) within the stream were used. The basic concept is that high flows carry suspended sediment loads (fine sediments) delivered to the channel from the hillslopes or stored with in channel. This load in transport during floods represents a relevant land cover disturbance condition in a watershed, and what settles in these depositional areas represents a “history” of the transported load. Therefore in theory, characteristics of the fine bed sediment in these “lateral” areas should be indirectly related to levels of disturbance on the landscape.

Fine bed sediment was collected with a modified McNeil stainless steel sediment sampler that is 20.2-cm long and has an inside diameter of 7.1-cm (Figure 9). The McNeil sampler has been shown to obtain a consistent and accurate estimate for bed composition in streams (Young *et al.* 1991). For every stream site, the stainless steel sediment sampler was used to scoop up a representative sediment distribution from a depositional point in the stream reach with one single scoop. In order to not lose any fine material, the mouth of the sediment sampler was oriented to face the upstream flow of the stream. Once the material from the sediment sampler was acquired, the fine sediments (and some bed pore water) were carefully poured into a plastic container with the RGA site number and date marked. All sediment particles that remained in the sediment sampler after the initial dispense were carefully rinsed so as to not affect future samples. Samples were collected from February through September 2007. To note, sediment accumulation behind objects was usually small and a large sample with one scoop could be a difficult task. Most bed sediment samples collected within the four study subwatersheds were found on side bars and behind large objects within the stream.

Figure 9. Modified McNeil sediment sampler (McNeil and Ahnell 1960; Williams 2005).

Bed sediment samples collected among the stream sites were then taken to the University of Tennessee Civil Engineering Geotechnical Laboratory. At the laboratory, the bed sediment was characterized through a *dry sieve analysis* and *hydrometer analysis* to define the particle size distribution of each sample in accordance with the standard procedures for the test method of particle-size analysis of soils (ASTM D, 422-63). The dry sieve analysis found the amount of sediment between a sieve #4 through #200 (4.75 mm – 0.075 mm), which defines the amounts of gravels and coarser sand particles. By incorporating the hydrometer analysis, the principles of Stokes Law (spherical particle falls at a constant velocity by equilibrium of its weight, drag forces, and buoyancy forces) can provide an estimate of the amount of sediment particles between 0.038 mm to 0.001 mm. Therefore, the hydrometer analysis is useful in defining the amount of silts and clays in the captured bed sediment.

The results of the dry sieve and hydrometer analyses were combined to collectively estimate the amount of gravel, sand, silt, and clays represented in each sediment sample. Provided in Figure 10, there are various standards that classify the particle sizes into sands, silts, and clays. Since the stream bed sediment samples collected were to be compared to the hillslope sediment yield in the AnnAGNPS model output, it was important that the particle size classification of bed sediment results matched that of the program, which is based on the USDA particle size classifications. Since the AnnAGNPS model was created by the USDA, the computer obviously uses the USDA's size classifications of clays, silts, sands, and gravels. As can be seen in Table 8, the particle size and characteristics that are used within the AnnAGNPS model for sediment yield are a simplified version of the USDA's particle size classification by not having different sub-classifications of sands. Also notice that in Table 8, the small and large aggregate sizes that encompass both silts and sands were not used in this study but are provided to show that the AnnAGNPS program contains five different particle size parameters. In the mountainous region, it would be assumed that aggregate do not exist because they are likely broken up as fine particles prior to entering the stream.

Another parameter that was analyzed with the classifications of clays, silts, sands, and gravels was the individual slopes of the percent finer particle size distribution curves for the clays, silts, sands, and gravels. The clay, silt, sand, and gravel slopes from the percent finer particle size distribution curves for all stream bed sediment samples were summarized and evaluated statistically with the hillslope sediment yield predicted from the AnnAGNPS model. The individual slopes of clays, silts, sands, and gravel for each particle size distribution curve is another technique to classify the quantity of sediment found in the streambed (Williams 2005).

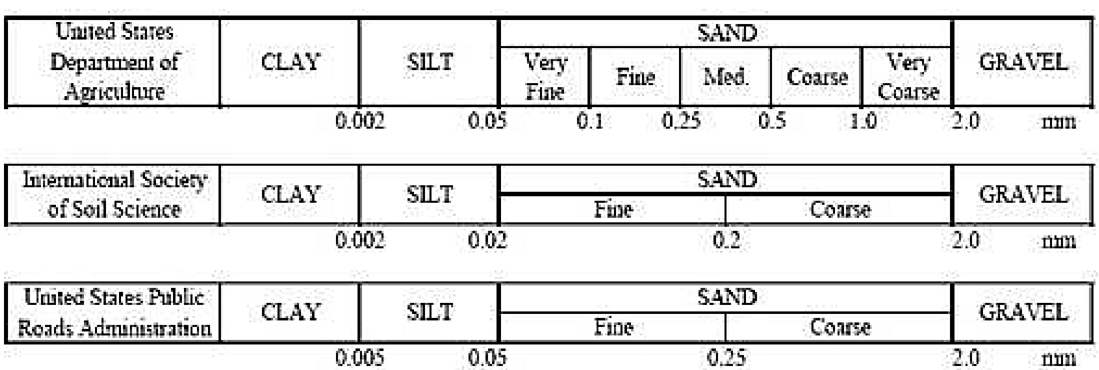


Figure 10. Common fine sediment particle-size classifications (Brady 1974; Haan *et al*. 1994).

Table 8. Fine sediment particle-size classification used in AnnAGNPS (Young *et al.* 1987).

Particle-Size Classifications	Particle Size Range (mm)	γ_D Particle Density (Mg/m3)	V_f Fall Velocity (mm/s)	k Transport Capacity Factor (---)	D_p Equivalent Sand Size (mm)
Clay	< 0.002	2.60	3.11E-03	6.34E-03	2.00E-03
Silt	0.002 - 0.050	2.65	8.02E-02	6.05E-03	1.00E-02
Sand	0.050 - 2.000	2.65	2.31E+01	6.05E-03	2.00E-01
Small Aggregates	0.020 - 0.075	1.80	3.81E-01	1.25E-02	3.51E-02
Large Aggregates	0.200 - 1.000	1.60	1.65E+01	1.66E-02	5.00E-01

5.3 Uplands Sediment Characterization

5.3.1 Sampling Collection Methods and Assessment

The Montgomery Fork, Brimstone Creek, and Smokey Creek subwatersheds within the New River Basin were chosen for uplands sampling, and four sample sites were identified in each subwatershed (White 2009). Ligias Fork was not included because of time limitations. These sites were selected to target the four areas believed to be the main sediment producers: logging, surface mining, dirt roads, and gravel roads (Section 3.5). Each test site was chosen to be representative of the land use/cover condition within each subwatershed. Other factors influencing selection of sampling locations were accessibility and proximity to RGA points. Location maps of the sample locations and site data are in Table 9 and Figures 11 through 13.

After choosing an uplands sample site, any forest litter, or debris was cleared from the surface. Using a hand scoop a sample consisted of 0.5 to 2 inches of material removed. As little of the topsoil was removed as possible, to ensure the sample was of material, which had a high chance of becoming runoff sediment. Next, at least 10 pocket penetrometer readings were taken using a Cole Parmer model EW-99039-00, which yields an approximate measure of the soil compressive strength, which can then be divided by 2 to yield the undrained shear strength in non-cohesive soils. This is illustrated with Mohr’s Circle (Figure 14). Tests were conducted within an area no smaller than 1 square foot. After this, at least 10 cone penetrometer tests were conducted using a Hogentogler model S-4615 in the same area, which yields a measure of the force required to push the cone into the soil for a distance of 1.16 inches. This cone resistance can then be correlated to shear strength as well. Outlaying data was discarded and an average was calculated for both the Pocket and Cone Penetrometers. Lastly, a soil sample to a depth no greater than 3 inches below the penetrometer tests was taken for index property tests, grain size distribution analysis, and soil classification.

Figure 15 is a plot of the pocket penetrometer readings of tons per square foot, versus the cone penetrometer readings of pounds. As can be seen, the correlation is strong with an R-squared value of 0.9606, which is not surprising since both are indirect measures of the soil shear strength. The cone penetrometer (CP), which has a slightly larger contact with the soil than does

Table 9. Uplands sediment collection site id numbers, location coordinates in NAD-83, and site land use descriptions.

Subwatershed	Site ID	NAD-83 UTM E/N Coordinates (meters)	Site Land Use Description
Brimstone Creek	U-BR-1	724,770; 4,015,955	Active Logging Road
Brimstone Creek	U-BR-2	724,325; 4,015,295	25% Logged Area
Brimstone Creek	U-BR-3	725,521; 4,011,968	75% Reclaimed Mine
Brimstone Creek	U-BR-4	725,875; 4,014,320	Inactive Mining Road
Montgomery Fork	U-MF-1	738,506; 4,024,486	100% Logged Area
Montgomery Fork	U-MF-2	738,223 4,024,742	50% Reclaimed Mine
Montgomery Fork	U-MF-3	739,365; 4,025,364	Active Logging Road
Montgomery Fork	U-MF-4	737,608; 4,026,003	Active Mining Road
Smokey Creek	U-SC-1	732,275; 4,009,463	50% Reclaimed Mine
Smokey Creek	U-SC-2	731,760; 4,009,876	Inactive Logging Road
Smokey Creek	U-SC-3	730,276; 4,012,510	75% Logged Area
Smokey Creek	U-SC-4	733,083; 4,007,983	Inactive Mining Road

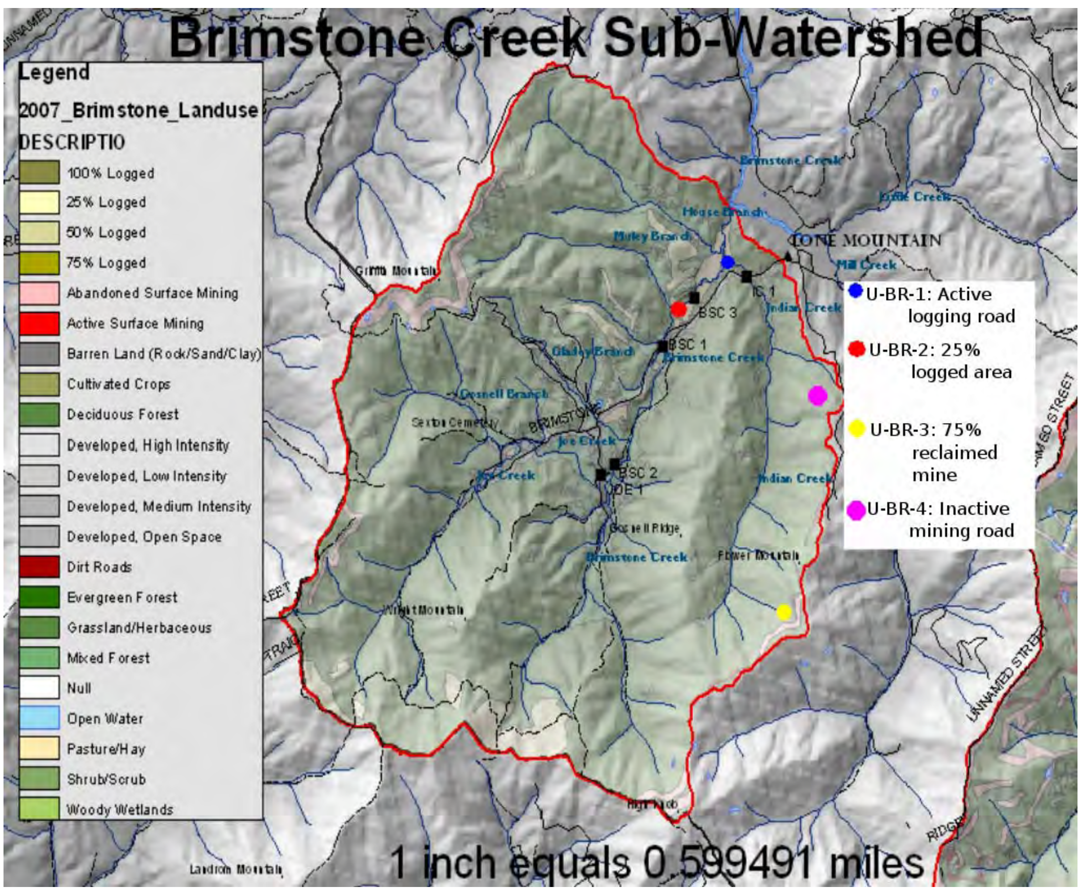


Figure 11. Map of Brimstone Creek subwatershed with locations of the uplands sample sites.

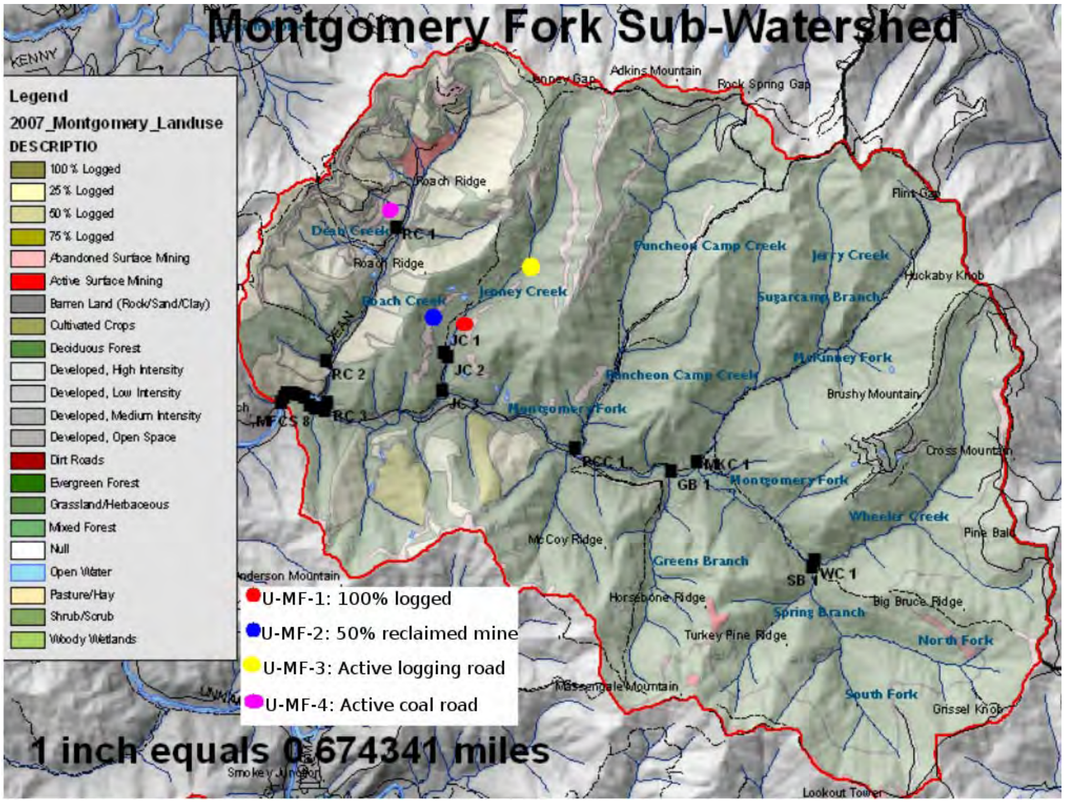


Figure 12. Map of Montgomery Fork subwatershed with location of the uplands sample sites.

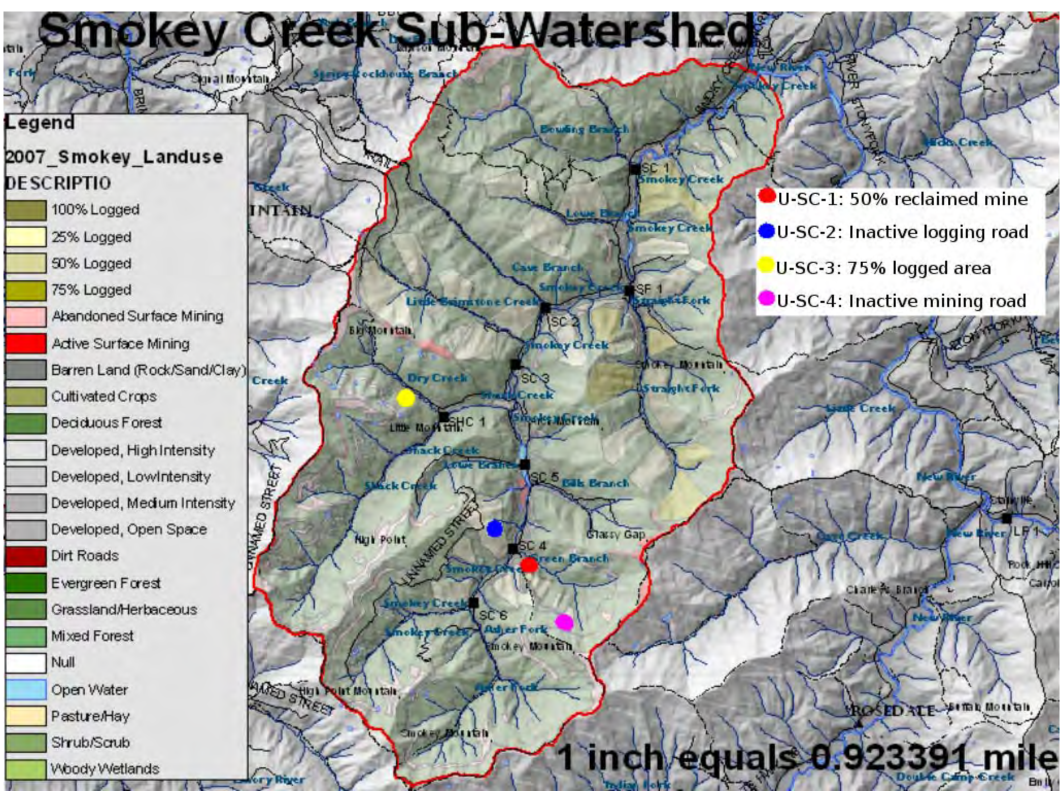


Figure 13. Map of Smokey Creek subwatershed with location of the uplands sample sites.

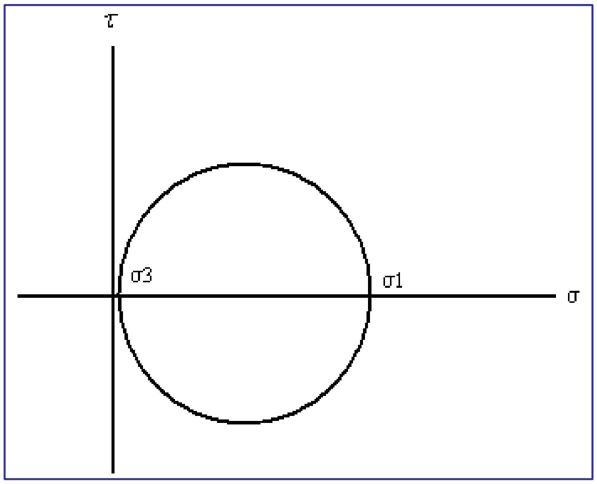


Figure 14. Mohr's circle for near surface testing using penetrometers.

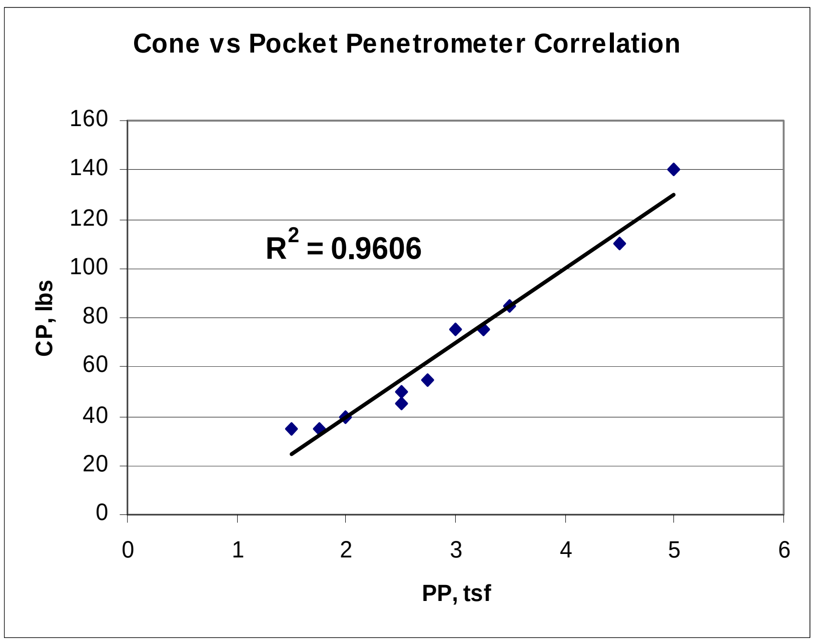


Figure 15. Comparison of cone penetration and pocket penetration strength measures for near surface uplands samples from all study subwatersheds.

the pocket penetrometer (PP), may represent the strength of a larger volume of soil. The PP and CP are described in the following subsection, Section 5.3.2.

Soil samples collected in the field were brought to the University of Tennessee Geotechnical Laboratory and tested in general accordance with ASTM D 4318 to determine the Atterberg limits, ASTM D 422 to determine the Unified Soil Classification, and ASTM D, 422-63 to conduct particle-size analysis of soils. Atterberg limits provide measures for plastic limit, liquid limit, and plasticity index. For this study, particle size distributions generated by this standard methods, were summarized into the following parameters: D50 in mm, D84 in mm, % clay, and

% finer on a #200 sieve. Particle size distributions are presented in Appendix B. Statistical correlations were conducted with the data comparing instream fine sediment D50 with uplands fine sediments D50 means (Section 5.8). According to Reid and Dunne (1996), a significant correlation indicates streams impacted by uplands disturbance, and soil erosion.

5.3.2 Soil Shear Stress Measurement Devices

A Cole Parmer model EW-99039-00 pocket penetrometer and a Hogentogler model S-4615 cone penetrometer were used in this research to conclude the undrained shear strength of surface soils likely to contribute to sedimentation. The Cole Parmer pocket penetrometer is a lightweight, spring-operated penetrometer, which quickly measures the compressive soil strength (Cole Parmer 2009). This tool reads out the approximate compressive strength of the soil in tons per square foot based on the resistance provided which is calibrated to the spring constant of the spring within the device. Shown below on the left in Figure 16 is the Cole Parmer EW-99039-00 pocket penetrometer used in testing; on the right in Figure 16 is the Hogentogler model S-4615 cone penetrometer used.

The Hogentogler model S-4615 cone penetrometer measures the force required to push a 60-degree cone into the ground 1.16 inches measured by a proving ring. This can then be divided by the projected area of the cone to calculate the compressive strength of the soil (McCarthy 2002). A plot of shear stress versus normal stress the Mohr’s Circle can be created as shown on Figure 14. Where $\sigma 3$ is the stress caused by overburden pressure, and therefore zero during surface testing, and $\sigma 1$ is the compressive stress measured by the penetrometer. Through the geometry of this illustration it can be seen that the shear stress, τ , of the given soil will be half of the compressive stress measured by the penetrometer.

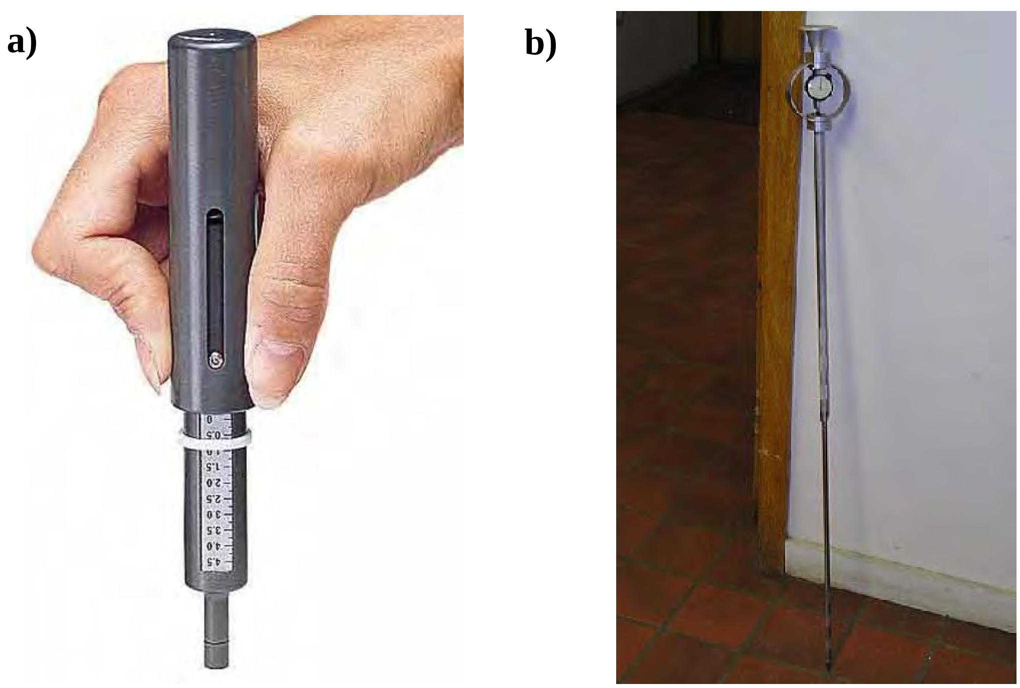


Figure 16. Illustration of a) Cole Parmer model EW-99039-00 pocket penetrometer, and b) Hogentogler model S-4615 cone penetrometer.

5.4 Relationships between Uplands Sediment and Streambed Fine Sediments

Statistical analysis was performed between uplands and streambed fine sediment characteristics in order to examine whether they compared. According to Reid and Dunne (1996), if the particle size characteristics from uplands disturbed areas correlate to streambed sediment it provides evidence that uplands sediment sources contribute to excessive streambed sediments. Using linear correlation and regression statistical approaches in SPSS (version 17), streambed sediment characteristics were used as the dependent variable. A "relevant" streambed sediment characteristic is a variable that can be a predictor of potential uplands sources. Exploratory statistical results and summary data tables are described in Section 7.0.

5.5 Streamflow Measurements for Model Runoff Calibration

Measured storm water runoff for each of the four subwatersheds was estimated through the combination of GlobalWater™Stage Recorders (Model No. WL-16) with stream velocity measurements taken with a Marsh-McBirney Flomate™ Model 2000 Flowmeter. Gauging stations with the stage recorders were located near the outlet of each subwatershed with their locations identified in Table 7 as GPS Site Numbers BSC1, LF1, MFCS1, and SC1 for Brimstone Creek, Ligias Fork, Montgomery Fork, and Smokey Creek, respectively. Stage recorders were installed at each subwatershed by November 2007 and units were set to read data continuously at 20-min increments. By multiplying the stage height by the average velocity at a specific moment in time, a stage-discharge relationship for each of the four subwatersheds was developed. Through the stage-discharge relationship developed for each station, an estimated discharge could be established from the continuous stage recordings taken (Appendix C). Standard USGS protocols were used to compute a discharge using the velocity-area method (Buchanan and Somers 1976).

For higher stage recordings, the in-stream velocities could not be measured with the flow meters; therefore, the U.S. Army Corp HEC-RAS model was used to estimate higher stage and discharge measurements encountered for each of the four study subwatersheds. The HEC-RAS model used a section of channel cross-section surveys upstream and downstream of the stage recorders with Manning's n values for mountainous stream conditions ($n = 0.040$) as well as stage and velocity measurements previously observed.

Once stage-discharge relationships were summarized for the four study subwatersheds, the data was organized to develop stream flow hydrographs. These hydrographs were then separated into surface runoff and base flow from the following empirical equation (Linsley *et al.* 1982):

$$N = A^{2.0} \quad (11)$$

where,

N is equal to the number of days after which surface runoff ceases from the peak of the hydrograph and A is equal to the watershed's area in square miles.

Therefore, the line that separates the stream flow and base flow of the hydrograph is approximately equal to $1.75 \cdot N$ for a precipitation event.

The method used to dissect the surface runoff from the base flow on the hydrograph for each subwatershed is defined as a combination of the Fixed-Interval Method and the Sliding-Interval Method (Maidment 1992). The stream and base flow separation method used in this study provided a means to draw a straight, horizontal line at the base of the hydrograph from the time when precipitation began to the time of the hydrograph's peak. From the time of peak, the height of the hydrograph at a time of N days past the peak would be drawn horizontally back to the time of peak. The area between the stream and base flow, on a hydrograph, would approximately determine the runoff experienced per storm event. Therefore, the difference in base flow and stream flow over a period of time is calculated to be the surface runoff for each subwatershed. Overall by establishing a stage-discharge relationship at the outlet of each subwatershed, the AnnAGNPS model's predicted runoff was calibrated to the measured runoff seen at each subwatershed per storm event.

5.6 Total Suspended Solids Analysis for Sediment Yield Calibration

For at least eight different storm events from January to March 2008, a set of suspended sediment was measured near the outlet of all four subwatersheds within the New River Basin using a DH-48 Depth Integrated Sediment Sampler (Model 5200) and Teledyne ISCO™ Automatic Portable Water Samplers (Model 6712). For several suspended sediment samples collected during recorded storm events, a *total suspended solids* (TSS) analysis was conducted in The University of Tennessee Environmental Engineering Laboratory using Standard Methods (Eaton *et al.* 1995; Edwards and Glysson 1999; Gray *et al*. 2000). To briefly describe the TSS procedure used for all the stream samples, a pre-washed, dried fiberglass filter with a 0.7 μm pore size was weighed on the analytical balance before use. Next, the filter was placed in the Millipore filtration apparatus and the vacuum pump connected to the device was turned on. To obtain an accurate weight of solid material trapped by the 0.7 μm filters, 50-mL of stream water (with a mixed concentration of clays, silts, and sands) was pipetted onto a pre-washed, dried filter attached to a Millipore filtration apparatus. Before 50-mL of stream water was extracted, each sample was stirred vigorously till the suspended solids (clays, silts, and sands) became thoroughly mixed. After the 50-mL of stream sample drained through the filter, the vacuum pump was turned off and the filtrate (solution that passes through the filter) from the initial solution was removed to estimate the dissolved solids concentration. After the suspended solids were trapped onto the filter, the vacuum pump was turned off and samples were removed with tweezers, placed in an aluminum dish, and placed in the oven to dry for one hour at 103°C. After each filter dried for one hour, the filters with a weight of suspended solids were transported to the desiccators to cool and were reweighed on the analytical balance.

The importance of the TSS results for each of the four study subwatersheds is to calibrate the RUSLE parameters, previously discussed in the AnnAGNPS program, to accurately predict sediment yield (Section 3.6; Appendix C). Because it is assumed that a majority of the sediment yield is caused from hillslope disturbances, a small amount of the TSS found per site should be from channel erosion. TSS values obtained for this study are discussed in Section 6.1 and data summarized in Appendix C.

5.7 AnnAGNPS Modeling: Sediment Yield Calibration

Calibration of the AnnAGNPS pollutant loading model required comparing measured stream discharge (hydrology) over time and instream suspended sediment loads to model output estimates. Model parameters, i.e., CN, time of concentration (tc), Manning n, RUSLE factors C and P, and others are adjusted within reasonable ranges reported in literature to qualitatively optimize the best fit between measured and model values. A detailed description of the calibration procedures is in Appendix C.

Before the measured sediment yield for each subwatershed could be used to calibrate the AnnAGNPS pollutant loading model, the CNs and the Manning's n roughness coefficients for each designated land use assigned within a watershed must produce a realistic runoff amount for historical precipitation recordings. The goal was to use a uniform set of CN and Manning's n values, which produced a predicted runoff value that resembled measured runoff amounts. The summarized CNs and Manning's n roughness coefficients for the dominant land uses in each of the four subwatersheds are presented in Appendix C. After the CNs and the Manning's n roughness coefficients were adjusted to better simulate actual runoff from precipitation events, the measured TSS analysis for specific daily storm events, at the outlet of each subwatershed, were used to adjust different RUSLE variables, as well as the Manning's n roughness coefficients for sheet, shallow, and concentrated flow within the AnnAGNPS model. Aside from the dominant land use classifications of the RUSLE C- and P- factors, which are manually adjusted for proper calibration of the model, the dirt roads, simulated through the classical gully command in AnnAGNPS, were also used to determine the overall sediment yield occurring in each subwatershed for calibration purposes. The summarized AnnAGNPS parameters that were used to calibrate measured to predicted sediment yield can also be found in Appendix C.

The AnnAGNPS model's predicted sediment yield was calibrated from several measured suspended solid concentrations collected during a variety of storm events in each subwatershed (Section 5.6). The TSS analysis was conducted to determine an estimated concentration of sediment yield occurring for each subwatershed during a storm event. The TSS values are commonly reported in mg/L (ppm) where as AnnAGNPS reports the sediment yield in Mg/day, where Mg is equal to a mega-gram or metric ton. To convert the TSS values in order to calibrate the AnnAGNPS model, the average TSS values for a precipitation event are multiplied by the runoff volume for a specific day to obtain a daily weight of sediment yield. After converting the measured TSS in terms of mega-gram per day (Mg/day), the predicted sediment yield produced by the AnnAGNPS model could be properly calibrated.

To account for the sediment yield generated by the dirt roads in the four study subwatersheds, a set of seven grab samples was taken from gullies, ditches, and culverts that routed storm water off of the roadways during February and March 2008 (Section 3.6.4). These runoff grab samples were used to obtain a TSS concentration of sediment yield from the dirt roads from a random selection of heavily used unpaved roads found in each of the subwatersheds. Because the AnnAGNPS model would not simulate dirt road land use features for runoff and sediment yield simulations, the classical gully command was used to produce a predicted sediment yield from the dirt roads in each of the subwatersheds. To use the classical gully command in AnnAGNPS, each flow cell had to be individually assessed, and only the flow cells that contained over 0.5 hectares of dirt roads or 5% of a cell's area dominated by dirt roads were considered. Methodology for predicting sediment yields for roads is described in more detail in Appendix C.

Calibrating hydrology between modeled output and measured values were accomplished using peak discharge from storm hydrographs, total daily flow (runoff) volumes, and discharge return frequencies (Appendix C). Predicted peak discharge was greater than measured; although measured peaks at high near bankfull discharges were estimated by HEC-RAS modeling rather than measurements. This will lead to uncertainty in the discharges comparisons at higher flow stages (Figures C.13 through C.16). Total daily flow volumes between modeled and measured were comparable, and qualitatively accepted as reasonable model estimates for this hydrologic parameter (Figures C.17 through C.20). Discharge return frequency plots for modeled output and measured found the model slightly overestimated discharges at higher return frequencies or lower flow stages, and the model slightly underestimated discharges at lower return frequencies or higher flow stages (Figures C.21 through C.24). Differences between the model and measured discharges were greatest at the mid return frequencies for discharges (Figure 17).

Calibrating sediment yields between modeled output and measured values were accomplished with yields estimated in Mg/day. Calibration plots for all study subwatersheds are in Appendix C, and an example plot is shown in Figure 18. Not all storm events were sampled therefore a model estimates may not have a comparable measured yield; this does not indicate the measured value was a zero on a day with a model output. In general, the model output creates a response to storms with reasonable estimates. Once the AnnAGNPS model was satisfactorily calibrated for each subwatershed, the model was used to compute an average annual sediment yield at specific depositional points where the fine bed sediment was collected. Per subwatershed, annual average sediment yield were from a 10-year weather period (1998-2008), and for land use cover based on 2006 aerial photography (Appendix C). The best utility of this data is a relative comparison of sediment yields among subwatersheds over long-term simulations in order for under- and over-estimating to “average” total yields.

5.8 Statistical Correlations between AnnAGNPS Yields and Streambed Fine Sediments

The JMP statistical software was used to compare the relationship and correlations between particle size parameters of stream bed sediment collected at specific channel deposition points with the average annual sediment yield characteristics produced by a calibrated AnnAGNPS pollutant loading model. The streambed sediment properties analyzed consisted of the percentage of clays, silts, sands, and gravels as well as the slope of the grain size distribution

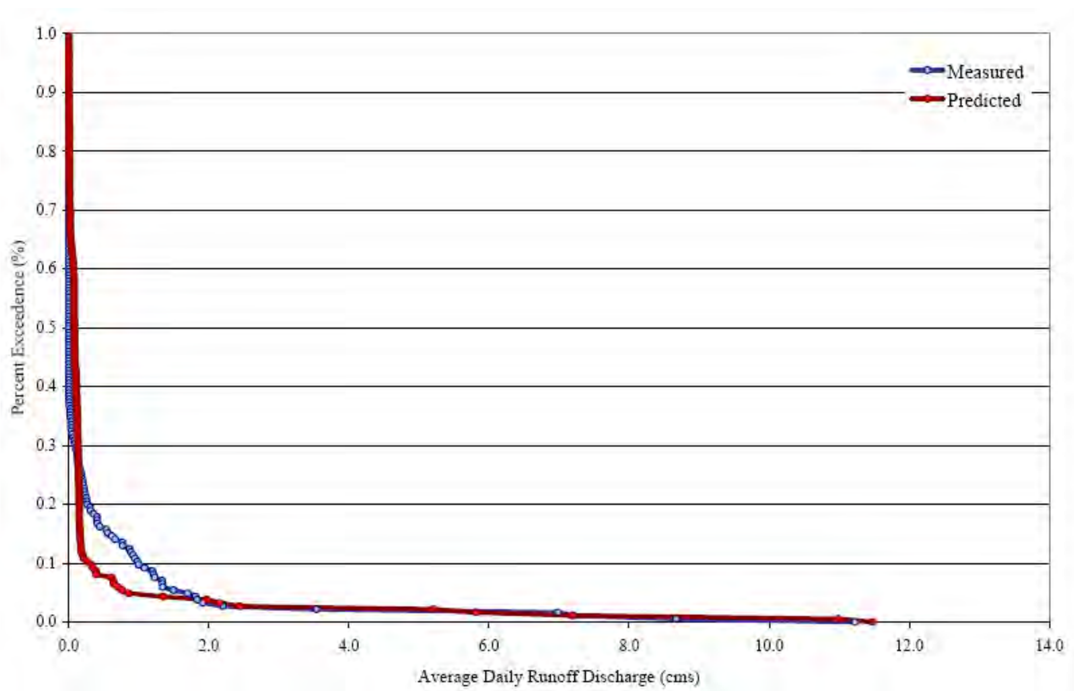


Figure 17. Discharge frequency curve showing modeled vs measured discharges. Example using Montgomery Fork, others subwatersheds are in Appendix C.

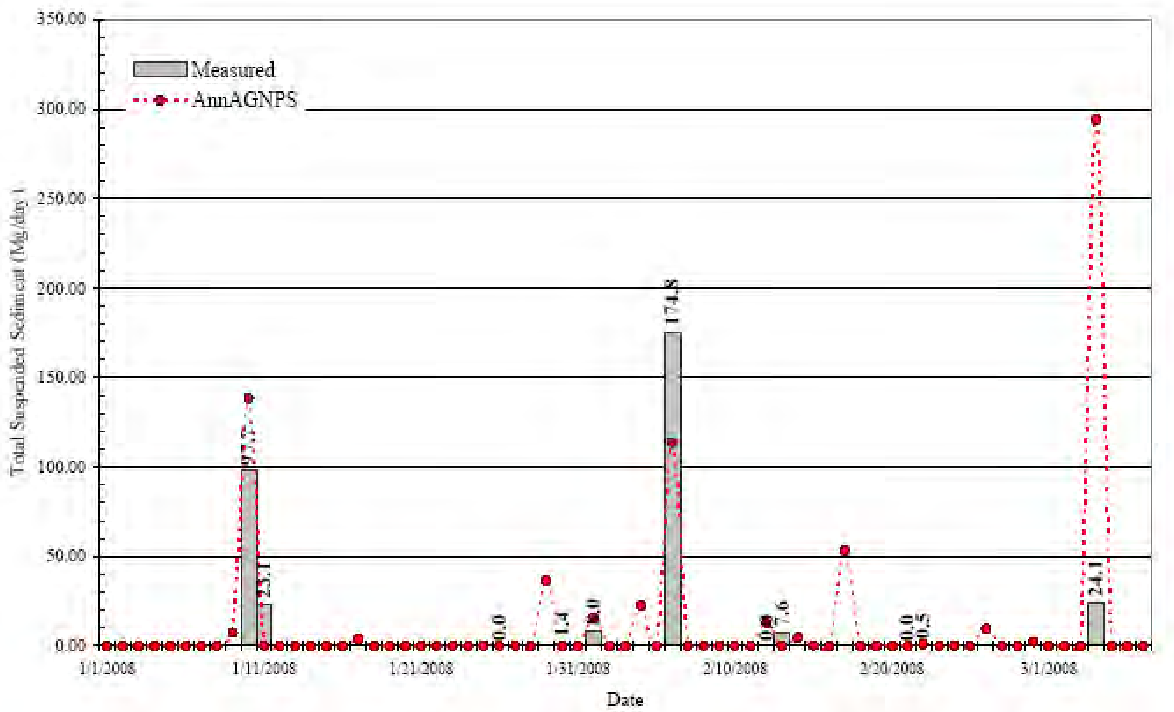


Figure 18. Comparisons of measured and modeled suspended sediment for Montgomery Fork.

plots for clays, silts, sands, and gravels. The AnnAGNPS annual average hillslope sediment yield properties, that were treated as predictor variables, were based on the percent of total weight of clays, silts, sands, as well as the total sediment yield for 2006 and 2007. The statistical procedures used for the particle size distribution of stream bed sediment deposition and the AnnAGNPS hillslope sediment yield consisted of box plot, multivariate, and stepwise regression through a standard least squares analysis. These procedures were used to analyze different combinations of the streambed sediment data to predict hillslope sediment yield properties that have previously been transported down to the point where samples were collected in the four subwatersheds. The statistical analysis of fine streambed sediment properties with the average annual hillslope sediment yield of the AnnAGNPS model are further discussed in Section 7.2.

5.9 ConCEPTS Modeling: Data Needs and Site Calibrations

Simulation of the ConCEPTS model requires the following data inputs: 1) channel geometry, 2) sediment (bed) and soil (bank) particle size distributions, 3) other bed sediment and soil properties, and 4) upstream boundary conditions for sediment and discharge flux. The following paragraphs discuss the acquisition of data input variables required by the model.

5.9.1 Channel Geometry Data

Channel geometry was defined by surveying a series of cross sections perpendicular to the direction of flow along a pre-defined channel reach. Each reach for the four study subwatersheds ended at the guaging station, the final cross-section was within a meter of the station. All surveys began at the downstream modeling extent and proceeded in the upstream direction. The number of upstream cross-section varied per study reach (Appendix D). An elevation of 30.488

m (100 ft) was assumed at a downstream bench mark. This elevation was transferred in the upstream direction via a series of foresights, back sights, and the measured height of the instrument at each setup. Cross section geometry was defined using a Nikon automatic level, a level rod, and a 100-m fiberglass tape. The reach length between cross sections was measured by extending a 100-m fiberglass tape between cross section locations. Cross section geometry data included: the cross section width, the distance between each surveyed point (perpendicular to the direction of flow), and a point's elevation. Floodplain geometry, geometry extending outside the channel, was interpreted based on visual observations and recorded in a field book. Floodplain geometry was added to channel geometry during post processing activities. Structures which have the potential to influence the hydraulics or sediment transport near or at the cross section geometry were documented in a field book. In addition, the top and toe of bank locations were identified, commonly existing at natural breaks in slope along the transverse section, and noted in the field. Field notes and cross section specific data (i.e., stations, elevations, reach lengths, toe of bank stations, and top of bank stations) were recorded in an excel spreadsheet at the end of each field day. Cross section geometry data was processed so that cross section stations increased from left to right (looking downstream), elevations decreased from the left top of bank station to the thalweg (i.e., lowest elevation), and elevations increased from the thalweg to the most right station.

5.9.2. Streambed and Bank Sediment Characterization

Pebble counts were performed to define the bed gradation or grain size distribution of the bed. Following the procedure outlined by Wolman (1954), 100 particles were sampled along a traverse at equal intervals along the bed (Section 5.2.1). This sampling technique only provided a sample of the "pavement" layer (i.e., the top layer or armoring layer of bed sediment particles) of the bed material. Field crews discovered that the pavement layer extends multiple feet into the bed at each site and provides sufficient sediment supply. Based on these observations, the sub-pavement layer was not sampled.

Dry sieve and hydrometer analysis were performed on bank and bed samples to establish the grain size distribution of the bank and bed material. Hydrometer test were performed in accordance with the standard procedures for the test method of particle-size analysis of soils (ASTMD, 422-63). The dry sieve analysis allowed for the determination of the percentage of sediment particles defined by gravels and coarse sand particles. The hydrometer analysis allowed for the determination of the percentage of sediment particles defined by silts and clay sized particles (*same as described in* Section 5.2.2).

5.9.3 Stream Discharge and Sediment Input Files

The AnnAGNPS computational model provided sediment and discharge values at the upstream modeling boundary at each site (i.e., Brimstone Creek, Ligias Creek, Montgomery Fork, and Smokey Creek). The AnnAGNPS exported event file (.evn) was converted using a DOS-based program (evn2dis.exe) supplied by the USDA NSL (Section 3.7). The resulting text file was defined at the upstream modeling boundary and included the date, time, discharge, and sediment discharge for each storm event. Stream discharge data was obtained by stage-discharge recording stations (Section 5.5). Data summaries from field measurements for model inputs and simulations, for each of the four study subwatersheds are in Appendix D.

Brimstone Creek was considered the "reference" reach due to the limited land use impacts in the subwatershed with respect to the three other study sites (Ligias Fork, Montgomery Fork, and

Smokey Creek). From field observations, the Brimstone reach showed few signs of instability such as widening, and only minor bank erosion. It contains steep riffles and large substrate. Based on the stability of the reach, model results were expected to produce minor morphological changes with respect to channel cross section geometry and longitudinal bed profile. Ligias Fork and Smokey Creek receive hydrological impacts from land disturbance within the contributing subwatershed, and study reaches exhibit bank erosion and failure, unstable longitudinal profile and channel dimensions. In these streams, the ConCEPTS model was implemented to simulate bank failure via toe erosion and bank mass failure, and the change in channel profile over time. Montgomery Fork included a well defined riffle-pool sequence, coarse substrate, and knick points created by bedrock outcrops.

6.0 AnnAGNPS-ConCEPTS MODELING RESULTS

6.1 AnnAGNPS Model: Subwatershed Sediment Yields, Sources, and Budgets

With the limited amount of precipitation and stream flow data available for this study, the AnnAGNPS pollutant loading model produced daily runoff amounts per storm event that usually paralleled the measured runoff amount estimated from stage recorders placed near the outlet of the subwatersheds (Appendix C). Figure 17 illustrates this result. The AnnAGNPS model also produced acceptable daily sediment yields that similarly matched the TSS concentrations at the outlet of each subwatershed (e.g., Figure 18).

The summarized annual average sediment yield results produced by AnnAGNPS for each subwatershed's land use disturbances are shown in Figures 19 through 27 with the location of different average annual sediment yield amounts seen in Figures 28 through 31 for AnnAGNPS model flow cell areas. Figure 19 is a stacked bar chart which collectively provides the amount of average annual sediment yield from each of the four subwatersheds of interest in the New River Basin. Figure 19 shows the major land use disturbances that seem to be generating excessive sedimentation to the local streams. For Figures 20 through 27, there are two different pie charts seen for each subwatershed. The annual average sediment yield pie chart that has units in mega-grams per year (Mg/yr) shows the types of land use in the entire watershed that contribute to the area's average sediment budget. This pie chart is useful in understanding the amount of sediment that being transported from the watershed. Note that the pie chart in Mg/yr can also be misleading because the land use areas are not normalized by the percentage of area occupied in the subwatershed. To compare the different land use types with the amount of annual average sediment yield estimated by the AnnAGNPS model, the second pie chart is supplied for each subwatershed, which contains units of Mg/ha/yr. This second pie chart can be used to compare the amount of sediment yield occurring from a normalized area.

From the AnnAGNPS model, the Brimstone Creek subwatershed, which is considered as the "*reference*" watershed, produced a small amount of sediment yield within each cell due to its abundance of forests. The largest source of excessive sediment yield in the Brimstone Creek subwatershed comes from abandoned surface mines on the steep outer portions of the watershed. It must also be shown that flow cells identified with a land use of 50% logged or greater produced a large sediment yield.

The Ligias Fork subwatershed's greatest amount of sediment yield, estimated by the AnnAGNPS model, comes from abandoned mines left unvegetated on the steep, outer edges of

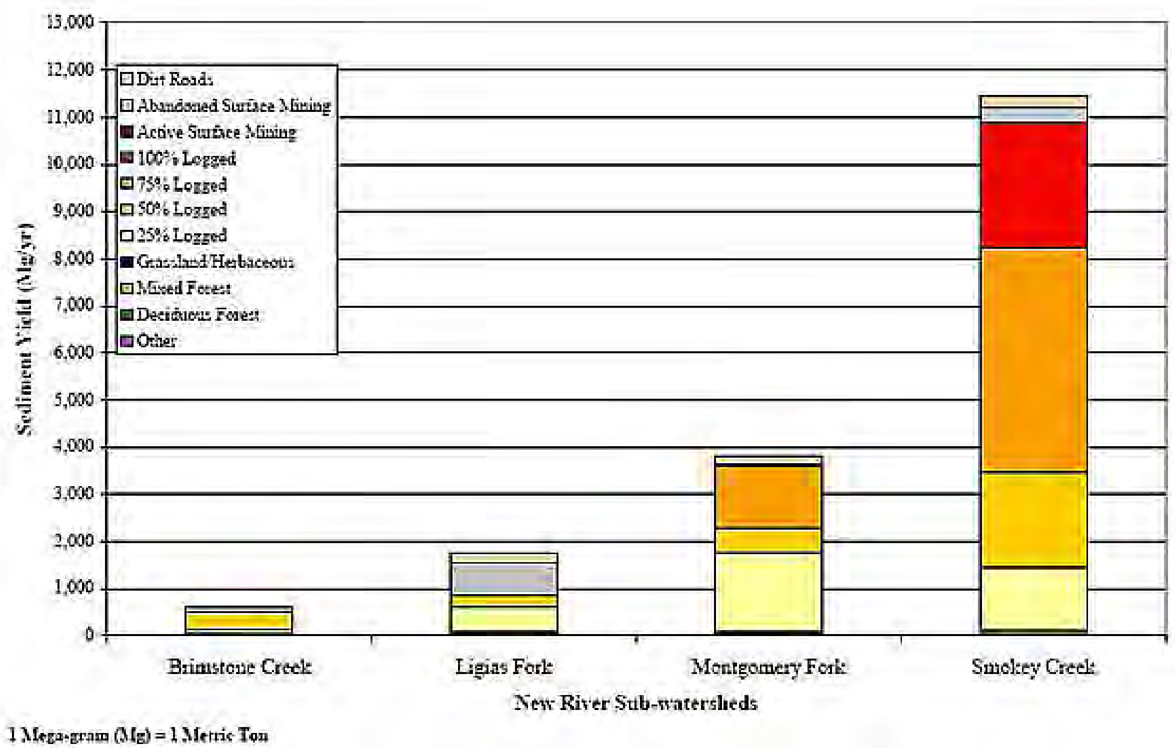


Figure 19. Average annual sediment yield (in Mg/yr) for Brimstone, Ligias, Montgomery, and Smokey subwatersheds based on a 10-yr simulation and 2006 land cover.

the watershed. Ligias Fork is impacted by excessive sediment yield, with areas that contain logging and dirt road networks. The Ligias Fork subwatershed contains the most abandoned mining and the least amount of logged areas (except for the reference subwatershed), so its disturbance due to mining or logging is limited. Ligias Fork subwatershed contains the largest area of dirt roads, which is a major source of its sediment budget. Overall, the Ligias Fork subwatershed appeared to have the least amount of excessive sediment yield from land use disturbances when compared with the next two disturbed subwatersheds of study (Figure 19).

Reviewing the AnnAGNPS model's annual average sediment yield values for Montgomery Fork subwatershed, the flow cells with various percentages of logging are the predominate sources of excessive sedimentation into the streams (Figures 19, 24, and 25). Montgomery Fork contains a large amount of 25% logged areas, which produces a large amount of sediment yield into the streams, but when normalized by area, the 50% and 75% logged areas are much more harmful sources of sedimentation. Aside from the logging activities in Montgomery Fork that seem to produce a large amount of sediment yield, the dirt roads found within this subwatershed also show to be a large source of pollution.

Finally, the Smokey Creek subwatershed is predicted by the AnnAGNPS model to have excessive sedimentation due to areas that contain more than 25% of logging and cells that have a large amount of dirt roads (Figure 19). Like that of Montgomery Fork, the logging activities and dirt roads seem to be the major causes of disproportionate sediment yield into the streams.

In all study subwatersheds analyzed in the New River Basin, areas containing more than 25% of its area removed by forest logging produced severe sediment yield to the nearby streams.

Cassie *et al*. (2002) observed that severely logged areas (more than 20% of the area of a watershed left deforested) showed an increase in peak flow rates due to a loss of evapo-transpiration and infiltration with the removal of trees, and decreasing soil permeability by large logging equipment. Observations from Cassie *et al*. (2002), land areas with more than 20% logged would create more runoff above undisturbed areas also increasing sediment yield.

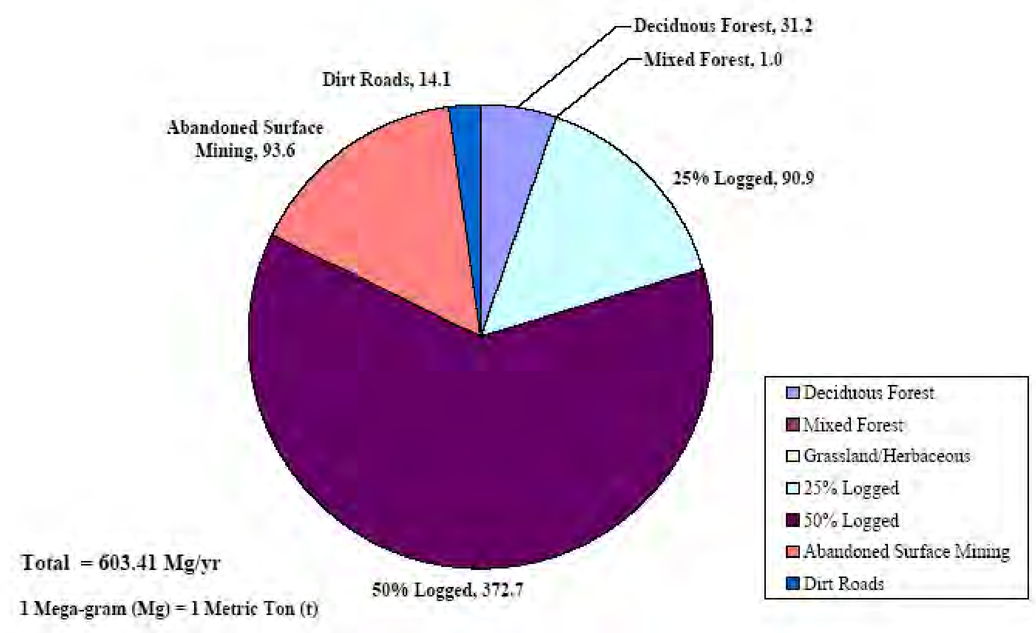


Figure 20. Brimstone Creek subwatershed: average annual sediment yields (Mg/yr) based on a 10-yr simulation and 2006 land cover.

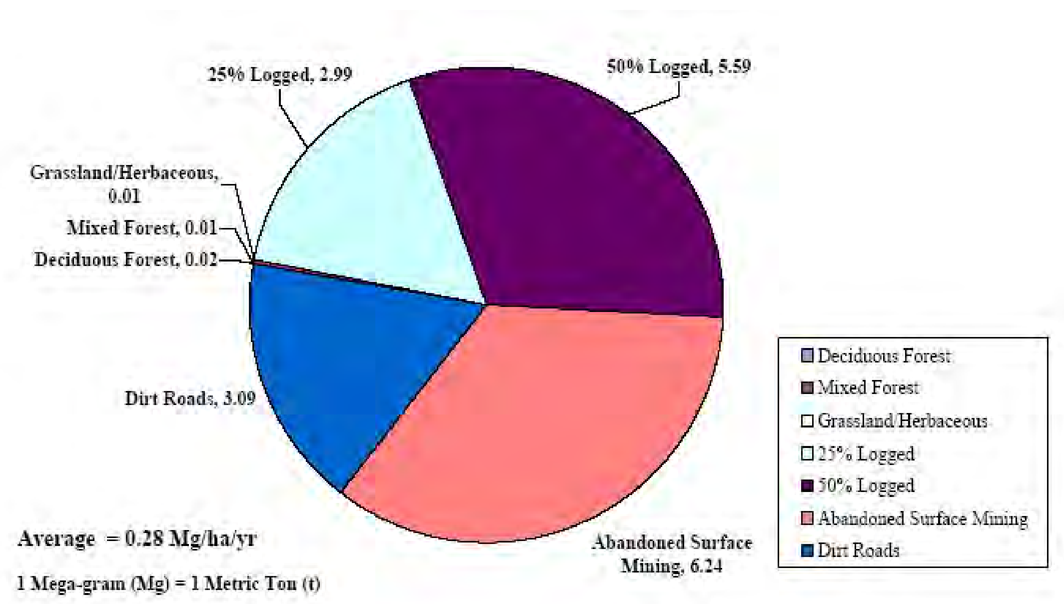


Figure 21. Brimstone Creek subwatershed: normalized average annual sediment yields (Mg/ha/yr) based on a 10-yr simulation and 2006 land cover

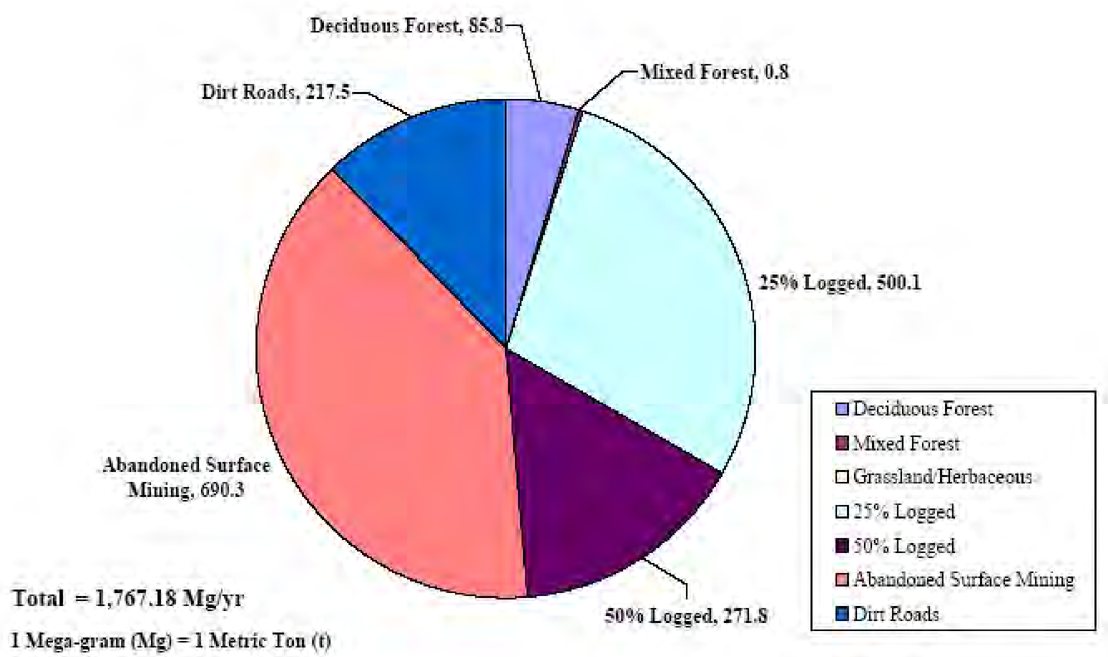


Figure 22. Ligias Fork subwatershed: average annual sediment yields (Mg/yr) based on a 10-yr simulation and 2006 land cover.

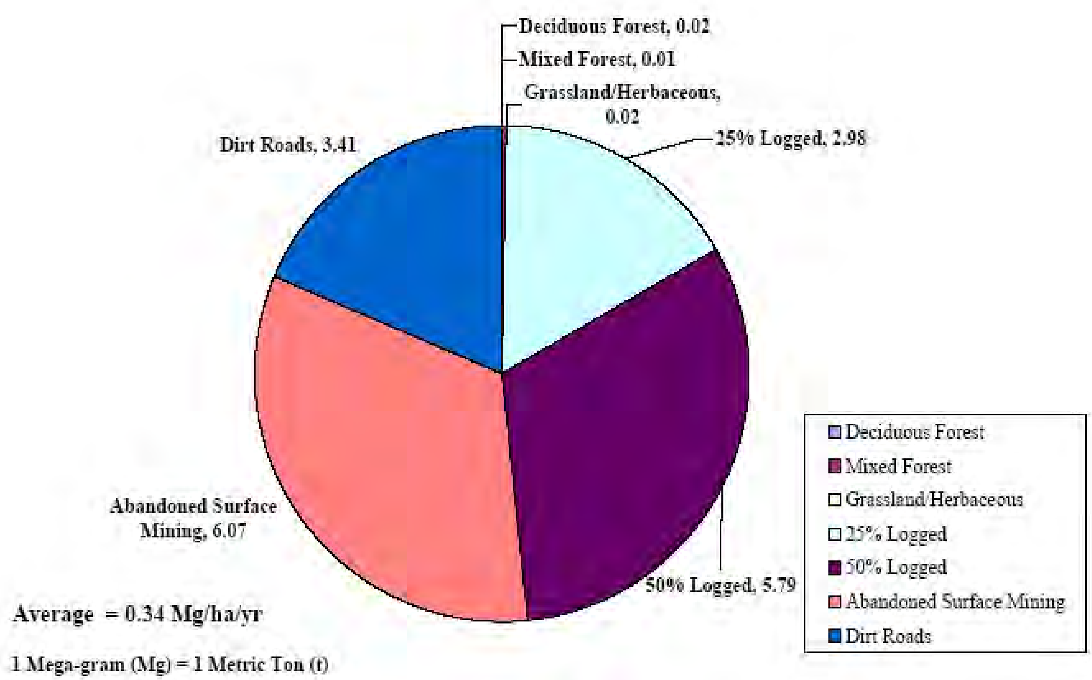


Figure 23. Ligias Fork subwatershed: normalized average annual sediment yields (Mg/ha/yr) based on a 10-yr simulation and 2006 land cover

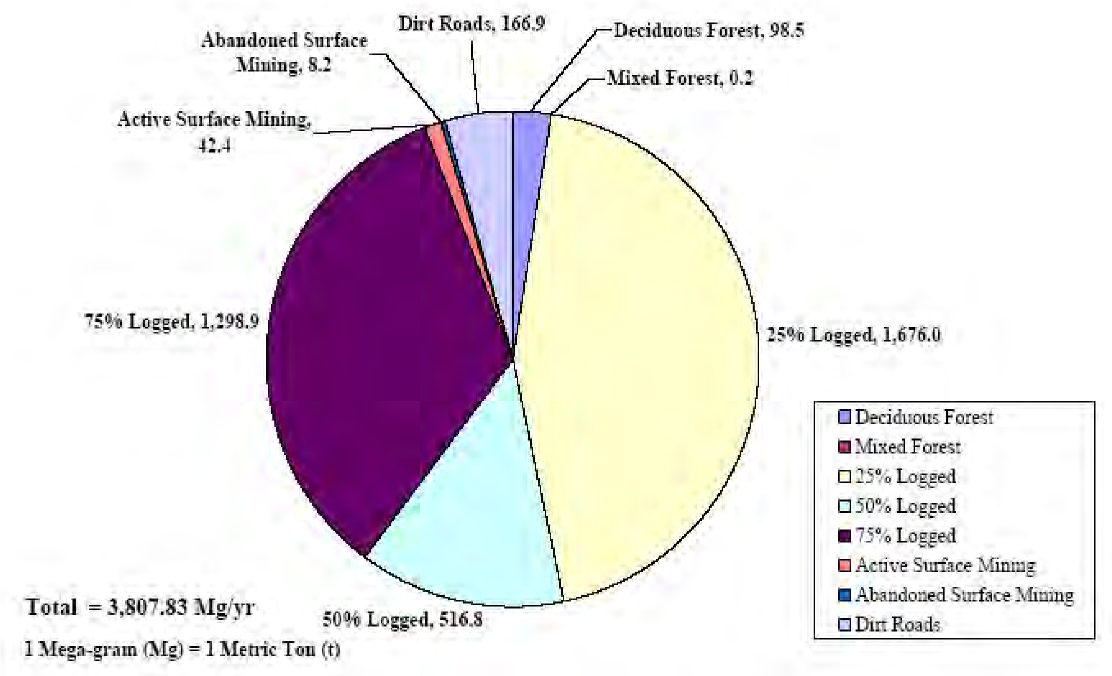


Figure 24. Montgomery Fork subwatershed: average annual sediment yields (Mg/yr) based on a 10-yr simulation and 2006 land cover.

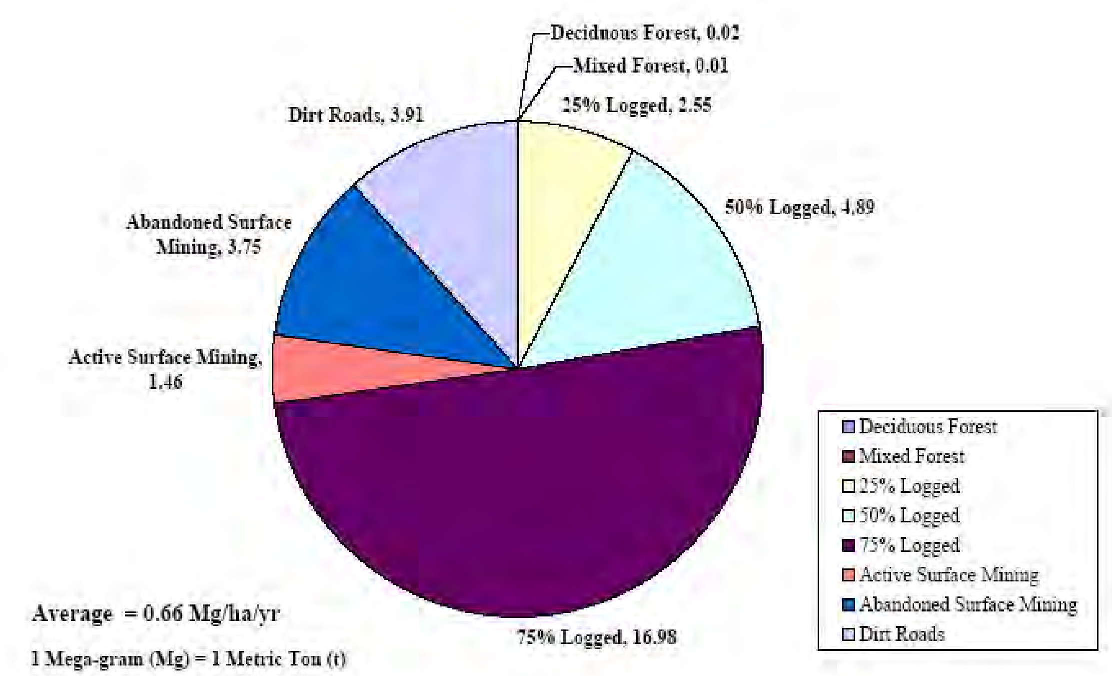


Figure 25. Montgomery Fork subwatershed: normalized average annual sediment yields (Mg/ha/yr) based on a 10-yr simulation and 2006 land cover.

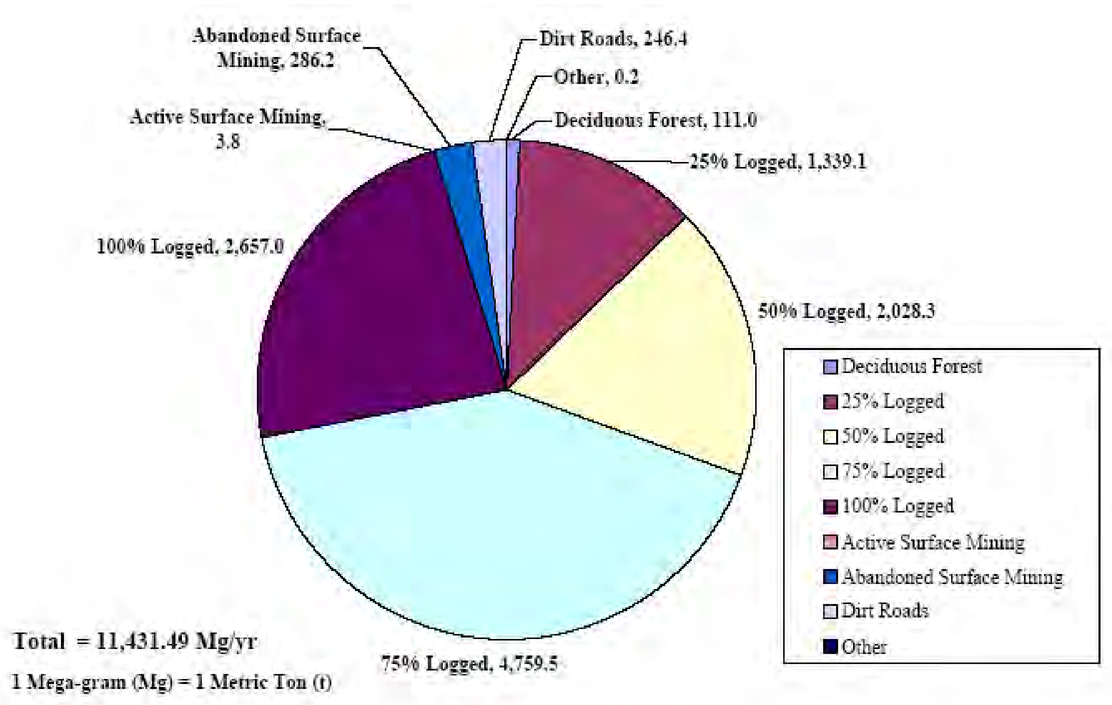


Figure 26. Smokey Creek subwatershed: average annual sediment yields (Mg/yr) based on a 10-yr simulation and 2006 land cover.

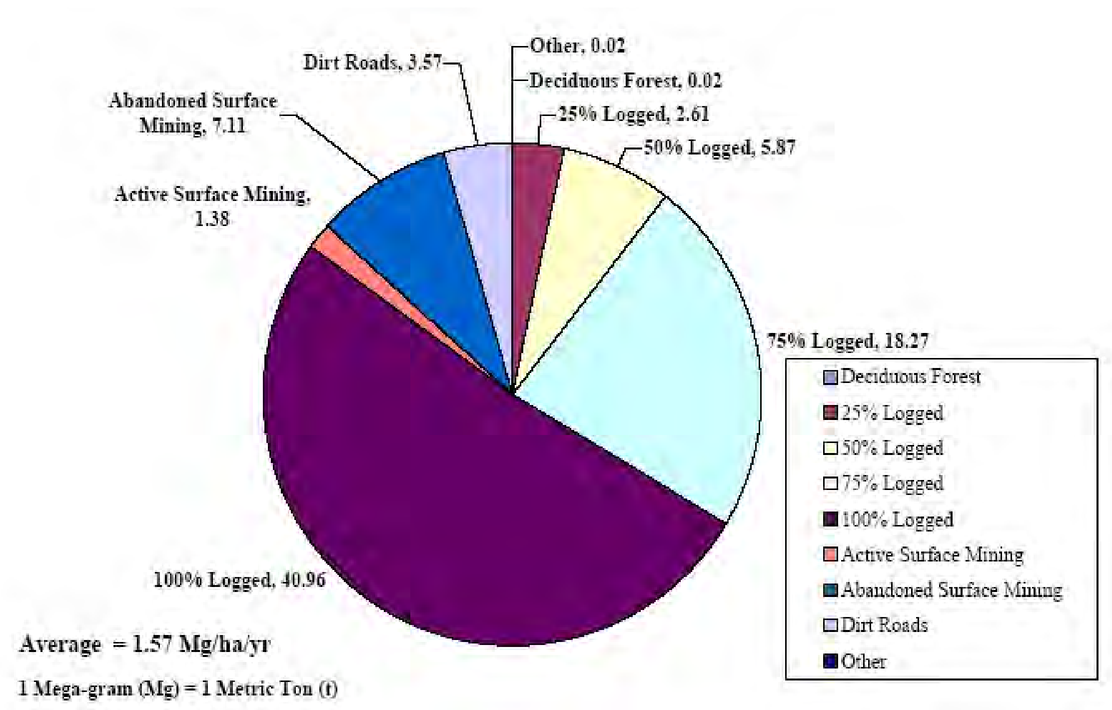


Figure 27. Smokey Creek subwatershed: normalized average annual sediment yields (Mg/ha/yr) based on a 10-yr simulation and 2006 land cover

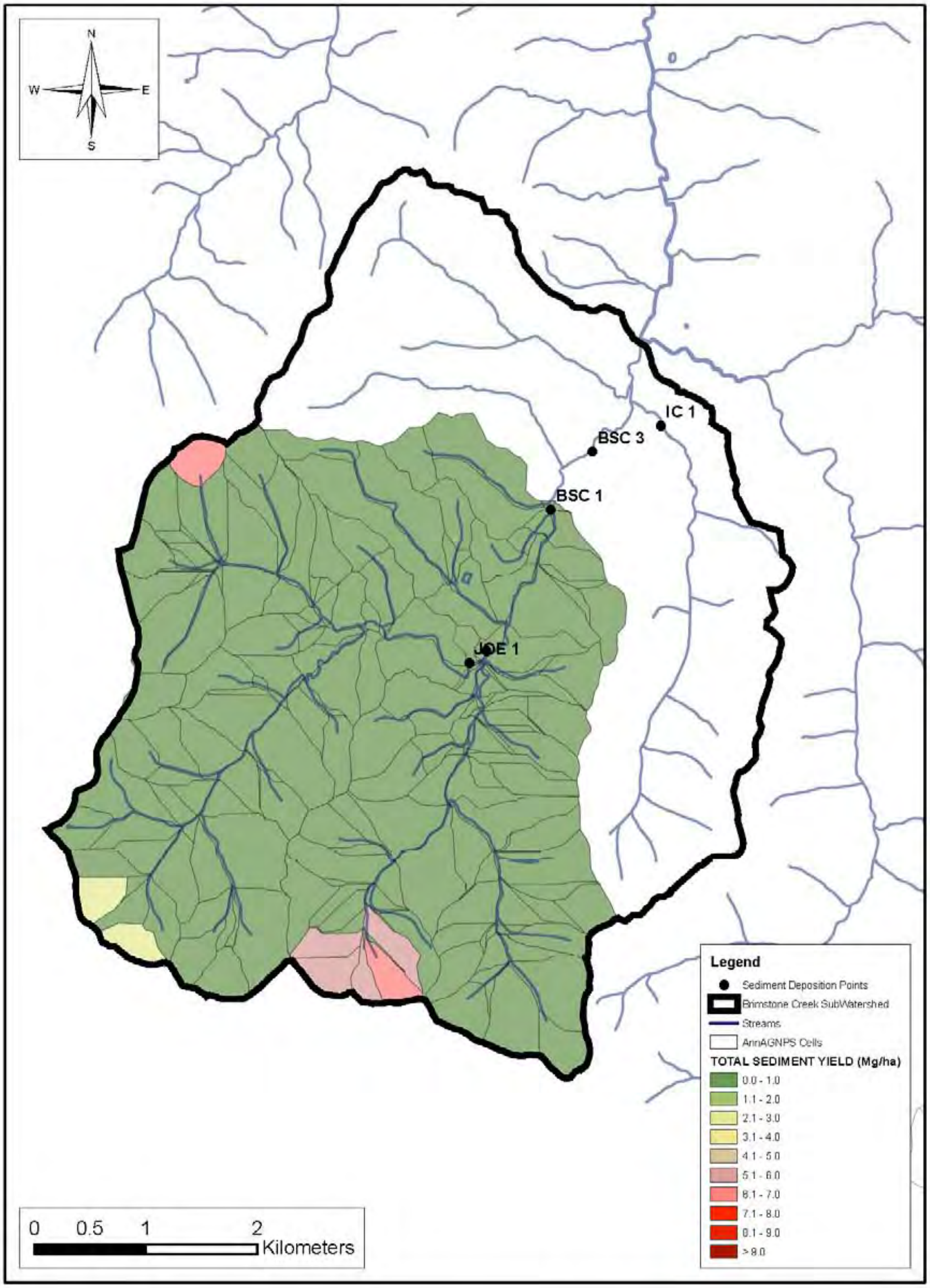


Figure 28. Distribution plot of average annual sediment yields (Mg/ha) in Brimstone Creek subwatershed based on a 10-yr simulation and 2006 land cover.

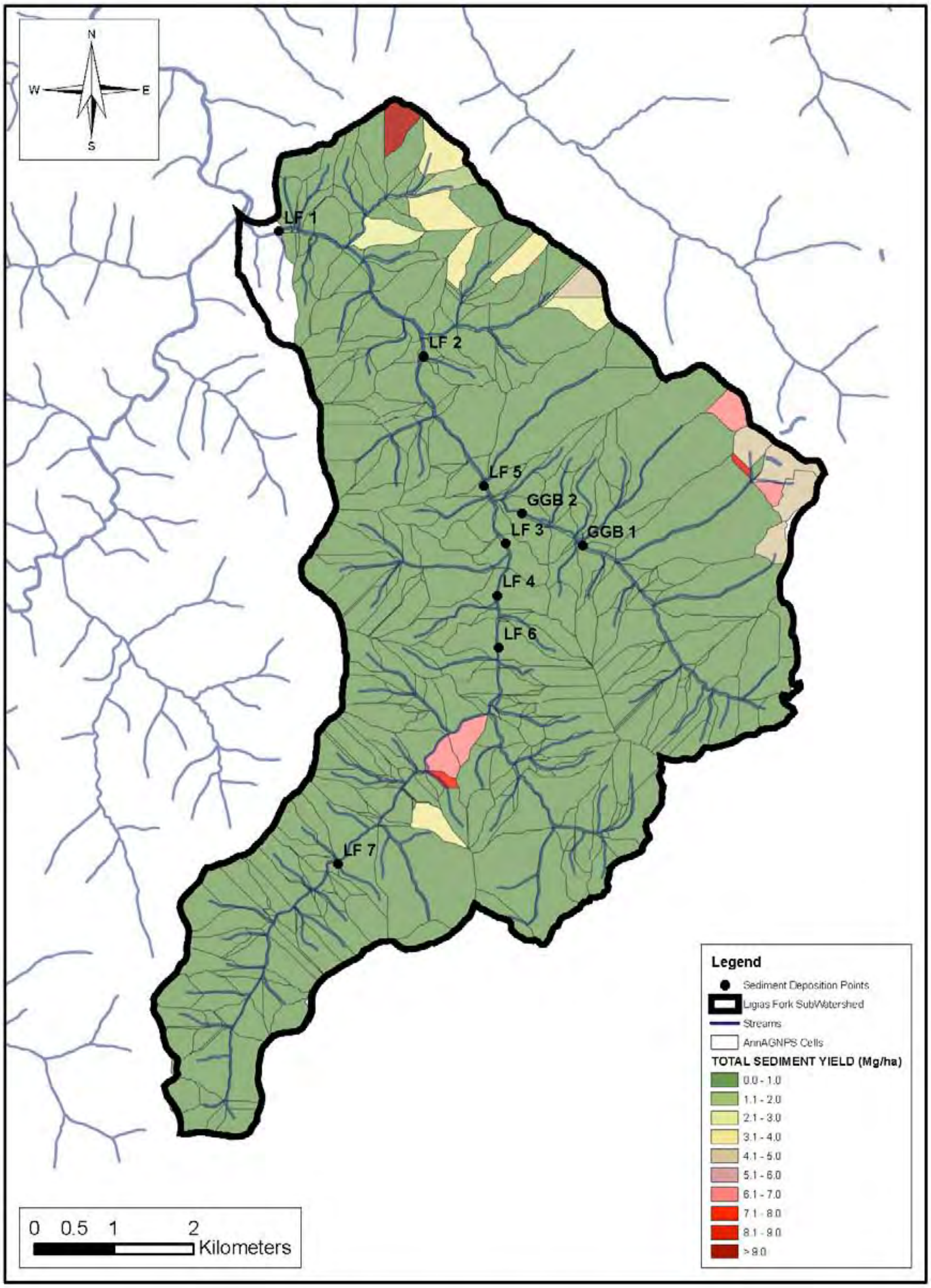


Figure 29. Distribution plot of average annual sediment yields (Mg/ha) in Ligias Fork subwatershed based on a 10-yr simulation and 2006 land cover.

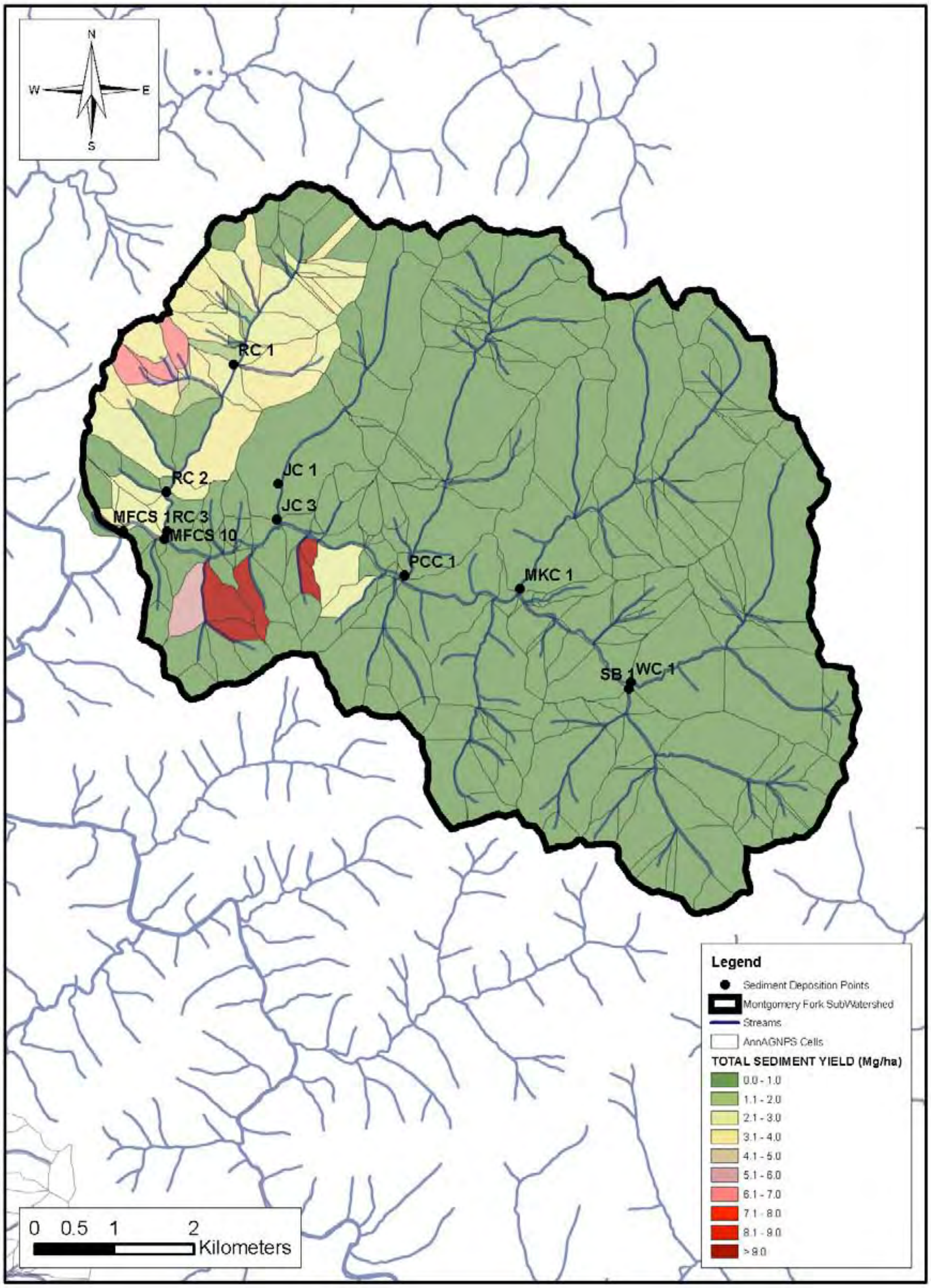


Figure 30. Distribution plot of average annual sediment yields (Mg/ha) in Montgomery Fork subwatershed based on a 10-yr simulation and 2006 land cover.

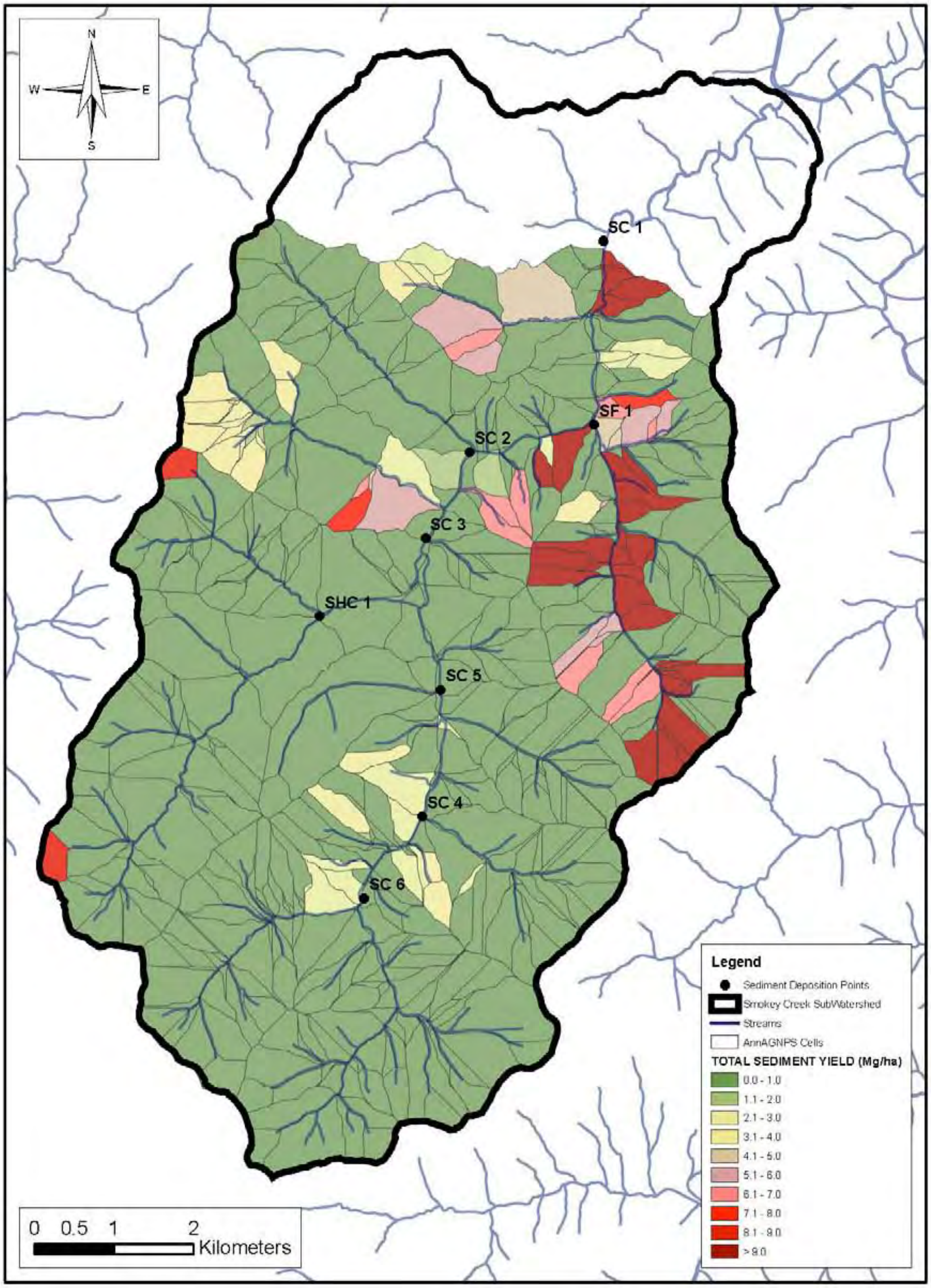


Figure 31. Distribution plot of average annual sediment yields (Mg/ha) in Smokey Creek subwatershed based on a 10-yr simulation and 2006 land cover.

6.2 ConCEPTS Model: Stream Sediment Transport and Bank Erosion

Sediment transport and bank erosion were modeled on Brimstone Creek, Ligias Fork, Smokey Creek, and Montgomery Fork varying in reach length and number of cross-sections (Appendix D). The downstream most location of each reach is located at the gauging stations defined by GPS Site ID numbers BSC1, LF1, SC1, and MFCS1, respectively (Table 7). Reaches are located at the In Brimstone Creek, eight cross sections were used in the ConCEPTS model to define the channel geometry and longitudinal profile along 0.82-km study reach (Appendix D). Pebble counts and particle size distributions were completed at cross-section #6 to characterize bed gradation along the entire reach (Appendix D). From field observations, bed sediment sizes were uniformly distributed through the modeled reach. Reflecting course substrate, calculated median particle diameter (D50) was equal to 90 mm and the D90 was equal to 165 mm. The pavement layer was determined to be deep with respect to the potential scour or degradation of the bed. Thus, only one sediment layer, defined by the pebble count, was incorporated into the model simulation. Critical shear stress and cohesion values defining the soil properties were specified to prevent bank erosion (Appendix D). Due to the inability of the banks to erode or fail, a grain size distribution was based on similar soil samples collected in the New River basin, which consisted of: 10% of the particle size distribution was assumed to be classified as very fine sand, 10% was fine sand, 20% was medium sand, 20% was coarse sand, 20% was very coarse sand, 10% was very fine gravel, and 10% was fine gravel. Soil profiles were defined for both the left and right banks. The soil was assumed uniform in character from the top of the bank to an arbitrarily high value of 100 m below the top of bank elevation to allow for unrestricted scour. Hydraulically, a Manning value of 0.05 was assumed to define the roughness of the left and right floodplains; a value of 0.04 to define the roughness of the left and right banks; and a value of 0.035 to define the roughness of the channel (Chow 1959). The percentage of fines for cohesion was assigned a value of 100 (i.e., defining a cohesion-less bed), the downstream grade control was assigned a value of 0 (i.e., allowing the bed to change at the most downstream cross section), and upstream capacity weighting was assigned a value of 0. The groundwater elevation was not measured along Brimstone Creek and thus was not defined in the model.

Model simulations in the Brimstone Creek study reach produced stable results without defining the bedrock elevation at each cross section (Figures 32 and 33). For this reason, the bedrock elevation was omitted during model simulations. Model output included sediment yield, peak discharge, and toe erosion for each day, with output derived over simulated period with storm events on the following days: 1/1/2005, 5/19/2005, 3/26/2006, 7/15/2006, 4/3/2007, 2/11/2008, 7/13/2008, and 12/31/2008 (Appendix E). The storm events previously mentioned were chosen to illustrate the cross section morphology change between 1/12005 and 12/31/2008. Recall, the AnnAGNPS model generates continuous hydrograph plots, discharge over time, which were used to select these days and obtain the peak discharges. Minimal morphological change occurred over the simulation period, whereby lateral bank erosion did not exceed 0.5 m as illustrated for cross-section #6 in Figure 32. In Brimstone, ConCEPTS simulated the development of a riffle structure over time raising the streambed 0.2 m in one location (Figure 33). This longitudinal output may be influenced by a rich supply of gravel sediment load.

In Ligias Fork, six cross sections were used in the model to define the channel geometry and longitudinal profile along 0.52 km study reach. Soil samples were collected and streambed sediment pebble counts were performed to define bank and bed gradations along the reach (Appendix D). The particle size distribution defining the bed gradation is fairly uniform along

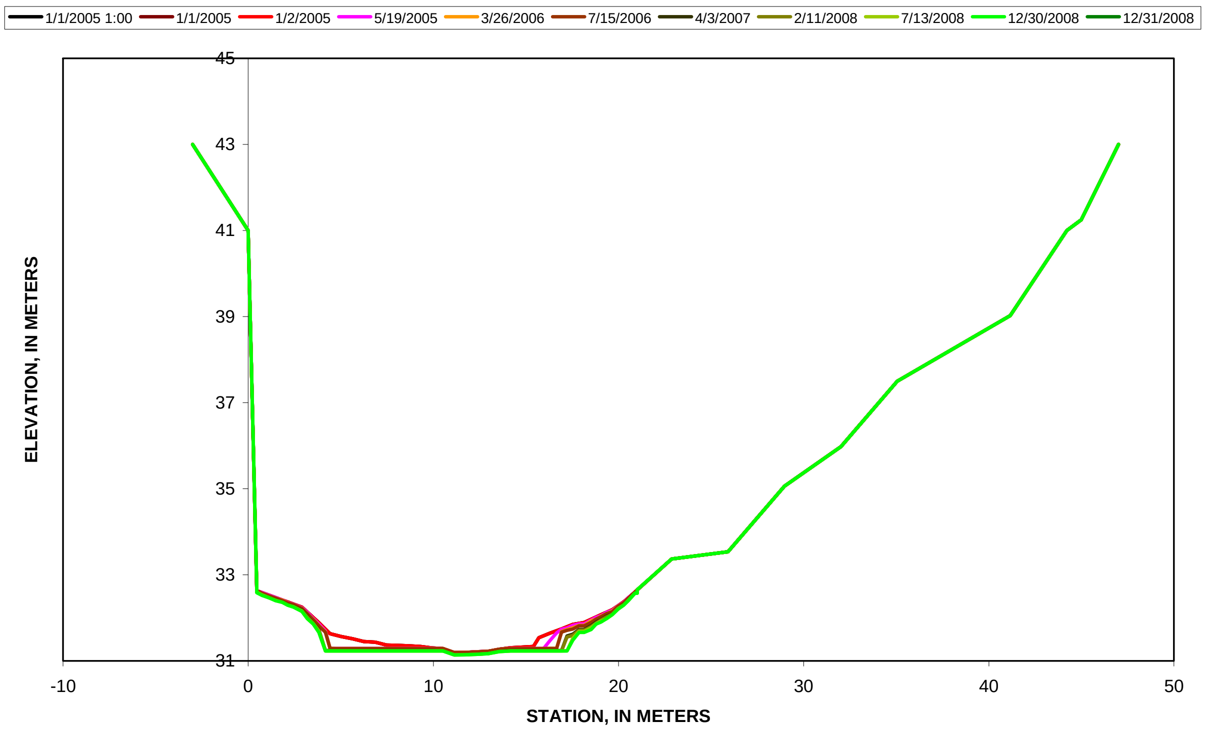


Figure 32. ConCEPTS model output for cross-section #6 in the Brimstone Creek study reach tracking morphological changes from 1/1/05 to 12/31/08.

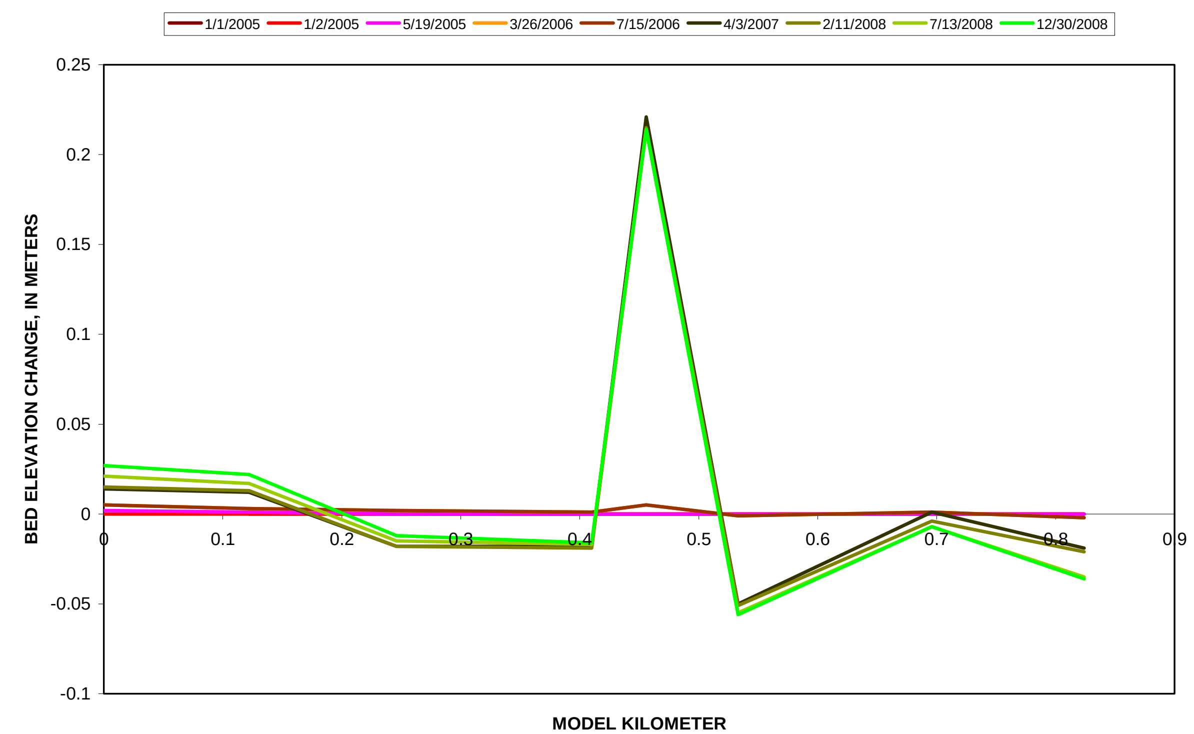


Figure 33. ConCEPTS model output for longitudinal profile in the Brimstone Creek study reach tracking morphological changes from 1/1/05 to 12/31/08.

the reach. The D50 was equal to 66 mm, and the D90 was equal 115 mm. The particle size distribution was computed as: 1% very fine gravel, 1% fine gravel, 4% medium gravel, 12% coarse gravel, 26% very coarse gravel, and 56% small cobble. Bank samples, collected from three separate banks along Ligias Fork, were analyzed by ASTM standards to define the particle size distribution of the banks along Ligias Fork. Two of the bank sediment samples were collected at stable banks (i.e., non-eroding), the third sample was taken at an eroding bank (i.e., cross section #5). Data are summarized in Appendix D. Hydraulic roughness included a Manning value of 0.05 for the left and right floodplains, 0.04 for the left and right floodplains, and 0.035 for the bed channel. The groundwater elevation was defined at an elevation equal to 0.75 m greater than the thalweg elevation or the lowest elevation along the cross section. Bedrock was not defined along the reach because preliminary simulation results showed the profile was relatively stable, degradation less than 0.35 m.

Model simulations in the Ligias Fork study reach produced stable bank results without defining the bedrock elevation at each cross section. The simulation period and identification of storms were the same as defined for Brimstone Creek above. Model output for channel cross-sections showed little change in lateral area less than 0.2 m (Appendix E). Minor streambed aggradation appears to dominant the reach with a rise of 6 cm (Figure 34).

In Montgomery Fork, ten cross sections were used in the model to define the channel geometry and longitudinal profile along 0.69 km study reach. Multiple pebble counts were performed along the Montgomery Fork study reach (Appendix D). Particle size distribution and sediment characteristics used in the model and interpolated based on the whether it was a riffle or pool cross section. Model input values for bank sediment and hydraulic variables are in

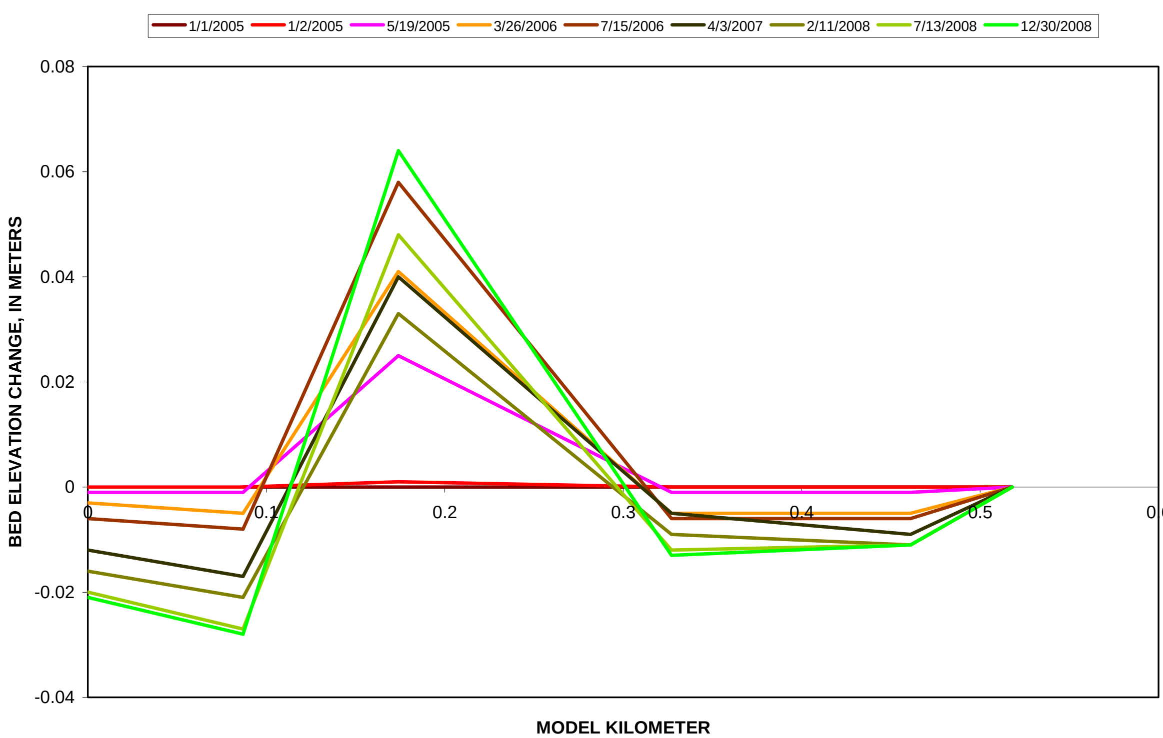


Figure 34.   ConCEPTS model output for longitudinal profile in the Ligias Fork study reach tracking morphological changes from 1/1/05 to 12/31/08.

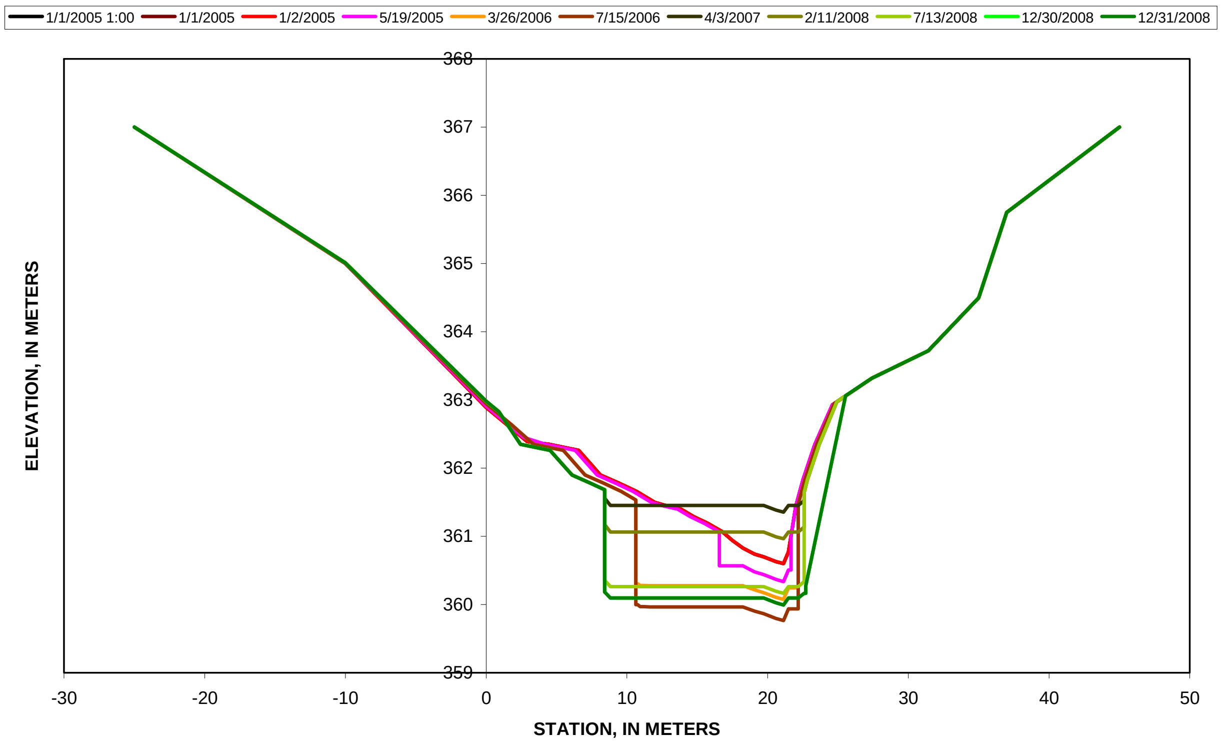


Figure 35. ConCEPTS model output for cross-section #5 in the Montgomery Fork study reach tracking morphological changes from 1/1/05 to 12/31/08.

Appendix E. The simulation period and identification of storms were the same as defined for Brimstone Creek above. Montgomery Fork appeared to be prone to some bank erosion as observed by cross-section #5 in Figure 35. In Figure 35, channel incision was predicted to be nearly 1.5 m, although this was the most unstable cross-section of the ten. The ConCEPTS model suggests that this reach may be prone to unstable conditions. This unstable condition was also observed in the longitudinal profile by the rapid and irregular adjustments to the streambed elevation (Figure 36).

In Smokey Creek, seven cross sections were used in the model to define the channel geometry and longitudinal profile along 1.29 km study reach. One pebble count was performed to define the substrate along the reach (Appendix D). Two soil samples were collected to define eroding and a non eroding banks, and samples were analyzed by dry sieve hydrometer and methods. Three soil profiles and one sediment profile were defined within ConCEPTS for the Smokey Creek simulation. Model output for channel cross-sections showed little change in lateral area less than 0.1 m, representing minimal bank erosion potential (Appendix E). The model predicts severe stream bed erosion in one location, as observed by 0.8 m deepening of the bed elevation (Figure 37). All other locations along the longitudinal profile appear relatively stable.

As an example of model output, sediment yield from bank erosion per storm event day for Smokey Creek is shown in Table 10. Sediment yield output is presented in metric tons per day, partitioned into silt, sand, and gravel classes. The same model output for the other three subwatersheds are in Appendix E.

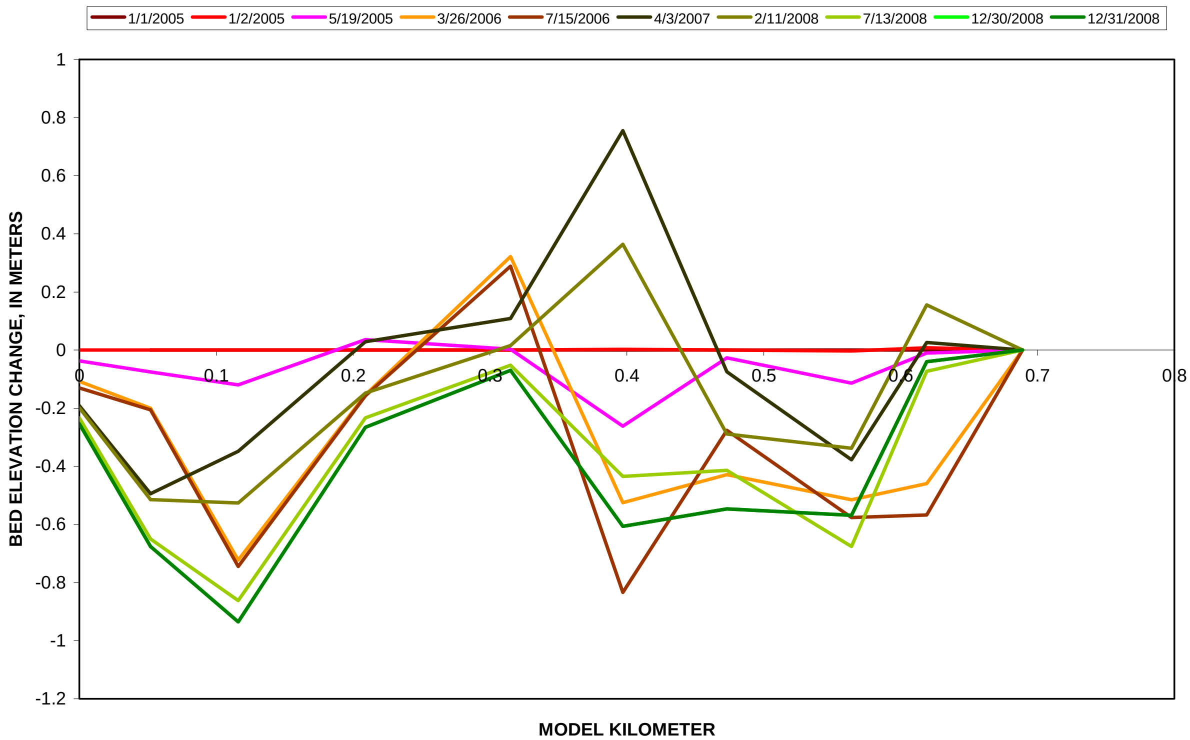


Figure 36. ConCEPTS model output for longitudinal profile in the Montgomery Fork study reach tracking morphological changes from 1/1/05 to 12/31/08.

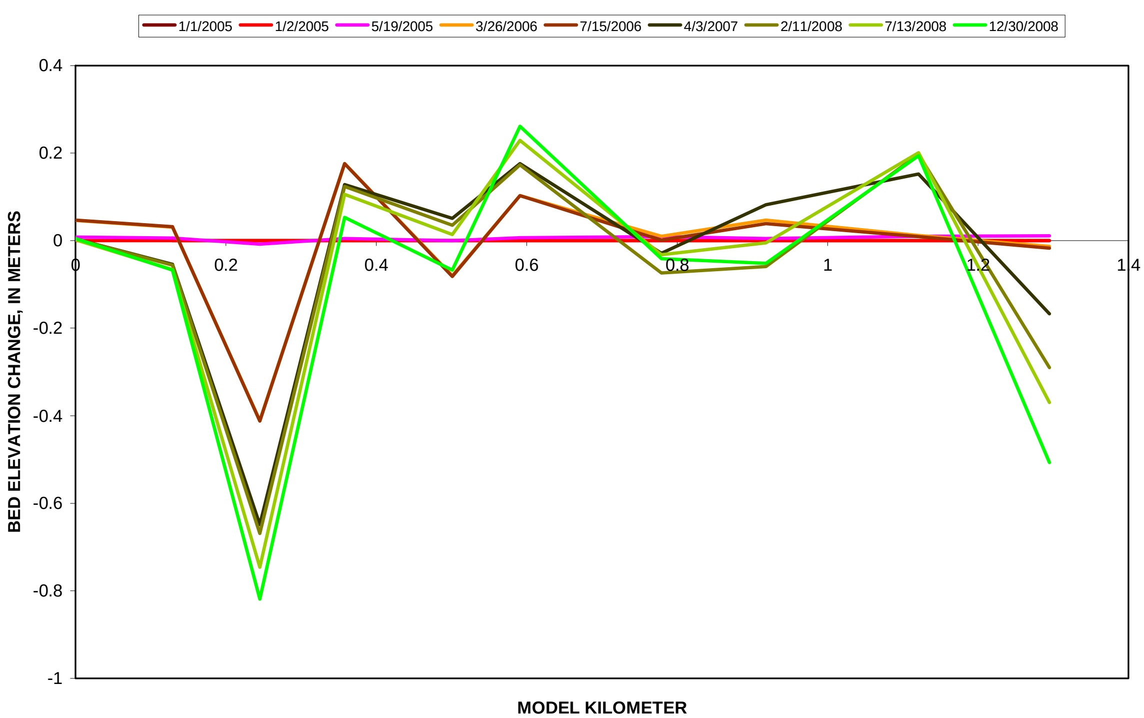


Figure 37. ConCEPTS model output for longitudinal profile in the Smokey Creek study reach tracking morphological changes from 1/1/05 to 12/31/08.

Table 10. Sediment yields per sediment size class from ConCEPTS model simulations for Smokey Creek. Yields in metric tons.

Smokey Creek Event File Summary									
		Storm event generated sediment yield				Cumulative sediment yield			
Date	Time	Silt YLD	Sand YLD	Gravel YLD	Total YLD	Silt YLD	Sand YLD	Gravel YLD	Total YLD
mm/dd/yyyy	hh:mm:ss	(TONS)	(TONS)	(TONS)	(TONS)	(TONS)	(TONS)	(TONS)	(TONS)
Initial	Initial								
01/01/2005	00:00:00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
01/02/2005	00:00:00	9.10E+00	4.07E-41	0.00E+00	9.10E+00	9.08E+00	4.07E-41	0.00E+00	9.08E+00
05/19/2005	00:00:00	2.07E+00	0.00E+00	0.00E+00	2.07E+00	3.99E+03	5.70E+02	3.33E-02	4.56E+03
03/26/2006	00:00:00	7.84E-01	0.00E+00	0.00E+00	7.84E-01	1.18E+04	1.39E+03	7.75E+01	1.33E+04
07/15/2006	00:00:00	2.25E+02	1.42E-01	0.00E+00	2.25E+02	1.39E+04	1.47E+03	8.08E+01	1.54E+04
04/03/2007	00:00:00	3.65E+01	5.44E-02	0.00E+00	3.66E+01	2.22E+04	6.43E+03	6.17E+02	2.92E+04
02/11/2008	00:00:00	2.08E+00	0.00E+00	0.00E+00	2.08E+00	2.54E+04	6.85E+03	7.56E+02	3.30E+04
07/13/2008	00:00:00	5.40E+01	1.36E+01	4.73E-02	6.76E+01	2.97E+04	7.80E+03	8.48E+02	3.83E+04
12/30/2008	00:00:00	1.30E+00	0.00E+00	0.00E+00	1.30E+00	3.15E+04	8.28E+03	9.66E+02	4.08E+04

7.0 RELATIONSHIPS of STREAM SEDIMENT to UPLANDS SOURCES

7.1 Reach Characterization of Streambed Fine Sediments and Geomorphic Stability

After collecting fine streambed sediment samples at specific channel deposition points, at each subwatershed, the sediment size characteristics were analyzed by particle size distributions as described in Section 5.2.2. Streambed sediment characteristics were summarized for each subwatershed in Tables 11 through 14. Each table provides the percentage of clays, silts, and sands found in each site sample per study subwatershed. Also contained in the tables are the RGA scores at the stream site, including the D50 and D84 values from the modified Wolman pebble counts. In all 33 stream sites where streambed sediments were collected, the RGA scores ranged from 5.0 to 12.5. An RGA score less than 10 indicates that a stream reach is stable, and between 10 and 20 it is determined by stage of channel evolution, in which in this study through streams were all Stage V indicating that they were stable channels. Therefore, all of study streams were in an equilibrium state or near equilibrium. Because the study reaches were shown to be stable, bank erosion was not considered a major source of excessive sedimentation in the headwater areas of New River basin. In these headwaters areas it appears a greater portion of instream sediment is from upland sources, generated by land use activities. The sediment characteristics in Tables 11 through 14 were further analyzed with the average annual sediment yield generated by the AnnAGNPS model to determine whether correlations exist between the fine stream bed sediment deposits and sediment yield from the upland sources (Section 7.2).

7.2 Correlations between AnnAGNPS Yields and Streambed Fine Sediments

The calibrated AnnAGNPS pollutant loading model was used to generate average annual sediment yields for 2006 and 2007 in order to statistically compare model output values with instream measured values, both suspended sediment in transport and streambed fine sediments (Appendix F). As discussed in Section 5.2.2, streambed fine sediment collections were used as a surrogate for a watershed’s suspended sediment load during floods. Significant relationships were established between average annual sediment yields for 2006 and 2007 and the percent of

Table 11. Brimstone Creek streambed sediment characterization (2007).

Site ID (--)	Principle Watershed (--)	Channel RGA Score (0-36)	Pebble Count D50 (mm)	Pebble Count D84 (mm)	Dry Sieve & Hydrometer Results Clays (%)	Silts (%)	Sands (%)	Gravels (%)	Particle Size Distribution Slope Clay (decimal)	Silt (decimal)	Sand (decimal)	Gravel (decimal)
BSC-1	Brimstone	8.5	38.0	98.0	0.00	0.21	39.19	60.60	0.00	4.37	20.10	3.56
BSC-2	Brimstone	5.0	34.0	94.0	0.05	0.99	47.60	51.36	7.07	20.72	24.41	3.02
BSC-3	Brimstone	7.0	33.0	94.0	0.05	0.90	25.85	73.21	7.02	18.70	13.26	4.31
JOE-1	Brimstone	5.0	50.0	124.0	0.11	0.47	33.43	66.01	14.73	9.85	17.14	3.88
IC-1	Brimstone	5.5	42.0	88.0	0.00	0.17	26.94	72.89	0.00	3.53	13.82	4.29
Average		6.2	39.4	99.6	0.0	0.5	34.6	64.8				

Table 12. Montgomery Fork streambed sediment characterization (2007).

Site ID (--)	Principle Watershed (--)	Channel RGA Score (0-36)	Pebble Count D50 (mm)	Pebble Count D84 (mm)	Dry Sieve & Hydrometer Results Clays (%)	Silts (%)	Sands (%)	Gravels (%)	Particle Size Distribution Slope Clay (decimal)	Silt (decimal)	Sand (decimal)	Gravel (decimal)
MFCS-1	Montgomery	10.5	30.0	88.0	1.85	9.30	55.29	33.56	197.00	193.83	28.35	3.56
MFCS-10	Montgomery	10.0	24.0	49.0	0.07	1.04	45.61	53.27	10.43	21.76	23.39	3.13
RC-1	Montgomery	11.0	16.0	38.0	0.06	0.67	36.34	62.94	13.79	13.86	18.63	3.70
RC-2	Montgomery	12.5	14.0	34.0	0.04	0.15	12.21	87.60	8.50	3.18	6.26	5.15
RC-3	Montgomery	10.5	12.0	32.0	0.01	0.30	33.68	66.01	4.69	6.20	17.27	3.88
JC-1	Montgomery	7.0	24.0	50.0	0.03	0.07	22.82	77.07	3.74	1.55	11.70	4.53
JC-3	Montgomery	6.0	12.0	24.0	0.03	0.37	58.29	41.31	8.44	7.69	29.89	2.43
SB-1	Montgomery	9.0	25.0	107.0	0.30	0.53	20.46	78.71	44.75	11.02	10.49	4.63
MKC-1	Montgomery	8.0	38.0	114.0	0.05	0.32	48.69	50.94	6.50	6.70	24.97	3.00
PCC-1	Montgomery	10.0	34.0	87.0	0.11	1.21	48.31	50.37	9.64	25.29	24.77	2.96
WC-1	Montgomery	7.0	41.0	104.0	0.01	0.14	25.52	74.33	2.99	2.91	13.09	4.37
Average		9.2	24.5	66.1	0.2	1.3	37.0	61.5				

Table 13. Ligias Fork streambed sediment characterization (2007).

Site ID (--)	Principle Watershed (--)	Channel RGA Score (0-36)	Pebble Count D50 (mm)	Pebble Count D84 (mm)	Dry Sieve & Hydrometer Results Clays (%)	Silts (%)	Sands (%)	Gravels (%)	Particle Size Distribution Slope Clay (decimal)	Silt (decimal)	Sand (decimal)	Gravel (decimal)
LF-1	Ligias	8.5	46.0	88.0	0.09	0.93	44.11	54.87	11.51	19.40	22.62	3.23
LF-2	Ligias	9.0	44.0	87.0	0.02	0.09	86.98	12.92	0.66	1.79	44.60	0.76
LF-3	Ligias	7.5	34.0	178.0	0.06	0.44	39.97	59.52	13.09	9.10	20.50	3.50
LF-4	Ligias	9.0	45.0	110.0	0.05	0.17	23.99	75.79	11.10	3.47	12.30	4.46
LF-5	Ligias	12.0	49.0	104.0	0.01	0.22	41.44	58.33	1.65	4.69	21.25	3.43
LF-6	Ligias	7.0	60.0	170.0	0.00	0.02	26.03	73.95	0.40	0.41	13.35	4.35
LF-7	Ligias	n/a	n/a	n/a	0.13	0.43	23.87	75.58	20.26	8.90	12.24	4.45
GGB-1	Ligias	6.0	56.0	232.0	0.07	0.32	55.68	43.93	8.44	6.60	28.56	2.58
GGB-2	Ligias	8.5	38.0	118.0	0.06	1.50	28.57	69.88	18.48	31.20	14.65	4.11
Average		8.4	46.5	135.9	0.1	0.5	41.2	58.3				

Table 14. Smokey Creek streambed sediment characterization (2007).

Site ID (--)	Principle Watershed (--)	Channel RGA Score (0-36)	Pebble Count D50 (mm)	Pebble Count D84 (mm)	Dry Sieve & Hydrometer Results Clays (%)	Silts (%)	Sands (%)	Gravels (%)	Particle Size Distribution Slope Clay (decimal)	Silt (decimal)	Sand (decimal)	Gravel (decimal)
SC-1	Smokey	9.0	30.0	58.0	0.43	3.01	84.62	11.93	29.54	62.81	43.40	0.70
SC-2	Smokey	9.0	40.0	96.0	0.04	0.23	33.66	66.07	3.61	4.80	17.26	3.89
SC-3	Smokey	8.0	38.0	96.0	0.02	0.33	43.10	56.55	5.21	6.88	22.10	3.33
SC-4	Smokey	9.5	46.0	102.0	0.03	0.39	54.67	44.90	0.00	8.20	28.04	2.64
SC-5	Smokey	9.0	34.0	74.0	0.01	0.15	29.91	69.93	1.82	3.14	15.34	4.11
SC-6	Smokey	10.0	45.0	112.0	0.13	1.45	50.13	48.29	18.18	30.17	25.71	2.84
SHC-1	Smokey	9.0	39.0	94.0	0.03	0.09	17.12	82.76	6.58	1.81	8.78	4.87
SF-1	Smokey	8.5	45.0	104.0	0.09	1.00	65.55	33.36	17.50	20.87	33.61	1.96
Average		9.0	39.6	92.0	0.1	0.8	47.3	51.7				

clays, silts, sands, and gravels among the 33 streambed sediment depositional sites in the four study subwatersheds, measured in 2007. Statistical results between single model and measured variables were similar for modeled years 2006 and 2007 at significance levels that ranged between 0.05 and 0.07 (Appendix F). Because of this similarly with 2006 and 2007 model data, a multivariate stepwise regression only used 2006 model data. Results from this analysis found average annual weights of clay, silt, and combined clay and silt, in addition to the annual average total sediment yield generated by the AnnAGNPS model to be significantly related to a combination of particle size characteristics of measured fine streambed sediment (Table 15). Four significant regression equations predicting model clay, silt, and total yield estimates to instream depositions of clay and silt % weights were:

$$06\text{-}PW\text{-}Cl = 254.13 - 162{,}109.87(MP\text{-}Cl) + 14{,}819.32(MP\text{-}Si/Gr)$$

$$06\text{-}PW\text{-}Si = 718.01 - 29{,}125.19(MP\text{-}Si/Sa) + 27{,}247.06(MP\text{-}Si/Gr)$$

$$06\text{-}PW\text{-}TSY = 798.79 - 512{,}783.35(MP\text{-}Cl) + 46{,}716.34(MP\text{-}Si/Gr)$$

$$06\text{-}PW\text{-}ClSi = 742.99 - 500{,}024.15(MP\text{-}Cl) + 46{,}001.31(MP\text{-}Si/Gr)$$

where, 06-PW-Cl, 06-PW-Si, 06-PW-TSY, 06-PW-ClSi are 2006 annual average sediment yield from AnnAGNPS model output for %clay, %silt, total yield in Mg, and %clay and silt summed, respectively; and MP-Cl, MP-Si/Gr, and MP-Si/Sa are instream measured sediment as %clay, a ratio of %silt to %gravel, and a ratio of %silt to %sand, respectively.

The key finding from this statistical analysis was that significant relationships were observed between fine sediment characteristics on the streambed and annual sediment yields generated by the AnnAGNPS model. Indirectly, this infers benthic condition on the streambed corresponds to levels land use activities or disturbances. It also infers that the new streambed fine sediment collection method (Section 5.2.2) can be useful as a surrogate for suspended sediment load in a watershed. Size characteristics of fine sediment can therefore be used to assess whether land use activities have potentially impaired a stream, biologically. These predictive models in Table 15 are only valid for the New River basin, likely varying among different physiographic regions.

Table 15. Summary of statistical relationships for sediment deposition and yield.

Sediment Yield	Stream Bed	Multivariate		Standard Least Squares Regression		
Response Variable	Sediment Variables	Spearman ρ	Prob > |ρ|	R-Square	F Ratio	Prob > F
06-PW-Cl	MP-Cl	0.1228	0.4961	0.69	33.86	< 0.0001
	MP-Si/Gr	0.3108	0.0783			
06-PW-Si	MP-Si/Sa	0.3038	0.0856	0.65	28.31	< 0.0001
	MP-Si/Gr	0.3195	0.0699			
06-PW-TSY	MP-Cl	0.1139	0.5280	0.64	26.57	< 0.0001
	MP-Si/Gr	0.3189	0.0705			
06-PW-ClSi	MP-Cl	0.1122	0.5341	0.69	33.14	< 0.0001
	MP-Si/Gr	0.3112	0.0780			

7.3 Characterization of Uplands Sediment

Soil shear stress properties were measured by pocket and cone penetrometers at each of the uplands sample locations, as identified in Table 9, representing locations with different land uses (White 2009). Atterberg limits tests were also conducted in the UT Geotechnical Laboratory to estimate the plastic limits, an indicator of soil shear stress. Measurement results for soil shear stress properties and particle size distributions of the uplands sediment samples are reported in Tables 16 and 17, respectively.

The shear strength data collected within the reclaimed mining areas fell near the average for all of the studied areas. In addition to these areas having average strengths they also had the lowest low plasticity clay contents. This result suggests that these areas would be less prone than other studied areas to producing high sediment loads. The highest shear strength data was collected within the logging roads. Although these areas had the highest strengths they also had higher than average low plasticity clay contents. This suggests that these areas would be slightly less susceptible to producing sediment loads than the other studied areas. The shear strength data from the mining roads was below average for the studied areas. In addition to low strength data these areas also had higher than average low plasticity clay contents. This result suggests that these areas would be more prone to producing sediment than the logging road areas. The lowest shear strength data was collected within the logged areas. In addition to low strength data these areas had the highest low plasticity clay contents. This result suggests that these logged areas would be more prone to producing sediment than the mining road areas.

7.4 Relationships between Uplands Sediment and Streambed Fine Sediments

Statistical analysis was performed between uplands and streambed fine sediment characteristics exploring whether streambed sediment correlated with uplands sediment

Table 16. Soil shear stress properties for uplands soil samples measured by pocket and cone penetrometers (PP, CP), and Atterberg plastic limits. See Table 9 for land use descriptions per site.

Sample ID	Shear Strength (PP, tsf)	Shear Resistance (CP, lbs)	Plastic Limit	Liquid Limit	Plasticity Index
U-BR-1	3.25	75	NP	NP	NP
U-BR-2	2.0	40	NP	NP	NP
U-BR-3	3.5	85	NP	NP	NP
U-BR-4	1.5	35	NP	NP	NP
U-SC-1	3.25	75	32	40	8
U-SC-2	5.0	140	24	33	9
U-SC-3	2.5	45	NP	NP	NP
U-SC-4	3.0	75	NP	NP	NP
U-MF-1	1.75	35	NP	NP	NP
U-MF-2	2.75	55	43	55	12
U-MF-3	4.5	110	32	33	1
U-MF-4	2.5	50	NP	NP	NP

Table 17. Summary metrics of particle size distributions for uplands soil samples. See Table 9 for land use descriptions per site.

Sample ID	% finer than 200	% clay	D50 (mm)	D84 (mm)	USCS Classification
U-BR-1	61	16	0.04	1.0	ML
U-BR-2	57	9	0.05	0.25	ML
U-BR-3	39	10	0.09	8.0	SM
U-BR-4	56	19	0.04	11.5	ML
U-SC-1	45	13	0.30	6.0	SM
U-SC-2	51	14	0.07	4.0	ML
U-SC-3	67	20	0.02	2.5	ML
U-SC-4	41	8	0.20	9.0	SM
U-MF-1	52	14	0.07	10.5	ML
U-MF-2	26	7	0.06	11.7	GM
U-MF-3	58	22	0.03	4.0	ML
U-MF-4	60	28	0.02	1.8	ML

characteristics as an indication of uplands sources that contribute to excessive streambed sediments. In streams, two major sources of sediment must be differentiated; they are uplands disturbed areas and/or stream bank erosion. Depending on the source, modeling tools can be determined. For example, if uplands sources are dominant in the system then AnnAGNPS only needs to be used, whereas if bank erosion is the dominant source then ConCEPTS can be used. Thus, this field-based uplands sediment assessment was examined as a possible tool to guide what model or models are needed to develop the sediment budget (Reid and Dunne 1996).

The statistical analysis between field-collected and model streambed sediment characteristics found % silt + clay to be the relevant streambed sediment characteristic (Section 7.2). Streambed percent silt+clay was the dependent variable used in the analysis. This is supported by the Phase I analysis that found streambed sediment with a percent particle size less than 0.016 mm (silt) to indicate a disturbed subwatershed (Schwartz *et al*. 2008a). Average values from the multiple sample points were used in this analysis (Table 18), although the full set of data are presented in Tables 11 through 14. Uplands sediment was collected in Brimstone, Montgomery, and Smokey subwatersheds, therefore are the watersheds used in this analysis (Table 9). The averaged parameters from multiple disturbed land collection sites as used were four: CP shear resistance, % finer on a #200 sieve, % clay, and D50 (Tables 16 and 17).

Using streambed percent silt + clay as the dependent variable, regression analyses was conducted among the uplands independent variables. No significant relationships were observed among variables. However, the relationship with uplands % clay was highly correlated (R^2 = 0.90; p = 0.21). Brimstone Creek, the undisturbed subwatershed was lower in stream % silt + clay and uplands % clay than Montgomery Fork and Smokey Creek, subwatersheds with land use disturbances (Figure 38). From Figure 38, it appears there may be some utility in this assessment approach but was not used in the final protocols for developing sediment budgets.

Table 18. Subwatershed / stream averaged site estimates of streambed and uplands sediments.

Sub-watershed / Stream	Streambed % Silt+Clay	Uplands CP Shear Resistance (lbs)	Uplands % Finer than #200 Sieve	Uplands % Clay	Uplands D50
Brimstone	0.584	58.75	53.3	13.50	0.055
Montgomery	0.929	83.75	51.0	13.75	0.148
Smokey	1.515	62.50	49.0	17.75	0.053

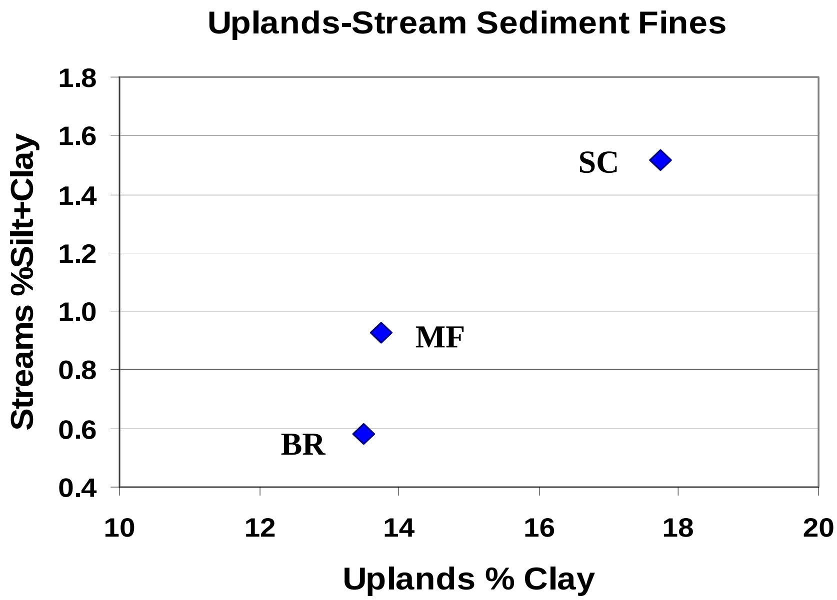


Figure 38. Scatterplot of site averages of streambed percent silt+clay and uplands soil percent clay for the Brimstone (BR), Montgomery (MF), and Smokey (SC) subwatersheds.

8.0 SEDIMENT BUDGET PROTOCOLS FOR ASSESSING STREAM DEGRADATION

8.1 Evaluation of Assessment Techniques and Models

Sediment assessment techniques and models evaluated as part of both Phase I and II studies included: 1) stream channel stability RGA; 2) comparison of streambed sediment characteristics between undisturbed (reference) and disturbed subwatersheds; 3) relationships between streambed and upland sediment characteristics in disturbed subwatersheds; 4) relationships between streambed sediment characteristics field-collected samples and AnnAGNPS model output; 5) AnnAGNPS model; and 6) ConCEPTS model.

8.1.1 Rapid Geomorphic Assessment (RGA)

The RGA is an assessment tool to determine whether a channel is stable or unstable (Section 3.4). Unstable channels result from hydrological modification once land use/cover has been disturbed, typically after the removal of vegetation. RGA protocols were described in Section 5.1. Implementation of the field-based RGA uses nine geomorphic scores per stream site, formulating a total index score between 0 and 36 (Appendix A). A stable channel has a score less than 10, and an unstable channel has a score greater than 20. Scores between 10 and

20 are determined to be stable or unstable based on the stage of channel evolution (Figure 3). Stages I, V, and VI are considered stable channels, and stages II, III an IV are unstable.

The RGA can be applied successfully as a tool for the CHIA process in the Appalachian region of the United States. In general, this study found most headwater streams to be stable due to geologic controls. Bank erosions problems were observed in lower subwatershed areas containing floodplains with alluvium, and if RGAs were conducted at those locations they would score as unstable channel geomorphic conditions. Although this study collected data from the New River watershed, East Tennessee, other data from Williams (2005) and the USDA NSL support this conclusion (Simon *et al*. 2004b; Simon and Klimetz 2008). Overall, The RGA is a useful field assessment tool to evaluate whether coal mining operations are having an impact on channel stability downstream of their hydrological influence.

In the context of generating watershed sediment budgets, the RGA would be applied for approximately 10 sites within a CHIA subwatershed, and used to determine whether stream channels were stable or unstable (Section 8.2). If channels are predominantly stable as delineated by RGA scores, the AnnAGNPS would be applied without the ConCEPTS model to estimate annual sediment yields for a sediment budget. If unstable channels occur in the CHIA subwatershed, the ConCEPTS model should be applied with the AnnAGNPS model to estimate annual sediment yields, in which bank erosion sources of stream sediment are accounted for from model outputs.

8.1.2 Streambed Sediment Characteristics: Reference and Disturbed Subwatersheds

Fine bed sediment samples collected in “lateral” depositional areas of streams appears to be useful and cost effective means to identify streams potentially impacted by uplands erosion, including coal mining operations (Section 7.2). This field assessment effort was initially an outcome of the Phase I study in which differences in fine sediment characteristics between disturbed and undisturbed subwatersheds were analyzed to identify a potential threshold metric that could be used to distinguish differences (Schwartz *et al*. 2008a). Results of the fine streambed sediment, collected and analyzed in the manner described in Section 5.2.2, indicated that when samples were greater than ‘*0.8% by weight of 0.016 mm diameter sediment*’, it appeared to indicate a subwatershed was disturbed (Figure 39). The 0.8% value represents the percent finer for the fine silt size class (0.016 mm diameter).

Although, fine sediment portions by weight were small, they did indicate a potential siltation problem. Reference or undisturbed subwatersheds always had percentages less than 0.8%. This field-based assessment approach was determined to be successful and needs to be incorporated into the overall sediment budget development protocols (Section 8.2). It could also be used to locate problem areas for sediment source identification, in conduction with AnnAGNPS modeling (Section 8.1.4). It should be cautioned that the threshold of ‘*0.8 % finer of 0.016 mm sediment*’ was observed for subwatersheds in the New River basin. Other CIA units may differ in a threshold value based on differences in geology, soils, and vegetation cover.

8.1.3 Relationships between Streambed and Uplands Fine Sediment Characteristics

In general, relationships between streambed and uplands fine sediment characteristics were weak (Section 7.4). Number of samples may have limited the analysis outcomes, although they were sufficient to evaluate whether this assessment approach could be helpful (Figure 38). One possible relationship that was observed that included the metric ‘% silt+clay in the streambed’ as

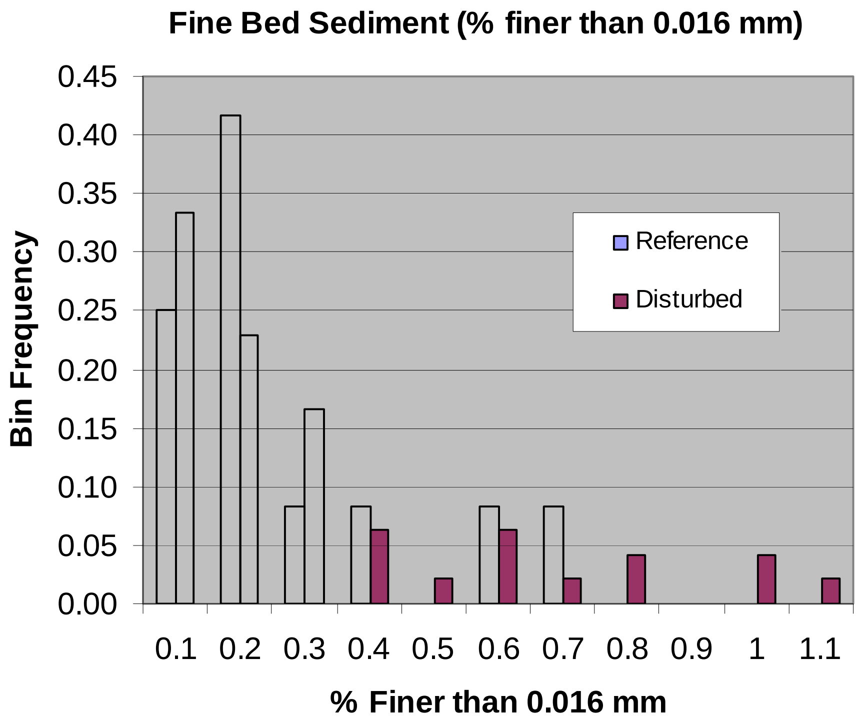


Figure 39. Frequency of occurrence of fine bed sediment, % finer than 0.016 mm by weight, for Phase I study reference and disturbed subwatershed sites. Frequency of occurrence was normalized by number of sites within each subwatershed category (12 reference sites from 3 watersheds, and 48 disturbed sites from 4 watersheds).

collected by methods defined in Section 5.2.2, and %clay sampled from a composite of disturbed uplands site samples. Because the pattern was not statistically significant it will not be included in the final set of watershed sediment budget protocols.

8.1.4 Streambed Sediment Characteristics Related to AnnAGNPS Model Output

A statistical analysis established that streambed fine sediment characteristics, as collected by methods defined in Section 5.2.2, were related to AnnAGNPS model output characteristics (Section 7.2, Appendix F). Modeled annual average sediment yields for %clay, %silt, %clay+silt, and total yield in Mg could be significantly predicted by regression equations using the following streambed fine sediment characteristics: %clay, a ratio of %silt to %gravel, and a ration of %silt to %sand. In general, these statistical relationships inferred that the AnnAGNPS model was able to simulate instream sediment values representing fine sediment in “lateral” deposition areas. This analysis supports the concept that fine sediments deposited in “lateral” areas can be used as a surrogate for the amount of suspended sediment in transport during flood events, and the amount eroded from the uplands disturbed areas. Therefore, sampling and analyzing for fine sediment in the streambed, as noted above in Section 8.1.2, appears to be a useful rapid assessment tool indicating whether there may be a siltation issue (Section 8.2). Siltation is defined as a stream impacted by excessive fine sediment delivery to the stream channel. AnnAGNPS modeling can provide additional evidence of the potential locations of excessive fine sediments in a CHIA subwatershed (Section 8.1.5).

8.1.5 AnnAGNPS Model: Sediment Source Identification and Yields

As observed from the model simulation results in Section 6.0 and the calibration-verification results in Appendix C, the AnnAGNPS performed reasonably well to estimate sediment yields from CHIA subwatersheds. This evaluation was based on comparing measured versus model outputs of daily water discharge and sediment yields (Appendix C, Figures 17 and 18). Measured data for water discharges were completed for approximately nine months and instream suspended sediment samples were three months. A longer period of field measurements would have lead to a more quantitative comparison. However, the model responded with outputs of suspended sediment yields on stormflow days, and annual sediment yields differed among the four study subwatersheds as expected. Brimstone Creek generated the least sediment annually being the "reference" subwatersheds, and Ligias Fork, Montgomery Fork, and Smokey Creek generated relatively higher levels of sediment as function of watershed area disturbed either by logging, roads, and surface coal mining on an annual basis. For the CHIA process, the AnnAGNPS model major utility is in its ability to estimate relative portions of instream sediment sources from uplands erosion (Figures 20 through 27), and identify in the subwatershed spatially where potential sediment sources are generated (Figures 28 through 31). Identifying where and how much instream sediment is generated by different land use activities are the main outcomes needed to develop a sediment budget.

The AnnAGNPS model can be a useful tool for OSM's CHIA process because of its capability to estimate changes in sediment yield from proposed new mining permits (Section 8.2). Once the DEM, land use, and soil spatial layers are compiled into the model, and climate data temporal files are compiled, new land use scenarios can be simulated easily. When a new permit application is being processed by OSM or state, the land use data later is modified in GIS adding a polygon designated as surface mining. OSM staff could choice to use the pond detention function in AnnAGNPS and simulate difference scenarios for sediment treatment by adjusting the RUSLE P factor as a %removal based on anticipated BMP performance. The land use layer would also need to be periodically updated to address land use changes, accounting for new logging or oil & gas activities, vegetative re-growth in prior logged area, new roads, etc.

Continued stream discharge and TSS samples measurements should be collected at nearest CHIA subwatershed outlet for periodic recalibration and verification of the AnnAGNPS model. Model calibration and verification are illustrated in Appendix C. Discharge can be obtained by recording flow stage with a pressure transducer and automatic data logger type device (Section 5.5). A single cross-section is surveyed near the stage recorder, and discharge measured at varying flow depths using USGS standard methods. A stage-discharge relationship is developed at the cross-section so that discharge can be computed for all stages recorded by the pressure transducer. Pressure transducers are easily purchased and installed. Grab samples for TSS should be collected at this stage recorder site, and data compiled for varying flow stages (Section 5.6). It is critical to have samples taken during high flows following precipitation events greater than 1.2-inch in 24 hours. This data acquisition could be incorporated into the PHC process.

8.1.6 ConCEPTS Model

The ConCEPTS Model has utility if bank erosion could be a major contributor to instream sediment, and yield estimates need to be generated and compared with uplands estimated generated from AnnAGNPS model. Results from the ConCEPTS modeling effort found model performance was acceptable and generated estimate of sediment yields from bank erosion in order to support development of watershed sediment budgets (Section 6.2, Table 10). However, an outcome of this modeling effort was the recognization that using ConCEPTS requires a significant time investment for obtaining input data necessary to run the model (Section 5.9). Model performance and successful simulation runs required careful entry and adjustment of boundary conditions of the upstream sediment flux. The model was ultimately helpful in identifying reaches that could have a bank failure (mass-wasting) problem. Others have incorporated bank stability modeling tools to supplement total sediment yields from watersheds including both uplands and bank sources (Amiri-Tokaldany *et al*. 2003; Staley *et al*. 2006). Fox (2009) specifically suggests bank erosion downstream of surface coal mining operations could be a dominant source of instream sediment. Having this modeling capability when needed provides OSM with the ability to comprehensively examine all possible sources of instream sediment, and the information for improved hydrological resource management.

8.2 Watershed Sediment Budgets

8.2.1 Protocols for Sediment Budget Development

Reid and Dunne (1996) defined a sediment budget as "an accounting of the sources and disposition of sediment as it travels from its point of origin to its eventual exit from the drainage basin." An outcome of developing sediment budgets is the estimation of sediment yields, which can be compared between reference and disturbed watersheds. This provides a relative measure of the increase in sediment yields from different active land use activities that disturb uplands and stream bank soils. Importantly, developing sediment budgets are to be applied and interpreted at a *large* watershed scale, in contrast to a local scale at surface mining sites. This exemplifies the differences in application of AnnAGNPS, a watershed-scale model, compared to SEDCAD applied at a local mining site scale. Modeling should be simulated over long periods of time (about 10+ years) to account for differences in climatic conditions year to year, thereby estimating an average annual sediment yield. It should also be noted that developing sediment budget accounts for dominant sources at the watershed-scale, and cannot account for minor, short-term disturbances such as water pipeline construction, residential activities, instream commercial rock mining etc. (Figure 40). These temporary direct inputs of sediment into the stream during large storm events would not be predicted by AnnAGNPS model, or any other computer software available applied at a watershed scale.

Figure 40. Temporary sediment yield increase due to water utility construction, Ligias Fork.

A main objective of developing a sediment budget for this study is to support the CHIA process in identifying potential impacts from surface mining. The general approach, formulated from Phase I and II studies on the New River, Tennessee, consists of the use of rapid field-based assessments to identify the extent of sediment erosion problems in the CHIA subwatersheds (Figure 41). This information then determines what model(s) are to be used to generate the sediment budget. In Figure 41, the protocols begin with field-based instream fine sediment sampling and geomorphic assessment (RGA) to determine whether more advanced watershed sediment modeling is needed for a CHIA. Obtaining a RGA score requires a field inspector to determine assess the reach's stage of channel evolution, which stage criteria are defined in Section 3.4 and Figure 3. A field inspector should have a background in the physical sciences, i.e., geology or geomorphology, to conduct RGAs.

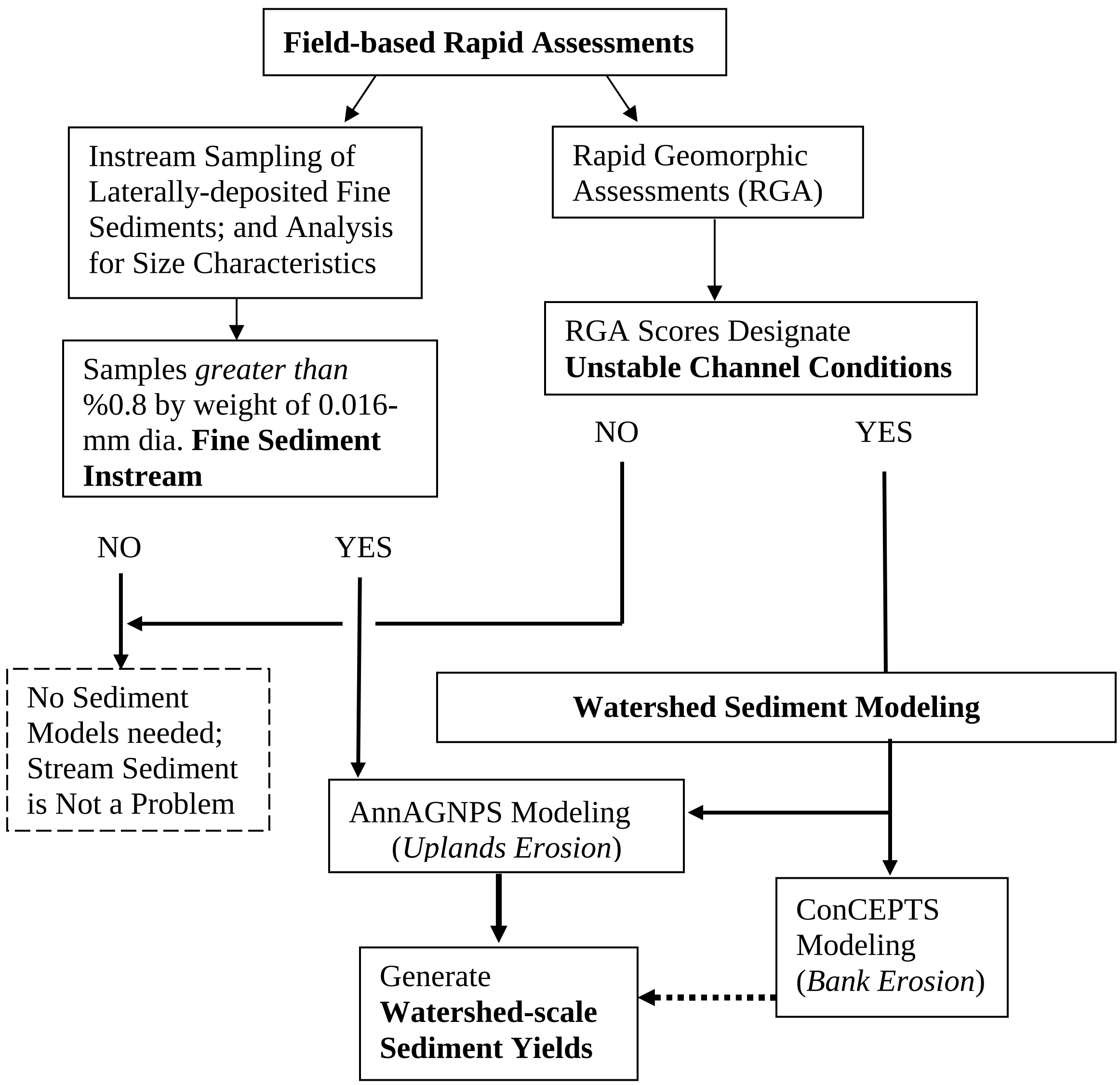


Figure 41. Flowchart of field-based assessment and sediment modeling tools for proposed use in developing watershed-scale sediment budgets.

The following interpretations can be made from the Figure 41 flow chart:

- If instream fine sediment samples are analyzed and determined to be less than '*%0.8 by weight of 0.016 mm diameter fine sediment*' and RGA scores are below 10 or below 20 and in Stage I, V or VI stage of channel evolution, then no watershed sediment modeling is required.
- If instream fine sediment samples are analyzed and determined to be greater than '*%0.8 by weight of 0.016 mm diameter fine sediment*' and RGA scores are below 10 or below 20 and in Stage I, V or VI stage of channel evolution, then it can be interpreted that most stream sediments are produced from upland sources, and only the AnnAGNPS model is needed to generate annual average sediment yields for a sediment budget.
- If instream fine sediment samples are analyzed and determined to be greater than '*%0.8 by weight of 0.016 mm diameter fine sediment*' and RGA scores are above 20, then it can be interpreted that sediments are produced from upland and stream bank sources, and both AnnAGNPS and ConCEPTS models are needed to generate annual average sediment yields for a sediment budget.

From field-based assessments, potential sediment erosion problems are identified in the CHIA, and gathered information can be used to define the specific problems. Field-based assessments can be supplemented with aerial photo interpretation looking for problem uplands erosion areas. Photos will need to be recent. Older photos provide some historical information, but are not useful for generating a current sediment budget. If sediment modeling is needed, the models are to be selected based on the identified problems. With the models selected, input data will need to be gathered and model simulations conducted to generate sediment budgets for CHIA subwatersheds.

Sediment budgets include: 1) an average annual sediment yield (e.g., Figure 19); 2) % average annual sediment yields per major source (e.g., Figures 21 through 27); and 3) plots of average annual sediment yields spatially defined per model flow cell (e.g., Figures 28 through 31). Major sources of sediment yields designated spatially on subwatershed plots at "erosion hot spots" should be checked by "ground-truthing" field surveys. If bank erosion is also a dominant sediment source, yields from ConCEPTS (e.g., Table 10) must be added to AnnAGNPS model estimates. Because the channels in this study were considered stable, watershed sediment budgets are constituted from AnnAGNPS model outputs only, as shown in Figure 19.

To supplement the development of sediment budgets for CHIA subwatersheds, a "reference" or undisturbed subwatershed can be modeled and compared to subwatersheds that have been identified with excessive sediments. Results from a "reference" subwatershed model provide sediment yield "targets" to achieve by BMP implementation. In addition, supplemental data may include state biotic integrity surveys, in which subwatersheds impaired by excessive sediment are identified and also modeled. Sediment budgets for impaired subwatersheds derived from watershed sediment modeling provides general ranges in which sediment yields may cause streams to become biologically impaired. Within the CHIA process, modeled sediment yields from "reference" and biologically impaired subwatersheds could be useful for a relative comparison of watershed condition. The AnnAGNPS model does have the ability to model reductions of sediment yields from different BMP scenerios, including pond detentions, providing the level of effort needed to correct any potential excessive stream sediment problems.

8.2.2 Data Support: Probable Hydrological Consequences

Data collected for PHCs could include the two proposed field-based rapid assessment for problem identification (Figure 41). The PHC protocol for collecting, analyzing, and interpreting results of fine sediment samples on the stream bed are as follows:

1) Collected fine bed sediment samples in lateral deposition zones, the lee end of point bars, behind boulders or large woody debris, or laterally near banks immediately downstream of a rapid channel width expansion. These are areas in the stream that form hydraulic recirculation zones during flooding, in, which fine sediment deposits.
2) Analysis the bed sediment samples following ASTM methods to generate a particle size distribution (PSD) curve. ASTM methods are specifically Standards Volume 4.08, Method D 422063.
3) Identify on PSD curve the value for % finer than 0.016 mm. Report value, if greater than 0.8% it is likely the stream is being impacted by excessive fine sediment delivery.

RGAs can be applied within CHIA subwatersheds just upstream of major tributaries, and within 0.5 to 1.0 km downstream in tributaries that drain any coal mining operation. The frequency of every five years is recommended for comprehensive RGA surveys throughout CHIA watersheds. However if a major coal mining operation is in progress, RGAs at the downstream tributary site(s) should be conducted annually at that location. Implementation of the RGA requires trained personnel in the geosciences. To obtain useful RGA scores, mining permittees would need to hire trained individuals for PHC data collection. Implementation of RGAs would likely be more valuable for the CHIA process if conducted by trained OSM personnel. However, with adequate OSM oversight, RGA implementation may be accurately conducted for PHC data collection for downstream sites of the coal mining operations.

8.3 Conclusion and Model Discussion

The combined use of field-based rapid geomorphic assessment and sediment modeling, as followed by the flow chart in Figure 41, provides OSM with a cost-effective and comprehensive approach to addressing sediment in CHIA subwatersheds. Importantly, results of modeling efforts specifically recognize all the major contributors of sediment in CHIA subwatersheds, and these results can put into context the percent contribution generated from surface mining. In addition, models supply OSM staff with valuable information on specifying BMPs in surface mining permits.

As a matter of discussion, other sediment models could be used in CHIAs, but were not evaluated as part of this study. In general, the AnnAGNPS model and the USEPA's *soil and water assessment tool* (SWAT) model are comparable. They both use the hydrological routing function. AnnAGNPS uses RUSLE and HUSLE functions for sediment erosion and yield estimates, whereas SWAT uses MUSLE (Borah *et al.*, 2003, 2006). One advantage of AnnAGNPS is that it can be linked to the ConCEPTS model, and SWAT cannot. ConCEPTS required a significant amount of data input to run the model. A steady-state, rather than a dynamic model, for bank erosion is available from the USDA NSL. This model is the bank stability and toe erosion model (BSTEM) (Simon et al. 2009a,b). It can provide estimates of sediment loads from bank mass wasting (failures). The last model to reference is CCHE2D sediment transport model developed by the University of Mississippi National Center for Computational Hydroscience and Engineering (Johnson 2008; Wu 2008). CCHE2D is a dynamic model that route sediment through a stream reach of interest. The utility of this model would be for a specific use in a landslide area. Sediment from a landslide delivered to the channel, and the movement of it could be simulated with the use of CCHE2D. The model would estimate how long it will take for the sediment to be transport evenly downstream. This model also requires a significant amount of data input, therefore its utility would only be valuable for very specific needs.

9.0 REFERENCES

Amiri-Tokaldany, E., S.E. Darby, and P. Tosswell. (2003). Bank stability analysis for predicting reach-scale land loss and sediment yield. *Journal of the American Water Resources Association* **39**(4): 897-909.

Ashida, K. and M. Michiue. (1971). An investigation of river degradation downstream of a dam. *Proceedings IAHR 14th Congress* **3**: 247-255; Paris, France.

ASTM. (2003). *Standard Test Method for Particle-Size Analysis of Soils.* Volume 4.08, No. D422-63. ASTM International, West Conshohocken, PA. 04.08: 10-17.

Babbit, G.S. (2005). *Bankfull Hydraulic Geometry of Streams Draining the Southwestern Appalachians of Tennessee*. MS Thesis, University of Tennessee, Knoxville.

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. (1999). *Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers; Periphyton, Benthic Macroinvertebrates, and Fish*. EPA 841-B-99-002. U.S. Environmental Protection Agency; Washington, D.C.

Bakaletz, S. 1991. *Mussel Survey of the Big South Fork National River and Recreational Area.* MS Thesis. Tennessee Technological University, Cookeville.

Bennett, J.P. (1974). Concepts of mathematical modeling of sediment yield. *Water Resources Research* **10**(3): 485-492.

Buchanan, T.J., and W.P. Somers. (1976). *Discharge Measurements at Gaging Stations*. USGS Techniques of Water-Resources Investigations, Book 3 - Chapter A8. Washington D.C.

Bunte, K., and S.R. Abt. (2001). *Sampling Surface and Subsurface Particle-size Distributions in Wadable Gravel- and Cobble-bed Streams for Analyses in Sediment Transport, Hydraulics, and Streambed Monitoring*. US Forest Service General Technical Report RM, RS-GTR-74.

Bunte, K., S.R. Abt, J.P. Potyondy, and S.E. Ryan. (2004). Measurement of coarse gravel and cobble transport using portable bedload traps. *J. of Hydraulic Engineering* **130**(9): 879-893.

Burges, S.J., M.S. Wigmosta, and J.M. Meena. (1998). Hydrological effects of land-use change in a zero-order catchment. *J. Hydrological Engineering* **3**(2): 86-97.

Bingner, R.L, F.D. Theurer, and Y. Yuan. (2003). *AnnAGNPS Technical Processes—Documentation—Version 3.3*. ARS-National Sedimentation Laboratory and NRCS-National Water and Climate Center, U.S. Department of Agriculture, Oxford, MS.

Borah, D.K., G. Yagow, A. Saleh, P.L. Barnes, W. Rosenthal, E.C. Krug, et al. (2006). Sediment and nutrient modeling for TMDL development and implementation. *Transactions of the American Society of Agricultural and Biological Engineers.* 49(4): 967-986.

Borah, D.K. and M. Bera. (2003). Watershed-scale hydrologic and nonpoint-source pollution models: Review of mathematical bases. *Transactions of the American Society of Agricultural and Biological Engineers,* **46**(6): 1553-1566.

Brady, N.C. (1974). *The Nature and Properties of Soils*. New York: Macmillan Publ, Inc.

Bunte, K., and L.H. MacDonald. (1995). Detecting changes in sediment loads: where and how is it possible? *Effects of Scale on Interpretation and Management of Sediment and Water Quality*. International Association of Hydrological Sciences Publication No. 226, 253-261.

Caissie, D., S. Jolicoeur, M. Bouchard, M., and E. Poncet. (2002). Comparison of streamflow between pre and post timber harvesting in Catamaran Brook (Canada). *Journal of Hydrology*, **258**(1-4): 232-248.

Carey, W.P. (1984). Effects of resource development on water quality in the Big South Fork National River and Recreational Area, Tennessee and Kentucky. *Conference Proceeding Paper, Water for Resource Development,* 624-628.

Chow, V.T. (1959). *Open Channel Flow*. McGraw-Hill Book Company, New York, NY.

Cole Parmer. (2009). http://www.coleparmer.com/catalog/product_view.asp?sku=9903900.

Costanti, A., R.J. Loch, R.D. Connolly, and R. Garthe. (1999). Sediment generation from forest roads: bed and eroded sediment size distributions, and runoff management strategies. *Australian Journal of Soil Research* **37**: 947-964.

Dietrich, W.E., C.J. Wilson, D.R. Montgomery, and J. McKean. (1993). Analysis of erosion thresholds, channel networks, and landscape morphology using a digital terrain model. *Journal of Geology* **101**: 259-278.

Eaton, A.D, L.S. Clesceri, M.A. Franson, and A.E. Greenberg. (1995). *Standard Methods for the Examination of Water and Wastewater* (19th Edition). Section 2540 Solids, pp. 2-53–2-58. Washington, D.C.: American Public Health Association.

Edwards, T.K., and G.D. Glysson. (1999). *Field Methods for Measurement of Fluvial Sediment*. USGS Survey Techniques of Water-Resources Investigations, Book 3 Chapter C2, revision from 1970 publication; U.S. Geological Survey, Reston, Virginia.

Evans, R.B. (1998). *Distribution of Fishes and Changes in Biotic Integrity in the New River, Tennessee.* MS Thesis. University of Tennessee, Knoxville.

Fargas, D., J.A. Martinez-Casasnovas, and R. Poch. (1997). Identification of critical sediment source areas at regional level. *Physical Chem. Earth* **22**: 355-359.

Foster, G.R, T.E. Toy, *et al*. (2003). *Comparison of the USLE, RUSLE1.06c, and RUSLE2 for Application to Highly Disturbed Lands*. First Interagency Conference on Research in the Watersheds, Benson, AZ, USDA Agricultural Research Service.

Fox, J.F. (2009). Identification of sediment sources in forested watersheds with surface coal mining disturbance using carbon and nitrogen isotopes. *Journal of the American Water Resources Association* **45**(5): 1273-1289.

Freeman, P.L., and M.S. Schorr. (2004). Influence of watershed urbanization on fine sediment and macroinvertebrate assemblage characteristics in Tennessee Ridge and Valley streams. *Journal of Freshwater Ecology* **19**(3): 353-362.

Fryirs, K. and G.J. Brierley. (2001). Variability in sediment delivery and storage along river courses in Bega catchment, NSW, Australia: implications for geomorphic river recovery." *Geomorphology* **38**: 237-265.

Garbrecht, J., R.A. Kuhnle, and C.V. Alonso. (1996a). A sediment transport capacity formulation for application to large channel networks. *Journal of Soil and Water Conservation*, **50**(5): 527-529.

Garbrecht, J., R.A. Kuhnle, and C.V. Alonso, C. V. (1996b). A transport algorithm for variable sediment sizes: Fundamental concepts and equations. *Proceedings, Sixth Federal Interagency Sedimentation Conference.* (pp. VI-8 – VI-15). Washington, D.C.

Garcia, M.H. (2007). *Sedimentation Engineering*. American Society for Civil Engineers. Reston, Virginia.

Gardner, E.S. (2006). *Cumberland Plateau – National Heritage Corridor Feasibility Study*. Retrieved March 1, 2007, from the Tennessee Department of Environmental Conservation – Alliance for the Cumberlands website, http://www.tdec.net/recreation/cumberlandplateau.pdf

Gray, J.R., G.D. Glysson, L.M. Turcios, and G.E. Schwartz. (2000). *Comparability of Suspended-Sediment Concentrations and Total Suspended Solids Data*. U.S. Geological Survey, Water-Resources Investigations Report 00-4191. Reston, VA.

Hann, C.T., B.J. Barfield, and J.C. Hayes. (1994). *Design Hydrology and Sedimentology for Small Catchments*. San Diego, CA: Academic Press, Inc.

Hanson, G.J. (1990). Surface erodibility of earthen channels at high stresses. Part II – Developing an in-situ testing device. *Transactions of the ASAE* **33**(1): 132-137.

Harvey, A.M. 2001. Coupling between hillslope and channels in upland fluvial systems: implications for landscape sensitivity, illustrated from the Howgill Fells, northwest England. *Catena* **42**: 225-250.

Henley, W.E., M.A. Patterson, R.J. Neves, and A.D. Lemly. (2000). Effects of Sedimentation and Turbidity on Lotic Food Webs: A Concise Review for Natural Resources Managers. *Reviews in Fisheries Science* **8**(2): 125-139.

Johnson, D.H. (2008). *The Application of a Two-dimensional Sediment Transport Model in a Cumberland Plateau Mountainous Stream Reach with Complex Morphology and Coarse Substrate*. MS Thesis, University of Tennessee, Knoxville.

Jones, J.A., F.J. Swanson, B.C. Wemple, and K.U. Snyder. (2000). Effects of roads on hydrology, geomorphology, and disturbance patches in stream network. *Conservation Biology* **14:** 76–85.

Julien, P.Y. (1995). *Erosion and Sedimentation*. Cambridge University Press, New York, NY.

Kaller, M.D., and K.J. Hartman. (2004). Evidence of a threshold level of fine sediment accumulation for altering ben. macroinvertebrate communities. *Hydrobiologia* **518**: 95-104.

Kirkby, M., L. Bracken, and S. Reaney. (2002). The influence of land use, soils and topography on the delivery of hillslope runoff to channels in SE Spain. *Earth Surface Processes and Landforms* **27**: 1459-1473.

Knighton, D. (1998). *Fluvial Forms & Processes, A New Perspective*. Oxford University Press Inc., London. 383 pp.

Langendoen, E.J. (2000). CONCEPTS – *Conservational Channel Evolution and Pollutant Transport System, Research Report 16*, U.S. Department of Agriculture, Agriculture Research Service, USDA-ARS National Sedimentation Laboratory, Oxford, MS.

Langendoen, E.J. (2001). *Evaluation of the Effectiveness of Selected Computer Models of Depth-averaged Free Surface Flow and Sediment Transport to Predict the Effects of Hydraulic Structures on River Morphology*. Project Report, USDA-ARS National Sedimentation Laboratory, Oxford M.S.

Langendoen, E.J., A. Simon, and R.E. Thomas. (2001). CONCEPTS-a process-based modeling tool to evaluate stream-corridor restoration designs. *Proc., 2001 Wetlands Engineering and River Restoration Conference*, Reno, NV, August 27-31, 2001. American Society of Civil Engineers, Reston, VA.

Langendoen, E.J., and C.V. Alonso. (2008). Modeling the evolution of incised streams: I. Model formulation and validation of flow and streambed evolution components. *Journal of Hydraulic Engineering* **134**(6): 749-762.

Licciardello, F., D.A. Zema, S.M. Zimbone, and R.L. Bingner. (2007). Runoff and soil erosion evaluation by the AnnAGNPS model in a small Mediterranean watershed. *Transactions of the American Society of Agricultural and Biological Engineers* **50**(5): 1585-1593.

Linsley, R.K., M.A. Kohler, and J.L. Paulhus. (1982). *Hydrology for Engineers* (3rd Ed.). New York, NY: McGraw-Hill Publishing.

Maidment, D.R. (1992). *Handbook of Hydrology*. McGraw Hill Publ., New York.

Mallison, T.L. (2008). *Comparing In-situ Jet Test Device and Laboratory Flume Methods to Estimate Erosional Properties of Cohesive Soils for Bank Stability Models*. MS Thesis, University of Tennessee, Knoxville, TN.

Massey, M.P. (2008). *Use of the AnnAGNPS Pollutant Loading Model for Prediction of Sediment Yields in a Mountainous Cumberland Plateau Region: Correlations with the Bed Sediment Characteristics*. MS Thesis, University of Tennessee, Knoxville.

Maul, J.L., J.L. Farris, C.D. Milam, C.M. Cooper, S. Testa III, and D.L. Feldman. (2004). The influence of stream habitat and water quality on macroinvertebrate communities in degraded streams of Northwest Mississippi. *Hydrobiologia* **518**: 79-94.

McCarthy, David F. (2002). *Essentials of Soil Mechanics and Foundations.* Prentice Hall, Columbus, Ohio.

McNeil, W.J. and W.H. Ahnell. (1960). *Measurement of gravel composition of salmon stream beds*. Seattle, WA: University of Washington Fisheries Research Institute.

Merritt, W. S., Letcher, R. A., & Jakeman, A. J. (2003). A review of erosion and sediment transport models. *Environmental Modeling and Software,* **18**, 761-799.

Ming-Shu, T., and Z. Xiao-Yong. (2004). Estimation of runoff and sediment yield in the Redrock Creek watershed using AnnAGNPS and GIS. *Journal of Environmental Sciences,* **16**(6): 865-867.

Montgomery, D.R. (1999). Process domains and the river continuum. *Journal of the American Water Resources Association* **35**(2): 397-410.

Nelson, E.J. and D.B. Booth. (2002). Sediment sources in an urbanizing, mixed land-use watershed. *Journal of Hydrology* **264**(1-4): 51-68.

Newcombe, C. (2003). Impact assessment model for clear water fishes exposed to excessively cloudy water. *Journal of the American Water Resources Association* **39**: 529-544.

Newham, L.T.H., J.P. Norton, I.P. Prosser, B.F.W. Croke, and A.J. Jakeman. (2003). Sensitivity analysis for assessing the behaviour of a landscape-based sediment source and transport model. *Environmental Modeling & Software* **18**: 741-751.

Nietch, C.T., M. Borst, and J.P. Schubauer-Berigan. (2005). Risk management of sediment stress: a framework for sediment risk management research. *Environmental Management* **36**(2), 175-194.

NOAA. (2002). *Tennessee Monthly Station Normals of Temperature, Precipitation, and Heating and Cooling Degree Days 1971-2000*. National Environmental Satellite, Data, and Information Service, National Oceanic and Atmospheric Administration, National Climatic Data Center, Ashville, NC.

NPS. (2007). *Geology and History of the Cumberland Plateau. Big South Fork National River and Recreation Area.* Retrieved May, 2007, from National Parks Service website, http://www.nps.gov/biso/planyourvisit/upload/webgeo.pdf

Olsen, D.S., B.B. Roper, J.L. Kershner, R. Henderson, and E. Archer. (2005). Sources of variability in conducting pebble counts: their potential influence on the results of stream monitoring programs. *Journal of the American Water Resources Association* **41**:1225–1236.

OSM. (2005a). Procedures for the cumulative hydrologic impact assessment (*for the Federal Program for Tennessee, Revised October 28, 2005*). U.S. Office of Surface Mining Reclamation and Enforcement, Technical Group, Knoxville Field Office.

OSM. (2005b). Support manual for the cumulative hydrologic impact assessment (*for the Federal Program for Tennessee, Revised October 28, 2005*). U.S. Office of Surface Mining Reclamation and Enforcement, Technical Group, Knoxville Field Office.

Overton, D.E. (1980). Simulation of Effects of Contour Coal Strip Mining on Stormwater Runoff and Pollutant Yields. In *Symposium on Surface Mining Hydrology, Sedimentology and Reclamation*. Lexington, KY: University of Kentucky.
Reid, L.M., and T. Dunne. (1996). *Rapid Evaluation of Sediment Budgets.* GeoEcology paperback, Catena Verl., Reiskirchen, Germany.
Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, and D.C. Yoder. (1997). Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). *USDA Agriculture Handbook No. 703* (pp. 404).
Rosgen. D. (2006). *Watershed Assessment of River Stability and Sediment Supply*. Wildland Hydrology, Ft. Collins, CO.
Rosgen, D. (1996). *Applied River Morphology*. Wildland Hydrology, Pagosa Springs, CO.
Sarangi, A., C.A. Cox, and C.A. Madramootoo. (2007). Evaluation of the AnnAGNPS model for prediction of runoff and sediment yields in St Lucia watersheds. *Biosystems Engineering* **97**(2): 241-256.
Schwartz, J., E. Drumm, M. Massey, D. Johnson, J. Baines, W. Cantrell. (2008a). *Development of a Rapid Geomorphic Assessment Technique to Support the CHIA/PHC Progress: A Focus on Model Improvement for Estimating Sediment Loads*. Report to OSM, 2006 Applied Science Program, Pittsburg, PA.
Schwartz, J.S., M. Dahle, and R.B. Robinson. (2008b). Concentration-frequency-duration curves for stream turbidity: possibilities for use assessing biological impairment. *Journal of the American Water Resources Association* **44**(4): 879-886.
Schwartz, J.S., S. Simon, and L. Klimetz. (2010). Use of fish functional traits to associate in-stream suspended sediment transport metrics with biological impairment. *Environmental Monitoring and Assessment. (in press*).
Sennatt, K.M., N.L. Salant, C.E. Renshaw, C.E., and F.J. Magilligan. (2006). Assessment of methods for measuring embeddedness: application to sedimentation in flow of 153 regulated streams. *Journal of the American Water Resources Association* **42**(6): 1671-1682.
Sheridan, G.J., P.J. Noske, R.K. Whipp, and N. Wijesinghe. (2006). The effect of truck traffic and road water content on sediment delivery from unpaved forest roads. *Hydrological Processes*, **20**, 1683-1699.
Shrestha, S., M.S. Babel, A.D. Gupta, and F. Kazama. (2006). Evaluation of annualized agricultural nonpoint source model for a watershed in the Siwalik Hills of Nepal. *Environmental Modeling and Software* **21**: 961-975.
Sidle, R.C., S. Sasaki, M. Otsuki, S. Noguchi, and A.R. Nik. (2004). Sediment pathways in a tropical forest: effects of logging roads and skid trails. *Hydrological Processes* **18**: 703-720.
Simon, A. (1995). Adjustment and recovery of unstable alluvial channels: identification and approaches for engineering management. *Earth Surface Process and Landforms* **20**: 611-628.
Simon, A. (1989). A model of channel response in disturbed alluvial channels, *Earth Surface Processes and Landforms* **14**(1): 11-26.
Simon, A., and S.E. Darby. (1999). The nature and significance of incised river channels. In Pages 3-18, S.E. Darby and A. Simon (eds). *Incised Rivers Channels: Processes, Forms, Engineering, and Management*; John Wiley and Sons, UK.
Simon, A., R.L. Bingner, E.J. Langendoen, and C.V. Alonso. (2002). *Actual and Reference Sediment Yields for the James Creek Watershed, Mississippi.* National Sedimentation Laboratory Report, 31, 185.

Simon, A., W. Dickerson, and A. Heins. (2004a). Suspended-sediment transport rates at the 1.5-year recurrence interval for ecoregions of the United States: transport conditions at the bankfull and effective discharge? *Geomorphology* **58**: 243-262.

Simon, A., E.J. Langendoen, R.L. Bingner, R. Wells, Y. Yuan, and C.V. Alonso. (2004b). *Suspended-sediment Transport and Bed-material Characteristics of Shades Creek, Alabama and Ecoregion 67: Developing Water-quality Criteria for Suspended and Bed-material Sediment*. Research Report No. 43, USDA National Sedimentation Laboratory, Oxford, M.S.

Simon, A. (2004c). *Completing the Rapid Geomorphic Assessment (RGA) Form*. USDA, Agricultural Research Service, National Sedimentation Laboratory, Oxford, MS:

Simon, A. and L. Klimetz. (2008). Magnitude, frequency, and duration relations for suspended sediment in stable ("reference") southeastern streams. *Journal of the American Water Resources Association* **44**(5): 1270-1283.

Simon, A., N. Pollen-Bankhead, V. Mahecek, and E. Langendoen. (2009a). Quantifying reductions of mass-failure frequency and sediment loading from streambanks using toe protection and other means: Lake Tahoe, United States. *Journal of the American Water Resources Association*, **45**(1), 170-186.

Simon, A., R. Thomas, A. Curini, and N. Bankhead. 2009b. *Bank-stability and Toe Erosion Model, User's Document*. Accessed: http://www.ars.usda.gov/SP2UserFiles/Place/64080510/XLS/BSTEM-5.0_Example_Use.pdf. USDA National Sedimentation Laboratory, Oxford, MS.

Staley, N.A. (2006). Modeling Channel Erosion at the Watershed Sclae: A Comparison of GWLF, SWAT, and CONCEPTS. MS Thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Sturm, T.W. (2001). *Open Channel Hydraulics*. McGraw-Hill, New York, NY.

Soil Conservation Service. (1986). *Urban Hydrology for Small Watersheds, Technical Release 55*, Second Edition, United States Department of Agriculture, Washington, DC.

Sugden, B.D., and S.W. Woods. (2007). Sediment production from forest roads in western Montana. *Journal of the American Water Resources Association*, **43**(1), 193-206.

Sutherland, A.B., J.L. Meyer, and E.P. Gardiner. (2002). Effects of land cover on sediment regime and fish assemblage structure in four southern Appalachian streams. *Freshwater Biology* **47**: 1791-1805.

TDEC. (2003). *Quality System Standard Operating Procedure for Macroinvertebrate Stream Surveys.* Tennessee Department of Environment and Conservation, Division of water Pollution Control, Nashville.

Thames, B.A. (2005). *Effects of Urbanization on the Streambed Sediment Characteristics in a Ridge and Valley Watershed*. MS Thesis, University of Tennessee - Knoxville.

Theurer, F.G., and C.D. Clarke. (1991). Wash load component for sediment yield Modeling. *In Proceedings of the 5th Federal Interagency Sedimentation Conference*. Washington, D.C. (pp. 7-1 to 7-8).

Thomas, R.E., and E.J. Langendoen. (2002). *Numerical Simulation of Post-disturbance Stream Channel Evolution: The Yalobusha River, Misissippi, USA*. Research Report No. 29. USDA-ARS, National Sedimentation Laboratory, Oxford, MS.

USDA. (2000). *AnnAGNPS Version 2: User Documentation*, Technical Report, National Sedimentation Laboratory, USDA Agricultural Research Service, Oxford, MS.

USDA. (1986). *Urban Hydrology for Small Watersheds*. USDA-NRCS Conservation Engineering Division Technical Release 55 (TR-55). U.S. Department of Agriculture, Soil Conservation Service, Washington, D.C.

USEPA: (2006). *Framework for Developing Suspended and Bedded Sediments (SABS) Water Quality Criteria*, EPA-822-R-06-001. USEPA, Office of Water, Office of Research and Development, Washington D.C.

USEPA. (1999). *Protocol for Developing Sediment TMDLs.* EPA 841-B-99-004. US Environmental Protection Agency, Office of Water, Washington DC.

USEPA. (1997). *Compendium of Tools for Watershed Assessment and TMDL Development*. EPA 841-B-97-006. US Environmental Protection Agency, Office of Water, Washington D.C.

USGS. (2003). *The Sedimentary Appalachians*. Retrieved December 2007. Confirmed Feb. 29, 2008. from the U.S. Geological Survey website, http://3dparks.wr.usgs.gov/nyc/valleyandridge/sedimentaryapp.htm

Vanoni, V.A. (2006). *Sedimentation Engineering*. ASCE, New York, NY.

Walling, D.E., and P.W. Moorehead. (1989). The particle size characteristics of fluvial suspended sediment: an overview. *Hydrobiologia* **176/177**: 125-149.

Walling, D.E., P.N. Owens, and G.J.L. Leeks. (1999). Fingerprinting suspended sediment sources in the catchment of the River Ouse, Yorkshire, UK. *Hydrological Processes* **13**: 955-975.

Walling, D.E., M.A. Russell, R.A. Hodgkinson, and Y. Zhang. (2002). Establishing sediment budgets for two small lowland agricultural catchments in the UK. *Catena* **47**: 323-353.

Wells, R.R., E.J. Langendoen, and A. Simon. (2007). Modeling pre- and post-dam removal sediment dynamics: The Kalamazoo River, Michigan. *Journal of the American Water Resources Association*, **43**(3), 773–785.

White, P.H. (2009). Classification of subwatershed slopes and geotechnical characterization of steep slopes on reclaimed mine lands in East Tennessee. MS Thesis, University of Tennessee, Knoxville.

White, S. (2005). Sediment yield prediction and modeling. *Hydrological Processes*, **19**, 3053-3058.

Whiting, P.J., and J.B. Bradley. (1993). A process-based classification system for headwater streams. *Earth Surface Processes and Landforms* **18**: 603-612.

Whiting, P.J., and J.G. King. (2003). Surface particle sizes on armoured gravel streambeds: effects of supply and hydraulics. *Earth Surface Processes and Landforms* **28**: 1459-1471.

Williams, K.H. (2005). *Linking Channel Stability and Bed Sediment Characteristics to Biological Integrity in Tennessee Ridge and Valley Streams*. M.S. Thesis. University of Tennessee, Knoxville.

Wischmeier, W.H., C.B. Johnson, and B.V. Cross. (1971). A soil erodibility nomograph for farmland and construction sites. *Journal of Soil and Water Conservation*, **26**, 189-193.

Wolman, M.G. (1954). A method of sampling course bed material. *Transactions, American Geophysical Union* **35**: 951-956.

Wood, P.J., and P.D. Armitage. (1997). Biological effects of fine sediment in the lotic environment. *Environmental Management* **21**: 203-217.

Wu, W. (2008). *Computational River Dynamics*. Taylor & Francis – Balkema, Leiden, The Netherlands.

Wu, W. (2001). *CCHE2D Sediment Transport Model* (Version 2.1). Technical Report No. NCCHE-TR-2001-3, National Center for Computational Hydroscience and Engineering, University of Mississippi, Oxford.

Wysocki, D.A., P.J. Schoeneberger, and H.E. La Garry. (2000). Geomorphology of soil landscapes. In: Sumner, M.E. (ed.). *Handbook of Soil Science*. CRC Press LLC, Boca Raton, FL. ISBN: 0-8493-3136-6.

Yarnell, S.M., J.F. Mount, and E.W. Larsen. (2006). The influence of relative sediment supply on riverine habitat heterogeneity. *Geomorphology* **80**: 310-324.

Young, M.K., W.A. Hubert, and T.A. Wesche. (1991). Biases associated with four stream substrate samplers. *Canadian Journal of Fisheries and Aquatic Sciences*, **48**,1882-1886.

Young, R.A., C.A. Onstad, D.D. Bosch, & Anderson, W.P. (1987). *AGNPS, Agricultural Nonpoint Source Pollution Model: A Large Watershed Analysis Tool. Conservation Research Report 35*. U.S.D.A., Agriculture Research Services. Washington, D.C.

Young, R.A., C.A. Onstad, D.D. Bosch, and W.P. Anderson. (1989). AGNPS: A nonpoint-source pollution model for evaluating agricultural watersheds. *Journal of Soil and Water Conservation* **44**(2): 168–173.

Zhang, Y. (2006). *CCHE-GUI – Graphical Users Interface for NCCHE Model User's Manual*. Version 3.0 Technical Report No. NCCHE-TR-2006-02. National Center for Computational Hydroscience and Engineering, University of Mississippi, Oxford.

Zhen, X.Y., S.L. Yu, and J.-Y. Lin. (2004). Optimal location and sizing of stormwater basins at watershed scale. *Journal of Water Resources Planning and Management* **130**(4): 339–347.