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I am submitting herewith a thesis written by Brantley Allison Thames entitled “The Effects of Urbanization on the Streambed Sediment Characteristics in a Ridge and Valley Watershed.” I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Environmental Engineering.

John S. Schwartz
Major Professor

We have read this thesis
and recommend its acceptance:

John R. Buchanan

Randall W. Gentry

Accepted for the Council:

Anne Mayhew
Vice Chancellor and
Dean of Graduate Studies

(Original signatures are on file with official student records.)

**THE EFFECTS OF URBANIZATION ON THE STREAMBED SEDIMENT
CHARACTERISTICS IN A RIDGE AND VALLEY WATERSHED**

**A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville**

**Brantley Allison Thames
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ABSTRACT

Urbanization causes flow and sediment regime changes, which leads to alterations in the bed sediment characteristics and degradation of the ecological habitat. Evidence shows that changes in the characteristics of streambed sediment occur in urbanized watersheds; however a link between urbanization and changes in streambed sediment is not well established in the literature. Limited support in the literature does suggest that urbanization is linked to a decline in the diversity of algae, invertebrate, and fish populations. Relationships between urbanization and bed sediment characteristics were explored by three studies using the AnnAGNPS and CONCEPTS models. AnnAGNPS is a GIS-based sediment delivery model with land erosion rates determined by the revised Universal Soil Loss Equation (RUSLE) and sediment yield rates determined by the Hydrogeomorphic USLE (HUSLE) for watersheds primarily dominated by agricultural land use. CONCEPTS is a sediment transport and channel adjustment model that routes sediment input from AnnAGNPS and sediment inputs from channel bed and bank erosion. Both models were developed by the United States Department of Agriculture – Agricultural Research Service (USDA ARS). The research objectives for this project included: 1) conducting a sensitivity analysis of the AnnAGNPS and CONCEPTS models to evaluate the significance of various model inputs that incorporate the mosaic of urban land use and require field measurements for the non-urbanized and urbanized subwatersheds, 2) producing and executing several combinations of model run simulations with altered runoff and erosion from the hillslope using the entire AnnAGNPS-CONCEPTS modeling couple to simulate varying levels of urbanization, and 3) evaluating AnnAGNPS model results of 15 urban and non-urban subwatersheds

across Beaver Creek watershed to gain insight to dominant sediment delivery dynamics resulting from urbanization using a multivariate cluster analysis between the model output, field measurements, stream power, subwatershed area, and percent urbanization. The studies addressing the first and second research objectives were conducted using the geographic data in two subwatersheds of the Beaver Creek watershed in Knox County, Tennessee, whereas the third study used data across the entire Beaver Creek watershed. The two subwatersheds include Hines Branch, which is a highly disturbed urban subwatershed, and Cox Creek, which is a subwatershed with minimal urban development. The results from the three studies included the following main conclusions: 1) the AnnAGNPS and CONCEPTS models were fairly insensitive to the model input parameters tested in the sensitivity analysis on an individual basis; however, when comparing the sensitivities between the urban and non-urbanized subwatersheds for the AnnAGNPS analysis, the percent difference between the sensitivity slopes for each model input parameter ranged from 150 to 300 percent; 2) simulations with altered runoff and erosion from the hillslope showed that altered runoff had a greater impact on the bed sediment characteristics and sediment yield; and 3) the cluster analysis of the five watershed characteristics illustrated that percent urbanization of each subwatershed and suspended sediment from AnnAGNPS model output over subwatershed stream power and total subwatershed area were the most related to the bed sediment size distributions collected at each site. Assuming the AnnAGNPS-CONCEPTS modeling couple represents the physical watershed and channel processes, then this thesis shows that urbanization does impact bed sediment characteristics, and it appears hydrology is more of a controlling factor to bed sediment characteristics than hillslope erosion.

TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION	1
CHAPTER 2: LITERATURE REVIEW	6
EFFECTS OF URBANIZATION	6
ANNUALIZED AGRICULTURAL NON-POINT SOURCE MODEL (ANNAGNPS)	9
<i>RUSLE – Sediment Erosion</i>	11
<i>HUSLE – Sediment Delivery</i>	19
<i>Case Studies</i>	20
CONSERVATIONAL CHANNEL EVOLUTION AND POLLUTANT TRANSPORT SYSTEM (CONCEPTS)	22
<i>Case Studies</i>	28
ANNAGNPS-CONCEPTS MODELING COUPLE - CASE STUDIES	30
CHAPTER 3: STUDY AREA	32
BEAVER CREEK WATERSHED	32
COX CREEK AND HINES BRANCH STUDY SITES	35
CHAPTER 4: SENSITIVITY ANALYSIS	41
INTRODUCTION	41
METHODS	41
<i>AnnAGNPS</i>	41
<i>CONCEPTS</i>	47
RESULTS AND DISCUSSION	51
<i>AnnAGNPS</i>	51
<i>CONCEPTS</i>	56
CHAPTER 5: EFFECTS OF ALTERED RUNOFF AND UPLAND EROSION ON STREAMBED SEDIMENT IN URBANIZING SUBWATERSHEDS	60
INTRODUCTION	60
METHODS	60
RESULTS AND DISCUSSION	61
CHAPTER 6: MULTIVARIATE CLUSTER ANALYSIS	73
INTRODUCTION	73
METHODS	73
RESULTS AND DISCUSSION	75

TABLE OF CONTENTS - CONTINUED

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS	79
LIST OF REFERENCES	84
APPENDICES	90
APPENDIX A	91
<i>AnnAGNPS Input</i>	92
<i>AnnAGNPS Output</i>	98
APPENDIX B	101
<i>CONCEPTS Input</i>	102
<i>CONCEPTS Output</i>	110
APPENDIX C	114
VITA	146

LIST OF TABLES

Table 2-1. Size Class Distribution and Equation used in CONCEPTS	27
Table 3-1. Percentage of Land Use Types for the Cox Creek Subwatershed	37
Table 3-2. Percentage of Land Use Types for the Hines Branch Subwatershed	37
Table 3-3. Percentages and Descriptions of Soil Types for the Cox Creek Subwatershed	38
Table 3-4. Percentages and Descriptions of Soil Types for the Hines Branch Subwatershed	39
Table 3-5. Channel Morphological Characteristics for the Cox Creek and Hines Branch Model Reaches	40
Table 4-1. Relevance of Model Input Parameters to Agricultural and Urban Land Uses	43
Table 4-2. AnnAGNPS Input Parameter Ranges	46
Table 4-3. CONCEPTS Input Parameter Ranges	50
Table 4-4. AnnAGNPS Sensitivity Analysis Results for Cox Creek	52
Table 4-5. AnnAGNPS Sensitivity Analysis Results for Hines Branch	52
Table 4-6. AnnAGNPS Sensitivity Curve Slopes for Cox Creek and Hines Branch	56
Table 4-7. CONCEPTS Sensitivity Analysis Results for Cox Creek	58
Table 4-8. CONCEPTS Sensitivity Analysis Results for Hines Branch	58
Table 4-9. CONCEPTS Sensitivity Curve Slopes for Cox Creek and Hines Branch	59
Table 5-1. Runoff Curve Numbers for each Land Use Type in Cox Creek and Hines Branch Subwatersheds	62
Table 5-2. Hydroerosion Simulations Summary Table for Cox Creek	65
Table 5-3. Hydroerosion Simulations Summary Table for Hines Branch	65
Table 5-4. Percent Difference between Sediment Yield as Runoff and Erosion Varies and Sediment Yield with Normal Runoff and Erosion for Cox Creek	71
Table 5-5. Percent Difference between Sediment Yield as Runoff and Erosion Varies and Sediment Yield with Normal Runoff and Erosion for Hines Branch	72
Table 6-1. Input Data for Multivariate Cluster Analysis (SPSS v.10 2000)	76
Table C-1. Particle Size Distributions for Cox Creek	115
Table C-2. Particle Size Distributions for Hines Branch	125
Table C-3. Particle Size Distributions for the Beaver Creek Watershed Sample Sites	135

LIST OF FIGURES

Figure 2-1. Isoerodent Map of Eastern United States.	14
Figure 2-2. EI Distribution Zones for Contiguous United States	14
Figure 2-3. Ten-yr-frequency Single-storm Erosion Index for Eastern United States.	15
Figure 3-1. Study Area for Beaver Creek Watershed in Northwestern Knox County, TN	33
Figure 3-2. Existing Land use Map of Beaver Creek Watershed in Knox County, TN	34
Figure 3-3. Stream Power Network of Beaver Watershed in Knox County, TN	36
Figure 4-1. Idealized Sensitivity Plot	47
Figure 4-2. Sensitivity Analysis of Annual Root Mass on Sediment Yield	53
Figure 4-3. Sensitivity Analysis of Annual Cover Ratio on Sediment Yield	53
Figure 4-4. Sensitivity Analysis of Annual Rain Fall Height on Sediment Yield	55
Figure 4-5. Sensitivity Analysis of Percent Surface Residue on Sediment Yield	55
Figure 4-6. Normal Hydrology for Cox Creek	57
Figure 4-7. Normal Hydrology for Hines Branch	57
Figure 5-1. Assumed Normal LS Factor Map for Cox Creek Subwatershed	63
Figure 5-2. Assumed Normal LS Factor Map for Hines Branch Subwatershed	63
Figure 5-3. Bed Profile for Cox Creek at the Beginning and After Simulations for Increased and Decreased Hydrology	66
Figure 5-4. Bed Profile for Hines Creek at the Beginning and After Simulations for Increased and Decreased Hydrology	66
Figure 5-5. Original and Final Particle Size Distributions for Varying Levels of Hydrology for Cox Creek	68
Figure 5-6. Original and Final Particle Size Distributions for Varying Levels of Hydrology for Hines Branch	68
Figure 5-7. Cumulative Percentage of Silt, Sand, and Gravel Transported through Cox Creek	69
Figure 5-8. Cumulative Percentage of Silt, Sand, and Gravel Transported through Hines Branch	69
Figure 5-9. Cumulative Bed Elevation versus Time for Hines Branch at Two Levels of Hydrology for a Single Storm Event	70
Figure 5-10. Gravel Discharge versus Time for Hines Branch at Two Levels of Hydrology for a Single Storm Event	70
Figure 6-1. Bed Sediment Sample Sites and Contributing Drainage Areas	74
Figure 6-2. Dendrogram of All Parameters	77
Figure 6-3. Dendrogram of All the Parameters Excluding Subwatershed Area	77
Figure 6-4. Dendrogram of AnnAGNPS output, Particle Size Distribution Data, and Percent Urbanization	78
Figure A-1. Input Editor Welcome Screen	92
Figure A-2. Project Setup and Identifier Screen	93
Figure A-3. Cell Data Screen	93

LIST OF FIGURES – CONTINUED

Figure A-4. Daily Climate Data Screen	94
Figure A-5. Management Field Data Screen	94
Figure A-6. Non-Crop Data Screen	95
Figure A-7. Output Options Screen	95
Figure A-8. Reach Data Screen	96
Figure A-9. Runoff Curve Number Screen	96
Figure A-10. Simulation Period Data Screen	97
Figure A-11. Soil Data Screen	97
Figure A-12. Output for Average Annual Sediment Yield from each Cell	98
Figure A-13. Event Output File	99
Figure A-14. Concepts Output File	100
Figure B-1. Hydrography Input File	102
Figure B-2. Lateral Flow Input File	103
Figure B-3. Run Control Input File	104
Figure B-4. Cross-Section Input File	106
Figure B-5. Output at a Certain Location and for a Certain Runoff Event	110
Figure B-6. Time Series Output at a Certain Location	111
Figure B-7. Output for a Certain Runoff Event along a Section of the Modeling Reach	112
Figure C-1. Particle Size Distribution for CC1B	118
Figure C-2. Particle Size Distribution for CC1LB	118
Figure C-3. Particle Size Distribution for CC1RB	119
Figure C-4. Particle Size Distribution for CC2B	119
Figure C-5. Particle Size Distribution for CC3B	120
Figure C-6. Particle Size Distribution for CC4B	120
Figure C-7. Particle Size Distribution for CC4LB	121
Figure C-8. Particle Size Distribution for CC4RB	121
Figure C-9. Particle Size Distribution for CC5B	122
Figure C-10. Particle Size Distribution for CC5LB	122
Figure C-11. Particle Size Distribution for CC6B	123
Figure C-12. Particle Size Distribution for CC7B	123
Figure C-13. Particle Size Distribution for CC7RB	124
Figure C-14. Particle Size Distribution for H1B	128
Figure C-15. Particle Size Distribution for H1LB	128
Figure C-16. Particle Size Distribution for H1RB	129
Figure C-17. Particle Size Distribution for H2B	129
Figure C-18. Particle Size Distribution for H3B	130
Figure C-19. Particle Size Distribution for H4B	130
Figure C-20. Particle Size Distribution for H5B	131
Figure C-21. Particle Size Distribution for H5LB	131
Figure C-22. Particle Size Distribution for H5RB	132
Figure C-23. Particle Size Distribution for H6B	132
Figure C-24. Particle Size Distribution for H7B	133

LIST OF FIGURES – CONTINUED

Figure C-25. Particle Size Distribution for H8B	133
Figure C-26. Particle Size Distribution for H8LB	134
Figure C-27. Particle Size Distribution for H8RB	134
Figure C-28. Particle Size Distribution for Allen Branch	138
Figure C-29. Particle Size Distribution for Beaver Creek at Beeler Rd	138
Figure C-30. Particle Size Distribution for Bishop Creek	139
Figure C-31. Particle Size Distribution for Cox Creek	139
Figure C-32. Particle Size Distribution for Grassy Creek	140
Figure C-33. Particle Size Distribution for Hines Branch	140
Figure C-34. Particle Size Distribution for Kerns Branch	141
Figure C-35. Particle Size Distribution for Knob Fork	141
Figure C-36. Particle Size Distribution for Lammie Branch	142
Figure C-37. Particle Size Distribution for Meadow Creek	142
Figure C-38. Particle Size Distribution for Mill Branch	143
Figure C-39. Particle Size Distribution for North Fork	143
Figure C-40. Particle Size Distribution for Plumb Creek	144
Figure C-41. Particle Size Distribution for Unnamed Trib at Emory Rd	144
Figure C-42. Particle Size Distribution for Unnamed Trib at Solway Rd	145

CHAPTER 1

INTRODUCTION

Urbanization negatively impacts three interlinked characteristics of a watershed: hydrology, geomorphology, and ecology. Urbanization imposes many hydrologic changes on a watershed including an increase in the peak and a decrease in the lag time of the storm hydrograph, which causes the flash flooding seen in urbanized areas (Graf 1977). In urban watersheds, a decrease in baseflow can also occur with a decrease of infiltration into the soil (Choi et al. 2003). With increased surface runoff and decreased infiltration, higher flow rates across the surface of the watershed causes more erosion on the hillslope and delivery of sediment to the stream network. Also, the larger surface runoff produces a more dynamic channel network through bed entrainment, bank failures, and headcut advance (Arnold et al. 1982). Hession (2001) has suggested that in a non-urbanized forested stream the median particle diameter (d_{50}) of the streambed is greater than that of urbanized streams, which suggests that fining of the bed material could be occurring in urban streams. In urban streams, channels are wider, straighter, and smoother with the 2 mm to 64 mm range of sediment sizes selectively being removed, which opposes the sediment size distributions of rural streams (Pizzuto et al. 2000). The effect of sedimentation on stream biota is a major concern of many of the studies looking at urbanization as the driving force behind habitat impairment (Finkenbine et al. 2000). In general, urbanization causes declines in the affluence and diversity of algae, invertebrate, macro invertebrate, and fish populations (Paul and Meyer 2001). Ecological degradation due to sediment impairment has become an increasing concern nationally. The Tennessee Department of Environment and Conservation (TDEC) has developed

sediment and habitat alteration total maximum daily load (TMDL) limits to address sediment impairment over the past decade. In fact, over 45% of the streams on the 303(d) list in Tennessee are noted as being impaired due to siltation and habitat alteration (TDEC 2004). Research is needed to improve development of TMDLs, and find solutions to these environmental issues. Research involving sediment delivery to streams has been focused mainly on agricultural watersheds; however, in recent times, urbanization is more frequently looked upon as a cause of sedimentation and habitat alteration issues.

Tools for estimating erosion, settling, and transport originating on the hillslope were needed to study soil erosion on the hillslope and sediment delivery into the channel network. Probably the most notable tool for soil erosion on the hillslope is the Universal Soil Loss Equation (Wischmeier and Smith 1978) created to produce average long term soil losses from a particular field with specific agricultural cropping. USLE employed thousands of data points over many years to describe six parameters important for determining hillslope erosion. The revised USLE (RUSLE) was an update to the original USLE model in that more data was included and a computer program facilitated its use (Renard et al. 1997). Currently, RUSLE2 is being developed to provide a more updated database and computer program capable of predicting soil erosion and sediment yield. However, these models do not incorporate dynamic variables such as routing through a multitude of fields and subwatersheds, and all of the USLE products were created to represent agricultural watersheds, which makes implementation of these tools in an urbanizing watershed difficult. The Soil and Water Assessment Tool (SWAT) and the Annualized Agricultural Non-Point Source (AnnAGNPS) pollution models were created

to allow for the use of RUSLE over a multitude of subwatersheds using geographic information systems (GIS). SWAT and AnnAGNPS allow for the prediction of hillslope erosion and sediment yield using soil and land use GIS databases (Borah and Bera 2003). These models are very similar in terms of input demands and estimating hillslope erosion. The main difference between these two models is the equation used to estimate sediment yield. AnnAGNPS uses the Hydrogeomorphic USLE (HUSLE) and SWAT uses the Modified USLE (MUSLE) to estimate sediment yield. Both the HUSLE and the MUSLE use an empirically derived relationship for runoff erosivity. The runoff erosivity is used to replace the rainfall erosivity in the RUSLE to estimate sediment yield. After sediment yield is estimated from the hillslope, a sediment transport model is needed to estimate sediment erosion and deposition with a stream reach. Several channel erosion models are capable of computing sediment transport through a channel. Hydrologic Engineering Center-6 (HEC-6) is probably the most common sediment transport model used in the engineering and scientific community. HEC-6 is a one-dimensional sediment transport model capable of estimating scour and deposition on a stream bed; however, one major disadvantage of the HEC-6 model is its inability to model bank failures caused by toe erosion (USACE 1993). The CONservational Channel Evolution and Pollutant Transport System (CONCEPTS) model was developed at the USDA Agricultural Research Service (ARS) located in Oxford, MS, and this model simulates one-dimensional sediment transport with unsteady flow conditions. In contrast to HEC-6, CONCEPTS estimates toe erosion and predicts bank failures (Langendoen 2000). For this project, AnnAGNPS was chosen based on its predictive capabilities using a well tested and robust soil erosion model (RUSLE) to estimate sediment yield in the watershed. CONCEPTS was chosen to

estimate sediment transport through the stream reach, because it predicts sediment transport for 13 particle size classes and includes an algorithm for estimating bank failures. These models were also chosen due to their compatibility with each other. AnnAGNPS can be linked with CONCEPTS to represent the entire system, which is central to understanding the governing processes in the watershed and channel network.

The objectives of this project were to test, explore, and utilize this model to better understand the dynamics of an entire system of sediment transport from hillslope to the end of a stream reach in urbanizing watersheds. The objectives were framed by three studies. They are in terms of research questions:

1. Which model input parameters relevant to an urbanizing watershed are most sensitive to estimating sediment yield from the AnnAGNPS and CONCEPTS models?
2. What changes in streambed sediment characteristics do the AnnAGNPS-CONCEPTS modeling couple predict when the runoff and erosion in the watershed are altered to represent various levels of urbanization?
3. Are the streambed sediment characteristics related to suspended sediment yield, percent subwatershed urbanization, and other key subwatershed parameters?

The first study was to test the sensitivity of various input parameters relevant to an urbanizing watershed in the AnnAGNPS and CONCEPTS models. Key parameters important to the question of urbanizing watersheds were first identified as being related to land use change. A sensitivity analysis was performed over a range of these values to determine the suitability of using an agricultural based model in urbanizing watersheds.

The second study explored what changes in bed sediment size characteristics occur in urbanizing watersheds predicted from AnnAGNPS-CONCEPTS model simulations. This objective was accomplished by altering runoff and erosion to represent different levels of urbanization to produce model results of the bed sediment size characteristics. The third study tested whether parameters related to urbanization, watershed characteristics, and channel sediment characteristics correlate in a way to better understand the governing geomorphic processes in urbanizing streams. To obtain this correlation, a multivariate cluster analysis was performed among five parameters; they were total watershed area, percent urbanization, subwatershed stream power, suspended sediment from AnnAGNPS output, and bed sediment size distribution data collected in the field.

CHAPTER 2

LITERATURE REVIEW

Effects of Urbanization

Many studies have been conducted on watersheds with varying levels of urbanization, and these studies have shown drastic changes in hydrologic and sediment contributions to stream networks (Graf 1977; Booth and Jackson 1997; Nelson and Booth 2002). Also, degradation of aquatic life has been linked to the effects of urbanization (Finkinbine et al. 2000). Sediment enters a stream network in essentially one of two ways: bed and bank erosion due to the erosive forces of a stream and sediment delivery from the watershed or through drainage systems (Delleur 2001).

Hydrological effects of urbanization are well documented and show that as urbanization increases so does surface runoff. From a hydrologic standpoint, the main problem with urbanization is the increase in impervious areas, thus limiting soil infiltration and increasing a watershed's ability to release water into the stream. Hollis (1975) shows that as percent urbanization increases the peak discharge for a particular recurrence interval increases as much as 20 times. Hollis (1975) also notes that the introduction of extensive drainage systems decreases the time that water flows overland and increases the concentration and speed at which the water reaches the stream. Graf (1977) expands on this idea by explaining that these drainage systems allow for a more efficient collection of runoff, which is increased due to urbanization, "so that lag time and kurtosis of storm hydrographs are altered to produce the familiar flash floods of urban areas."

With increased flow rates due to urbanization, flow depths and velocities increase, thus increasing a stream's ability to move sediment and exert erosive forces. Hammer (1972) performed an empirical study of 78 small watersheds near Philadelphia, Pennsylvania by comparing channel geometry with land use data and showed that urbanization causes an enlargement of stream channels. Arnold et al. (1982) attributed these major effects of urbanization on the increase in frequency of bankfull discharge, which is responsible for the greatest transport capacity of sediment in the channel (Knighton 1998). Gregory et al. (1992) took a closer look at individual components of channel geometry by investigating the effect of urbanization on capacity, channel width, and bed lowering. Probably the most important aspect of this research is the incorporation of temporal changes in the three factors of concern. Gregory et al. (1992) also showed the effects of vegetation and hydraulic structures on the widening of channels downstream of urbanization.

Many scientists attribute the problems with sediment in stream networks to increased flow rates causing increased bed and bank erosion; however, the problem of sediment seems to involve the finer sediment fractions, which could be a result of sediment delivery from the watershed landscape. When urbanization begins, large areas of topsoil are removed exposing disturbed soils to erosive rain events. Obviously, the typical flows over the landscape are not powerful enough to move larger sediment to streams, but the flows are powerful enough to move finer sediments through the landscape and into the stream network (Graf 1975). As these bare surfaces are made impervious, sediment production is decreased, but the flow rates in the stream are increased forming the situation of bed and bank erosion discussed in the previous

paragraph (Graf 1975). However, fine sediment and pollutants can still be transported through a drainage system, many times directly into the stream, degrading aquatic habitat (Delleur 2001). Ghani et al. (2001) conducted a survey of the sediment size distributions in the drainage systems of five Malaysian cities and found that a majority was fine sediment (between 0.6 and 0.9 mm), which supports that drainage systems are viable route of delivery.

The sediment processes described above can affect aquatic habitat in a few ways. The increase in flow rates due to urbanization can degrade the physical habitat of aquatic biota by removing a pool-riffle sequence, which provides areas for breeding, protection, and feeding. Pizzuto et al. (2000) conducted a study on eight paired urban and rural watersheds in Pennsylvania to describe the effects of the changes in flow regimes from urbanization. Pizzuto et al. (2000) shows that, with increased urbanization, stream sinuosity decreases. Sinuosity produces good pool-riffle sequences and provides fish with areas of protection from the high flows. Urbanization also affects stream habitat from a ground water perspective, in that as urbanization increases, paved areas block infiltration of surface water into the ground, which decreases base flow into the stream (Choi et al. 2003). During periods of drought or fewer rainfall events, the water surface in the stream is lowered due to the lack of base flow contributions, which can adversely affect aquatic life. The removal of riparian zones around streams by the onset of urbanization can compromise habitat quality by producing unstable banks and eliminating nutrient production for benthic invertebrates (Finkenbine et al. 2000).

Fine sediment builds up and embeddedness also pose problems for aquatic biota, specifically fish, because fish need a good substrate for breeding and feeding (USEPA

2000). Fine sediment can also result in gill abrasion. Further, pollutants commonly attach to fine sediment, which can be harmful to fish.

Annualized Agricultural Non-Point Source Model (AnnAGNPS)

One of the main tasks in this research project was to identify modeling software that would best answer the fundamental questions about the effects of urbanization on bed sediment size distributions. Several modeling packages were considered for this project through researching the governing equations, applied projects, and compatibility with overall scope of the project.

In researching various different sediment delivery models, two specific models proved to possess attributes that satisfy this project's needs as well as future needs. The first model was the Soil and Water Assessment Tool (SWAT), developed at the Agricultural Research Service in Temple, TX. The second model was also developed by the Agricultural Research Service. However, the Annualized Agricultural Non-Point Source (AnnAGNPS) sediment delivery model was created and is maintained at the National Sedimentation Laboratory in Oxford, MS. Both models use a modified version of the Universal Soil Loss Equation (USLE).

Determination of which model to use in this project was difficult in that SWAT and AnnAGNPS both seemed to be very good modeling tools. AnnAGNPS was chosen based on a few key characteristics. This project has a need for the incorporation of sediment size distributions in the analysis of urban effects on sediment yield, and AnnAGNPS fulfills this need by the ability to route sediment size fractions through the watersheds. AnnAGNPS also has a developed compatibility with a channel sediment

transport model, CONCEPTS. These two factors were the main reasons behind choosing AnnAGNPS over SWAT.

AnnAGNPS is an annualized agricultural non-point source model that simulates the fate and transport of water, sediment by size fraction and source of detachment, and chemicals, such as nutrients and pesticides, through an ArcView 3.x GIS interface.

Bosch et al. (1998) explains that “AnnAGNPS is a continuous-simulation, multi-event modification of single-event model AGNPS with improved technology and the addition of new features.” AnnAGNPS is based on the soil erosion model known as the Revised Universal Soil Loss Equation (RUSLE), which is a revised version of the Universal Soil Loss Equation (USLE). Most sediment delivery models representing watershed processes are based on some form of USLE (Borah and Bera 2003). SWAT, as mentioned above, is actually derived from USLE in the form of the MUSLE equation. These derivations of USLE do not differ much from each other, and, for the most part, these derivations are just created for modeling certain situations, such as continuous storm events.

AnnAGNPS is a fairly new model, which is constantly being updated.

AnnAGNPS is mainly used for modeling runoff of nutrients, pesticides, water, and sediment. This project is concerned with the delivery of water and sediment to the stream system, and AnnAGNPS can be used to predict these outputs.

The inputs into the model can be classified in two ways: Digital Elevation Models (DEM's) for the Flownet Generator and soil, land use, and climate data for the Input Editor. Most of the data for this model can be located through government

agencies. For instance, to begin the process, the only data required is a DEM, a soil layer, and land use layer.

AnnAGNPS uses the SCS Curve Number method to produce the hydrology for the model (SCS TR-55). The curve number method is a simplified way of estimating runoff rates based on land use and basin features for a specific storm event. AnnAGNPS uses the curve method in a similar way to the TR-55 model; however, AnnAGNPS incorporates the curve number method to simulate multiple storm events.

RUSLE – Sediment Erosion

RUSLE does not incorporate a GIS interface; however, after further research, most GIS interfaced sediment delivery models use some form of the RUSLE equation. RUSLE is explained in great detail in the Agriculture Handbook 703: Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (AH703). The RUSLE model is an empirical method used to predict the average soil loss rate by water. As mentioned earlier, RUSLE is an update of the Universal Soil Loss Equation described in the Agriculture Handbook 537 (Wischmeier and Smith 1978). The USLE was developed to provide a convenient, simple tool for determining average annual soil losses in explicit circumstances by requiring only historically based factors for the equation (Renard et al. 1997).

RUSLE is an attempt to model the physical properties in an environment of soil erosion using empirical data. Foster (1982) states that, “erosion and sedimentation by water involve the processes of detachment, transport, and deposition of soil particles.” Therefore a functional relationship between erosion and soil properties, topography, climate, and human activities was produced by Renard and Foster (1983) in the form:

$$E = f(C, S, T, SS, M) \quad [2-1]$$

where,

E = erosion

f = function of ()

C = climate

S = soil properties

T = topography

SS = soil surface conditions, and

M = human activities

From this functional relationship, RUSLE incorporates all of these factors into an empirical equation in the form (Wischmeier and Smith 1965,1978):

$$A = R \bullet K \bullet L \bullet S \bullet C \bullet P \quad [2-2]$$

where,

A = computed spatial average soil loss and temporal average soil loss per unit area

R = rainfall-runoff erosivity factor – the rainfall erosion index plus a factor for any significant runoff from snowmelt

K = soil erodibility factor – the soil-loss rate per erosion index unit for a specified soil as measured on a standard plot of 72.6-ft (22.1-m) length of uniform 9% slope in continuous clean-tilled fallow

L = slope length factor – the ratio of soil loss from the field slope length to soil loss from a standard plot

S = slope steepness factor – the ratio of soil loss from the field slope length to soil loss from a 9% slope under otherwise identical conditions

C = cover-management factor – the ratio of soil loss from an area with specified cover and management to soil loss from an identical area in tilled continuous fallow

P = support practice factor – the ratio of soil loss with a support practice like contouring, strip-cropping, or terracing to soil loss with straight-row farming up and down the slope

The factors in RUSLE are used to estimate average annual soil loss over a long period of time, which can be useful for long-term best management practice (BMP) implementation and TMDL determinations. Understanding these factors and how they are derived is paramount in the use of RUSLE and AnnAGNPS.

The rainfall-runoff erosivity factor (R) is derived from data associated with an important rainstorm parameter known as EI_{30} , which is the total storm energy times the maximum rainfall intensity over 30-min interval. According to Renard et al. (1997), “the product term EI is a statistical interaction term that reflects how total energy and peak intensity are combined in each particular storm.” The EI parameter is a representation of the storm event in that larger values typically represent larger runoff and raindrop size, which facilitates greater erosion. The rainfall-runoff erosivity factor (R) can be determined using the following equation:

$$R = \frac{\sum_{i=1}^j (EI_{30})_i}{N} \quad [2-3]$$

where, $(EI_{30}) = EI_{30}$ for storm i, j = number of storms in an N year period

Many studies have been conducted in regional areas, and from these areas, isoerodent maps (Figure 2-1) have been constructed to produce the values of the rainfall erosion index. EI distribution zone (Figure 2-2) and ten-yr-frequency single-storm (Figure 2-3) index maps have also been constructed from regional analysis.

The soil-erodibility factor (K) is a parameter that represents the rate of soil loss per rainfall erosion index unit for a particular soil type. Renard et al. (1997) describes K as the “ease with which soil is detached by splash during rainfall or by surface flow or both.” In general, K represents the ability of a certain soil type to erode under certain climatic conditions. In practice, K is determined on a regression basis, and can be found in the literature, which describes the K values according to soil type and region.

Wang et al. (2001) performed a study measuring the uncertainty of the soil

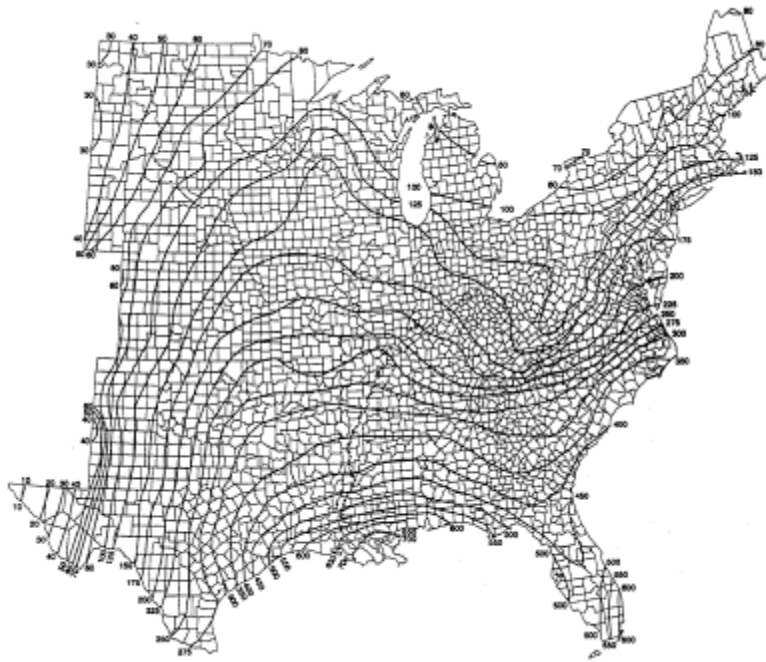


Figure 2-1. Isoerodent Map of Eastern United States. Units are hundreds $\text{ft} \cdot \text{tonf} \cdot \text{in}(\text{ac} \cdot \text{h} \cdot \text{yr})^{-1}$ (Renard et al., 1997)

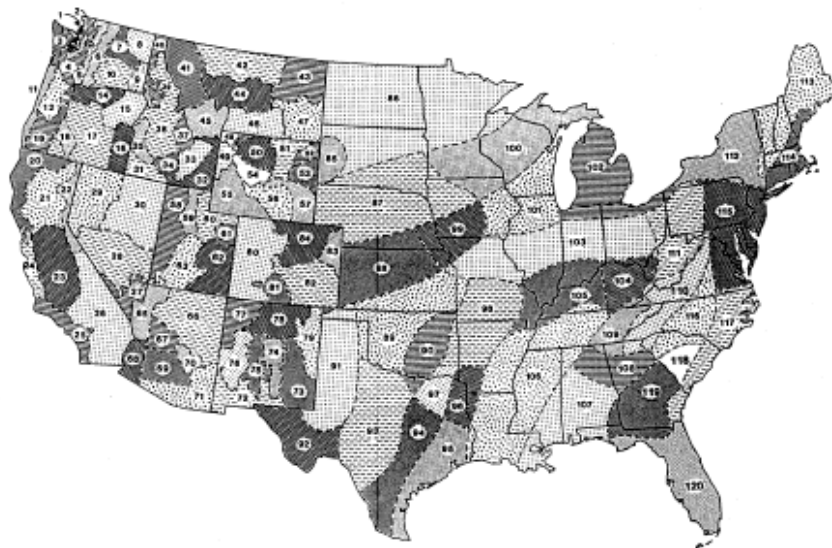


Figure 2-2. EI Distribution Zones for Contiguous United States (Renard et al., 1997)



Figure 2-3. Ten-yr-frequency Single-storm Erosion Index for Eastern United States.
Units are hundreds $\text{ft} \cdot \text{tonf} \cdot \text{in}(\text{ac} \cdot \text{h})^{-1}$ (Renard et al., 1997)

erodibility used in RUSLE. Wang sampled in 186 locations for the actual K-value, and then in turn, compared the measured K-value with the published K-value. He then plotted them on a map to show this comparison and aided this figure with a map showing where the samples had a positive, negative, and insignificant difference from the published data. Only 21 samples (i.e., 11.3%) had an insignificant difference from the published K-values at the respective sites. Wang et al. (2001) proposed that the differences between measured and published values can be explained by the change in soil properties over space and time, and therefore, published K-values should be used with discretion.

The slope length and steepness factors (LS) are functions of the topography and rill development. Generally, as slope length increases, erosion increases, thus the slope

length factor (L) is introduced into RUSLE to account for this area of topography.

Wischmeier and Smith (1978) define slope length as “the horizontal distance from the origin of overland flow to the point where either (1) the slope gradient decreases enough that deposition begins or (2) runoff becomes concentrated in a defined channel.” The steepness factor (S) is a function of the slope gradient of the topography, and naturally, as slope increases, velocities across the landscape increase, thus increasing erosion. With the advent of GIS, slopes and slope lengths are easily computed using a digital elevation model (DEM), which is a gridded layer consisting of equally spaced elevation attributes over an area. The slope length factor is represented by the equation (Wischmeier and Smith 1978):

$$L = \left(\frac{\lambda}{72.6} \right)^m \quad [2-4]$$

where,
 λ = slope length (in ft)
 m = a variable slope-length exponent

Foster et al. (1977) related m to the ratio β of rill erosion to interrill erosion by the following equation:

$$m = \frac{\beta}{(1+\beta)} \quad [2-5]$$

where,

$$\beta = \left(\frac{\sin \theta / 0.0896}{[3.0(\sin \theta)^{0.8} + 0.56]} \right) \quad (\text{McCool et al. 1989}) \quad [2-6]$$

where,
 θ = slope angle

McCool et al. (1987) determines that soil loss increases at a greater rate with S than it does with L, and he produces an equation for evaluating S based on the following constraints:

$$S = 10.8 \sin \theta + 0.03 \quad \text{for } s < 9\% \quad [2-7]$$

$$S = 16.8 \sin \theta - 0.50 \quad \text{for } s \geq 9\% \quad [2-8]$$

Stipulations to the above relationships include an equation for S when the slopes are shorter than 15 ft (McCool et al. 1987):

$$S = 3.0 (\sin \theta)^{0.8} + 0.56 \quad [2-9]$$

For slopes greater than or equal to 9%, McCool et al. (1987,1993) posed another relationship for S:

$$S = \left(\frac{\sin \theta}{0.0896} \right)^{0.6} \quad \text{for } s \geq 9\% \quad [2-10]$$

For the purposes of RUSLE, the length slope and steepness factors are combined to represent “the ratio of soil loss on a given slope length and steepness to soil loss from a slope that has a length of 72.6 ft and steepness of 9%, where all conditions are the same (Renard et al. 1997).” This plot with a length of 72.6 ft and slope of 9% is considered a standard plot by RUSLE and is used in several of the RUSLE factors.

The cover-management factor (C) is an important factor in this project, because land use in an urbanized watershed is so different from that in an agricultural watershed. This factor allows for the implementation of urban surfaces in a model derived for agricultural uses. The C-factor reflects the effects of surface and canopy cover and management practices within the watershed. In fact, the C-factor can be broken into several subfactors related to: Prior-Land use, Canopy-cover, Surface-cover, Surface-

roughness, and Surface-moisture. Using these subfactors, a soil loss ratio can be determined temporally (Laflen et al. 1985) using the following equation:

$$SLR = PLU \bullet CC \bullet SC \bullet SR \bullet SM \quad [2-11]$$

Soil loss ratios can be computed for each time interval being investigated using this equation (Wischmeier and Smith 1978):

$$C = \left(\frac{\sum_{i=1}^n (SLR_i * EI_i)}{EI_t} \right) \quad [2-12]$$

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

The final factor in the RUSLE model is the support practice factor (P). The support practice factor is a ratio of soil loss with respect to a certain farming practice, such as contouring, strip farming, etc. Because this project was primarily concerned with urban landscapes, the P-factor was assumed to be one, which represents that the watershed uses no practices to prohibit sediment detachment or transport on the hillslope. In general, practices are implemented to reduce erosion; however, poorly implemented practices can produce P factors greater than one. Renard and Foster (1983) express that practices affecting the P-factor “principally affect erosion by modifying the flow pattern, grade, or direction of surface runoff and by reducing the amount and rate of runoff.” The P-factor for various watersheds is determined based on the dominating practices within the given watershed. The practices affecting the P-factor are far too numerous for this discussion,

and in calculating P-factors for a specific practice, one should refer to USDA's document AH 703.

HUSLE – Sediment Delivery

AnnAGNPS determines sediment delivery through the implementation of the Hydrogeomorphic Universal Soil Loss Equation (HUSLE) (Theurer and Clarke 1991). The soil erosion estimated by RUSLE that occurs in a particular AnnAGNPS subwatershed cell is not completely delivered to a downstream cell. The deposition, which occurs in a natural system, is accounted for in AnnAGNPS by HUSLE. As with RUSLE, HUSLE is based on empirical data collected on several diverse watersheds for many storm events (Theurer and Clarke 1991). For HUSLE, the factors remain the same as for RUSLE with one key exception. The R factor is replaced with an empirical relationship, which is related to runoff volume, peak flow rate, and drainage area. The best fit equation established through the regression that defines the empirical relationship replacing the R factor is described below (Theurer and Clarke 1991):

$$S_y = \left[0.22 \times (Q^{0.68}) \times (q_p^{0.95}) \times KLSCP \right] \quad [2-13]$$

where,

S_y = sediment yield (Mg/ha)

Q = surface runoff volume (mm)

q_p = peak rate of surface runoff (mm/hr)

D_a = drainage area (ha)

KLSCP are USLE factors

C_f is a concentrated flow factor assumed to equal 1

The HUSLE equation accounts for sheet and rill erosion occurring on the hillslope. AnnAGNPS essentially uses this equation to route the sediment erosion estimated by RUSLE from one cell downstream to the next in the form of sediment yield.

If aggregates are routed to the channel, aggregates are assumed to return to their primary particle size through disturbance and contribute to total sediment yield.

Case Studies

Due to the stage of development of AnnAGNPS, very few case studies exist using AnnAGNPS, and even fewer studies exist using a sediment delivery model such as AnnAGNPS coupled with a channel sediment transport model. In fact, many of the studies located in the literature involve nutrient transport and don't deal with sediment delivery; however, this lack of research attention emphasizes a need for progression of research in this area due to the growing concerns with siltation. Most of the watersheds that AnnAGNPS has been used are agricultural in land use; however, the use of the single event version of AnnAGNPS, AGNPS, in urban watersheds and the ability of the USLE C-factor to be modified to represent urban land uses show that AnnAGNPS can be used to make comparisons between non-urbanized and urbanized watersheds. As mentioned earlier, RUSLE is the backbone of AnnAGNPS, and if RUSLE can be manipulated to represent urban lands, AnnAGNPS can be used to simulate surface runoff and soil erosion. In the Agriculture Handbook #537, Wischmeier and Smith (1978) show that procedures and data for predicting soil erosion can be "adapted to conditions on highway, residential, and commercial developing areas."

AnnAGNPS began as simply the Agricultural Non-Point Source pollution (AGNPS) model, which uses many of the same functions as AnnAGNPS; however, AGNPS is used to predict single storm events and does not incorporate GIS analysis. AGNPS then evolved to utilize a GIS interface in a piece-wise fashion until AnnAGNPS was created with a fully integrated GIS platform. The original AGNPS model was used

frequently in public practice and found to produce good results. In fact, a decision-making risk analysis was performed by S.C. Parson et al. (1998). Essentially, Parson et al. produced output distributions using a random Monte Carlo simulation to determine the differences between results using a random distribution of input variables. By comparing the output files of 1000 AGNPS simulations, Parson et al. (1998) came to a few conclusions from his work. Decisions involving water output entails much less risk than those involving sediment output, because sediment output calculations require many more equations. However, all in all, the decision making risk in AGNPS does not rely on a precise value for input variation (Parson et al. 1998).

The wide-range use of the model provides some proof of stability in the AGNPS model, and in terms of this specific project, AGNPS has been used to make comparisons between urban and non-urban watersheds. Corbett et al. (1997) used AGNPS to evaluate a case study between a forested watershed and an urban watershed on the South Carolina coast. Corbett et al. (1997) compared the flow of water and sediment using AGNPS in these watersheds. The flow and sediment delivery predicted by AGNPS was similar to observed data. The results from this study show that greater runoff of water and sediment occurred in the urban watershed. More importantly, this study shows that AGNPS, primarily created for agricultural watersheds, can be used in watersheds with different land use characteristics (Corbett et al. 1997). Lenzi and Luzio (1997) used AGNPS integrated with GIS in the Alpone watershed of Italy to illustrate the spatial correlation of land use in predicting surface runoff and soil erosion, but they note that with variable spatial and temporal correlations in rainfall events, this model should be used to conduct many more case studies (Lenzi and Luzio 1997). All models involving hydrologic

parameters will vary spatially and temporally, and with limited research attention, improvements to these models may be years away. He (2002) added some insight to the spatial correlation of land use in a study using an Arc View-AGNPS interface. The simulations conducted in an urban watershed show that the magnitude of the effect of urbanization is based on the amount and location of urbanization in relation to the receiving stream.

Ming-Shu and Xiao-Yong (2004) used AnnAGNPS in small agricultural watershed draining into Redrock Creek, Kansas. The purpose of their study was to determine the appropriateness of using AnnAGNPS as a watershed management tool. The model was used to simulate monthly runoff and sediment yield allowing for the effects of management practices used in this watershed, and the predicted data was compared with United States Geological Survey (USGS) gage data for calibration and verification of the AnnAGNPS model. The results of the study suggested ways in which sediment yield could be reduced by analyzing changes in land use and field operation through BMP implementation (Ming-Shu and Xiao-Yong 2004). Ultimately, this study shows that AnnAGNPS can be used as a useful watershed management tool by identifying areas of sediment contribution. With an understanding of the location of contributing areas of sediment, a BMP implementation strategy can be established to manage the sediment delivery from the watershed.

CONservational Channel Evolution and Pollutant Transport System (CONCEPTS)

This project requires a sediment transport model with the ability to predict the transport of sediment size fractions and lateral changes to cross-sectional geometry. HEC-6 is one of the more common transport models used in practice and has the ability

to model fractional transport dynamics. However, HEC-6 only allows for bed scour and deposition and does not technically consider lateral erosion. CONCEPTS 1.0 is an unsteady, one-dimensional flow computer model with the capability of modeling sediment transport based on sediment fraction and channel adjustment based on bank failures (Langendoen 2000). CONCEPTS 1.0 is also compatible with the sediment delivery model AnnAGNPS.

Some of the limitations of CONCEPTS 1.0 include: simulating only gradually-varying, one-dimensional flow, accounting for a limited number of hydraulic structures, modeling only straight channels or channels with low sinuosity, assuming only homogenous bed and bank material for transport, and allowing for only slab or planar bank failures (Langendoen 2000). Some of these limitations are currently being addressed in an updated version of the model (CONCEPTS 2.0). For this project, CONCEPTS 1.0 has the ability to model lateral migration of the channel through bank failure and to account for 13 different size classes in sediment transport, which will be beneficial to this project.

The mechanics of CONCEPTS are supported by research and practice. The governing equations of the model are commonly used in other models and real world engineering practice. CONCEPTS is composed of essentially three components: 1) flow hydraulics, 2) sediment transport and bed adjustment, and 3) bank erosion and channel widening (Langendoen 2000).

Commonly, two types of procedures are used to model flow routing (Fread 1996): lumped flow routing and distributed flow routing. Lumped flow routing methods are very robust. However, they are unable to simulate backwater curves caused by instream

structures and debris or stream confluences (Langendoen 2000). CONCEPTS utilizes the advantages of distributed flow routing. Hydraulic models incorporate the continuity and momentum equation for determining flow characteristics. CONCEPTS is no different in this case, because in hydraulic modeling, the conservation of mass and momentum are required to produce robust results. The continuity and momentum equations are shown below:

$$B \frac{\partial y}{\partial t} + \frac{\partial Q}{\partial x} = q_L \quad (\text{Sturm 2001}) \quad [2-14]$$

where,

B = top width

Q = discharge

t = time

x = distance in stream wise direction

q_L = lateral flow into channel per unit length of channel

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} \left(\frac{Q^2}{A} \right) + gA \left(\frac{\partial y}{\partial x} + S_f \right) = 0 \quad (\text{Langendoen 2000}) \quad [2-15]$$

where,

Q = discharge

t = time

x = distance in stream wise direction

A = cross-sectional area

g = gravitational acceleration

y = flow depth

$S_f = \frac{n^2 Q^2}{A^2 R^{4/3}}$; energy slope

n = Manning's roughness coefficient

R = hydraulic radius

As mentioned earlier, the continuity and momentum equations are known as the Saint Venant Equations, which are also known as the dynamic wave model. The dynamic wave model can be simplified to provide a more robust numerical approximation. If the

inertia terms are neglected in the momentum equation, which is commonly done in subcritical flow, the momentum equation simplifies to:

$$\frac{\partial y}{\partial x} + S_f = 0 \quad (\text{Langendoen 2000}) \quad [2-16]$$

The continuity equation and the simplified form of the momentum equation are known as the diffusion wave model. In some cases, the diffusion wave model produces an erroneous or no solution, so CONCEPTS switches between the dynamic and diffusion wave models when appropriate (Langendoen 2000).

CONCEPTS uses the generalized Preissmann method (Cunge et al. 1980) of discretization to solve for the dynamic and diffusion wave models. This method is frequently used by scientists because it is simple and robust, compatible to a spatially varying grid, and implicit in time (Langendeon 2000). The Preissmann method is a forward time finite difference numerical method. For any function represented by f , the spatial and time derivatives representing the governing equations of the Preissmann method are shown as:

$$\frac{\partial f}{\partial x} = \frac{\theta(f_{i+1}^{k+1} - f_i^{k+1}) + (1-\theta)(f_{i+1}^k - f_i^k)}{\Delta x} \quad (\text{Sturm 2001}) \quad [2-17]$$

$$\frac{\partial f}{\partial t} = \frac{(f_i^{k+1} + f_{i+1}^{k+1}) - (f_i^k + f_{i+1}^k)}{2\Delta t} \quad (\text{Sturm 2001}) \quad [2-18]$$

where,

θ = temporal weighting factor ($0 < \theta < 1$)

k = time index

i = space index

These equations are applied to the continuity and momentum equations to model the flow characteristics of the given problem.

Sediment transport is directly related to flow hydraulics, bed-material composition, and upstream sediment contribution (Langendoen 2000). In reality, sediment transport can be separated into two separate regimes based on the water column. First, bed material slides, rolls, or saltates and exists in the lower portion of the water column. Second, the suspended load moves through the remaining space in the water column in suspension either due to size or flow mechanics. As would be expected based on Stoke's Law (Sturm 2001), a majority of the sediment concentration is found in the lower portion of the water column. However, an interaction does occur between the bed and suspended layers, but due to the need for long term simulations, CONCEPTS represents the total load as the sum of the bed and suspended load, thus neglecting this interaction (Langendoen 2000). Conservation of mass for each size class is achieved using the following equation:

$$\frac{\partial C_k}{\partial t} + \frac{\partial u C_k}{\partial x} = E_k - D_k + q_{s_k} \quad (\text{Langendoen 2000}) \quad [2-19]$$

where,

t = time

x = stream wise distance

u = flow velocity

E = entrainment rate of particles

D = deposition rate of particles

q_{s_k} = rate of sediment inflow from banks and fields adjacent to channel

k = kth size class

C = sediment mass

CONCEPTS uses a modification of the SEDTRA sediment transport capacity predictor developed by Garbrecht et al. (1996) to predict the sediment transport of the 13 individual size classes. Table 2-1 denotes the size ranges and transport equations used in CONCEPTS.

Table 2-1. Size Class Distribution and Equation used in CONCEPTS

Size Class	Upper Bound (mm)	Representative diameter (mm)	Description	Transport Equation
1	0.010		clay-very fine silt	Washload
2	0.025	0.016	fine-medium silt	Laursen
3	0.065	0.040	medium-coarse silt	Laursen
4	0.250	0.127	fine sand	Laursen
5	0.841	0.458	medium-coarse sand	Yang
6	2.000	1.297	very coarse sand	Yang
7	3.364	2.594	very fine gravel	Meyer-Peter and Mueller
8	5.656	4.362	fine gravel	Meyer-Peter and Mueller
9	9.514	7.336	fine gravel	Meyer-Peter and Mueller
10	16.000	12.338	medium gravel	Meyer-Peter and Mueller
11	26.909	20.749	coarse gravel	Meyer-Peter and Mueller
12	38.055	32.000	coarse gravel	Meyer-Peter and Mueller
13	50.000	43.713	very coarse gravel	Meyer-Peter and Mueller

The final component of CONCEPTS is the bank erosion and channel widening portion of the model. This component provides the user with the ability to model channel adjustment due to bank failures and possibly predict the migration of the stream morphology through meandering.

One huge advantage to this capability is that as the channel width changes then so do other key hydraulic parameters such as roughness, flow depth, and slope. In cohesive soils, such as those of East Tennessee, particles are held together primarily by an electrochemical bond between these particles. Erosion may occur at the toe of a bank until the weight above the toe fails the entire bank by mass wasting. CONCEPTS uses a more simplified planar failure analysis. Planar failure analysis assumes that the failure block extends from some point near the toe of the bank at angle to some point at the ground surface at some distance from the channel. Huang (1983) assumes that any

surface water projecting onto the failure block consists of no strength. Using the method of slices, several forces are acting to bring the slab into a failure condition. Internal forces between the particles, the hydrostatic force acting on the slab by the water, shear force along the failure plane, and the normal force opposing the weight of the slab allows the slab to remain in place. However, the weight of the slab aids in the failure of the slab (Langendoen 2000). As erosion occurs from hydraulic forces, the bank becomes weaker due to the loss of opposing force to the weight of the slab. Eventually, the bank will fail and a new cross-section will be left in the wake. CONCEPTS models these changes and applies new bank characteristics at each time step.

Case Studies

CONCEPTS is a relatively new and untested model, which is why a sensitivity analysis is important in determining the applicability of this model. Very few case studies have been conducted using CONCEPTS; therefore, literature supporting the sensitivity of particular parameters to the model output of CONCEPTS could not be found. In fact, all of the studies using CONCEPTS have been performed by the ARS in Oxford, MS.

CONCEPTS has been used by the ARS to describe some unique cases of sediment discharge dynamics. On the Little Salt and West Papillion Creeks in eastern Nebraska, major channel adjustments have occurred due to channelization in the early 1990's and have endangered areas of wetlands and urban development (Langendoen and Simon 2000). Langendoen and Simon (2000) attempted to define positions along the channel to implement bed controls in order to stop incision near the concerned areas. These authors used a combination of procedures to define and carry out this project

including flow data, bed and bank material testing, and simulation execution. This study is very unique in that long-term gauging stations are located within both watersheds. Very rarely can long-term flow data be found for most of the watersheds in Tennessee. Complex analysis was performed on the cohesive bed and bank materials. Langendoen and Simon (2000) used the submersible jet device (Hanson 1990) to find the erodibility coefficient (K) and the critical shear stress (τ_c) of the bed material. The borehole shear test (BST) device (Luttenegger and Hallberg 1981) was used to find the shear strength of the bank material. After running several simulations, Langendoen and Simon (2000) determined the best placement of control structures that greatly reduced the incision in and around the concerned areas. However, having long-term flow data and time to run the complex analysis on bed and bank material, represents more of a perfect world situation than that of the Beaver Creek study, but the lack of data in Beaver Creek is not necessarily a concern. One of the objectives of the Beaver Creek project is to determine the usability of CONCEPTS on a watershed with no historical data.

The ARS has performed a few other studies in Mississippi to show the effectiveness of the CONCEPTS model in a variety of situations. One of the more interesting situations was in the Upper Yalobusha River basin. Channelization of the river in the 1960's caused an incision and widening of the channel forcing woody debris in the river (Langendoen et al. 2002). Debris flowing into the stream produced a large debris jam at the downstream end of the channelization. After removal of this debris jam, Langendoen et al. (2002) had strong concern of channel adjustment after clearing. Preliminary results from CONCEPTS show satisfactory results on the trends of incision

and deposition along the model reach, but with calibration, CONCEPTS can be used to predict channel adjustment after the removal of the debris jam (Langendoen et al. 2002).

AnnAGNPS-CONCEPTS Modeling Couple - Case Studies

The advantage of using the AnnAGNPS-CONCEPTS modeling couple is that these two models have a predefined compatibility and are maintained in the same office (ARS Oxford, MS). The ARS has performed several studies using the AnnAGNPS-CONCEPTS couple. In fact, the study mentioned previously on the Upper Yalobusha River in Mississippi incorporated the sediment and hydrologic delivery from an AnnAGNPS simulation with the CONCEPTS simulation to study the effects of the debris dam removal (Langendoen et al. 2002).

The ARS conducted two case studies that are applicable to the Beaver Creek project. Shades Creek in Alabama is faced with many of the same issues of siltation as Beaver Creek in Knox County. Almost all of Shades Creek is listed as being impaired by sediment and one of the major contributing factors to the siltation issue is urban runoff (Simon et al. 2004b). The main goal of the Shades Creek project was to use the AnnAGNPS-CONCEPTS couple to determine acceptable sediment loads from a “reference” stream. These results will be compared to the sediment loadings from Shades Creek (Simon et al. 2004b). In order to determine “reference” conditions, Simon et al. (2004b) created an empirical relationship for sediment loads in Ecoregion 67. Using historical data and studies of channel stability at individual sites, a multivariate statistical analysis was computed for the region to define a “reference” condition for Shades Creek. The AnnAGNPS-CONCEPTS couple is used to produce scenarios showing the changes in sediment dynamics into and out of Shades Creek based on increases in urbanization

(Simon et al. 2004b). A similar study was done earlier on James Creek in Mississippi by Simon et al. (2002), in that, a “reference” condition was determined in essentially the same way and an approach to define a TMDL using the AnnAGNPS-CONCEPTS was described based on sediment loadings. In the James Creek project, the modeling couple was also used to explore the effects of urbanization and the role of BMP’s in reducing sediment runoff into the stream (Simon et al. 2002), which is a future goal of the work being done in Beaver Creek watershed.

CHAPTER 3

STUDY AREA

Beaver Creek Watershed

The Beaver Creek watershed is located in the northwestern portion of Knox County, Tennessee in the Ridge and Valley region known as Ecoregion 67 (Figure 3-1). This watershed offers a graduated class of subwatersheds in terms of percent urbanization. The Beaver Creek watershed area has recently received much attention because of its placement on the 303(d) list by TDEC (TDEC 2004). The entire Beaver Creek watershed is approximately 90 square miles and drains into the Clinch River, which is a large tributary of the Tennessee River. The Beaver Creek watershed has a maximum elevation difference of approximately 400 meters, which is fairly indicative of the area and ecoregion.

The GIS land use layer describes Beaver Creek watershed as having very little agricultural development with the exception of a few hay fields and pasture lands (Figure 3-2). The watershed has become urbanized over the past several decades due to urban sprawl from the city of Knoxville, Tennessee. Due to the recent urbanization, Beaver Creek watershed has a considerable amount of residential areas with concentrations of industrial and commercial areas. Non-urbanized areas are mostly forest and are located in the uplands of the watershed. Overall, Beaver Creek watershed is fairly urbanized with plans for more development in progress.

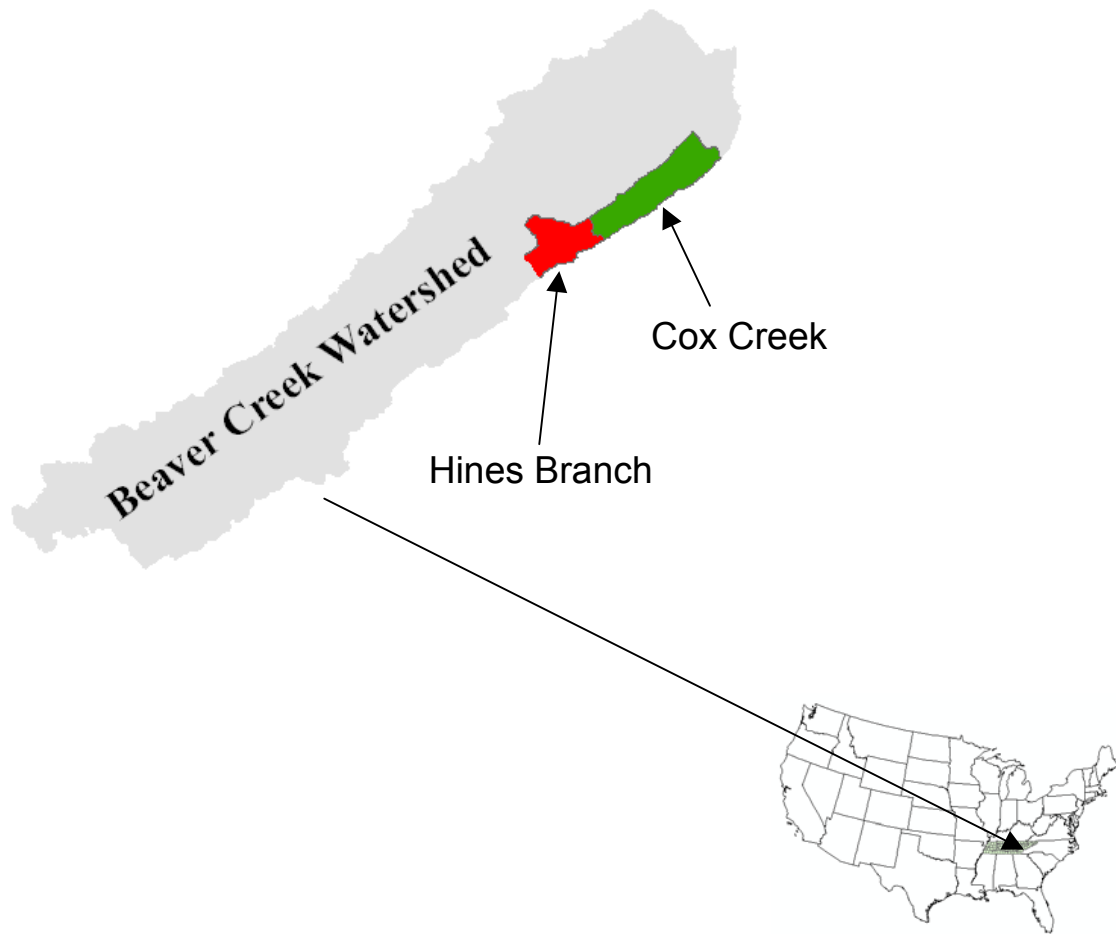


Figure 3-1. Study Area for Beaver Creek Watershed in Northwestern Knox County, TN

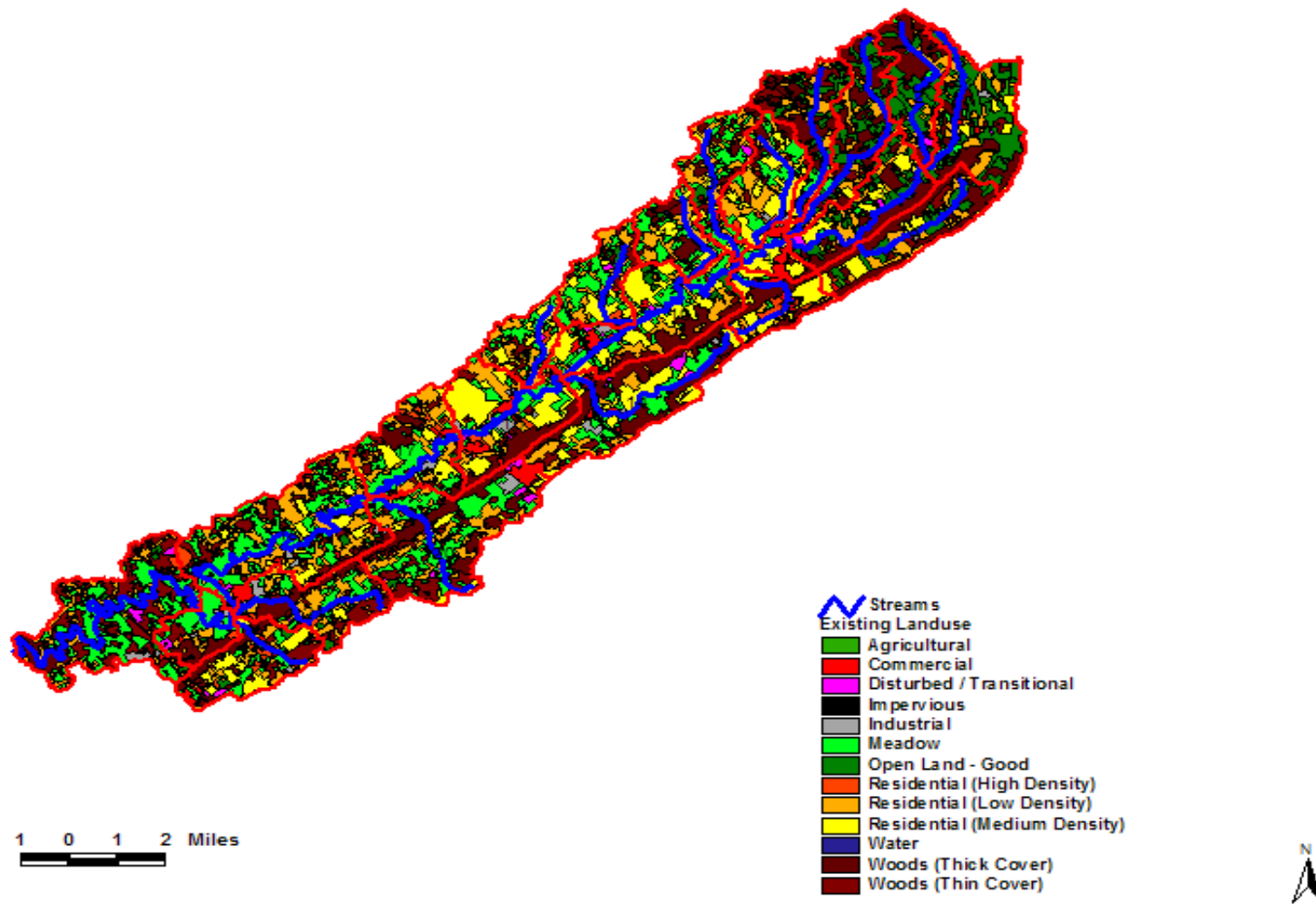


Figure 3-2. Existing Land use Map of Beaver Creek Watershed in Knox County, TN

Cox Creek and Hines Branch Study Sites

Based on watershed characteristics such as, soil types, land use, and channel morphological data the Cox Creek and Hines Branch subwatersheds were selected for the testing of the AnnAGNPS-CONCEPTS modeling couple. Channel morphology is an important aspect of this project, because how the channel evolves due to erosion and sedimentation over time is important in understanding how the bed sediment characteristics relate to an urbanizing watershed. A stream power analysis was used to select subwatersheds in the Beaver Creek watershed with similar physiographic characteristics. Stream power is a ratio of energy slope and effective discharge to stream width. Brookes (1987) defines stream power as a representation of energy disbursement at a particular point within a river system. Stream power is therefore related to sediment transport, geomorphology, and channel stability. Figure 3-3 shows the stream power network across Beaver Creek watershed, in which a channel typically aggrades with stream power less than 35 W/m^2 , and erodes with stream power greater than 35 W/m^2 .

Subwatersheds 9 and 13 in this site selection analysis represent the Cox Creek and Hines Branch subwatersheds, respectively, which were used in the first and second studies of this research project. The soil and channel morphological characteristics of both subwatersheds are similar (Figure 3-3); however, the percent urbanization of each subwatershed is very different (Figure 3-2). This is the basis for selecting these two sites. Tables 3-1 and 3-2 show the differences between the makeup of land uses for the two subwatersheds. Tables 3-3 and 3-4 show the differences between the compositions of soil types for the two subwatersheds.

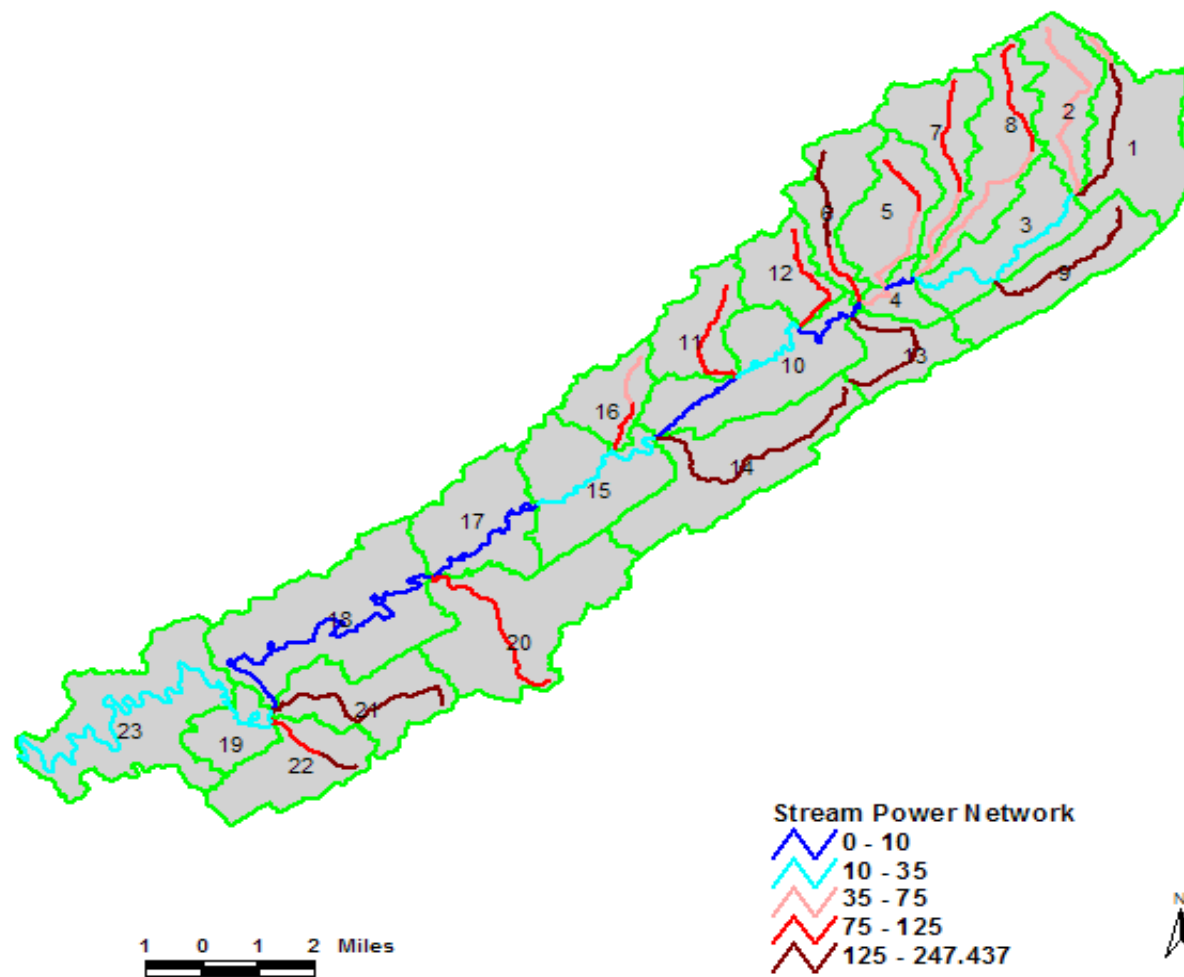


Figure 3-3. Stream Power Network of Beaver Watershed in Knox County, TN

Table 3-1. Percentage of Land Use Types for the Cox Creek Subwatershed

Land Use	% of Total Area(%)
Open Land	28.09
Residential (Low Density)	16.10
Residential (Medium Density)	7.36
Water	0.22
Woods (Thick Cover)	42.22
Woods (Thin Cover)	6.01

Table 3-2. Percentage of Land Use Types for the Hines Branch Subwatershed

Land Use	% of Total Area(%)
Commercial	6.85
Meadow	3.03
Open Land	0.58
Residential (High Density)	10.68
Residential (Low Density)	10.25
Residential (Medium Density)	35.54
Woods (Thick Cover)	30.48
Woods (Thin Cover)	2.60

Table 3-3. Percentages and Descriptions of Soil Types for the Cox Creek Subwatershed

Soil Symbol	Soil Name	Soil Description	% of Total Area	Clay Ratio	Silt Ratio	Sand Ratio
Am	Apison-Montevallo Complex	Fine-Loamy	50.95	0.17	0.537	0.293
Bh	Bloomington-Hamblen Complex	Silt Loam	6.01	0.26	0.583	0.157
Ct	Corryton-Townley Complex	Fine	1.13	0.165	0.4	0.435
De	Dewey	Silt Loam	1.18	0.22	0.369	0.411
Ev	Etowah-Minvale Complex	Fine-Loamy	0.25	0.21	0.374	0.416
Fv	Fullerton-Minvale Complex	Fine-Loamy	3.92	0.21	0.374	0.416
He	Heiskell	Silt Loam	0.29	0.17	0.565	0.265
Mf	Minvale-Bodine-Fullerton Complex	Fine-Loamy with Stones	14.04	0.26	0.368	0.372
Sb	Salacoa-Apison Complex	Fine-Loamy	11.64	0.18	0.39	0.43
Sw	Swafford	Fine-Loamy	10.34	0.25	0.545	0.205
Weighted Averages (%)				19.93	48.81	31.01

Table 3-4. Percentages and Descriptions of Soil Types for the Hines Branch Subwatershed

Soil	Soil Name	Soil Description	% of Total Area	Clay Ratio	Silt Ratio	Sand Ratio
Am	Apison-Montevallo Complex	Fine-Loamy	27.77	0.17	0.537	0.293
Bd	Bloomingtondale	Fine	1.25	0.26	0.583	0.157
Bh	Bloomingtondale-Hamblen Complex	Silt Loam	1.56	0.26	0.583	0.157
Co	Corryton	Loam	2.30	0.165	0.4	0.435
Ct	Corryton-Townley Complex	Fine	2.40	0.165	0.4	0.435
Cz	Corryton-Udorthents-Urban Complex	Fine	2.20	0.165	0.4	0.435
De	Dewey	Silt Loam	15.67	0.22	0.369	0.411
Dy	Dewey-Udorthents-Urban Complex	Silt Loam	0.16	0.22	0.369	0.411
Ev	Etowah-Minvale Complex	Fine-Loamy	0.78	0.21	0.374	0.416
He	Heiskell	Silt Loam	2.52	0.17	0.565	0.265
Nn	Nonaberg	Clayey	0.84	0.3	0.535	0.165
Sa	Salacoa	Gravelly Loam	0.56	0.18	0.39	0.43
Sb	Salacoa-Apison Complex	Gravelly Loam	4.60	0.18	0.39	0.43
Se	Salacoa-Udorthents-Urban Complex	Gravelly Loam	25.06	0.18	0.39	0.43
St	Steadman	Silt Loam	0.41	0.195	0.689	0.116
Sw	Swafford	Silt Loam	5.52	0.25	0.545	0.205
Ur	Urban Land	Fine-Loamy	3.72	0.18	0.39	0.43
Uu	Urban Land-Udorthents Complex	Fine-Loamy	2.68	0.18	0.39	0.43
Weighted Averages (%)				18.97	44.89	36.14

As Tables 3-1 and 3-2 show, the land use compositions of each subwatershed were dissimilar with the Hines Branch subwatershed consisting of larger areas of urbanization. Tables 3-3 and 3-4 illustrated that the soil types are very similar between the two subwatersheds. Most importantly, the composition of the soil types, in terms of clay, silt, and sand, was very similar for the two subwatersheds.

The Cox Creek and Hines Branch subwatersheds maintained a relative similarity to each other with the exception to land use. Channel morphology was also similar between these two watersheds, so that relative properties of sediment transport calculated in the CONCEPTS model could be compared (Table 3-5).

Table 3-5. Channel Morphological Characteristics for the Cox Creek and Hines Branch Model Reaches

	Average Bed Slope (m/m)	Average Bankfull Top Width (m)	Average Bankfull Height (m)	Average Bankfull Shear Stress (Pa)	Stream Power (Watts/m²)
Cox	0.00566	5.00	1.05	41.09	97.77
Hines	0.00543	6.62	1.00	41.06	119.12

CHAPTER 4

SENSITIVITY ANALYSIS

Introduction

In the first study, urban-related model input parameters for the AnnAGNPS and CONCEPTS models were used in a sensitivity analysis. In order to determine if these models were suitable for simulations in urban watersheds, a range of input parameters were used to generate estimates of sediment yield. In addition, results from this sensitivity analysis support the Study 2 effort related to understanding streambed sediment changes in urbanizing watersheds.

Study 1 Question: Which model input parameters relevant to an urbanizing watershed are most sensitive to estimating sediment yield from the AnnAGNPS and CONCEPTS models?

Methods

AnnAGNPS

In order to conduct a sensitivity of the AnnAGNPS model, an understanding of its inputs was needed to establish model input parameters that can be related to urbanization. AnnAGNPS required several GIS input layers initially to create a model. A digital elevation model (DEM), land use, and soil layer must be obtained, and this data can usually be located through a variety of government agencies. AnnAGNPS also required that these data layers be in Universal Transverse Mercator (UTM) projections. The model will not run without these layers being in the UTM projection. Once these data layers were found and put in the correct projection, soil and land use databases were created to describe factors and descriptions of each soil and land use type. These

databases were then read into the Input Editor portion of the model, which is where any RUSLE or hydrological factors were placed to run a simulation. The storm and climate data was also entered into the Input Editor, and a synthetic weather generator was offered to create this data generically based on local climate gauging stations. Examples of the AnnAGNPS input data in the Input Editor environment are located in Appendix A. After all input was correctly put into the Input Editor, the user has several output options to choose from in order to analyze results. In the case of this project, sediment and water were the output parameters of interest, and these outputs were formatted into output files, which can be used as input files for the delivery of sediment and water into the CONCEPTS model.

The parameters tested in the AnnAGNPS model had some relevance to the areas of urbanized land use, because the changes in land use from undisturbed to disturbed (urbanizing) to urbanized seems to be a weakness of a model developed for agricultural watersheds. Table 4-1 describes various model inputs of AnnAGNPS, the relevance of the inputs to an agricultural system, and the implications of the inputs to an urbanized system. For the most part, RUSLE is the main driving force for calculation of erosion in AnnAGNPS, and, therefore, most of the modeling parameters are related to RUSLE with the exception of some hydrologic parameters handled by TR-55. The RUSLE parameters are either related to some climate aspect of the watershed (R factor), some soil aspect of the watershed (K factor), or some topographic aspect of the watershed (LS Factor). However, the parameters of interest are related to the cover or land use aspect of the watershed (C factor). The P factor relates to best management practices (BMPs) used

Table 4-1. Relevance of Model Input Parameters to Agricultural and Urban Land Uses

Parameter	Agricultural Role	Urban Implications
RUSLE Parameters		
<i>LS Factor</i>	Physiographic Parameter	Physiographic Parameter – Related to rill development in urban setting
<i>P factor</i>	Support practice factor representing changes in erosion through agricultural practices such as strip-cropping, contouring, terracing, and subsurface drainage usually to reduce runoff and erosion	Parameter can be used to described BMPs such as silt fencing and retention ponds; however, these practices are not being considered in this project.
<i>R Factor</i>	Climate parameter	Climate parameter - Inputs of this parameter act on an urban landscape in the same manner as an agricultural landscape
<i>K Factor</i>	Soil Parameter - Based on the ability of a certain soil type to detach and runoff from the energy exerted on the soil through rain drop or runoff	Soil Parameter - Implications in urban land use are the same - any effects of impervious or urban areas are dealt with in the C factor
<i>C Factor</i>	Cover-Management factor - In terms of erosion, the C factor is based on the erosion of some reference condition and represents effects of previous cropping and management, surface cover and roughness, and soil moisture.	Parameter can be used to describe areas of urbanization and imperviousness, canopy cover and height, and most importantly residue cover.
C Factor Parameter: <i>Annual Root Mass</i>	This parameter inversely affects the PLU C sub factor - used to represent the amount of live root mass in top 4 in. of soil	This parameter affects the C factor, which is directly affected by the land use - with greater root mass more binding of soil particles takes place thus decreasing erosion. Also, root mass provides a food source for microorganisms that can produce other organic binding agents

Table 4-1. Continued

Parameter	Agricultural Role	Urban Implications
C Factor Parameter: <i>Annual Cover Ratio</i>	This parameter inversely affects the CC C sub factor - used to represent the amount of ground covered by canopy to total ground area - usually based on type of crop covering the field.	This parameter affects the C factor, which is directly affected by the land use - with greater canopy cover more raindrops are intercepted thus decreasing erosion.
C Factor Parameter: <i>Annual Rainfall Height</i>	This parameter inversely affects the CC C sub factor - used to represent the height at which a rainfall will drop from an intercepting canopy to the ground - usually based on type of crop covering the field.	This parameter affects the C factor, which is directly affected by the land use - with greater rainfall height more erosion occurs.
C Factor Parameter: <i>Percent Surface Residue</i>	This parameter inversely affects the SC C sub factor - used to represent the amount of surface covered by residue as a function of percent	This parameter affects the C factor, which is directly affected by the land use - with greater surface residue less area is susceptible to erosion.
TR-55 Parameters		
Curve Number	This parameter describes the ability of an area with similar land use to allow for runoff - areas of varying crop type will yield different runoff volumes	This parameter describes the ability of an area with similar land use to allow for runoff - areas of varying development will yield different runoff volumes
Overland Flow Manning's n	This is a roughness coefficient that describes the ground roughness for essentially the first 100 ft of flow length for a raindrop falling within the upper portion of a watershed	This parameter may vary drastically depending on the type of land use in the upper portion of a watershed
Concentrated Flow Manning's n	This a roughness coefficient that describes the concentrated channel roughness after the runoff is concentrated from the sheet flow condition of overland flow and before the flow concentrates to form the main channels of the system	This parameter may vary drastically depending on the type of linings within these concentrated flow channels. In a relatively non-urbanized watershed the lining may be more grassy or weedy than in an urbanized watershed, which may have some sort of rock or even concrete linings

Table 4-1. Continued

Parameter	Agricultural Role	Urban Implications
Reach Manning's n	This is a roughness coefficient that describes the main reach roughness.	This parameter may vary depending upon whether the main channel has been straightened or armor has been added to provide channel stability (Chow 1959)

across a watershed to reduce erosion, which is relevant in this discussion; however, the P factor is assumed to be equal to one for the purposes of this modeling exercise.

A P factor equal to one would represent a watershed with no measures taken to remove sediment from detaching and transporting downstream.

With an understanding of the relationship of the parameters in Table 4-1 to urbanization, the four parameters used to calculate the C factor were chosen as the input AnnAGNPS model parameters to be tested for sensitivity. Those four factors include: annual root mass, annual cover ratio, annual rain fall height, and percent surface residue. Due to the lack of published values for these model input parameters with respect to urban land uses, an assumed average value is determined using values from a similar study in the urbanized Shades Creek watershed in Alabama (Simon et al. 2004b). The assumed average value defined a median point from which the range of each model input parameter is tested for the AnnAGNPS sensitivity analysis. The assumed average value for each model input parameter and the range for which the parameter was tested can be found in Table 4-2. The assumed average value is noted in the table as bold type. The AnnAGNPS model was run for each model input parameter over the range described in Table 4-2 to observe the sensitivity of each model input parameter. The sensitivity

Table 4-2. AnnAGNPS Input Parameter Ranges

	Proportion of Range (%)				
Parameter	0%	25%	50%	75%	100%
Annual Root Mass (kg/ha)	3484	3984	4484	4984	5484
Annual Percent Cover (%)					
For Residential High and Medium, Commercial, and Industrial	0.80	0.85	0.90	0.95	1.00
For Residential Low Density	0.70	0.75	0.80	0.85	0.90
Annual Rainfall Height (m)	0	0.03	0.06	0.09	0.12
Percent Surface Residue (%)					
For Residential High and Medium, Commercial, and Industrial	40	45	50	55	60
For Residential Low Density	15	20	25	30	35

analysis of AnnAGNPS and CONCEPTS follows a specific step-by-step process, because the output of AnnAGNPS becomes input for the CONCEPTS model. For AnnAGNPS, a time scale of 10 years was selected to ensure that the effects of any model input parameters can be observed in the model output over a long-term simulation. The model input parameters were only tested for urban land uses such that a direct impact of the urban areas was exhibited in the model output. Examples of the output for the AnnAGNPS model are located in Appendix A.

The model input parameters determined to be relevant to urban land use were analyzed for sensitivity by plotting the dependent variables (the model input parameters) on the abscissa and the independent variables (sediment size output and sediment metrics) on the ordinate (Figure 4-1). The slope of the sensitivity curve in Figure 4-1

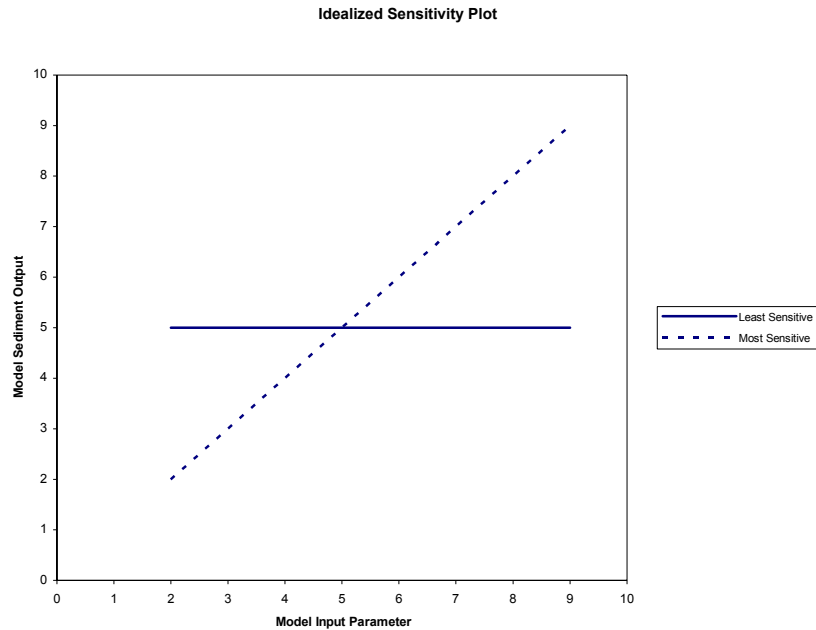


Figure 4-1. Idealized Sensitivity Plot

indicates the sensitivity of the AnnAGNPS model to each model input parameter in relation to the model sediment output. The output data from the sensitivity runs are displayed later in this chapter in the form of plots resembling Figure 4-1. A table was also produced comparing the sensitivities between the non-urbanized Cox Creek subwatershed and the urbanized Hines Branch subwatershed in the form of a percent difference.

CONCEPTS

In order to conduct a sensitivity of the CONCEPTS model, an understanding of the model input parameters and the model in general was needed to ascertain the parameters most suitable to be tested in the analysis. The fieldwork involved in this portion of the modeling process was much more intensive than that of the AnnAGNPS

portion. Inputs required for this model were surveyed cross-sections at an acceptable interval along the stream longitudinally. The placement of these cross-sections was dependent upon the scale of the reach length and changes in topography. The locations of these cross-sections were also spaced such that the model remains stable throughout simulations. Sediment size distributions were required at each cross-section for bed and bank material, and the procedures for determining sediment size distributions for this project follow the guidelines set out by the American Society for Testing and Materials (ASTM) (ASTM D421, D422 1998). For this project, the particle size distribution of the banks was only conducted for representative cross-sections, and an average distribution was applied to all the cross-sections over each reach. For Hines Branch, only eight samples were taken for bed particle size distributions, so the bed sediment size distributions were allocated over all the cross-sections based on location of cross-section with respect to location of sediment sample location. For Cox Creek, the locations of the bed sediment size distribution samples match with the location of the cross-sections. The particle size distributions for Cox Creek and Hines Branch can be located in Appendix C. The output files from AnnAGNPS that represent the routing of sediment and water into the reach must also be entered into the input files to route the deliveries through the study reach length. CONCEPTS utilizes two other input file types. A hydrography file, derived from AnnAGNPS output, is used containing the flow hydrograph and sedimentgraphs for different size classes to be routed through the reach. A run control file is also used that sets the simulation period, identifies the cross-sections to be considered in analysis, and other information crucial to initializing the model. Input files for the CONCEPTS model are located in Appendix B.

The sensitivity analysis for the CONCEPTS model was conducted in the same manner as for the AnnAGNPS model. CONCEPTS is a more physically based model, which places an emphasis on hydraulics and channel properties while ignoring the effects of urbanization in its input parameters, so the model input parameters being tested are related to difficulty of data compilation through field work. Cohesive materials in the bed and banks require extensive field tests for input parameters related to the soil characteristics in the bed and banks of the stream channel. Therefore, a sensitivity analysis of CONCEPTS was performed to test how sensitive the parameters, determined through the extensive field work procedures, were for the two stream reaches (Cox Creek and Hines Branch).

The banks of these stream reaches consist of very cohesive soft clays as determined through the particle size distribution procedures. To determine the model inputs for this type of soil, a triaxial shear or unconfined compression test must be conducted in the lab or an *in-situ* test can be conducted with a BST to determine the cohesion (c) and angle of internal friction (ϕ) of the particular soil type (Luttenegger and Hallberg 1981). The saturated bulk unit weight (γ) of the soil can be estimated by collecting a sample of the bank material, and then back in the lab, the sample can be weighed, dried, and weighed again to determine the value for saturated bulk unit weight. An assumed average value for these three parameters was established from the Bank Stability Model documentation at the National Sedimentation Lab in Oxford, MS (Simon et al. 2004a). The first three parameters in Table 4-3 show the three bank properties and ranges that were tested for sensitivity.

Table 4-3. CONCEPTS Input Parameter Ranges

	Proportion of Range (%)				
Parameter	0%	25%	50%	75%	100%
Cohesion (Pa)	0	5000	10000	15000	20000
Effective Angle of Internal Friction (°)	15	22.5	30	32.5	45
Saturated Bulk Unit Weight (N/m³)	4000	10000	16000	22000	28000
Critical Shear Stress for Erosion (Pa)	0	2	4	6	8
Erodibility Coefficient (m/sPa)	0.00E+00	2.50E-06	5.00E-06	7.50E-06	1.00E-05

The bed materials in these stream reaches consisted of cohesive clays, fine sands, sands, and some gravel. Two model input parameters were tested for sensitivity in the CONCEPTS model, and as with the bank, these parameters are related to characteristics of the soil present in the bed. The last two parameters in Table 4-3 show the two bed properties and ranges that were tested for sensitivity. The two tested parameters were the critical shear stress for erosion (τ_e) and the erodibility coefficient (k), and these parameters also require a specialized piece of equipment, known as the submerged jet tester, for determination in the field (Hanson 1990). Because it was resource intensive to conduct these tests, these parameters will be tested for sensitivity, and the mean values were assumed based on the Shades Creek Study due to the similarity between the Shades Creek watershed and Beaver Creek watershed as ridge and valley watersheds (Simon et al. 2004b).

Using the AnnAGNPS output with the assumed average model input parameter values, a sensitivity analysis was performed with the CONCEPTS model in the same way

as for the AnnAGNPS model. Sensitivity curves were plotted for each model input parameter, and a table showing the percent difference between the Cox Creek and Hines Branch sensitivity curve slopes was created. The sensitivity analysis of CONCEPTS was very important in the progression of the model, because CONCEPTS has had very little exposure in public use with the exception of the studies conducted by the ARS in Oxford, MS. Examples of the output for the CONCEPTS model are located in Appendix B.

Results and Discussion

AnnAGNPS

The output for the results was normalized by contributing drainage area so that visual comparisons could be made between the output of Cox Creek and Hines Branch. The results of the modeling runs for sediment yield normalized by drainage area varied over the proportion of range of input values for each parameter and subwatershed (Tables 4-4 and 4-5).

By observing the sediment yields per drainage area in Tables 4-4 and 4-5, the values for sediment yield as a function of drainage area show a general trend of being lower for Hines Branch than for Cox Creek. This phenomenon was expected since Hines Branch is much more urbanized than Cox Creek and therefore provides more surface cover from land use to prevent erosion.

In Figures 4-2 and 4-3, the sediment yield per drainage area is actually higher for Hines Branch at the lower end of the range for the annual root mass and the annual cover ratio. This phenomenon is probably a result of the mosaic of land uses in each of these watersheds. Changing the urban model input parameter in Cox Creek has less of an influence in the lower range of parameter values, because Cox Creek has fewer areas of

Table 4-4. AnnAGNPS Sensitivity Analysis Results for Cox Creek. With Drainage Area of 441.44 ha and Percent Urbanization of 7.36%

		Proportion of Sensitivity Parameter Range				
Sensitivity Parameter		0%	25%	50%	75%	100%
Annual Root Mass	Sediment Yield (Mg/ha/yr)	0.0672	0.0658	0.0648	0.0640	0.0635
Annual Cover Ratio		0.0662	0.0655	0.0648	0.0640	0.0633
Annual Rainfall Height		0.0646	0.0648	0.0649	0.0650	0.0651
Percent Surface Residue		0.0658	0.0652	0.0648	0.0644	0.0640

Table 4-5. AnnAGNPS Sensitivity Analysis Results for Hines Branch. With Drainage Area of 576.43 ha and Percent Urbanization of 53.06%

		Proportion of Sensitivity Parameter Range				
Sensitivity Parameter		0%	25%	50%	75%	100%
Annual Root Mass	Sediment Yield (Mg/ha/yr)	0.0712	0.0661	0.0624	0.0597	0.0578
Annual Cover Ratio		0.0679	0.0651	0.0624	0.0596	0.0569
Annual Rainfall Height		0.0619	0.0624	0.0629	0.0633	0.0638
Percent Surface Residue		0.0659	0.0640	0.0624	0.0610	0.0599

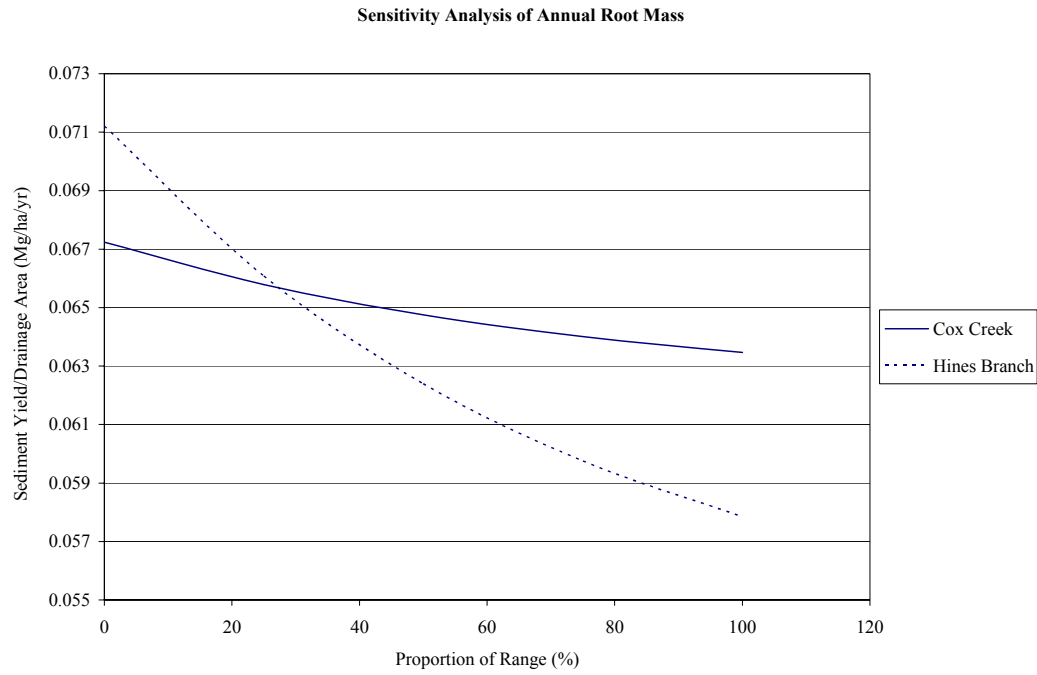


Figure 4-2. Sensitivity Analysis of Annual Root Mass on Sediment Yield

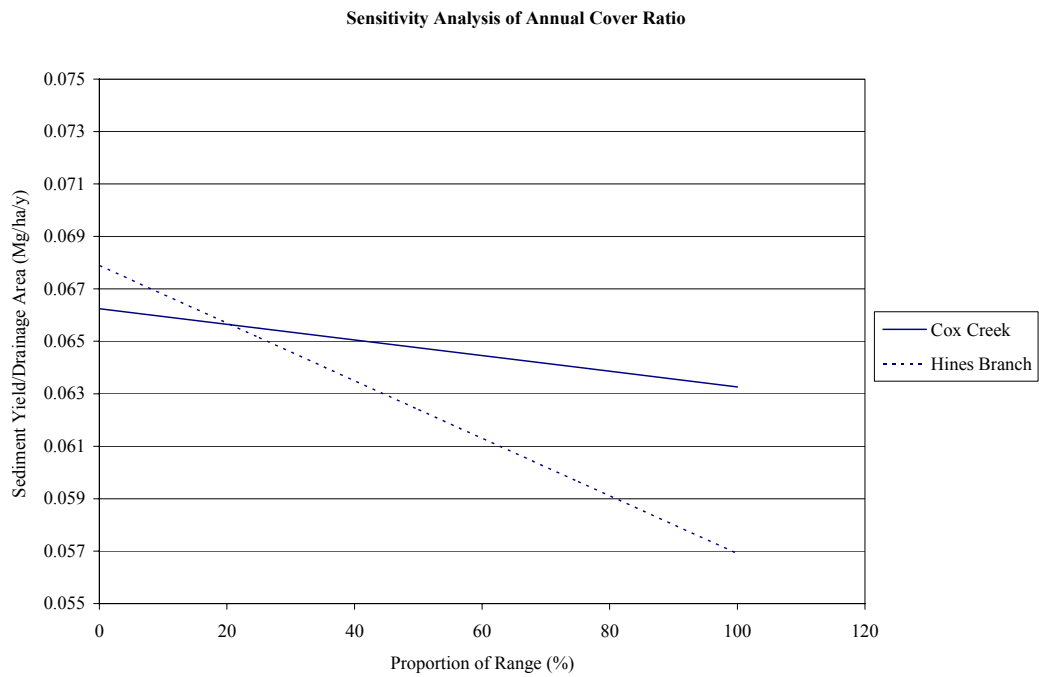


Figure 4-3. Sensitivity Analysis of Annual Cover Ratio on Sediment Yield

urbanization (Tables 3-1 and 3-2). Therefore, as the values for the annual root mass and the annual cover ratio are lowered to that representing pastures, meadows, and open land, the urban areas of Hines Branch resemble the non-urbanized areas of Cox Creek, and thus, produce similar or greater sediment yields per drainage area than Cox Creek. For the annual rainfall height sensitivity parameter (Figure 4-4), the sediment yield per drainage area for both the Cox Creek and Hines Branch subwatersheds trend upward as the sensitivity parameter increases with the values for sediment yield per drainage area being greater for Cox Creek than Hines Branch. This tendency is logical, because the Hines Branch subwatershed consists of more soil protection from urbanization and, therefore, should produce less sediment yield. In considering the percent surface residue sensitivity parameter (Figure 4-5), the trend of the sensitivity curves decreases as the sensitivity parameter increases, which is reasonable considering that more surface residue over an area should produce less sediment yield. As with the annual rainfall height, the values for sediment yield per drainage area for percent surface residue are greater for Cox Creek than for Hines Branch. This phenomenon is expected based on the larger amount of surface residue provided in the Hines Branch urban subwatershed.

In general, both of these watersheds are fairly insensitive to the model input parameters when considering a particular watershed individually. However, when comparing the sensitivities of an urban to a non-urban watershed, the results are remarkably different. The slopes of the sensitivity curves for Hines Branch tend to be greater than the slopes of the sensitivity curves for Cox Creek (Table 4-6). The slopes of the sensitivity curves for Hines Branch range from 150% to 300% greater than the slopes of the sensitivity curves for Cox Creek.

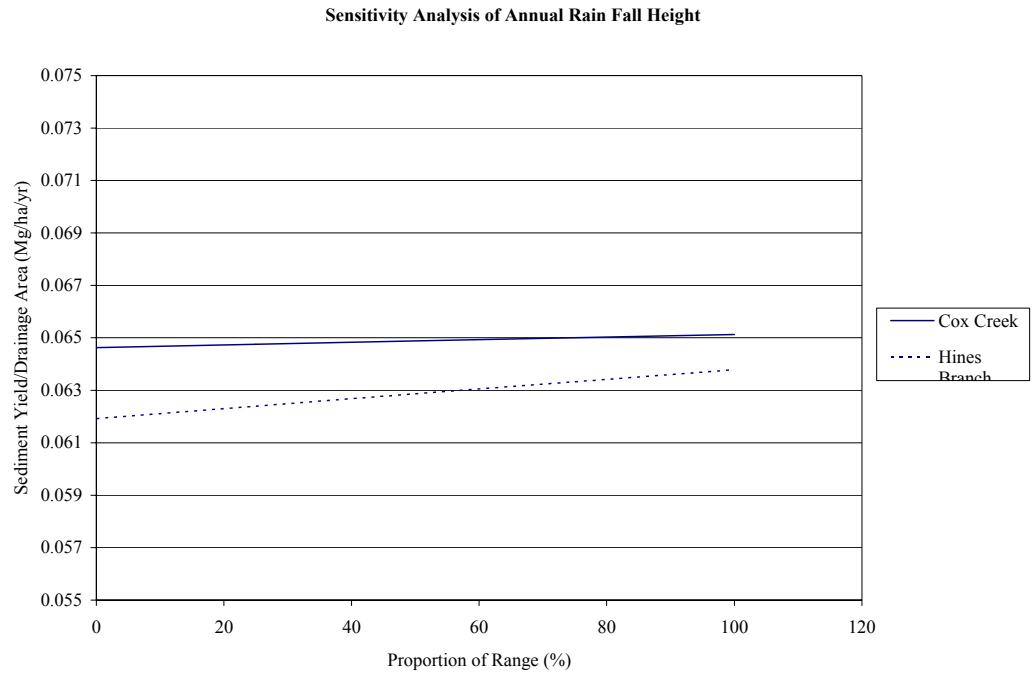


Figure 4-4. Sensitivity Analysis of Annual Rain Fall Height on Sediment Yield

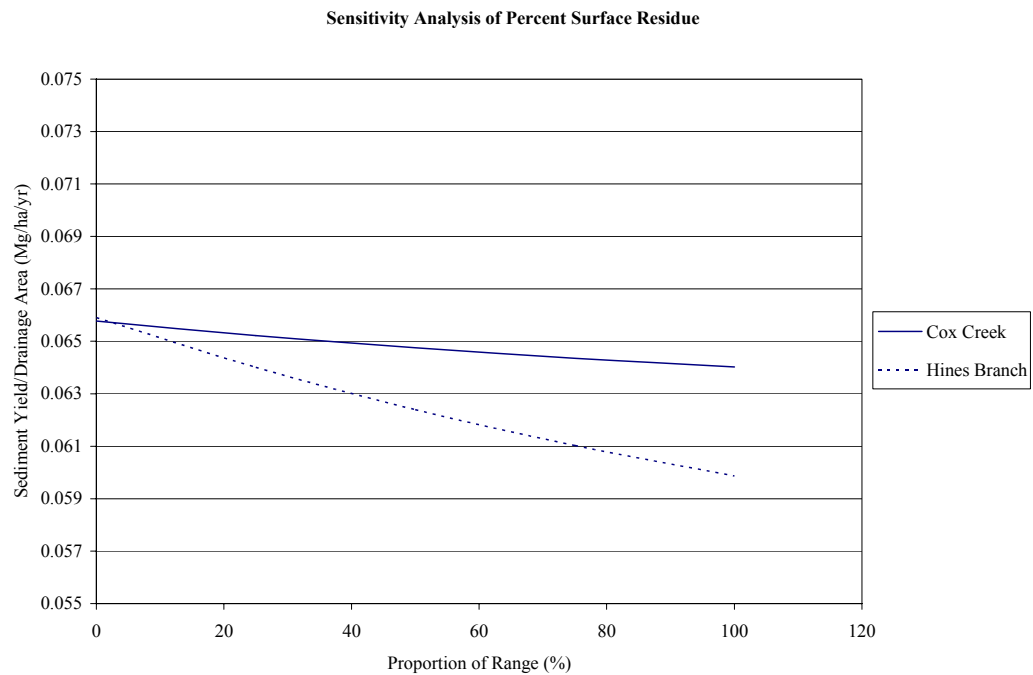


Figure 4-5. Sensitivity Analysis of Percent Surface Residue on Sediment Yield

Table 4-6. AnnAGNPS Sensitivity Curve Slopes for Cox Creek and Hines Branch

	Cox Creek	Hines Branch	Percent Difference (%)
Annual Root Mass	-4.00E-05	-0.0001	150
Annual Cover Ratio	-3.00E-05	-0.0001	233
Annual Rainfall Height	5.00E-06	2.00E-05	300
Percent Surface Residue	-2.00E-05	-6.00E-05	200

CONCEPTS

To better understand the flow characteristics of each model reach, Figures 4-6 and 4-7 show the model output of normal flow hydrographs for the synthetic climate data of Cox Creek and Hines Branch.

The CONCEPTS model was run for each subwatershed and for each parameter range in Table 4-3. The results for each subwatershed show that most parameters are not sensitive to final sediment yield as predicted by the CONCEPTS model (Tables 4-7 and 4-8). The cohesion and saturated bulk unit weight parameters do have some inherent sensitivity. The cohesion parameter is constant until the value gets closer to resembling a soil type such as sand. As the cohesion goes to zero, the value for sediment yield in tons grows substantially in both subwatersheds. The model sees a non-erodible bank with clays and silts and the flow hydraulics are not powerful enough to detach the material from the banks; however, when the cohesion represents a sandy bank material, the flow hydraulics become great enough to detach material and cause bank failures. Because the bank parameter values for this study are most certainly representative of clay or silt, a constant sensitivity can be assumed for cohesion in this study. The slopes of the

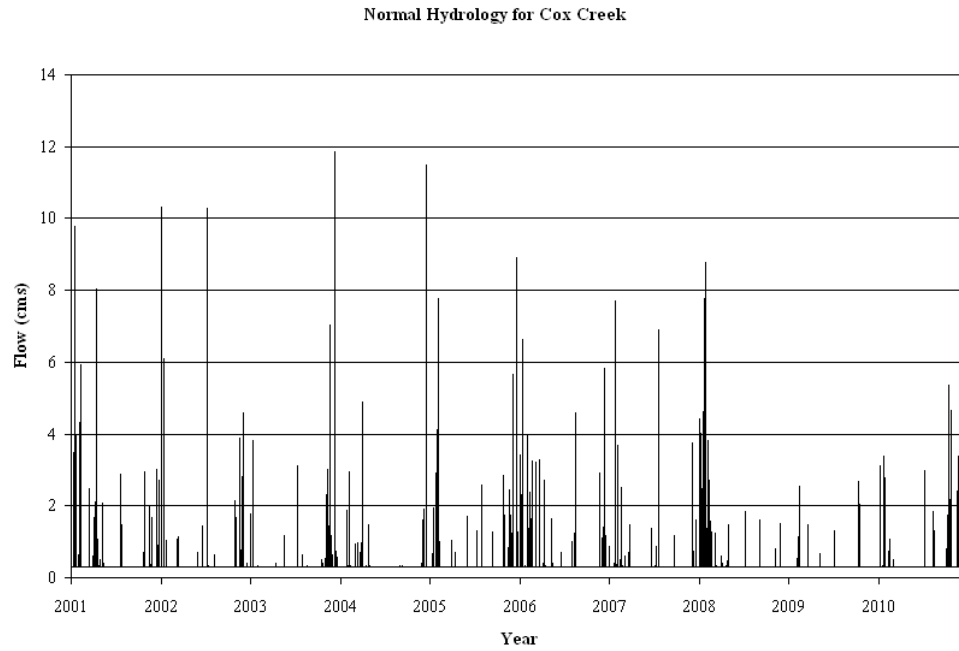


Figure 4-6. Normal Hydrology for Cox Creek

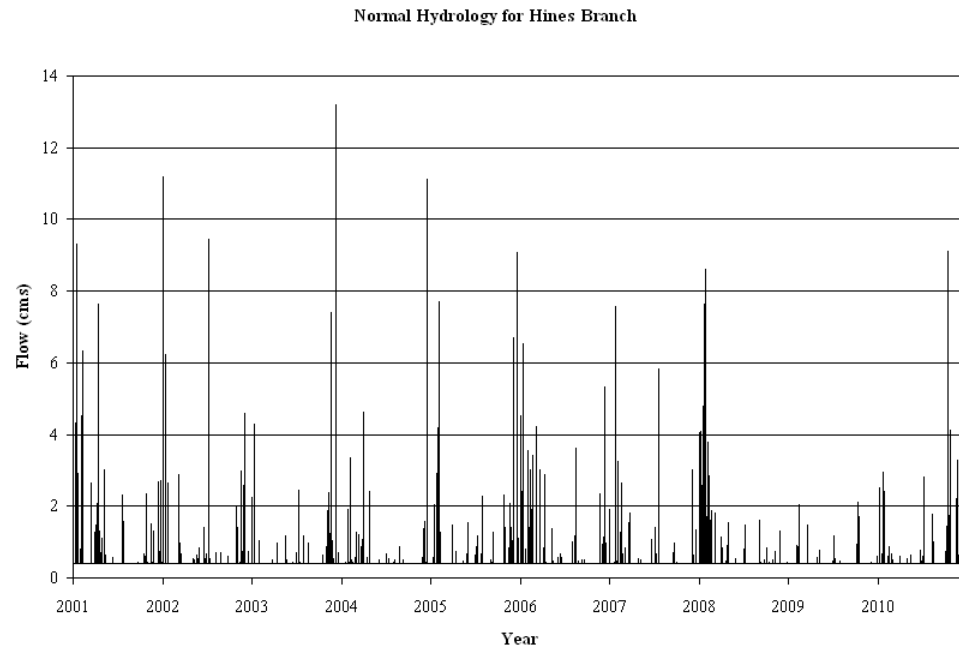


Figure 4-7. Normal Hydrology for Hines Branch

Table 4-7. CONCEPTS Sensitivity Analysis Results for Cox Creek. With Drainage Area of 441.44 ha over a Ten-year Simulation

		Proportion of Sensitivity Parameter Range				
Sensitivity Parameter		0%	25%	50%	75%	100%
Cohesion	Sediment Yield (tons)	2336	1927	1927	1927	1927
Effective Angle of Internal Friction		1927	1927	1927	1927	1927
Saturated Bulk Unit Weight		1709	1818	1927	2003	2067
Critical Shear Stress for Erosion		1927	1927	1927	1927	1927
Erodibility Coefficient		1927	1927	1927	1927	1927

Table 4-8. CONCEPTS Sensitivity Analysis Results for Hines Branch. With Drainage Area of 576.43 ha over a Ten-year Simulation

		Proportion of Sensitivity Parameter Range				
Sensitivity Parameter		0%	25%	50%	75%	100%
Cohesion	Sediment Yield (tons)	5705	5247	5247	5247	5247
Effective Angle of Internal Friction		5247	5247	5247	5247	5247
Saturated Bulk Unit Weight		5047	5146	5247	5344	5449
Critical Shear Stress for Erosion		5247	5247	5247	5247	5247
Erodibility Coefficient		5247	5247	5247	5247	5247

sensitivity curves for each parameter and subwatershed are fairly constant for each model input parameter with the exception of saturated bulk unit weight (Table 4-9). The sensitivity of the saturated bulk unit weight value is definitely related to the input value, and, therefore, care should be taken when choosing this input value. Due to the sensitivity of saturated bulk unit weight in this modeling exercise, a field test for saturated bulk unit weight would be useful for future studies.

Table 4-9. CONCEPTS Sensitivity Curve Slopes for Cox Creek and Hines Branch

	Cox Creek	Hines Branch	Percent Difference (%)
Cohesion (Pa))	0.000	0.000	0
Effective Angle of Internal Friction (°)	0.000	0.000	0
Saturated Bulk Unit Weight (N/m³)	3.604	4.008	11
Critical Shear Stress for Erosion (Pa)	0.000	0.000	0
Erodibility Coefficient (m/sPa)	0.000	0.000	0

CHAPTER 5

EFFECTS OF ALTERED RUNOFF AND UPLAND EROSION ON STREAMBED SEDIMENT IN URBANIZING SUBWATERSHEDS

Introduction

The second study utilized the AnnAGNPS-CONCEPTS modeling couple to explore the differences in upland runoff and erosion affect streambed sediment characteristics in urbanizing subwatersheds. Cox Creek and Hines Branch were selected to represent a minimally urbanized basin and an intensively urbanized basin, respectively.

Study 2 Question: What changes in streambed sediment characteristics do the AnnAGNPS-CONCEPTS modeling couple predict when the runoff and erosion in the watershed are altered to represent various levels of urbanization?

Methods

The subwatershed models created in the sensitivity analysis were used in a combination of nine model simulations, in which the runoff and erosion was increased by 20%, decreased by 20%, or kept normal. AnnAGNPS simulations were set up for nine situations of runoff and erosion: 1) runoff and erosion increased, 2) runoff increased and normal erosion, 3) runoff increased and erosion decreased, 4) normal runoff and erosion increased, 5) normal runoff and erosion, 6) normal runoff and erosion decreased, 7) runoff decreased and erosion increased, 8) runoff decreased and normal erosion, and 9) runoff and erosion decreased. The CONCEPTS model reach geometry and input parameters were held constant throughout this exercise for Cox Creek and Hines Branch, while the runoff and erosion were only altered in the watershed through alteration of the

runoff curve number and LS factor in the AnnAGNPS portion of the modeling couple. All nine situations were run through the AnnAGNPS model, which produced output to be converted to input for the CONCEPTS model. The AnnAGNPS output was then run through the CONCEPTS model for all nine simulations to represent how changes in the watershed land use affected the change in bed elevation, change in bed sediment size, and sediment yield. The output from CONCEPTS represents the modeling couples as a whole for Cox Creek and Hines Branch, and the results are discussed later in this chapter.

Assumed average values for runoff curve number were obtained from the TR-55 database, and these values were altered for the various model run simulations to represent varying levels of runoff (Table 5-1). Assumed normal LS factors were calculated from the DEM using the GIS data preparation portion of the AnnAGNPS model for each subwatershed, and these values were altered for the nine model run simulations to represent varying levels of erosion (Figures 5-1 and 5-2).

The output from these model run simulations was organized into three categories to understand how altering runoff and erosion affects bed sediment characteristics in an urban setting. The three categories of output included: bed deposition, bed sediment median diameter size (d_{50}), and sediment yield at the cross-section just upstream of the most downstream cross-section. This cross-section was chosen because the most downstream cross-section bed elevation is held constant throughout the ten-year simulation as a boundary condition.

Results and Discussion

This exercise uses AnnAGNPS to produce varying levels of runoff and sediment yield by altering the runoff curve number in TR-55 and the LS factor in RUSLE to

Table 5-1. Runoff Curve Numbers for each Land Use Type in Cox Creek and Hines Branch Subwatersheds

Land Use	Hydrologic Soil Group			
	A	B	C	D
Residential (High Density)	61	75	83	87
Residential (Medium Density)	54	70	80	85
Residential (Low Density)	45	65	77	82
Commercial	89	92	94	95
Industrial	81	88	91	93
Disturbed/Transitional	77	86	91	94
Agricultural	66	77	85	89
Open Land	30	48	65	73
Meadow	30	58	71	78
Woods (Thick Cover)	30	55	70	77
Woods (Thin Cover)	32	58	72	79
Impervious	98	98	98	98

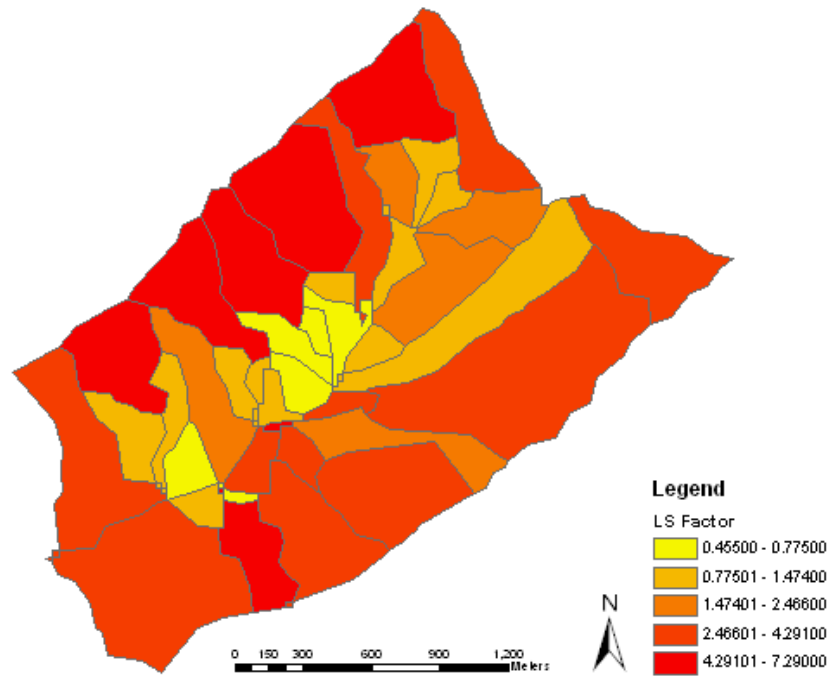


Figure 5-1. Assumed Normal LS Factor Map for Cox Creek Subwatershed

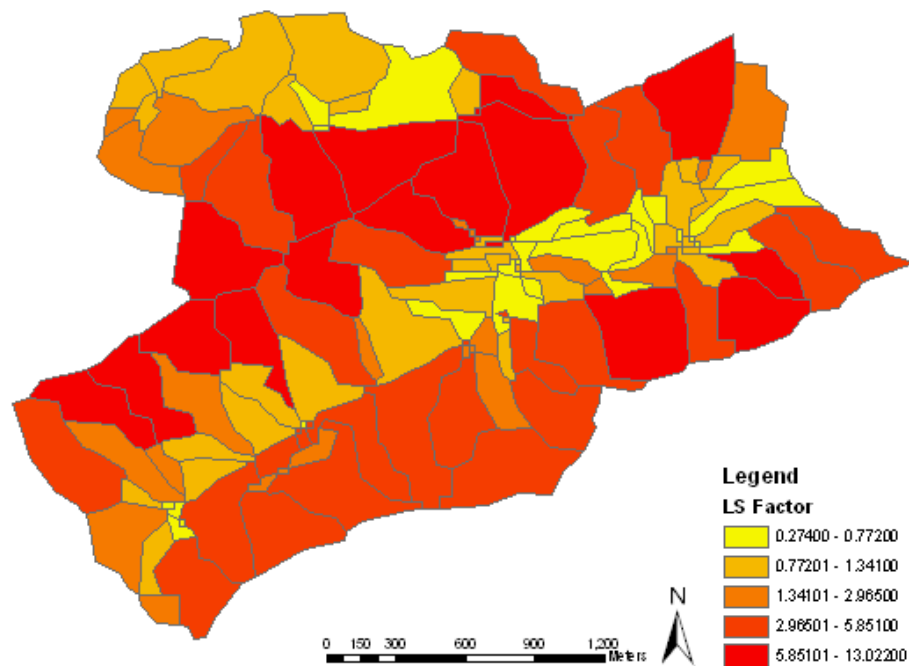


Figure 5-2. Assumed Normal LS Factor Map for Hines Branch Subwatershed

explore how the AnnAGNPS-CONCEPTS model predicts changes in the streambed sediment characteristics. Summary tables for each subwatershed show how the bed elevation, median particle size diameter, and sediment yield changes over the ten-year altered runoff and erosion model simulations (Tables 5-2 and 5-3).

The bed profile at the beginning and end of the ten-year simulation for Cox Creek and Hines Branch changes over each stream reach for varying levels of runoff and erosion (Figures 5-3 and 5-4). These plots show that over the ten-year simulation aggradation and degradation are at least partially related to the flow hydraulics and thalweg topography for each stream reach. Degradation occurs at high points in the thalweg topography, and aggradation occurs in low points of the thalweg topography and behind the high points of the thalweg topography.

From a steady-state perspective, the median sediment diameter size (d_{50}) decreases with decreasing watershed runoff, because lower flows typically produce lower velocities, which allows smaller particles to settle more readily (Haan et al. 1994). From an unsteady-state perspective, as a storm event occurs, more of the finer and intermediate sediment sizes were washed out leaving the larger material behind. In the increased runoff simulations, the storm events were larger and removed more of the finer and intermediate sediment sizes than in the decreased runoff simulations, which explains the larger d_{50} in the increased runoff simulations. The simulations for Hines Branch indicate this same general trend in d_{50} (Table 5-3). Particle size distributions for varying levels of hydrology at the beginning and end of the ten-year simulations were created to demonstrate that the model predicts a loss of the finest and coarsest particle sizes and an

Table 5-2. Hydroerosion Simulations Summary Table for Cox Creek

Hydrology	Erosion	Change in Bed (m)	Original d50 (mm)	Final d50 (mm)	Sediment Yield (tons)
+	+	0.2570	5.9650	4.319	3216
+	0	0.2620	5.9650	4.603	3053
+	-	0.2680	5.9650	4.692	2932
0	+	0.2760	5.9650	4.012	2087
0	0	0.2790	5.9650	4.020	2010
0	-	0.2790	5.9650	3.958	1937
-	+	0.3120	5.9650	3.122	1519
-	0	0.3110	5.9650	3.122	1464
-	-	0.3100	5.9650	3.106	1421

Table 5-3. Hydroerosion Simulations Summary Table for Hines Branch

Hydrology	Erosion	Change in Bed (m)	Original d50 (mm)	Final d50 (mm)	Sediment Yield (tons)
+	+	0.163	5.863	2.252	6448
+	0	0.163	5.863	2.252	6299
+	-	0.162	5.863	2.252	6148
0	+	0.123	5.863	1.789	5284
0	0	0.123	5.863	1.790	5182
0	-	0.122	5.863	1.796	5077
-	+	0.094	5.863	1.477	4792
-	0	0.093	5.863	1.473	4697
-	-	0.092	5.863	1.475	4590

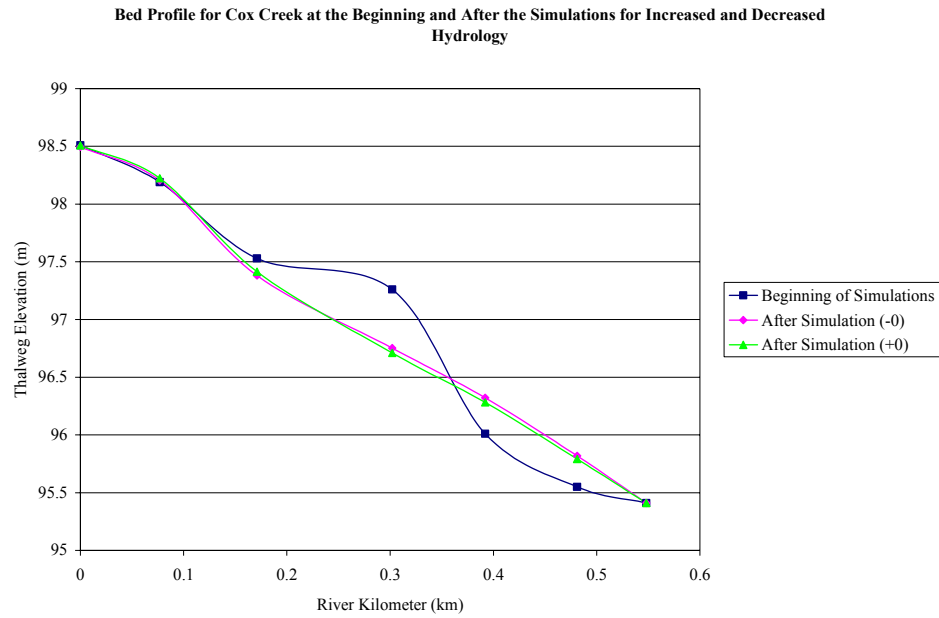


Figure 5-3. Bed Profile for Cox Creek at the Beginning and After Simulations for Increased and Decreased Hydrology

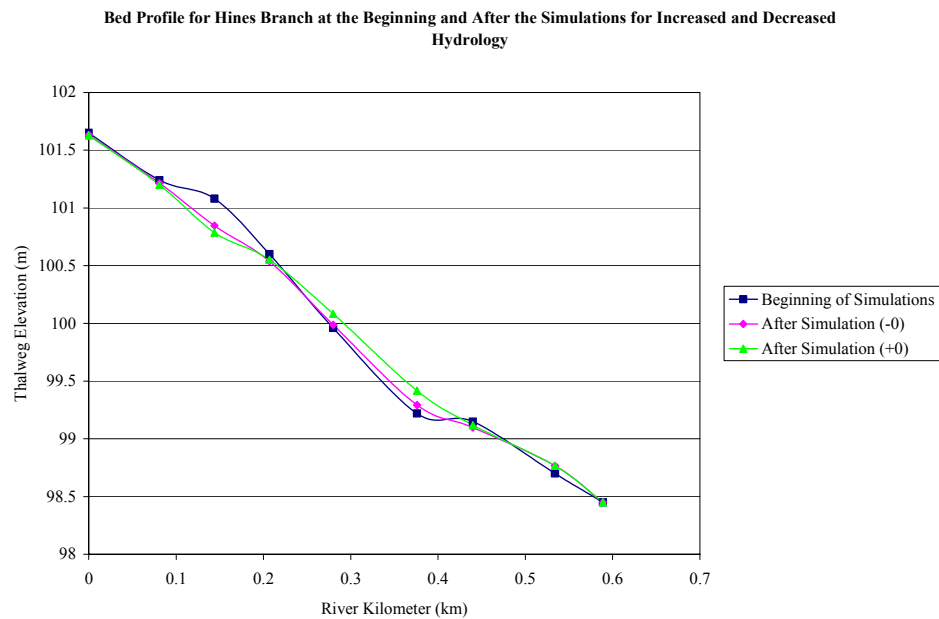


Figure 5-4. Bed Profile for Hines Creek at the Beginning and After Simulations for Increased and Decreased Hydrology

increase in the medium range particle sizes like sands and fine gravels (Figures 5-5 and 5-6). These figures support the decrease in d_{50} for Cox Creek and Hines Branch over the ten-year simulations. Also, the percentages of silt, sand, and gravel discharged through Cox Creek and Hines Branch, respectively, vary over the ten-year run simulation on an annual basis with sand transported at much larger masses than silt and gravel for both stream reaches (Figures 5-7 and 5-8).

For Cox Creek, deposition on the bed decreases as runoff increases, which logically makes sense from a physical perspective (Table 5-2). Turbulence and velocities in lower flow regimes tends to be lower, which generally allows a particular size of sediment to settle more readily than in higher, more turbulent flow events. The model also predicts fairly similar values for bed deposition independent of the amount of upland erosion in the watershed for Cox Creek and Hines Branch, which indicates that deposition is more a function of runoff hydrology than upland erosion. The bed deposition in Hines Branch actually increases as runoff increases, which is probably more a function of the particle size distribution in relation to the runoff hydrology. In larger flow events, larger materials can be transported on the bed during a particular storm event, which are not transported with a smaller flow regime. If the larger particles can not be moved, then the larger particles do not possess the ability to deposit downstream. This phenomenon is explained in Figures 5-9 and 5-10. These figures show how the bed elevation increases as gravel particles are discharged over a particular storm event. This particular storm event is actually the first storm event in the ten-year simulation. The bed deposition is actually greater at the beginning of this storm event for the low runoff simulation, because at baseflow in the low and high runoff simulations, a storm event

Original and Final Particle Size Distributions with Assumed Normal Hydrology over the Ten Year Simulation

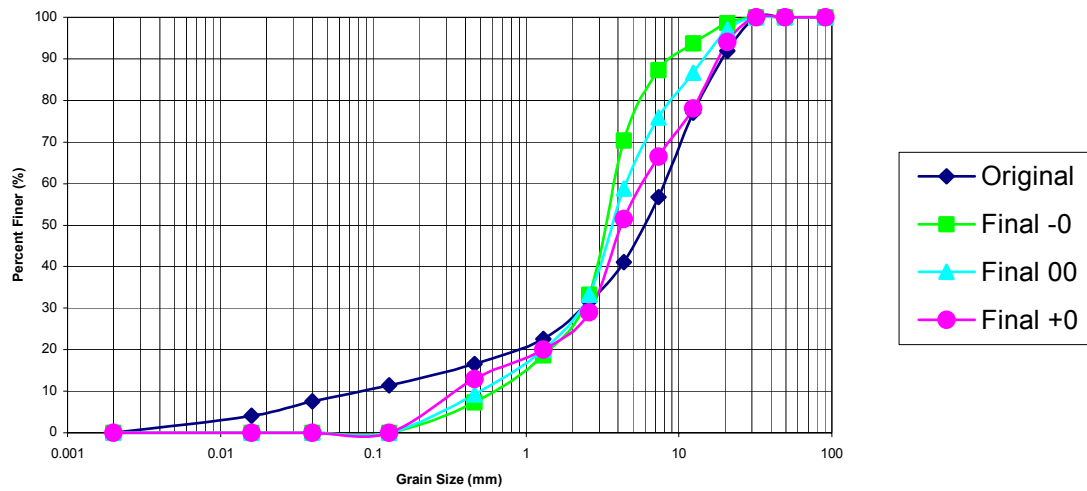


Figure 5-5. Original and Final Particle Size Distributions for Varying Levels of Hydrology for Cox Creek

Original and Final Particle Size Distributions with Assumed Normal Hydrology over the Ten Year Simulation

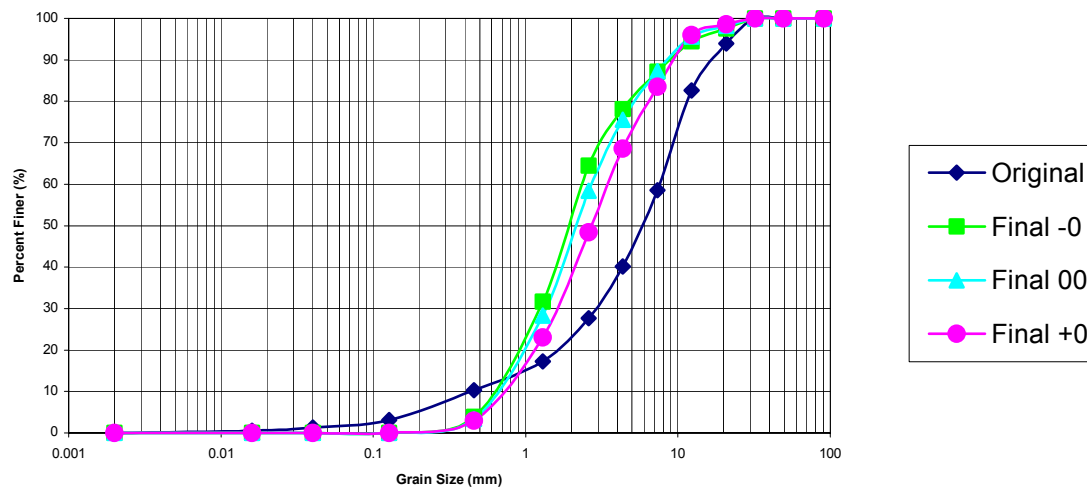


Figure 5-6. Original and Final Particle Size Distributions for Varying Levels of Hydrology for Hines Branch

Cox Creek - Cumulative Annual Percentage of Silt, Sand, and Gravel for Normal Runoff and Erosion

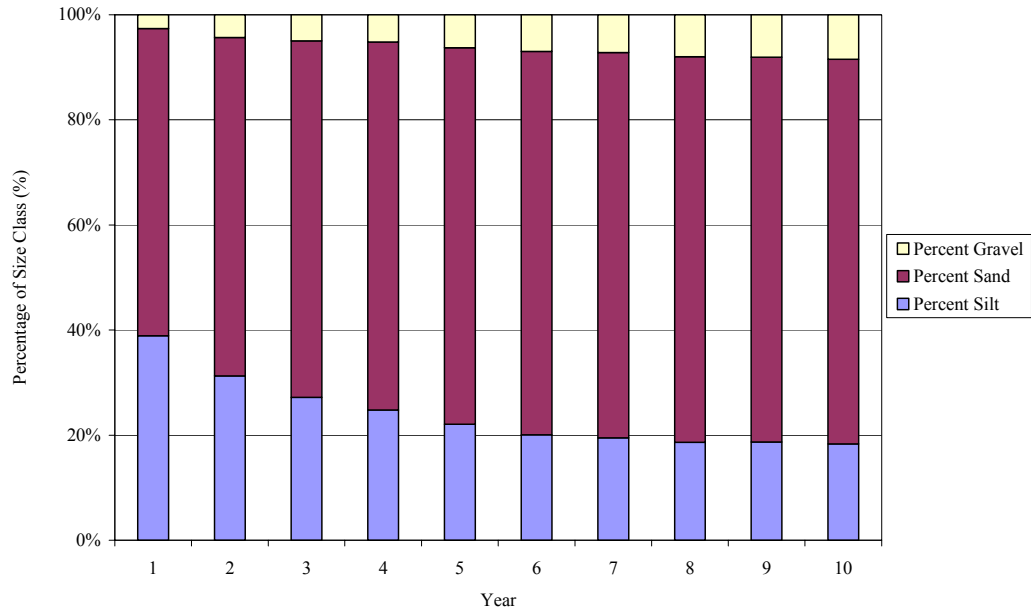


Figure 5-7. Cumulative Percentage of Silt, Sand, and Gravel Transported through Cox Creek

Cox Creek - Cumulative Annual Percentage of Silt, Sand, and Gravel for Normal Runoff and Erosion

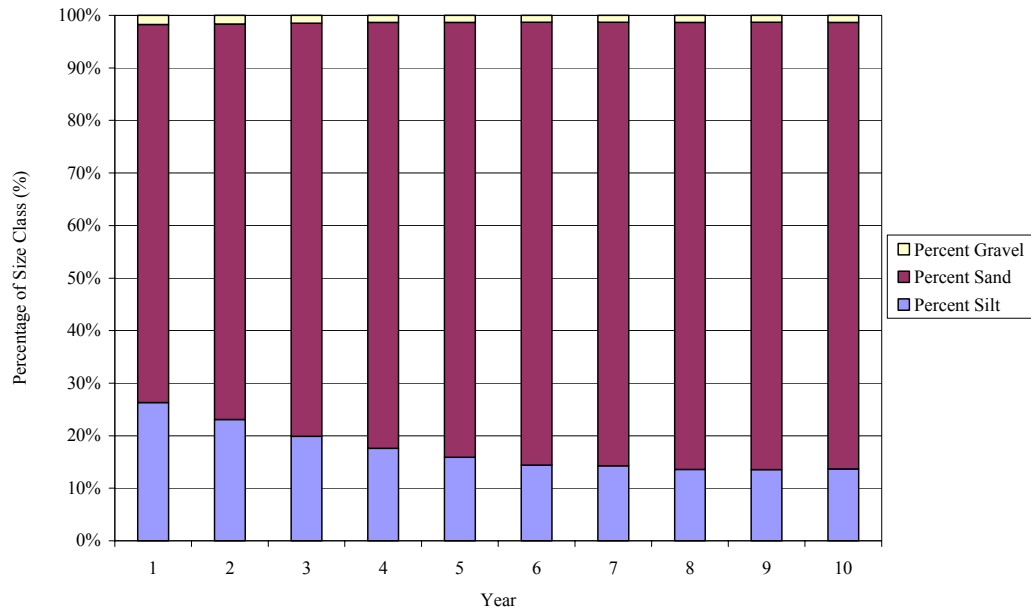


Figure 5-8. Cumulative Percentage of Silt, Sand, and Gravel Transported through Hines Branch

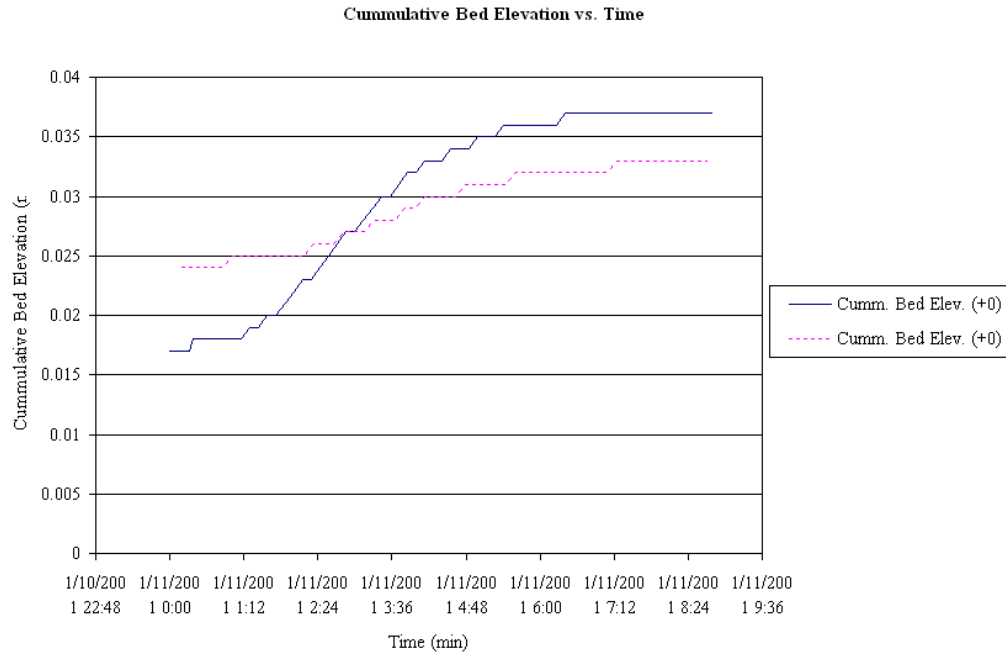


Figure 5-9. Cumulative Bed Elevation versus Time for Hines Branch at Two Levels of Hydrology for a Single Storm Event

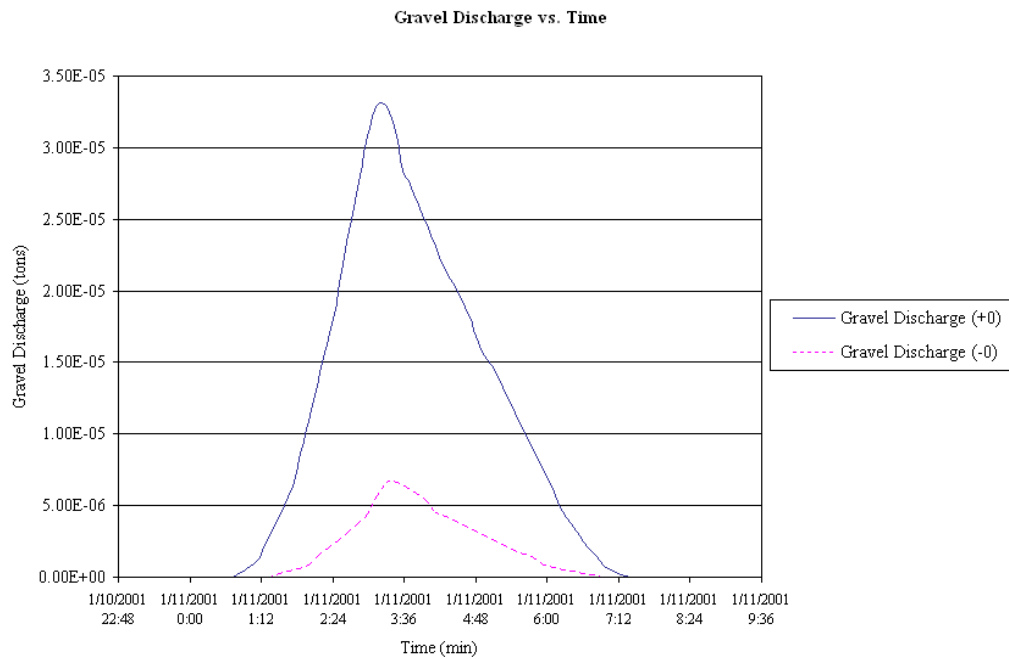


Figure 5-10. Gravel Discharge versus Time for Hines Branch at Two Levels of Hydrology for a Single Storm Event

has not occurred to produce gravel entrainment and transportation from the bed. Once this storm event took place, gravel transport occurred at higher masses for the high runoff simulation, and bed deposition for the high runoff simulation remains greater throughout the remainder of the ten-year simulation for each low and high runoff scenario.

Sediment yield increases as erosion or runoff increases for Cox Creek and Hines Branch, and sediment yield occurs mostly at the highest runoff and upland erosion in the watershed (Tables 5-2 and 5-3). Sediment yield changes as the runoff and erosion varies through the nine simulations (Tables 5-4 and 5-5). This phenomenon is logical, because higher flows have a larger sediment transport capacity, which carries more sediment into, through and out of the system (Haan et al. 1994). These results support that hydrology is more important than sediment delivery when considering that sediment yield, d_{50} of the bed material, and bed deposition does not change significantly as erosion is increased or decreased. However, all of these output parameters change more drastically as runoff is increased and decreased.

Table 5-4. Percent Difference between Sediment Yield as Runoff and Erosion Varies and Sediment Yield with Normal Runoff and Erosion for Cox Creek

Erosion Runoff		Low 0 High		
		-	0	+
Low	-	-29%	-27%	-24%
	0	-4%	0%	4%
High	+	46%	52%	60%

Table 5-5. Percent Difference between Sediment Yield as Runoff and Erosion Varies and Sediment Yield with Normal Runoff and Erosion for Hines Branch

Erosion Runoff		Low			High		
		-	0	+	-	0	+
Low	-	-11%	-9%	-8%	High	-	-
	0	-2%	0%	2%		0	0
High	+	19%	22%	24%			

CHAPTER 6

MULTIVARIATE CLUSTER ANALYSIS

Introduction

In the third study, a multivariate cluster analysis was used to correlate several key watershed characteristics including: 1) suspended sediment size of yield generated from an AnnAGNPS simulation of Beaver Creek watershed, 2) bed sediment size from field samples collected for 15 subwatersheds of Beaver Creek (Appendix C), 3) stream power of the 15 selected subwatersheds, 4) total subwatershed area, and 5) percent urbanization of the 15 selected subwatersheds.

Study 3 Question: Are the streambed sediment characteristics related to suspended sediment yield, percent subwatershed urbanization, and other key subwatershed parameters?

Methods

The SPSS statistical modeling program using a cluster analysis correlated the five key variables normalized by their variance (SPSS v.10 2000). The five parameters run through the SPSS statistical modeling program were: the bed particle size distribution samples collected in the field, subwatershed stream power, percent subwatershed urbanization, total subwatershed area, and AnnAGNPS suspended sediment size output. This analysis is important in showing the correlation between these watershed characteristics. The cluster analysis is displayed with dendrograms using the Ward Method correlative cluster analysis in Chapter 4 (Ward 1963).

The locations of these sample sites are located across the entire Beaver Creek watershed (Figure 6-1). The values for each parameter in relation to individual

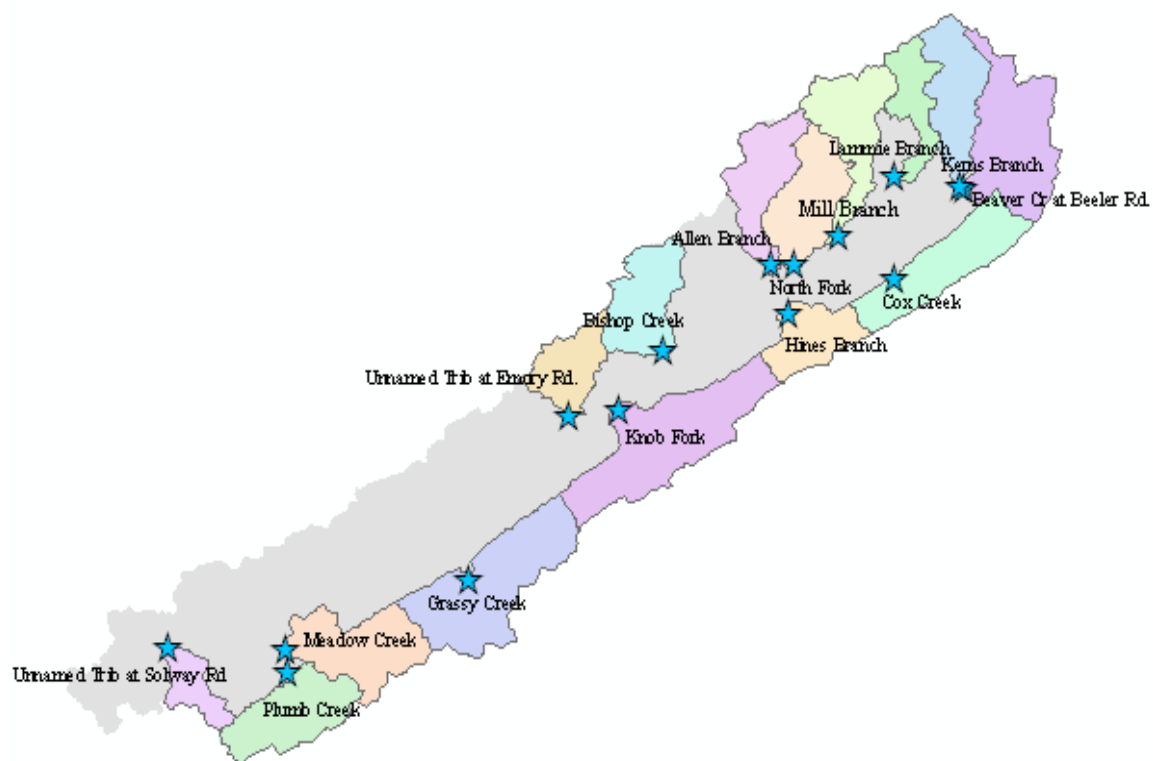


Figure 6-1. Bed Sediment Sample Sites and Contributing Drainage Areas

subwatersheds were determined using several techniques (Table 6-1). The subwatershed area, percent urbanization, and stream power were all calculated using land use and elevation layers provided by the Knoxville Geographic Information Systems office (KGIS). AnnAGNPS data was extracted from a simulation of the entire Beaver Creek watershed using the assumed average values used in the previous studies. For 15 subwatersheds of the Beaver Creek watershed, bed sediment size distribution samples were taken and analyzed in the lab using the guidelines set out by ASTM (ASTM D421, D422 1998). The silt to sand ratio for the particle size distributions was based on a range of sands from 0.062 mm to 2 mm and a range of silts from 0.004 mm to 0.062 mm (Julien 1998).

Results and Discussion

The results of this study were very interesting when considering the first and second studies of this project. The correlations between all of the parameters in the analysis were represented using dendrograms (Figure 6-2). The dendrogram is actually a measure of the dissimilarity of the individual parameters with the range being from 0 to 25. In Figure 6-2, the AnnAGNPS output, silt to sand ratio from the particle size distribution, percent urbanization, and stream power correlated well with the subwatershed area not correlating with the rest of the cluster. Figure 6-3 shows a new analysis excluding subwatershed area from the cluster to further observe which parameters in the first cluster correlate together.

With the omission of subwatershed area, the silt to sand ratio from the AnnAGNPS output, the silt to sand ratio from the particle size distributions, and percent urbanization still correlated well; however, stream power did not correlate well with the

Table 6-1. Input Data for Multivariate Cluster Analysis (SPSS v. 10 2000)

	Watershed Characteristics			AnnAGNPS Output	Field Data
Sediment Sample Site	Total Drainage Area (ha)	% Urban	Stream Power (Watts/m ²)	Silt/Sand Ratio	Silt/Sand Ratio from PSDs
Allen Branch at Clear Cr Ct.	1784.3	11.3	106.75	0.99819	0.12277
Beaver Creek at Beeler Rd.	3068.8	8.3	171.30	2.18097	0.11266
Bishop Branch at Bishop Rd.	1720.4	22.9	113.00	1.02538	0.11057
Cox Creek at Brown Gap Pike	2346.3	14.4	188.41	2.00015	0.09022
Grassy Creek at Ball Rd.	3513.1	13.4	31.23	1.42870	0.10858
Hines Branch at Fraker Rd.	1371.7	52.9	243.42	1.63355	0.15378
Kerns Branch at Beeler Rd.	1912.0	2.1	65.17	1.08712	0.22687
Knob Fork at Beaver Cr Dr.	3775.0	29.6	128.00	2.00138	0.05109
Lammie Branch at Bell Rd.	1166.2	0.0	47.83	1.07566	0.14861
Meadow Creek at Cross Ln.	2308.7	11.1	147.83	1.59435	0.12278
Mill branch at Maynardville Pk.	2033.5	3.9	53.44	1.04817	0.04030
North Fork at Emory Rd.	2064.3	33.7	69.78	0.98448	0.05032
Plumb Creek at Hardin Valley Rd.	2065.1	32.7	100.54	1.65803	0.17758
Unnamed Branch at Emory Rd.	1319.5	27.4	102.43	0.94923	1.55995
Unnamed Branch at Solway Rd.	795.1	15.5	32.76	1.00109	0.06884

Dendrogram using Ward Method

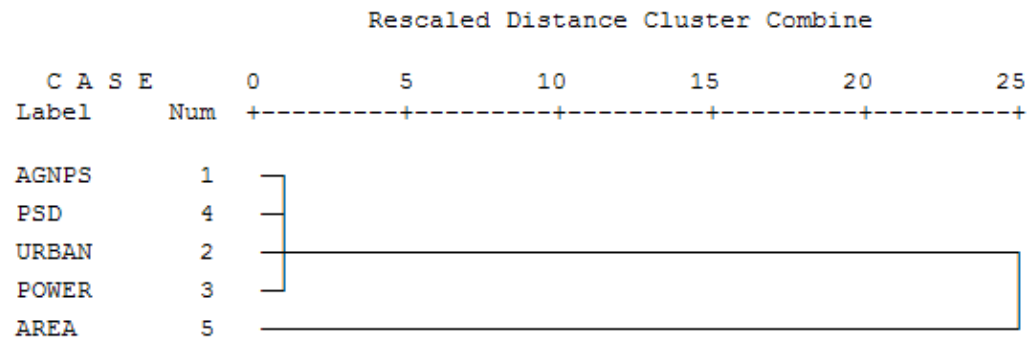


Figure 6-2. Dendrogram of All Parameters

Dendrogram using Ward Method

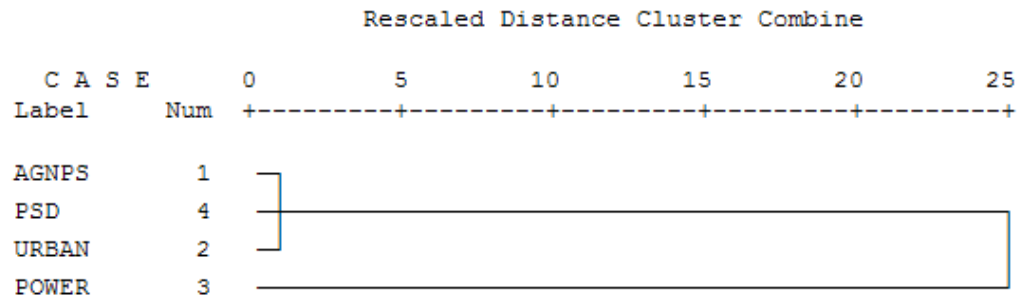


Figure 6-3. Dendrogram of All the Parameters Excluding Subwatershed Area

cluster when area is excluded (Figure 6-3). In keeping with the process of analysis, stream power was then removed from the analysis, and a cluster analysis was performed on the AnnAGNPS output, particle size distribution data, and percent urbanization to observe how these correlated with each other (Figure 6-4).

Figure 6-4 illustrates that the silt to sand ratios of the AnnAGNPS output and particle size distributions correlate to each other better than any other parameters. Therefore, AnnAGNPS was adequate in predicting sediment yield on a basis of relating silt to sand. Also from this analysis, percent urbanization is related to the particle size distribution on the bed as well as the particle size distribution of the suspended sediment estimated by AnnAGNPS.

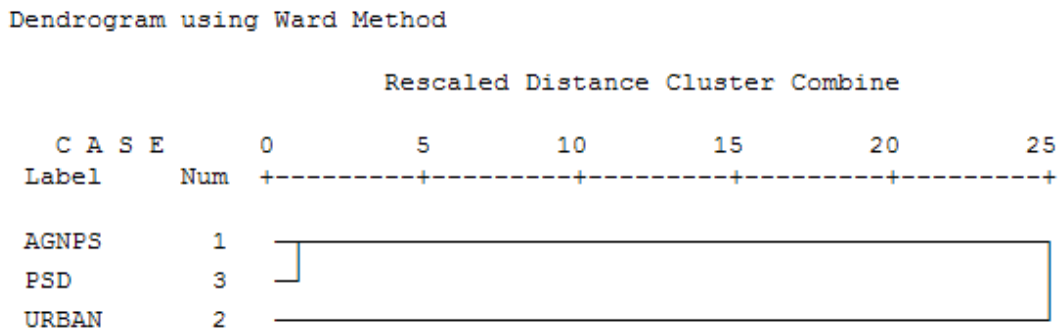


Figure 6-4. Dendrogram of AnnAGNPS Output, Particle Size Distribution Data, and Percent Urbanization

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

This research project was a three-study approach to test, explore, and utilize the AnnAGNPS-CONCEPTS modeling couple in urbanizing subwatersheds. The first study was to learn the model limitations by conducting a sensitivity analysis of urban-related input parameters. The second study was conducted to explore the limitations of the modeling couple by altering runoff and upland erosion to generate sediment yields. The second study also produced results in order to better understand the impact of urbanization on streambed sediment characteristics. The third study was to examine if percent subwatershed urbanization or other key watershed parameters correlate with suspended and streambed sediment characteristics.

In the first study, the sensitivity analysis produced interesting results. On an individual watershed basis, the sensitivity of the AnnAGNPS model to tested parameters was very low when considering the range of sediment yield output varied very little over the range of values for each tested parameter. However, when comparing the sensitivities of both watersheds, the difference in sensitivity curves slopes shows that the sensitivity of the urbanized Hines Branch is much more sensitive than the non-urbanized Cox Creek. This difference is a result of the land use mosaic, which exists in these watersheds. The Hines Branch subwatershed has a more diverse composition of land uses with more areas of urbanization than the Cox Creek subwatershed. Because the parameters were only altered for urban land uses, the sensitivity of Hines Branch is naturally much higher.

In the second study, the runoff and upland erosion of the watershed was systematically changed to produce various simulations to observe the effects of these

changes on bed elevation, median particle size, and sediment yield. The most interesting results from the model simulations demonstrated that hydrology plays a larger role than upland erosion in altering the subwatershed sediment yield, amount of bed deposition, and composition of bed sediment in each stream channel. The purpose of the variable runoff and erosion was to emulate a variety of levels of watershed development. Increasing runoff while decreasing erosion would represent a more urbanized watershed than present condition. The results of running this combination of model simulations for Cox Creek and Hines Branch seemed to be consistent with the conceptual model of how sediment is delivered to an outlet. If runoff increases, the model output suggests that yield increases, which is a reasonable result considering an increase in runoff produces an increase in transport capacity of sediment. Also, as erosion increases, the model output suggests that sediment yield increases due to the larger volume of sediment moving from the watershed into the channel system. Where the modeling couple produces conflicting results is when the bed deposition over the ten-year simulation is considered for the urban and non-urban watershed. The bed composition of Hines Branch consists of a combination fines, sands, and gravels. In the high flow events, gravels can be transported and settle out within the model reach in high flow events. This phenomenon actually produces more bed deposition with the higher flow regime, because less gravel is transported in the lower flow regime simulations. The model simulations with the smaller flow regime are not capable of transporting as much of the gravels in the Hines Branch model reach such that the transported load can settle out downstream of detachment like in the higher flow regime simulations. In both model reaches, the change in bed elevation from the beginning of the ten-year simulation to the end is

positive for the most downstream cross-section in each stream reach, which suggests an aggrading stream. However, when looking at all the cross-sections at the end of the ten-year simulation, aggradation and degradation occurred over each model reach as a function of thalweg topography and flow hydraulics. This result illustrated a smoothing of the bed topography, which was indicative of an urban stream as stated by Pizzuto et al. (2000). In an effort to determine if fining of bed sediment in these streams occurs, results showed that the d_{50} in both model reaches decreases substantially from the beginning of the simulation to the end for all combinations of simulations. However, in the Hines Branch model reach, the d_{50} is decreased much more drastically than in the Cox Creek Model reach. The simulation representing increased runoff with decreased sediment erosion represents a watershed development equivalent to a watershed that has become urbanized due to more impervious areas increasing runoff while decreasing erosion. The model output shows that for the situation, with increased runoff and decreased erosion, the d_{50} is larger than any other simulation combination. However, what if urbanization is not causing fining in the bed, which is commonly observed in urban streams and is suggested in the literature (Hession 2001; Pizzuto et al. 2000)? The most destructive time period for a watershed is at the point of disturbance during construction (Graf 1975). The soil is exposed directly to rain drop impact with little protection from vegetation or roughness. BMPs were developed to prevent sediment from being transported downstream, but in most cases, only the larger material is trapped from being transported. Detention and retention ponds are implemented to lower the peak runoff rate, which can provide a better situation for deposition of finer materials. Therefore, during construction and at the time of disturbance, the runoff can be decreased while erosion increases

producing a finer bed if BMPs are properly implemented, which is supported in the model output. When runoff decreases or remains normal and erosion increases, the d_{50} in both the Cox Creek and Hines Branch model reaches is considerably lower than the d_{50} for each respective model reach in the higher flow regime simulations. However, the understanding of how urbanization changes the streambed sediment characteristics needs further analysis with a two-dimensional sediment transport channel model to better understand and explain the effects of deposition laterally across a streambed, because in a one-dimensional analysis, all of the fine materials are washed completely out of the reach, which is unreasonable considering that fines do exist within natural streams.

The third study involved a multivariate cluster analysis of several key watershed characteristics, AnnAGNPS output, and particle size distributions collected in the field. The results show that the silt to sand ratio found in the suspended sediment over a ten-year AnnAGNPS simulation is related to the silt to sand ratio found on the bed at each site. Percent urbanization correlated fairly well with the AnnAGNPS output and bed particle size distribution data. The results also show that subwatershed area and stream power is not relatively similar to any of the other parameters tested. The stream power values used were calculated over the entire subwatershed and theoretically should not correlate well with data taken at one particular site.

Overall, the AnnAGNPS model is fairly insensitive in a non-urban and urban subwatershed when analyzed on an individual basis; however, when comparing the sensitivity of the subwatershed types, the sensitivity of AnnAGNPS in an urban subwatershed proved to be much greater in comparison with the output of the non-urban subwatershed. A certain level of confidence in using AnnAGNPS in an urban watershed

does exist based on the low sensitivity of the individual subwatershed. Further research on a multitude of gaged watersheds at multiple levels of urbanization should be conducted to develop relationships for RUSLE parameters in urban watersheds. Otherwise the data can always be tweaked to produce a calibrated model. CONCEPTS can possibly be used on a broader scale such as TMDL development; however, using a one-dimensional model does not provide an analysis at the ecologically meaningful scale that the problem of fining on the bed could be a lateral deposition issue, which can not be described with CONCEPTS. The second study showed fairly strong evidence that hydrology not upland erosion played a major role in the amount of sediment delivered to a reach outlet and the characteristics of the bed sediment. Finally, suspended sediment output from AnnAGNPS and percent urbanization seemed to be related to the bed sediment size characteristics more so than any of the other watershed characteristics considered in several urbanized streams. This supports the conclusion that hydrology plays a major role in the characteristics of the streambed sediment. Percent urbanization and the suspended sediment from the AnnAGNPS output is related to how hydrology changes in an urbanizing system, and these parameters were more related to the streambed sediment characteristics than the other parameters in the analysis.

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APPENDICES

APPENDIX A

AnnAGNPS Input

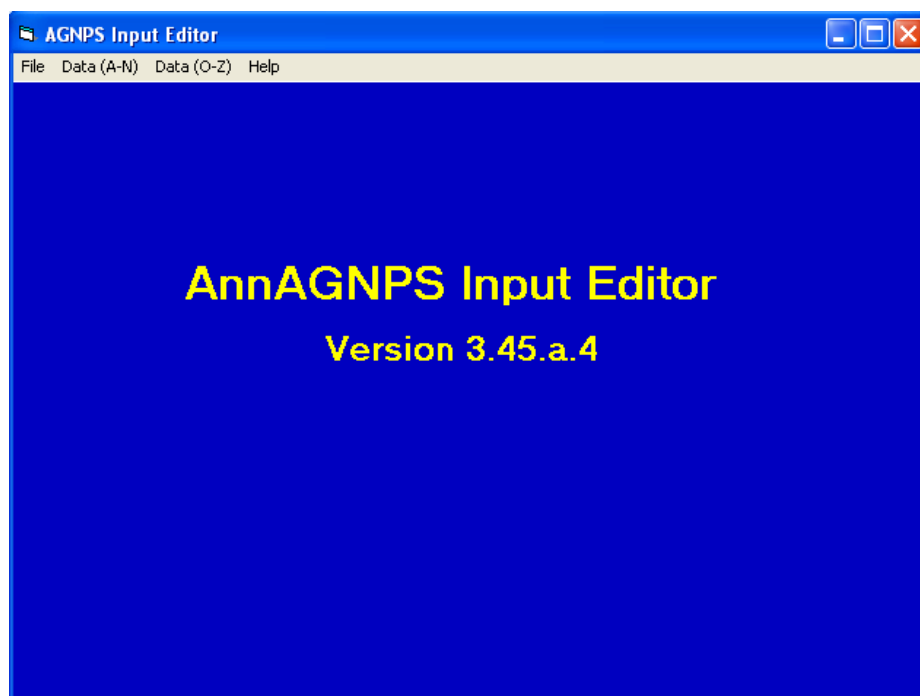


Figure A-1. Input Editor Welcome Screen

AnnAGNPS Identifier & Watershed Data

AnnAGNPS Identifier:

AnnAGNPS: Version 3.45 (Continuous Simulation)

Input Units Code: 1

Output Units Code: 1

CCHE1D Output Units Code: 1

Screen Output Code:

Watershed Data:

Watershed Name: Cox Creek

Watershed Description: Cox Creek - 600m DS of Tazewell Pike

Watershed Location: (Optional) Knoxville, TN

Latitude: 36.02 Longitude: 84

Forget Accept

Figure A-2. Project Setup and Identifier Screen

CELL DATA

Watershed: Cox Creek No. Cells: 41

The following three field sets repeat for the number of cells (specified above). For cells with a Cell-Field identifier of WATER, only the following field set is used.

Cell ID: 22

Soil ID: SwC

Management Field ID: 2

Reach ID: 2

Reach Location code: 1

Cell Area: 23.31

Cell time of conc:

Cell average elevation: 352.0

Climate File Number:

Sheet flow Manning's 'n': 0.150

Sheet flow slope: 0.09400

Sheet flow length: 50.00

Shallow Conc. flow slope: 0.21800

Shallow Conc. flow length: 50.00

Conc. flow slope: 0.08300

Conc. flow length: 981.0

Concentrated flow hydraulic depth:

Concentrated flow Manning's "n": 0.020

The following field set is needed for all cells except those designated with a Cell-Field identifier of WATER.

Cell average land slope: 0.11287

Cell aspect: 158.0

RUSLE/USLE 'ls' factor: 2.34200

Current Cell: 1

Previous Next

Insert Replicate Delete

Delete ALL Forget Accept

Figure A-3. Cell Data Screen

Daily Climate Data

Watershed: No. Daily Climate Recs.

Climate Station Name:

Station Latitude:

Station Longitude:

Station Elevation:

Temperature Change:

Precipitation Nitrogen:

Climate Input Units Code:

Climate Begin Date: Month Day Year

Elevation Difference (1):

Elevation Rain Factor (1):

Elevation Difference (2):

Elevation Rain Factor (2):

2 Year 24 Hour Precipitation:

Annual Calibration Factor:

Climate End Date: Month Day Year

Minimum Interception Evaporation:

Maximum Interception Evaporation:

The following field set is repeated for each day of climate record.

Daily Climate Date: Month Day Year

Daily Maximum Temperature:

Daily Minimum Temperature:

Daily Precipitation:

Daily Dew Point Temperature:

Daily Sky Cover:

Daily Wind Speed:

Daily Wind Direction:

Current Record:

Previous

Insert

Delete ALL

Figure A-4. Daily Climate Data Screen

MANAGEMENT FIELD DATA

Watershed: No. Fields:

The following two field sets repeat for the number of farm fields (specified above).

Management Field ID:

Field Landuse Type:

Management Schedule ID:

Relative Rotation Year:

Percent Rock Cover:

RUSLE sub P-factor:

Inter-rill Erosion code:

Random Roughness:

Terrace Horizontal Distance:

Terrace Grade:

Tile Drain ID:

Current Field:

Previous

Insert

Delete ALL

Figure A-5. Management Field Data Screen

NON-CROP DATA

Watershed: No. Non-Crop Records:

The following two field sets repeat for the number of non-crop landuses (specified above).

Non-Crop ID:

Non-Crop Description:

Annual Root Mass:

Annual Cover Ratio:

Annual Rain Fall Height:

Surface Residue Cover:

List of Current Non-crop Identifiers:

1
2
3
4
5
6
7
8
9
10
11
12
13

RUSLE

Figure A-6. Non-Crop Data Screen. (Sensitivity Parameter Inputs for Different Urban Land Uses)

OUTPUT OPTIONS

Watershed:

Global Output Options:

FILES:	T	F
All Comma-separated Values Files	☐	☐
All Data Preparation Verification Files	☐	☐
All Input Data Verification Files	☐	☐
All Simulation Verification Files	☐	☐
All Table Files	☐	☐
Program Log Output	☐	☐
Screen Output	☐	☐
Warning File	☐	☐
Versions 1 and 2 Output	☐	☐

SOURCES:

	T	F
All Cells	☐	☐
All Feedlots	☐	☐
All Field Ponds	☐	☐
All Gullies	☐	☐
All Point Sources	☐	☐
All Reaches	☐	☐

Average Annual Output:

	T	F
Nutrients	☐	☐
Pesticides	☐	☐
Sediment	☐	☐
Water	☐	☐

Continue >>>

Figure A-7. Output Options Screen

REACH DATA

Watershed: Cox Creek No. Reaches: 18

The following three field sets repeat for the number of reaches (specified above).

Reach ID: 1

Receiving Reach ID: OutLet

Reach Vegetation code:

Reach Elevation: 329.4

Reach Slope: 0.00270

Reach Manning's n:

Reach Infiltration Rate:

Reach Channel Geometry ID:

Reach Length: 0.0

Reach Top Width:

Reach Flow Depth:

Valley Width:

Valley Manning's n:

Start Diversion:

Stop Diversion:

Scour code:

Clay	Silt	Sand	Sm. Ag.	Lg. Ag.

Valley Scour code:

Clay	Silt	Sand	Sm. Ag.	Lg. Ag.

Reach Impoundment ID:

Current Reach: 1

Previous Next

Insert Replicate Delete

Delete ALL Forget Accept

Figure A-8. Reach Data Screen

RUNOFF CURVE NUMBER

Watershed: Cox Creek No. Curve Numbers: 12

The following field set repeats for the number of runoff curve numbers (specified above).

Curve Number ID: 1

Residue Adjustment code:

Curve Number "A": 61

Curve Number "B": 75

Curve Number "C": 83

Curve Number "D": 87

Current CN: 1

Previous Next

Insert Replicate Delete

Delete ALL Forget Accept

Figure A-9. Runoff Curve Number Screen

SIMULATION PERIOD DATA

Watershed: Cox Creek No. of Initial Pesticides: 0

Simulation Period Data

Simulation Begin Date:	Month	Day	Year	Use Winter Bouts List: Annual K-factor code: Variable K-factor code: Number Initialization Years: Initialization Method Code: Default Reach Geometry:
	1	1	1	
Simulation End Date:	Month	Day	Year	
	12	31	10	
Rainfall Distribution code:				
Rainfall Factor:				
10 Year EI:				
EI Number:	Distributions			
Irrigation Climate code:				
Soil Moisture Steps:				

< Prev Next >

Forget Accept

Figure A-10. Simulation Period Data Screen

SOIL DATA

Watershed: Cox Creek Total Soils: 65

Soil Data:

The following 2 field sets repeat for the number of soils (specified above).

Soil ID:	AmC	<i>The following 3 field sets repeat for each soil layer in the soil profile.</i> Number of Soil Layers for this Soil: Current Soil Layer: Prev. Layer Next Layer Insert Layer Delete Layer Layer Depth: Bulk Density: (More Soil Layer data on next page.) < Prev Next >
Hydrologic Soil Group:	B	
K-factor:	0.049	
Albedo:		
Time to Consolidation:	3	
Impervious Depth:		
Specific Gravity:		
Soil Name:	Apison-Montevallo	
Soil Texture:	Fine-loamy to loamy	

Prev. Soil Next Soil
 Insert Soil Replicate Soil Delete Soil
 Delete ALL Forget Accept

Figure A-11. Soil Data Screen

AnnAGNPS Output

AnnAGNPS_TXT_AA_Sediment_Yield_(mass).txt - Notepad

Run Date: 03/05/2005 AnnAGNPS v3.43.a.05 Run Time: 18:54:11
 PRIMARY CLIMATE FILE HEADER: Knoxville, monthly dew point(deg C), sky cover(%), wind speed(M/sec)
 WATERSHED ID: Cox Creek
 WATERSHED DESCRIPTION: Cox Creek - 600m DS of Tazewell Pike
 WATERSHED LOCATION: Knoxville, TN Lat: 36.0200 Long: 84.0000

Begin & end simulation dates respectively: 01/01/0001 & 12/31/0010
 Number initialization & simulation years respectively: 2 & 10.000
 Number of rainfall events during simulation period: 1292; Average number of rainfall events per year: 129.20
 Number of surface runoff events that exceeded 0.0000 mm and are included as runoff: 1419
 Number of surface runoff events that exceeded 0.0000 mm, had met the user-specified limits,
 and had been written to the user-requested event output files: 0
 Corresponding sediment events were not requested.

***** AVERAGE ANNUAL FILE: LANDSCAPE & WATERSHED SEDIMENT YIELD TO THE STREAM [Mass per Annum] *****

Cell & Drainage	Area of	Source	LANDSCAPE SEDIMENT YIELD [Mg/yr]					
Rec. Reach	Area	of	Clay	Silt	Sand	Sm. Agg.	Lg. Agg.	Subtotals
-- ID's --	[ha]	sediment						
22	23.31	Gully	0.000	0.000	0.000	0.000	0.000	0.000
		Pond	0.000	0.000	0.000	0.000	0.000	0.000
2		Sheet & Rill	0.024	0.052	0.019	0.000	0.000	0.094
		Subtotal	0.024	0.052	0.019	0.000	0.000	0.094
23	37.69	Gully	0.000	0.000	0.000	0.000	0.000	0.000
		Pond	0.000	0.000	0.000	0.000	0.000	0.000
2		Sheet & Rill	0.258	0.364	0.339	0.000	0.000	0.962
		Subtotal	0.258	0.364	0.339	0.000	0.000	0.962
31	15.00	Gully	0.000	0.000	0.000	0.000	0.000	0.000
		Pond	0.000	0.000	0.000	0.000	0.000	0.000
3		Sheet & Rill	0.460	0.936	0.449	0.000	0.000	1.845
		Subtotal	0.460	0.936	0.449	0.000	0.000	1.845
32	7.50	Gully	0.000	0.000	0.000	0.000	0.000	0.000
		Pond	0.000	0.000	0.000	0.000	0.000	0.000
3		Sheet & Rill	0.003	0.006	0.002	0.000	0.000	0.012
		Subtotal	0.003	0.006	0.002	0.000	0.000	0.012
33	5.12	Gully	0.000	0.000	0.000	0.000	0.000	0.000
		Pond	0.000	0.000	0.000	0.000	0.000	0.000
3		Sheet & Rill	0.001	0.002	0.002	0.000	0.000	0.005
		Subtotal	0.001	0.002	0.002	0.000	0.000	0.005
42	5.00	Gully	0.000	0.000	0.000	0.000	0.000	0.000
		Pond	0.000	0.000	0.000	0.000	0.000	0.000
4		Sheet & Rill	0.001	0.001	0.001	0.000	0.000	0.003
		Subtotal	0.001	0.001	0.001	0.000	0.000	0.003

Ln 1, Col 1

Figure A-12. Output for Average Annual Sediment Yield from each Cell

AnnAGNPS.evn - Notepad

File Edit Format View Help

AnnAGNPS: v3.43.a.05Event File03/05/2005 18:54:11

Cox Creek

Simulation Period111123110

2Y N Y Y Y N N N N
adapted from version 3 flags

outletY N Y Y Y Y Y Y N

2111N

waterUpstream0.00.00.106E-040.0

waterDnstream0.00.106E-040.0

Bed & BankUpstream0.00.00.00.00.0

Bed & BankDnstream0.00.00.00.00.0

GullyUpstream0.00.00.00.00.0

GullyDnstream0.00.00.00.00.0

Sheet&RillUpstream0.00.00.00.00.0

Sheet&RillDnstream0.00.00.00.00.0

Size TotalUpstream0.00.00.00.00.0

Size TotalDnstream0.00.00.00.00.0

Source TotUpstream0.00.00.00.0

Source TotDnstream0.00.00.00.0

outlet111N

water0.00.00.11E-04

Pond0.00.00.00.0

Bed & Bank0.00.00.00.0

Gully0.00.00.00.0

Sheet&Rill0.00.00.00.0

Size Total0.00.00.00.0

Source Tot0.00.00.0

Nitrogen0.00.0

Org Carbon0.00.0

Phosphorus0.00.0

2121N

waterUpstream0.00.00.108E-040.0

waterDnstream0.00.108E-040.0

Bed & BankUpstream0.00.00.00.00.0

Bed & BankDnstream0.00.00.00.0

GullyUpstream0.00.00.00.0

GullyDnstream0.00.00.00.0

Sheet&RillUpstream0.00.00.00.0

Sheet&RillDnstream0.00.00.00.0

Size TotalUpstream0.00.00.00.0

Size TotalDnstream0.00.00.00.0

Source TotUpstream0.00.00.0

Source TotDnstream0.00.00.0

outlet121N

water0.00.00.11E-04

Pond0.00.00.00.0

Bed & Bank0.00.00.00.0

Figure A-13. Event Output File. This file is converted into the Hydrography file for CONCEPTS

AnnAGNPS.cpt - Notepad

File Edit Format View Help

AnnAGNPS: v3.43.a.05 CCHE1D File 03/05/2005 18:54:11

Cox Creek

Simulation Period 1 1 1 12 31 10

33	01/01/0001	N	cell	2	0.0	5.120	0.36033	0.0
	water			0.0	0.0	0.117E-05	0.0	0.0
42	01/01/0001	N	cell	104	0.0	5.000	0.56742	0.0
	water			0.0	0.0	0.422E-06	0.0	0.0
52	01/01/0001	N	cell	4	0.0	13.000	0.34152	0.0
	water			0.0	0.0	0.121E-05	0.0	0.0
62	01/01/0001	N	cell	5	0.0	3.810	0.33562	0.0
	water			0.0	0.0	0.101E-05	0.0	0.0
63	01/01/0001	N	cell	5	0.0	1.440	0.43163	0.0
	water			0.0	0.0	0.869E-06	0.0	0.0
72	01/01/0001	N	cell	5	0.0	2.500	0.41072	0.0
	water			0.0	0.0	0.362E-06	0.0	0.0
82	01/01/0001	N	cell	7	0.0	4.380	0.71682	0.0
	water			0.0	0.0	0.458E-06	0.0	0.0
92	01/01/0001	N	cell	8	0.0	4.750	0.25592	0.0
	water			0.0	0.0	0.633E-06	0.0	0.0
122	01/01/0001	N	cell	11	0.0	2.440	0.513122	0.0
	water			0.0	0.0	0.765E-06	0.0	0.0
123	01/01/0001	N	cell	11	0.0	11.940	0.329123	0.0
	water			0.0	0.0	0.184E-05	0.0	0.0
142	01/01/0001	N	cell	13	0.0	5.810	0.401142	0.0
	water			0.0	0.0	0.188E-05	0.0	0.0
33	01/02/0001	N	cell	2	0.0	5.120	0.36033	0.0
	water			0.0	0.0	0.119E-05	0.0	0.0
42	01/02/0001	N	cell	104	0.0	5.000	0.56742	0.0
	water			0.0	0.0	0.431E-06	0.0	0.0
52	01/02/0001	N	cell	4	0.0	13.000	0.34152	0.0
	water			0.0	0.0	0.123E-05	0.0	0.0
62	01/02/0001	N	cell	5	0.0	3.810	0.33562	0.0
	water			0.0	0.0	0.103E-05	0.0	0.0

Ln 1, Col 1

Figure A-14. Concepts Output File. This file is used to produce a lateral flow file for CONCEPTS input.

APPENDIX B

CONCEPTS Input

[illegible]

Figure B-1. Hydrography Input File.



```

RunControl.txt - Notepad
File Edit Format View Help

! Main Input File
! case name
Cox
! project title
Cox Creek channel evolution simulation between 2001 and 2010
!----- Run Control Data -----
! upstream flow discharge file
Hydrography.txt
! lateral inflow and downstream rating curve
0.0 0
! sediment discharge at upstream end of the channel
-1 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0
! silt fraction and downstream bed control
1.00 1.0 0.0
! bank failure analysis
7 4 50 0.
! type of flow resistance formulation
1
! water temperature
10.0
! sediment and streambank mechanics options
1 1 1
!----- Simulation Times -----
! start end time step
01/01/2001 00:00:00 12/31/2010 24:00:00 50
!----- Makeup of Modeling Reach -----
! number of links
1
! linktypes for the above number of links
1
!----- Link 1 -----
! REACH: number of cross sections and their data filenames
7
CCxsect01.txt
CCxsect02.txt
CCxsect03.txt
CCxsect04.txt
CCxsect05.txt
CCxsect06.txt
CCxsect07.txt
!----- output -----
! single point and time
1
49392
1 6
1
12/30/2010 24:00:00
Ln 1, Col 1

```

Figure B-3. Run Control Input File

```
RunControl.txt - Notepad
File Edit Format View Help
! silt Fraction and downstream bed control
1.00 1.0 0.0
! bank failure analysis
7 4 50 0.
! type of flow resistance formulation
1
! water temperature
10.0
! sediment and streambank mechanics options
1 1 1
!----- simulation times -----
!      start      end      time step
! 01/01/2001 00:00:00 12/31/2010 24:00:00 50
!----- Makeup of Modeling Reach -----
! number of links
1
! linktypes for the above number of links
1
!----- Link 1 -----
! REACH: number of cross sections and their data filenames
7
CCxsect01.txt
CCxsect02.txt
CCxsect03.txt
CCxsect04.txt
CCxsect05.txt
CCxsect06.txt
CCxsect07.txt
!----- output -----
! single point and time
1
49392
1 6
1
12/30/2010 24:00:00
! single point, continuously in time
1
73733
1 6
1
01/01/2001 00:00:00 12/31/2010 24:00:00
! profile at specific time points
1
255
1 1 1 7
2
12/31/2001 02:00:00
12/31/2010 02:00:00
Ln 1, Col 1
```

Figure B-3. Continued

```

CCxsect01.txt - Notepad
File Edit Format View Help
!
! Input file of cross section 01.
!
! Name of xsection and rivermile in (km)
Cox Creek at Cross-Section 01
0.0
! friction factor
0.06
! discharge fraction due to tributary inflow
0
!----- Left FloodPlain -----
! number of nodes
5
! station and elevation for above number of coordinates in (m)
0.00 102.29
10.22 99.82
23.88 99.71
39.30 99.71
43.85 99.70
! Manning's n of left floodplain
0.10
!----- Left Bank -----
! number of nodes
5
! station and elevation for above number of coordinates in (m)
43.85 99.70
44.17 99.31
44.82 99.10
45.13 99.02
45.25 98.82
! soil layer data
! number of layers
1
! layer 1: elevation
102.0
! layer 1: bank material properties
10000.0 30.0 15.0 16000.0
! layer 1: critical shear stress for erosion
5.0
! layer 1: bank sediment composition
25.37
8.40
18.84
14.52
3.72
5.06
3.53
3.36
3.83
Ln 1, Col 1

```

Figure B-4. Cross-Section Input File

```
CCxsect01.txt - Notepad
File Edit Format View Help
3.83
8.58
4.78
0.00
0.00
0.00
! groundwater table
! 99.00
! Manning's n
! 0.06
! ----- Channel Bed -----
! number of nodes
6
! station and elevation for above number of coordinates in (m)
45.25 98.82
46.67 98.58
47.37 98.55
47.90 98.51
48.29 98.68
48.70 98.74
! Elevation of bedrock (m)
0.00
! porosity
0.4
! hiding factor
0.25 0.95 0.70
! Surface layer and substratum data
! number of sediment layers composing the bed
1
! Layer 1, layer depth below bed surface
0.00
! bed composition
5.74
3.82
4.13
8.38
13.65
20.50
17.13
13.05
11.36
1.50
0.73
0.00
0.00
0.00
! critical shear stresses for erosion of and deposition on cohesive beds
! and erodibility coefficient
0.10 4.00 5.00E-06
Ln 1, Col 1
```

Figure B-4. Continued

```

CCxsect01.txt - Notepad
File Edit Format View Help
0.10 4.00 5.00E-06
! Manning's n
0.04
! ----- Right Bank -----
! number of nodes
3
! station and elevation for above number of coordinates in (m)
48.70 98.74
48.91 98.90
49.21 99.37
! soil layer data
! number of layers
1
! layer 1: elevation
102.0
! layer 1: bank material properties
10000.0 30.0 15.0 16000.0
! layer 1: critical shear stress for erosion
5.0
! layer 1: bank sediment composition
35.96
17.09
28.32
14.32
1.84
1.67
0.24
0.26
0.28
0.01
0.00
0.00
0.00
0.00
! groundwatertable
99.00
! Manning's n
0.06
! ----- Right FloodPlain -----
! number of nodes
6
! station and elevation for above number of coordinates in (m)
49.21 99.37
52.67 99.69
71.25 100.01
93.83 100.50
100.75 101.19
102.51 102.15
! Manning's n of right floodplain

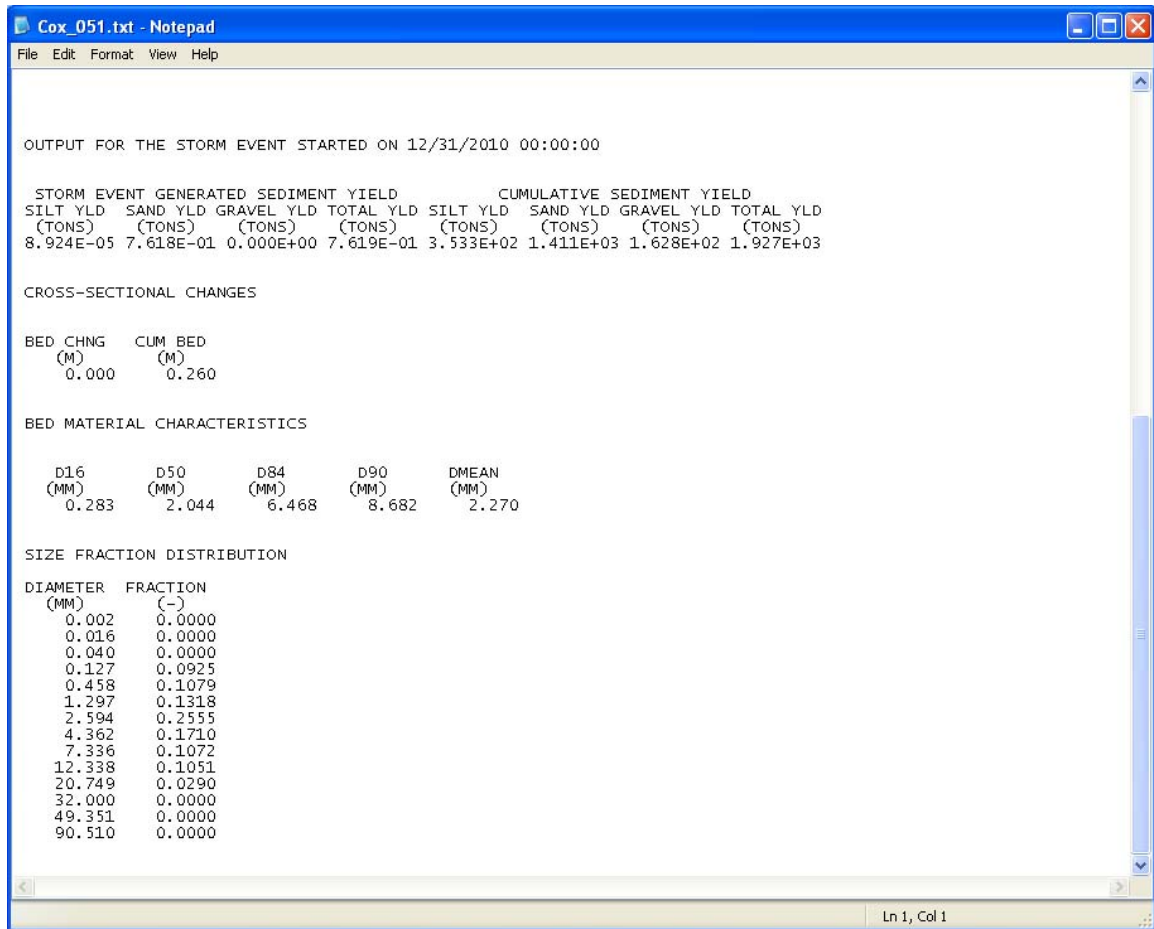
```

Figure B-4. Continued

```
CCxsect01.txt - Notepad
File Edit Format View Help
0.04
! ----- Right Bank -----
! number of nodes
3
! station and elevation for above number of coordinates in (m)
48.70 98.74
48.91 98.90
49.21 99.37
! soil layer data
! number of layers
1
! layer 1: elevation
102.0
! layer 1: bank material properties
10000.0 30.0 15.0 16000.0
! layer 1: critical shear stress for erosion
5.0
! layer 1: bank sediment composition
35.96
17.09
28.32
14.32
1.84
1.67
0.24
0.26
0.28
0.01
0.00
0.00
0.00
0.00
! groundwatertable
99.00
! Manning's n
0.06
! ----- Right FloodPlain -----
! number of nodes
6
! station and elevation for above number of coordinates in (m)
49.21 99.37
52.67 99.69
71.25 100.01
93.83 100.50
100.75 101.19
102.51 102.15
! Manning's n of right floodplain
0.10
Ln 1, Col 1
```

Figure B-4. Continued

CONCEPTS Output



```
Cox_051.txt - Notepad
File Edit Format View Help

OUTPUT FOR THE STORM EVENT STARTED ON 12/31/2010 00:00:00

STORM EVENT GENERATED SEDIMENT YIELD          CUMULATIVE SEDIMENT YIELD
SILT YLD  SAND YLD GRAVEL YLD TOTAL YLD SILT YLD  SAND YLD GRAVEL YLD TOTAL YLD
(TONS)    (TONS)    (TONS)    (TONS)    (TONS)    (TONS)    (TONS)    (TONS)
8.924E-05 7.618E-01 0.000E+00 7.619E-01 3.533E+02 1.411E+03 1.628E+02 1.927E+03

CROSS-SECTIONAL CHANGES

BED CHNG  CUM BED
(M)        (M)
0.000      0.260

BED MATERIAL CHARACTERISTICS

D16      D50      D84      D90      DMEAN
(MM)     (MM)     (MM)     (MM)     (MM)
0.283    2.044    6.468    8.682    2.270

SIZE FRACTION DISTRIBUTION

DIAMETER  FRACTION
(MM)      (-)
0.002     0.0000
0.016     0.0000
0.040     0.0000
0.127     0.0925
0.458     0.1079
1.297     0.1318
2.594     0.2555
4.362     0.1710
7.336     0.1072
12.338    0.1051
20.749    0.0290
32.000    0.0000
49.351    0.0000
90.510    0.0000

Ln 1, Col 1
```

Figure B-5. Output at a Certain Location and for a Certain Runoff Event

Cox_052.txt - Notepad

File Edit Format View Help

Output time-series file for cross section "Cox Creek at Cross-Section 06" at river kilometer 0.481

Output type = 73733
Output periods are: from 01/01/2001 00:00:00 to 12/31/2010 24:00:00

TIME	DISCHARGE (CMS)	DEPTH (M)	SILT DIS (CMS)	SAND DIS (CMS)	GRAVEL DIS (CMS)	TOTAL DIS (CMS)	THALWEG (M)
01/01/2001 00:01:02	0.300	0.309	6.438E-04	8.333E-08	0.000E+00	6.439E-04	95.550
01/01/2001 00:02:19	0.301	0.309	9.097E-04	9.182E-08	0.000E+00	9.098E-04	95.550
01/01/2001 00:03:55	0.301	0.309	1.127E-03	1.032E-07	0.000E+00	1.127E-03	95.550
01/01/2001 00:05:55	0.301	0.309	1.162E-03	1.240E-07	0.000E+00	1.162E-03	95.551
01/01/2001 00:08:25	0.301	0.309	1.040E-03	1.544E-07	0.000E+00	1.040E-03	95.551
01/01/2001 00:11:32	0.301	0.309	7.777E-04	1.930E-07	0.000E+00	7.779E-04	95.551
01/01/2001 00:15:25	0.301	0.308	4.702E-04	2.141E-07	0.000E+00	4.704E-04	95.551
01/01/2001 00:20:16	0.301	0.308	2.842E-04	2.077E-07	0.000E+00	2.844E-04	95.551
01/01/2001 00:26:19	0.300	0.308	2.076E-04	1.781E-07	0.000E+00	2.078E-04	95.550
01/01/2001 00:33:52	0.300	0.309	1.719E-04	1.360E-07	0.000E+00	1.721E-04	95.550
01/01/2001 00:43:18	0.300	0.308	1.465E-04	8.904E-08	0.000E+00	1.466E-04	95.549
01/01/2001 00:52:44	0.300	0.309	1.188E-04	6.782E-13	0.000E+00	1.188E-04	95.549
01/01/2001 01:02:10	0.300	0.309	9.596E-05	6.897E-13	0.000E+00	9.596E-05	95.549
01/01/2001 01:11:36	0.300	0.309	7.757E-05	6.740E-13	0.000E+00	7.757E-05	95.549
01/01/2001 01:21:02	0.300	0.309	6.485E-05	6.594E-13	0.000E+00	6.485E-05	95.548
01/01/2001 01:30:28	0.300	0.309	5.563E-05	6.482E-13	0.000E+00	5.563E-05	95.548
01/01/2001 01:39:54	0.300	0.309	4.826E-05	6.374E-13	0.000E+00	4.826E-05	95.548
01/01/2001 01:49:20	0.300	0.309	4.223E-05	6.270E-13	0.000E+00	4.223E-05	95.548
01/01/2001 01:58:46	0.300	0.309	3.724E-05	6.233E-13	0.000E+00	3.724E-05	95.548
01/01/2001 02:08:12	0.300	0.309	3.308E-05	6.163E-13	0.000E+00	3.308E-05	95.548
01/01/2001 02:17:38	0.300	0.309	2.995E-05	5.990E-13	0.000E+00	2.995E-05	95.547
01/01/2001 02:27:04	0.300	0.309	2.743E-05	5.877E-13	0.000E+00	2.743E-05	95.547
01/01/2001 02:36:30	0.300	0.309	2.541E-05	5.791E-13	0.000E+00	2.541E-05	95.547
01/01/2001 02:45:56	0.300	0.309	2.353E-05	5.704E-13	0.000E+00	2.353E-05	95.547
01/01/2001 02:55:22	0.300	0.310	2.194E-05	5.641E-13	0.000E+00	2.194E-05	95.547
01/01/2001 03:04:48	0.300	0.310	2.063E-05	5.558E-13	0.000E+00	2.063E-05	95.547
01/01/2001 03:14:14	0.300	0.310	1.943E-05	5.476E-13	0.000E+00	1.943E-05	95.547
01/01/2001 03:23:40	0.300	0.310	1.849E-05	5.342E-13	0.000E+00	1.849E-05	95.547
01/01/2001 03:33:06	0.300	0.310	1.760E-05	5.253E-13	0.000E+00	1.760E-05	95.547
01/01/2001 03:42:32	0.300	0.310	1.681E-05	5.184E-13	0.000E+00	1.681E-05	95.547
01/01/2001 03:51:58	0.300	0.310	1.609E-05	5.126E-13	0.000E+00	1.609E-05	95.547
01/01/2001 04:01:24	0.300	0.310	1.550E-05	5.057E-13	0.000E+00	1.550E-05	95.547
01/01/2001 04:10:50	0.300	0.310	1.494E-05	4.992E-13	0.000E+00	1.494E-05	95.547
01/01/2001 04:20:16	0.300	0.310	1.438E-05	4.929E-13	0.000E+00	1.438E-05	95.547
01/01/2001 04:29:42	0.300	0.310	1.386E-05	4.819E-13	0.000E+00	1.386E-05	95.547
01/01/2001 04:39:08	0.300	0.310	1.347E-05	4.748E-13	0.000E+00	1.347E-05	95.547
01/01/2001 04:48:34	0.300	0.310	1.307E-05	4.693E-13	0.000E+00	1.307E-05	95.547
01/01/2001 04:58:00	0.300	0.310	1.263E-05	4.648E-13	0.000E+00	1.263E-05	95.547
01/01/2001 05:07:26	0.300	0.310	1.228E-05	4.595E-13	0.000E+00	1.228E-05	95.546
01/01/2001 05:16:52	0.300	0.310	1.195E-05	4.541E-13	0.000E+00	1.195E-05	95.546

Ln 1, Col 1

Figure B-6. Time Series Output at a Certain Location

Cox_053.txt - Notepad

File Edit Format View Help

output profile file from cross section "Cox Creek at Cross-Section 01" at river kilometer 0.000
to cross section "Cox Creek at Cross-Section 07" at river kilometer 0.548

output type = 255
Number of output dates = 2
output dates are: 12/31/2001 02:00:00
12/31/2010 02:00:00

OUTPUT FOR THE STORM EVENT STARTED ON 12/31/2001 00:00:00

RIVER KM (KM)	DISCHARGE (CMS)	STAGE (M)	THALWEG (M)	BED CHNG (M)	TOP WIDTH (M)	BANK HEIGHT		STORM EVENT GENERATE	
						LEFT (M)	RIGHT (M)	SILT YLD (TONS)	SAND YLD GR (TONS)
0.000	0.300	98.782	98.491	-0.019	5.380	0.894	0.650	0.000E+00	0.000E+00 0
0.077	0.300	98.410	98.195	-0.005	3.723	0.975	0.806	0.000E+00	0.000E+00 0
0.171	0.300	97.747	97.501	-0.029	3.956	1.039	0.820	4.281E-05	1.277E-01 0
0.302	0.300	97.117	96.894	-0.366	4.114	1.156	1.156	3.584E-04	3.830E-01 0
0.392	0.300	96.547	96.307	0.297	6.875	1.003	1.243	4.089E-04	5.852E-01 0
0.481	0.300	95.996	95.748	0.198	5.398	1.050	0.794	3.709E-04	7.405E-01 0
0.548	0.300	95.635	95.410	0.000	5.654	1.690	1.330	4.148E-04	8.456E-01 0

OUTPUT FOR THE STORM EVENT STARTED ON 12/31/2010 00:00:00

RIVER KM (KM)	DISCHARGE (CMS)	STAGE (M)	THALWEG (M)	BED CHNG (M)	TOP WIDTH (M)	BANK HEIGHT		STORM EVENT GENERATE	
						LEFT (M)	RIGHT (M)	SILT YLD (TONS)	SAND YLD GR (TONS)
0.000	0.300	98.790	98.502	-0.008	5.488	0.914	0.646	0.000E+00	0.000E+00 0
0.077	0.300	98.394	98.215	-0.025	3.914	0.955	0.791	0.000E+00	0.000E+00 0
0.171	0.300	97.628	97.396	-0.134	4.046	1.144	0.928	0.000E+00	1.391E-01 0
0.302	0.300	96.973	96.736	-0.524	4.118	1.314	1.314	6.988E-05	3.521E-01 0
0.392	0.300	96.540	96.303	0.293	6.907	1.007	1.247	7.867E-05	4.787E-01 0
0.481	0.300	96.047	95.810	0.260	5.449	0.815	0.557	8.185E-05	6.987E-01 0
0.548	0.300	95.618	95.410	0.000	5.675	1.690	1.330	8.874E-05	7.746E-01 0

Ln 9, Col 1

Figure B-7. Output for a Certain Runoff Event along a Section of the Modeling Reach

Cox_053.txt - Notepad										
File Edit Format View Help										
1" at river kilometer 0.000										
0.548										
STORM EVENT GENERATED SEDIMENT YIELD						BED MATERIAL CHARACTERISTIC DIAMETERS				
HEIGHT	SILT YLD	SAND YLD	GRAVEL YLD	TOTAL YLD		D16	D50	D84	D90	DMEAN
RIGHT	(TONS)	(TONS)	(TONS)	(TONS)		(MM)	(MM)	(MM)	(MM)	(MM)
(M)										
4	0.650	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.212	1.329	4.426	5.624	1.633
5	0.806	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.351	8.842	14.525	16.603	7.418
9	0.820	4.281E-05	1.277E-01	0.000E+00	1.278E-01	0.431	3.787	11.501	13.987	3.639
6	1.156	3.584E-04	3.830E-01	0.000E+00	3.834E-01	0.741	1.902	3.441	4.048	2.270
3	1.243	4.089E-04	5.852E-01	0.000E+00	5.856E-01	0.633	1.821	3.099	3.708	2.107
0	0.794	3.709E-04	7.405E-01	0.000E+00	7.408E-01	0.263	1.583	3.086	4.062	1.702
0	1.330	4.148E-04	8.456E-01	0.000E+00	8.460E-01	0.140	1.493	4.977	6.095	1.263
STORM EVENT GENERATED SEDIMENT YIELD						BED MATERIAL CHARACTERISTIC DIAMETERS				
HEIGHT	SILT YLD	SAND YLD	GRAVEL YLD	TOTAL YLD		D16	D50	D84	D90	DMEAN
RIGHT	(TONS)	(TONS)	(TONS)	(TONS)		(MM)	(MM)	(MM)	(MM)	(MM)
(M)										
4	0.646	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.227	1.381	4.856	6.186	1.746
5	0.791	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.684	8.210	13.925	16.172	5.789
4	0.928	0.000E+00	1.391E-01	0.000E+00	1.391E-01	0.694	3.403	9.853	11.369	3.805
4	1.314	6.988E-05	3.521E-01	0.000E+00	3.522E-01	0.290	1.895	7.704	9.797	2.333
7	1.247	7.867E-05	4.787E-01	0.000E+00	4.788E-01	0.253	2.011	7.883	9.994	2.309
5	0.557	8.185E-05	6.987E-01	0.000E+00	6.988E-01	0.283	2.044	6.468	8.682	2.270
0	1.330	8.874E-05	7.746E-01	0.000E+00	7.746E-01	0.140	1.493	4.977	6.095	1.263

Figure B-7. Continued

APPENDIX C

Table C-1. Particle Size Distributions for Cox Creek

Cox Creek Cross-Section 1 Bed		Cox Creek Cross-Section 1 Left Bank		Cox Creek Cross-Section 1 Right Bank		Cox Creek Cross-Section 2 Bed		Cox Creek Cross-Section 3 Bed		Cox Creek Cross-Section 4 Bed	
Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)
25.4000	100.000	25.4000	100.000	25.4000	100.000	25.4000	100.000	25.4000	100.000	25.4000	100.000
12.5000	97.9753	12.5000	99.2115	12.5000	100.000	12.5000	32.5280	12.5000	72.6922	12.5000	100.000
9.5000	94.1852	9.5000	96.4832	9.5000	99.6869	9.5000	27.7629	9.5000	66.4930	9.5000	100.000
4.7500	77.1235	4.7500	89.2288	4.7500	98.7357	4.7500	19.4741	4.7500	51.6983	4.7500	100.000
2.3600	53.9630	2.3600	82.2741	2.3600	97.8928	2.3600	14.1618	2.3600	41.0085	2.3600	33.0654
2.0000	47.1605	2.0000	80.7444	2.0000	97.6761	2.0000	13.0406	2.0000	38.3413	2.0000	25.6029
0.4250	21.5456	0.4250	69.5662	0.4250	91.2644	0.4250	3.7860	0.4250	18.5634	0.4250	11.8416
0.2500	17.1337	0.2500	56.4854	0.2500	86.6261	0.2500	3.1550	0.2500	14.2609	0.2500	10.7777
0.1500	14.4351	0.1500	56.4854	0.1500	80.6237	0.1500	2.7181	0.1500	11.9708	0.1500	9.7601
0.0750	12.0364	0.0750	45.4261	0.0750	68.6188	0.0750	2.2489	0.0750	9.8889	0.0750	8.5343
0.0331	9.0777	0.0331	25.3852	0.0307	44.3815	0.0357	1.6479	0.0352	4.2228	0.0336	4.6642
0.0215	7.1325	0.0212	22.9676	0.0206	31.8992	0.0230	1.1535	0.0227	3.1671	0.0217	3.9645
0.0155	5.6195	0.0151	20.5500	0.0148	27.7385	0.0164	0.8239	0.0162	2.6393	0.0157	3.0317
0.0127	5.1873	0.0126	16.9235	0.0124	22.1908	0.0134	0.6592	0.0133	2.2874	0.0129	2.7985
0.0091	4.3227	0.0090	14.5059	0.0089	17.3365	0.0096	0.4944	0.0094	1.9355	0.0092	2.3321
0.0065	3.8904	0.0065	10.8794	0.0064	13.8692	0.0068	0.3296	0.0067	1.5836	0.0066	1.8657
0.0032	2.1614	0.0032	7.2529	0.0032	8.3215	0.0033	0.3296	0.0033	1.2317	0.0033	1.3992
0.0014	0.6484	0.0014	4.8353	0.0014	4.1608	0.0014	0.0000	0.0014	1.0557	0.0014	0.4664

Table C-1. Continued

Cox Creek Cross- Section 4 Left Bank		Cox Creek Cross- Section 4 Right Bank		Cox Creek Cross- Section 5 Bed		Cox Creek Cross- Section 5 Left Bank		Cox Creek Cross- Section 6 Bed		Cox Creek Cross- Section 7 Bed	
Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)
25.4000	100.0000	25.4000	100.0000	25.4000	100.0000	25.4000	100.0000	25.4000	100.0000	25.4000	100.0000
12.5000	100.0000	12.5000	100.0000	12.5000	74.8663	12.5000	60.9908	12.5000	77.6025	12.5000	95.7870
9.5000	100.0000	9.5000	100.0000	9.5000	70.9076	9.5000	58.4318	9.5000	68.0244	9.5000	90.2368
4.7500	99.7086	4.7500	99.8945	4.7500	56.5977	4.7500	51.7170	4.7500	43.2430	4.7500	67.9555
2.3600	99.5337	2.3600	99.8206	2.3600	34.2101	2.3600	44.5210	2.3600	30.3035	2.3600	44.0712
2.0000	99.4987	2.0000	99.7573	2.0000	29.7076	2.0000	41.6448	2.0000	27.5339	2.0000	38.4646
0.4250	97.8915	0.4250	96.8146	0.4250	12.9335	0.4250	33.4820	0.4250	16.3863	0.4250	14.5578
0.2500	92.6317	0.2500	92.8420	0.2500	10.7309	0.2500	30.9537	0.2500	14.1269	0.2500	12.7214
0.1500	82.8425	0.1500	86.6623	0.1500	9.3754	0.1500	28.1003	0.1500	12.0911	0.1500	11.2189
0.0750	66.1864	0.0750	72.9788	0.0750	7.9070	0.0750	24.4523	0.0750	9.7573	0.0750	9.4826
0.0307	47.0809	0.0318	40.7810	0.0349	4.0523	0.0248	20.2264	0.0316	6.9628	0.0351	4.4161
0.0201	39.7245	0.0206	34.7393	0.0223	3.4734	0.0165	18.7817	0.0211	4.9373	0.0224	3.9065
0.0145	35.3107	0.0150	28.6977	0.0160	2.6051	0.0119	18.0593	0.0152	4.0511	0.0160	3.2271
0.0120	32.3681	0.0124	24.1665	0.0132	2.3156	0.0099	17.3369	0.0126	3.5447	0.0132	2.7176
0.0086	27.9543	0.0090	18.1249	0.0093	2.1709	0.0072	16.2534	0.0090	3.0383	0.0094	2.3779
0.0062	25.0117	0.0064	15.1041	0.0067	1.7367	0.0052	15.5310	0.0064	2.5319	0.0067	1.8683
0.0031	19.8623	0.0032	9.0624	0.0033	1.3025	0.0026	14.0863	0.0032	1.3926	0.0033	1.3588
0.0013	16.9197	0.0014	4.5312	0.0014	0.8684	0.0011	12.2803	0.0014	0.7596	0.0014	1.0191

Table C-1. Continued

Cox Creek Cross- Section 7 Right Bank	
Grain Size (mm)	Percent Finer (%)
25.4000	100.0000
12.5000	100.0000
9.5000	100.0000
4.7500	99.8959
2.3600	99.8215
2.0000	99.8066
0.4250	98.7852
0.2500	95.2832
0.1500	88.8629
0.0750	75.2927
0.0290	58.8122
0.0190	52.9310
0.0139	47.0498
0.0115	42.6389
0.0084	36.7577
0.0061	30.8764
0.0031	24.9952
0.0013	16.9085

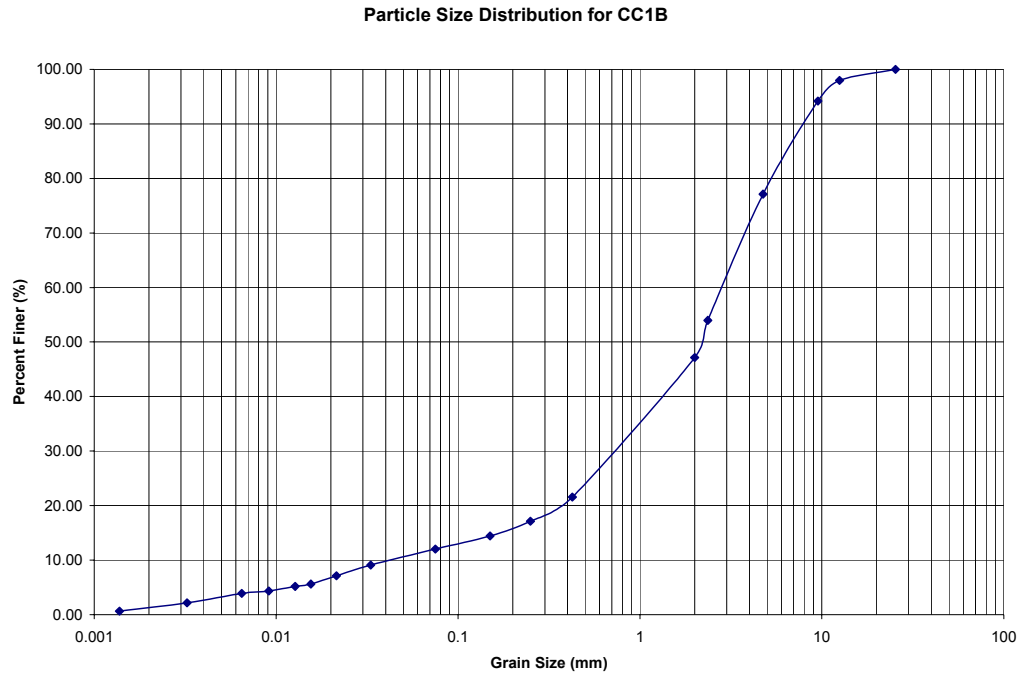


Figure C-1. Particle Size Distribution for CC1B

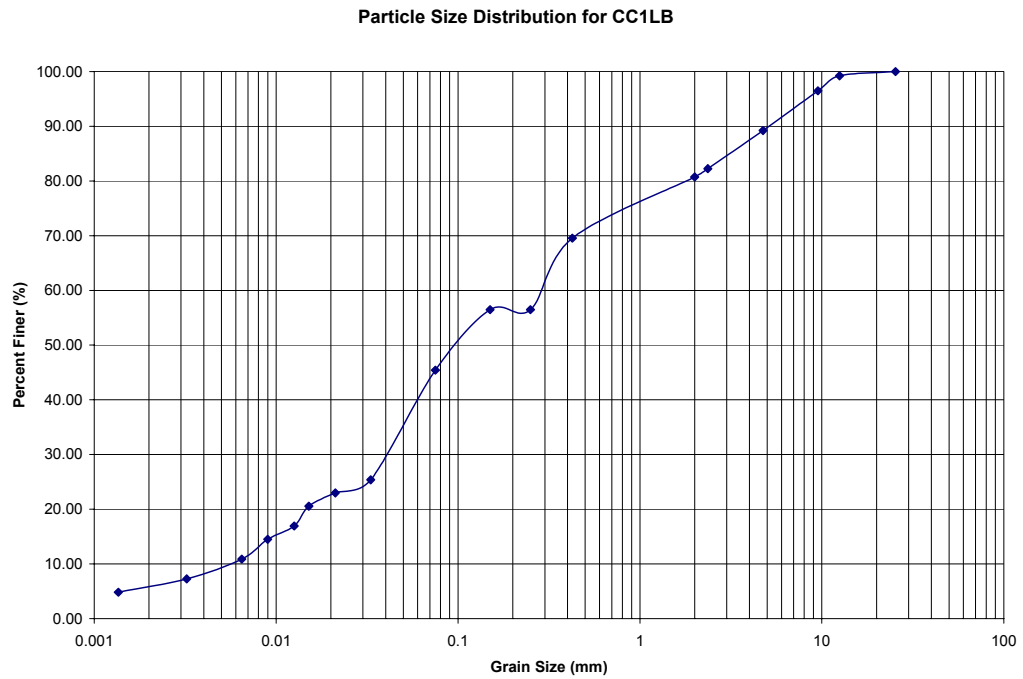


Figure C-2. Particle Size Distribution for CC1LB

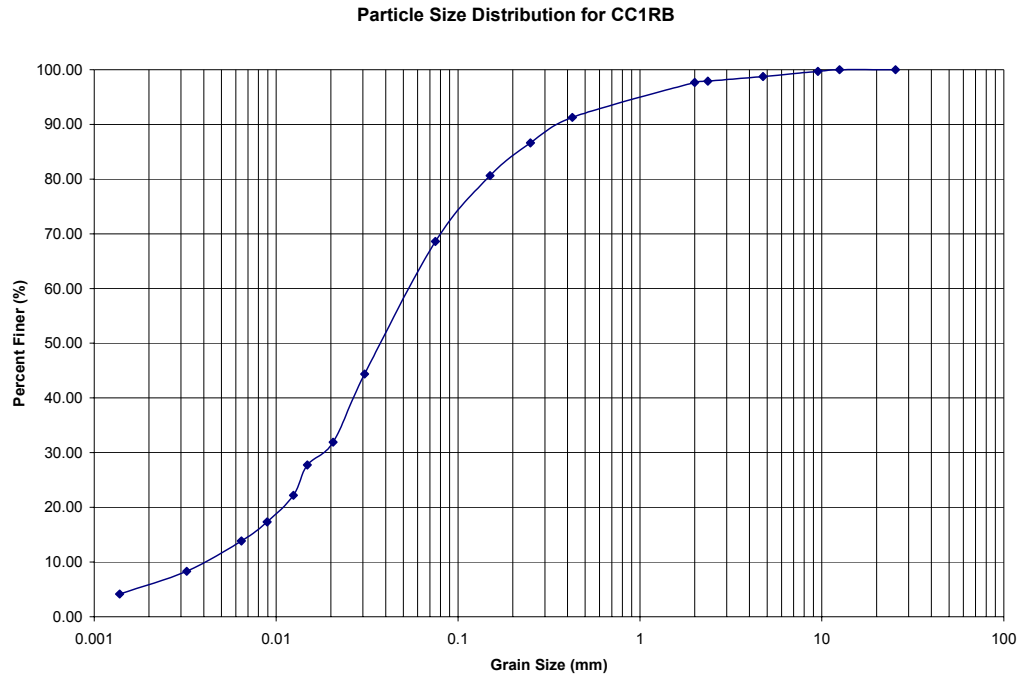


Figure C-3. Particle Size Distribution for CC1RB

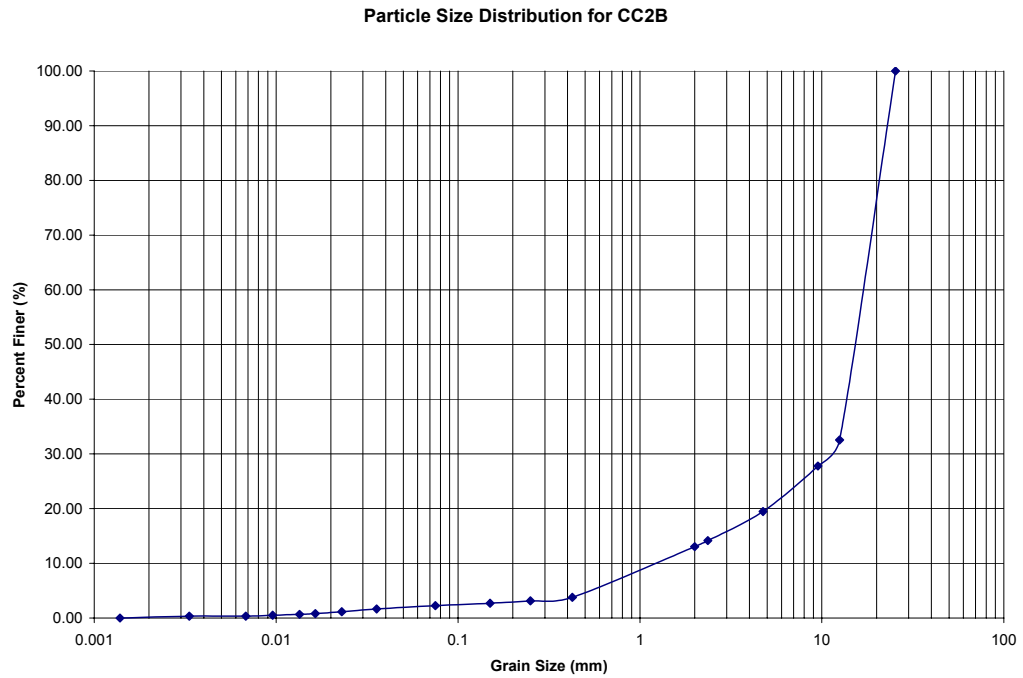


Figure C-4. Particle Size Distribution for CC2B

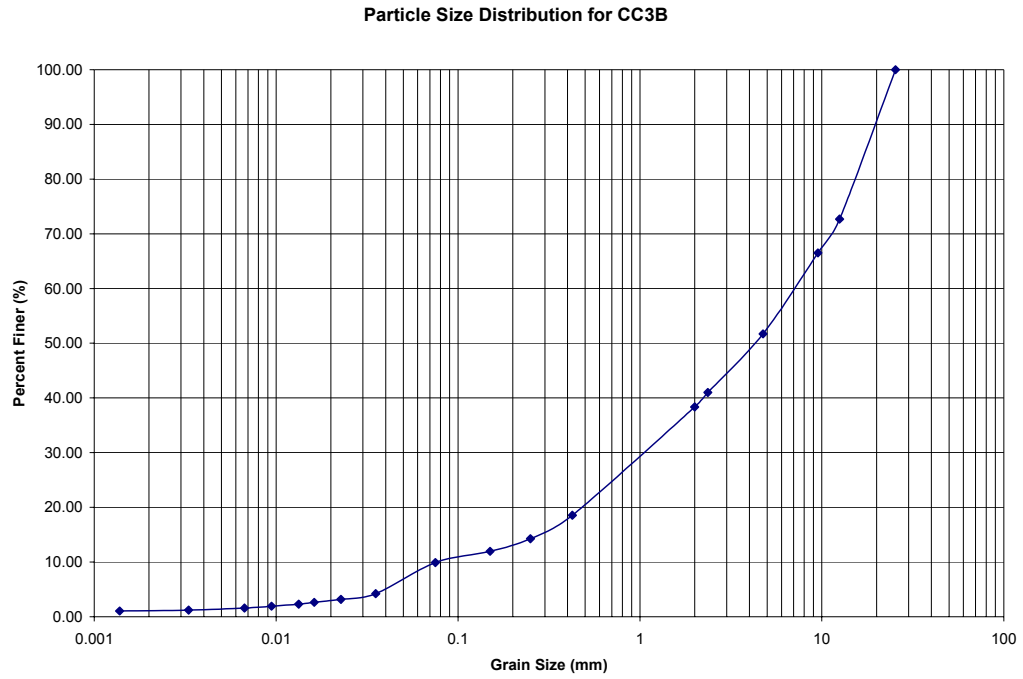


Figure C-5. Particle Size Distribution for CC3B

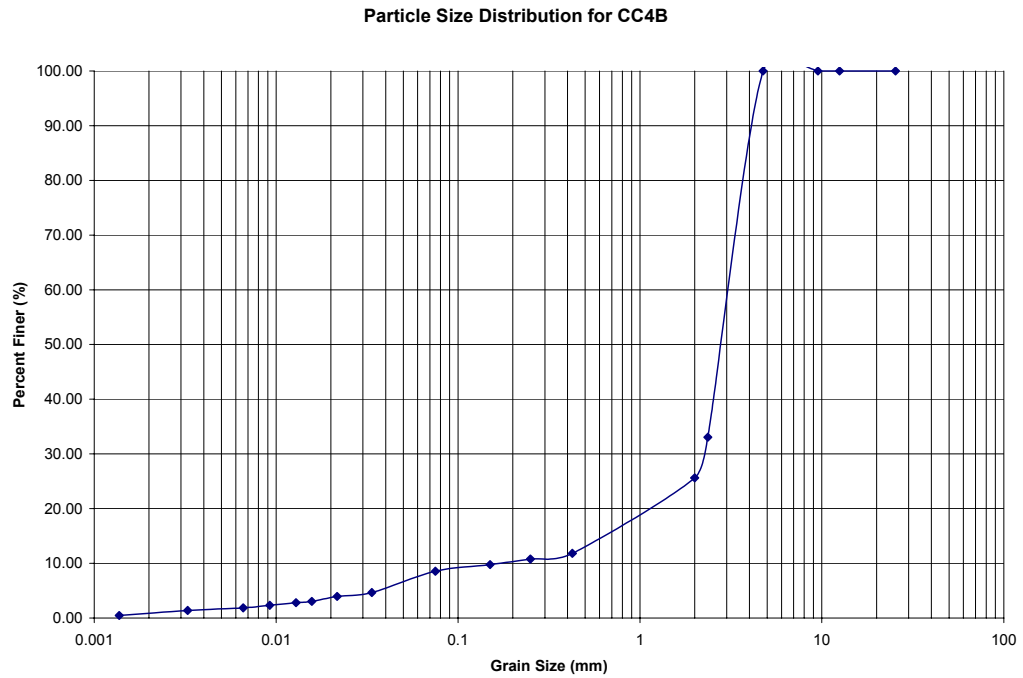


Figure C-6. Particle Size Distribution for CC4B

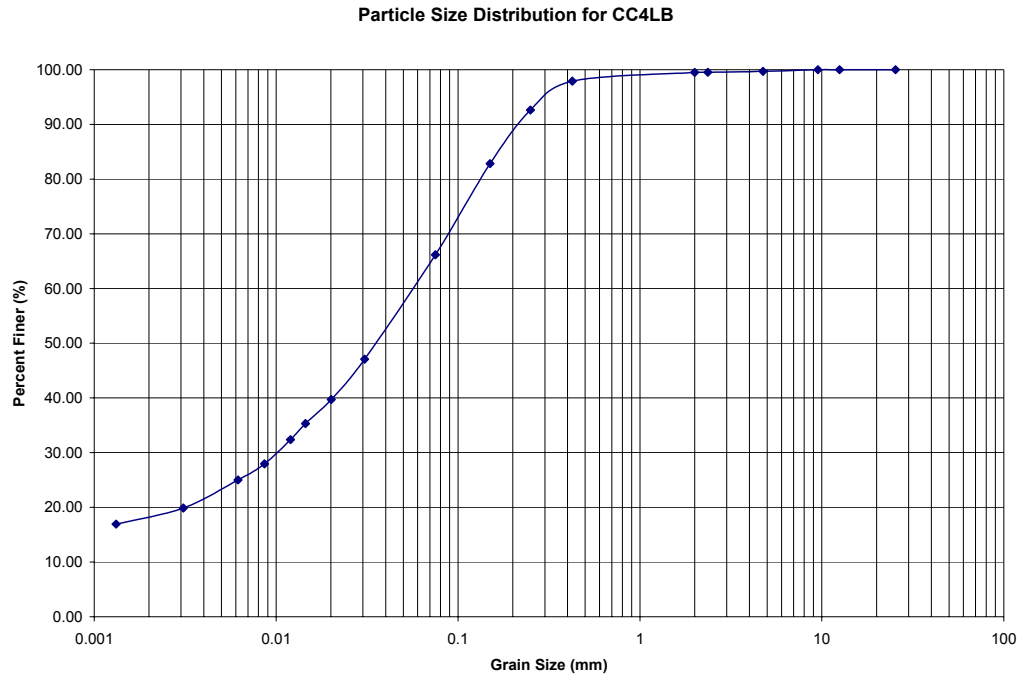


Figure C-7. Particle Size Distribution for CC4LB

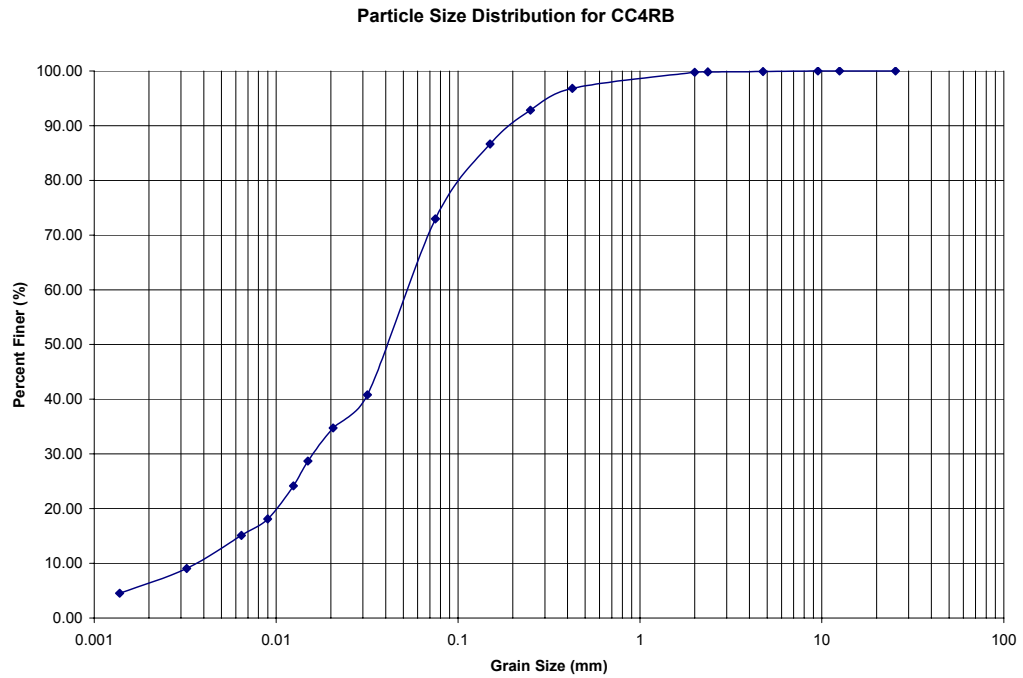


Figure C-8. Particle Size Distribution for CC4RB

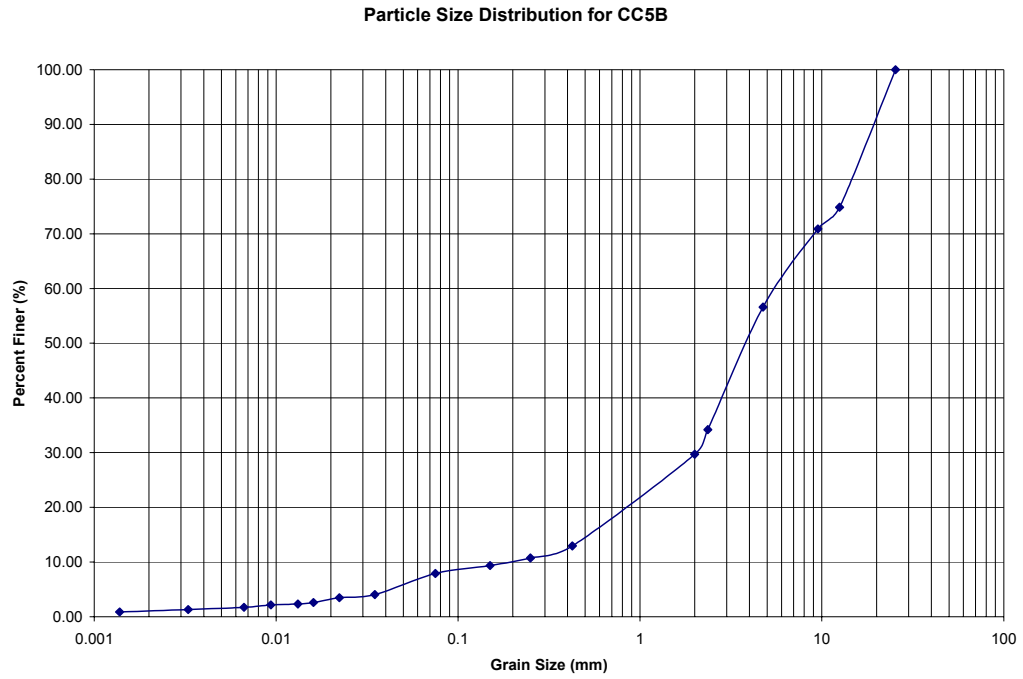


Figure C-9. Particle Size Distribution for CC5B

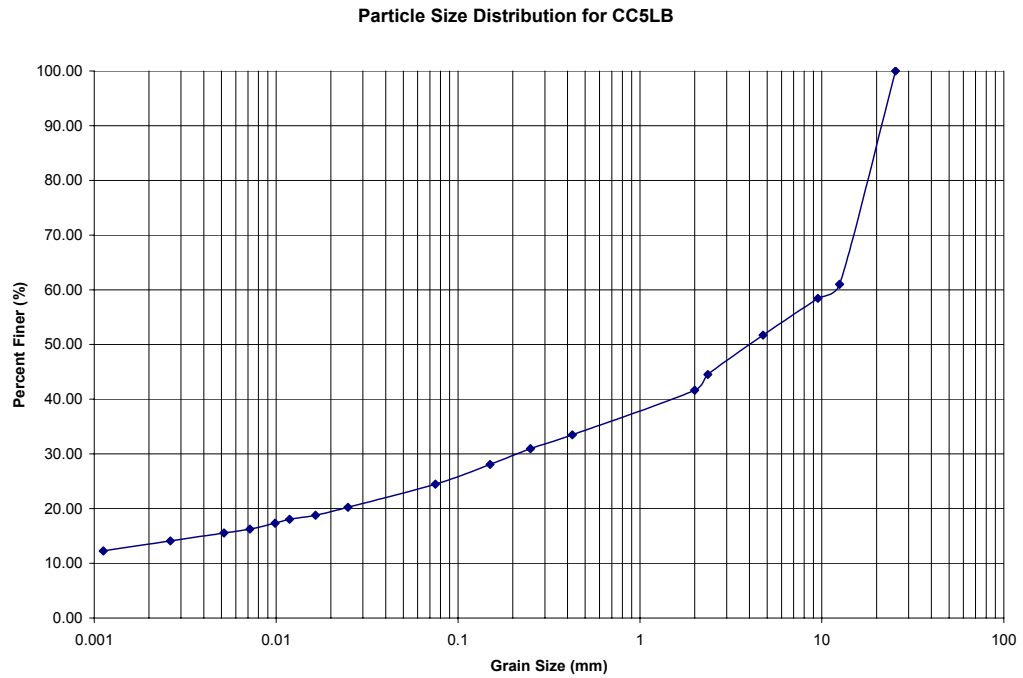


Figure C-10. Particle Size Distribution for CC5LB

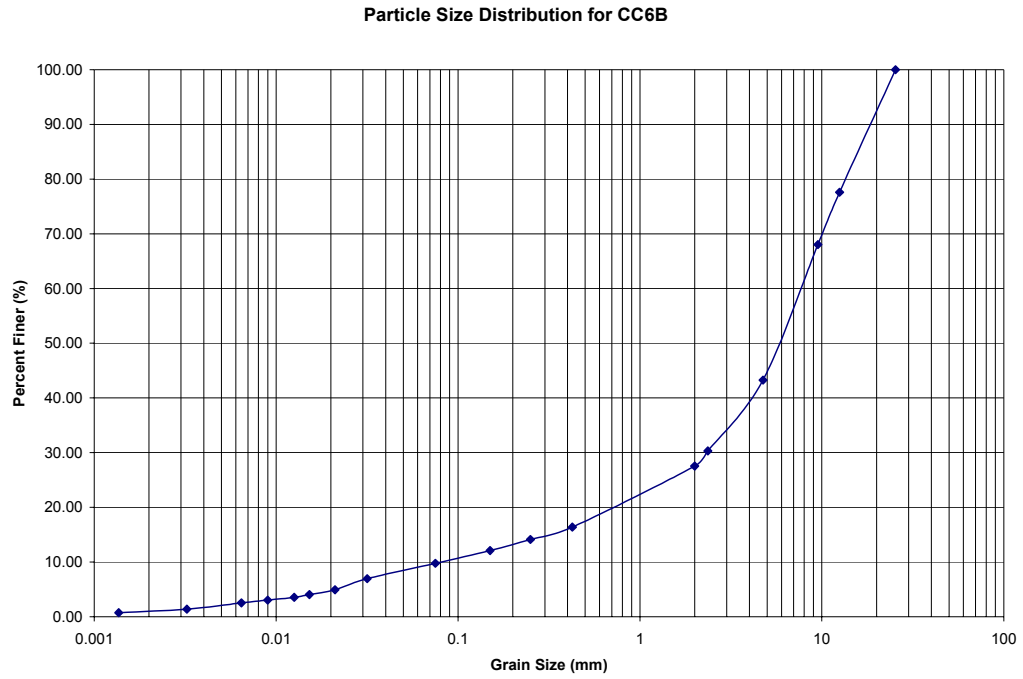


Figure C-11. Particle Size Distribution for CC6B

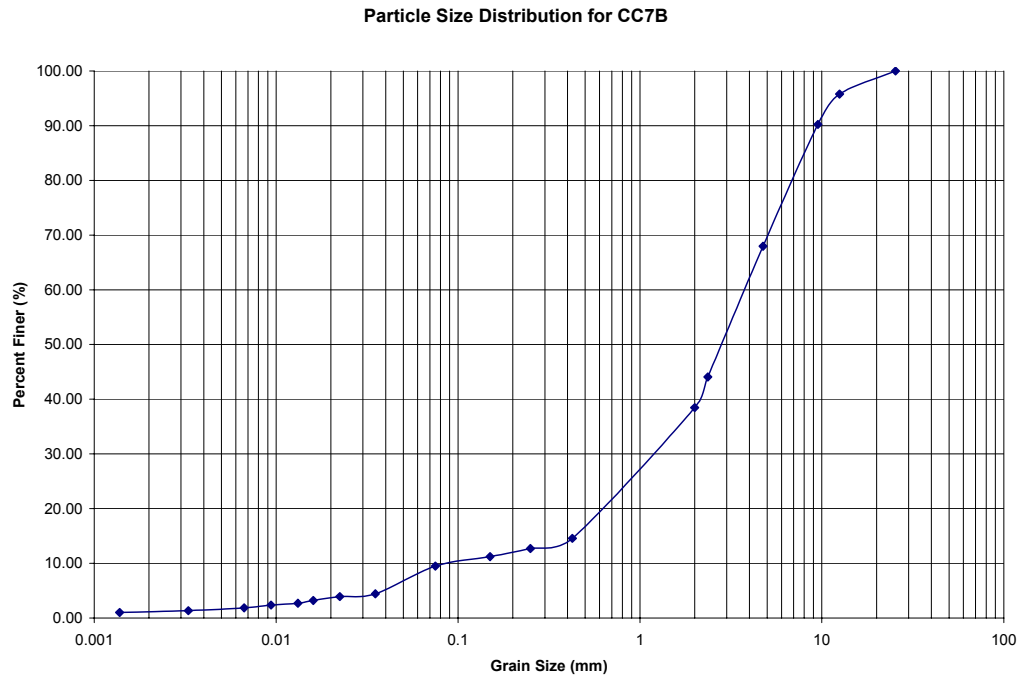


Figure C-12. Particle Size Distribution for CC7B

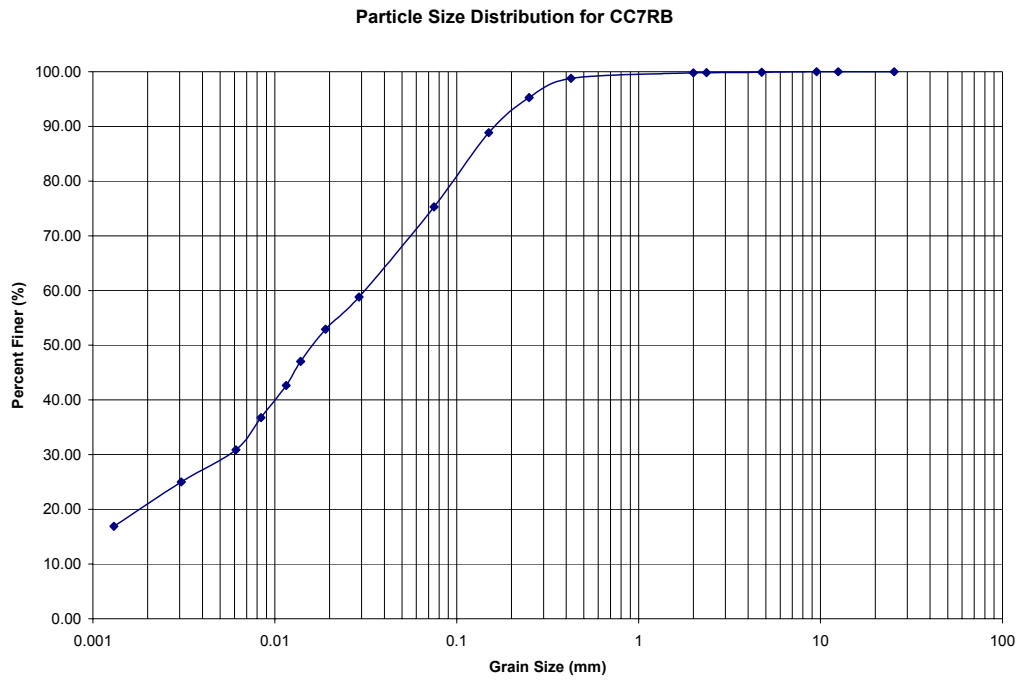


Figure C-13. Particle Size Distribution for CC7RB

Table C-2. Particle Size Distributions for Hines Branch

Hines Branch Sample 1 Bed		Hines Branch Sample 1 Left Bank		Hines Branch Sample 1 Right Bank		Hines Branch Sample 2 Bed		Hines Branch Sample 3 Bed	
Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)
25.4000	100.0000	25.4000	100.0000	25.4000	100.0000	25.4000	100.0000	25.4000	100.0000
12.5000	92.7298	12.5000	86.2853	12.5000	100.0000	12.5000	83.3006	12.5000	98.7837
9.5000	90.3168	9.5000	84.3064	9.5000	100.0000	9.5000	71.7473	9.5000	96.7665
4.7500	72.7444	4.7500	80.5839	4.7500	99.9452	4.7500	42.8988	4.7500	84.5966
2.3600	47.5241	2.3600	78.0760	2.3600	99.8356	2.3600	26.0283	2.3600	66.7161
2.0000	41.4079	2.0000	77.5078	2.0000	99.8082	2.0000	22.9862	2.0000	61.8807
0.4250	6.8694	0.4250	73.1429	0.4250	93.2340	0.4250	10.0297	0.4250	13.3107
0.2500	3.7702	0.2500	69.6037	0.2500	81.7292	0.2500	5.5222	0.2500	7.6938
0.1500	2.7158	0.1500	65.5926	0.1500	69.7761	0.1500	3.4538	0.1500	5.9473
0.0750	1.7892	0.0750	57.2166	0.0750	52.1453	0.0750	2.2440	0.0750	4.5785
0.0375	0.9705	0.0304	43.0011	0.0340	30.2564	0.0369	1.1854	0.0368	1.9117
0.0238	0.6470	0.0204	33.4453	0.0217	27.2307	0.0237	0.5927	0.0236	0.9558
0.0169	0.3235	0.0148	28.6674	0.0157	22.6923	0.0168	0.4939	0.0167	0.7169
0.0138	0.3235	0.0123	26.2785	0.0128	22.6923	0.0138	0.3951	0.0136	0.7169
0.0098	0.3235	0.0088	22.6950	0.0092	19.6666	0.0098	0.1976	0.0097	0.4779
0.0069	0.1618	0.0063	20.3061	0.0065	17.3974	0.0069	0.1976	0.0068	0.4779
0.0034	0.0000	0.0032	14.9309	0.0033	12.8590	0.0034	0.0000	0.0034	0.2390
		0.0012	9.5558	0.0013	7.5641			0.0014	0.0000
		0.0010	9.5558	0.0010	7.5641				

Table C-2. Continued

Hines Branch Sample 4 Bed		Hines Branch Sample 5 Bed		Hines Branch Sample 5 Left Bank		Hines Branch Sample 5 Right Bank		Hines Branch Sample 6 Bed	
Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)
25.4000	100.0000	25.4000	100.0000	25.4000	100.0000	25.4000	100.0000	25.4000	100.0000
12.5000	99.6951	12.5000	97.9700	12.5000	99.8438	12.5000	100.0000	12.5000	93.3205
9.5000	99.4360	9.5000	95.3467	9.5000	99.8438	9.5000	100.0000	9.5000	86.8267
4.7500	95.9680	4.7500	88.5801	4.7500	99.6165	4.7500	99.9614	4.7500	62.9809
2.3600	85.7012	2.3600	80.7464	2.3600	99.3680	2.3600	99.9420	2.3600	39.6060
2.0000	80.9223	2.0000	77.8107	2.0000	99.3325	2.0000	99.9324	2.0000	34.0939
0.4250	29.0014	0.4250	22.1960	0.4250	98.1248	0.4250	97.5566	0.4250	9.6942
0.2500	19.2703	0.2500	11.9709	0.2500	96.9171	0.2500	94.5868	0.2500	7.0652
0.1500	13.5724	0.1500	10.2875	0.1500	95.5585	0.1500	91.6171	0.1500	5.6139
0.0750	10.1793	0.0750	7.9806	0.0750	91.0296	0.0750	82.2623	0.0750	4.1077
0.0371	3.2411	0.0371	3.1564	0.0273	73.3675	0.0297	58.6344	0.0364	1.8543
0.0235	2.5929	0.0237	1.8938	0.0188	59.6111	0.0195	51.1172	0.0232	1.5452
0.0168	1.9446	0.0169	1.2626	0.0139	50.4401	0.0142	45.1034	0.0165	1.2362
0.0137	1.9446	0.0138	1.2626	0.0116	45.8547	0.0119	40.5931	0.0135	0.9271
0.0097	1.6205	0.0098	0.6313	0.0085	38.2122	0.0086	36.0827	0.0096	0.9271
0.0069	1.2964	0.0069	0.6313	0.0062	31.3340	0.0062	31.5724	0.0068	0.6181
0.0034	0.0000	0.0034	0.0000	0.0031	22.9273	0.0031	23.3034	0.0033	0.3090
				0.0012	15.2849	0.0012	16.5379	0.0014	0.0000
				0.0010	13.7564	0.0010	15.0345		

Table C-2. Continued

Hines Branch Sample 7 Bed		Hines Branch Sample 8 Bed		Hines Branch Sample 8 Left Bank		Hines Branch Sample 8 Right Bank	
Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)
25.4000	100.0000	25.4000	100.0000	25.4000	100.0000	25.4000	100.0000
12.5000	96.5038	12.5000	95.0356	12.5000	100.0000	12.5000	100.0000
9.5000	91.2224	9.5000	89.3528	9.5000	100.0000	9.5000	100.0000
4.7500	76.9414	4.7500	73.6707	4.7500	99.8858	4.7500	99.8119
2.3600	58.4156	2.3600	55.4102	2.3600	99.8067	2.3600	99.4121
2.0000	53.3646	2.0000	50.4522	2.0000	99.7980	2.0000	99.2710
0.4250	26.4401	0.4250	15.1912	0.4250	98.5697	0.4250	91.6919
0.2500	17.3173	0.2500	10.7885	0.2500	96.5737	0.2500	83.5184
0.1500	11.5852	0.1500	7.1395	0.1500	92.5818	0.1500	74.3047
0.0750	7.9118	0.0750	3.2128	0.0750	78.6101	0.0750	56.1743
0.0362	3.8828	0.0375	1.2048	0.0307	54.4093	0.0333	34.6075
0.0233	2.4523	0.0238	0.8032	0.0202	45.0820	0.0217	28.5888
0.0166	2.0436	0.0169	0.4016	0.0148	37.3092	0.0154	27.0842
0.0136	1.6349	0.0138	0.4016	0.0123	34.2001	0.0129	21.0655
0.0097	1.0218	0.0098	0.2008	0.0088	29.5365	0.0092	19.5608
0.0069	0.8174	0.0069	0.0000	0.0064	24.8728	0.0065	17.3038
0.0034	0.4087			0.0032	18.6546	0.0032	13.5421
0.0014	0.2044			0.0012	12.4364	0.0013	9.7804
0.0000	0.0000			0.0010	12.4364	0.0010	9.0281

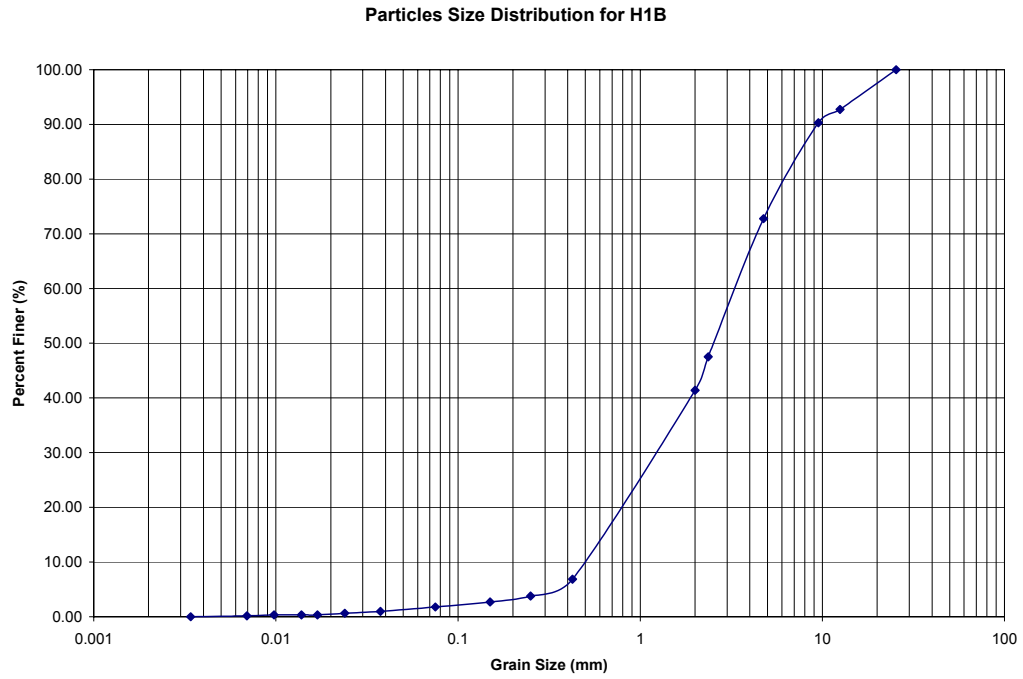


Figure C-14. Particle Size Distribution for H1B

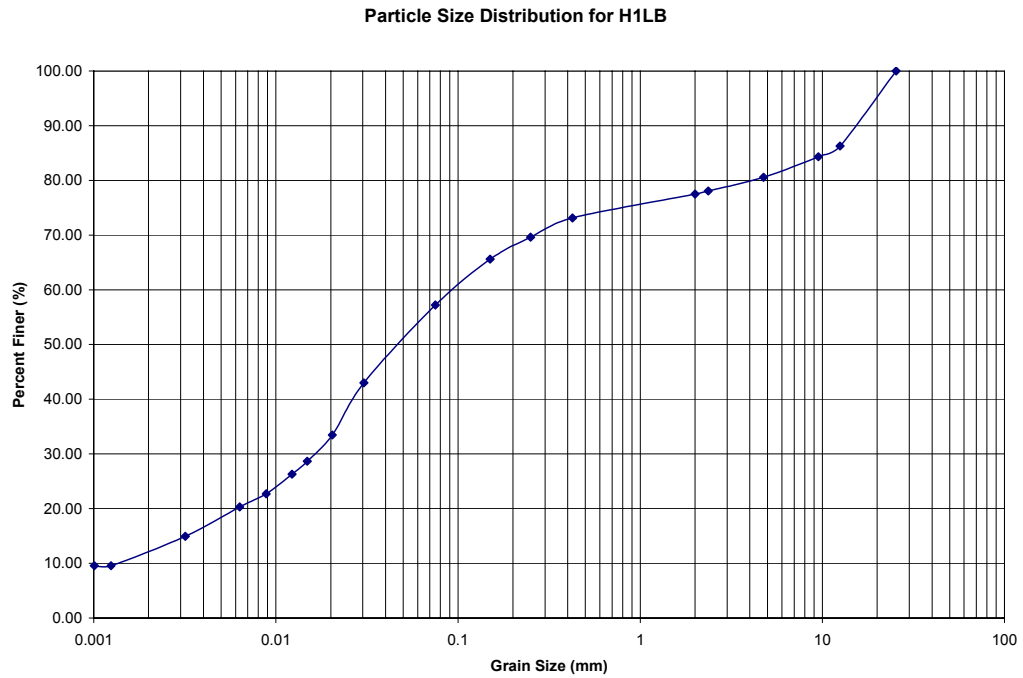


Figure C-15. Particle Size Distribution for H1LB

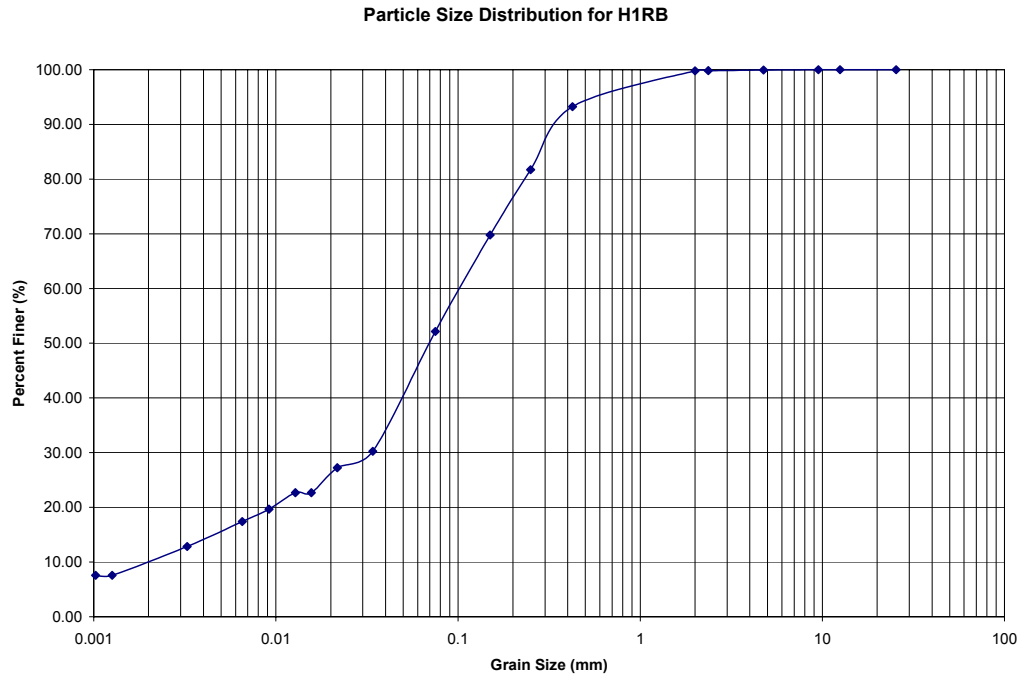


Figure C-16. Particle Size Distribution for H1RB

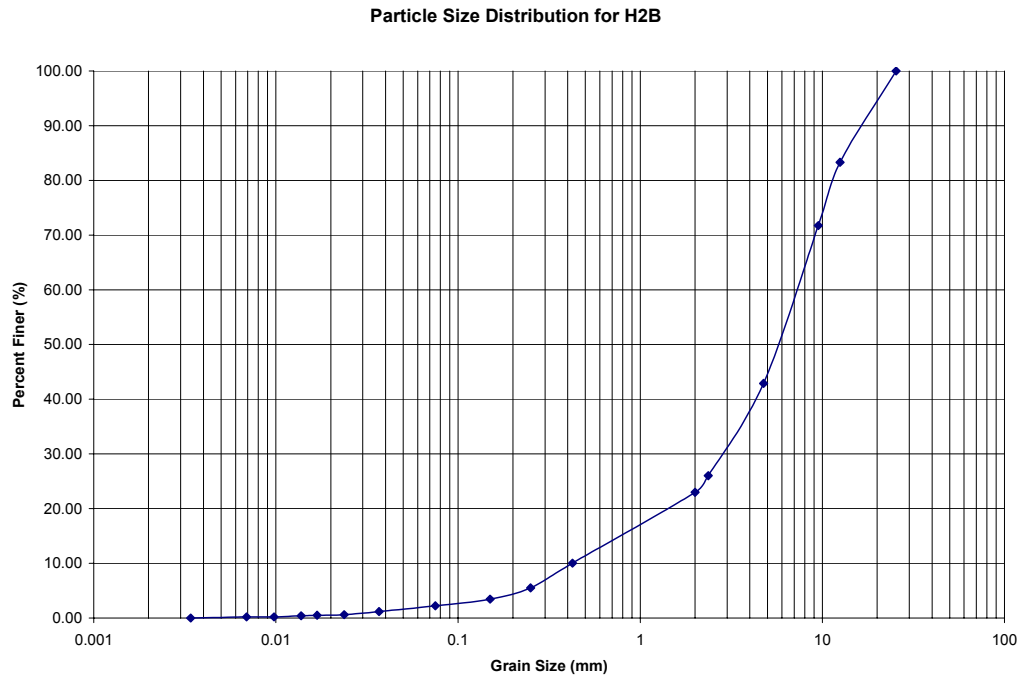


Figure C-17. Particle Size Distribution for H2B

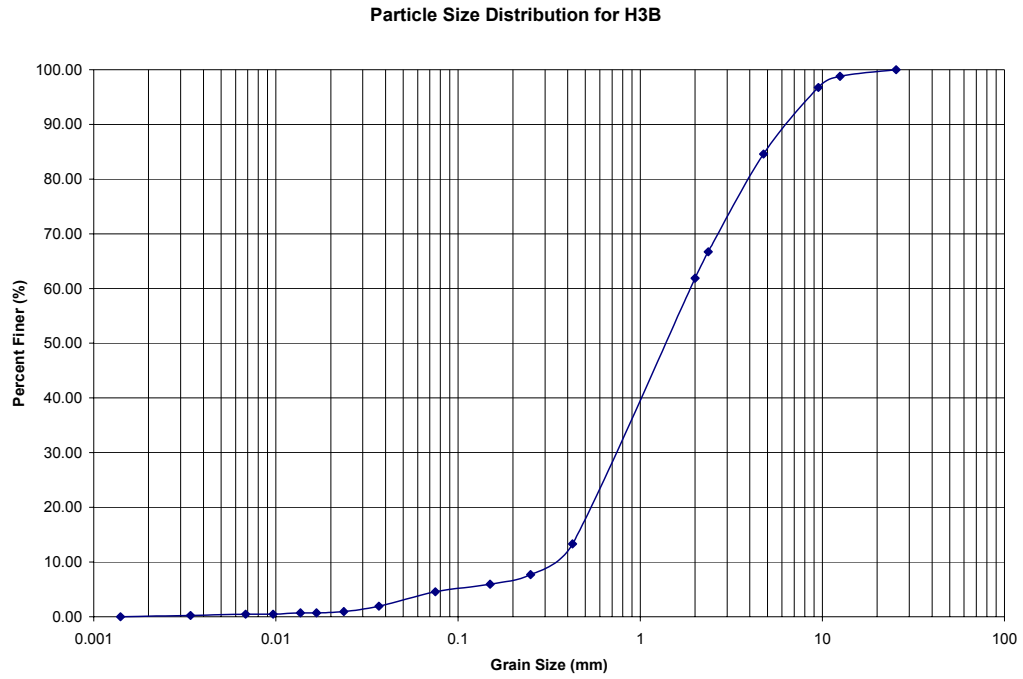


Figure C-18. Particle Size Distribution for H3B

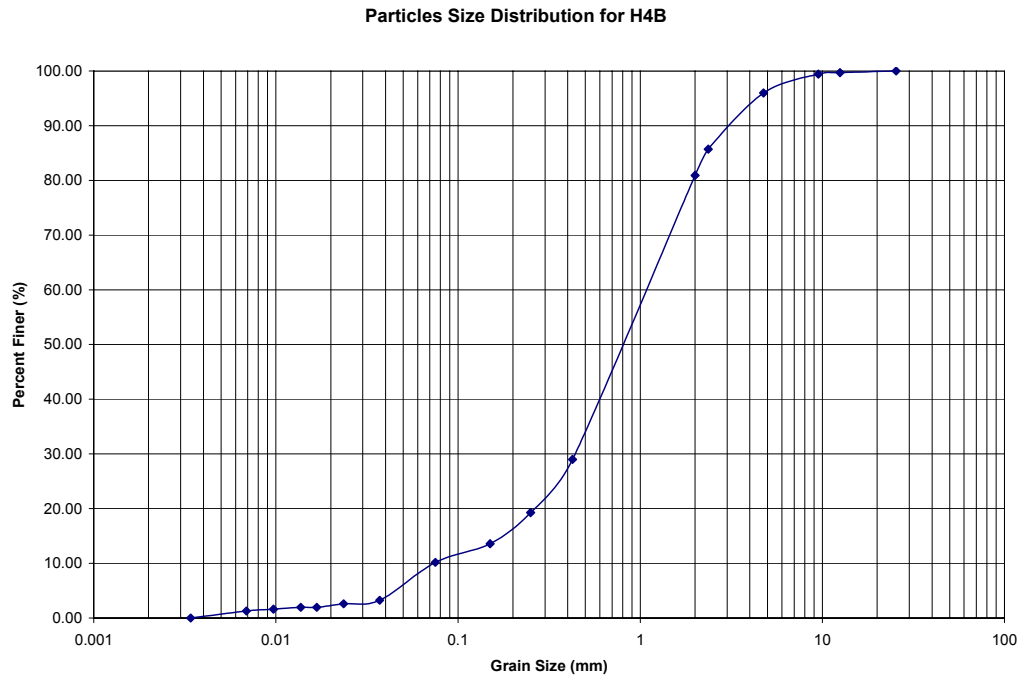


Figure C-19. Particle Size Distribution for H4B

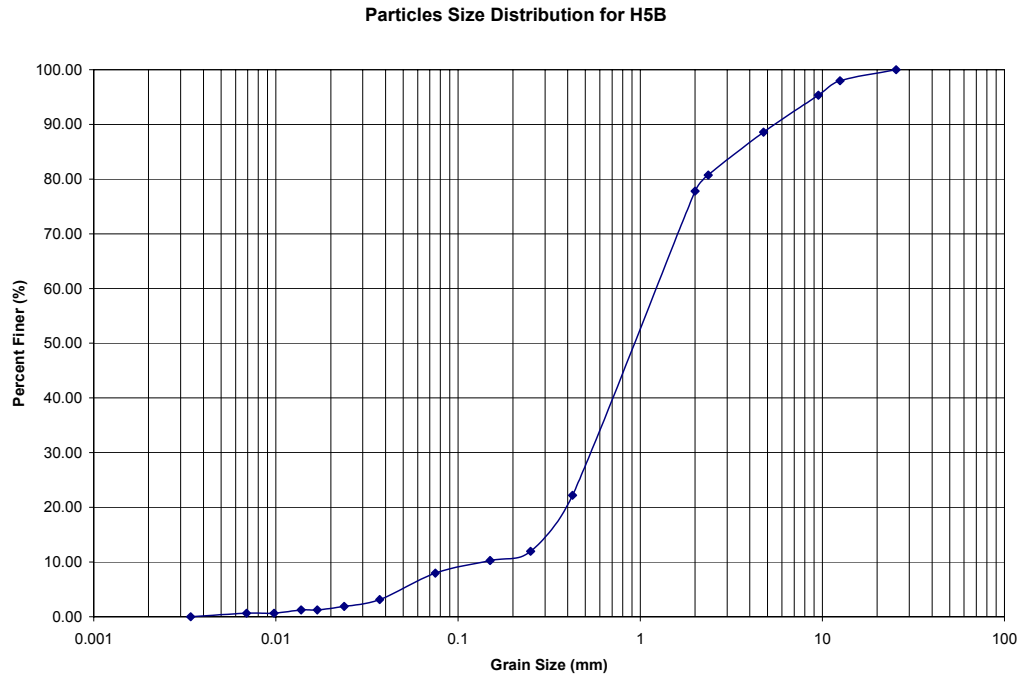


Figure C-20. Particle Size Distribution for H5B

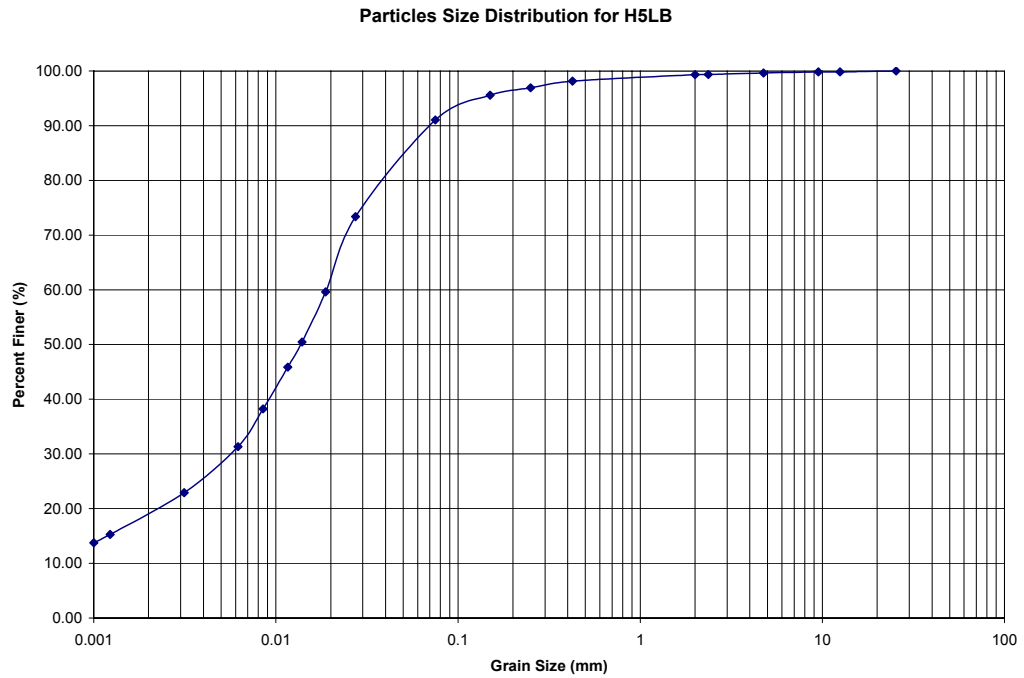


Figure C-21. Particle Size Distribution for H5LB

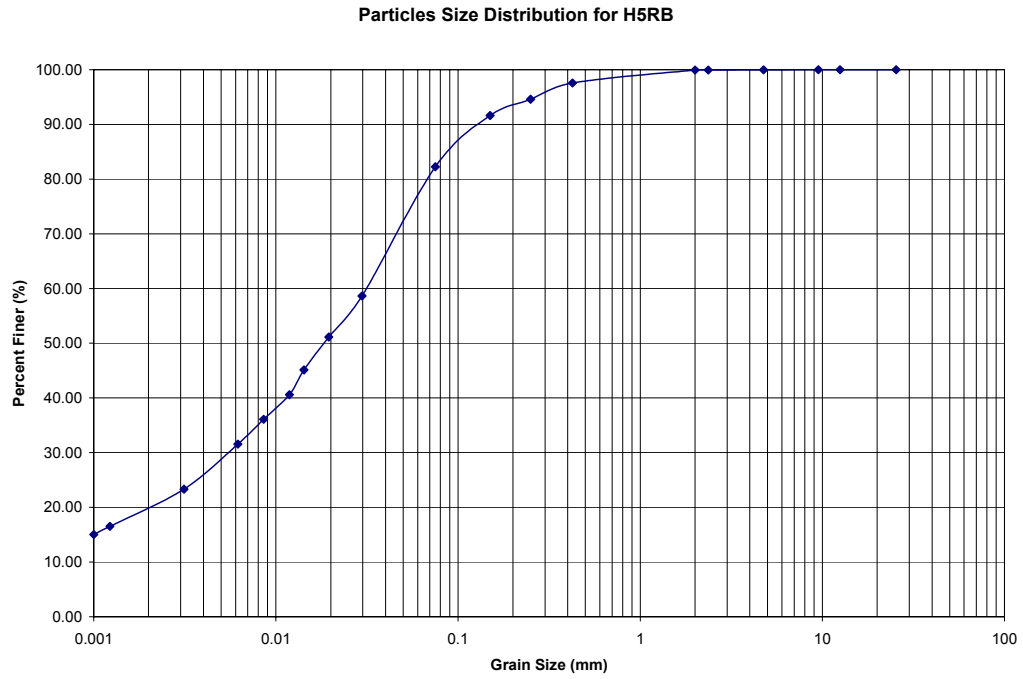


Figure C-22. Particle Size Distribution for H5RB

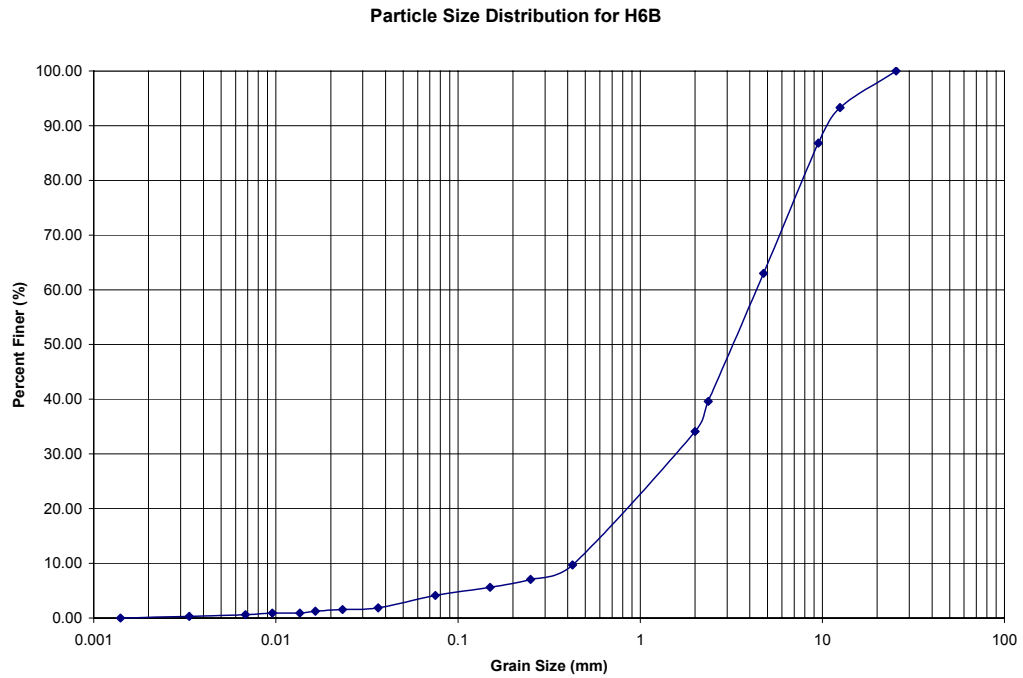


Figure C-23. Particle Size Distribution for H6B

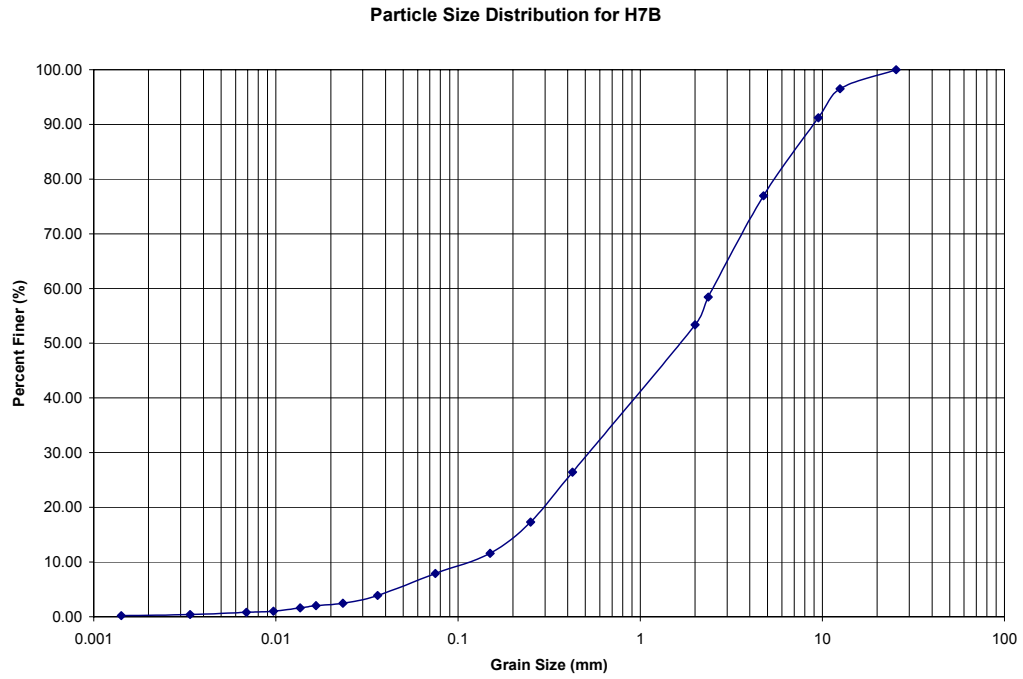


Figure C-24. Particle Size Distribution for H7B

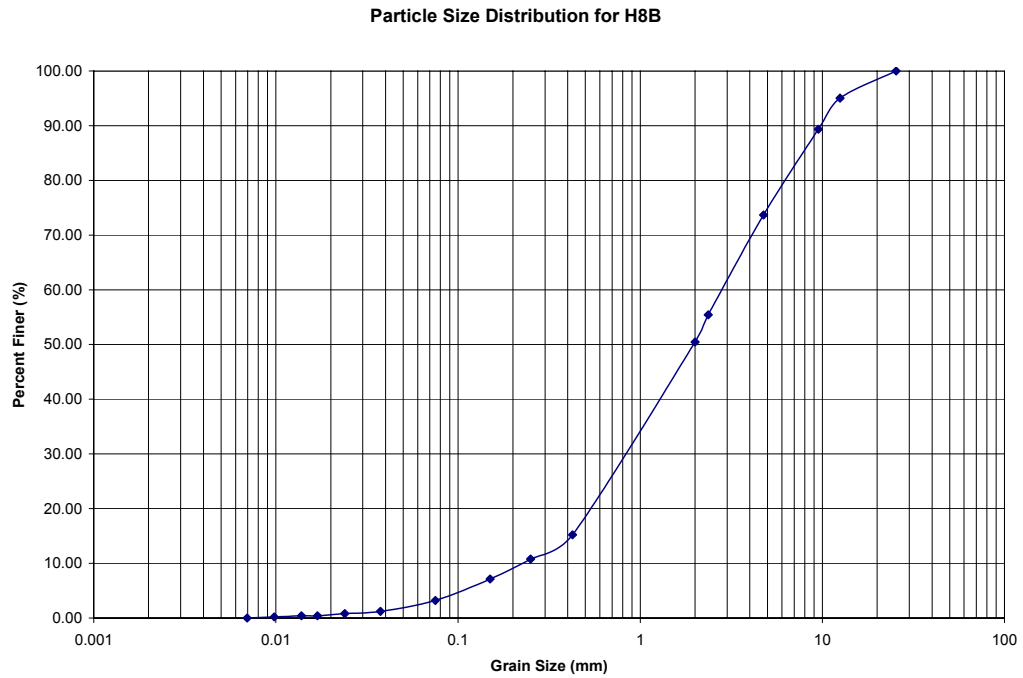


Figure C-25. Particle Size Distribution for H8B

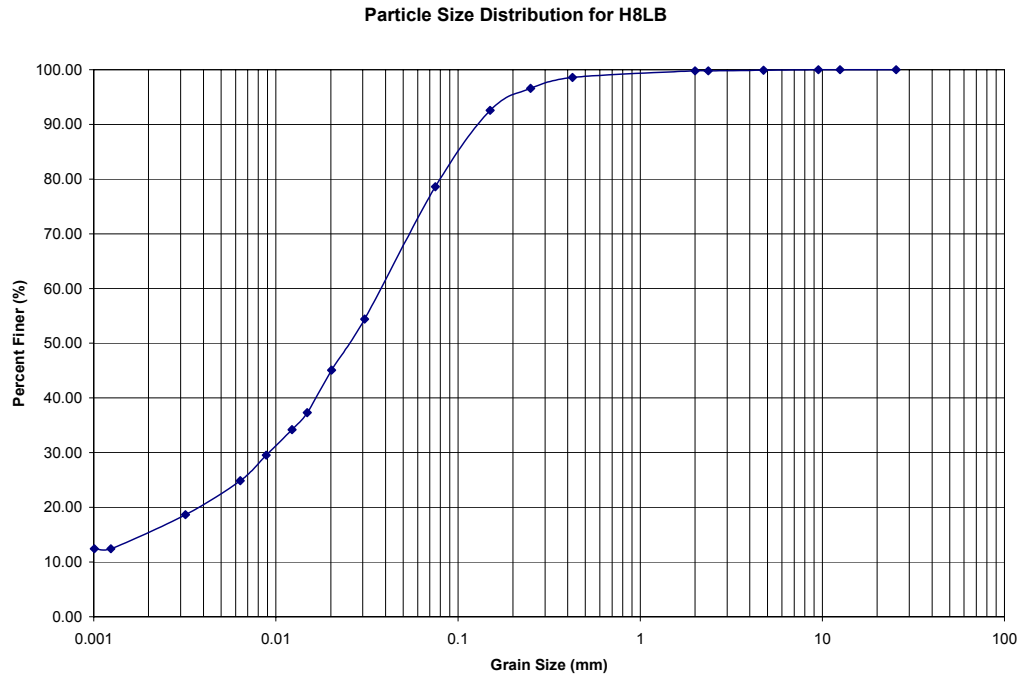


Figure C-26. Particle Size Distribution for H8LB

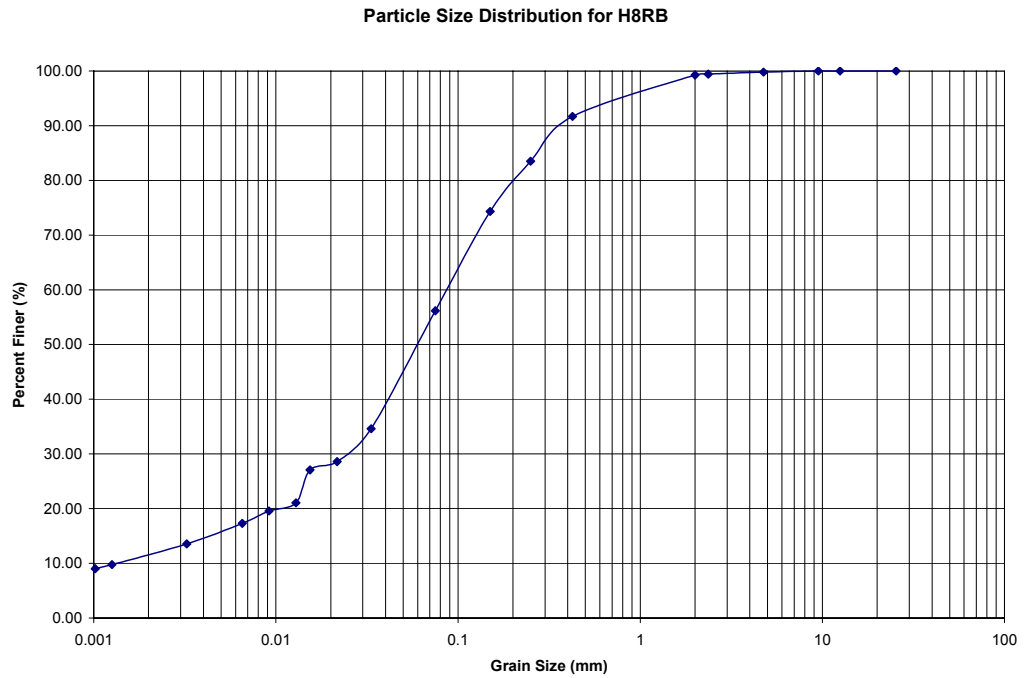


Figure C-27. Particle Size Distribution for H8RB

Table C-3. Particle Size Distributions for the Beaver Creek Watershed Sample Sites

Allen Branch - PSD		Beaver Creek at Beeler Rd - PSD		Bishop Creek - PSD		Cox Creek - PSD		Grassy Creek - PSD		Hines Branch - PSD	
Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)
25.4	100.00	25.4	100.00	25.4	100.00	25.4	100.00	25.4	100.00	25.4	100.00
12.5	32.79	12.5	90.97	12.5	44.63	12.5	62.50	12.5	90.27	12.5	87.60
9.5	26.84	9.5	85.43	9.5	39.60	9.5	56.48	9.5	84.49	9.5	78.74
4.75	12.82	4.75	68.07	4.75	25.27	4.75	43.95	4.75	61.52	4.75	51.48
2.36	5.89	2.36	56.47	2.36	18.54	2.36	35.06	2.36	41.55	2.36	32.74
2	5.00	2	54.17	2	17.56	2	33.28	2	37.96	2	29.64
0.425	1.40	0.425	18.62	0.425	7.13	0.425	10.91	0.425	15.18	0.425	9.97
0.25	0.95	0.25	10.79	0.25	4.21	0.25	6.54	0.25	7.95	0.25	7.37
0.15	0.79	0.15	8.16	0.15	2.79	0.15	4.25	0.15	5.65	0.15	6.28
0.075	0.71	0.075	7.08	0.075	2.08	0.075	3.44	0.075	4.85	0.075	5.22
0.0367	0.23	0.0367	2.38	0.0359	1.08	0.0367	1.42	0.0363	1.48	0.0366	1.47
0.0233	0.18	0.0233	1.91	0.0230	0.69	0.0236	0.57	0.0231	0.99	0.0233	1.07
0.0165	0.09	0.0167	0.95	0.0163	0.54	0.0167	0.57	0.0165	0.66	0.0167	0.54
0.0136	0.00	0.0136	0.95	0.0134	0.46	0.0137	0.28	0.0135	0.33	0.0136	0.54
		0.0097	0.48	0.0095	0.31	0.0097	0.00	0.0096	0.00	0.0097	0.27
		0.0068	0.24	0.0067	0.15					0.0069	0.00
		0.0025	0.00	0.0025	0.00						

Table C-3. Continued

Kerns Branch - PSD		Knob Fork - PSD		Lammie Branch - PSD		Meadow Creek - PSD		Mill Branch - PSD		North Fork - PSD	
Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)
25.4	100.00	25.4	100.00	25.4	100.00	25.4	100.00	25.4	100.00	25.4	100.00
12.5	82.82	12.5	83.90	12.5	76.99	12.5	89.01	12.5	95.43	12.5	76.80
9.5	70.51	9.5	72.16	9.5	57.25	9.5	79.24	9.5	88.33	9.5	66.72
4.75	48.00	4.75	43.34	4.75	26.46	4.75	42.71	4.75	54.75	4.75	43.53
2.36	32.46	2.36	28.80	2.36	12.37	2.36	18.53	2.36	30.08	2.36	29.72
2	29.72	2	25.76	2	10.37	2	15.70	2	26.56	2	27.22
0.425	16.04	0.425	6.20	0.425	3.24	0.425	5.34	0.425	10.42	0.425	5.96
0.25	10.49	0.25	2.95	0.25	2.62	0.25	3.82	0.25	3.38	0.25	2.36
0.15	7.98	0.15	2.09	0.15	2.09	0.15	2.96	0.15	1.51	0.15	1.88
0.075	6.75	0.075	1.66	0.075	1.81	0.075	2.30	0.075	1.26	0.075	1.66
0.0351	2.90	0.0368	0.46	0.0367	0.43	0.0364	0.57	0.0367	0.58	0.0367	0.61
0.0226	2.11	0.0233	0.46	0.0234	0.17	0.0231	0.43	0.0234	0.23	0.0233	0.49
0.0162	1.32	0.0165	0.23	0.0166	0.09	0.0165	0.22	0.0165	0.23	0.0165	0.24
0.0133	1.06	0.0136	0.00	0.0136	0.00	0.0135	0.14	0.0135	0.12	0.0135	0.24
0.0095	0.66					0.0096	0.00	0.0096	0.00	0.0096	0.00
0.0067	0.26										
0.0025	0.00										

Table C-3. Continued

Plumb Creek - PSD		Unnamed at Emory Rd - PSD		Unnamed at Solway Rd - PSD	
Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)	Grain Size (mm)	Percent Finer (%)
25.4	100.00	25.4	100.00	25.4	100.00
12.5	80.18	12.5	100.00	12.5	84.06
9.5	72.13	9.5	99.86	9.5	73.07
4.75	56.92	4.75	96.96	4.75	46.17
2.36	44.48	2.36	89.14	2.36	28.53
2	41.45	2	84.66	2	26.02
0.425	18.34	0.425	72.01	0.425	16.10
0.25	14.07	0.25	70.56	0.25	6.56
0.15	11.12	0.15	69.33	0.15	2.54
0.075	7.83	0.075	67.09	0.075	2.05
0.0354	3.02	0.0237	43.00	0.0364	0.94
0.0229	1.85	0.0152	42.28	0.0233	0.47
0.0163	1.34	0.0109	41.55	0.0165	0.24
0.0134	1.01	0.0094	37.90	0.0135	0.12
0.0095	0.50	0.0070	34.26	0.0096	0.00
0.0067	0.34	0.0052	30.61		
0.0025	0.00	0.0020	24.05		
		0.0012	18.22		

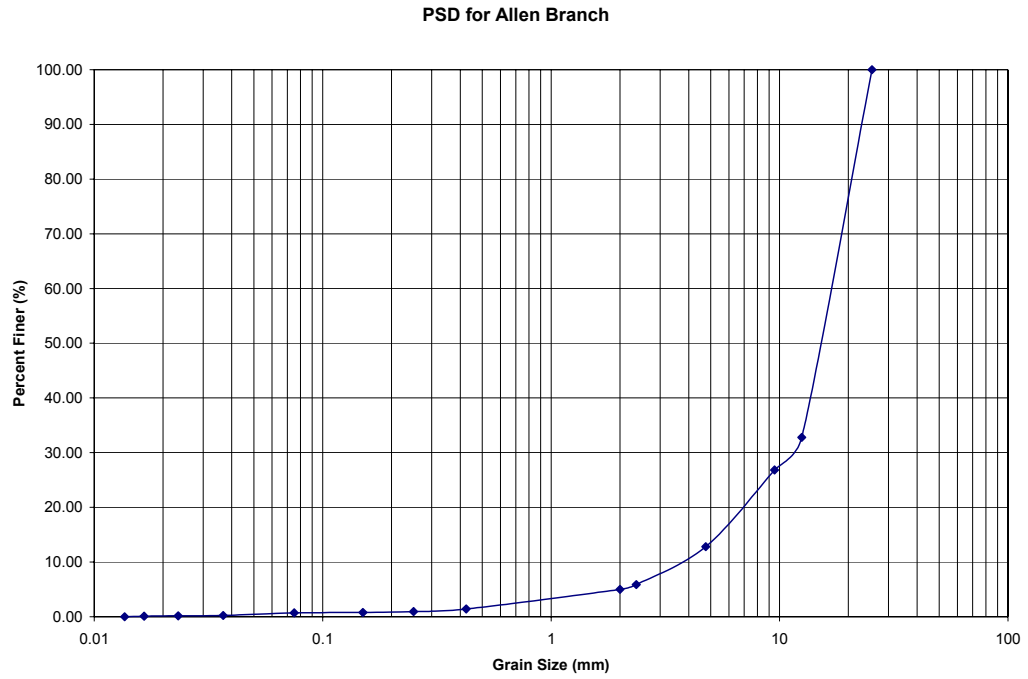


Figure C-28. Particle Size Distribution for Allen Branch

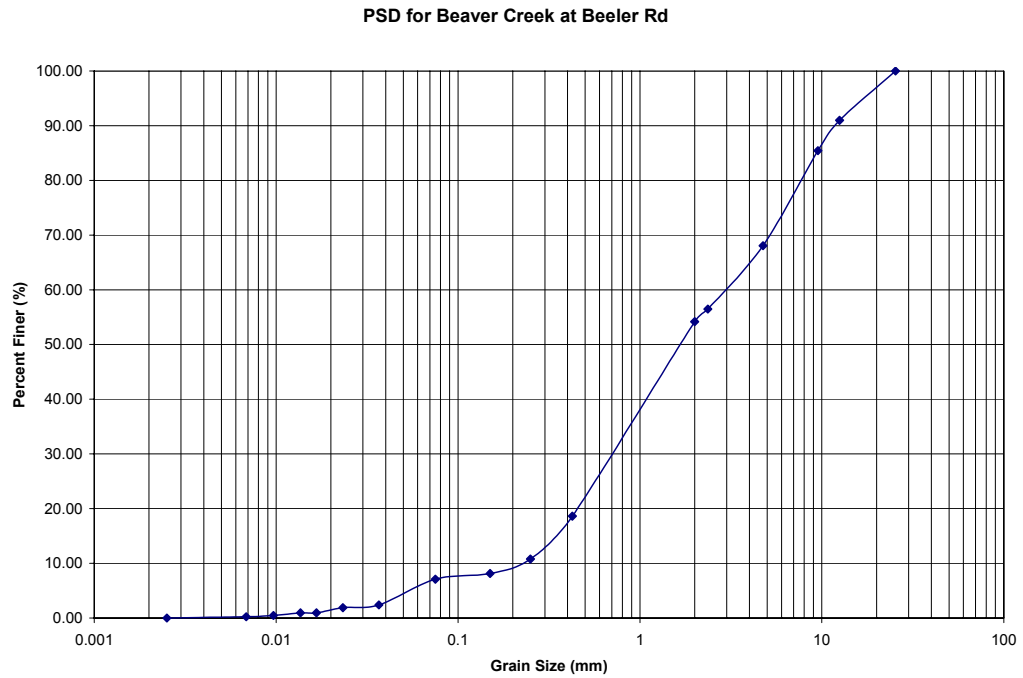


Figure C-29. Particle Size Distribution for Beaver Creek at Beeler Rd

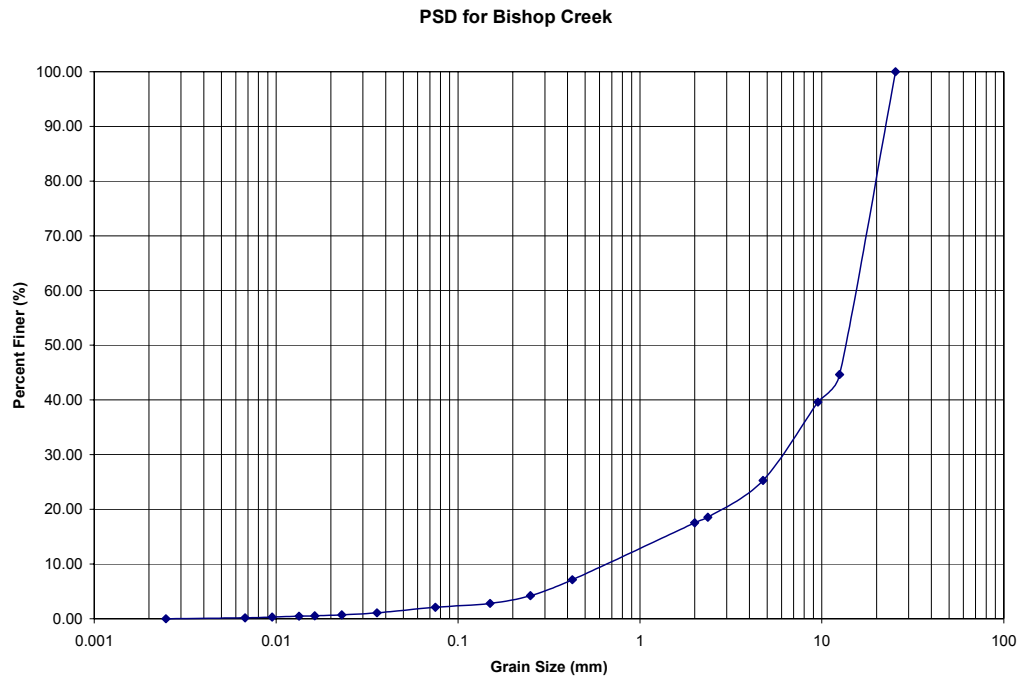


Figure C-30. Particle Size Distribution for Bishop Creek

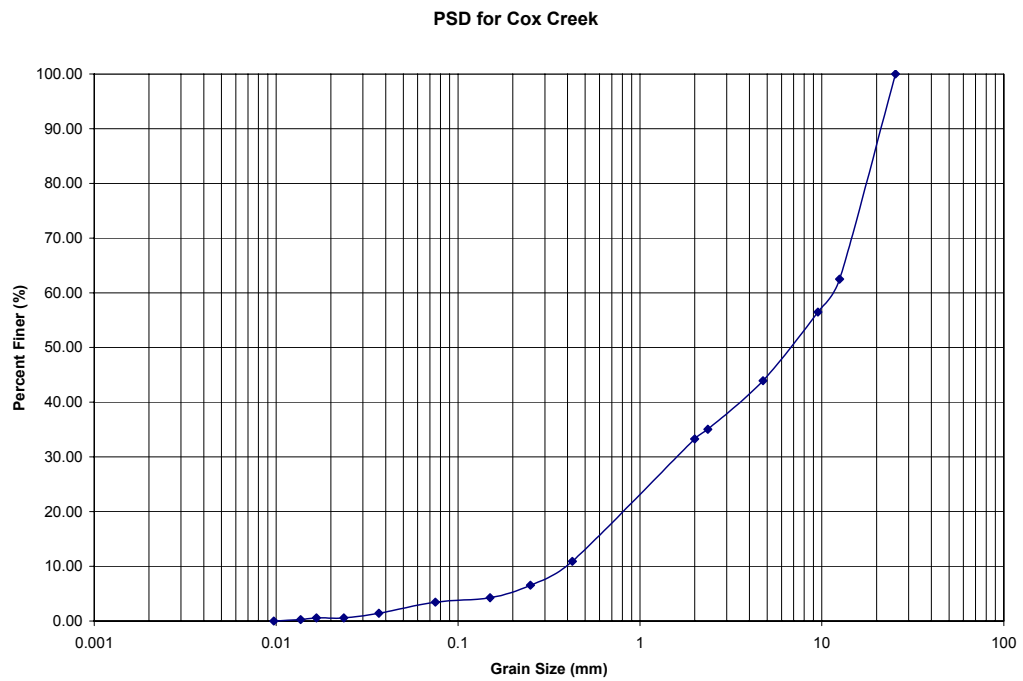


Figure C-31. Particle Size Distribution for Cox Creek

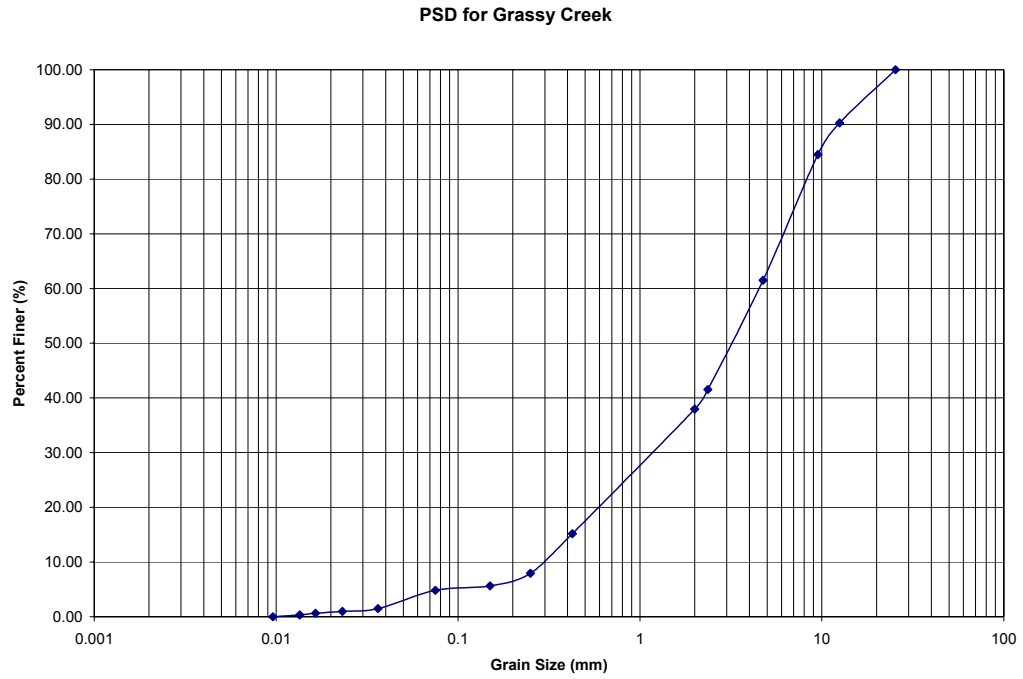


Figure C-32. Particle Size Distribution for Grassy Creek

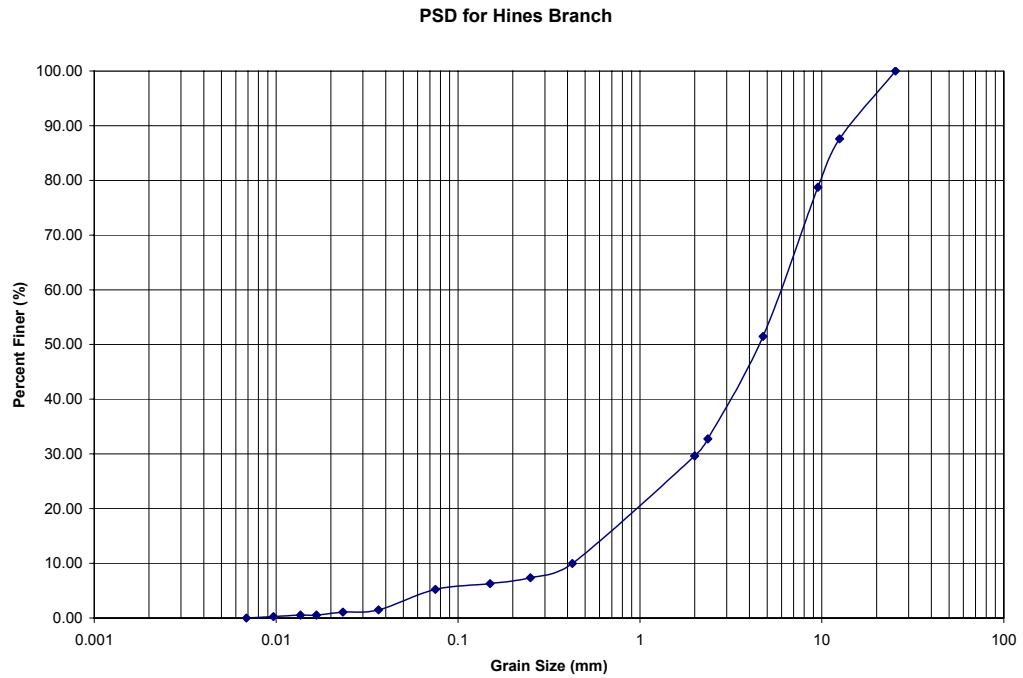


Figure C-33. Particle Size Distribution for Hines Branch

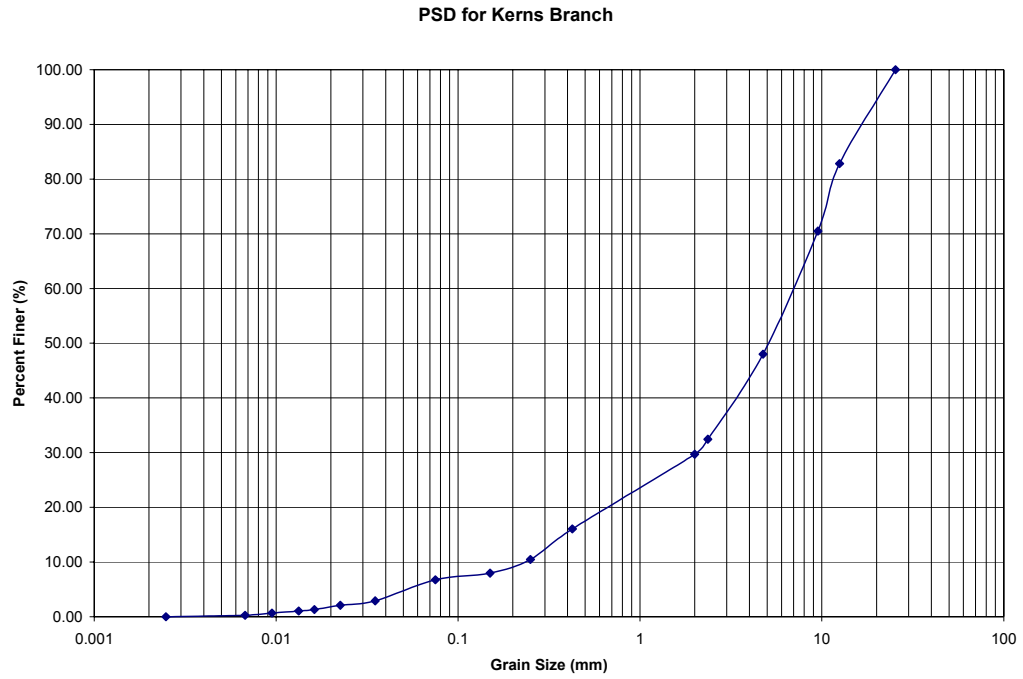


Figure C-34. Particle Size Distribution for Kerns Branch

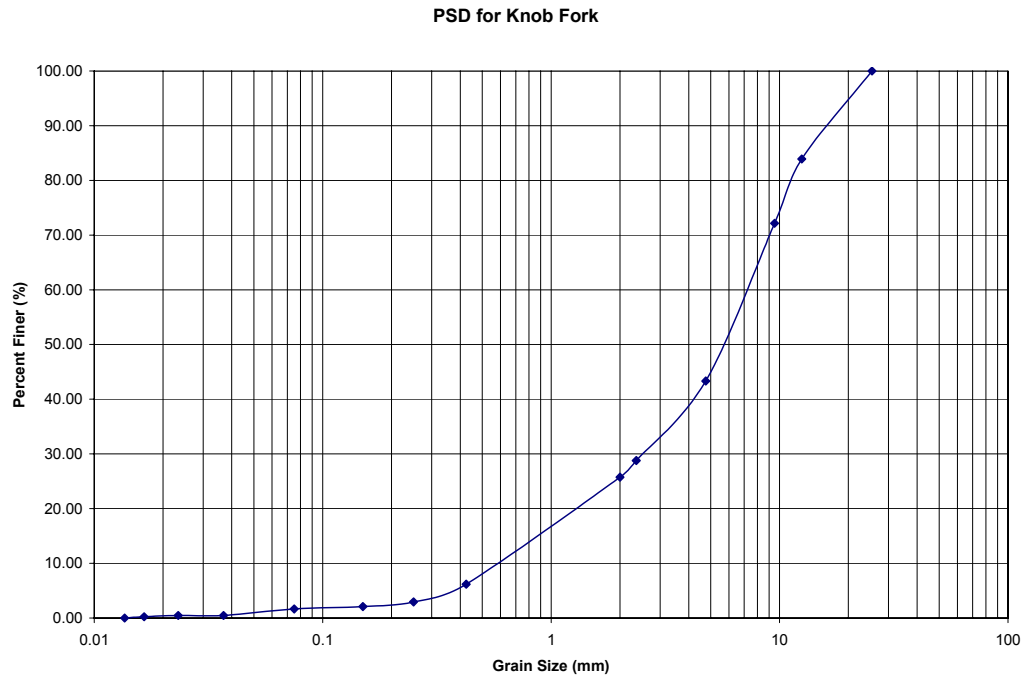


Figure C-35. Particle Size Distribution for Knob Fork

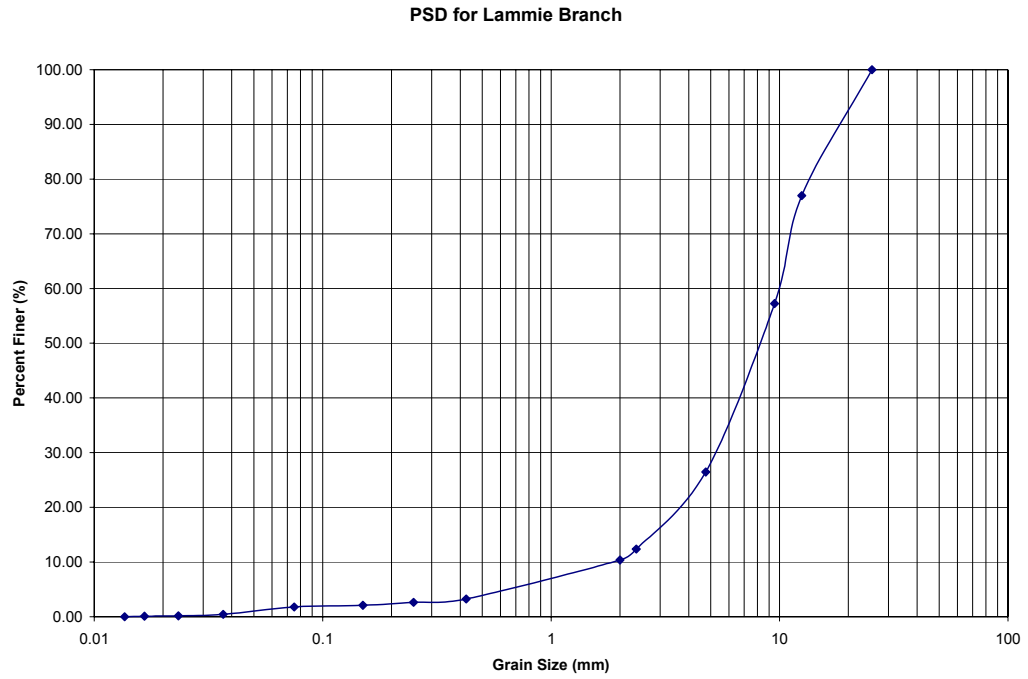


Figure C-36. Particle Size Distribution for Lammie Branch

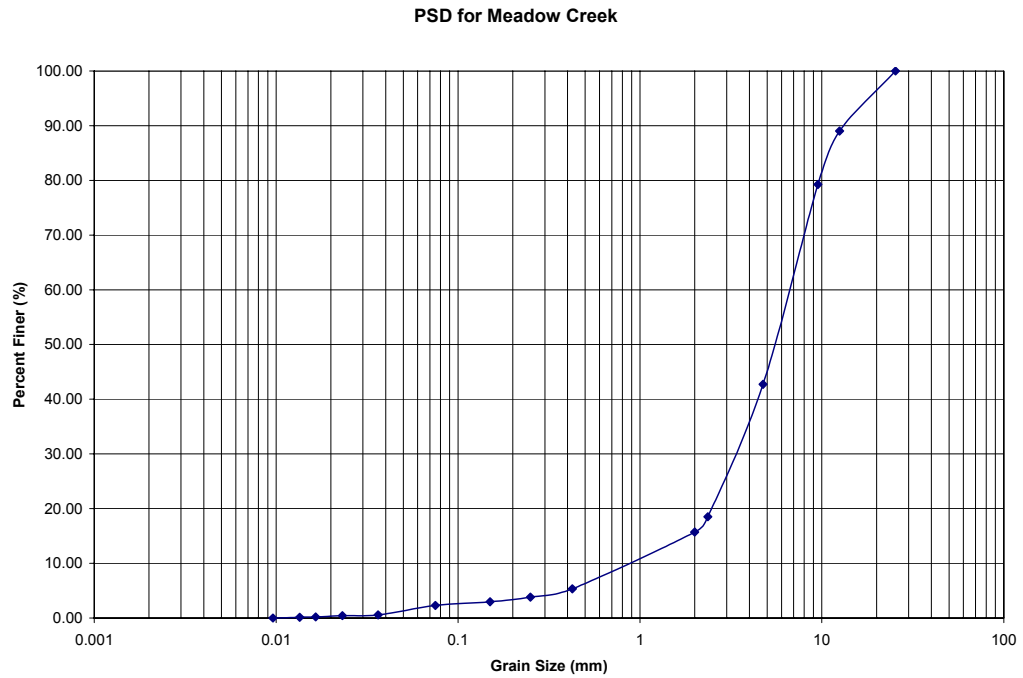


Figure C-37. Particle Size Distribution for Meadow Creek

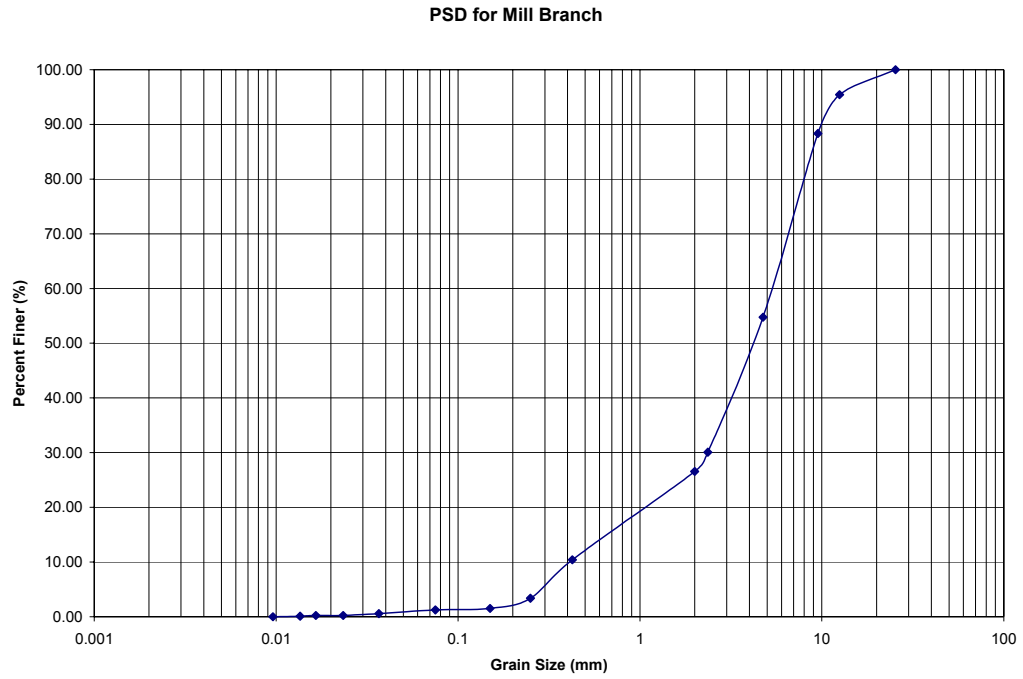


Figure C-38. Particle Size Distribution for Mill Branch

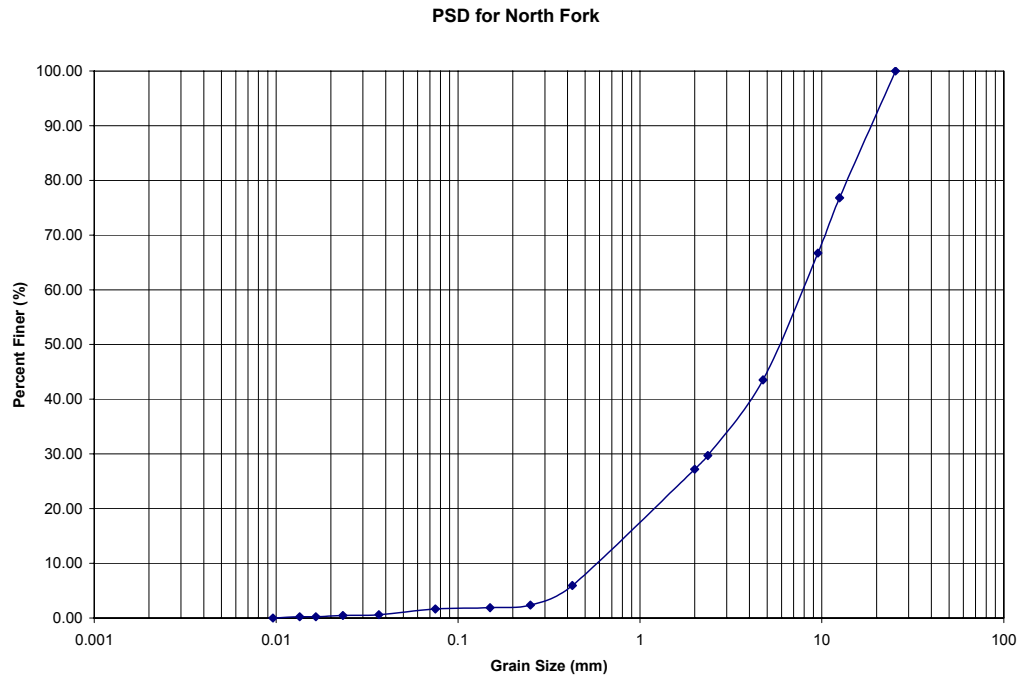


Figure C-39. Particle Size Distribution for North Fork

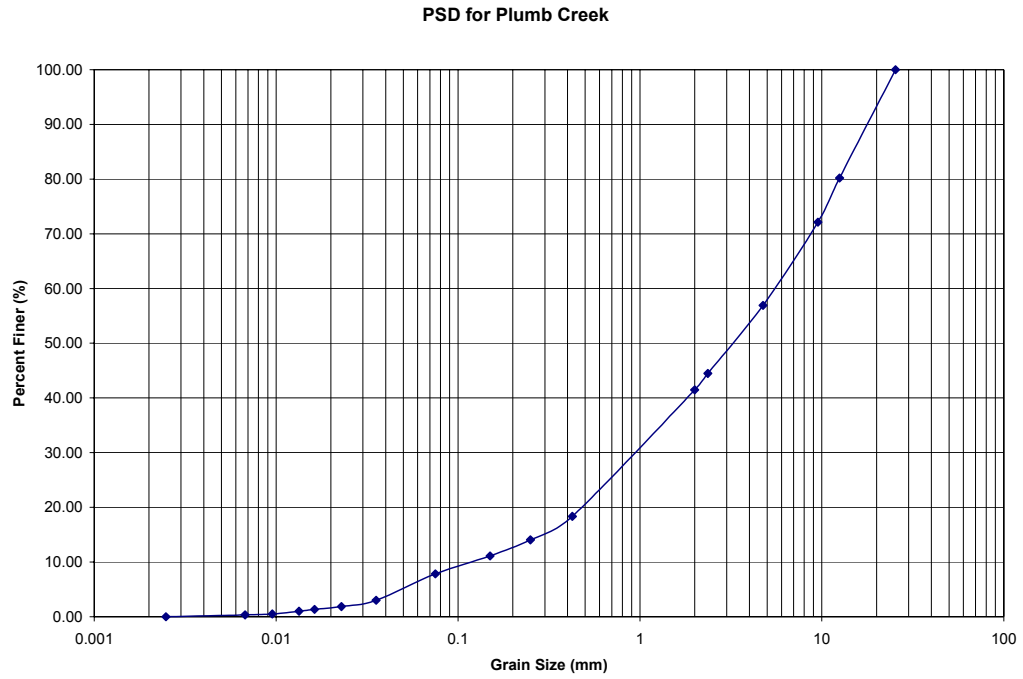


Figure C-40. Particle Size Distribution for Plumb Creek

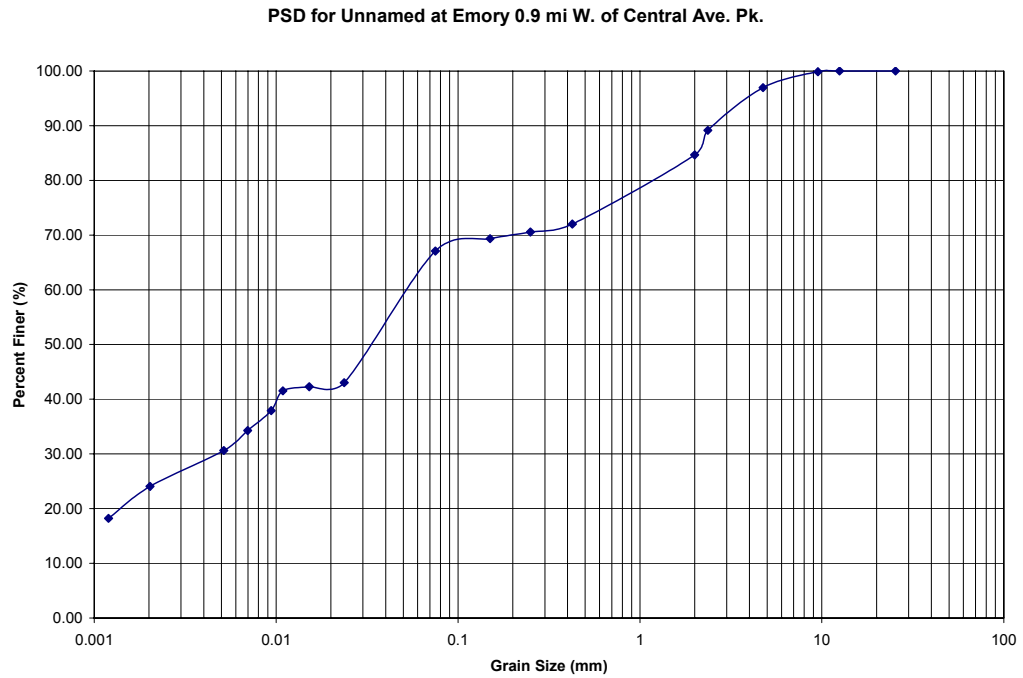


Figure C-41. Particle Size Distribution for Unnamed Trib at Emory Rd

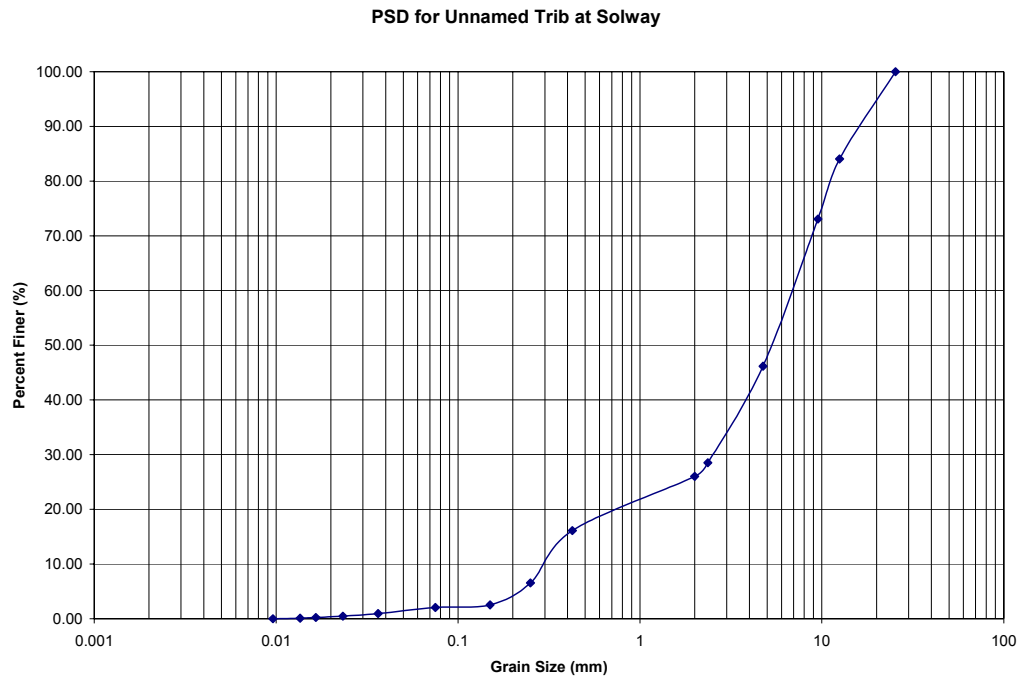


Figure C-42. Particle Size Distribution for Unnamed Trib at Solway Rd

VITA

Brantley Allison Thames was born on April 15, 1979 in Sumter, SC. Until the age of 10, he lived in Pinewood, SC attending Manchester Elementary School. At the age of 10, he moved to Manchester, TN where he attended Hickerson Elementary, Coffee County Middle, and Coffee County Central High School. He graduated from Coffee County Central High School in May, 1997.

Brantley earned his Associate of Arts degree at Santa Fe Community College in Gainesville, FL in May of 2000. In December of 2003, he went on to earn his Bachelor of Science degree in Civil Engineering from the University of Tennessee, Knoxville. While earning his BS in Civil Engineering at UT, he worked for the US Army Corps of Engineers through the university cooperative engineering program. Brantley entered the Environmental Engineering graduate program at the University of Tennessee, Knoxville in the spring of 2004. He will receive his Master of Science degree in Environmental Engineering in May, 2005.