Suspended-Sediment Transport and Bed-Material Characteristics of Shades Creek, Alabama and Ecoregion 67: Developing Water-Quality Criteria for Suspended and Bed-Material Sediment

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Andrew Simon, Eddy Langendoen, Ron Bingner, Robert Wells,
Yongping Yuan, and Carlos Alonso

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1 INTRODUCTION

Excessive erosion, transport, and deposition of sediment in surface waters are major water quality problems in the United States. The 1996 National Water Quality Inventory (Section 305(b) Report to Congress) indicates that sediments are ranked as a leading cause of water-quality impairment of assessed rivers and lakes. Impairment by sediment can be separated into problems resulting from chemical constituents adsorbed onto the surface of fine-grained sediments (sediment quality), problems resulting from sediment quantities (clean sediment) irrespective of adsorbed constituents, and alteration of substrate (bed material) by erosion or deposition. The maximum allowable loadings to, or in a stream or waterbody that does not impair designated uses has been termed the "TMDL" (total maximum daily load). The 1998 list of impaired waterbodies in the state of Alabama lists Shades Creek, Jefferson County as having impaired conditions for aquatic life support due to turbidity and siltation.

Impairment due to turbidity refers to excessive amounts of fine-grained materials being transported in the water column. Impairment due to siltation implies that deposition of fine-grained materials on the channel bed has hampered oxygenation of coarser bed material (gravels and cobbles), creating poor habitat for aquatic organisms. To determine the severity of the sediment problem and along Shades Creek, rates of suspended-sediment transport and characteristics of the channel bed need to be compared to un-impacted streams from the same climatic and physiographic region. In the case of Shades Creek, this region is Ecoregion # 67, the Ridge and Valley.

1.1 Background and Problem

Virtually the entire length of Shades Creek is listed as impaired by the Alabama Department of Environmental Management (ADEM). Surveys conducted between 1990 and 1993, and again in 1997 indicated impairment due to the following reasons: collection system failure, highway/road/bridge construction, land development, urban runoff, removal of riparian vegetation, and bank/shoreline modification. By law a TMDL must, therefore, be developed for Shades Creek.

Water quality criteria for the State of Alabama does not contain a numerical target for sediment but is in narrative form for turbidity: "*there shall be no turbidity other than natural origin that will cause substantial visible contrast with the natural appearance of waters or interfere with any beneficial uses which they serve. Furthermore, in no case shall turbidity exceed 50 Nephelometric units above background. Background will be interpreted as the natural condition of the receiving waters, without the influence of man-made or man-induced causes. Turbidity levels caused by natural runoff will be included in establishing background levels*" (ADEM, 2003, written communication). In the absence of a numerical target for suspended-sediment loads and bed-material characteristics along Shades Creek, conditions need to be compared to unimpaired streams in the region. Sediment conditions in these unimpaired streams are thus termed "reference" streams or reaches.

Preliminary-reference suspended-sediment transport rates have been developed for various ecoregions of the United States (Simon *et al*., 2003). However, reference conditions for the ecoregion containing Shades Creek (# 67; Ridge and Valley) needed to be determined to provide a mechanism to compare suspended-sediment transport rates and bed-material characteristics along Shades Creek.

Only limited historical sediment-transport data are available for Shades Creek and a number of stable/“reference” reaches can be identified. More specifically, these sediment-transport data must be expressed in the same form as those data developed for reference conditions. To accomplish these tasks a combination of empirical and numerical techniques can be used. Suspended-sediment loads from typical streams in the region with historical data can be analyzed by relating the geomorphic conditions at those streams with the conditions along Shades Creek (Simon *et al*., 2003). Water and sediment contributions from uplands areas can be obtained with the watershed simulation model AnnAGNPS (Cronshey and Theurer, 1998). This information is also supplied as the boundary conditions used to determine the channel contributions from main channel streambeds and banks using the channel-evolution model CONCEPTS (Langendoen, 2000).

1.2 Objectives and Scope

The overall objectives of this study are to determine sediment yields and sources in the Shades Creek watershed and to compare these to “reference” sediment yields for unimpaired streams in the region, and to develop a methodology for determining “reference” bed-material characteristics supportive of aquatic health. Sediment sources can potentially include sheet and rill erosion from uplands and agricultural fields, gullies, and streambeds and banks. Specific objectives include:

1. Determine an applicable suspended-sediment “reference” condition and sediment yield for the Ridge and Valley Ecoregion and apply it to conditions along Shades Creek using geomorphic techniques and historical data from the U.S. Geological Survey gauging station on Shades Creek near Greenwood, Alabama;
2. Develop a methodology to determine “reference” bed-material characteristics for the Ridge and Valley Ecoregion and apply it to conditions along Shades Creek.
3. Determine sediment loadings emanating from Shades Creek using historical flow and suspended-sediment transport data and by upland flow and sediment modeling using AnnAGNPS and the channel-evolution model CONCEPTS;
4. Determine the contributions to sediment loads from various channel and upland sources in the Shades Creek watershed and simulate the effects of gross upland and streambank best management practices.

The project encompasses the entire Shades Creek watershed. Watershed reconnaissance, channel surveys, sampling and testing of stream-boundary sediments, and rapid geomorphic assessments were conducted along the entire length of Shades Creek (Figure 1-1). AnnAGNPS modeling was conducted for the entire watershed to produce water and sediment loadings from tributaries and adjoining land along the main channel that was modeled using CONCEPTS.

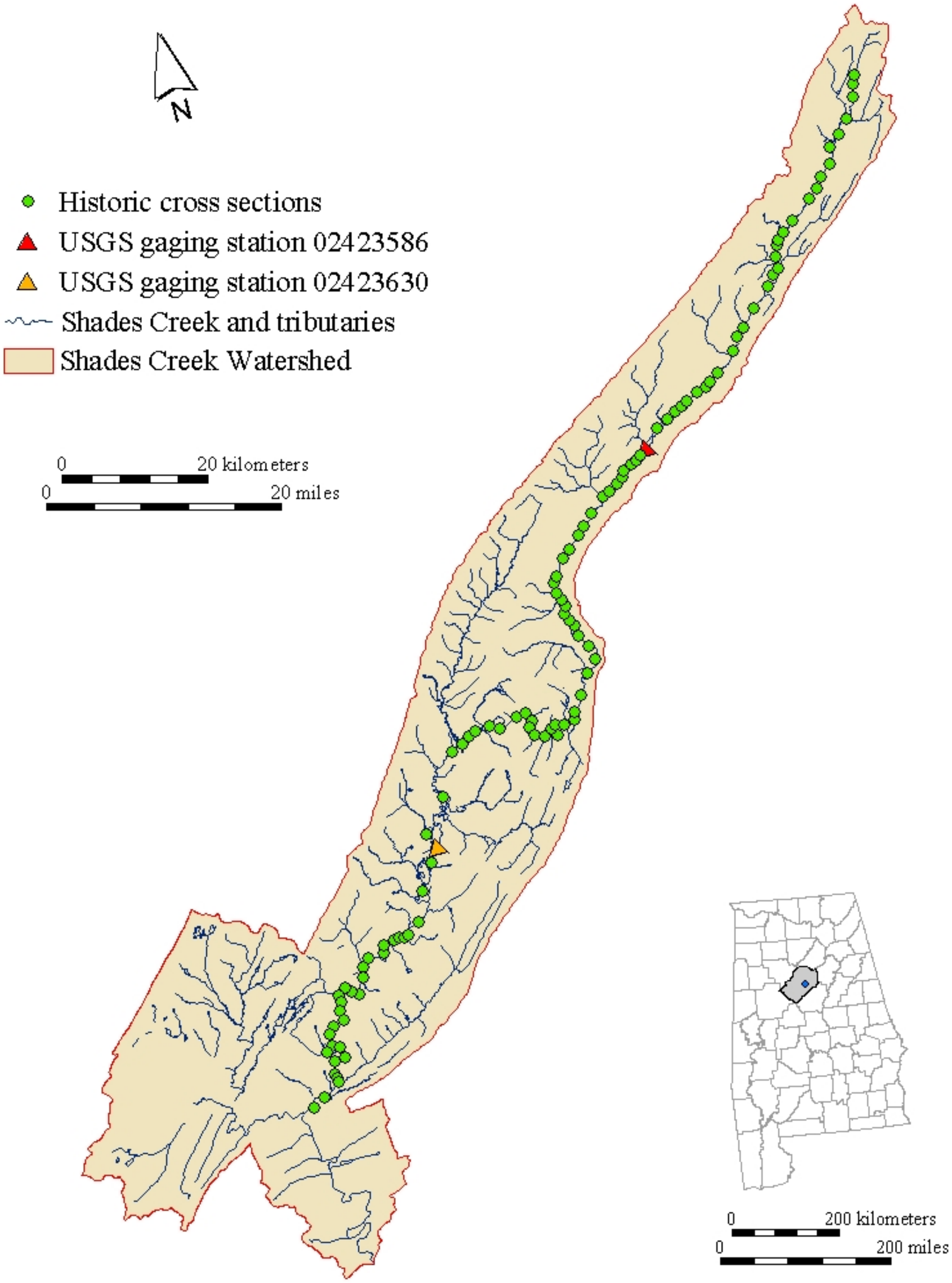


Figure 1-1. Map of Shades Creek watershed showing locations of historical surveys that were used for sampling and rapid geomorphic assessments (RGAs) in this study.

1.3 Overview of Methodology

The methods used in this study follow a conceptual procedure aimed at developing defensible estimates of current sediment loads and sources relative to a "reference" sediment load for the Shades Creek watershed. Data must be acquired and analyzed to support each of the following phases of analysis, with each phase building on the previous. This methodology is outlined below.

1.3.1 Characterization of "Reference" Suspended-Sediment Loading and Bed-Material Composition

A "reference" suspended-sediment loading condition can be defined as a concentration (in milligrams per liter; mg/l), load (in metric tonnes per day or year; T/d or T/y) or yield (in tonnes per day per square kilometer ($T/d/km^2$) representative of "natural", stable, or non-impaired conditions. For Shades Creek this means that data from similar watersheds in the Ridge and Valley (Ecoregion 67) must be used (Figure 1-2). The following tasks are outlined:

1. Empirically derive regional sediment loads for the Ridge and Valley using historical flow and sediment-transport data;
2. Based on diagnostic geomorphic criteria, determine relative stability of each site where historical data is available;
3. Determine regional sediment loadings by stage of channel evolution, dominant bed-material size class and relative stability;
4. Derive a general "reference" for Shades Creek using data from the Ridge and Valley and stability conditions from Shades Creek.

A similar approach is used to determine a "reference" bed-material composition for streambeds dominated by coarse-grained materials (gravel and coarser) with data from both the Ridge and Valley as well as stable reaches of Shades Creek. This directly addresses those reaches listed as impaired due to siltation by evaluating the percentage of fine-grained materials (sands and finer) present within a coarser matrix (embeddedness).

1.3.2 Characterization of "Actual" Sediment Loading and Bed-Material Composition

"Actual" sediment loading in Shades Creek can be defined as the amount of sediment that is being transported through and out of the watershed outlet. This is accomplished in two ways. Firstly, limited historical sediment-transport data is available for Shades Creek and can be used to estimate suspended-sediment transport over a range of flows and on an average, annual basis. Secondly, field and digital data are required as inputs to run the numerical-simulation models AnnAGNPS and CONCEPTS to estimate upland and channel contributions, respectively. The simulation period 1978-2001 was selected because this period coincides with measured channel-survey data. In general terms the work plan involved:

1. Simulate flow and sediment transport between known channel conditions 1978-2001;
2. Simulate the contributions from uplands and tributaries using the non-point source pollution loading model AnnAGNPS;
3. Use runoff and erosion data obtained from AnnAGNPS as water and sediment inputs for CONCEPTS;
4. Simulate channel erosion along Shades Creek between 1978 and 2001 over a 76 km reach;
5. Simulate the contributions from the main stem of Shades Creek using the channel-evolution model CONCEPTS with AnnAGNPS loadings;
6. Determine sediment-transport rating relations, loads, and bed-material compositions from the combined AnnAGNPS with CONCEPTS simulations to determine “actual” sediment loadings and bed-material compositions in the same dimensions (units) as those defined for the “reference” condition; and
7. Provide detailed analysis of upland contributions from the Little Shades Creek Watershed using results from the AnnAGNPS simulations.

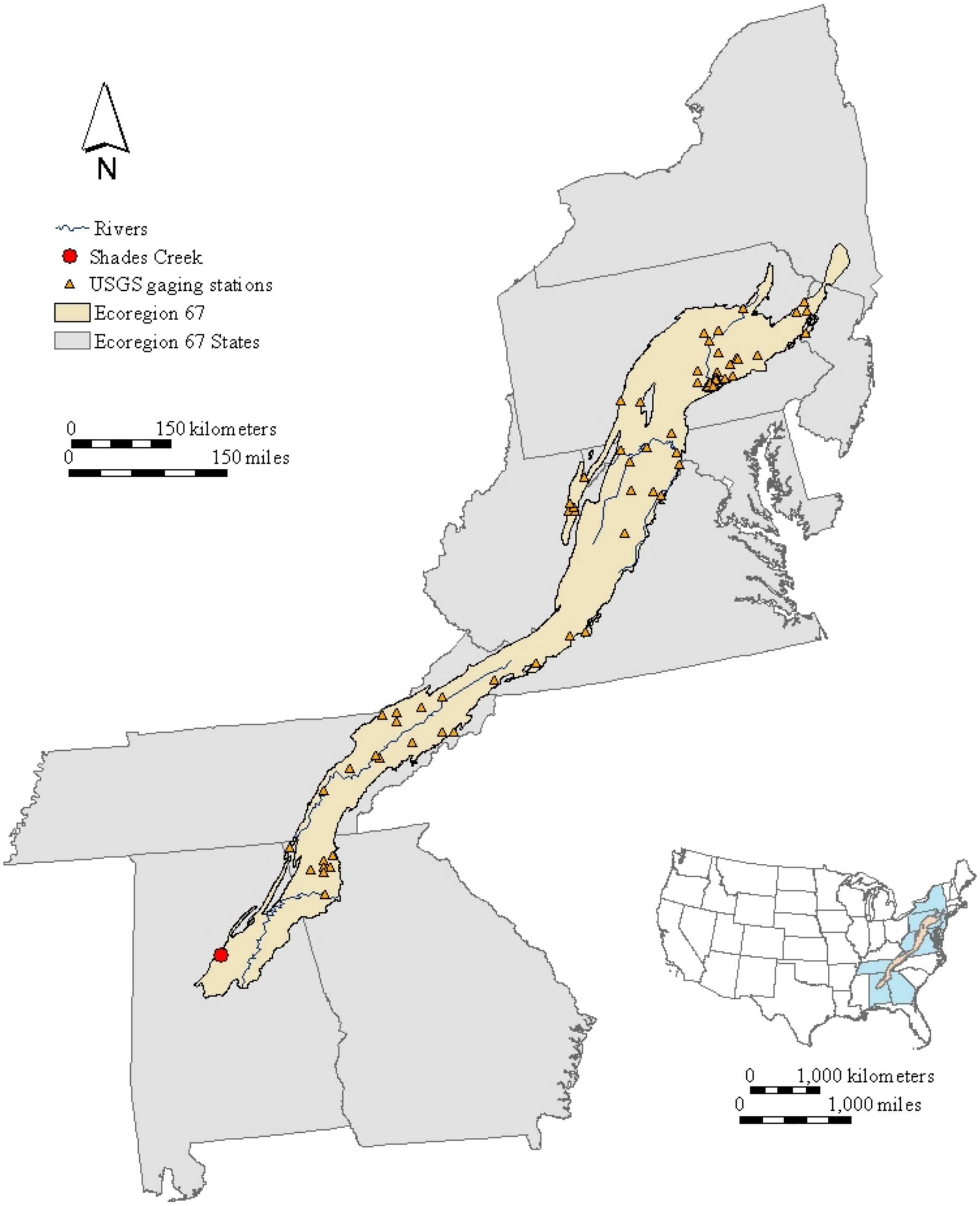


Figure 1-2. Map showing Ecoregion 67 (Ridge and Valley), and locations of Shades Creek and sites with historical suspended-sediment data.

2 DATA COLLECTION AND METHODS

2.1 Introduction

Collection of field data was required to support several aspects of the research. Given that the research scope covered the entire basin, it was essential to collect as much first hand information as possible to evaluate channel, upland, and sediment-transport conditions. This section concentrates on field work that was used to evaluate geomorphic conditions, support numerical modeling, and re-surveying of historical, channel cross sections. Computational techniques used to analyze suspended-sediment transport loadings and bed-material characteristics are also included in this section.

2.2 Site Selection

Study sites were selected along the main stem of Shades Creek to coincide with locations that were surveyed in 1978 as part of a flood-hazard study. A total of 105 cross sections were used over 76.4 km, labeled from *DD* at the upstream end to *A*, approximately 10 km above the confluence with the Cahaba River (Figure 2-1). At each site, rapid geomorphic assessments (RGAs) were conducted and samples of bed, bank, and bank-toe materials were collected and tested.

Additional field work was conducted at 73 locations throughout the Ridge and Valley stretching from Georgia to New Jersey for the purpose of characterizing geomorphic conditions and bed-material composition. RGAs were conducted at these sites and samples of bed material were collected. Figure 1-2 shows the extent of the Ridge and Valley and the location of study sites.

2.3 Geotechnical Data for Analysis of Streambank Stability

The adjustment of channel width by mass-wasting and related processes represents an important mechanism of channel response and a potential major contributor to sediment loads in Shades Creek. In the loess area of the Midwest United States, for example, bank material contributes as much as 80% of the total sediment eroded from incised channels (Simon and Rinaldi, 2000). In the Shades Creek Watershed sediment entrained from bank failures are blamed as a contributor to fine-grained sediment deposition on channel beds.

Conceptual models of bank retreat and the delivery of bank sediments to the flow emphasize the importance of interactions between hydraulic forces acting at the bed and bank toe, and gravitational forces acting on *in situ* bank materials (Carson and Kirkby, 1972; Thorne, 1982; Simon *et al*., 1991). Failure occurs when erosion of the bank toe and the channel bed adjacent to the bank have increased the height and angle of the bank to the point that gravitational forces exceed the shear strength of the bank material. After failure, failed bank materials may be delivered directly to the flow and deposited as bed material, or dispersed as wash load, or deposited along the toe of the bank as intact blocks, or as smaller, dispersed aggregates (Simon *et al*., 1991). Analysis of streambank stability within CONCEPTS is based on measured field data using *in situ* devices such as the borehole shear test (Figure 2-2) and the submerged jet-test device (Figure 2-3).

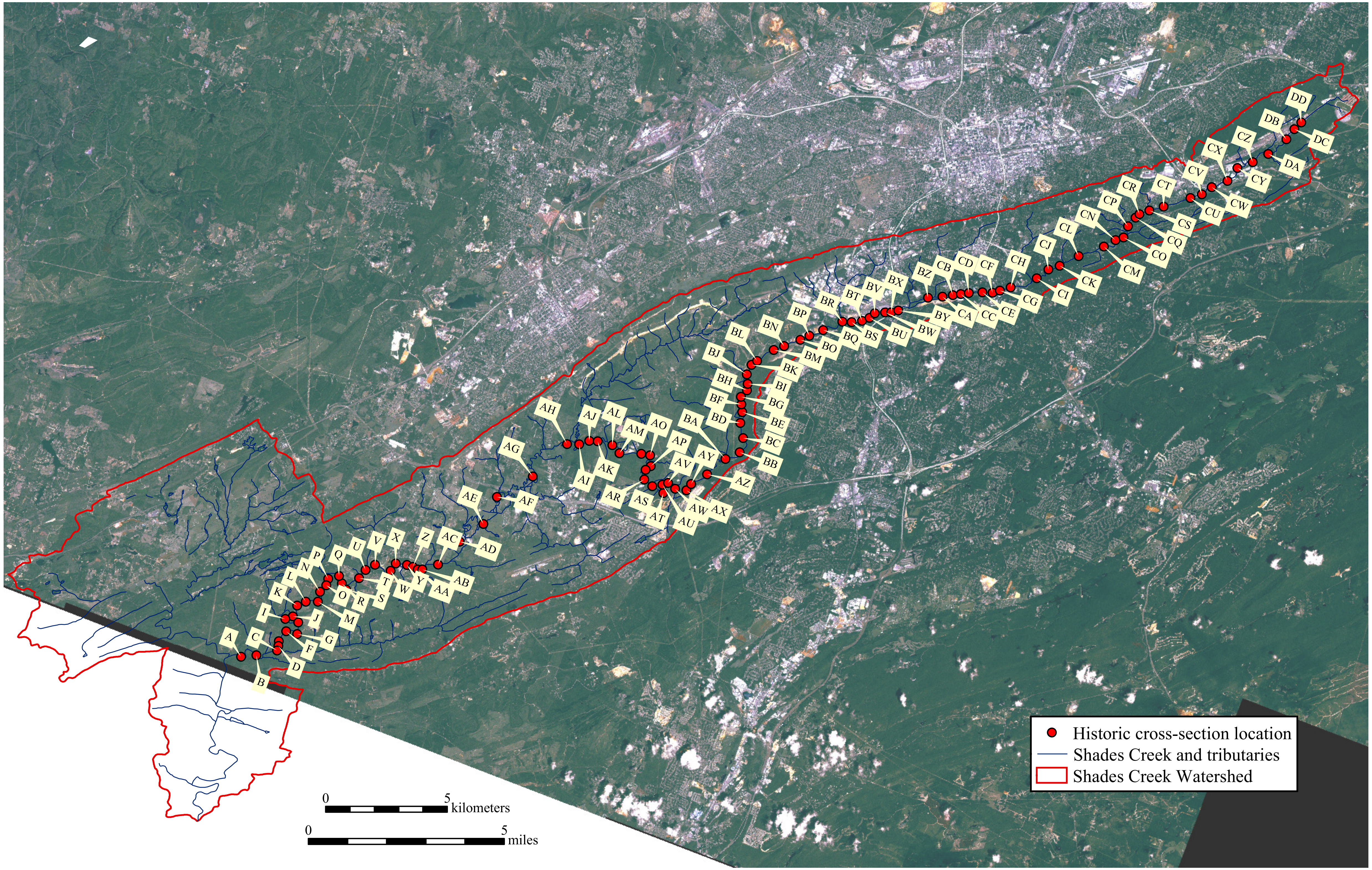


Figure 2-1. Map of Shades Creek showing labels applied to historical cross-section locations and sites of data collected in this study.

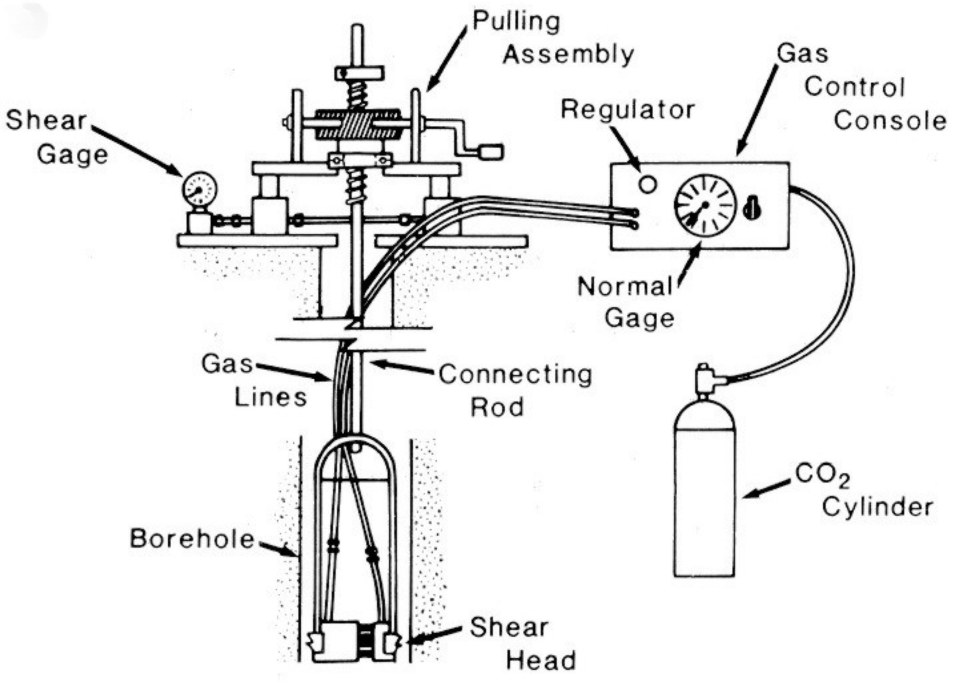


Figure 2-2. Schematic representation of borehole shear tester (BST) used to determine cohesive and frictional strengths of in situ streambank materials. Modified from Thorne et al., 1981.

2.3.1 Borehole Shear Testing and Bulk Unit Weights

To properly determine the resistance of cohesive materials to erosion by mass movement, data must be acquired on those characteristics that control shear strength; that is cohesion, angle of internal friction, pore-water pressure, and bulk unit weight. Cohesion and friction angle data can be obtained from standard laboratory testing (triaxial shear or unconfined compression tests), or by *in-situ* testing with a borehole shear-test (BST) device (Lohnes and Handy 1968; Thorne *et al.* 1981; Little *et al*. 1982; Lutenegger and Hallberg 1981). The BST provides, direct, drained shear-strength tests on the walls of a borehole (Figure 2-2). BST results for Shades Creek are shown in Table 2-1. Advantages of the instrument include:

1. The test is performed *in situ* and testing is, therefore, performed on undisturbed material;
2. Cohesion and friction angle are evaluated separately with the cohesion value representing apparent cohesion (c_a). Effective cohesion (c') is then obtained by adjusting c_a according to measured pore-water pressure and ϕ^b.
3. A number of separate trials are run at the same sample depth to produce single values of cohesion and friction angle based on a standard Mohr-Coulomb failure envelope.
4. Data and results obtained from the instrument are plotted and calculated on site, allowing for repetition if results are unreasonable; and

5. Tests can be carried out at various depths in the bank to locate weak strata (Thorne *et al*. 1981).

Table 2-1. Borehole shear tests conducted at sites along Shades Creek.

Site	Test	Bank	Depth (m)	Material	c_a (kPa)	c' (kPa)	ϕ' (degrees)	Matric suction (kPa)
DD	1	R	0.50	Clay	15.1	14.9	17.7	1.00
CY	1	L	0.90	Silt	8.24	0.720	23.5	5.90
CW	1	L	0.90	Silt	11.3	10.0	20.3	7.30
CW	2	L	1.60	Clay/silt	5.18	4.90	21.8	1.60
CT	1	L	0.25	Clay/silt/sand	11.6	8.07	21.4	19.9
CP	1	L	0.65	Clay/silt	2.96	2.54	27.4	2.40
CK	1	R	0.75	Sandy silt	9.75	8.64	8.21	8.61
CG	1	R	0.68	Mixed sand/gravel/silt	8.86	7.80	16.8	7.78
CE	1	L	0.70	Silty Clay	6.20	5.10	23.2	6.25
CE	2	L	2.20	Sand	0.710	0.143	30.6	6.48
CA	2	L	1.65	Clay/silt	12.5	11.5	20.0	5.88
BW	1	L	0.90	Silt	1.10	0.0564	31.5	11.9
BW	2	L	1.32	Silty clay	3.90	2.88	30.6	5.80
BT	1	R	1.00	Clay	5.43	3.76	29.9	9.50
BT	3	R	2.10	Clay/sand	2.12	1.30	31.0	4.80
BQ	2	L	1.65	Sandy silt	5.20	0.388	31.0	7.16
BO	1	L	0.65	Clay/silt	0.900	0.134	33.0	8.75
BO	2	L	1.00	Clay/silt	5.00	3.03	32.0	11.2
BO	1	R	0.90	Sand	2.76	2.50	29.8	2.60
BO	2	R	1.40	Clay	2.17	0.400	28.3	8.60
BJ	1	R	0.85	Sandy silt	3.94	3.00	33.0	5.10
BJ	2	R	0.55	Silty sand	4.07	3.18	25.0	5.10
BG	2	L	2.03	Clay	0.450	0.00	35.3	5.70
BA	1	R	1.60	Clay	6.13	5.40	30.2	4.30
BA	2	R	3.00	Clay	1.59	1.30	31.8	1.90
AX	1	R	0.65	Silty/sand	3.08	2.07	25.4	5.75
AX	2	R	1.40	Clay/sand	1.80	0.78	33.1	5.80
AV	2	R	1.50	Sand	1.10	0.00	31.0	6.40
AS	1	L	0.60	Silty sand	3.29	2.18	25.5	6.30
AO	1	R	1.05	Clay/sand	2.60	2.28	31.7	1.80
AO	2	R	1.30	Clay/sand	1.76	1.45	34.0	1.80
AL	2	R	1.50	Silty/sand	2.20	1.52	32.3	3.85
AK	1	R	0.80	Sand	1.47	0.500	29.2	5.50
AG	1	R	0.90	Clay	6.38	5.00	32.4	7.80
AF-AE	1	R	0.80	Silty clay	14.1	12.9	8.00	6.99
AF-AE	2	R	1.70	Silty clay	8.28	7.84	21.8	2.52
AA	2	R	0.85	Silty sand	3.06	1.69	32.8	7.75
X	1	L	1.80	Clay	7.62	6.53	27.6	6.16
U	1	R	1.40	Silt	4.40	2.32	35.5	11.8
U	2	R	2.50	Silty sand	1.90	1.55	35.5	1.97

S	1	L	0.60	Clay/sand	0.964	0.0103	31.6	10.9
Q	1	R	1.20	Silty sand	3.60	1.06	28.6	14.4
Q	2	R	1.70	Silty sand	3.30	0.761	30.5	14.4
L	1	L	0.40	Sand/gravel	4.54	4.01	15.6	3.00
J	1	R	1.70	Clay	3.69	2.29	31.4	7.97
J	2	R	0.70	Sand	4.51	3.43	21.8	6.15
F	1	R	0.37	Sand	2.21	0.741	32.2	8.33
B	1	L	0.68	Sand	1.19	0.376	27.0	9.30
B	2	L	1.45	Clay/sand	0.214	0.0113	31.8	1.15

2.3.2 Submerged Hydraulic Jet Testing: Erodibility of Fine-Grained Materials

The submerged jet-test device is used to estimate erosion rates due to hydraulic forces in fine-grained *in situ* materials (Hanson 1990; 1991; Hanson and Simon, 2001) (Figure 2-3). The device shoots a jet of water at a known head (stress) onto the streambed causing it to erode at a given rate. As the bed erodes, the distance between the jet and the bed increases, resulting in a decrease in the applied shear stress. Theoretically, the rate of erosion beneath the jet decreases asymptotically with time to zero. A critical shear stress for the material can then be calculated from the field data as that shear stress where there is no erosion.

The rate of erosion ε (m/s) is assumed to be proportional to the shear stress in excess of a critical shear stress and is expressed as:

$$\varepsilon = k\,(\tau_o - \tau_c)^{a} = k\,(\tau_e)^{a} \qquad (1)$$

where k = erodibility coefficient (m^3/N-s); τ_o = average boundary shear stress (Pa); τ_c = critical shear stress; a = exponent assumed to equal 1.0 and τ_e = excess shear stress (Pa). An inverse relation between τ_c and k occurs when soils exhibiting a low τ_c have a high k or when soils having a high τ_c have a low k. The measure of material resistance to hydraulic stresses is a function of both τ_c and k. Based on observations from across the United States, k can be estimated as a function of τ_c (Hanson and Simon, 2001; Figure 2-4). This is generalized to

$$k = 0.1\,\tau_c^{-0.5} \qquad (2)$$

Two jet tests were conducted at each site where cohesive bed or bank-toe material was present. In general, the average value of the two tests were used to represent the cross section and for input into CONCEPTS. Values are shown in Table 2-2 and plotted in Figure 2-4).

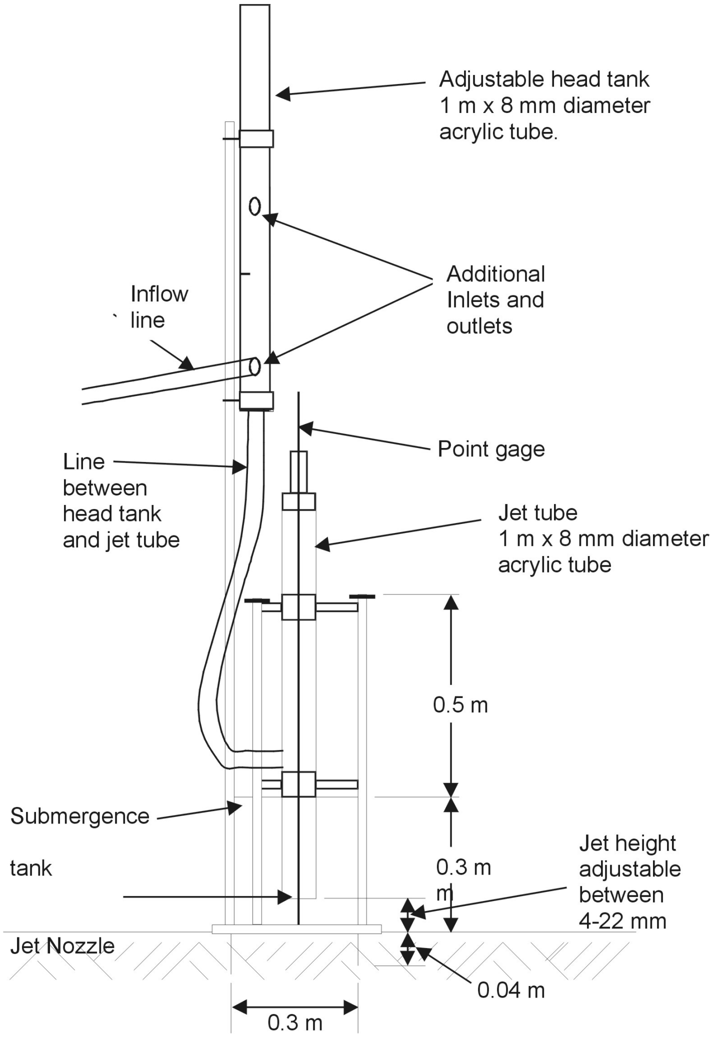


Figure 2-3. Schematic of submerged jet-test device used to measure the erodibility coefficient k, and the critical shear stress τ_c, of fine-grained materials.

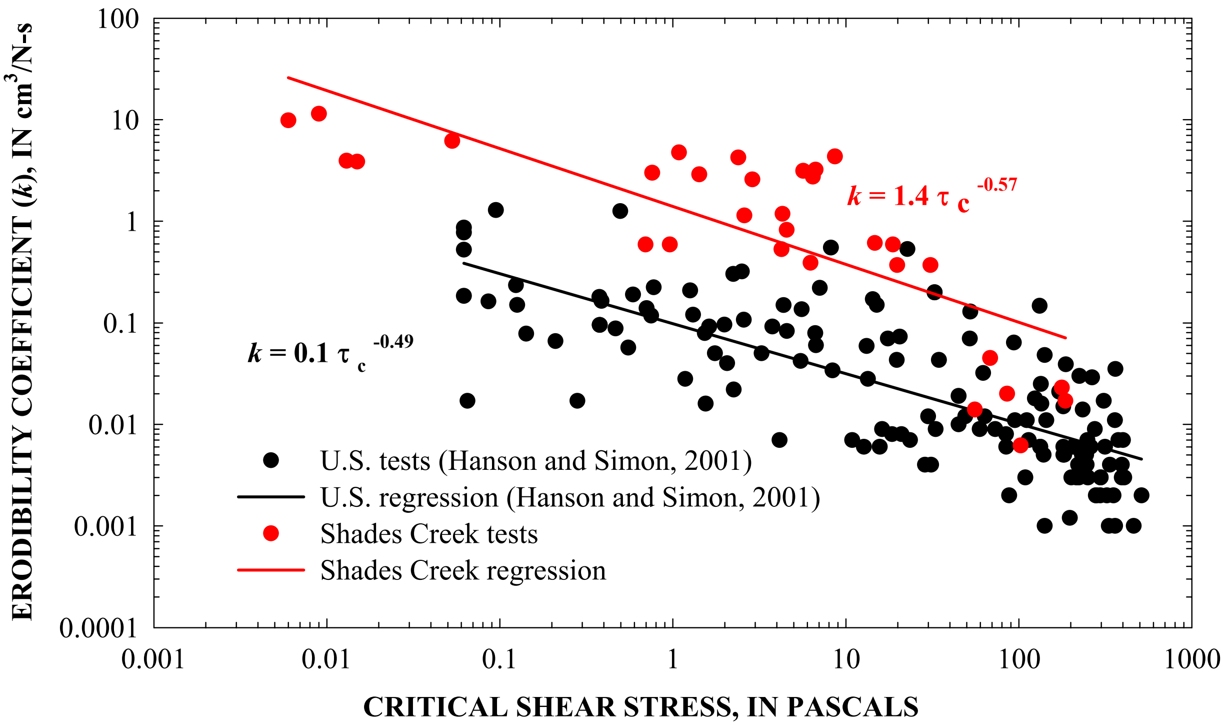


Figure 2-4. General relation between the erodibility coefficient k, and critical shear stress τ_c for fine-grained materials based on jet tests from across the United States (Hanson and Simon, 2001), and from Shades Creek.

Table 2-2. Submerged jet-test values obtained for Shades Creek.

Site	**Location**	**τ_c (Pa)**	**k (cm³/N-s)**
CY	Bank toe	18.3	1.75
CW	Bank toe	1.58	4.98
CT	Bank toe	3.42	0.84
CP	Bank toe	2.88	2.58
CK	Bank toe	76.9	0.065
CE	Bank toe	4.3	1.18
CA	Bank toe	0.031	8.81
BY	Bank toe	18.7	0.59
BA	Bank toe	0.37	8.52
AG	Bank toe	6.69	3.22
AE	Bank toe	6.61	2.59
X	Bank toe	6.45	2.75
DD	Bed	10.5	0.51
CG	Bed	3.38	0.72
BO	Bed	181	0.02
BA	Bed	79.0	0.010

2.4 Bank-Toe Erodibility

In Shades Creek *in situ* bank-toe materials are composed of a wide range of materials ranging from silts and clays to bedrock. In cases where bank-toe material is fine-grained alluvium a submerged jet-test device (modified to operate on inclined surfaces) was used to determine values of τ_c and k. Values for sites along the main channel of Shades Creek are shown in Table 2-2. Erosion of bank-toe materials is then calculated using an excess shear stress approach (equation 1). For coarse-grained materials, bulk samples were obtained for particle-size analysis. Critical shear stress of these types of materials can then be calculated using conventional techniques as a function of particle size and weight.

2.5 Texture of Bed Materials and Embeddedness

CONCEPTS requires information on sediment texture to determine sediment routing and sorting processes. Bulk samples of bed materials were collected for this reason and to determine the degree of fine-sediment deposition where beds were dominated by gravels and/or cobbles. Deposition of fine-grained sediment (silts, clays and sands) is one of the main concerns along Shades Creek because of the potential filling of interstitial spaces in gravel and cobble beds. This condition is described as embeddedness and is often represented by the percentage of material finer than 2 mm within a coarser matrix of gravels and/or cobbles.

Samples were analyzed in the laboratory for particle-size distributions. If the bed was dominated by gravel-sized and cobble-sized material, a count of a minimum of 100 particles was made to determine the distribution of particle sizes. In cases where streambeds were composed of a bi-modal mixture of sediment sizes with coarser-grained gravels, cobbles and boulders, particle-size distributions were weighted by the percentage of the bed covered by each type of sample (ie. bulk and particle count). In these cases, if 16 or more points registered sand-sized particles during a particle count, a bulk ample of these materials was obtained and analyzed in the laboratory.

The composition of bed material for each study site is shown in Table 2-3. Interpretations of the degree of embeddedness apply to those sites having more than 50% coarse material. Of the 102 sites sampled for bed material along Shades Creek, 53 are considered coarse-grained (dominated by gravel or larger clasts), 30 bedrock, and 19 fine grained (dominated by sand or finer clasts). In terms of overall stream lengths, 32% of the reach contains bedrock beds, about 41% has coarse-grained beds, and 27% has fine-grained beds. Those sites that are dominated by bedrock are not considered coarse grained although they are shown in Table 2-3 as containing 100% coarser than 64 mm.

Table 2-3. Composition of bed material for sites along Shades Creek. [1] = sum of gravel and cobble fractions; [2] = sum of clay, silt, and sand fractions.

Site	River kilometer	Percent classified grain size (%)				% Coarse[1]	% Fines[2]
		Boulder/cobble	Gravel	Sand	Silt+clay		
		>64mm	2-64mm	0.062-2mm	<0.062mm		
DD	86.45	0.00	0.00	86.2	13.8	0	100
DC	86.05	8.50	75.5	12.3	3.74	84	16
DB	85.49	-	-	-	-	-	-
DA	84.31		68.9	31.0	0.139	69	31
CZ	83.31	15.6	81.3	3.13	0.00	97	3
CY	82.61	100	0.00	0.00	0.00	100	0
CX	81.85	100	0.00	0.00	0.00	100	0
CW	81.08	100	0.00	0.00	0.00	100	0
CV	80.54	100	0.00	0.00	0.00	100	0
CU	80.05	100	0.00	0.00	0.00	100	0
CT	78.87	100	0.00	0.00	0.00	100	0
CS	78.26	100	0.00	0.00	0.00	100	0
CR	77.82	100	0.00	0.00	0.00	100	0
CQ	77.60	100	0.00	0.00	0.00	100	0
CP	77.07	2.67	85.3	12.0	0.00	88	12
CO	76.41	19.4	67.7	12.9	0.00	87	13
CN	75.91	100	0.00	0.00	0.00	100	0
CM	75.17	-	-	-	-	-	-
CL	74.02	-	-	-	-	-	-
CK	73.09	60.0	15.8	23.9	0.347	76	24
CK	73.09	0.0	0.00	82.1	17.9	0	100
CK	73.09	0.0	28.7	63.7	7.55	29	71
CJ	72.53	100	0.00	0.00	0.00	100	0
CI	71.74	100	0.00	0.00	0.00	100	0
CH	70.51	33.6	37.0	29.4	0.0545	71	29
CG	70.05	33.6	37.0	29.4	0.0545	71	29
CF	69.73	33.3	58.6	6.06	2.02	92	8
CE	69.24	27.0	61.2	10.1	1.77	88	12
CD	68.65	6.00	82.0	12.0	0.00	88	12
CC	68.32	6.00	84.0	10.0	0.00	90	10
CB	67.99	16.0	76.0	8.00	0.00	92	8
CA	67.55	22.0	75.0	3.00	0.00	97	3
BZ	66.96	6.00	84.0	6.00	4.00	90	10
BY	65.49	35.0	60.0	5.00	0.00	95	5

BX	65.17	20.5	47.1	32.4	0.0570	68	32
BW	64.91	12.8	6.4	80.5	0.27	19	81
BV	64.43	52.0	19.5	28.5	0.00	72	28
BU	64.14	61.6	36.0	2.40	0.00	98	2
BT	63.78	20.2	58.8	21.0	0.0487	79	21
BS	63.35	0.00	86.0	14.0	0.00	86	14
BR	62.95	20.0	78.0	2.00	0.00	98	2
BQ	61.92	35.0	53.0	12.0	0.00	88	12
BP	61.26	13.2	76.9	9.89	0.00	90	10
BO	60.84	0.00	0.00	83.1	16.9	0	100
BO	60.84	95.5	4.20	0.350	0.00	100	0
BN	60.10	100	0.00	0.00	0.00	100	0
BM	59.63	54.4	45.6	0.00	0.00	100	0
BL	58.78	41.2	56.5	2.35	0.00	98	2
BK	58.49	49.0	51.0	0.00	0.00	100	0
BJ	58.02	5.00	91.0	4.00	0.00	96	4
BI	57.60	6.00	79.2	14.7	0.0467	85	15
BH	57.26	10.0	77.2	12.5	0.303	87	13
BG	56.75	80.0	20.0	0.00	0.00	100	0
BF	56.17	84.4	15.6	0.00	0.00	100	0
BE	55.14	12.6	50.8	36.4	0.247	63	37
BD	54.56	20.0	63.3	16.6	0.114	83	17
BC	53.91	40.6	50.1	9.28	0.00	91	9
BB	53.13	4.80	39.8	55.3	0.167	45	55
BA	52.14	0.00	79.6	19.1	1.32	80	20
BA	52.14	0.00	0.00	81.1	18.9	0	100
AZ	51.03	0.00	50.3	43.2	6.49	50	50
AY	50.18	36.0	58.0	6.00	0.00	94	6
AX	49.86	0.00	46.7	53.1	0.18	47	53
AW	48.81	60.0	28.0	12.0	0.00	88	12
AV	48.34	60.8	4.20	34.3	0.707	65	35
AU	48.10	62.0	4.86	33.1	0.00	67	33
AT	47.56	96.8	3.20	0.00	0.00	100	0
AS	46.99	40.0	22.4	36.9	0.639	62	38
AR	46.43	0.00	76.3	23.4	0.241	76	24
AQ	45.61	0.00	0.00	93.4	6.65	0	100
AP	45.25	0.00	88.7	10.4	0.879	89	11
AO	44.59	80.0	13.6	6.38	0.0216	94	6
AN	44.21	58.8	11.8	29.4	0.00	71	29
AM	43.27	85.0	1.19	13.8	0.00	86	14
AL	42.74	0.00	31.7	68.0	0.233	32	68

AK	41.57	0.00	0.00	100	0.00	0	100
AJ	41.21	0.00	0.00	98.3	1.69	0	100
AI	40.73	0.00	0.00	100	0.00	0	100
AH	39.59	0.00	1.61	98.4	0.00	2	98
AG	35.16	0.00	0.00	100	0.00	0	100
AF	31.55	0.00	0.00	99.7	0.338	0	100
AE	29.49	0.00	39.4	59.4	1.24	39	61
AD	27.93	-	-	-	-	-	-
AC	25.31	0.00	0.00	100	0.00	0	100
AB	24.52	-	-	-	-	-	-
AA	24.29	-	-	-	-	-	-
Z	24.07	0.00	49.8	45.7	4.53	50	50
Y	23.78	85.0	7.47	6.85	0.679	92	8
X	22.94	100	0.00	0.00	0.00	100	0
W	22.57	0.00	0.00	100	0.00	0	100
V	21.41	97.6	2.40	0.00	0.00	100	0
U	20.96	0.00	0.0639	93.0	6.96	0	100
T	20.52	-	-	-	-	-	-
S	19.73	100	0.00	0.00	0.00	100	0
R	19.33	100	0.00	0.00	0.00	100	0
Q	19.01	0.00	0.635	83.1	16.2	1	99
P	18.06	100	0.00	0.00	0.00	100	0
O	17.77	0.00	79.3	20.2	0.492	79	21
N	17.35	100	0.00	0.00	0.00	100	0
M	16.84	100	0.00	0.00	0.00	100	0
L	16.32	100	0.00	0.00	0.00	100	0
K	15.81	57.3	30.2	12.5	0.00	88	13
J	15.42	100	0.00	0.00	0.00	100	0
I	14.74	100	0.00	0.00	0.00	100	0
H	13.83	76.0	24.0	0.00	0.00	100	0
G	13.18	90.1	9.90	0.00	0.00	100	0
F	12.68	100	0.00	0.00	0.00	100	0
E	12.09	100	0.00	0.00	0.00	100	0
D	11.56	100	0.00	0.00	0.00	100	0
C	11.36	100	0.00	0.00	0.00	100	0
B	11.11	100	0.00	0.00	0.00	100	0
A	10.04	100	0.00	0.00	0.00	100	0

Many study sites along Shades Creek are characterized by streambeds composed of sand, gravel and cobbles. Resistance of these non-cohesive materials is a function of particle size (weight), and is expressed in terms of a dimensionless critical shear stress (Shields 1936):

$$\tau^* = \tau_o / (\rho_s - \rho_w)\, g\, D \tag{3}$$

where τ^* = critical dimensionless shear stress; ρ_s = sediment density (kg/m^3); ρ_w = water density (kg/m^3); g = gravitational acceleration (m/s^2); and D = characteristic particle diameter (m). Average boundary shear stress (τ_o) is the drag exerted by the flow on the bed and is defined as:

$$\tau_o = \gamma_w\, R\, S_b \tag{4}$$

where γ_w = unit weight of water (N/m^3); R = hydraulic radius (area/wetted perimeter)(m), and S_b = bed slope (m/m). Critical shear stress (τ_c) in dimensional form can be obtained by invoking the Shields criterion and, for hydrodynamically rough beds, utilizing a value of 0.06 for τ^*.

$$\tau_c = 0.06\, (\rho_s - \rho_w)\, g\, D \tag{5}$$

Thus, the shear stress required to entrain a grain of diameter D can be estimated. Other commonly used values of τ^* are 0.03 and 0.047 (Vanoni, 1975). CONCEPTS uses 13 particle-size classes to analyze entrainment and sorting of non-cohesive sediment by invoking the Shields' criteria (Equations 3 and 5).

2.6 Suspended-Sediment Data

2.6.1 Availability of Data for Transport Ratings

Analysis of the impacts of suspended sediment requires a database of suspended-sediment concentrations with associated instantaneous water discharge. Data of this type permit analysis of sediment-transport characteristics and the development of rating relations (Porterfield, 1972; Glysson, 1987). Collection of suspended-sediment data is time consuming and expensive in that it must take place over a broad range of flows to accurately evaluate the sediment-transport regime at a site. However, the USGS has identified more than 2,900 sites nationwide where at least 30 matching samples of suspended sediment and instantaneous flow discharge have been collected (Turcios and Gray, 2000). This historical database serves as the foundation for analyzing sediment-transport characteristics over the range of physiographic conditions that exist in the United States. For the Ridge and Valley, 74 sites in seven states have at least 30 matching samples of suspended sediment and instantaneous flow discharge (Table 2-4).

Fortunately, suspended-sediment data were also available for Shades Creek near Greenwood, AL (USGS station 02423630) from the USGS and from Stormwater Management Authority (SWMA; Birmingham, Alabama). When used in conjunction with the instantaneous discharge at the time of sample collection, sample data were used to compute suspended-sediment transport rates. Integration with continuous flow records allows annual suspended-sediment loads to be calculated.

Table 2-4. List of USGS gaging stations in the Ridge and Valley (Ecoregion 67) having a minimum of 30 matching samples of flow and suspended-sediment concentration data.

State	USGS number	USGS name	Drainage area (km^2)
GA	02383500	COOSAWATTEE RIVER NEAR PINE CHAPEL, GA.	2152
GA	02385800	HOLLY CREEK NEAR CHATSWORTH, GA.	166
GA	02387000	CONASAUGA RIVER AT TILTON, GA.	1779
GA	02387500	OOSTANAULA RIVER AT RESACA, GA.	4149
GA	02388000	WEST ARMUCHEE CREEK NEAR SUBLIGNA, GA.	94
GA	02395000	ETOWAH RIVER NEAR KINGSTON, GA.	4232
GA	03568933	LOOKOUT CREEK NEAR NEW ENGLAND, GA.	386
MD	01603000	NB POTOMAC R NR CUMBERLAND, MD	2271
MD	01614500	CONOCOCHEAGUE C AT FAIRVIEW, MD	1279
NJ	01440000	FLAT BROOK NEAR FLATBROOKVILLE NJ	166
NJ	01443500	PAULINS KILL AT BLAIRSTOWN NJ	326
NJ	01457000	MUSCONETCONG RIVER NEAR BLOOMSBURY NJ	365
PA	01470500	SCHUYLKILL RIVER AT BERNE, PA	919
PA	01540500	SUSQUEHANNA RIVER AT DANVILLE, PA	29060
PA	01553500	WEST BRANCH SUSQUEHANNA RIVER AT LEWISBURG, PA	17734
PA	01554000	SUSQUEHANNA RIVER AT SUNBURY, PA	47397
PA	01555400	EAST MAHANTANGO CREEK AT KLINGERSTOWN, PA	116
PA	01559795	BOBS CREEK NEAR PAVIA, PA	43
PA	01562000	RAYSTOWN BRANCH JUNIATA RIVER AT SAXTON, PA	1958
PA	01567000	JUNIATA RIVER AT NEWPORT, PA	8687
PA	01568000	SHERMAN CREEK AT SHERMANS DALE, PA	536
PA	01568750	STONY CREEK AT WATER TANK TRAIL NR DAUPHIN, PA	57
PA	01570000	CONODOGUINET CREEK NEAR HOGESTOWN, PA	1217
PA	01570010	UNNAMED TRIB TO TRINDLE SP RUN, SITE 1, NR MECHBRG	2.7
PA	01570030	UNNAMED TRIB TO TRINDLE SP RUN, SITE 2, NR MECHBRG	3.3
PA	01570060	UNNAMED TRIB TO TRINDLE SP RUN, SITE 3, NR MECHBRG	4.0
PA	01570200	CONODOGUINET CR. TRIB. NO. 2 NR. ENOLA, PA	2.0
PA	01570300	CONODOGUINET CREEK TRIB NO. 3 NR	1.0

		ENOLA, PA	
PA	01570500	SUSQUEHANNA RIVER AT HARRISBURG, PA	62419
PA	01571000	PAXTON CREEK NEAR PENBROOK, PA	29
PA	01571490	CEDAR RUN AT EBERLYS MILL, PA	33
PA	01571919	SWATARA CR AB HWY BRIDGE 895 AT PINE GROVE, PA	188
PA	01572000	LOWER LITTLE SWATARA CREEK AT PINE GROVE, PA	89
PA	01573095	BACHMAN RUN AT ANNVILLE, PA	19
PA	01573560	SWATARA CREEK NEAR HERSHEY, PA	1251
TN	03465500	(N) NOLICHUCKY RIVER AT EMBREEVILLE, TN	2085
TN	03470500	(N) FRENCH BROAD RIVER NEAR KNOXVILLE, TN	13212
TN	03495500	(N) HOLSTON RIVER NEAR KNOXVILLE, TN	9705
TN	03527220	(N) CLINCH RIVER NEAR LOONEYS GAP, TN	2989
TN	03528000	(N) CLINCH RIVER ABOVE TAZEWELL, TN	3818
TN	03531680	(N) POWELL RIVER AT ALANTHUS HILL, TN	1321
TN	03535912	(N) CLINCH RIVER AT MELTON HILL DAM (TAILWATER),TN	8658
TN	03543005	(N) TENNESSEE RIVER AT WATTS BAR DAM (TAILWATER),	44833
VA	01621050	MUDDY CREEK AT MOUNT CLINTON, VA	37
VA	01631000	S F SHENANDOAH RIVER AT FRONT ROYAL, VA	4253
VA	01634000	N F SHENANDOAH RIVER NEAR STRASBURG, VA	1989
VA	02054500	ROANOKE RIVER AT LAFAYETTE, VA	666
VA	02055000	ROANOKE RIVER AT ROANOKE, VA	1023
VA	03167000	REED CREEK AT GRAHAMS FORGE, VA	640
VA	03474000	M F HOLSTON RIVER AT SEVEN MILE FORD, VA	342
WV	01608500	SOUTH BRANCH POTOMAC RIVER NEAR SPRINGFIELD, WV	3849
WV	01610200	LOST RIVER AT MCCAULEY NEAR BAKER, WV	401
WV	01611500	CACAPON RIVER NEAR GREAT CACAPON, WV	1748
WV	01618000	POTOMAC R AT SHEPHERDSTOWN, WV	15374
WV	01636500	SHENANDOAH RIVER AT MILLVILLE, WV	7827
WV	03068800	SHAVERS FORK BELOW BOWDEN, WV	391

2.6.2 Availability of Data for Annual-Load Calculations

Sufficient mean-daily flow data were available for 56 of the USGS gauging stations in the Ridge and Valley to calculate annual suspended-sediment loads (Table 2-5). Flow data were downloaded from a USGS web site and discharge units were converted from ft^3/s to m^3/s. Daily loads were calculated for each gage by applying the appropriate rating equation to the mean discharge for each day, giving a suspended-sediment load in T/d. Daily-load values were summed by calendar year and divided by drainage area to obtain the annual suspended-sediment yield (in T/y/km^2) for each year of flow record. Mean annual suspended-sediment yields were calculated by dividing by the number of years of complete flow record (Table 2-5). An annual concentration (in mg/l) was calculated for each station-year of record by dividing the suspended-sediment load by the total volume of water during the year. A mean-annual concentration was then obtained by summing the annual concentrations and dividing by the number of years of complete flow record.

Table 2-5. Summary of data from the Ridge and Valley with sufficient flow data to calculate annual suspended-sediment loads, yields, and concentrations.

State	Station number	Maximum flow (m^3/s)	Period of mean-daily flow data	Number of complete calendar years
NJ	01440000	179	10/1/1923 - 9/30/2001	77
NJ	01443500	168	10/1/1921 - 9/30/2001	77
NJ	01457000	165	10/1/1903 - 9/30/2001	82
PA	01470500	736	8/1/1947 - 9/30/2001	53
PA	01540500	9480	4/1/1905 - 9/30/2001	95
PA	01553500	8070	10/1/1939 - 9/30/2001	61
PA	01554000	17200	10/1/1937 - 9/30/2001	63
PA	01555400	64.8	10/1/1992 - 10/16/2000	4
PA	01559795	51.5	6/1/1993 - 9/30/2000	2
PA	01562000	1650	10/1/1911 - 9/30/2002	89
PA	01567000	4870	1899-04-01 - 9/30/2002	101
PA	01568000	518	10/1/1929 - 9/30/2002	71
PA	01568750	101	4/1/1974 - 9/30/1986	2
PA	01570000	694	10/1/1911 - 9/30/2002	66
PA	01570010	0.59	9/25/1992 - 9/30/1993	2
PA	01570030	0.45	9/10/1992 - 9/30/1993	2
PA	01570060	0.31	10/1/1992 - 9/30/1993	2
PA	01570200	5.27	4/1/1969 - 9/30/1976	8
PA	01570300	2.80	3/1/1969 - 9/30/1976	6
PA	01570500	27000	1890-10-01 - 9/30/2002	110
PA	01571000	25.9	3/1/1940 - 9/30/1995	15
PA	01571490	4.81	4/1/1993 - 9/30/1995	1
PA	01571919	73.1	10/23/1981- -9/30/1984	2
PA	01572000	52.4	10/1/1919 - 9/30/1984	14
PA	01573095	2.60	4/1/1993 - 9/30/1995	3
PA	01573560	674	10/1/1975 - 9/30/2002	25
MD	01603000	1340	5/24/1929 - 9/30/2002	71
WV	01608500	4110	1899-07-01 - 9/30/2000	75
WV	01610200	340	10/1/1971 - 1/31/1980	8
WV	01611500	1920	12/12/1922 - 9/30/2000	75
MD	01614500	756	6/1/1928 - 9/30/2002	72
WV	01618000	8130	8/1/1928 - 9/30/2002	65
VA	01621050	49.8	4/13/1993 - 9/30/2002	7
VA	01631000	3230	10/1/1930 - 9/30/2002	70
VA	01634000	1720	4/1/1925 - 9/30/2002	75

WV	01636500	5440	1895-04-01 - 9/30/2000	84
VA	02054500	331	10/1/1943 - 9/30/2002	57
VA	02055000	515	1899-02-13 - 9/30/2002	100
GA	02383500	892	11/11/1938 - 9/30/2002	60
GA	02385800	280	6/1/1960 - 9/30/2002	39
GA	02387000	929	6/5/1937 - 9/30/2002	62
GA	02387500	1420	1892-11-01 - 9/30/2002	107
GA	02388000	97.1	4/1/1939 - 9/30/1981	20
GA	02395000	1160	7/18/1928 - 10/23/1995	60
WV	03068800	255	8/31/1973 - 9/30/2000	9
VA	03167000	300	10/1/1908 - 9/30/2002	80
TN	03465500	1440	8/31/1900 - 9/30/2002	80
TN	03470500	1380	10/1/1945 - 9/30/1982	41
VA	03474000	170	10/1/1942 - 9/30/2002	44
TN	03495500	1550	10/1/1930 - 9/30/1982	60
TN	03527220	722	10/1/1988 - 4/5/1992	3
TN	03528000	2360	4/1/1919 - 9/30/2002	81
TN	03531680	501	10/1/1988 - 3/31/1992	3
TN	03535912	943	1/1/1975 - 9/30/1982	7
TN	03543005	4560	10/1/1974 - 9/30/1982	7
GA	03568933	337	8/30/1979 - 9/30/2001	19
TN	03466208	107	3/1/1996 - 2002/09/30	7
TN	03532000	1420	10/1/1919 - 2002-09-30	67

2.7 General Description of AGNPS Modeling Technology

The Agricultural Non-Point Source Pollutant (AGNPS) watershed simulation model (Bingner and Theurer, 2001a) has been developed as a tool for evaluating pollutant loadings within a watershed and the impact farming and mixed-use activities have on pollution control. Various modeling components have been integrated within AGNPS to form a suite of modules. Each module provides information needed by other modules to enhance the predictive capabilities of each. The modules in AGNPS critical to the Shades Creek watershed include: (1) AnnAGNPS Version 3.32 (Cronshey and Theurer, 1998; Bingner and Theurer, 2001c), a watershed-scale, continuous-simulation, pollutant loading computer model designed to quantify and identify the source of pollutant loadings anywhere in the watershed for optimization and risk analysis; and, (2) Conservational Channel Evolution and Pollutant Transport System (CONCEPTS) (Langendoen, 2000), a set of stream network, corridor, and water quality computer models designed to predict and quantify the effects of bank erosion and failures, bank mass wasting, bed aggradation and degradation, burial and re-entrainment of contaminants, and streamside riparian vegetation on channel morphology and pollutant loadings.

The Annualized Agricultural Non-Point Source Pollutant loading model (AnnAGNPS) is an advanced technological watershed evaluation tool, which has been developed through a partnering project with the United States Department of Agriculture – Agriculture Research Service (USDA-ARS) and Natural Resources Conservation Service (NRCS) to aid in the evaluation of watershed response to agricultural management practices. Through continuous simulation of surface runoff, sediment and chemical non-point source pollutant loading from watersheds, the impact of BMPs on TMDLs can be evaluated for risk and cost/benefit analyses.

AnnAGNPS is a continuous simulation, daily time step, pollutant-loading model and includes significantly more advanced features than the single-event AGNPS 5.0 (Young et al., 1989). Daily climate information is needed to account for the temporal variation in the weather. The spatial variability of climate can also be included by assigning appropriate climate files to any location in the watershed. The spatial variability within a watershed of soils, landuse, and topography, is accounted for by dividing the watershed into many homogeneous drainage areas. These simulated drainage areas are then integrated together by simulated rivers and streams, which route the runoff and pollutants from each individual homogeneous area to downstream. From individual fields, runoff can be produced from precipitation events that include rainfall, snowmelt and irrigation. A daily soil water balance is maintained, so runoff can be determined when a precipitation event occurs. The erosion within each field is predicted based on the technology incorporated from the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997). The model can be used to examine the effects of implementing various conservation alternatives within a watershed such as alternative cropping and tillage systems including the effects of fertilizer, pesticide, irrigation application rate as well as point source yields and feedlot management (Bosch et al., 1998).

2.7.1 Input Data Requirements

As part of the input data preparation process there are a number of component modules that support the user in developing the needed AnnAGNPS databases. These include: (1) the TOpographic PArameteriZation program (TOPAZ) (Garbrecht and Martz, 1995), to generate cell and stream network information from a watershed digital elevation model (DEM) and provide all of the topographic related information for AnnAGNPS. A subset of TOPAZ, TOPAGNPS, is the set of TOPAZ modules used within AGNPS. The use of the TOPAGNPS generated stream network is also incorporated by CONCEPTS to provide the link of where upland sources are entering the channel and then routed downstream; (2) The AGricultural watershed FLOWnet generation program (AGFLOW) (Bingner et al., 1997; Bingner et al., 2001b) is used to determine the topographic-related input parameters for AnnAGNPS and to format the TOPAGNPS output for importation into the form needed by AnnAGNPS; (3) The Generation of weather Elements for Multiple applications (GEM) program (Johnson et al., 2000) is used to generate the climate information for AnnAGNPS if historical climate is not used; (4) The program Complete Climate takes the information from GEM and formats the data for use by AnnAGNPS, along with determining a few additional parameters; (5) A graphical input editor that assists the user in developing the AnnAGNPS database (Bingner et al., 1998); (6) A visual interface program to view the TOPAGNPS related geographical information system (GIS) data (Bingner et al., 1996); (7) A conversion program that transforms a single event AGNPS 5.0 dataset into what is needed to perform a single event simulation with AnnAGNPS and, (8) An Arcview program to facilitate the use of Items 1-7. There is an output processor that can be used to help analyze the results from AnnAGNPS by generating a summary of the results in tabular or GIS format.

2.7.2 Contributions from Cells Adjacent to the Main Channel

Loading information to the main channel for use with CONCEPTS is obtained by routing the AnnAGNPS water and sediment discharged by each AnnAGNPS cell through the channel system. At the outlet of each tributary that flows into the main channel AnnAGNPS provides: the flow; sediment by particle sizes of clay, silt, and sand; peak discharge; and, the time of concentration as part of an output file that can be used as an input file into CONCEPTS. This information is used in routing water and sediment by CONCEPTS in the main channel. All tributary channels in each of the Shades Creek watershed simulated by AnnAGNPS are assumed to be stable and therefore, not eroding; although, sediment in transport can be deposited within the tributaries before reaching the main channel simulated by CONCEPTS.

2.7.3 Contributions from Tributaries into the Main Channel

The discharges from the tributaries provide the link between AnnAGNPS cells and CONCEPTS for the water and sediment that does not flow directly into the main channel. There are also AnnAGNPS cells that are along the main channel and deposit water and sediment directly into the main channel. These AnnAGNPS cells are also simulated and provide discharge information to CONCEPTS through an AnnAGNPS output file.

2.8 General Description of CONCEPTS Modeling Technology

CONCEPTS simulates unsteady, one-dimensional flow, transport of cohesive and cohesionless sediments in suspension and on the bed selectively by size class, and bank erosion processes in stream corridors (Langendoen 2000). Hence, it can predict the dynamic response of flow, sediment transport and channel form (‘channel evolution’) to disturbances including channelization, altered hydrologic regime (e.g. by dam construction or urbanization), or instream hydraulic structures.

2.8.1 Hydraulics

CONCEPTS assumes stream flow to be one-dimensional along the centerline of the channel. It computes the flow as a function of time simultaneously at a series of cross sections along the stream using the Saint Venant equations. The governing equations are discretized using the generalized Preissmann scheme, and the resulting set of algebraic equations are solved using Gaussian elimination with partial pivoting for banded matrices. Four types of hydraulic structures are included in CONCEPTS: box and pipe culverts, bridge crossings, grade control (drop) structures, and any structure for which a rating curve is available.

2.8.2 Sediment Transport and Bed Adjustment

CONCEPTS calculates total-load sediment transport rates by size fraction from a mass conservation law, and taking into account the differing processes governing entrainment and deposition of cohesive and cohesionless bed material (Langendoen, 2000). CONCEPTS handles particle sizes ranging from clay to cobbles. For graded bed material, the sediment transport rates depend on the bed material composition, which itself depends on historical erosion and deposition rates. CONCEPTS divides the bed into a surface or active layer and a subsurface layer. These layers constitute the so-called ‘mixing layer’. Sediment particles are continuously exchanged between the flow and surficial layer, whereas particles are only exchanged between the surface layer and substrate when the bed scours and fills. For cohesive materials, the erosion rate is calculated by an excess shear-stress approach while the deposition rate is based on particle settling velocity.

2.8.3 Streambank Erosion

CONCEPTS simulates channel width adjustment by incorporating the fundamental physical processes responsible for bank retreat: (1) fluvial erosion or entrainment of bank toe material by flow, and (2) bank mass failure due to gravity (Langendoen 2000). Natural streambank material may be cohesive or noncohesive and may comprise numerous soil layers reflecting the depositional history of the bank materials; each layer can have physical properties quite different from those of other layers. CONCEPTS accounts for streambank stratigraphy by allowing variable critical shear-stresses to be assigned to the bank materials. An average shear-stress on each soil layer is computed, which increases with depth. Because of the resulting shear stress distribution, CONCEPTS is able to more realistically simulate streambank erosion caused by undercutting and cantilever failures.

Bank stability is analyzed via the limit equilibrium method, based on static equilibrium of forces and/or moments. Streambank failure occurs when gravitational forces that tend to move soil downslope exceed the forces that resist movement. The risk of failure is usually expressed by a factor of safety, defined as the ratio of resisting to driving forces or moments. CONCEPTS performs stability analyses of planar slip failures and cantilever failures of overhanging banks by dividing the bank into slices, and evaluating the balance of forces on each slice in vertical and horizontal directions. The slope of the failure surface is defined as that slope for which the factor of safety is a minimum. The bank’s geometry, soil shear-strength (effective cohesion, c', and angle of internal friction, ϕ'), pore-water pressure, confining pressure, and riparian vegetation determine the stability of the bank.

2.8.4 Input Data Requirements

Typical CONCEPTS input data are: water and sediment inflow at the upstream boundary of the model channel and any tributaries; the geometry (cross sections) of the channel; Manning’s *n* roughness coefficients; and composition of bed and bank material.

In addition, the user needs to supply bank-material properties for the streambank erosion component of CONCEPTS, such as the critical shear stress required to entrain bank-material particles, and the shear-strength parameters effective cohesion, c', and angle of internal friction, ϕ'.

3 DEVELOPING A "REFERENCE" SEDIMENT-TRANSPORT CONDITION FOR SHADES CREEK, ALABAMA

Sediment loads (transport rates) in streams vary by orders of magnitude over time and by location. Controls such as geology and channel-boundary materials, landuse, channel stability, and the type and timing of precipitation events make prediction of sediment loads difficult and complex. Still, in order to determine the amount of sediment that impairs a given waterbody (TMDL), one must first be able to determine the sediment load that would be expected in an unimpaired stream of a given type and location. However, baseline conditions of flow, sediment concentrations, and transport rates for streams in the wide variety of physiographic provinces and under a wide variety of landuses are poorly understood. Initiating a data collection program to obtain a comprehensive data set from a sufficient number of streams from different physiographic provinces for use in developing clean sediment TMDL's is impractical from both time and monetary standpoints. A logical alternative is to make use of high-quality, historical data sets containing corresponding flow and sediment-transport information that have been collected by government and private agencies at various locations.

3.1 Regionalization by Level III Ecoregion

To be useful for TMDL practitioners sediment-transport relations must be placed within a conceptual and analytic framework such that they can be used to address sediment-related problems at sites such as those along Shades Creek where no or only limited data exists. To accomplish this, sediment-transport characteristics and relations need to be regionalized according to attributes of channels and drainage basins that are directly related to sediment production, transport, and potential impairment. In a general way, these attributes include among others, physiography, geology, climate and ecology, differentiated collectively as an ecoregion (Omernik, 1995). The region that includes Shades Creek is the Ridge and Valley (Ecoregion 67).

3.1.1 "Reference" Conditions

To identify those sediment-transport conditions that represent impacted or impaired conditions, it is essential to first be able to define a non-disturbed, stable, or "reference" condition for the particular stream reach. In some schemes the "reference" condition simply means "representative" of a given category of classified channel forms or morphologies (Rosgen, 1985) and as such, may not be analogous with a "stable", "undisturbed", or "background" rate of sediment production and transport. Although the Rosgen (1985) stream classification system is widely used to describe channel form, stream types D, F, and G are by definition, unstable (Rosgen, 1996, p. 4-5). These stream reaches, therefore, would be expected to produce and transport enhanced amounts of sediment and represent impacted, if not impaired conditions. Thus, although it may be possible to define a "representative" reach of stream types D, F, and G, for the purpose of TMDL development, a "reference" condition transporting "natural" or background rates of sediment will be difficult to find.

3.1.2 Stages of Channel Evolution

As an alternative scheme for TMDL practitioners, the channel evolution framework set out by Simon and Hupp (1986) and Simon (1989b) is used (Figure 3-1) and has proved successful in numerous ecoregions (Simon *et al*., 2003). In most alluvial channels, disruption of the dynamic equilibrium generally results in a certain degree of upstream channel degradation and downstream aggradation. If the predisturbed channel is considered as the initial stage (I) of channel evolution and the disrupted channel as an instantaneous condition (stage II), rapid channel degradation can be considered stage III (Figure 3-1). Degradation flattens channel gradients and consequently reduces the available stream power for given discharges with time. Concurrently, bank heights are increased and bank angles are often steepened by fluvial undercutting and by pore-pressure induced bank failures near the base of the bank. Thus, the degradation stage (III) is directly related to destabilization of the channel banks and to channel widening by mass-wasting processes (stage IV) once bank heights and angles exceed the critical conditions of the bank material (as determined by shear-strength characteristics). If streambeds are composed of highly resistant materials as is the case with some reaches of Shades Creek, adjustment to heightened flow-energy conditions can occur by lateral migration, bank erosion and channel widening (Simon and Darby, 1997).

As degradation migrates further upstream, aggradation (stage V) becomes the dominant trend in previously degraded downstream sites because the flatter gradient and lower hydraulic radius at the degraded site cannot transport the heightened sediment loads originating from degrading reaches upstream. This secondary aggradation occurs at rates roughly 60% less than the associated degradation rate (Simon 1992). These reduced aggradation rates indicate that bed-level recovery will not be complete and that attainment of a new dynamic equilibrium will take place through (1) further channel widening, (2) the establishment of riparian vegetation that adds roughness elements and reduces the stream power for given discharges, and (3) further gradient reduction by meander extension and elongation.

The lack of complete bed-level recovery often results in a two-tiered channel configuration with the original floodplain surface becoming a terrace. Flood flows are, therefore, constrained within this enlarged channel below the terrace level. Without proliferation of riparian vegetation within the channel, this results in a given flow having greater erosive power than if an equivalent flow could dissipate energy by spreading across the floodplain. Where vegetation does re-establish, the additional roughness limits the erosive power of flood events within the incised channel and constrains shear-stress values to near bankfull levels (Simon *et al*., 1999). Aggrading conditions (stage V) are also common in reaches downstream from the area of maximum disturbance immediately after the disturbance is imposed on the stream channel.

With stages of channel evolution tied to discrete channel processes and not strictly to specific channel shapes, they have been successfully used to describe systematic channel-stability processes over time and space in diverse environments subject to various disturbances such as stream response to: channelization in the Southeast US

Coastal Plain (Simon, 1994); volcanic eruptions in the Cascade Mountains (Simon, 1992); and dams in Tuscany, Italy (Rinaldi and Simon, 1998). Because the stages of channel evolution represent shifts in dominant channel processes, they are systematically related to suspended-sediment and bed-material discharge (Simon, 1989b; Kuhnle and Simon, 2000), fish-community structure (Simon *et al.*, 2002), rates of channel widening (Simon and Hupp, 1992), and the density and distribution of woody-riparian vegetation (Hupp, 1992).

An advantage of a process-based channel-evolution scheme for use in TMDL development is that Stages I and VI represent two true “reference” conditions. In some cases, such as in the Midwestern United States where land clearing activities near the turn of the 20th century caused massive changes in rainfall-runoff relations and landuse, channels are unlikely to recover to Stage I, pre-modified conditions. Stage VI, re-stabilized conditions are a more likely target under the present regional landuse and altered hydrologic regimes (Simon and Rinaldi, 2000).

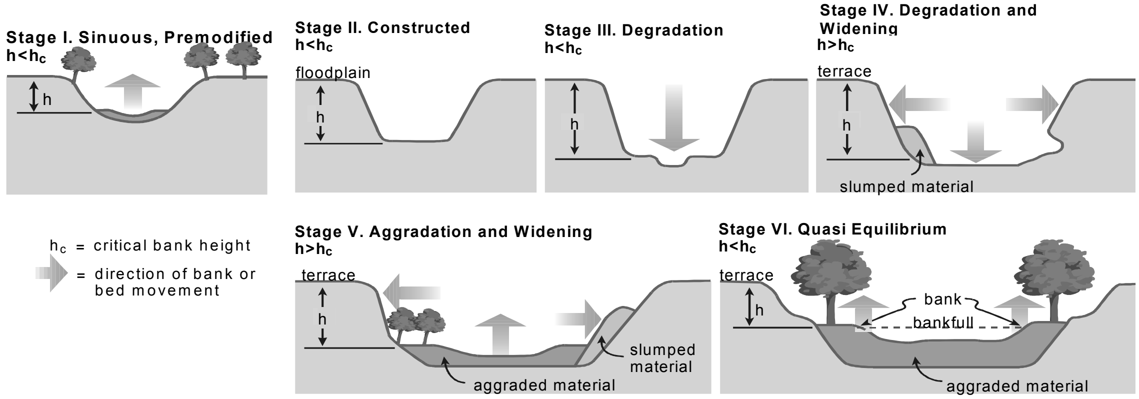


Figure 3-1. Six stages of channel evolution from Simon and Hupp (1986) and Simon (1989b) identifying Stages I and VI as stable, “reference” conditions.

3.2 Rapid Geomorphic Assessments: RGA’s

To determine the relative stability and stage of channel evolution for all of the sites with available sediment data in the Ridge and Valley, rapid geomorphic assessments (RGA’s) are conducted. RGA techniques utilize diagnostic criteria of channel form to infer dominant channel processes and the magnitude of channel instabilities. Granted that evaluations of this sort do not include an evaluation of watershed or upland conditions, however, stream channels act as conduits for energy, flow and materials as they move through the watershed and will reflect a balance or imbalance in the delivery of flow and sediment. Given the large number of sites in the Ridge and Valley and other ecoregions where these techniques are being used, it is not feasible to perform detailed, time-consuming field surveys at every site. RGA’s provide an efficient alternative to determine stability conditions.

The RGA procedure consists of four steps, which collectively take about 1.5 hours to complete on site:

1. Take photographs looking upstream, downstream and across the reach;
2. Take sample of bed material. This could be a bulk sample, a particle count if the bed is dominated by gravel and coarser fractions, or a combination of the two;
3. Make observations of channel conditions and diagnostic criteria listed on the channel-stability ranking scheme; and
4. Perform a survey of channel gradient, or water-surface slope if the water is too deep to wade.

RGA's were conducted at 73 of the 74 sites in the Ridge and Valley and at 105 sites along Shades Creek. At the Ridge and Valley sites, all but nine were considered stable, while 41 of the sites along Shades Creek were considered stable, most of them where beds are composed of bedrock.

3.2.1 Channel-Stability Index

A simple field form containing nine criteria is used to record observations of field conditions during RGAs (Figure 3-2). Each criterion is ranked and all values are then summed to obtain an index of channel stability. The higher the number, the greater the instability indicated. However, the rankings are not weighted and for example, a ranking of 16 does not mean that the site is twice as unstable as a site with a value of 8. Experience has shown that values of 20 or greater are indicative of significant instability; values below 10 are indicative of stability. Intermediate values denote reaches of moderate instability. Figure 3-3 shows the channel-stability index plotted against river kilometer for all sites evaluated during 2003 along Shades Creek. The mean channel-stability index for Shades Creek was about 14.0 indicative of low to moderate instabilities over the entire length studied. All but one of the unstable sites was evaluated as stage V, characterized by deposition and channel widening (Figure 3-4). Bank failures are relatively common with about one third of all banks failing (Figures 3-5 and 3-6). Figure 3-7 shows the spatial distribution and intensity of failing banks along the studied length of Shades Creek.

1. **Primary bed material**

Bedrock	boulder/cobble	gravel	sand	silt/clay
0	1	2	3	4

2. **Bed/bank protection**

Yes	No	(with) 1 bank	2 banks Protected
0	1	2	3

3. **Degree of incision (Relative elev. of "normal" low water; floodplain/terrace @ 100%)**

0 – 10%	11 – 25%	26 – 50%	51 – 75%	76 – 100%
4	3	2	1	0

4. **Degree of constriction (Relative decrease in top-bank width from up to downstream)**

0 – 10%	11 – 25%	26 – 50%	51 – 75%	76 – 100%
0	1	2	3	4

5. **Streambank erosion (Each bank)**

	None	fluvial	mass wasting (failures)
Left	0	1	2
Right	0	1	2

6. **Streambank instability (Percent of each bank failing)**

	0 – 10%	11 – 25%	26 – 50%	51 – 75%	76 – 100%
Left	0	0.5	1	1.5	2
Right	0	0.5	1	1.5	2

7. **Established riparian woody-vegetative cover (Each bank)**

	0 – 10%	11 – 25%	26 – 50%	51 – 75%	76 – 100%
Left	2	1.5	1	0.5	0
Right	2	1.5	1	0.5	0

8. **Occurrence of bank accretion (Percent of each bank with fluvial deposition)**

	0 – 10%	11 – 25%	26 – 50%	51 – 75%	76 – 100%
Left	0	0.5	1	1.5	2
Right	0	0.5	1	1.5	2

9. **Stage of channel evolution**

I	II	III	IV	V	VI
0	1	2	4	3	1.5

Figure 3-2. Channel stability ranking scheme used to conduct rapid geomorphic assessments (RGA's). The channel stability index is the sum of the values obtained for the nine criteria.

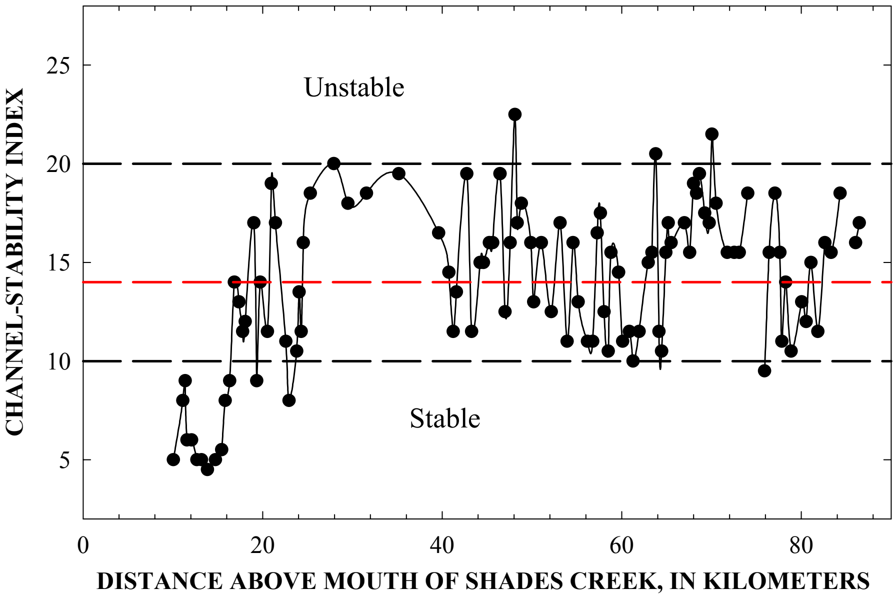


Figure 3-3. Channel-stability index for sites evaluated during 2003 along Shades Creek. Red line denotes average for all sites evaluated.

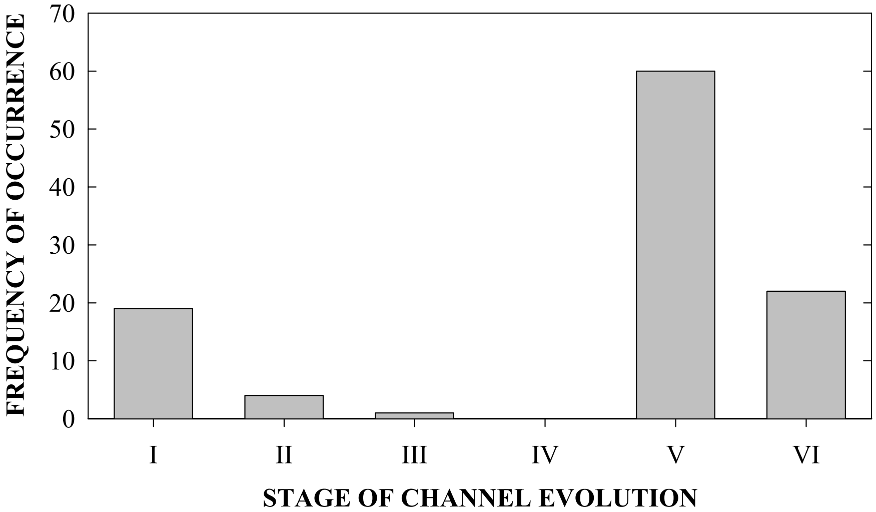


Figure 3-4. Distribution of stages of channel evolution along Shades Creek.

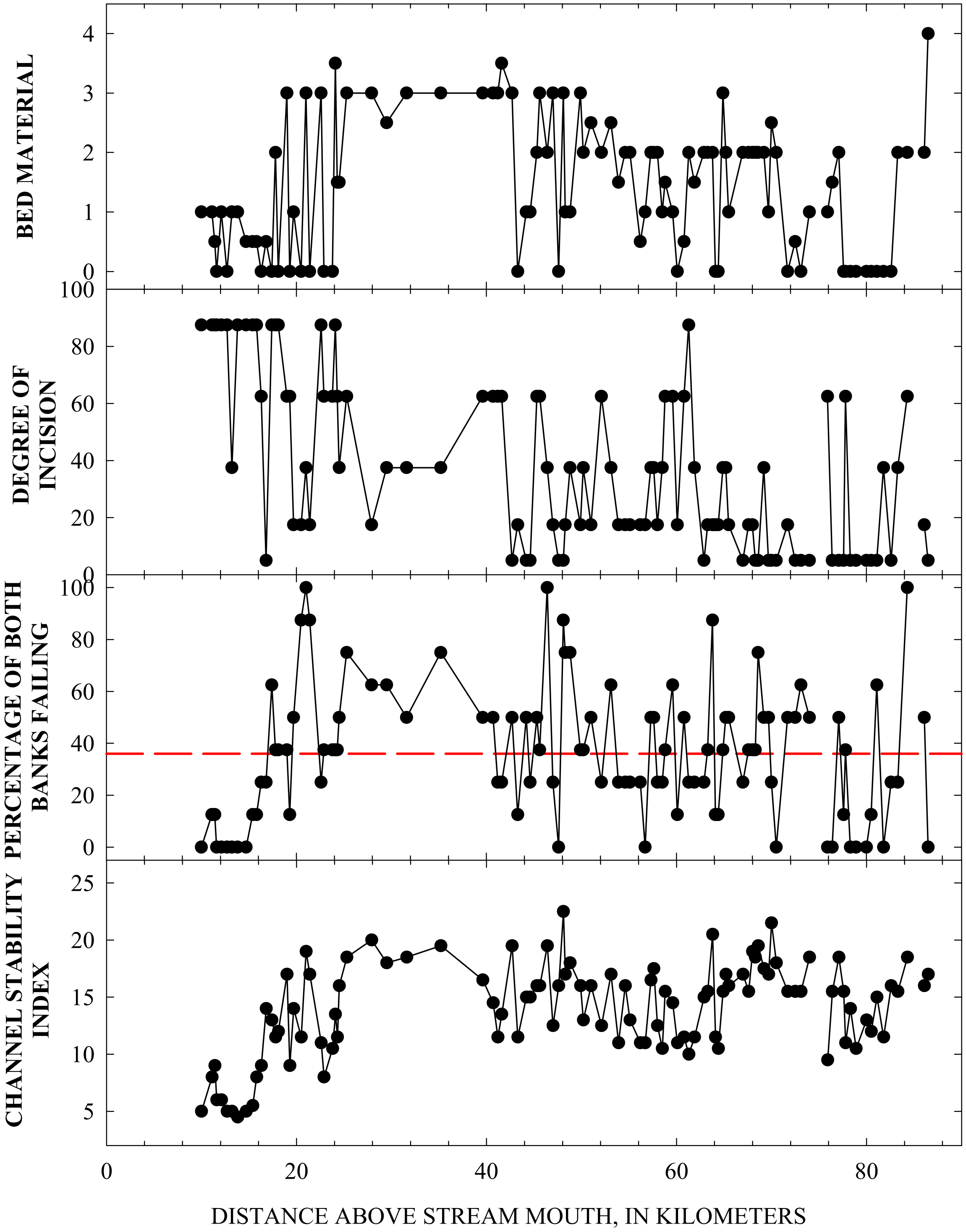


Figure 3-5. Longitudinal trends of diagnostic criteria of geomorphic conditions along Shades Creek. Ordinate values on plots refer to rankings shown in Figure 3-2. Dotted line indicates average length of observed banks that are failing (36%).

Figure 3-6. Example of unstable banks providing fine-grained sediment to Shades Creek.

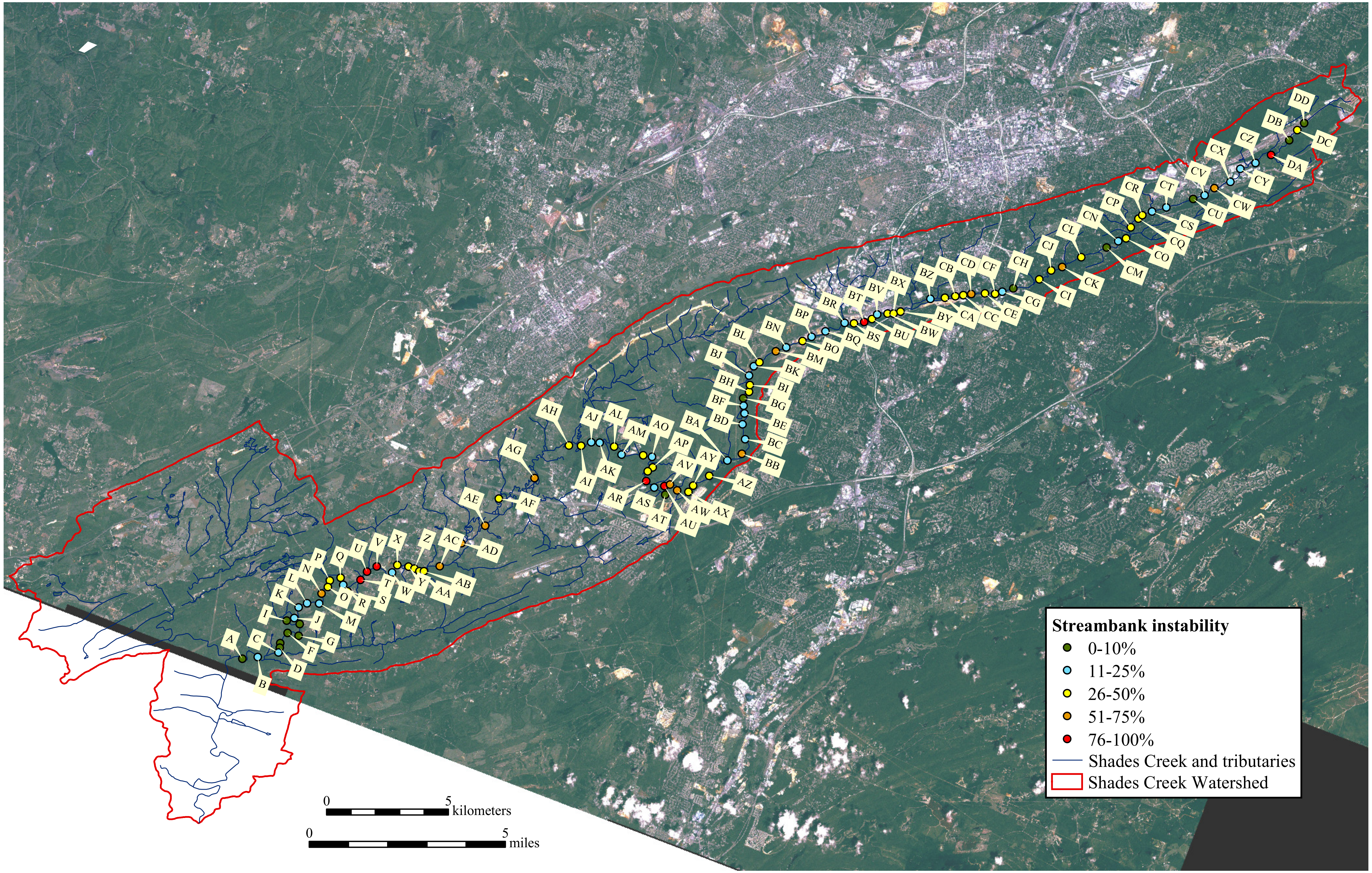


Figure 3-7. Map showing location and extent of bank failures along Shades Creek.

3.3 Analysis of Suspended-Sediment Data

Suspended-sediment data were analyzed in two ways:

1. At a single flow rate, representing a channel-forming or "effective discharge", and
2. As an integration of all mean-daily flows to determine mean-annual suspended-sediment loads, yields and concentrations.

Both of these techniques rely initially on a relation between flow and suspended-sediment concentration or load at a given site.

Instantaneous-concentration data combined with either an instantaneous flow value or flow data representing the value obtained from the stage-discharge relation at 15-minute intervals are best for developing the transport relation. Continuous (15-minute interval) time-series flow data are advantageous to calculate daily, monthly or annual loads. However, experience has shown that the stored data rarely are continuous requiring the use of mean-daily flow data to calculate annual loads. Mean-daily values tend to be biased towards lower flows, particularly in small, flashy basins. For establishing sediment-transport rating relations, instantaneous concentration and 15-minute flow data were used from USGS gauging-station records while mean-daily flow values were used to calculate annual loads and yields. The use of mean-daily values for calculating annual loads was not considered problematic in this study due to the relatively large watershed areas encompassed by the historical gages in the Ridge and Valley. Although the minimum drainage area for gages in the Ridge and Valley is 1 km^2, the average and median drainage areas are 5610 and 1120 km^2, respectively. In fact, 75% of the gages drain areas of at least 154 km^2.

A suspended-sediment transport rating is developed (Porterfield, 1972; Glysson, 1987; Simon, 1989a) by plotting discharge versus concentration in log-log space and obtaining a power function by regression. Trends of these data (in log-log space) often increase linearly and then break off and increase more slowly at high discharges. A transport rating developed with a single power function commonly over-estimates concentrations at high flow rates, leading to errors in calculating the effective discharge. To alleviate this problem, a second or third linear (in log-log space) segment is sometimes developed with the upper end of data set (Figure 3-8). The division point between these data ranges was identified by eye, and a manual iterative procedure was carried out to ensure the division point was optimal. This procedure was followed for each of the 74 sites in the Ridge and Valley.

A daily load was calculated for each day of flow record using the following formula:

$$L = 0.0864\ C\ Q \tag{6}$$

where: L = load in T/d;
C = instantaneous concentration, in mg/l; and
Q = instantaneous discharge, in m^3/s.

The value 0.0864 is to convert from seconds to days and from milligrams to tonnes.

Linear regression in log-log space results in power function describing the relation between instantaneous discharge and load as:

$$L = a\,Q^{b} \tag{7}$$

where *a* and *b* are regression coefficients.

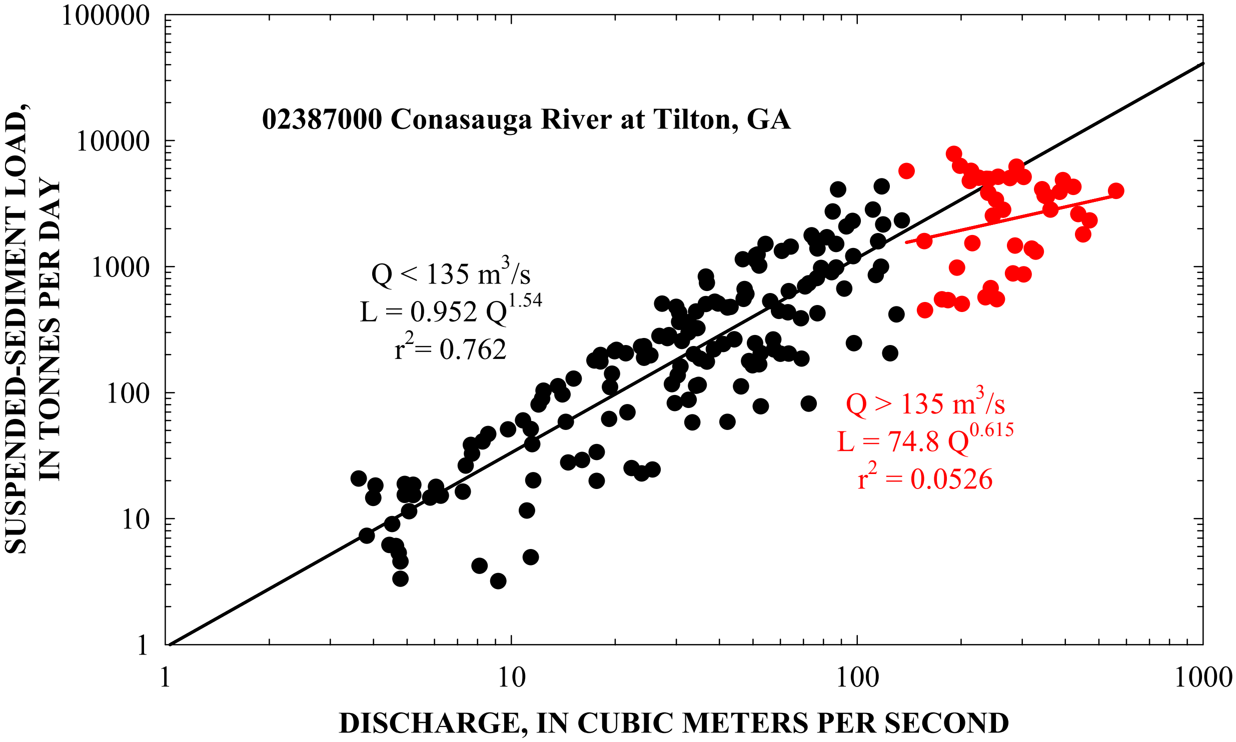


Figure 3-8. Development of suspended-sediment rating relation in log-log space showing potential error at high discharges without incorporating a second linear segment.

3.3.1 Suspended-Sediment Transport Rating for Shades Creek near Greenwood

A suspended-sediment rating relation was developed for the gage near Greenwood based on data obtained from the USGS and, more recently, from a Stormwater Management Authority (Figure 3-9). Note that both the 95% confidence limits of the regression and the 95% prediction limits are shown in Figure 3-9, highlighting the relative uncertainty inherent in predicting a suspended-sediment load at a given discharge.

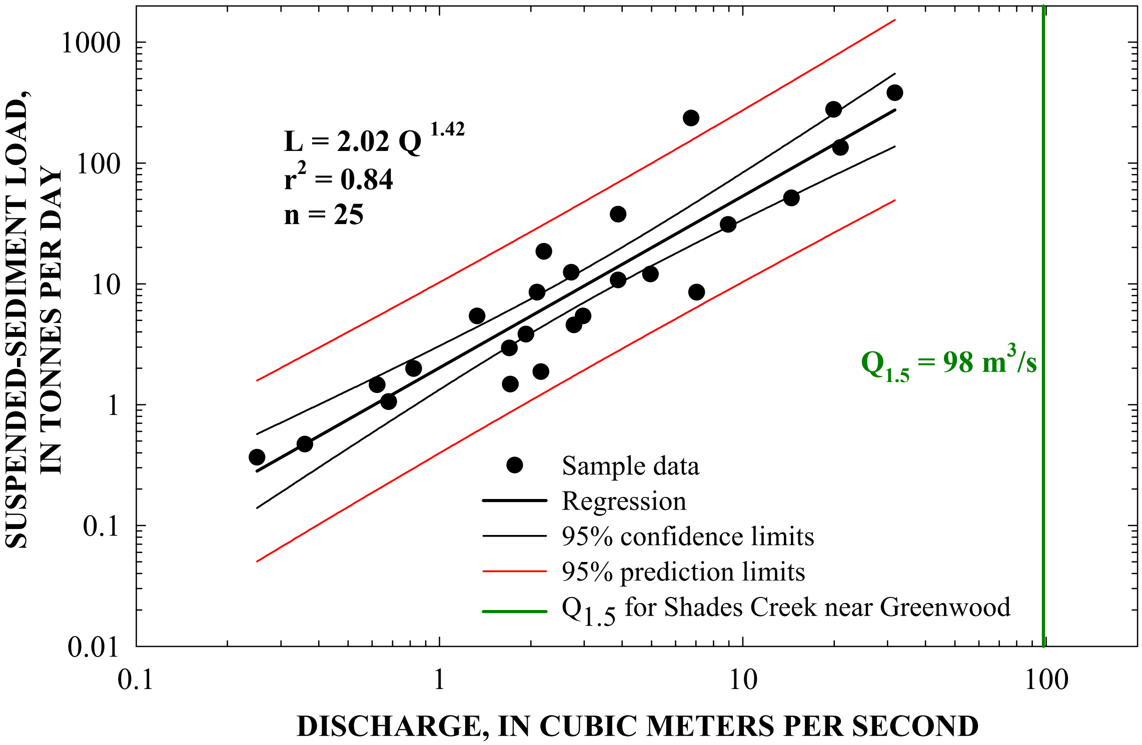


Figure 3-9. Suspended-sediment rating relation for Shades Creek at Greenwood, Alabama (station 02423630) showing regression statistics, confidence and prediction limits, and the $Q_{1.5}$.

3.3.2 Selecting a Discharge Rate to Compare Loadings from Impacted and Reference Conditions

Because the "effective discharge" is that discharge or range of discharges that shape channels and perform the most geomorphic work (transport the most sediment) over the long term it can serve as a useful indicator of regional suspended-sediment transport conditions for "reference" and impacted sites. In many parts of the United States, the effective discharge is approximately equal to the peak flow that occurs on average, about every 1.5 years ($Q_{1.5}$; for example, Andrews, 1980; Andrews and Nankervis, 1995) and may be analogous to the bankfull discharge in stable streams. The recurrence interval of the effective discharge calculated for 10 streams in Mississippi was about 1.5 years (Simon *et al.*, 2002). For 17 ecoregions across the United States, the recurrence interval of the effective discharge ranged from 1.1 years to 2.3 years (Simon *et al.*, 2003). The value for the Ridge and Valley was 1.1 years. Still, for consistency of analysis between ecoregions, the $Q_{1.5}$ was used as a measure of establishing the effective discharge at the remaining study sites in the Ridge and Valley.

3.3.3 Calculating an Effective Discharge ($Q_{1.5}$) and Load at the Effective Discharge

Using the annual-maximum peak-flow series for each of the sites with available data, the effective discharge ($Q_{1.5}$) was then calculated from the log-Pearson Type III distribution. The example shown in Figure 3-10 is for the Shades Creek gage near Greenwood where the $Q_{1.5}$ was determined to be 98 m^3/s from the annual-maximum series. Where peak-flow data were not available, the $Q_{1.5}$ was calculated from regional relations based on drainage area obtained from the U.S. Geological Survey (1993) and calculated in Simon *et al*., 2003.

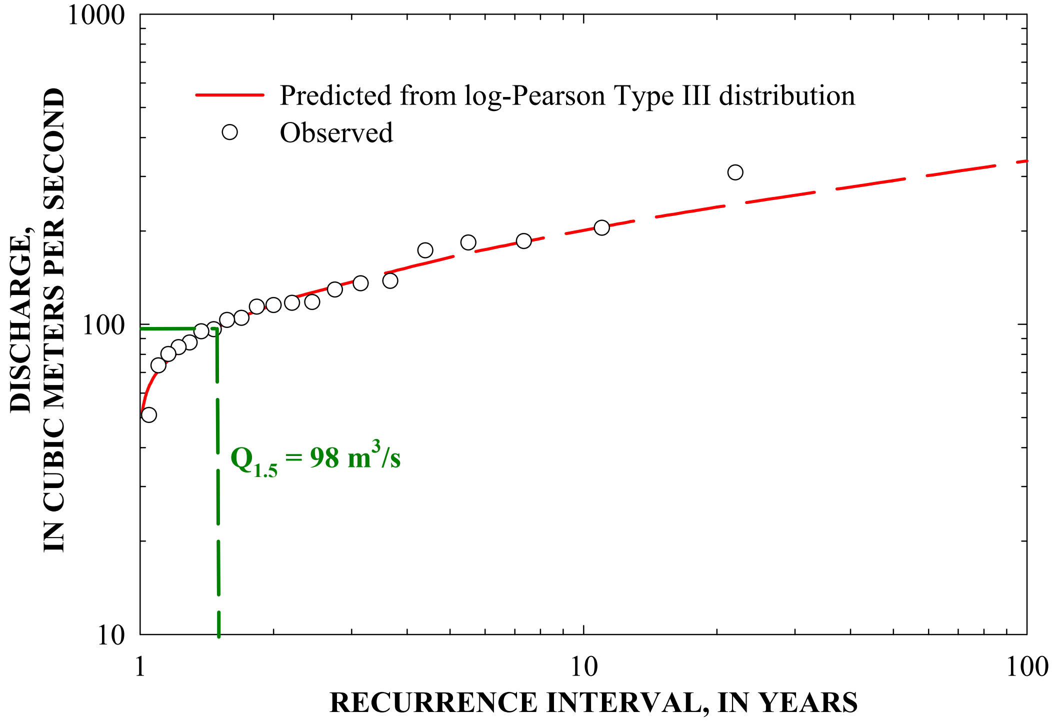


Figure 3-10. Flood-frequency distribution for Shades Creek near Greenwood, Alabama showing the $Q_{1.5}$ to be used in calculating sediment loads and yields at the effective discharge.

The suspended-sediment load at the $Q_{1.5}$ was then obtained by using the transport rating developed for the site and by solving for the discharge of the $Q_{1.5}$ (Figure 3-11). For sites in Ecoregion 67 with peak flow and sediment-transport data, sediment load at the effective discharge was obtained directly from the rating relation. A summary of transport ratings for the Ridge and Valley stations is shown in Table 3-1.

To normalize the data for watersheds of different size, the sediment load is divided by drainage area to obtain sediment yield (in $T/d/km^2$). All rating relations are checked to be sure that the $Q_{1.5}$ was within the measured bounds of the data set. If the $Q_{1.5}$ is more than 100% greater than the maximum sampled discharge, the calculated sediment yield is not included in the data set. This was the case for six of the 74 stations in the

Ridge and Valley leaving 68 stations where suspended-sediment loads could be calculated at the $Q_{1.5}$. Results are shown in Table 3-2

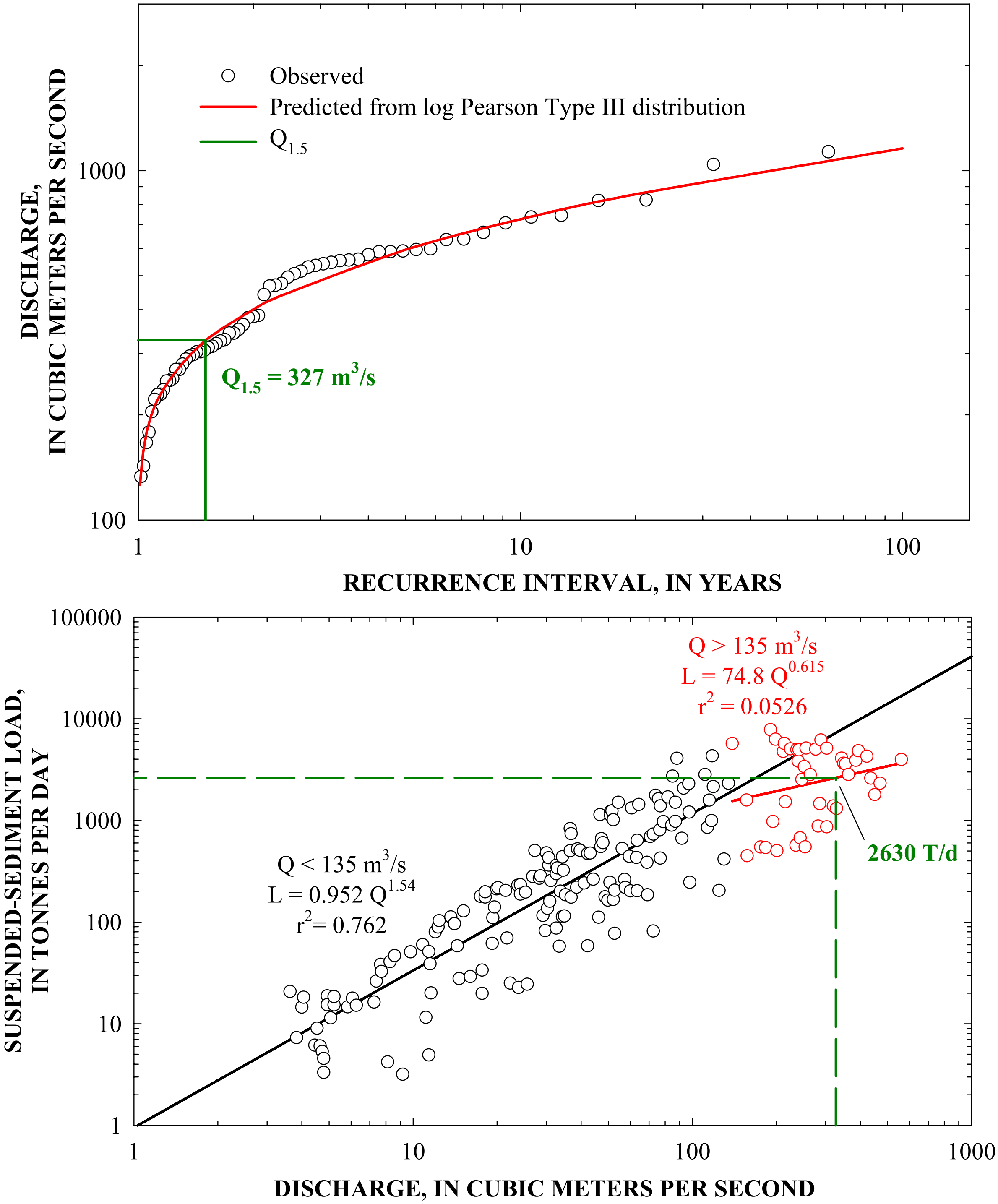


Figure 3-11. Determination of effective discharge ($Q_{1.5}$) from the annual-maximum flow series (A) and suspended-sediment load at the effective discharge (2630 T/d) using the sediment-transport rating relation (B). Site is the Conasauga River at Tilton, GA (02397000).

Calculated suspended-sediment loads for the Shades Creek site near Greenwood may be higher than actual because of the lack of high-flow samples and the associated uncertainty in the shape of the transport rating at high flows. For example, the maximum flow rate sampled for suspended sediment at the Shades Creek gauge was $31.7m^3/s$ compared to a discharge of $98m^3/s$ at the 1.5-year recurrence interval. Of the 6940 mean-daily flow records used to calculate annual loads, 132 days or 1.9% had flow rates exceeding the maximum sampled discharge. We assume that the transport rating shown in Figure 3-9 is linear (in log-log space) through the un-sampled higher discharges. Because transport ratings often flatten at higher discharges (Figure 3-8 for example) calculations of suspended-sediment load at the $Q_{1.5}$ may be overestimated for Shades Creek.

Table 3-1. Rating equations used to calculate suspended-sediment loads in the Ridge and Valley. *L* = load in tones; *Q* = discharge in m^3/s; n^1 = number of ratings; n^2 = number of samples.

Station number	State	n^1	Equation 1 ($L =$)	Flow boundary (m^3/s)	Equation 2 ($L=$)	Flow boundary (m^3/s)	Equation 3 ($L =$)	n^2
02383500	GA	1	$0.4048Q^{1.7118}$					482
02385800	GA	1	$1.8085Q^{1.2965}$					56
02387000	GA	2	$0.952Q^{1.5449}$	135	$74.79Q^{0.6148}$			195
02387500	GA	2	$0.2058Q^{1.6439}$	355	$0.824Q^{1.3485}$			389
02387530	GA	1	$0.1255Q^{1.8089}$					47
02388000	GA	1	$1.1307Q^{1.3809}$					38
02395000	GA	1	$0.0134Q^{2.2899}$					183
03568933	GA	1	$0.331Q^{1.7642}$					40
01603000	MD	1	$0.0679Q^{2.088}$					63
01614500	MD	1	$0.186Q^{1.8444}$					329
01440000	NJ	1	$0.2148Q^{1.8861}$					46
01442750	NJ	1	$0.0017Q^{2.2613}$					41
01443500	NJ	1	$0.1774Q^{1.6327}$					34
01457000	NJ	1	$0.0759Q^{2.5421}$					60
01470500	PA	1	$0.4844Q^{1.6899}$					36
01537700	PA	2	$0.382Q^{1.3079}$	800	$3E\text{-}05Q^{2.689}$			72
01540500	PA	2	$0.1994Q^{1.3447}$	500	$0.0003Q^{2.412}$			404
01553500	PA	1	$0.0065Q^{1.9037}$					400
01554000	PA	1	$0.0325Q^{1.6246}$					70
01555400	PA	2	$0.4397Q^{0.8298}$	0.9	$0.7936Q^{1.795}$			77
01559795	PA	1	$0.3732Q^{1.1967}$					50
01562000	PA	1	$0.292Q^{1.5131}$					60
01567000	PA	1	$0.0042Q^{1.0292}$					301
01568000	PA	1	$0.2617Q^{1.8392}$					209

01568750	PA	1	$0.4009Q^{0.7249}$					61
01570000	PA	1	$0.0814Q^{1.9169}$					66
01570010	PA	2	$2.9878Q^{1.119}$	1	$2.8721Q^{1.901}$			158
01570030	PA	1	$4.5516Q^{1.1904}$					159
01570060	PA	1	$7.4416Q^{1.3289}$					109
01570200	PA	1	$462.68Q^{1.1775}$					33
01570300	PA	1	$432.76Q^{1.0835}$					30
01570500	PA	1	$0.0043Q^{1.915}$					461
01570980	PA	2	$0.2075Q^{0.8905}$	0.03	$25.328Q^{1.965}$			80
01570984	PA	1	$11.825Q^{1.778}$					75
01570988	PA	1	$64.119Q^{1.2899}$					60
01570992	PA	1	$9.3348Q^{1.3036}$					58
01570996	PA	2	$0.165Q^{0.9028}$	0.06	$57.325Q^{2.512}$			76
01571000	PA	2	$L = 7.022Q^{1.9806}$	36	$16.071Q^{1.452}$			426
01571490	PA	1	$7.2504Q^{1.6068}$					99
01571831	PA	1	$1.4534Q^{3.2032}$					109
01571919	PA	1	$1.0369Q^{1.9122}$					197
01572000	PA	2	$0.3382Q^{0.8752}$	0.7	$0.7123Q^{2.110}$			244
01572200	PA	1	$0.1487Q^{2.0116}$					67
01573095	PA	1	$6.5395Q^{1.885}$					67
01573560	PA	3	$0.605Q^{1.1363}$	15	$0.0087Q^{2.730}$	110	$48.53Q^{0.892}$	221
03465500	TN	1	$0.047Q^{1.9617}$					46
03466208	TN	1	$1.3139Q^{2.1712}$					63
03467609	TN	1	$0.0166Q^{2.1826}$					66
03470500	TN	1	$0.2402Q^{1.3448}$					98
03495500	TN	1	$0.2184Q^{1.3322}$					102
03527220	TN	1	$0.0142Q^{2.2656}$					42
03528000	TN	1	$0.0347Q^{2.0242}$					104
03531680	TN	1	$0.0853Q^{2.0332}$					79
03532000	TN	2	$0.0387Q^{2.2972}$	180	$1261Q^{0.3167}$			152
03535912	TN	1	$0.4461Q^{1.0615}$					90
03543005	TN	1	$0.1573Q^{1.2112}$					91
01621050	VA	1	$10.07Q^{1.7917}$					48
01631000	VA	1	$0.0133Q^{2.1088}$					74
01634000	VA	1	$0.0767Q^{1.9319}$					74
02054500	VA	1	$0.4699Q^{1.2824}$					97
02055000	VA	1	$0.7072Q^{1.2904}$					101
03167000	VA	1	$0.0806Q^{1.9831}$					40
03474000	VA	1	$0.2484Q^{1.842}$					40
03526000	VA	1	$0.2077Q^{1.912}$					60

01111230	WV	1	$0.331Q^{1.7642}$					40
01608500	WV	1	$0.0269Q^{2.0758}$					13
01610200	WV	1	$0.6131Q^{1.8291}$					132
01611500	WV	1	$0.0458Q^{1.9465}$					26
01618000	WV	1	$0.0119Q^{1.8943}$					58
01636500	WV	2	$1.709Q^{0.8388}$	100	$0.0019Q^{2.457}$			69
03068800	WV	1	$0.116Q^{1.6763}$					48
03068900	WV	1	$0.0603Q^{1.9971}$					85
390134079491139	WV	1	$5.6431Q^{1.7178}$					65
391952079303339	WV	1	$9.1946Q^{1.7486}$					52

Table 3-2. Suspended-sediment load, yield, and concentration at the $Q_{1.5}$ for stations in the Ridge and Valley.

State	Station number	Load at $Q_{1.5}$ (T/d)	Yield at $Q_{1.5}$ (T/d/km^2)	Concentration at $Q_{1.5}$ (mg/l)
GA	03568933	2100	5.44	170
GA	02388000	480	5.09	69.4
GA	02385800	498	3.00	75.8
GA	02383500	5890	2.74	252
GA	02387000	2630	1.48	93.0
GA	02387500	3470	0.836	82.4
GA	02387530	9500	2.25	222
GA	02395000	11300	2.67	338
MD	01614500	2680	2.10	172
MD	01603000	16900	7.44	509
NJ	01457000	1010	2.76	278
PA	01570000	1470	1.21	102
PA	01554000	33200	0.70	77.0
PA	01570500	86500	1.39	154
PA	01570060	43.8	10.9	134
PA	01568750	54.9	0.969	39.7
PA	01571000	4930	170	1840
PA	01562000	1780	0.912	65
PA	01570996	102	39.4	426
PA	01540500	81000	2.79	304
PA	01559795	15.1	0.351	7.93
PA	01570984	94.2	29.6	339
PA	01470500	5760	6.27	258
PA	01568000	2730	5.09	206
PA	01570980	167	70.2	741
PA	01573560	6480	5.18	311
PA	01570300	918	932	5308
PA	01570200	1220	620	6202
PA	01567000	18300	2.10	208
PA	01572000	805	9.06	333

PA	01571919	4530	24.1	655
PA	01537700	13300	0.506	74.0
PA	01553500	16700	0.944	83.2
PA	01570010	20.8	7.78	85.0
PA	01555400	678	5.85	182
PA	01572200	1860	4.30	197
PA	01570030	18.6	5.72	65.9
TN	03465500	7840	3.76	198
TN	03466208	1810	8.85	748
TN	03467609	31600	7.22	481
TN	03531680	13700	10.3	435
TN	03527220	25400	8.50	517
TN	03470500	1540	0.116	26.3
TN	03528000	13036	3.41	266
TN	03495500	849	0.0875	19.8
TN	03532000	11500	6.48	349
TN	03535912	305	0.0353	7.53
TN	03543005	1460	0.0326	8.93
VA	01631000	4990	1.17	131
VA	01634000	2610	1.31	125
VA	03474000	705	2.06	109
VA	02054500	284	0.426	23.1
VA	02055000	537	0.525	36.3
VA	03526000	316	1.15	79.3
VA	03167000	654	1.02	80.4
WV	01608500	10700	2.79	252
WV	391952079303339	290	14.5	278
WV	01636500	7530	0.963	121
WV	03068800	1020	2.60	52.2
WV	03068900	8230	19.7	809
WV	390134079491139	1230	26.2	619
WV	01618000	86800	5.64	593
WV	01611500	2610	1.49	109
WV	01610200	12300	30.6	632

3.4 Results from Evaluations of “Reference” Sediment Loading

Suspended-sediment yields at the effective discharge were calculated for each of the sites in the Ridge and Valley by the procedures outlined earlier (Table 3-2). The median suspended-sediment yield value at the $Q_{1.5}$ for all sites is 2.78 T/d/km^2 (Figure 3-12). This is placed in a national context in Figure 3-13 where median values for most of the 84 ecoregions in the continental United States are shown. The median concentration for the Ridge and Valley, also at the $Q_{1.5}$ is 162 mg/l (Figure 3-14). To reduce the effect of outliers on the maximum and minimum values shown in Figures 3-12 and 3-14, they are calculated as the mean of the five largest, and smallest, respectively. The significance of the median values should not be overestimated in that both are derived from data throughout the ecoregion for sites of varying degrees of stability as well as for a range of bed material types. It is encouraging to note, however, that the central 50% of each distribution falls within a single order of magnitude.

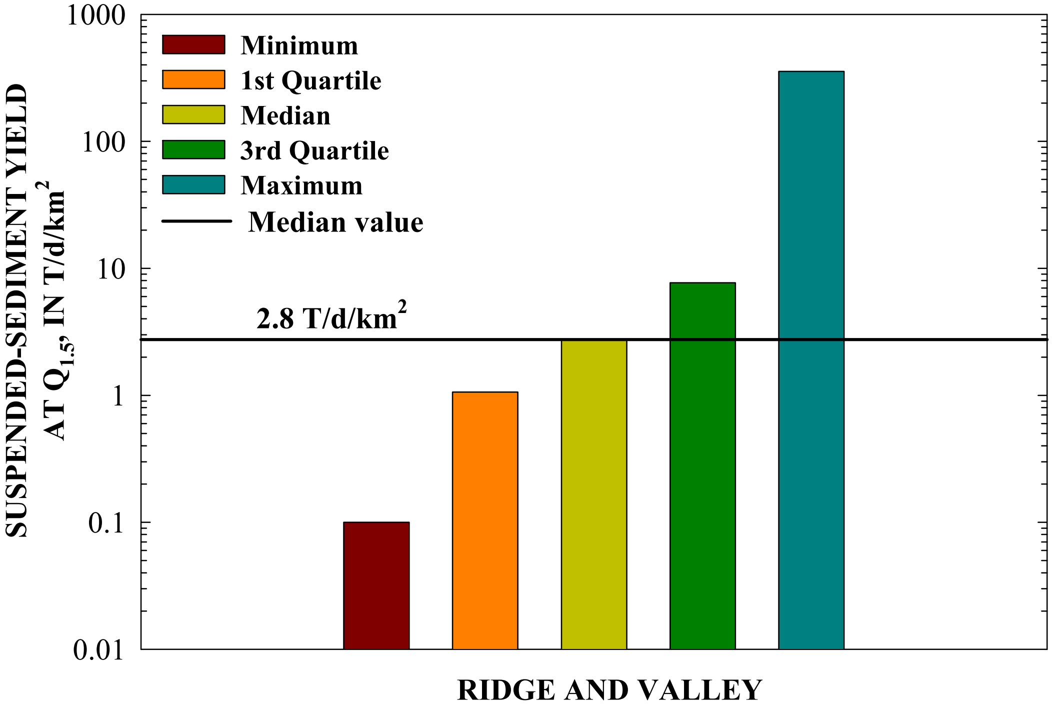


Figure 3-12. Distribution of suspended-sediment yields at the $Q_{1.5}$ for the Ridge and Valley ecoregion.

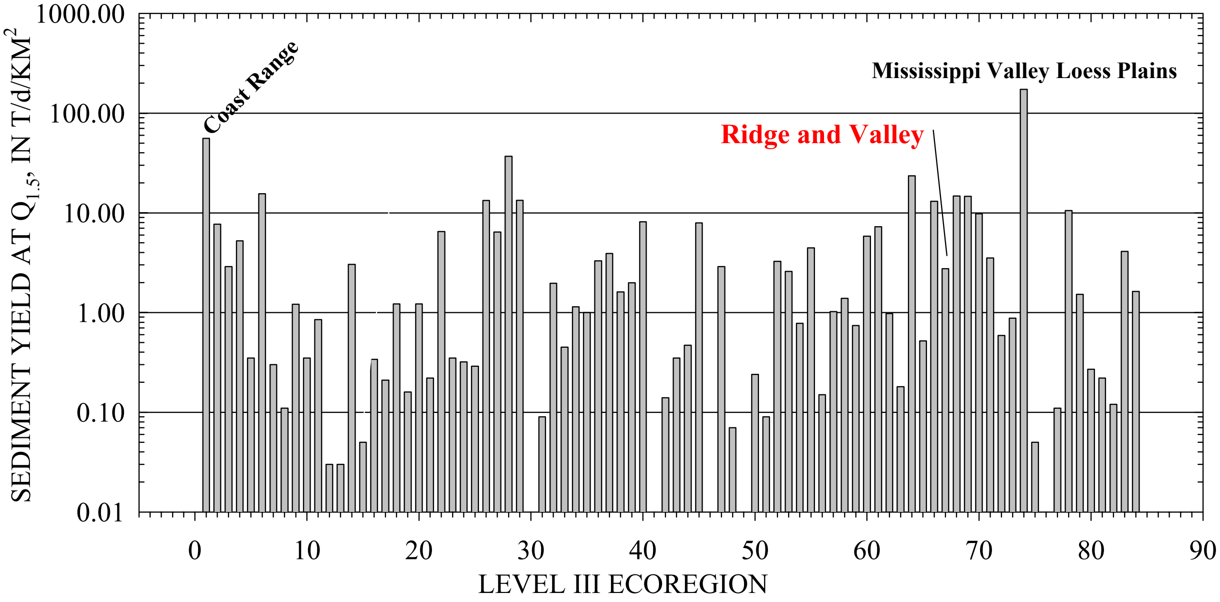


Figure 3-13. Comparison of median suspended-sediment yields at the $Q_{1.5}$ for 84 ecoregions of the continental United States. Modified from Simon et al., 2002.

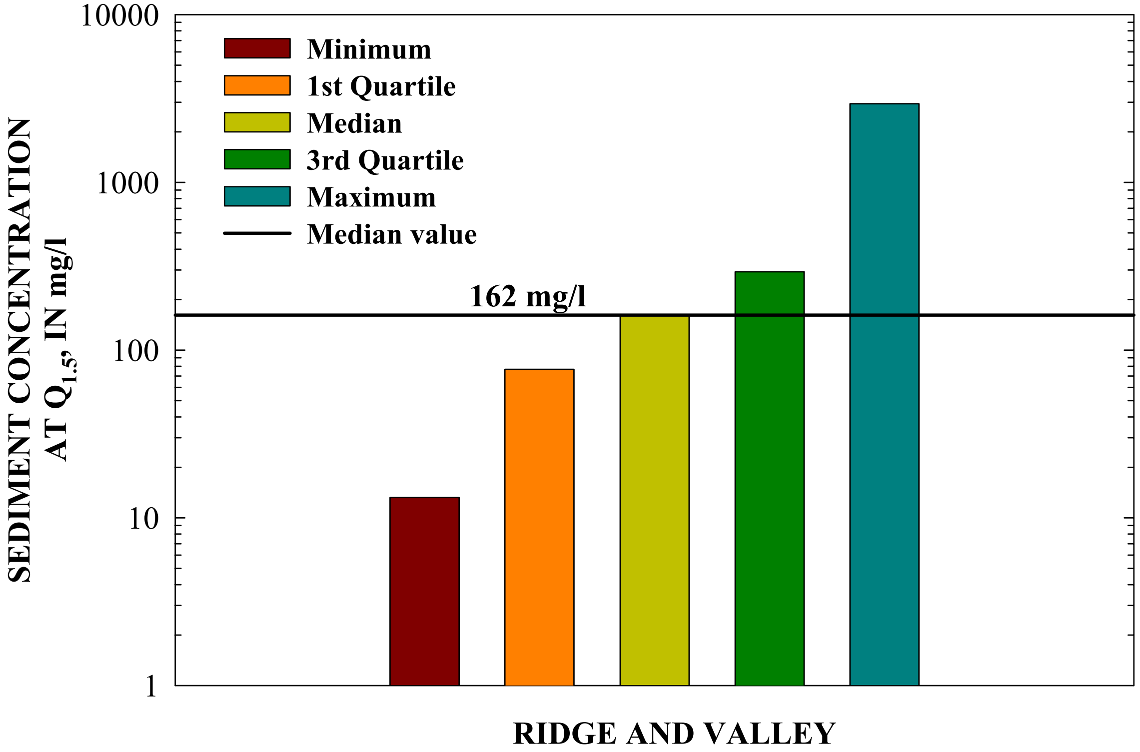


Figure 3-14 – Distribution of suspended-sediment concentrations at the $Q_{1.5}$ for the Ridge and Valley ecoregion.

3.4.1 "Reference" Sediment-Transport Conditions at the $Q_{1.5}$

A total of 73 sites in the Ridge and Valley were visited to determine stage of channel evolution and relative channel stability for the purpose of determining which sites could be characterized as "reference" (Figure 1-2). Stage I (pristine) conditions were found at 21 sites and 38 Stage VI (re-stabilized) sites were found in the region, thereby providing a reasonable number of sites to determine reference transport rates. In Shades Creek, 19 stage I sites were identified, mostly along the stream's downstream-most reaches (Appendix A) coinciding with beds composed of bedrock (Figure 3-15). In addition, 22 stage VI sites, indicative of recovery from disturbance were identified. "Reference" conditions for bed-material types other than bedrock were obtained from elsewhere in the Ridge and Valley. The channel stability index for sites in the Ridge and Valley are shown plotted against stage of channel evolution in Figure 3-16.

Figure 3-15. Example of Stage I (stable/reference) sites (I and S) along Shades Creek.

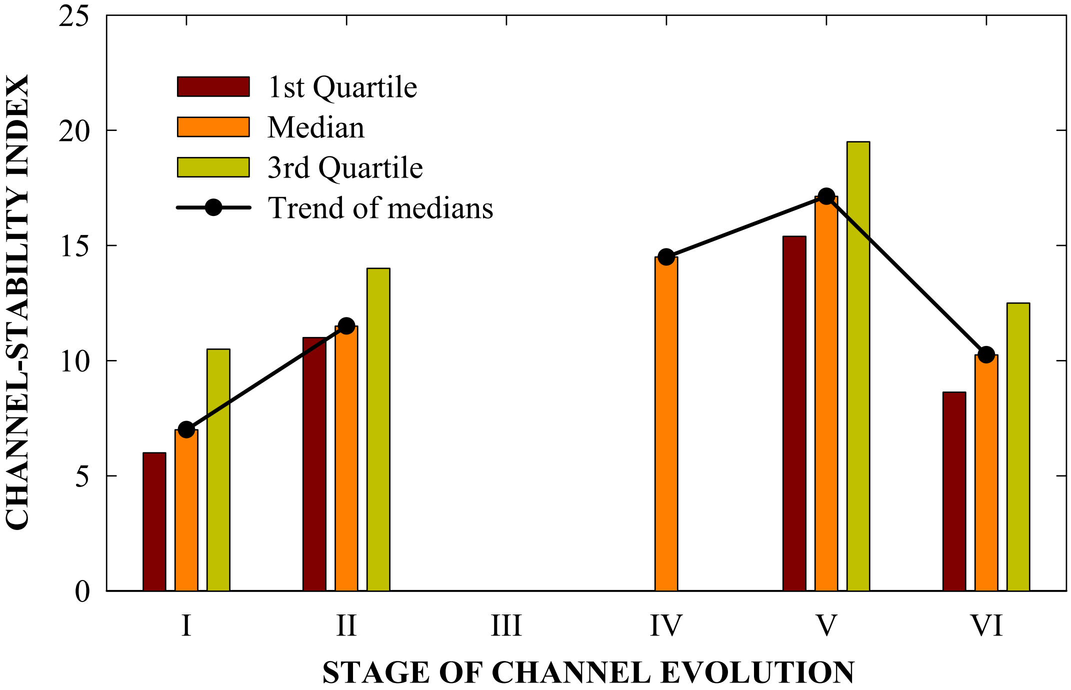


Figure 3-16. Relation between stage of channel evolution and channel-stability index (I) for the Ridge and Valley ecoregion.

Suspended-sediment yield and concentration data from the 59 “reference” sites were separated from those sites that were characterized as unstable to create more meaningful sediment-transport distributions representing unstable and “reference” sites. These are shown in Figures 3-17 and 3-18. The median value for the stable sites is termed the “general reference” for the particular parameter (yield or concentration).

The “general reference” for suspended-sediment yield at the $Q_{1.5}$ is 2.76 T/d/km^2. For the gage on Shades Creek near Greenwood, the suspended- sediment load at the $Q_{1.5}$ is calculated to be about 1360 T/d, equivalent to a yield of 7.3 T/d/km^2 (Figure 3-17).

This value is about 165% higher than the median reference yield for the Ridge and Valley at the $Q_{1.5}$ indicating that Shades Creek is somewhat impacted due to suspended sediment.

Perhaps a better way to interpret the data for the “general reference” is in terms of a range covering the central tendency of the reference distribution. The central 50% of the reference distribution falls within an order of magnitude (1.04 – 6.85 T/d/km^2). Thus, the Shades Creek gage near Greenwood still yields about 7% more suspended sediment at the $Q_{1.5}$ than the 75th percentile (3rd quartile) of the Ridge and Valley reference yield. This would provide for a “general reference” load at the Greenwood gage of between 19.5 and 1280 T/d at the effective discharge compared to the calculated load of 1360 T/d. The central 50% of the distribution for unstable sites in the Ridge and Valley ranges from 5.2 to 473 T/d/km^2 at the effective discharge. The median value for these sites is 18.0 T/d/km^2.

A similar “general reference” transport condition can be characterized for suspended-sediment concentration at the $Q_{1.5}$ (Figure 3-18). Here, a median value for stable sites of 208 mg/l was obtained with the central 50% of the distribution ranging from 83 to 388 mg/l. The suspended-sediment concentration for Shades Creek near Greenwood at the $Q_{1.5}$ is calculated to be 161 mg/l, indicating concentrations similar to stable sites in the Ridge and Valley ecoregion. This compares to a central inter-quartile range of 296 to 1950 mg/l with a median of 646 mg/l for unstable sites in the Ridge and Valley. The apparent discrepancy between sediment transport rates along Shades Creek relative to the “general references” (yield and concentration) lends support to using a range rather than a single value as a target.

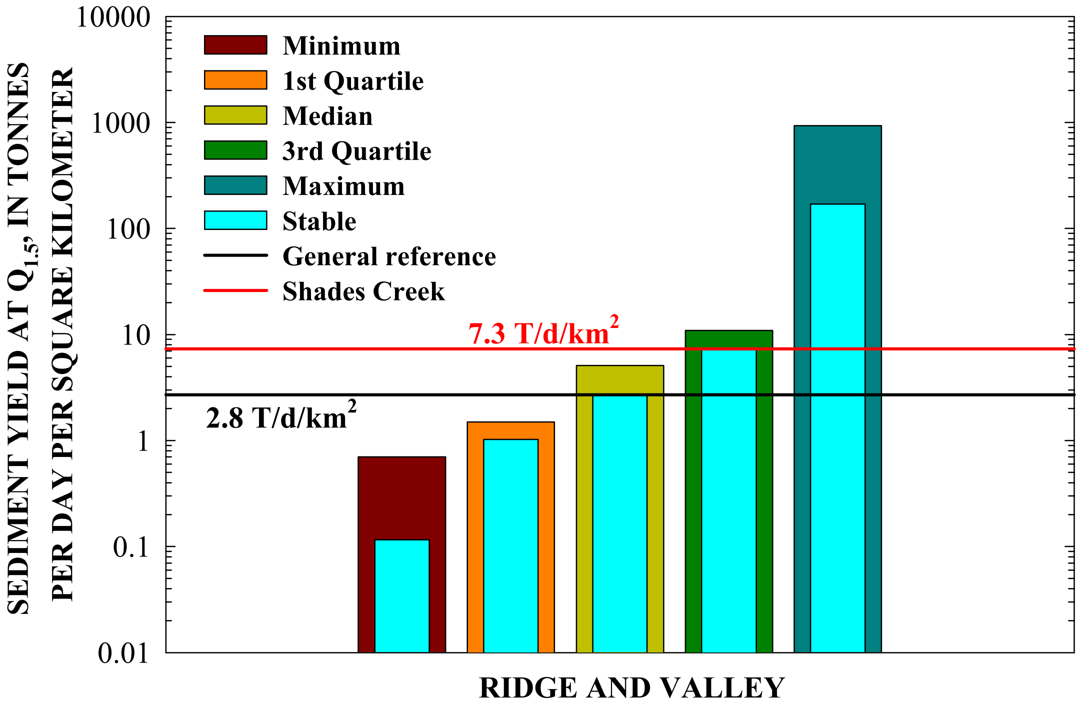


Figure 3-17. Comparison of suspended-sediment yields at the $Q_{1.5}$ for stable "reference" sites and for evaluated, unstable sites. Yield shown is a general reference for the Ridge and Valley ecoregion.

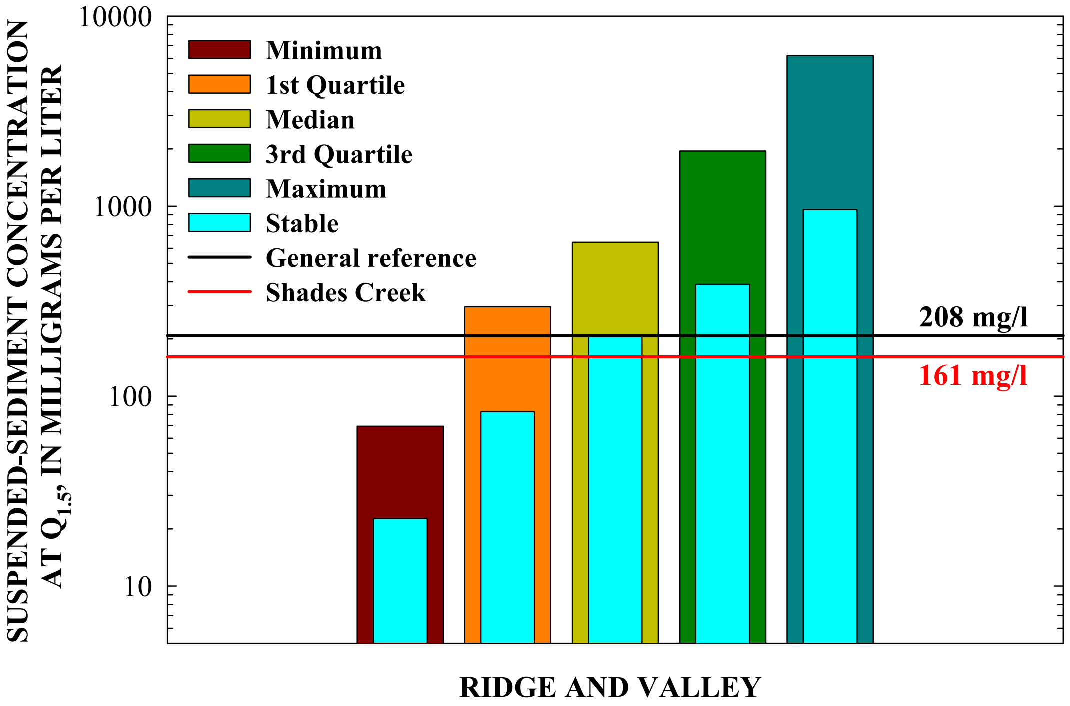


Figure 3-18. Comparison of suspended-sediment concentrations at the $Q_{1.5}$ for stable "reference" sites and for evaluated, unstable sites. Concentration shown is a general reference for the Ridge and Valley ecoregion.

3.4.2 "Reference" Sediment-Transport Conditions Using Mean-Annual Values

Annual suspended-sediment yields were calculated for all sites with available data in the Ridge and Valley using mean-daily flow data (Table 2-5) and the suspended-sediment transport relations described earlier. This measure of suspended-sediment transport was tested as a possible alternative to the reference yields developed using the $Q_{1.5}$. A total of 53 sites from the Ridge and Valley were analyzed with a summary of results shown in Table 3-3. It is particularly encouraging that the inter-quartile range of the mean-annual reference values are well within an order of magnitude for both yield and concentration and that results are consistent with those using the $Q_{1.5}$.

Mean annual suspended-sediment yield for stable/reference sites in the Ridge and Valley is 24.7 T/y/km^2. In comparison, Shades Creek at Greenwood discharges almost twice that amount per unit area on an annual basis (52.6 T/y/km^2; Figure 3-19). Mean annual suspended-sediment load is 9850 T/y. Again, the yield value for Shades Creek is slightly greater than the 75th percentile of the reference yield for the Ridge and Valley where the inter-quartile range is 10.7 to 44.7 T/y/km^2. The difference between the reference mean-annual suspended-sediment concentration and the value for Shades Creek near Greenwood is strikingly similar to the reference yield results. In this case, the reference (median) value for Ridge and Valley sites is 45.1 mg/l compared to 77.6 mg/l for the gage on Shades Creek (Figure 3-20). This value is again close to the 75th percentile of the reference concentration for the Ridge and Valley where the inter-quartile range is 21.6 to 93.5 mg/l, indicating that Shades Creek displays moderate impact due to sediment in the water column.

Table 3-3. Mean-annual suspended-sediment loads and yields for stations in the Ridge and Valley.

Station number	State	Mean annual load (T/y)	Drainage area (km^2)	Mean annual yield (T/y/km^2)
01440000	NJ	1550	166	9.33
01443500	NJ	1650	326	5.06
01457000	NJ	9830	365	26.9
01470500	PA	49900	919	54.3
01540500	PA	952000	29058	32.7
01553500	PA	299000	17733	16.9
01554000	PA	914000	47394	19.3
01555400	PA	2620	116	22.6
01559795	PA	106	43	2.45
01562000	PA	25200	1958	12.9
01567000	PA	219	8686	0.03
01568000	PA	14300	536	26.7
01568750	PA	1070	57	18.7
01570000	PA	16800	1217	13.8
01570300	PA	2320	1	2360
01570500	PA	1830000	62415	29.3
01571000	PA	2330	29	80.2

01571490	PA	1680	33	51.0
01571919	PA	15800	188	84.1
01572000	PA	1940	89	35.8
01573560	PA	87600	1251	64.1
01603000	MD	164000	2271	72.3
01608500	WV	109000	3849	28.3
01610200	WV	25800	401	64.4
01611500	WV	19900	1748	11.4
01614500	MD	5	1279	0.004
01618000	WV	1140000	15373	74.5
01621050	VA	3480	37	94.5
01631000	VA	75200	4253	17.7
01634000	VA	26900	1989	13.6
01636500	WV	126000	7827	42.0
02054500	VA	2540	666	3.82
02055000	VA	6730	1023	6.58
02383500	GA	146000	2152	67.6
02385800	GA	4800	166	28.9
02387000	GA	102000	1779	57.4
02387500	GA	142000	4149	34.3
02388000	GA	1680	94	17.9
02395000	GA	230000	4232	54.3
03068800	WV	4990	391	12.8
03167000	VA	4380	640	6.85
03465500	TN	47500	2085	22.8
03466208	TN	8860	205	43.3
03470500	TN	134000	13211	10.2
03474000	VA	3710	342	10.8
03495500	TN	61100	9704	6.30
03527220	TN	160000	2989	53.6
03528000	TN	163000	3817	42.7
03531680	TN	112000	1321	84.7
03532000	TN	136000	1774	76.9
03535912	TN	31200	8658	3.61
03543005	TN	201000	44830	4.49
03568933	GA	13900	386	36.1

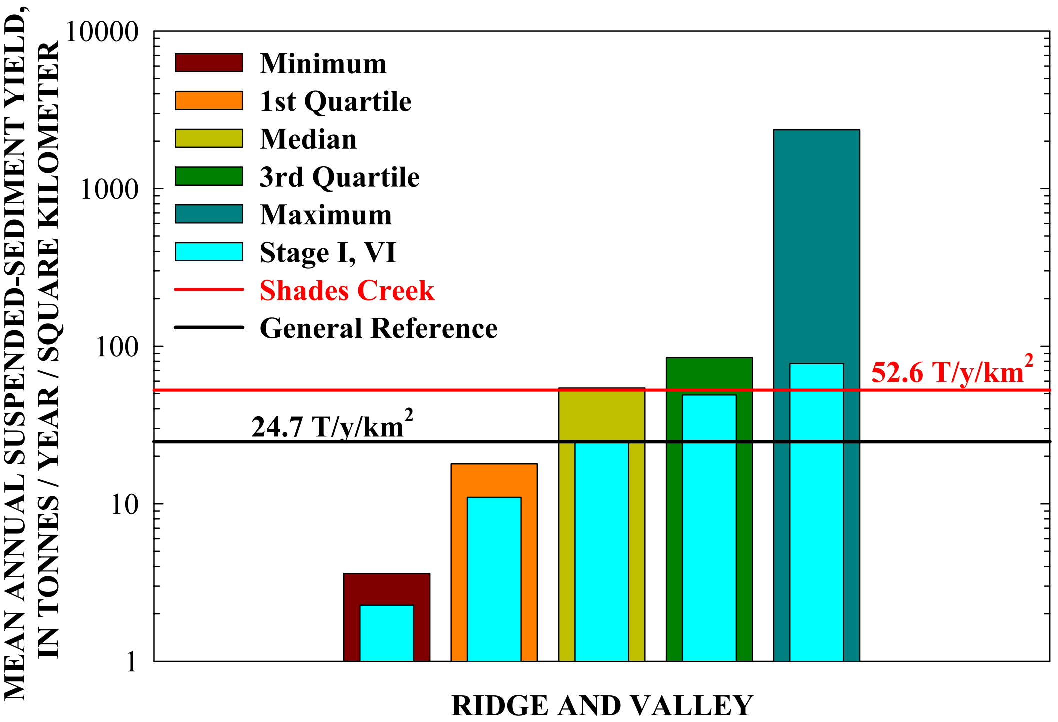


Figure 3-19. Comparison of mean annual suspended-sediment yields for stable "reference" sites and for evaluated, unstable sites. Yield shown is a general reference for the Ridge and Valley ecoregion.

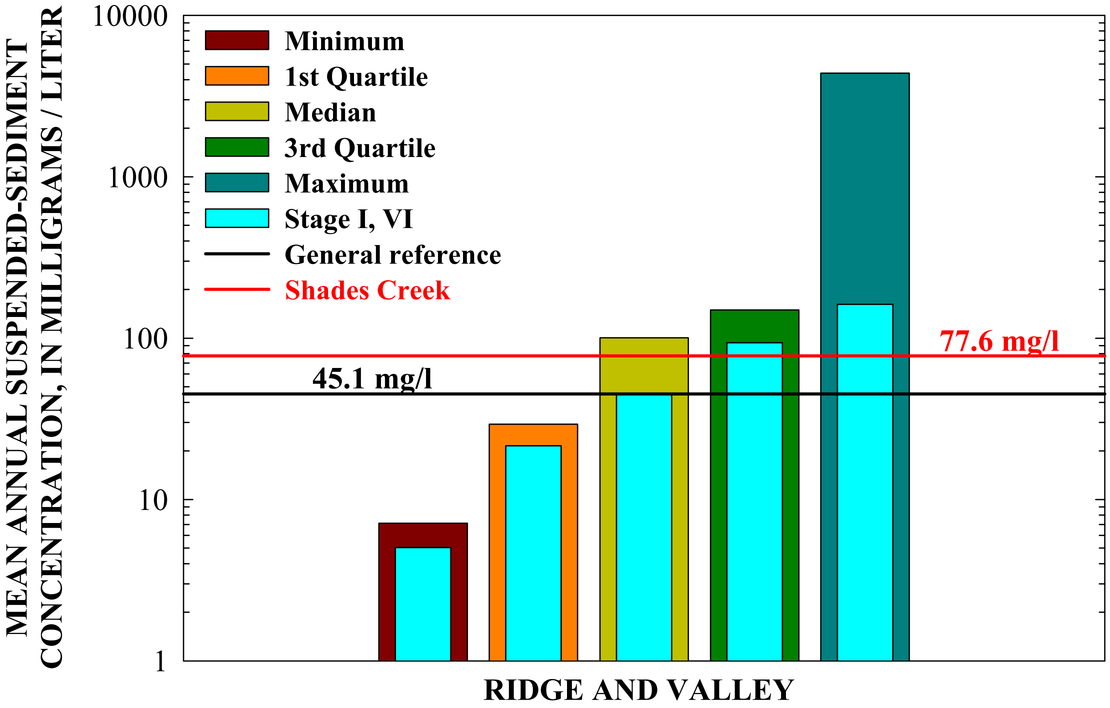


Figure 3-20. Comparison of mean annual suspended-sediment concentrations for stable "reference" sites and for evaluated, unstable sites. Concentration shown is a general reference for the Ridge and Valley ecoregion.

3.5 Developing a “Reference” Bed-Material Composition for Shades Creek, Alabama

Using the same concept for bed material as was used for suspended sediment, sites from the Ridge and Valley (Ecoregion 67) were sorted into stable and unstable sites to determine a reference bed-material composition for coarse-grained reaches. Coarse-grained reaches are singled out because streams designated as impaired due to siltation impact spawning habitats and other biologic life functions by clogging interstitial spaces in gravel-cobble beds. Because a reasonably large number of stable sites were also located on Shades Creek, reference conditions developed for the Ridge and Valley can be directly compared to reference conditions along Shades Creek itself. Sites designated as being Stage I or Stage VI are mapped in Figure 3-21 and listed in Appendix A.

A reference bed-material composition, therefore, is based on a measure of embeddedness; the percentage of materials finer than 2 mm (sand, silt and clay) in gravel or gravel/cobble-dominated streambeds. This applies then to 53 of the sites evaluated along Shades Creek (Figures 3-22 and 3-23). An implicit assumption in this technique is that the bi-modal particle-size distributions indicative of embeddedness are representative of the entire streambed and not characterizing coarse materials in one location on the bed and the fines in another.

Bed-material data from both the Ridge and Valley and Shades Creek were filtered to include only those sites that are dominated by coarse-grained sediment (more than 50% of the streambed composed of materials coarser than 2 mm). Further sorting of the data into stable and unstable sites provided a means of comparing the degree of embeddedness in coarse-grained stream reaches (Table 3-4). A reference value of 4%, based on the median percentage of streambed material finer than 2 mm was determined for not only the Ridge and Valley (Figure 3-24) but for Shades Creek as well (Figure 3-25).

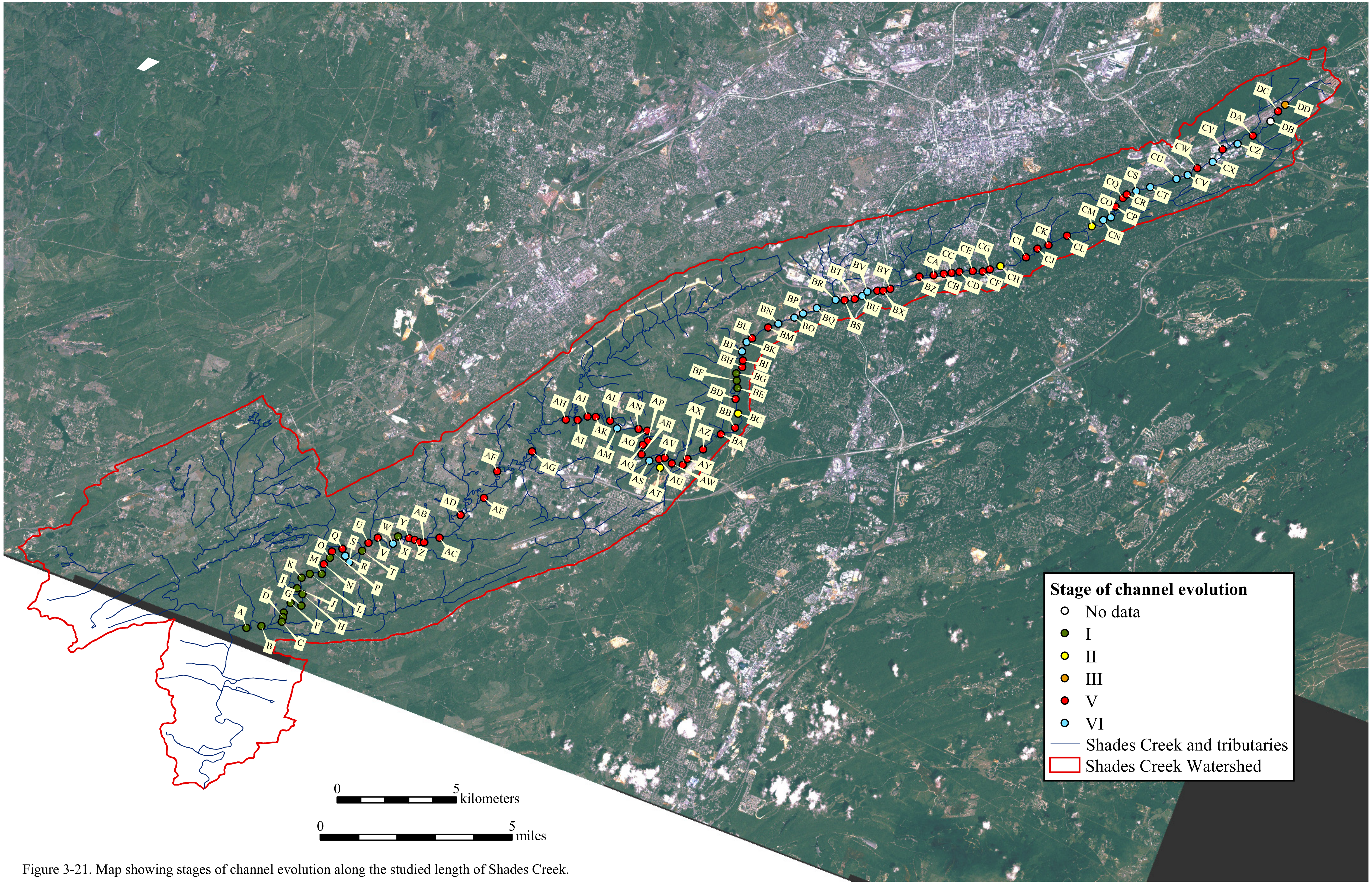


Figure 3-21. Map showing stages of channel evolution along the studied length of Shades Creek.

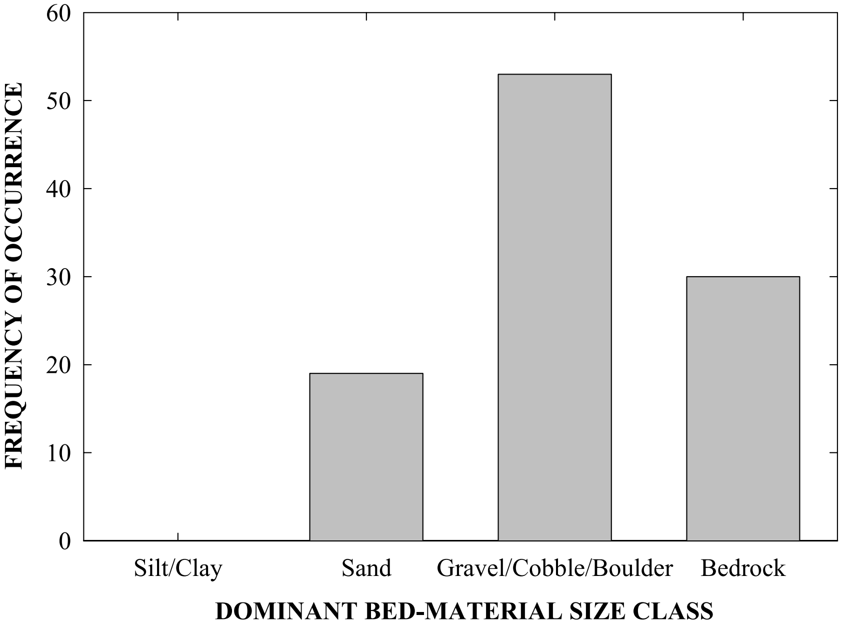


Figure 3-22. Frequency of bed-material types along Shades Creek.

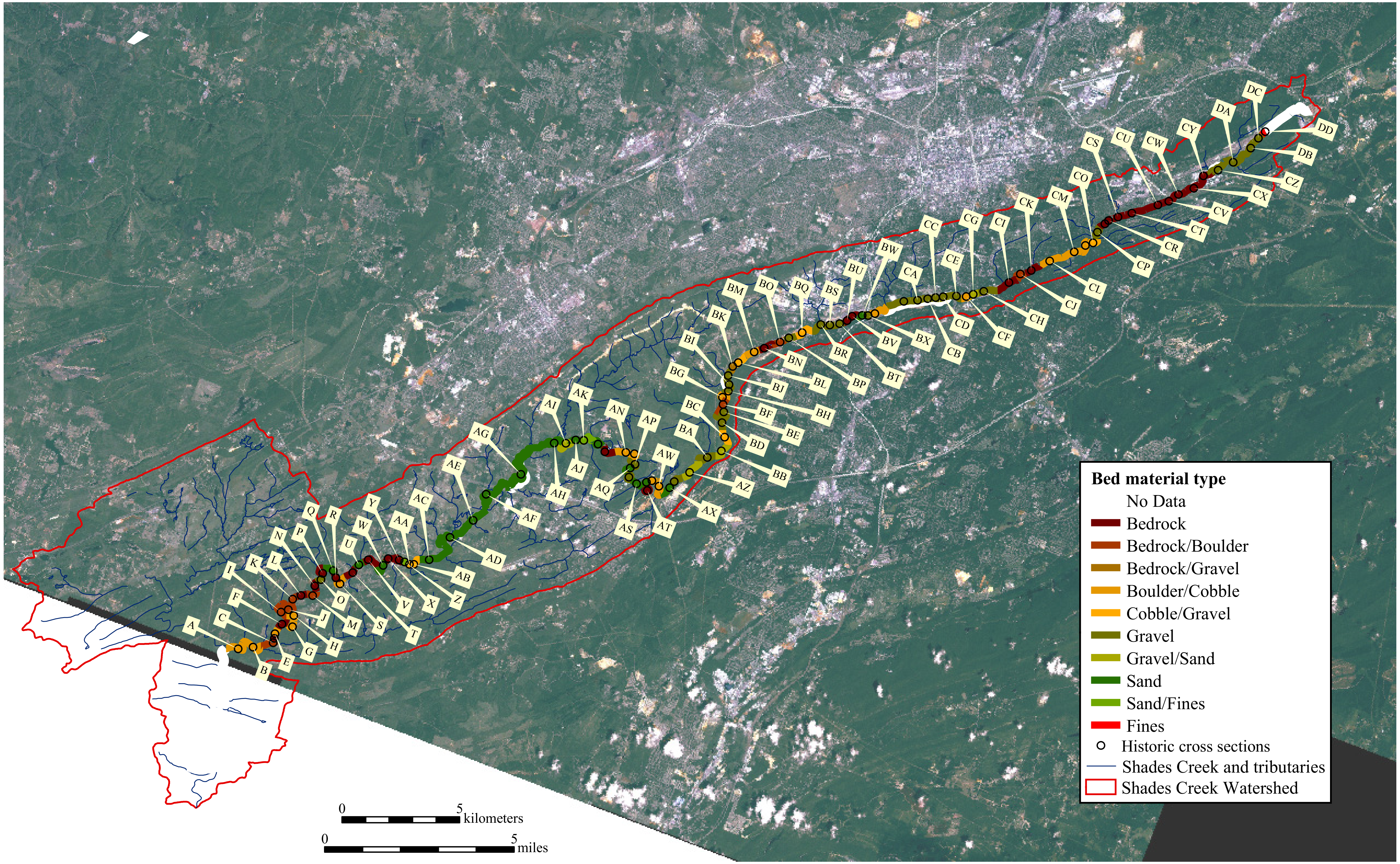


Figure 3-23. Map of dominant bed-material types along Shades Creek.

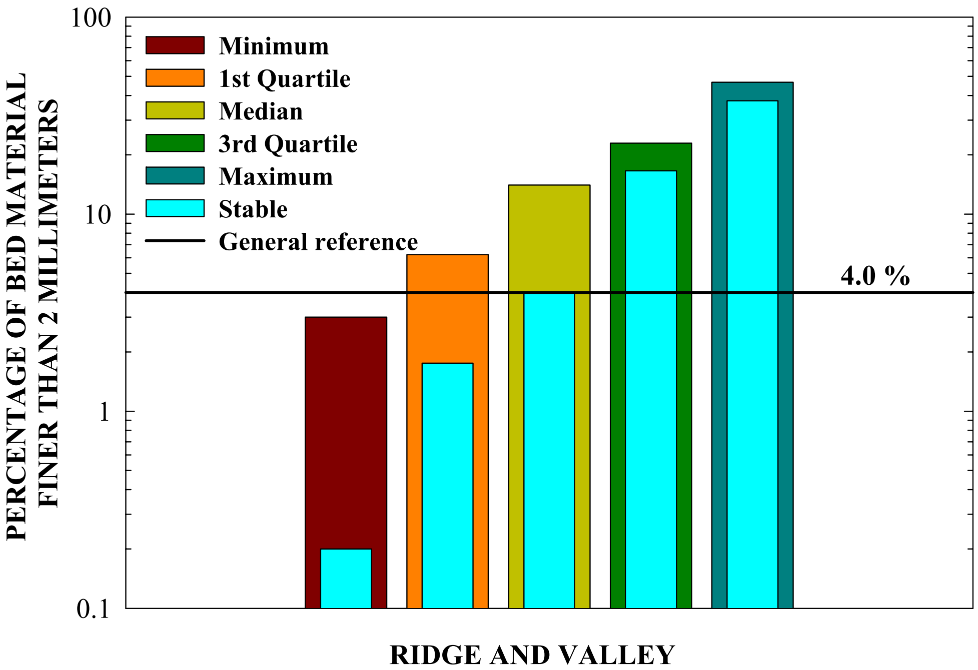


Figure 3-24. Comparison of percentage of bed material finer than 2 mm (sand) for stable “reference” sites and for evaluated, unstable sites. Percentage of fine materials shown is a general reference for the Ridge and Valley ecoregion.

Table 3-4. Summary of bed-material data for the Ridge and Valley.

State	Station number	%Silt / Clay	% Sand	%Gravel/ Cobble	Dominant bed material	Embeddedness *	Stability
NJ	01440000	0.0	2.0	98.0	Boulder/ Cobble	2.0	Stable
NJ	01442750	0.0	46.0	54.0	Gravel	46.0	Stable
NJ	01443500	0.0	7.2	92.8	Gravel	7.2	Stable
PA	01470500	0.0	4.0	96.0	Gravel	4.0	Stable
PA	01559795	2.1	33.3	65.3	Gravel	35.4	Stable
PA	01567000	0.1	24.2	75.7	Gravel	24.3	Stable
PA	01568000	0.0	9.0	91.0	Gravel	9.0	Stable
PA	01568750	0.0	3.0	97.0	Boulder/ Cobble	3.0	Stable
PA	01570200	0.0	7.0	93.0	Gravel	7.0	Unstable
PA	01570300	11.0	6.0	83.0	Gravel	17.0	Unstable
PA	01570980	5.6	37.5	57.0	Gravel	43.0	Stable
PA	01570984	0.7	40.5	58.8	Gravel	41.2	Stable
PA	01570988	0.0	4.0	96.0	Gravel	4.0	Stable
PA	01570992	0.2	10.9	88.9	Gravel	11.1	Unstable
PA	01570996	0.0	0.0	100	Boulder/ Cobble	0.0	Stable
PA	01571000	0.0	0.0	100	Boulder/ Cobble	0.0	Stable

PA	01571490	3.0	11.0	86.0	Gravel	14.0	Stable
PA	01571831	0.0	1.0	99.0	Gravel	1.0	Stable
PA	01571919	0.0	0.0	100	Gravel	0.0	Stable
PA	01572000	0.0	8.0	92.0	Gravel	8.0	Stable
PA	01573095	0.5	19.0	80.5	Gravel	19.5	Unstable
PA	01573560	0.6	46.8	52.6	Gravel	47.4	Stable
WV	01610200	0.0	3.0	97.0	Gravel	3.0	Unstable
WV	01611500	0.0	3.0	97.0	Gravel	3.0	Stable
VA	01621050	0.2	32.9	66.9	Gravel	33.1	Unstable
VA	02054500	0.0	30.9	69.0	Gravel	31.0	Stable
VA	02055000	0.0	3.0	97.0	Gravel	3.0	Stable
GA	02388000	2.4	44.3	53.3	Gravel	46.7	Unstable
VA	03474000	0.0	3.0	97.0	Gravel	3.0	Stable
VA	03526000	0.0	25.4	74.6	Gravel	25.4	Stable
TN	03527220	13.5	0.0	86.5	Gravel	13.5	Stable
GA	03568933	0.0	3.9	96.1	Gravel	3.9	Unstable
WV	390134079491139	0.0	0.0	100	Boulder/ Cobble	0.0	Stable
WV	391952079303339	0.0	1.0	99.0	Boulder/ Cobble	1.0	Stable

* Embeddedness denotes the sum of silt / clay and sand percentages

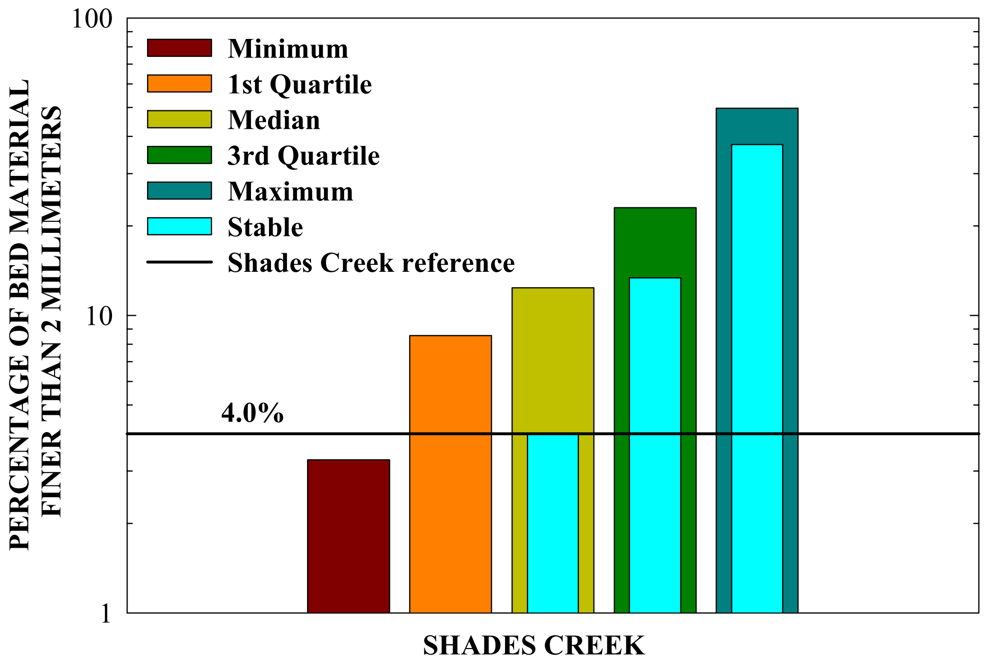


Figure 3-25. Comparison of percentage of bed material finer than 2 mm (sand) for stable, "reference" and unstable sites along Shades Creek. Percentage of fine materials shown is a general reference for Shades Creek, Alabama.

That the median values for both Shades Creek and the Ridge and Valley are identical is coincidental, yet the similarity in the values of the1st and 3rd quartiles as well as the inter-quartile ranges for both stable and unstable sites is encouraging of a viable technique (Table 3-5). In the absence of associated biologic data it is impossible to state whether the degree of embeddedness as shown for stable sites is in fact a threshold for biologic communities or if the embeddedness for unstable sites is of sufficient magnitude to impair biologic function.

Table 3-5. Comparison of embeddedness values for stable/reference and unstable sites in the Ridge and Valley and for Shades Creek.

Location	1st Quartile	Median	3rd Quartile	Inter-quartile range
Stable/reference sites				
Ridge and Valley	1.8	4.0	16.6	14.8
Shades Creek	0	4.0	13.4	13.4
Unstable sites				
Ridge and Valley	6.2	14.1	22.9	16.4
Shades Creek	8.6	12.4	23.0	14.4

Perhaps it is again more reasonable to use the central 50% of the reference distribution, particularly the 3rd quartile as a target for embeddedness in coarse-grained reaches as these values (13.4% for Shades Creek and 16.6% for the Ridge and Valley) are in the range of those reported in the literature (Barbour *et al*., 1999; Kondolf *et al*., 2003). Hausle and Coble (1976) indicated that 10% fine sediment (finer than 2 mm) was a threshold level for 50% emergence of brook trout. An average threshold value for salmonid fry of 13.7% fine sediment (finer than 0.83 mm) was reported in Kondolf *et al*. (2003) based on four studies by others. Work by Relyea *et al*. (2000) along 562 streams in four northwestern states noted that changes to invertebrate community structures resulting from fine sediment (finer than 2 mm) occurred at fine-sediment values of between 20 and 35%. In comparing results reported herein with those from other studies, it is important to clearly understand the metric for fine sediment being used by a particular investigator. Although 2 mm is used more often than other grain sizes, in some cases fine-sediment is defined as particles finer than 3.35 mm, 6.35 mm and 9.5 mm (Kondolf *et al*. 2003).

3.5.1 Application of Bed-Material References to Shades Creek

Given the range of bed material types along Shades Creek it is important to understand that measures of embeddedness pertain to only coarse-grained reaches. Reaches dominated by bed materials finer than 2mm (> 50%)) are not included in embeddedness measures but should not be excluded from considerations of impact and impairment due to fine-grained deposition. Specifically, sand-dominated, Stage V sites between *AC* and *AL* (rkm 25.3 to 42.7) may have been stable, coarse-grained reaches sometime in the past and, therefore, represent presently-impacted streambeds. However, because of the definition of embeddedness, these reaches are not applicable to the measures of reference defined earlier. Still, they represent reaches significantly impacted by sediment deposition. This 17.4 km reach of Shades Creek is probably diagnostic of upstream erosion problems within the watershed of Little Shades Creek and other tributaries entering in the reach. Coarse-grained reaches that where fine-sediment percentages exceed one of the reference levels may, in fact, represent an intermediate case between coarse-grained stable reaches with little fine sediment and the unstable, sand-dominated reaches.

Using the bed-material reference levels shown in Figures 3-24 and 3-25 and the definition reiterated above, impacted sites are shown color-coded in Table 3-6 and in Figure 3-26. Sites exceeding the most-stringent reference (4% fines) are shown in green while sites exceeding the upper end of the central 50% of the reference distribution (3^{rd} quartile) are shown in orange (Shades Creek reference; 13.4%) and yellow (Ridge and Valley reference; 16.6%).

Table 3-6. Percentage of fines (embeddedness) for coarse-grained sites along Shades Creek relative to references developed for the Ridge and Valley and for Shades Creek.

Dominant bed material	% Fines	Site	River kilometer
Gravel/Sand	49.7	AZ	51.0
Gravel	36.6	BE	55.1
Boulder/Cobble	35.0	AV	48.3
Boulder/Cobble	33.1	AU	48.1
Gravel	32.4	BX	65.2
Gravel	31.1	DA	84.3
Gravel/Cobble	29.4	CH	70.5
Gravel/Cobble	29.4	CG	70.0
Gravel	23.7	AR	46.4
Gravel	21.0	BT	63.8
Gravel	20.7	O	17.8
Gravel	20.4	BA	52.1
Gravel	16.7	BD	54.6
Gravel	16.0	DC	86.1
Gravel	14.8	BI	57.6
Gravel	14.0	BS	63.3
Gravel	12.9	CO	76.4
Gravel	12.8	BH	57.3
Gravel	12.0	CP	77.1
Gravel	12.0	CD	68.6
Gravel	12.0	BQ	61.9
Boulder/Cobble	12.0	AW	48.8
Gravel	11.8	CE	69.2
Gravel	11.3	AP	45.3
Gravel	10.0	CC	68.3
Gravel	10.0	BZ	67.0
Gravel	9.9	BP	61.3
Gravel/Cobble	9.3	BC	53.9
Gravel	8.1	CF	69.7

Gravel	8.0	CB	68.0
Gravel	6.0	AY	50.2
Gravel	5.0	BY	65.5
Gravel	4.0	BJ	58.0
Gravel	3.1	CZ	83.3
Gravel	3.0	CA	67.6
Gravel/Cobble	2.4	BL	58.8
Gravel	2.0	BR	62.9
Gravel/Cobble	0.0	BK	58.5
Boulder/Cobble	0.0	BG	56.7
Boulder/Cobble	0.0	BF	56.2
Boulder/Cobble	0.0	E	12.1
Boulder/Cobble	0.0	B	11.1

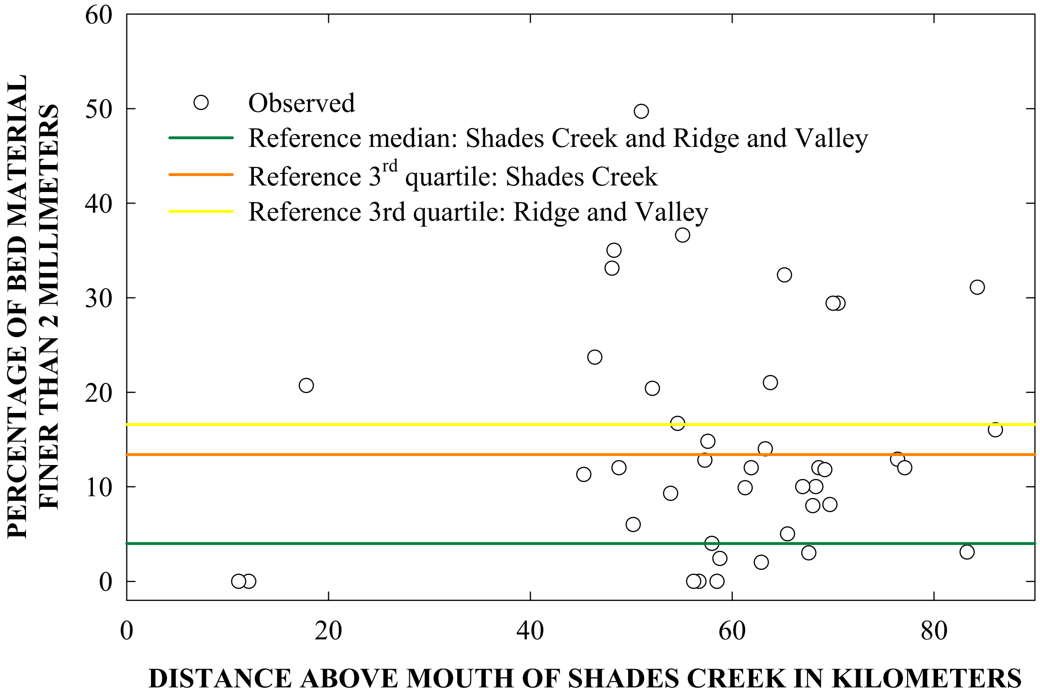


Figure 3-26. Longitudinal distribution of the percentage of fine-grained sediment within coarse-grained streambeds. Colored lines refer to various reference levels determined for Shades Creek and the Ridge and Valley. See also Table 3-6.

4 NUMERICAL MODELING OF SHADES CREEK

4.1 Introduction

Numerical simulations of upland (AnnAGNPS) and channel (CONCEPTS) processes were carried out on Shades Creek watershed to:

(1) Determine the relative contributions of sediment from upland and channel sources;
(2) Evaluate 25-year trends in suspended-sediment delivery within the watershed based on current conditions, and various alternative watershed conditions defined by EPA.

In order to accomplish these items, the watershed model AnnAGNPS and the channel evolution model CONCEPTS were used to determine the impact of four scenarios on the watershed. The following four modeling scenarios were developed:

1. Evaluate the current distribution of sediment sources within the Shades Creek watershed based on the 1991 landuse, 1978-2001 weather, and starting with the channel characteristics defined from 1978 channel surveys (Validation Scenario);
2. Evaluate the effects of recent landuse changes on sediment loads and bed material composition based on the 2001 landuse, 25 years of the most recent weather (1977-2001), and starting with the channel characteristics defined from CONCEPTS at the end of the Validation Scenario (2001 Landuse Scenario);
3. Evaluate the effects of future landuse changes on sediment loads and bed material composition based on the 2001 landuse with all forest conditions changed to urban conditions, 25 years of the most recent weather (1977-2001), and starting with the channel characteristics defined from CONCEPTS at the end of the Validation Scenario (2001LUFU);
4. Evaluate the effects of instream best management practices (BMPs) on sediment loads and bed material composition based on the 2001 landuse, 25 years of the most recent weather (1977-2001), starting with the channel characteristics defined from CONCEPTS at the end of the Validation Scenario, and with selected reaches that were protected (2001LURP).

As part of the first three scenarios, the loadings from Little Shades Creek to Shades Creek were described in more detail in order to illustrate the capabilities of AnnAGNPS to supply loadings from a tributary in the watershed to the CONCEPTS simulated main channel. Portions of the period of 1964-1977 that has measured data available will be used to validate the results from AnnAGNPS, but without using CONCEPTS since there was no channel survey data available for this period.

4.2 Input Database for the AGNPS Model

The development of input parameters used to describe the Shades Creek watershed involves assembling data from a variety of sources. This includes elevation maps, soil data, landuse and land-management data, and weather data. All required model parameters are selected from publicly available data. Data compilation was performed using the AGNPS ArcView Interface and AnnAGNPS Input Editor.

4.2.1 GIS Database

The use of a geographic information system (GIS) is critical in constructing the dataset to perform simulations for a watershed the size containing Shades Creek. The GIS data provides the link between the characteristics of the watershed and the parameters used by the model.

To apply the entire AGNPS suite of programs, basic GIS data are needed. These include: (1) the digital elevation models (DEMs) to describe the topography; (2) a landuse GIS layer to describe the vegetative cover; and (3) a soils GIS layer. Together, GIS data provide the spatial variation of important characteristics within the watershed. Additional GIS data are useful in assessing model parameter creation and the impact various features may have on the watershed. This can include digitized quad sheets, aerial photographs, location of streams, roads, erosion control structures on fields and in the channels, lakes, and other features impacting the watershed. Information that is not available from digital sources may be digitized from other maps, or from field measurements located using a global positioning system (GPS). The Storm Water Management Authority (SWMA) located in Birmingham, Alabama provided all of the GIS layer information.

The projection used for all of the GIS data layers was *UTM NAD27 zone 16*. This provided consistency among all layers when data were analyzed or paper maps were produced. Other GIS layers can easily be reprojected from any other projection to the UTM projection.

Topographic Analysis

Topographic information is crucial to determine many aspects of flow boundaries and directions as well as slope length parameters. Digital Elevation Models (DEMs) provide a convenient source of topographic information, but is often derived from contours drawn on USGS 7.5 minute quad maps. Thus, resolutions can range from 120m x 120m raster grids with 5m elevations to 10m x 10m with 0.1m elevations, or better depending on the source of the DEMs. The 10m x 10m raster grid can provide better definition of the watershed topography, but generates a much larger file size requiring more computer resources to execute AGNPS topographic tools. The Shades Creek Watershed modeling effort used a 30m x 30m x 0.1m raster grid provided by SWMA (Figure 4-1). From this DEM, a clipped DEM was produced to develop AnnAGNPS data sets to minimize the computational time needed for topographic analysis of the watershed.

Elevations within the watershed boundary ranged from 110 meters above sea level (asl) at the lower end to 378 meters (asl) at the upper end. Land slopes ranged from nearly flat along the floodplain of Shades Creek to steep slopes up to 25% along the ridges. The average land slope for the entire watershed is 9%.

Modification of Digital Elevation Models (DEMs)

Modification of DEMs may be required when local features within a watershed are not included during the development of the DEM. This could be because of recent human activities that change the elevation within areas of the watershed. Examples include land-leveling of fields, channel straightening, construction of roads, or ditches dug to route water around fields or residential areas. Watershed characteristics generated by AGNPS components may not correspond to actual stream locations or watershed boundaries. To account for these topographic variances, the DEM is modified to adopt the required features. The DEM was modified using the digitized stream network to reduce the elevation by 0.5 meters wherever the stream was located throughout the watershed. The 0.5 meter depth was chosen to minimize the effect of decreasing a DEM raster elevation would have on land slope next to the channel. Uniformly decreasing the DEM along the channel would not affect the channel slope. A 0.5 meter depth was also chosen from experience with watersheds of similar topography. Watersheds with flatter terrain will often require less of a depth along the channel needed to satisfactorily modify the DEM. There was also a constructed roadbed that elevated the ground to a degree that the topographic analysis perceived this elevated road to be a dam, while in reality there is a culvert underneath it. In this case the DEM was modified significantly more than one meter at this elevated roadway to allow the topographic analysis component to produce a flow path through the culvert.

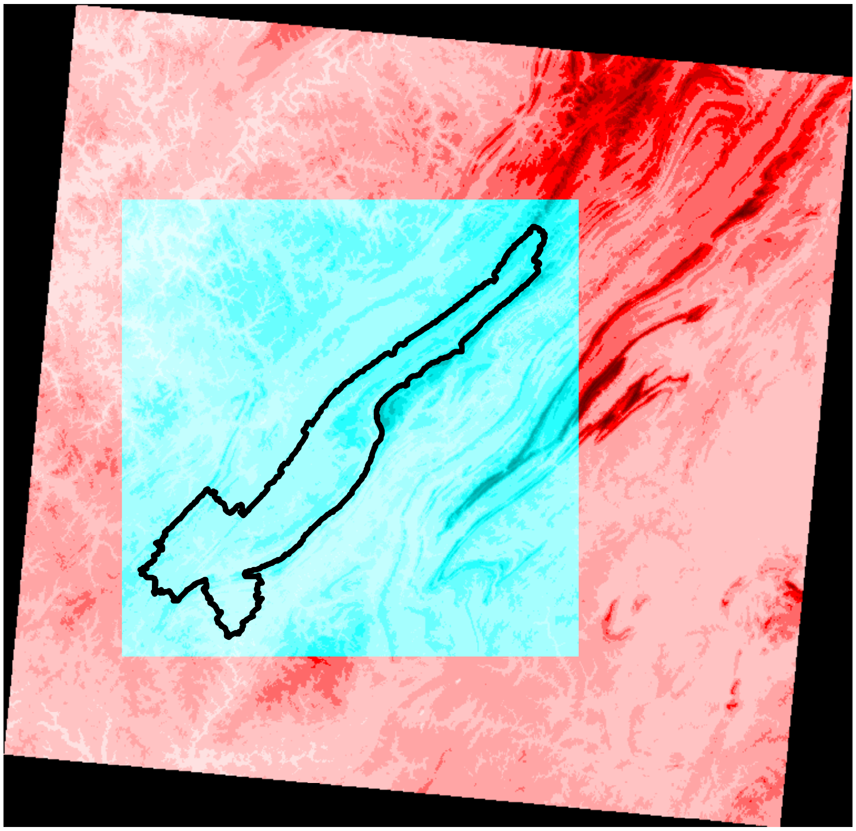


Figure 4-1. The Shades Creek watershed with the digital elevation model (DEM) obtained from SWMA at the 30 m x 30 m resolution (red) and the clipped DEM used for AnnAGNPS (cyan).

Digitized Soil Maps

A soils GIS layer (80% complete for the counties containing the watershed) was provided for the watershed by SWMA and is typically produced by the USDA - Natural Resources Conservation Service (NRCS) as a Soil Survey Geographic (SSURGO) data base layer based on the NRCS County Soil surveys. To complete the coverage, a NRCS developed State Soil Geographic (STATSGO) database layer was provided by SWMA. The STATSGO layer is a collection of soils that are compiled by generalizing more detailed soil information and is available for most areas of the U.S. The SSURGO and STATSGO layers were merged together to form a complete soil coverage of the watershed. From the merged soils GIS layer, every digitized soil is assigned a mapping-unit symbol that corresponds to a database of soil characteristics developed by NRCS. Soils in the Shades Creek Basin are too numerous to list; however, the soils are displayed in Figure 4-2 to show the spatial variability within the Shades Creek watershed. Generally, the dominant soils along the channels are Sullivan silty and Holston loamy soils. Along the steeper sections of the watershed along the ridges are Bodine and Montevallo silty soils and Leesburg sandy loams. There are a few soils defined as completely impervious because of urban development scattered throughout the watershed.

Digitized Landuse Maps

An accurate description of landuse is critical in evaluating the impact land-management practices may have on soil erosion. Determination of historical landuse for large watersheds such as the Shades Creek watershed can be difficult without the use of satellite imagery. Although, local information based on documented aerial photography can be used, this often requires considerable time in analyzing and digitizing data. SWMA provided the GIS information used to derive the landuse in the Shades Creek watershed.

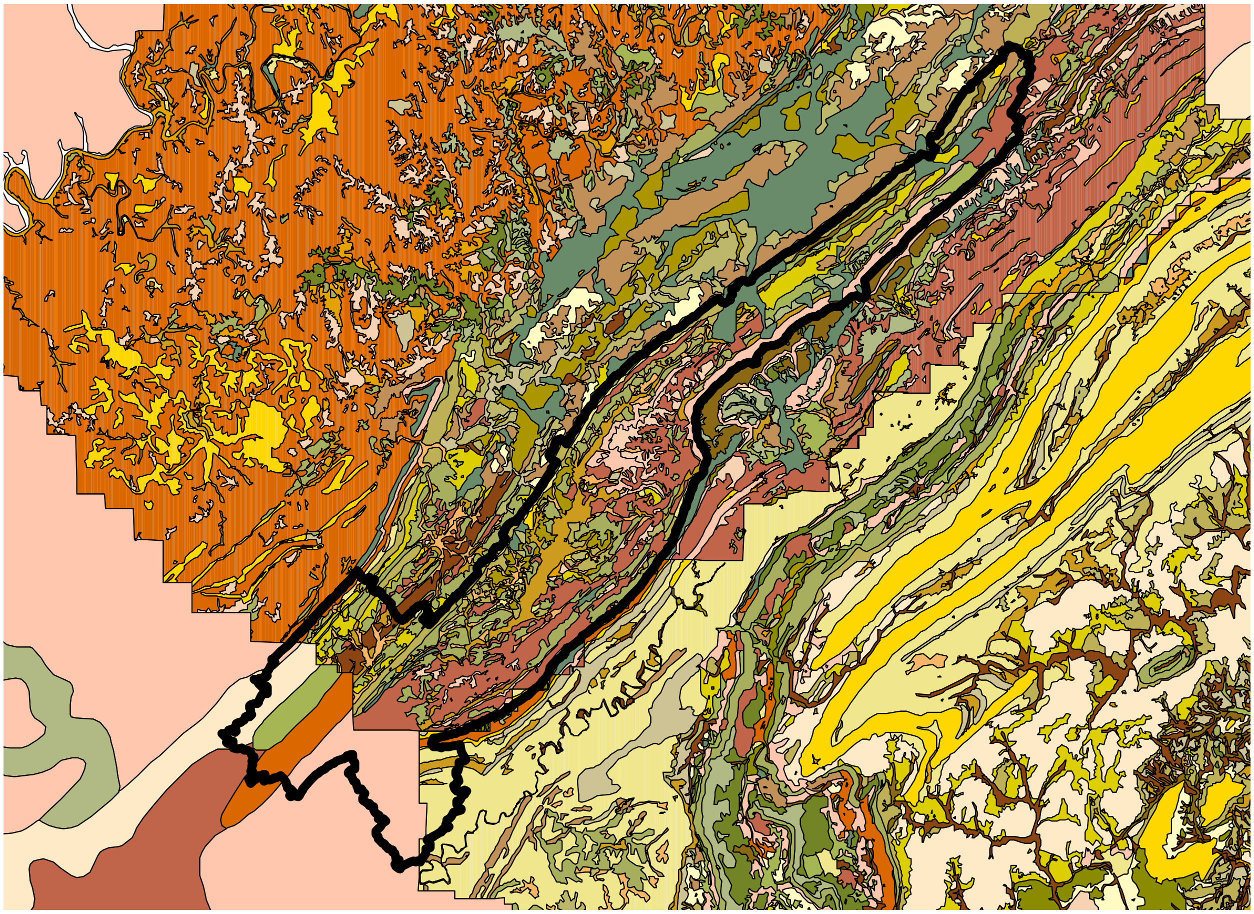


Figure 4-2. The Soil Survey Geographic (SSURGO) GIS layer for Shades Creek Watershed with the STATSGO GIS layer filling in the Southwest corner of the watershed.

Two periods of landuse information were used. One described the landuse during 1991 and the other during 2001. The 1991 landuse layer was used to describe landuse conditions during the simulation period of 1964-2001 (Figure 4-3). For 1991, the 359 km^2 watershed was comprised of land areas representing 74% forest, 14% pasture, 9% urban, and 3% water. Some categories were grouped together to form a single landuse, with the barren, transitional, agriculture, shrub land, and grassland grouped as pasture. The wetlands and water categories were grouped as a single water category. The 2001 landuse was used to provide the future landuse conditions for the 25-year simulations (Figure 4-4). Since the 2001 landuse GIS layer did not provide complete coverage of the watershed at the lower end of the watershed, the 1991 landuse GIS layer was used to complete the layer (Figure 4-5). The combined landuse for 2001 was comprised of land areas representing 70% forest, 16% pasture, 11% urban, and 3% water.

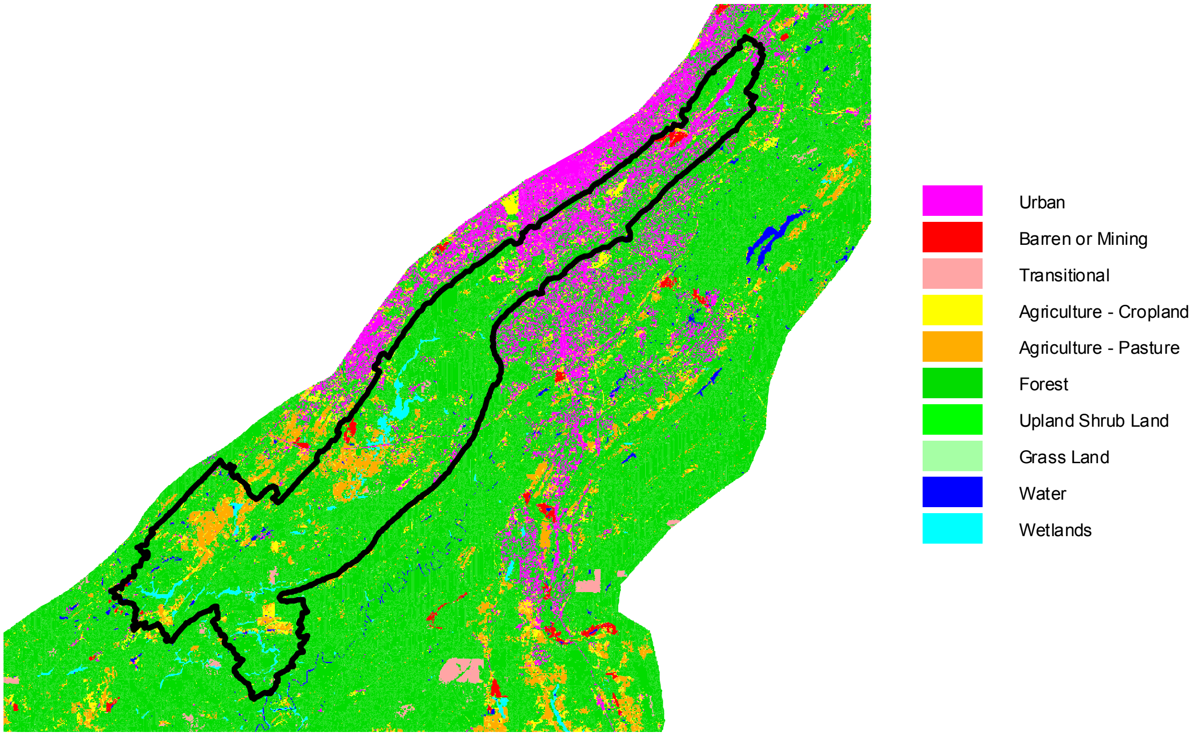


Figure 4-3. Landuse based on images from 1991 containing Shades Creek Watershed.

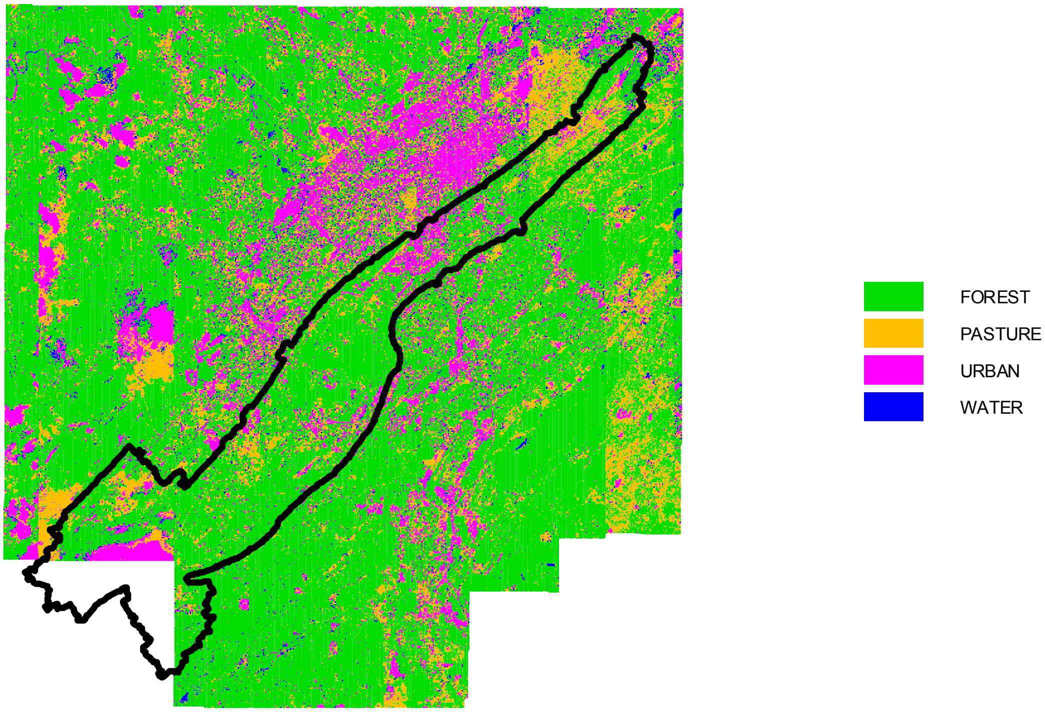


Figure 4-4. Landuse based on images from 2001 containing Shades Creek Watershed.

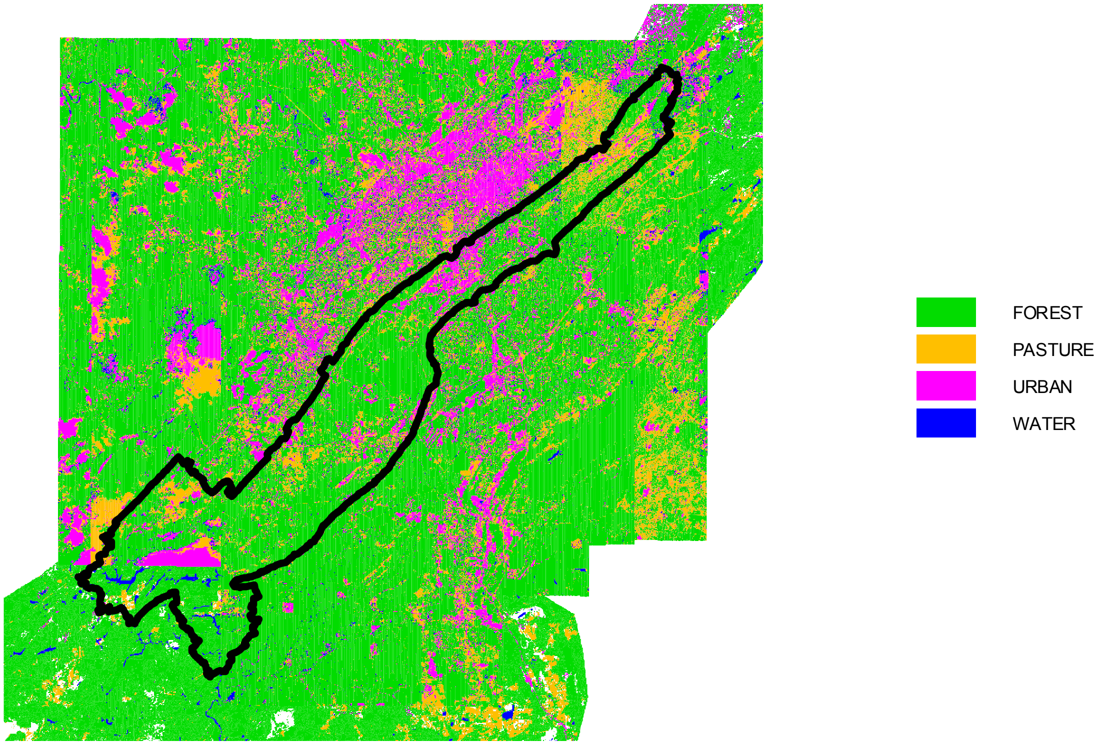


Figure 4-5. Landuse based on merged 1991 and 2001 landuse layers containing Shades Creek Watershed.

Additional GIS Layers

Digital Raster Graphics (DRG). Digital Raster Graphics (DRG) are digital copies of 7.5 minute - 1:24,000 topographic maps published by the USGS. DRGs are very useful in evaluating the location of the watershed boundary and channels generated by the AGNPS topographical analysis program, TOPAGNPS, to help ensure there are no major gaps in the boundary. The USGS produces their DRG product by scanning paper copies of the map at 500dpi and then re-sampling them to 250 dpi. USGS topographic maps covering Shades Creek were likely published over a number of years.

Perennial and Intermittent Streams. The location of perennial and intermittent streams is important in determining if the stream network generated by TOPAGNPS is of sufficient accuracy to use with AnnAGNPS. The location of streams can also provide information about the accuracy of the watershed boundary. An example would be a stream crossing the watershed boundary. A technique used in this project to improve the accuracy of the watershed boundary and generated streams is to adjust the DEM based on the location of the digitized streams. Whenever a digitized stream falls onto a DEM raster, then the elevation of the DEM raster can be adjusted by a set amount, in this case subtracting 0.5 meters from the DEM raster value. This would help to ensure that the slope of the streams would be maintained when the TOPAGNPS module generates the stream network. For the Shades Creek Basin, the digitized perennial and intermittent streams were obtained from SWMA.

4.2.2 AGNPS ArcView Interface Application

The use of the AGNPS ArcView interface simplifies many of the steps needed in developing the input parameters required by AnnAGNPS. By combining the DEM, soils and landuse GIS layers, many of the spatially-oriented parameters can be obtained. Additional input parameters are required that can be obtained from existing databases, such as soil and land management parameters.

4.2.3 Shades Creek Watershed Segmentation

Drainage Boundary

A determination of the drainage boundary for the Shades Creek watershed simulation is critical prior to proceeding to other issues. Using the AGNPS ArcView interface, the watershed boundary was produced from TOPAGNPS files and the DEM based on the watershed outlet. For the Shades Creek watershed, the outlet coincides with the mouth of the creek as it flows into the Cahaba River. The exact location of the outlet in terms of the position within the DEM was determined using perennial streams and the DRG. This also allows the DEM to be reduced in size by clipping the drainage area that includes only Shades Creek watershed (Figure 4-1) using the AGNPS ArcView Interface. This reduces the computational time needed when using TOPAGNPS and displaying the final determinations with ArcView. The watershed boundary (Figure 4-6) along with the generated stream network was used to identify any noticeable problems when compared with the digitized data.

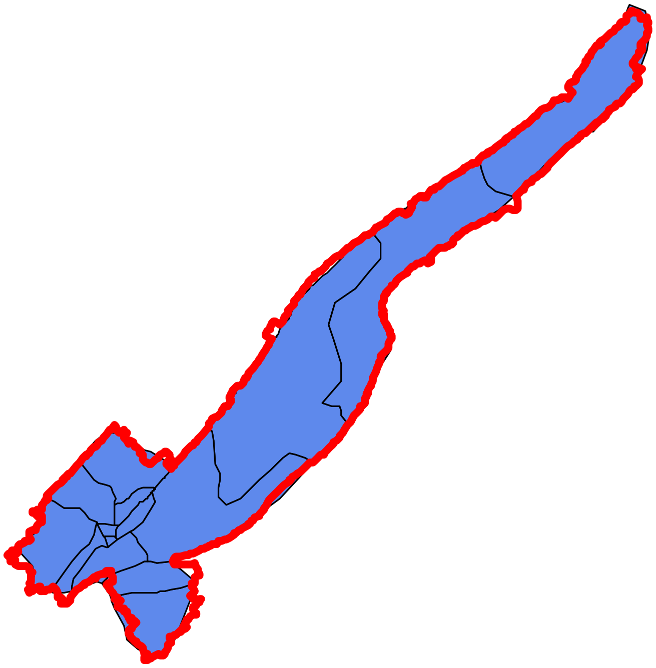


Figure 4-6. The Shades Creek generated watershed boundary (red line) and digitized watershed boundary blue area).

From previous experience, the location of the stream network generated by TOPAGNPS may not define very well the location of the major confluences as observed from the digitized streams. Thus, a modification of the clipped DEM was made based on the location of the digitized perennial and intermittent stream locations as discussed previously. This provides information within the DEM concerning the location of concentrated flows and the generated stream network that would likely produce a stream network similar to the digitized stream network.

Subdrainage Areas: AnnAGNPS Cells

Subdividing drainage areas into AnnAGNPS cells provides more detailed information on the watershed characteristics and eventually the source of runoff and erosion. Determining subdrainage areas of the Shades Creek watershed into AnnAGNPS cells was based on the spatial variation of landuse and the location of the digitized stream network (Figure 4-7). The watershed was subdivided into a significant number of cells to appropriately reflect landuse. The process started with an assumption of the critical source area (CSA) and minimum source channel length (MSCL) required with the use of TOPAGNPS. Values of 100 hectare CSA and 150 m MSCL were used to produce 620 AnnAGNPS cells and 252 channel reaches distributed throughout the watershed (Figure 4-7). The relatively uniform AnnAGNPS cell sizes throughout the watershed can be used to adequately describe the spatial variability of topography, landuse, and soils.

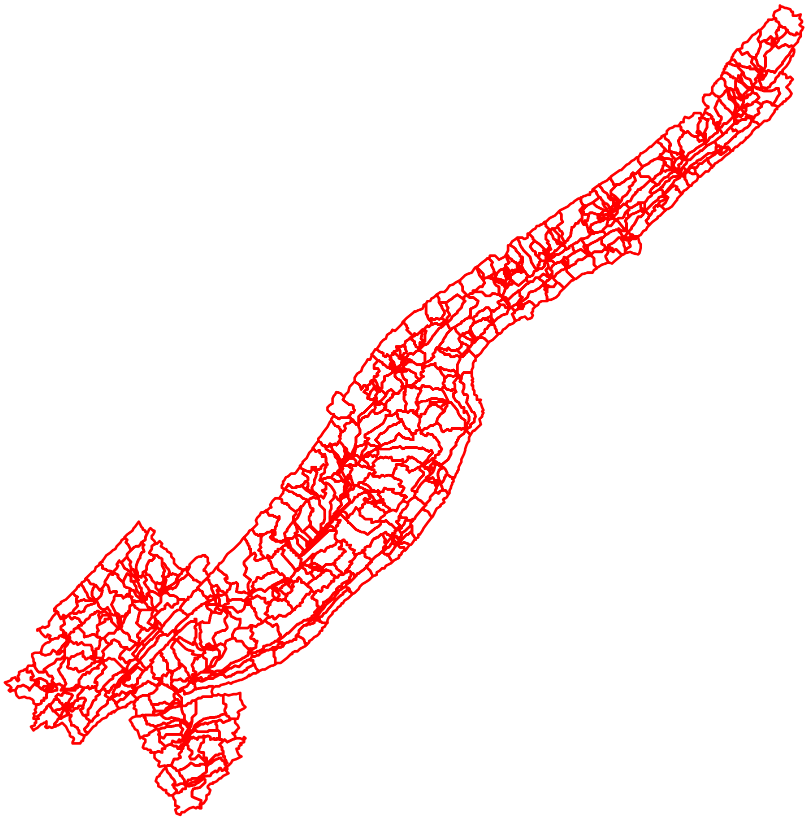


Figure 4-7. AnnAGNPS cells defined for Shades Creek Watershed.

Stream Network

Generated and Digitized Drainage Network. In order to ensure that the process of using TOPAGNPS produced an adequate stream network to link with the CONCEPTS model, the stream network was compared to the digitized location of the perennial and intermittent streams (Figure 4-8). Major confluences of tributaries and the main channel were examined along with the physical location of the channels as observed using the DRGs. The generated stream network reflected the digitized stream network in most cases.

Location of Tributary Confluences Within the Main Channel. The confluences of tributaries generated by TOPAGNPS that flow into the main channel of Shades Creek simulated by CONCEPTS were determined from visual inspection of the generated stream network (Figure 4-8). Simulated AnnAGNPS results from each designated tributary outlet were produced for use by CONCEPTS for each runoff event that occurred between January 1, 1978 and December 31, 2001.

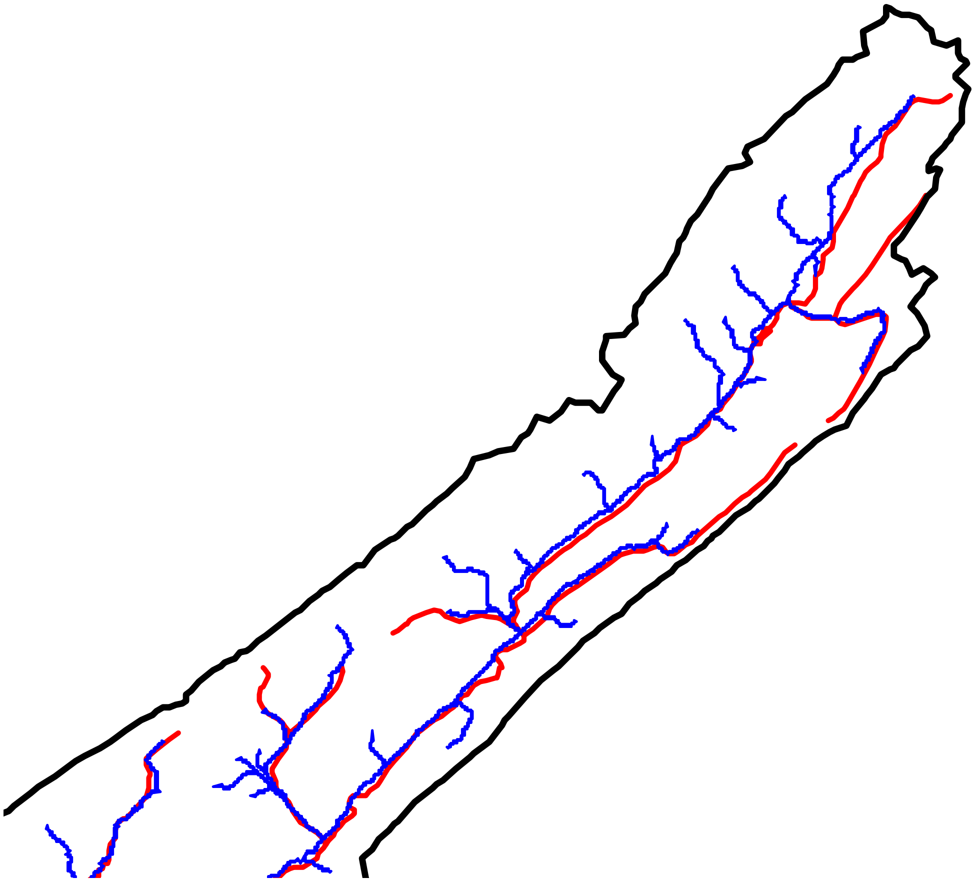


Figure 4-8. Generated stream network (blue) in comparison with the digitized streams (red) in the upper part of the Shades Creek Watershed (black).

4.2.4 Weather Data

Development of the AnnAGNPS Climate Database

All weather data was provided by USEPA for the Birmingham airport site and was assigned to each of the modeled AnnAGNPS cells (Figure 4-9). This station was used to determine the individual event information describing measured precipitation and temperature for the years 1964-2001 used in the AnnAGNPS simulation, with 1978-2001 weather used by AnnAGNPS to provide loadings for CONCEPTS. Climate information was comprised of sky cover, dew point, wind speed, precipitation, and temperature data.

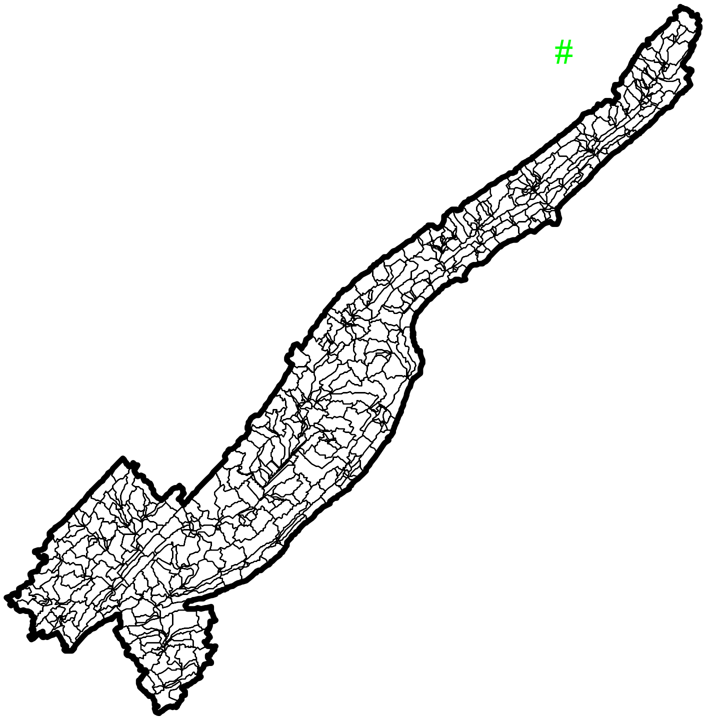


Figure 4-9. Birmingham airport climate station site (green dot) used in the AnnAGNPS simulations.

4.2.5 Landuse Simulation Data

Information pertaining to landuse is examined closely for areas that have a direct impact on runoff and sediment loadings. The type of landuse assigned to each AnnAGNPS cell was determined using the AGNPS ArcView interface procedure. This procedure assigned a landuse to each cell based on the predominate landuse in the landuse GIS and the AnnAGNPS cell GIS layer for the 1991 and 2001 simulation scenarios (Figures 4-10 and 4-11, respectively). For the validation scenario 86% of the AnnAGNPS cells were defined as forest, with 6% pasture, 7% urban, and 1% water for the other cells. For the 2001 landuse scenarios 85% of the AnnAGNPS cells were defined as forest, with 2% pasture, 13% urban, and less than 1% water for the other cells. When all of the forest conditions in the 2001 landuse are redefined as urban for the 2001LUFU scenario, the result is 98% of the watershed is defined as urban. Some of the differences in the amount of landuse areas defined within the GIS layer earlier and those assigned to AnnAGNPS cells can be attributed to areas too small within each AnnAGNPS cell to become the dominate landuse within that cell. This was often the case with scattered pasture areas that might occur within a larger forested area. For instance, the 1991 GIS landuse layer attributed 74% to forest and 14% to pasture, while the AnnAGNPS cells described the watershed as 86% forest and 6% pasture. Some forest areas in the 2001 landuse layer that actually were urban areas as a result of an analysis of the DRG's and on-site inspections were reclassified as urban. Some of the same areas that were classified as urban in the 1991 layer were classified as forest in the 2001 layer. This could have resulted from increased trees or wooded areas within urban areas that have grown during 1991 to 2001 being classified as forest areas in 2001.

Soil Conservation Service (SCS) Runoff Curve Numbers Associated with Watershed Characteristics

The Soil Conservation Service (SCS) runoff curve number (CN) is a key factor in obtaining an accurate prediction of runoff and sediment. Curve numbers were selected based on the National Engineering Handbook, Section 4 (USDA, Soil Conservation Service, 1972). The CN's used in the model simulation are listed in Table 4-1 and are based on typical values used by NRCS for the land cover classes present in the watershed. Each AnnAGNPS cell assumes that the area within the cell is defined homogeneously throughout the cell.

Table 4-1. SCS curve numbers for the Shades Creek Watershed simulations, by land cover class.

Land Cover Class	Curve Number			
	Hydrologic soil group			
	A	B	C	D
Forest	45	66	77	83
Pasture, Poor	68	79	86	89
Urban, Commercial, and Business	89	92	94	95

4.2.6 Soil Properties

Within the Shades Creek watershed there are 50 separate soil types identified in the soil GIS layer. The soils information was derived from the NRCS Soils 5 database. The dominant soils are silty to fine sandy loam. Input parameters that had no impact on soil erosion, such as nutrient levels, were set using default parameters. The soil assigned to each AnnAGNPS cell was based on the predominant soil type within each AnnAGNPS cell.

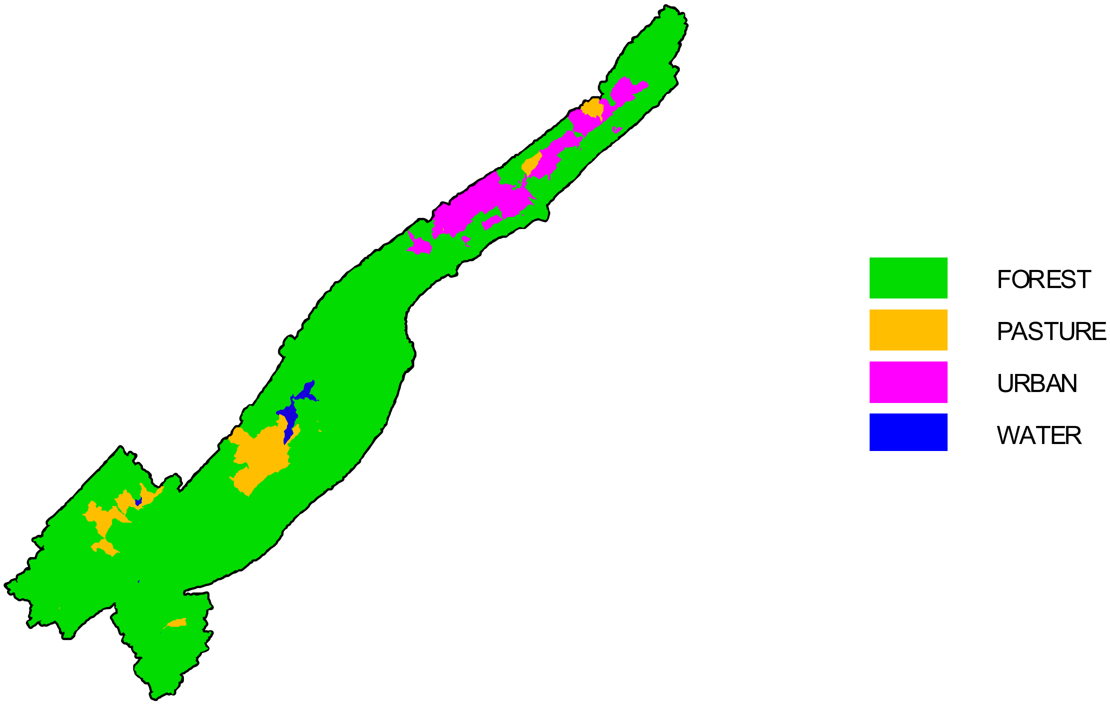


Figure 4-10. 1991 landuse assigned to each AnnAGNPS cell for Shades Creek Watershed.

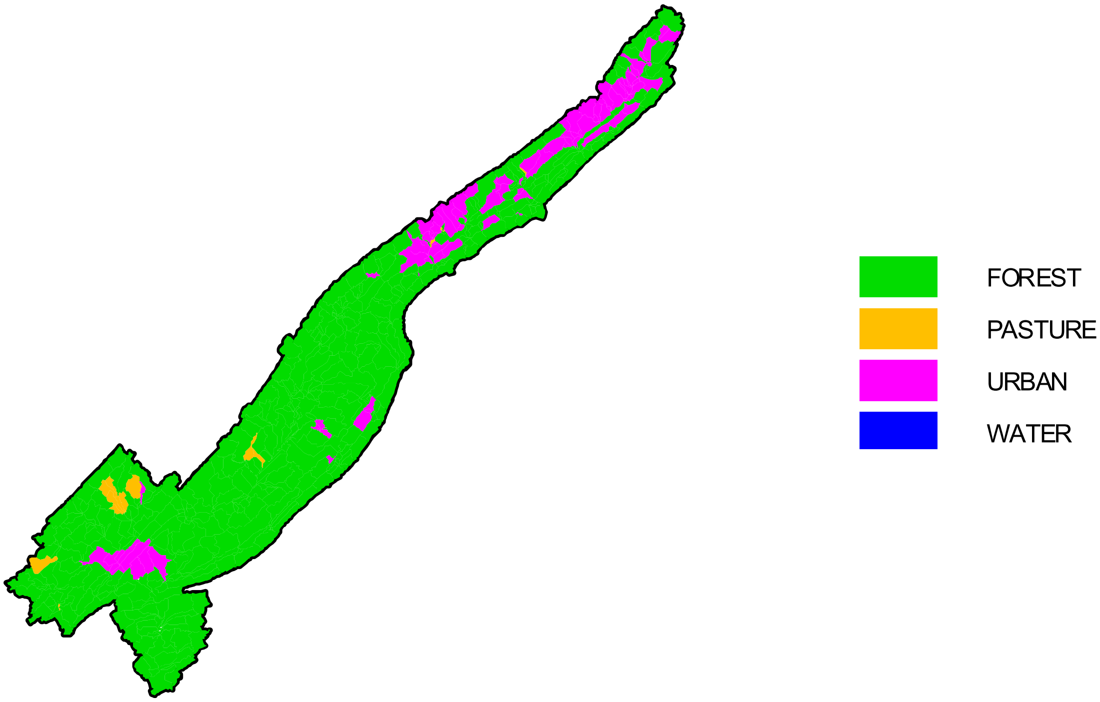


Figure 4-11. 2001 landuse assigned to each AnnAGNPS cell for Shades Creek Watershed.

4.3 AnnAGNPS Model Validation and 25-Year Future Simulations

AnnAGNPS provides runoff and sediment loadings into the main channel for simulation by CONCEPTS. An evaluation of the capability of AnnAGNPS to reproduce measured trends in runoff, sediment, and peak rates contributes to the reliability of input parameters used by CONCEPTS. A USGS gaging station (#02423630) within the watershed near Greenwood, Alabama provided data needed for comparison and calibration. While AnnAGNPS can produce information at any point in the watershed, the gage was the best point to compare simulated results with measured data. Annual runoff and sediment loads simulated by AnnAGNPS were compared with data measured at the gage. An evaluation of the sources of the runoff and sediment within the watershed was also conducted.

4.3.1 Annual Runoff

Annual runoff for the Validation scenario was simulated from 1964 to 2001 to the location of the USGS Greenwood monitoring station (Figure 4-12). Measured runoff was only available from 1964 to 1981, with some periods of missing data, and from 1997 to 2001. Simulated average annual runoff was 78% of the measured (Figure 4-13). A comparison of the simulated results matching the period of available measured runoff also shows similar trends with the associated rainfall (Figure 4-14). The measured runoff contains base flow that the simulated results do not reflect. There was no analysis available that estimated the base flow. The elimination of base flow from measured runoff would have improved the comparison with simulated runoff.

Average annual runoff simulated for the Validation scenario at the outlet of Shades Creek was 462 mm/y. Average annual runoff simulated at the outlet of Shades Creek for the 25-year 2001 Landuse scenario was 457 mm/y and 702 mm/y for the 2001LUFU scenario.

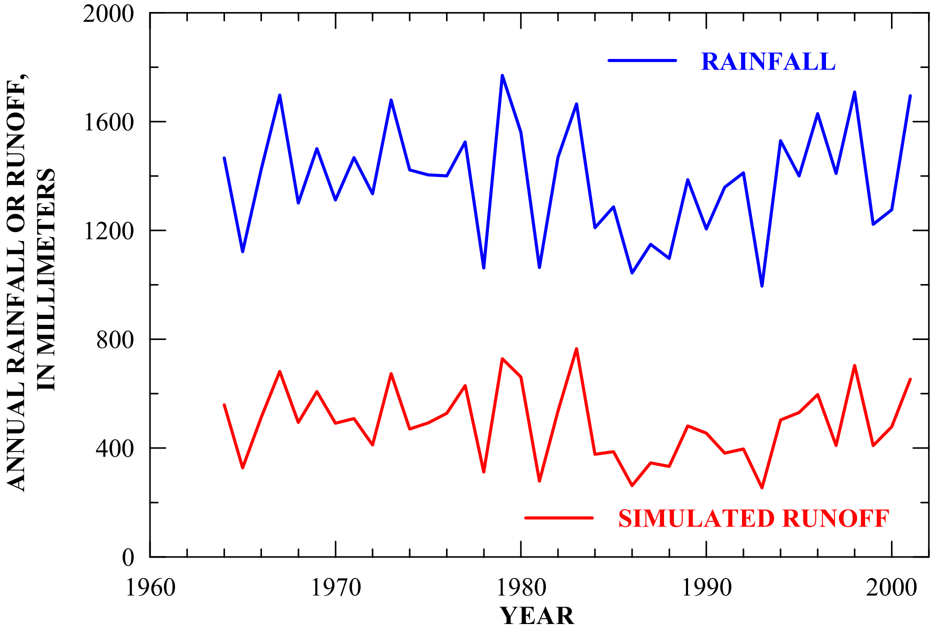


Figure 4-12. Annual rainfall measured at the Birmingham Airport climate station and the associated simulated runoff at the USGS gaging station (#02423630) near Greenwood, AL.

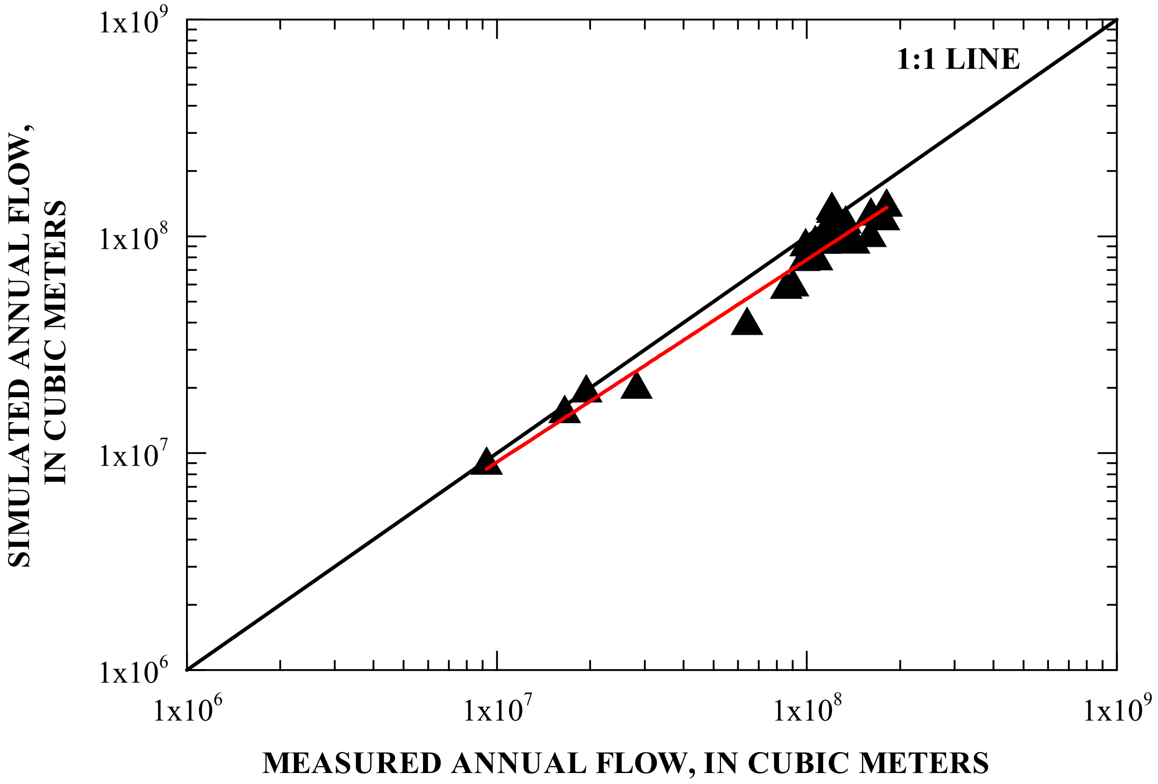


Figure 4-13. AnnAGNPS simulated versus measured annual runoff from 1964-1981, 1997-2001 at the USGS gaging station (#02423630) near Greenwood, AL.

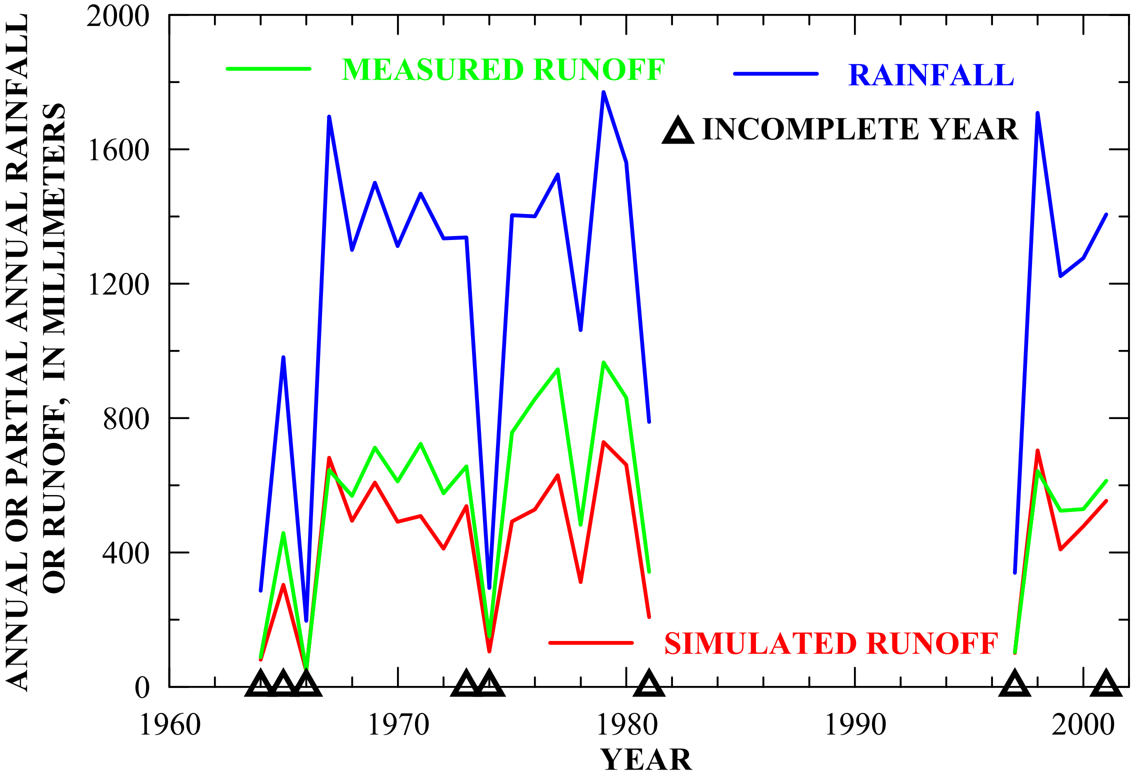


Figure 4-14. AnnAGNPS simulated and measured annual runoff at the USGS gaging station (#02423630) near Greenwood, AL.

Recurrence Interval for the Annual Maximum Instantaneous Peak Discharge

The annual peak discharge measured at the Greenwood gage during 1964 to 1981 and 1997 to 2001 compared with AnnAGNPS simulated results shows relatively close agreement (Figure 4-15). AnnAGNPS simulated results were somewhat lower than measured except for 2.5 to 3.5 year flows. Improved flow routing in the main channel by CONCEPTS will provide a closer comparison with measured. The comparisons using AnnAGNPS are only performed to indicate how well AnnAGNPS may be producing peaks to CONCEPTS at the tributaries. Since there are no gages at the tributaries the Greenwood gage is used for this even though it is located within the main channel simulated by CONCEPTS.

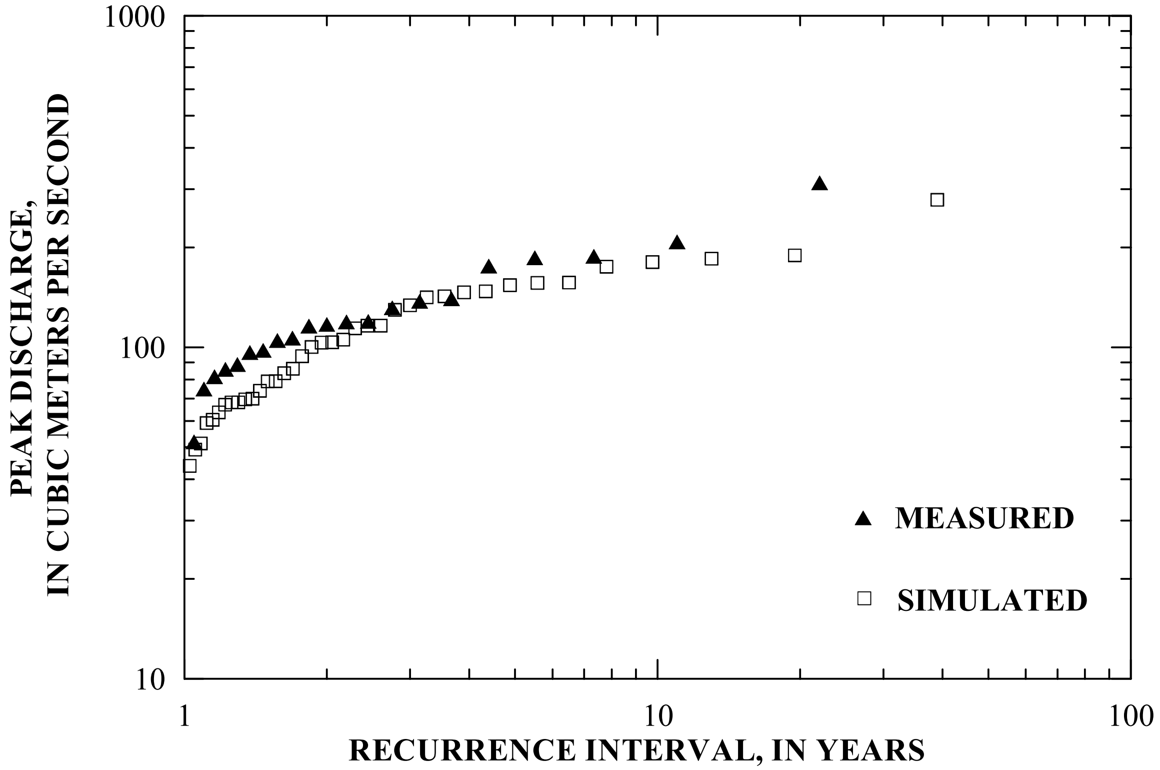


Figure 4-15. Measured and AnnAGNPS simulated peak discharge versus recurrence interval from 1964-1981, 1997-2001 at the USGS gaging station (#02423630) near Greenwood, AL.

Annual Suspended-Sediment Loads

For loads simulated by AnnAGNPS only, suspended-sediment is defined as containing clay, silt, and fine sand particle sizes. Simulated, annual suspended-sediment loads were compared to annual values calculated at the Greenwood station from 1964 to 1981 and 1997 to 2001 (Figure 4-16). Simulated annual sediment load at the Greenwood gage from AnnAGNPS simulation results is 40% of the calculated values at the gage indicating that sediment may be coming from channel sources. Simulated results were close to or slightly higher than calculated at the gage for years when low sediment loads occurred (Figure 4-17). The combined sediment load simulated by AnnAGNPS from the upland sources with those simulated by CONCEPTS from channel sources will show considerable improvement in comparison with measured values.

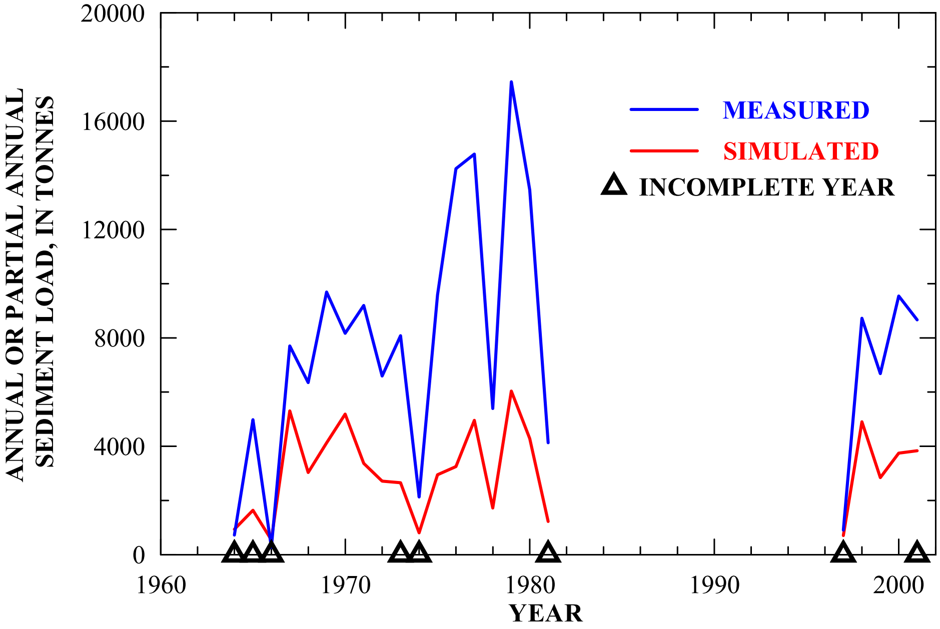


Figure 4-16. AnnAGNPS simulated and measured annual fine sediment load at USGS gaging station (#02423630) near Greenwood, AL.

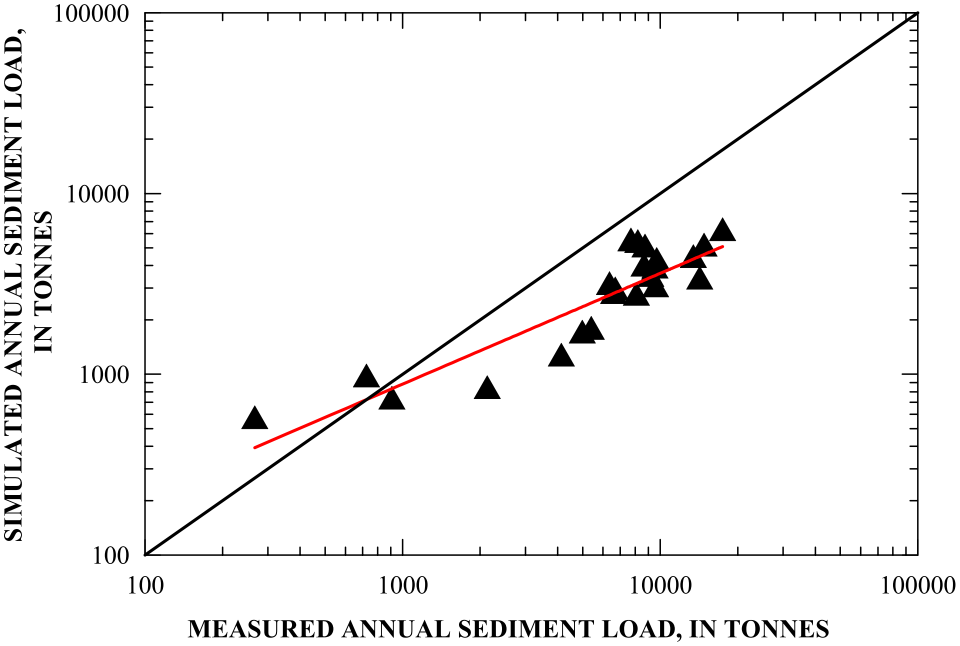


Figure 4-17. AnnAGNPS simulated versus measured annual fine sediment during 1964-1981, 1997-2001 at USGS gaging station (#02423630) near Greenwood, AL.

Sources of Runoff and Sediment

Runoff simulated by AnnAGNPS for the Validation scenario is shown in Figure 4-18. A significant amount of runoff occurs towards the upper end of the watershed where urban conditions dominate. In the central portion of the watershed, forest conditions dominate, resulting in lower levels of runoff. The runoff produced from the 2001 landuse scenario shows the higher producing sources at some different locations in the central portion and decreasing towards the outlet (Figure 4-19), while the total average annual runoff at the outlet was similar to the Validation scenario. Runoff produced from the 2001LUFU scenario shows almost all areas of the watershed producing higher amounts of runoff compared to the other scenarios (Figure 4-20). This is a result of higher SCS CN's defined for urban areas. The variability of soil characteristics between soils would be another major cause of any variability among the runoff from the AnnAGNPS cells in the 2001LUFU scenario since the landuse is mainly all forest.

Average annual erosion produced from, as well as the average annual sediment yield delivered to the edge of each AnnAGNPS cell, for the Validation scenario, is highly variable throughout the watershed, ranging from 0 to 3 T/ha/y (Figure 4-21). This erosion is fairly low since cultivated agriculture may produce 5 to 15 T/ha/y and still be within tolerable limits set by NRCS. Erosion indicates the amount of sediment that has been detached in each AnnAGNPS cell. Sediment yield indicates how much eroded sediment is transported to the edge of an AnnAGNPS cell before entering a channel. Deposition often occurs after sediment has eroded resulting in lower sediment yield values. The highest eroding areas occur in the upper end of the watershed as well as along some of the ridges. One of the principal indicators why these areas produce such high erosion values is the effect of slope and gradient on erosion, as associated with the RUSLE LS factor (Figure 4-22).

Average annual erosion and sediment yield produced by each AnnAGNPS cell for the 2001 landuse scenario (Figure 4-23) shows higher levels compared to the Validation scenario especially along the ridges and in the lower sections of the watershed because of differences in landuse and climate used. The forest to urban scenario produced even higher amounts of sediment (Figure 4-24) from most of the AnnAGNPS cells because of the increased runoff produced from urban areas. Additionally, the land cover provided in urban areas is less than from forested areas. The cover for urban areas was assumed to have 50% impervious and 50% grass cover, since the GIS landuse layer did not provide this information. A landuse layer describing cover conditions in more detail, such as defining urban into more categories such as 25% urban or 50% urban, would provide better information to describe the conditions on the watershed for use with the model.

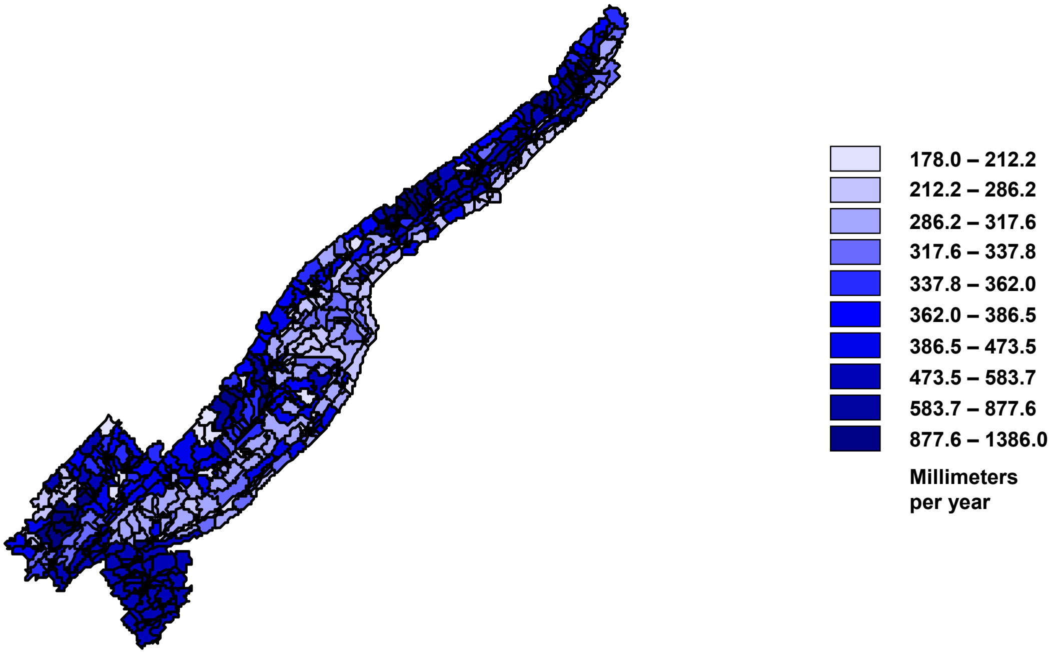


Figure 4-18. Average annual runoff simulated by AnnAGNPS for each cell in the Shades Creek Watershed for the validation period of 1978-2001.

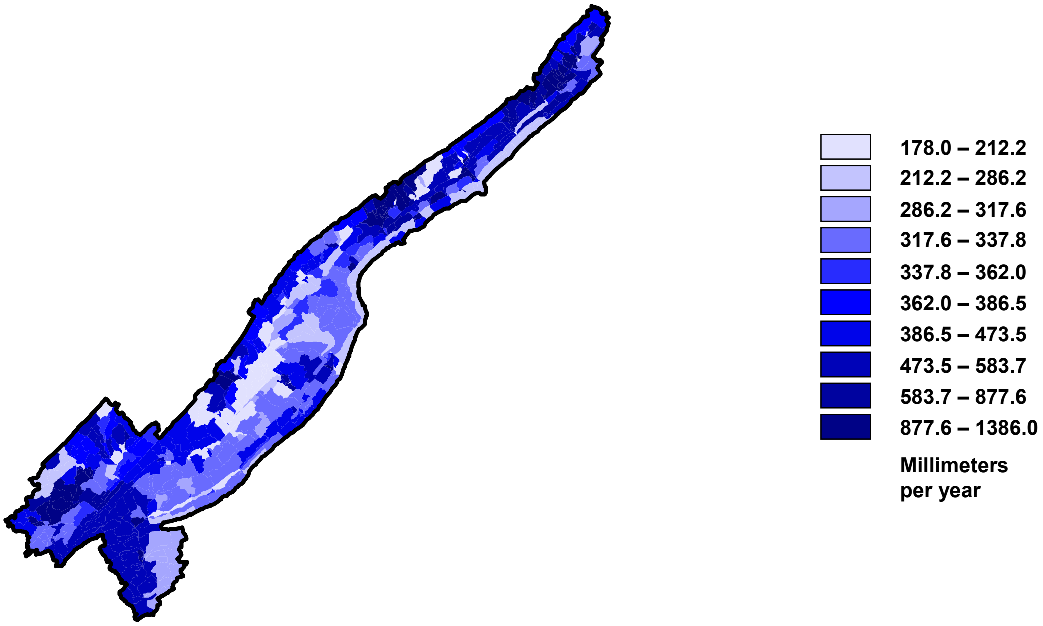


Figure 4-19. Average annual runoff simulated by AnnAGNPS for each cell in the Shades Creek Watershed for the future 25 year simulation using 2001 landuse.

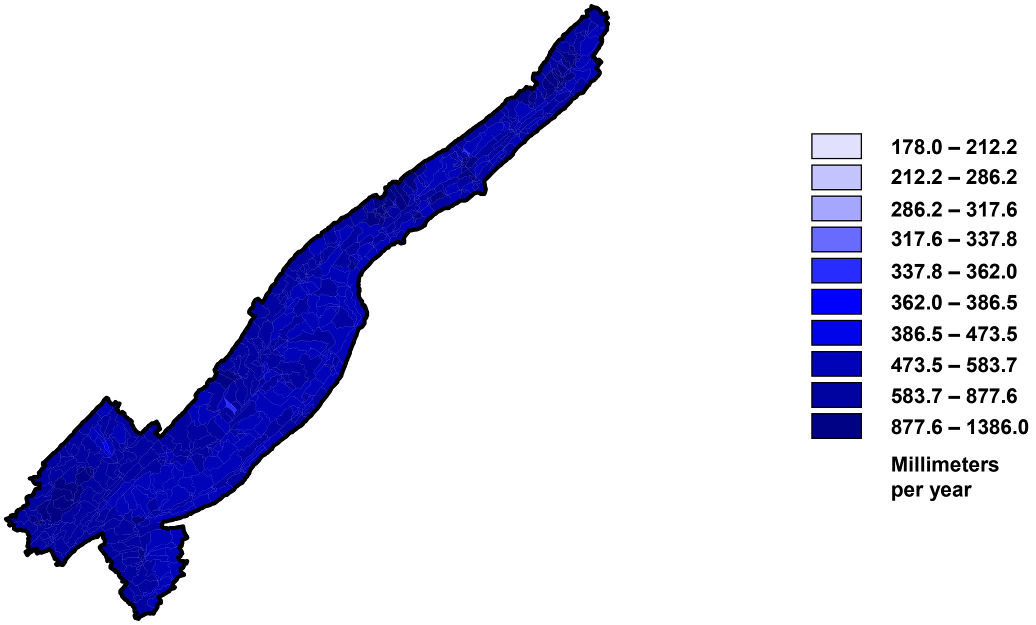


Figure 4-20. Average annual runoff simulated by AnnAGNPS for each cell in the Shades Creek Watershed for the future forest to urban, 25 year simulation (2001LUFU).

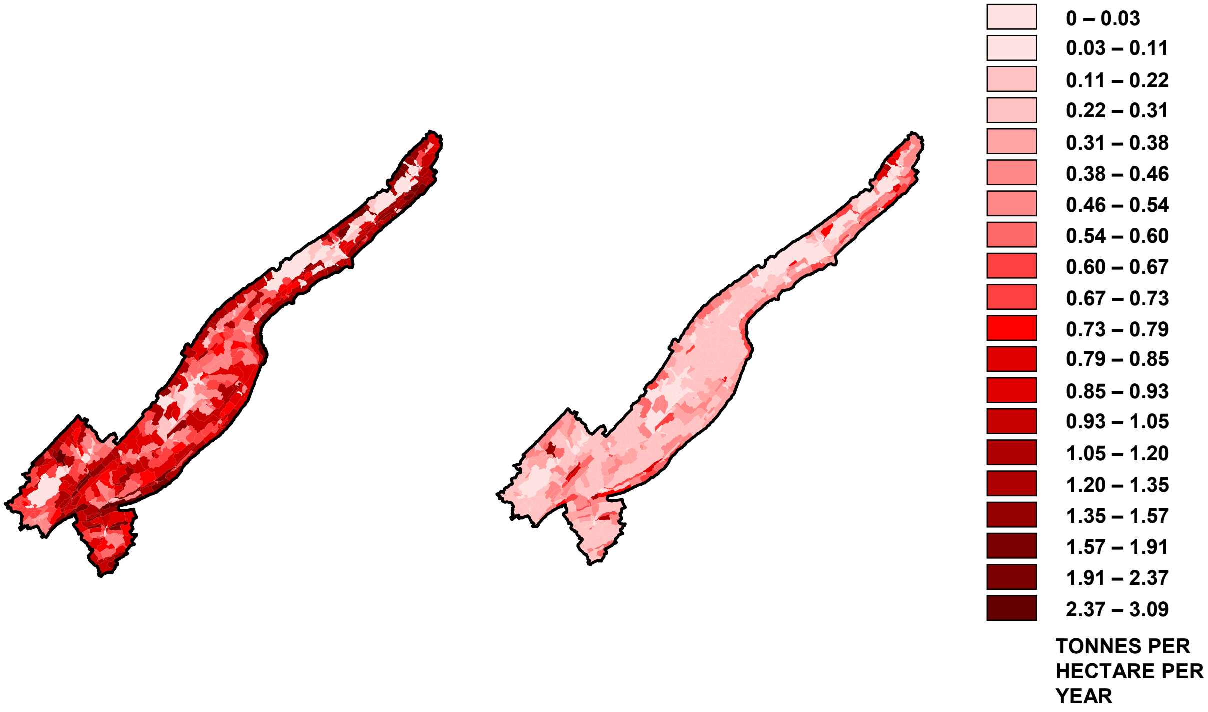


Figure 4-21. Average annual erosion (left) and sediment yield (right) simulated by AnnAGNPS for each cell in the Shades Creek Watershed for the validation period, 1978 to 2001.

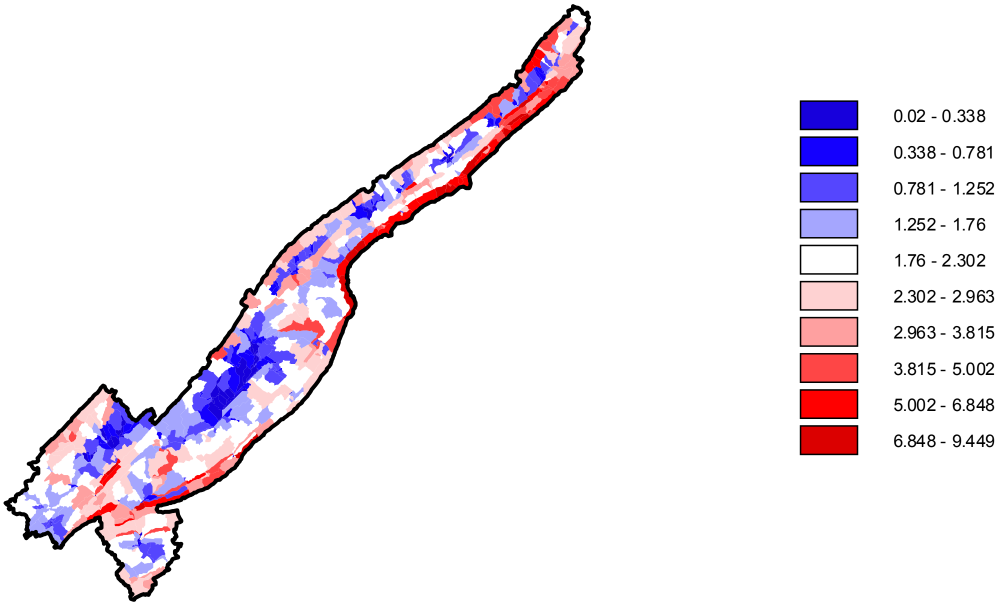


Figure 4-22. Variability of slope length and gradient (RUSLE LS-Factor).

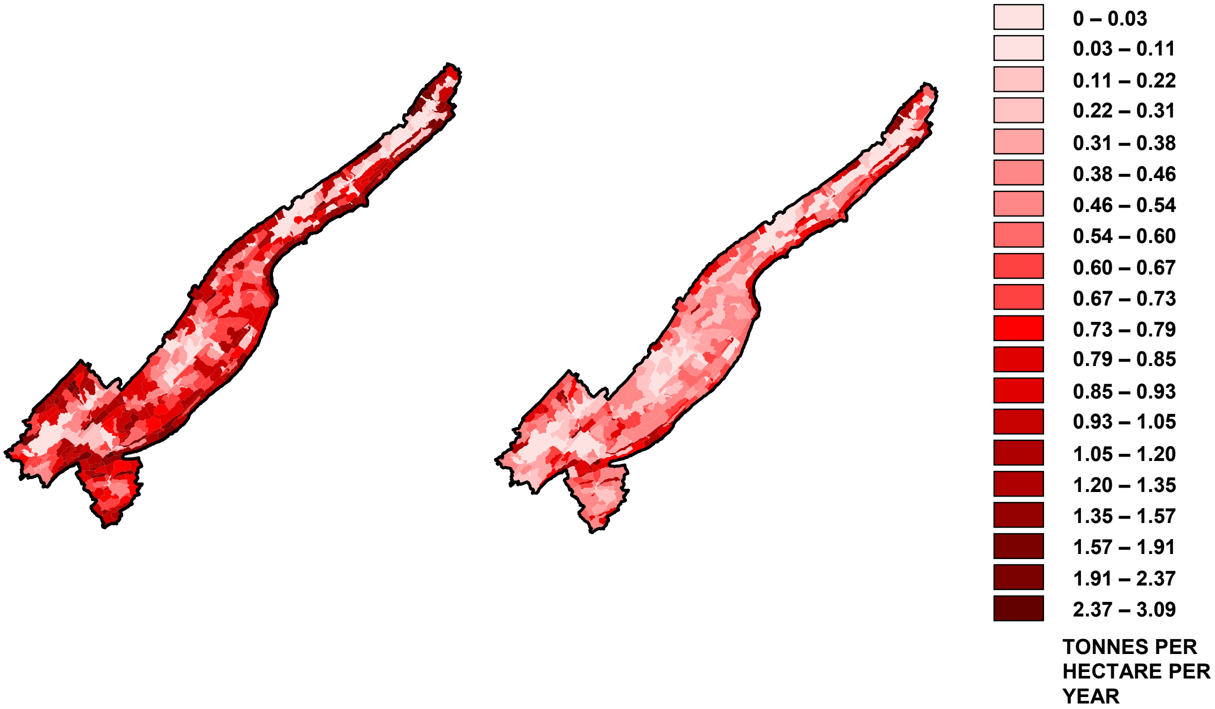


Figure 4-23. Average annual erosion (left) and sediment yield (right) simulated by AnnAGNPS for each cell on Shades Creek Watershed for the future simulation using 2001 landuse.

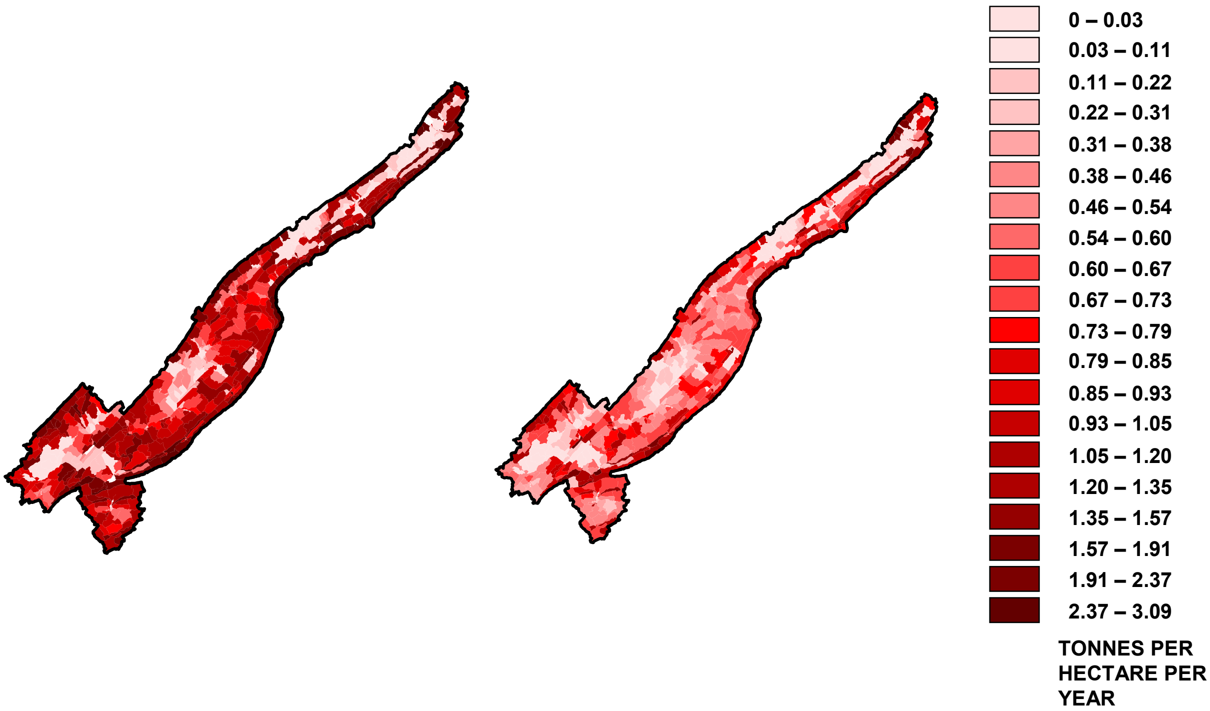


Figure 4-24. Average annual erosion (left) and sediment yield (right) simulated from AnnAGNPS for each cell on Shades Creek Watershed for the future simulation using forest to urban conditions (2001LUFU).

4.4 CONCEPTS Modeling

4.4.1 Modeling Reach and Parameters

Modeling Reach

The Shades Creek modeling reach extends from approximately 10.0 km above the confluence with the Cahaba River (cross-section A, downstream end), to cross-section DD (upstream end), approximately 86.5 km above the confluence with the Cahaba River (Figure 4-25). The modeling reach is composed of 156 cross sections. Cross sections are labeled A-Z, AA-AZ, BA-BZ, CA-CZ, and DA-DD. The modeling reach of Shades Creek contains 43 structures: 38 bridges and 5 culverts. Of the 156 cross sections used in the modeling reach, 108 were surveyed in 1978 by Walter Schoel Engineering and 48 were synthesized. Synthetic cross-sections were generated from the 1978 surveyed cross-section data. They were necessary to provide adequate spacing throughout the modeling reach and to provide upstream and downstream boundaries for the structures. Cross-section labels for synthetic sections are denoted by an ending numeral in their name (e.g. AG3, see Figure 4-25).

Test runs of CONCEPTS revealed that only two structures may significantly affect flow hydraulics: 1) a pipe culvert under a railroad bridge at rkm 83.4, and 2) the Mountain Brook Parkway bridge crossing at rkm 72.3. Other structures do not contract flow or have a negligible head loss as compared to friction losses at their upstream and downstream ends.

Visual observations did not show significant deposition or scour upstream or downstream of the above structures. Therefore, it was decided to perform the simulation scenarios without any structures.

Physical Properties

Roughness values were assigned to bed, bank, and floodplain sections of each cross section based on Manning *n* values used in a FEMA flood insurance study (Walter Schoel Engineering, 1999). Bed- and bank-material composition and geotechnical properties at each cross section were obtained from local sediment samples and BST tests (section 2.3). Measured effective cohesion (c') values were adjusted for root-reinforcement by riparian vegetation by adding 2 to 4 kPa depending on riparian vegetation density and species. Measured critical shear stresses of (τ_c) were adjusted for shielding of bank-face material by riparian vegetation. Streambank materials have an average silt/clay content of 15%, an average sand content of 81%, and an average gravel content of 4%. Bank-toe materials have an average silt/clay content of 13%, an average sand content of 67%, an average gravel content of 5%, and an average boulder/cobble content of 15%. The streambed materials have an average silt/clay content of 1%, an average sand content of 24%, an average gravel content of 28%, and an average boulder/cobble content of 47%.

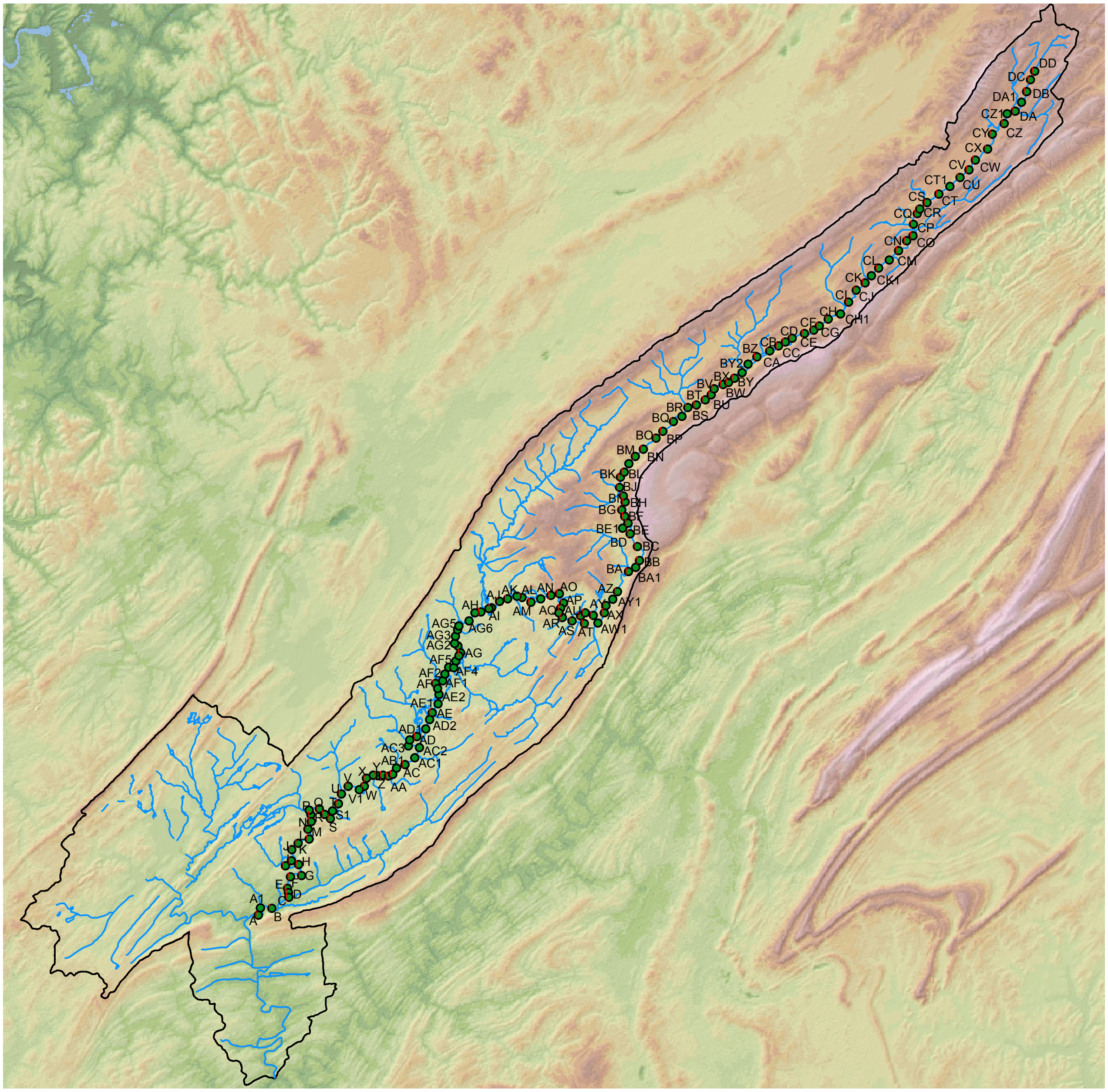


Figure 4-25. Cross sections used by CONCEPTS. Surveyed cross sections are denoted by a red dot, whereas synthetic cross sections are denoted by a green dot.

4.4.2 Tributary and Lateral Inflow

AnnAGNPS provides peak flow discharge (m^3/s), runoff volume (m^3), and clay, silt, and sand mass (T) for each runoff event for reaches and cells draining into the modeling reach. These data are then converted into triangular-shaped hydrographs (NRCS, 1986). The duration (s) of the hydrograph is calculated as twice the runoff volume divided by the peak discharge. The time to peak occurs at 37.5% of the hydrograph duration. Table 4-2 lists the locations receiving tributary and lateral inflow. Figures 4-26 through 4-28 show the upland sediment contributions into the modeling reach for the three scenarios simulated by AnnAGNPS.

Table 4-2. List of cross sections receiving inflow of water and sediment from AnnAGNPS through tributaries and cells adjacent to the modeling reach.

Cross section ID	River kilometer	AnnAGNPS channel ID	AnnAGNPS Cell ID
DD	86.5	1974	
DC	86.1		1972, 1973
DB	85.5	1964, 2004	1952, 1953
DA	84.3	2014	1942, 1943
CZ1	83.8	1924	1932, 1933
CZ	83.3		1912, 1913
CY	82.6	1904, 2024	1892, 1893
CX	81.8	1874, 2034	1862, 1863, 1882, 1883
CW	81.1		1852, 1853
CV	80.5	1844	
CT1	79.5	1824	1832, 1833
CS	78.3		1812, 1813
CR	77.8	1804	
CP	77.1	1764	1752, 1753, 1792, 1793
CO	76.4	2044	
CN	75.9		1742, 1743
CL1	74.6	2094	
CL	74.0		1732, 1733
CK	73.1	1724	
CI	71.7	1604	1712, 1713
CH1	71.1	2104	1592, 1593
CG	70.0	2114	1582, 1583
CE	69.2		1572, 1573
CD	68.6	1564	
CA	67.6		1552, 1553
BZ	67.0	1544	
BY2	66.5		1532, 1533
BY1	66.0	1464	
BY	65.5	2124	1452, 1453
BV	64.4		1442, 1443
BS	63.3	2134	
BR	62.9	1324	1432, 1433
BQ	61.9		1312, 1313
BP	61.3	1304	
BO	60.8		1292, 1293
BM	59.6	1284	1272, 1273
BL	58.8	1264	
BJ	58.0		1252, 1253

BH	57.3	1244	
BC	53.9		1232, 1233
BA	52.1	1204	
AY	50.2		1192, 1193
AW1	49.3	2144	
AS	47.0	2174	1182, 1183
AM	43.3		1172, 1173
AK	41.6	1164	
AJ	41.2		1152, 1153
AI	40.7	2184	
AH	39.6		1142, 1143
AG7	39.0	954	942, 943
AG6	38.5	934	
AG4	37.4	914	922, 923
AG	35.2		902, 903
AF4	33.6	2194	
AF1	32.1		892, 893
AE3	31.0	854	
AE1	30.0	2204	882, 883
AE	29.5		842, 843
AD	27.9	834	822, 823
AC3	26.9	794	
AC1	25.8	2334	782, 783
AB1	24.9		772, 773
AB	24.5	2364	
Y	23.8		762, 763
X	22.9	2374	
V1	22.0		752, 753
U	21.0	744	
T	20.5	2384	732, 733
Q	19.0		722, 723
P	18.1	674	
K	15.8		662, 663
I	14.7	654	
F	12.7		642, 643
D	11.6	2394	
B	11.1	2484	632, 633
A1	10.6	614	623

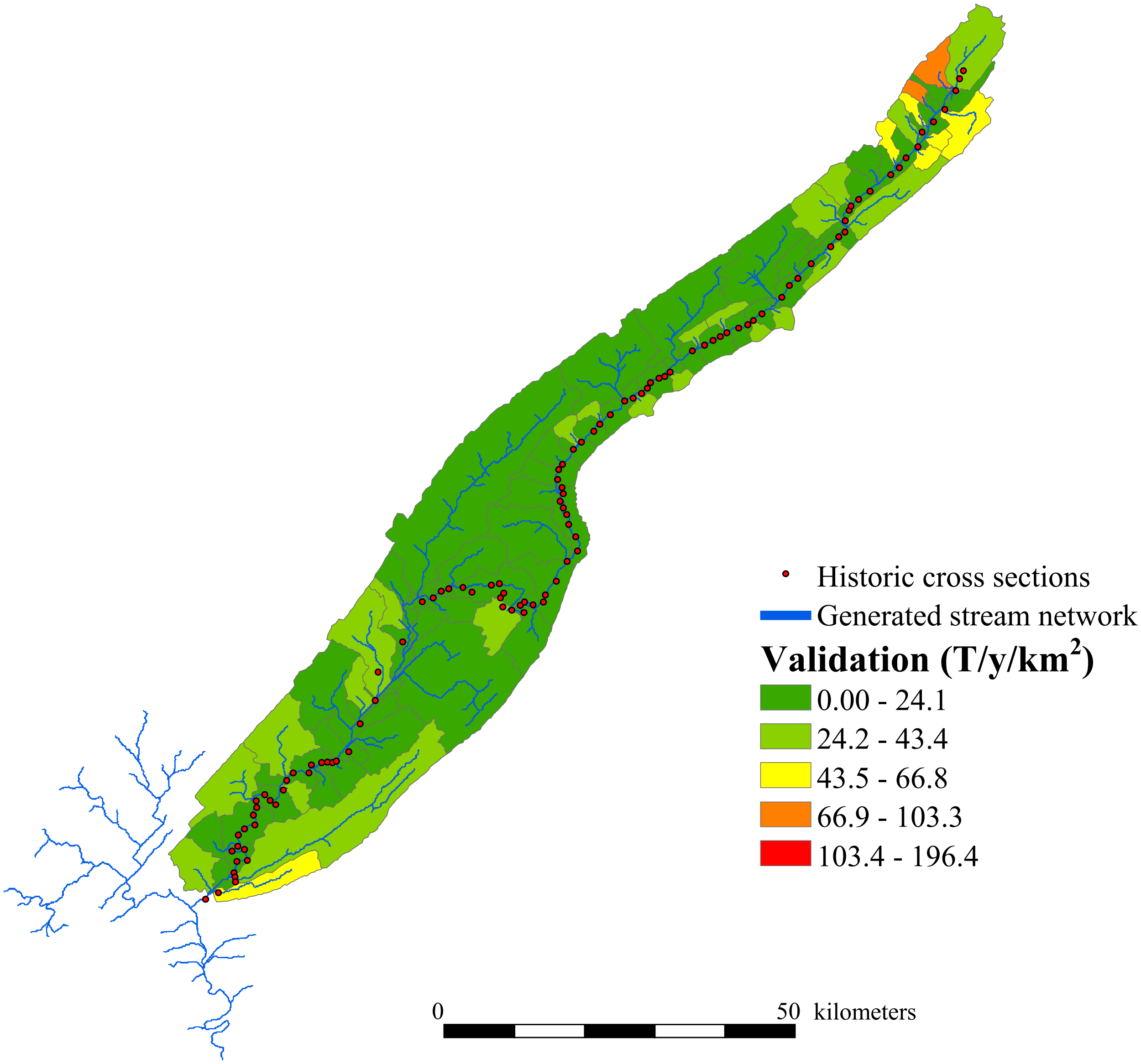


Figure 4-26. Simulated annual-average upland sediment yield into the modeling reach based on 1991 landuse for the validation scenario.

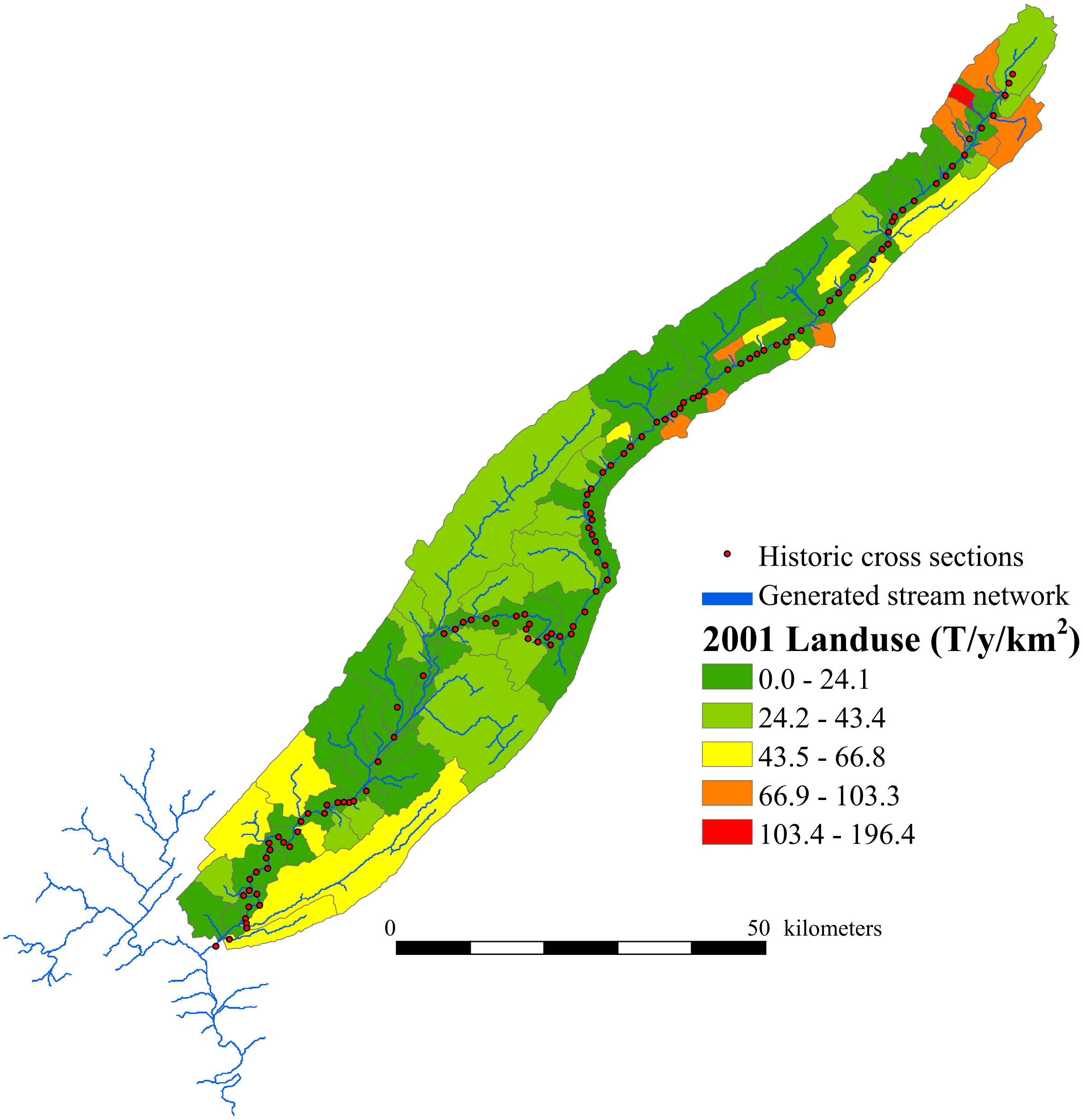


Figure 4-27. Simulated annual-average upland sediment yield into the modeling reach based on 2001 landuse for 2001 landuse and 2001LURP scenarios.

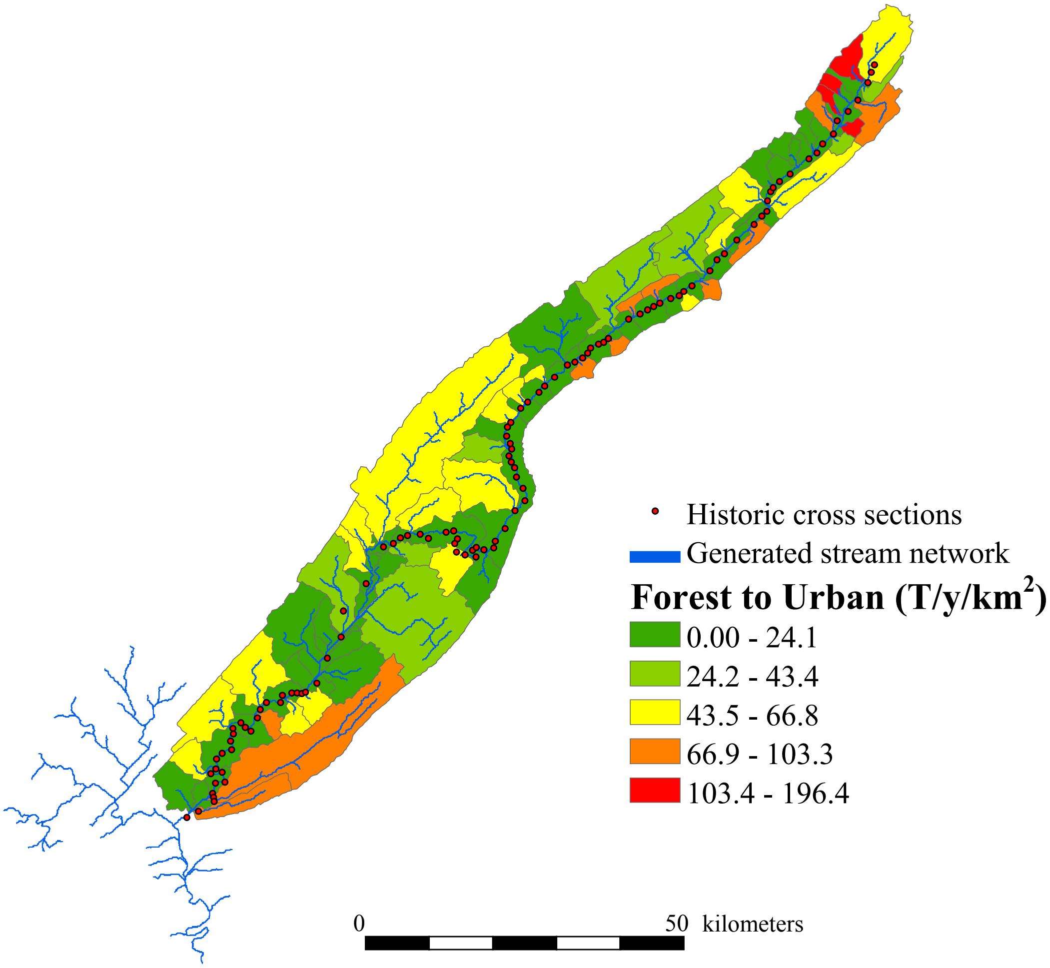


Figure 4-28. Simulated annual-average upland sediment yield into the modeling reach based on 2001 landuse in which forest landuse has been changed to urban landuse for the 2001LUFU scenario.

4.4.3 Validation Scenario

Calculated sediment loads at station 02423630 were used to validate CONCEPTS for the period from January 1978 through December 2001. Figures 4-29 through 4-31 and Figure 4-33 show the results of the validation.

Runoff

Figures 4-13 and 4-14 compare simulated and measured annual runoff (section 4.3). Table 4-3 lists the simulated and measured annual peak discharges at station 02423630. It is difficult to compare annual peak discharges, because for five of the eight water years the date of the simulated and measured annual peak discharge differed. There exist various reasons why measured and simulated peak discharges of individual runoff events may not compare well, see section 4.3. However, we can compare the peak discharge occurring at a certain recurrence interval. Table 4-4 lists observed and simulated 1.1-, 1.5-, 2-, 5-, 10-, and 100-year peak discharges. The simulated bankfull discharge, commonly assumed to be the peak discharge that occurs only once every 1.5 or 2 years, agrees well with that observed. The 5-year, 10-year, and 100-year peak discharges are slightly overpredicted. The simulated 5-year peak discharge is 17% larger than that observed. The simulated 10-year peak discharge is 19% larger than that observed and simulated 100-year peak discharge is 24% greater than that observed. This overprediction may be due to excluding the effects of hydraulic structures. Hydraulic structures probably will attenuate the peak discharges of the largest (5-year and higher) runoff events.

Channel Geometry

Figure 4-29 shows the simulated changes in bed elevation and channel top width between January 1978 and December 2001 for the validation scenario. Large variations in changes in bed elevation along the modeling reach are caused by tributary inflow (Fig 4-29A). Differences between sediment transport capacity and sediment discharge rates at tributary inflow points produce a pattern of local scour or deposition. To remove this pattern, the simulated change in bed elevation has been smoothed using a running average of three data points, see Figure 4-30. Figures 4-29A and 4-30 show a net deposition along the modeling reach. The simulated change in bed elevation appears to be correlated to the bed-material type along the modeling reach (Figure 3-23). There is a small amount of deposition along the bedrock and gravel reaches between rkm 71.1 and rkm 86.5. There is an average of 0.2 m of deposition along the two gravel sections (rkm 62.5-64.1 and rkm 67.0-69.2) within a section dominated by bedrock, boulders, and cobbles (rkm 55.1-70.5). There is significant deposition along the gravel/sand reach between rkm 44.5 and 55.1. The bed-material downstream of rkm 44.5 up to the confluence with Little Shades Creek (rkm 40.2) is composed of fines and sands.

Table 4-3. Comparison of measured and simulated annual peak discharge.

	Annual peak discharge (m^3/s)			Annual peak discharge (m^3/s)	
Water year	Measured	Simulated	Water year	Measured	Simulated
1978†	105	67.1	1998	135	177
1979	309	210	1999	94.9	151
1980†	185	194	2000†	173	218
1981†	115	84.2	2001†	118	210

† Measured and simulated peak discharges do not occur on the same date for the water year.

Table 4-4. Comparison of measured and simulated (validation scenario) peak discharge at certain recurrence intervals.

Recurrence interval (years)	Discharge (m^3/s)	
	Measured	Simulated
1.1	72	70
1.5	98	103
2	116	127
5	164	192
10	201	240
100	336	418

There is significant deposition downstream of the confluence with Little Shades Creek and rkm 34.1. Shades Creek is degradational along this section. The bed material between the confluence with Little Shades Creek and rkm 25.3 is primarily sand. The downstream part of this section is degradational. The largest amount of deposition occurs immediately downstream between rkm 21.4 and 25.3, the bed material of which alternates between sand and bedrock. The bed material of the most downstream section of the modeling reach (rkm 10.0-20.5) ranges from boulders and cobbles to bedrock. This section is slightly aggradational.

The profile of simulated changes in top width along the modeling reach can be divided into three segments (Figure 4-31): 1) segment from rkm 10.0 to approximately rkm 27.5; 2) segment from rkm 27.5 to rkm 68.0; and 3) segment from rkm 68.0 to rkm 86.5. This profile is determined, among others, by coarser materials in the first and third segments and hydraulic radius of the flow on average is larger in the second segment. The average increase in channel top width is approximately 0.5 m along the first segment. The maximum increase in channel top width along this segment is 2.2 m at rkm 12.7 (cross section F). The average increase in channel top width is approximately 0.6 m along the third segment. The maximum increase in top width along this segment is 2.4 m at rkm 80.5 (cross section CV). Along the second segment the average change in channel top width gradually increases from 0.5 m at its downstream end and 0.6 m at its upstream end to a maximum of 1.5 m around rkm 47.0. Significant widening is modeled at rkm 40.2 (3.2 m, cross section AH1), rkm 43.3 (5.5 m, cross section AM), rkm 49.3 (3.6 m, cross section AW1), and rkm 52.1 (4.7 m, cross section BA). Figure 4-32 shows that streambank erosion is prevalent in these reaches.

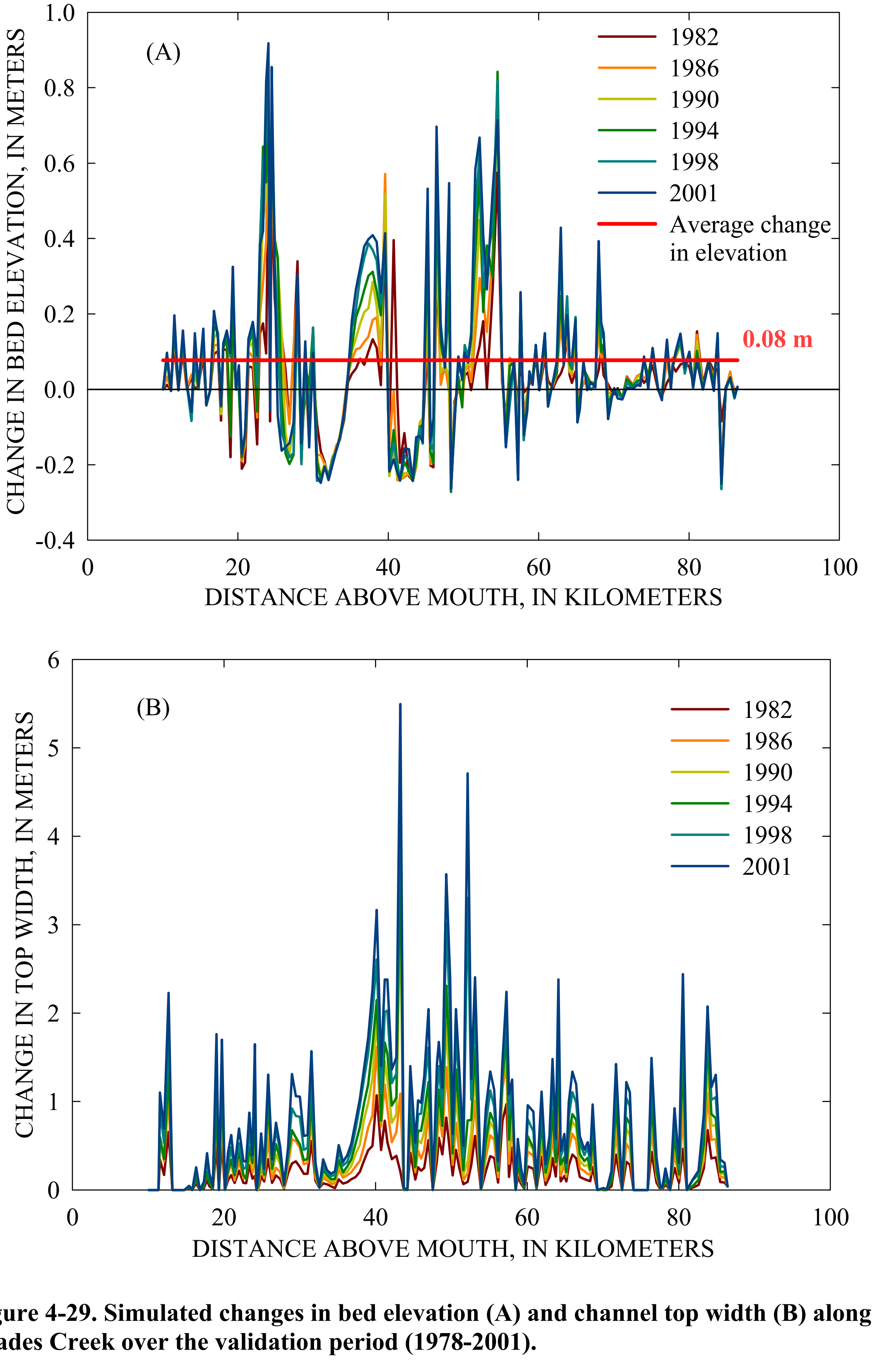


Figure 4-29. Simulated changes in bed elevation (A) and channel top width (B) along Shades Creek over the validation period (1978-2001).

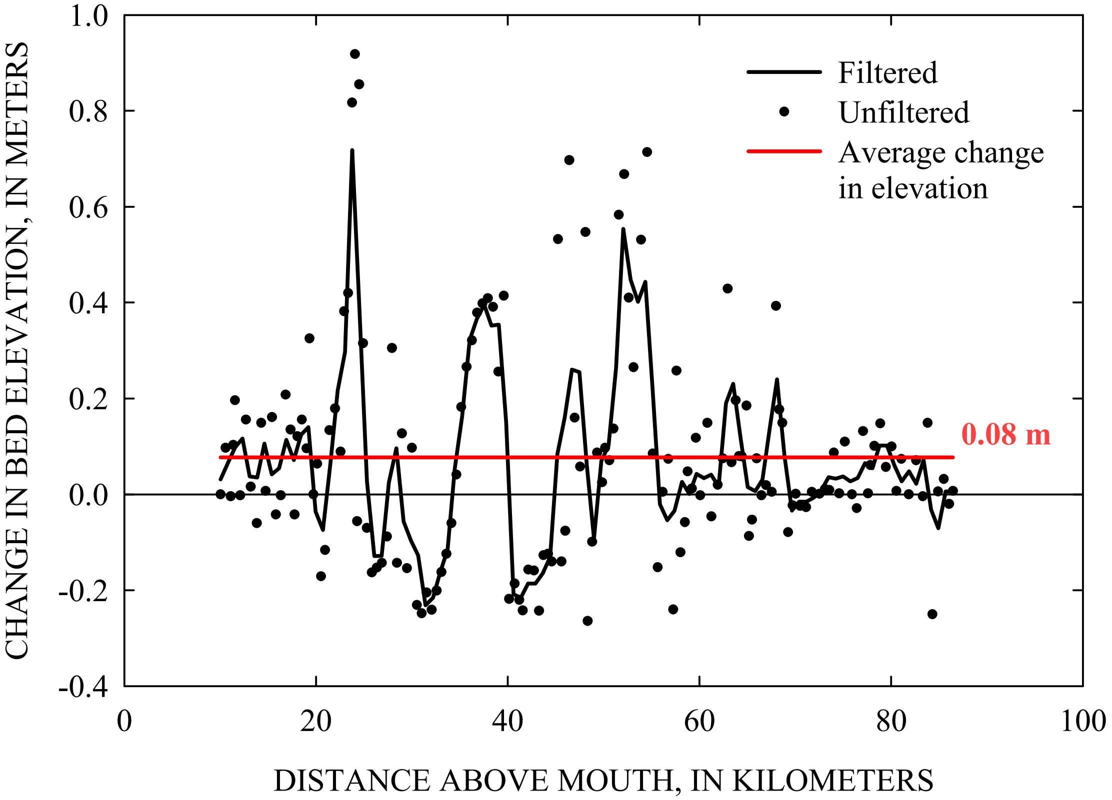


Figure 4-30. Simulated change in bed elevation along Shades Creek on December 2001 for the validation scenario: •, unsmoothed data; and —, smoothed data using a running average of three data points.

Sediment Load

Figure 4-33 compares measured and simulated annual loads of suspended sediments at station 02423630 and presents annual loads of suspended sediments at the downstream boundary of CONCEPTS. Generally, annual loads appear to be correlated with annual runoff (Figure 4-33). Years with low runoff correspond to years with low annual sediment loads. Between 1978 and 2001, gaging station 02423630 has eight (8) years of measured data. The measured average-annual suspended sediment load was 9,850 T and the corresponding simulated average-annual load of suspended sediment over the same period (1978-1981 and 1998-2001) was 10,400 T, a 5% difference. The mean load value shown in red in Figure 4-33A represents the average load over the entire simulation period. Between 1978 and 2001, the simulated average-annual suspended sediment load at the downstream boundary of CONCEPTS (cross-section A) is 18,900 T (Figure 4-33B).

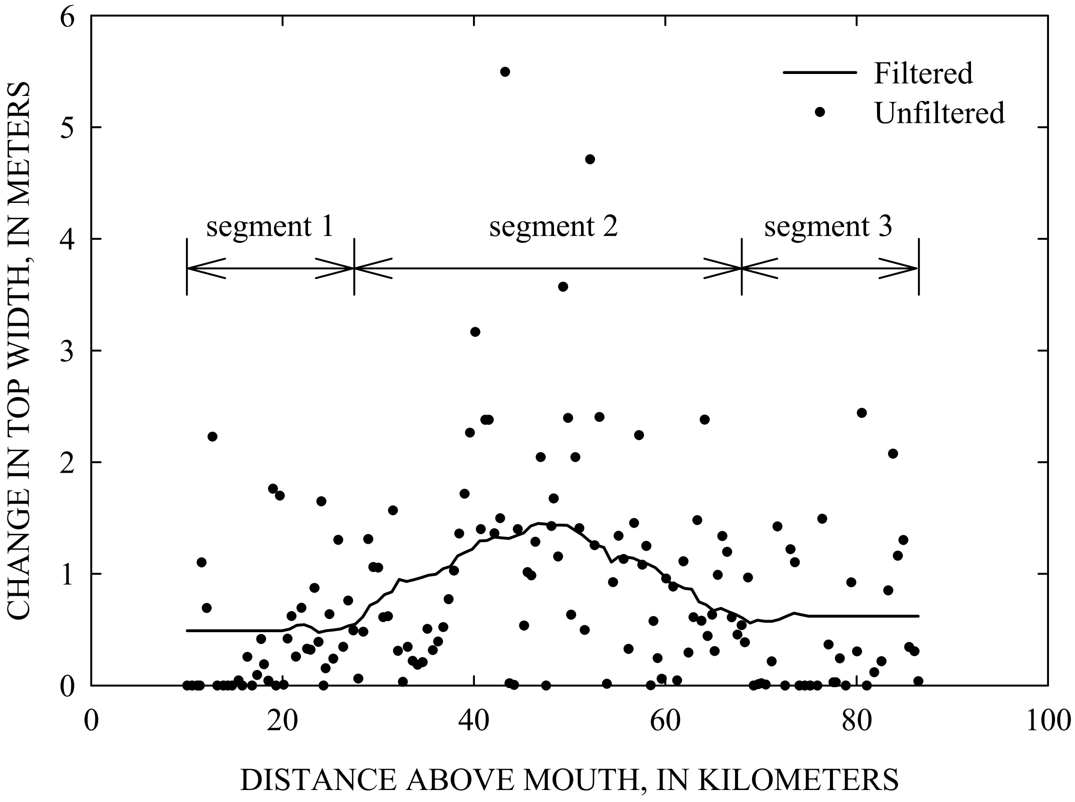


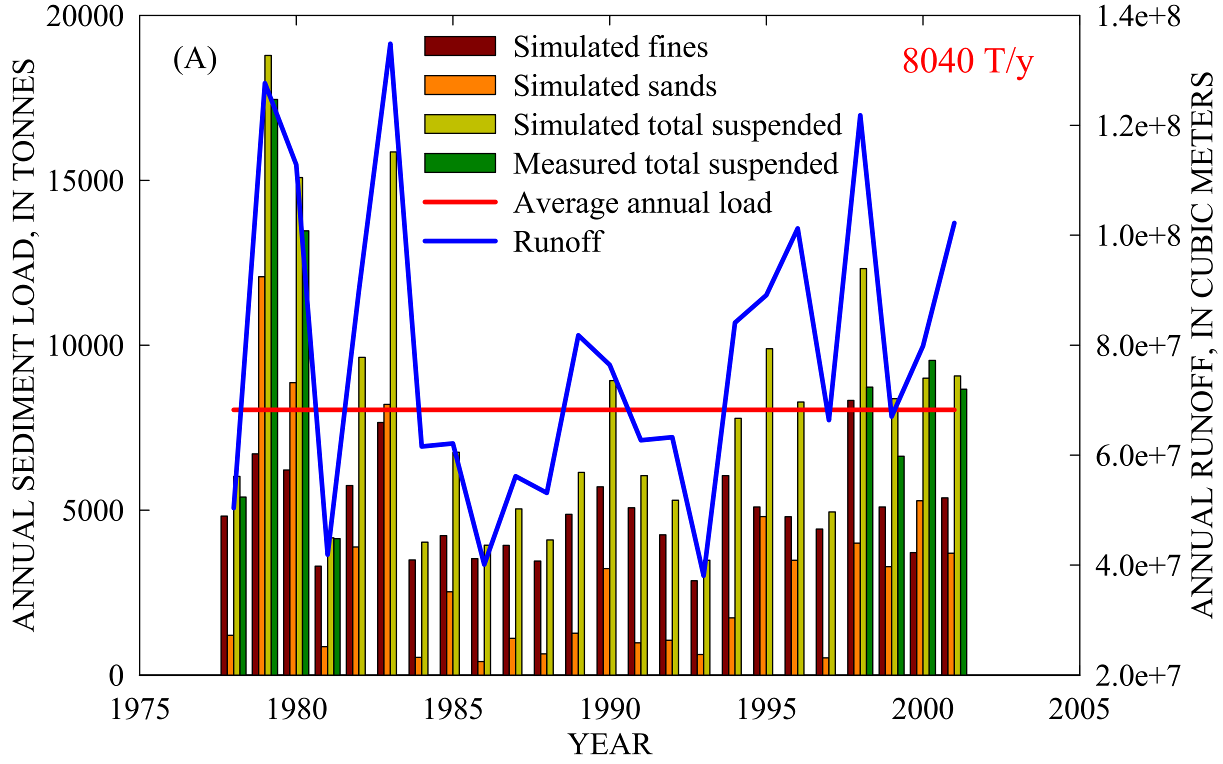
Figure 4-31. Simulated change in channel top width along Shades Creek on December 2001 for the validation scenario: •, unsmoothed data; and —, smoothed data using a running average of 45 data points.

Table 4-5. Relative source contributions of uplands and streambanks to suspended sediment integrated over the study reach for the validation scenario.

Sediment size	Uplands (%)	Streambanks (%)	Total (T/y)
Fines	29.2	70.8	20,700
Sands	17.8	82.2	5,190
Total suspended	26.9	73.1	25,800

The streambanks are the greatest source of sediments to suspended load. They contribute 70.8% of fines and 82.2% of sands. Table 4-5 lists the loadings of fines (clays and silts) and sands, emanating from uplands and streambanks, into the modeling reach. The totals listed in the "Total" column of the table do not equate to the reported sediment loads at the downstream boundary of the modeling reach. For example, 25,800 T of sediments annually enter the modeling reach from streambanks and uplands, however only 18,900 T make it to the downstream boundary.

Figure 4-32. Photos depicting streambank erosion at cross section AH (top) and AX (bottom).



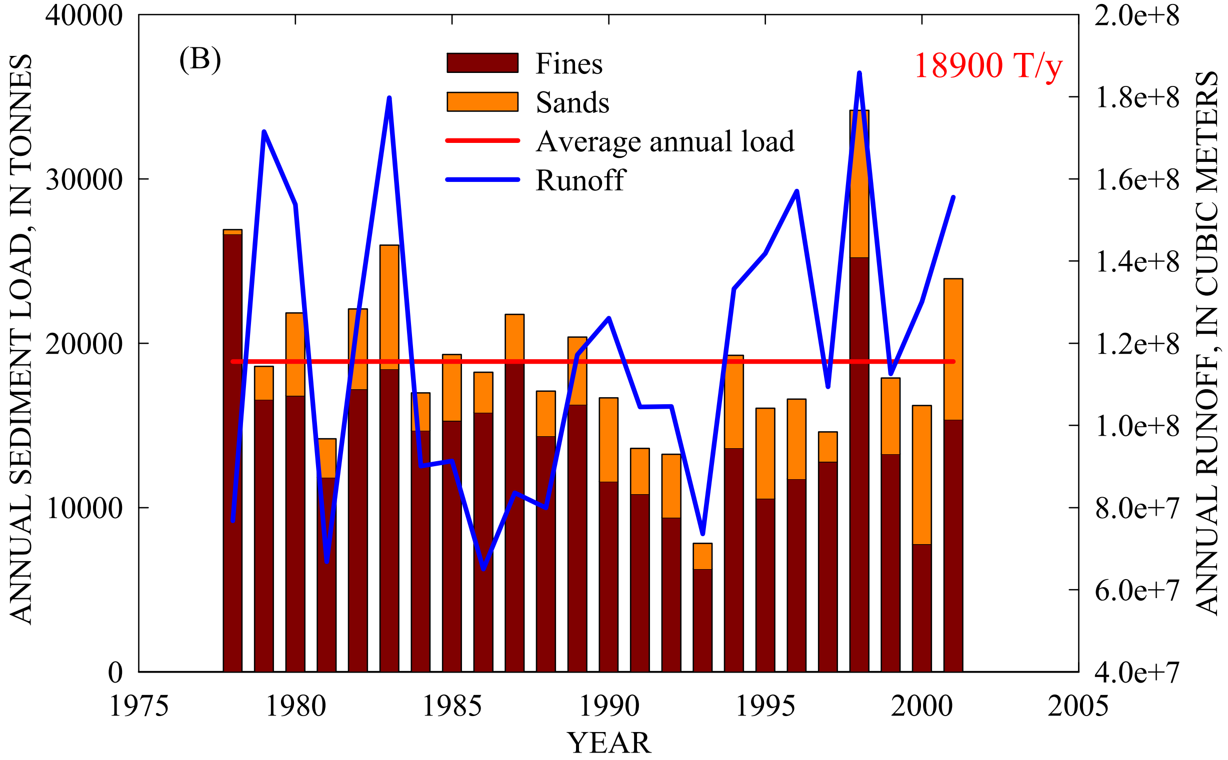


Figure 4-33. Comparison of simulated and measured annual sediment loads at station 02423630 (A), and simulated sediment loads and runoff at the CONCEPTS downstream boundary (B).

4.4.4 2001 Landuse Scenario

A 25-year simulation was performed to determine trends in sediment loads due to recent changes in landuse. The 1991 landuse distribution used in the validation scenario was replaced by the 2001 landuse distribution. Weather data from 1977 through 2001 were used to construct a 25-year climate record. Figure 4-27 shows the upland sediment contributions into the modeling reach as simulated by AnnAGNPS. For presentation purposes it is assumed that the simulation starts on January 1, 2004 and ends on December 31, 2028. The simulated channel geometry at the end of the validation simulation (December 31, 2001) is used as the initial channel geometry for this scenario. The physical properties of the study reach in this scenario are the same as those in the validation scenario. Figures 4-34 through 4-37 show the simulation results of the 2001 landuse scenario. Simulated annual peak discharges are listed in Table 4-6.

Runoff

The average annual runoff at the mouth of Shades Creek with the Cahaba River is 1% smaller for the 2001 landuse scenario (457 mm/y) than that for the validation scenario (462 mm/y), section 4.3. The effect of landuse on annual peak discharge is evaluated by comparing simulated discharges for different recurrence intervals. Table 4-6 lists the simulated 1.1-, 1.5-, 2-, 5-, 10-, and 100-year peak discharge at station 02423630 for the validation and 2001 landuse scenarios. The peak discharges are approximately 9.3% larger for the 2001 landuse scenario than those for the validation scenario in which landuse was based on a 1991 survey.

Channel Geometry

Figure 4-34 shows the changes in bed elevation and channel top width over the 25-year simulation period. Variations in bed elevation along the modeling reach caused by tributary inflow are smaller than for the validation scenario. Figure 4-35 shows the net change in bed elevation at the end of the simulation smoothed using a running average of three data points. The average change in bed elevation along the modeling reach has reduced to 0.04 m from 0.08 m for the validation scenario. This is mainly due to the significant decrease in deposition between rkm 22 and rkm 24, and between rkm 50 and rkm 54 (compare Figures 4-30 and 4-35). The rate of deposition between rkm 35 and rkm 40 (downstream of the confluence with Little Shades Creek) and between rkm 44 and rkm 48 is similar to that of the validation scenario. Scour along the modeling reach has been greatly reduced because of the presence of bedrock.

Table 4-6. Comparison of simulated annual peak discharge for validation and 2001 landuse scenarios.

	Discharge (m^3/s)	
Recurrence interval (years)	Validation	2001 landuse
1.1	70	76
1.5	103	114
2	127	140
5	192	210
10	240	262
100	418	450

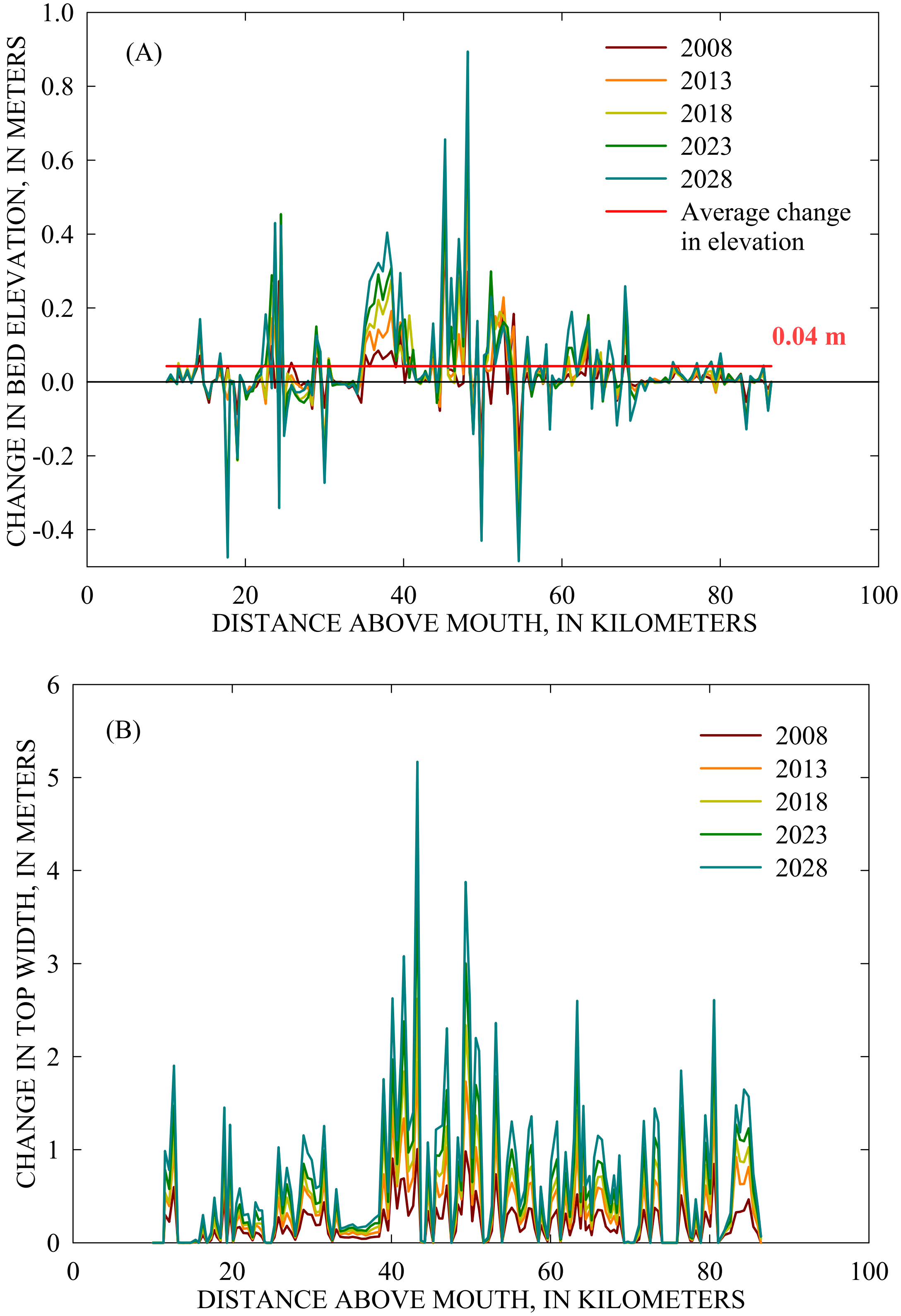


Figure 4.34. Simulated changes in bed elevation (A) and channel top-width (B) along Shades Creek over a 25-year period for the 2001 Landuse Scenario.

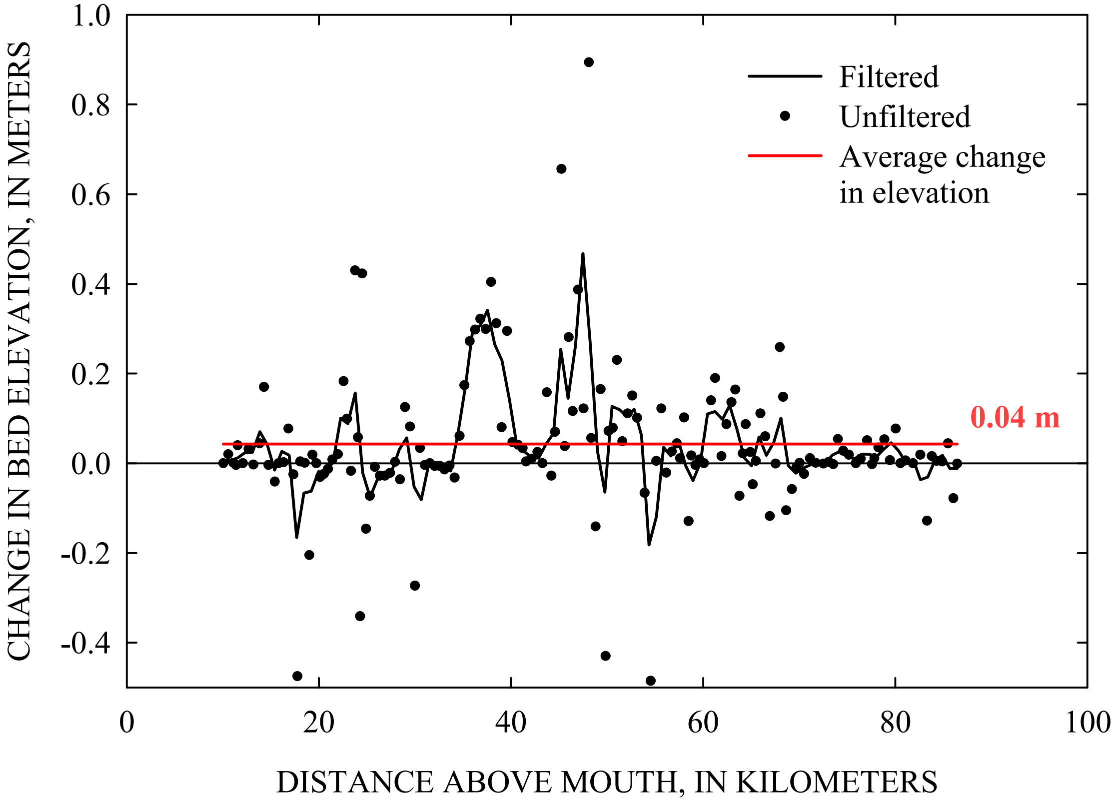


Figure 4-35. Simulated change in bed elevation along Shades Creek on December 2028 for the 2001 landuse scenario: •, unsmoothed data; and —, smoothed data using a running average of three data points.

The trend of simulated changes in top width along the modeling reach can be divided into the same three segments as those for the validation scenario (Figure 4-36). The average increase in channel top width is approximately 0.4 m along the first segment, which is 0.1 m smaller than in the validation scenario. The maximum increase in channel top width along this segment is 1.9 m at rkm 12.7 (cross section F). The average increase in channel top width is approximately 0.7 m along the third segment, which is 0.1 m greater than in the validation scenario. The maximum increase in top width along this segment is 2.6 m at rkm 80.5 (cross section CV). Along the second segment the average change in channel top width gradually increases from 0.4 m at its downstream end and 0.7 m at its upstream end to a maximum of 1.2 m around rkm 49.5. This is slightly smaller than for the validation scenario. Significant widening is modeled at rkm 41.6 (3.1 m, cross section AK), rkm 43.3 (5.5 m, cross section AM), and rkm 49.3 (3.6 m, cross section AW1). Generally, the same cross sections as in the validation scenario experience the greatest widening.

Sediment Load

Figure 4-37 shows the simulated annual runoff, and annual loads of suspended sediments at gaging station 02423630 of Shades Creek and at the CONCEPTS downstream boundary (cross-section A). The average annual suspended load at the gaging station is 6,950 T. This is 13.6% smaller than that for the validation scenario. The average annual suspended load at the outlet is 16,700 T. This is 11.6% smaller than that for the validation scenario. Lower rates of channel adjustment, compared to those in the 1978-2001 period (validation scenario), led to this reduction in simulated sediment loads.

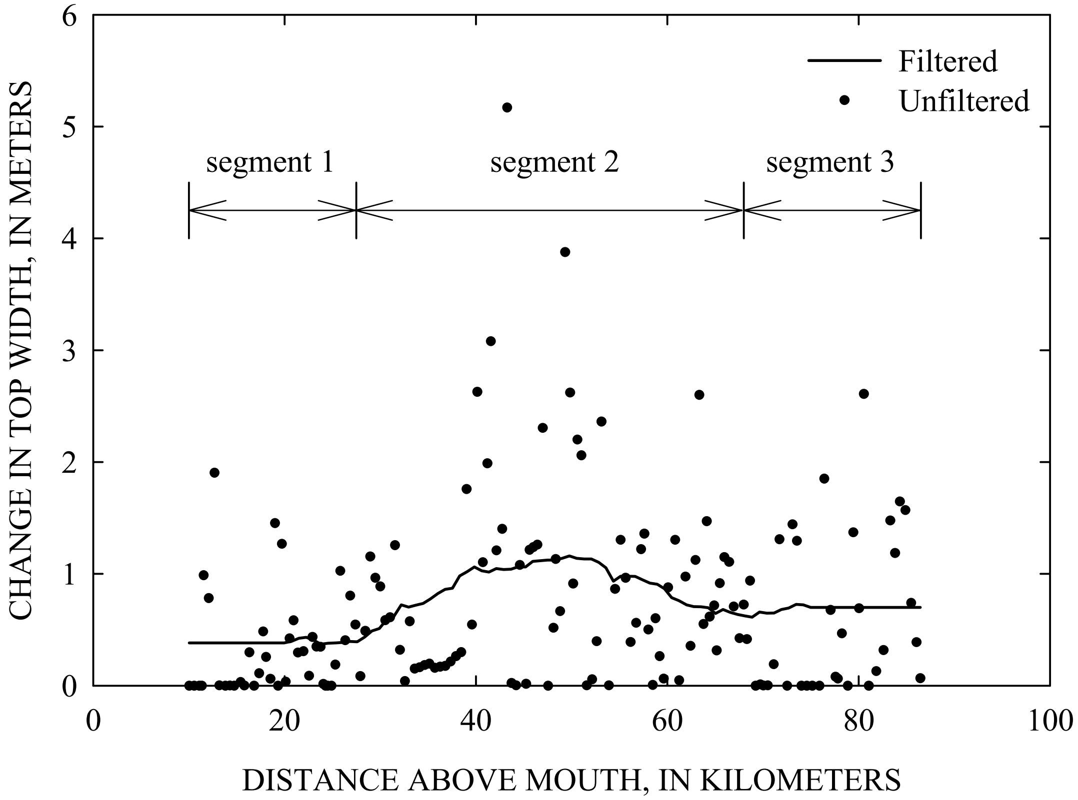
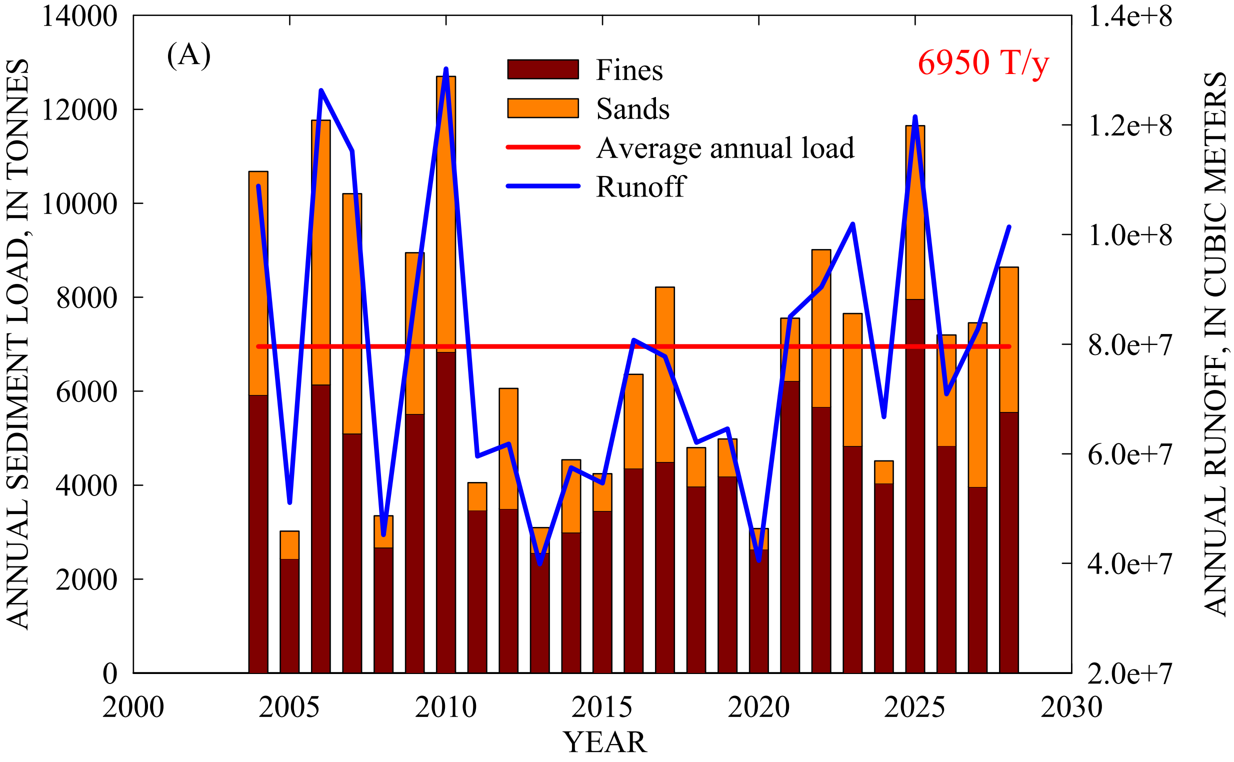


Figure 4-36. Simulated change in channel top width along Shades Creek on December 2028 for the 2001 landuse scenario: •, unsmoothed data; and —, smoothed data using a running average of 45 data points.

Table 4-7. Relative source contributions of uplands and streambanks to suspended sediment integrated over the study reach for the 2001 landuse scenario.

Sediment size	Uplands (%)	Streambanks (%)	Total (T/y)
Fines	40.3	59.7	18,700
Sands	31.2	68.8	8,000
Total suspended	37.6	62.4	26,700

Table 4-7 lists the sources of sediments entering the modeling reach. Upland contributions of sediment have increased with respect to the validation scenario which was based on 1991 landuse (Figures 4-26 and 4-27). Streambank contributions to suspended load have decreased 2,230 T/y or 11.8% with respect to the validation scenario due to channel adjustment between 1978 and 2001. This reduction is solely due to a large decrease in fines, 3,470 T/y or 23.7%. Loadings of sands emanating from uplands and streambanks have increased by 1,680 T/y (181%) and 1,240 T/y (29.1%), respectively.



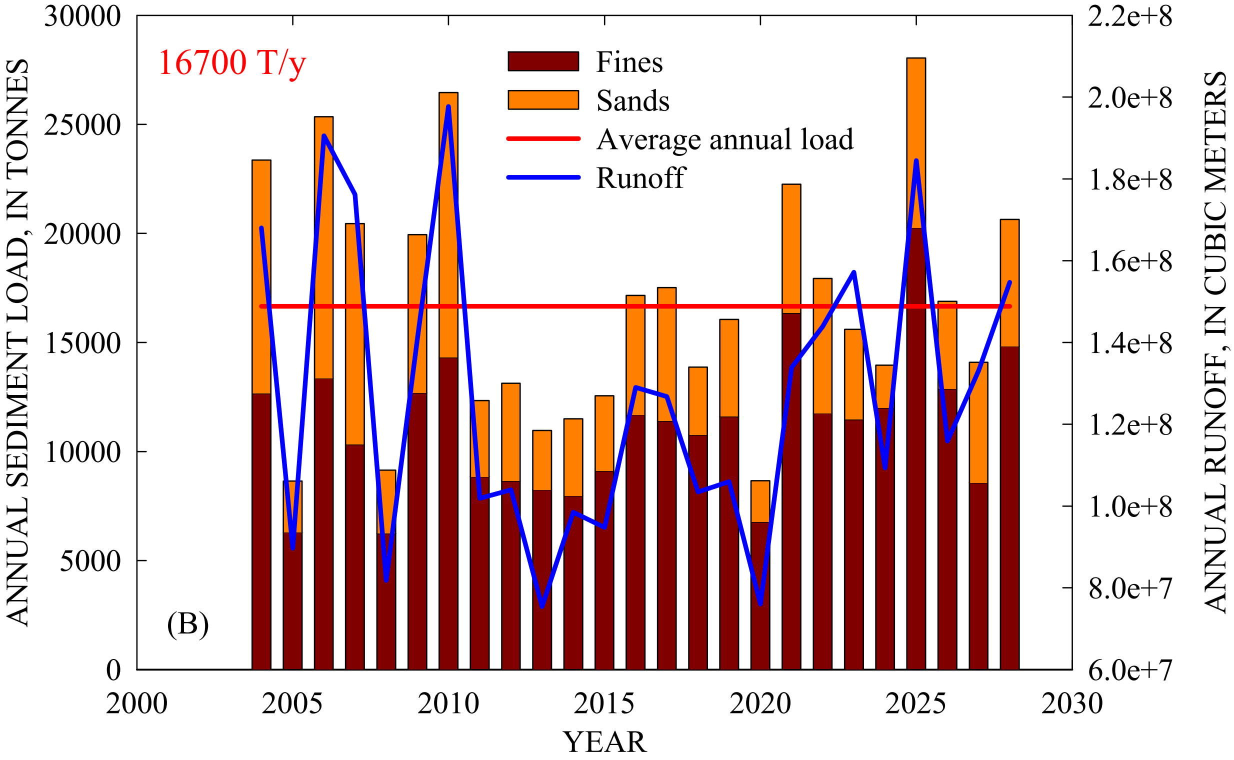


Figure 4-37. Simulated annual runoff and sediment loads at station 02423630 (A) and at the CONCEPTS downstream boundary (B) for the 2001 Landuse Scenario.

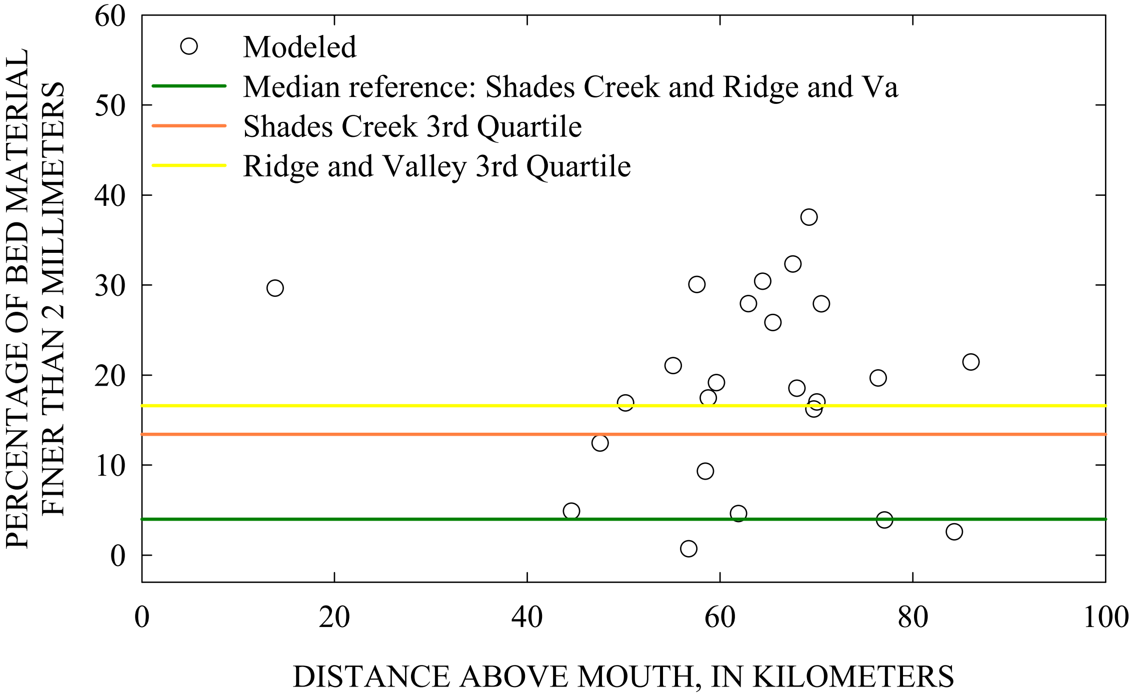


Figure 4-38. Percentage of fine-grained sediment within coarse-grained streambeds on December 2028 for the 2001 landuse scenario. Colored lines refer to various reference levels determined for Shades Creek and the Ridge and Valley (see section 3.5).

Embeddedness

Section 3.5 introduced embeddedness as a parameter used to characterize bed-material composition. Embeddedness is defined as the percentage of bed material finer than 2 mm (sand, silt and clay) in gravel or gravel/cobble-dominated streambeds. Figure 3-1 shows the current embeddedness along the study reach. There are 53 sections with a coarse-grained streambed, 42 of which are located within stable reaches. The embeddedness of 10 cross sections is smaller than the reference median of 4%, and the streambed of 26 cross sections has an embeddedness value smaller than the reference third quartile of 13.4% (see Table 3.5 and Figure 3-25 of section 3.5).

Figure 4-38 plots the simulated embeddedness along the study reach on December 2028 for the 2001 landuse scenario. The number of coarse-grained cross sections has reduced to 24 due to aggradation. Only three sites have an embeddedness value smaller than 4%: cross section DA at rkm 84.3, cross section CP at rkm 77.1, and cross section BG at rkm 56.8. There are seven sites with an embeddedness value smaller than 13.4%. Figures 4-29A and 4-34A showed significant deposition between rkm 45 and 55 for the validation and 2001 landuse scenarios. The number of sites with coarse-grained streambeds along this segment has reduced from ten to only one, indicating significant deposition of fines.

4.4.5 2001 Landuse with Selected Reaches Protected (2001LURP) Scenario

The effect of streambank protection on sediment loads was studied for the 2001 landuse scenario. Streambanks of cross sections experiencing widening greater than 1.5 m for the 2001 landuse scenario were stabilized by armoring the bank face. The 17 stabilized cross sections were: F (rkm 12.7), AG7 (rkm 39.0), AH1 (rkm 40.2), AJ (rkm 41.2), AK (rkm 41.6), AM (rkm 43.3), AS (rkm 47.0), AW1 (rkm 49.3), AX (rkm 49.9), AY1 (rkm 50.6), AZ (rkm 51.0), BB (rkm 53.1), BS (rkm 63.4), CO (rkm 76.4), CV (rkm 80.5), DA (rkm 84.3), and DA1 (rkm 84.9). The total length of channel protected was 8.77 km, which is 11.5% of the length of the model reach. Figures 4-39 through 4-42 show the results of the simulation for the 2001 Landused with Selected Reaches Protected (2001LURP) scenario.

Runoff

As expected, annual runoff and peak discharge are nearly identical to those of the 2001 landuse scenario and are, therefore, not shown.

Channel Geometry

Figure 4-39 shows the changes in bed elevation and channel top width over the 25-year simulation period. Figures 4-39A and 4-34A show that simulated changes in bed elevation are generally similar with or without bank protection. The average change in bed elevation along the modeling reach has reduced to 0.03 m from 0.04 m for the 2001 landuse scenario without bank protection. This is mainly due to a significant decrease in deposition between cross sections AN (rkm 44.2) and AY (rkm 50.2) (Figure 4-39). This part of the channel exhibited significant channel adjustment in the 2001 landuse scenario without bank protection (Figure 4-34B) and was greatly reduced with bank protection (Figure 4-39B). It appears that for the 2001 landuse scenario the sediments eroded from the streambanks of cross sections AS, AW1, AX, AY1, AZ, and BB are mostly deposited in the reach between AN (rkm 44.2) and AY (rkm 50.2).

Figure 4-39B shows that simulated changes in channel top width do not exceed 1.5 m due to bank protection at the 17 cross sections listed at the top of the page. A comparison of Figures 4-41 and 4-36 shows that the average widening rate along the study reach has been significantly reduced. The average increase in channel top width reduced from 0.4 m to 0.3 m along the downstream section of the modeling reach, and from 0.7 to 0.4 m along the upstream section of the modeling reach. The maximum increase in top width along the downstream section is 1.4 m at rkm 19.0 (cross section Q). The maximum increase in top width along the upstream section is 1.4 m at rkm 83.8 (cross section CZ1). The middle segment shows a gradual increase in channel top width in upstream direction.

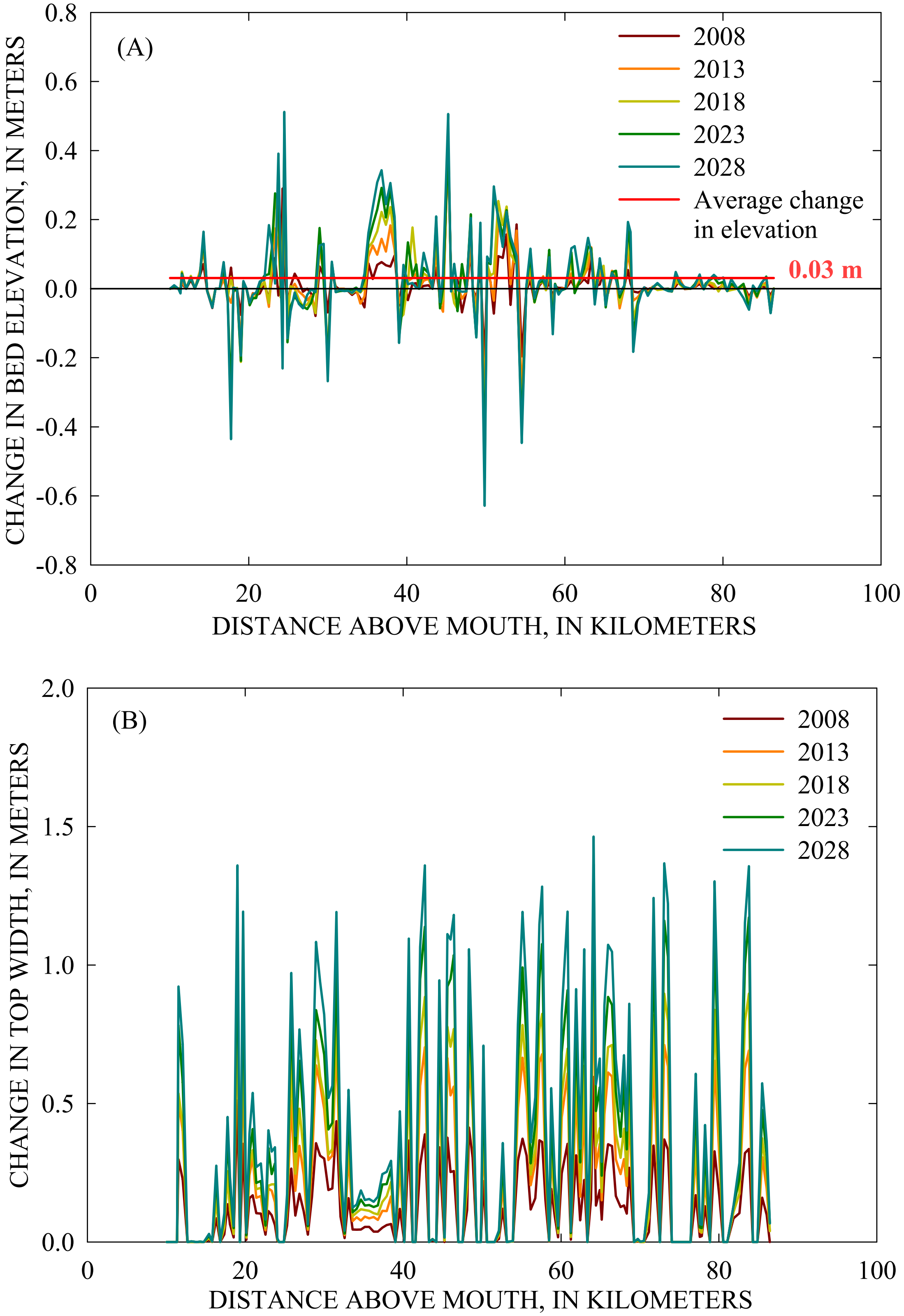


Figure 4-39. Simulated changes in bed elevation (A) and channel top-width (B) along Shades Creek over a 25-year period for the 2001LURP scenario.

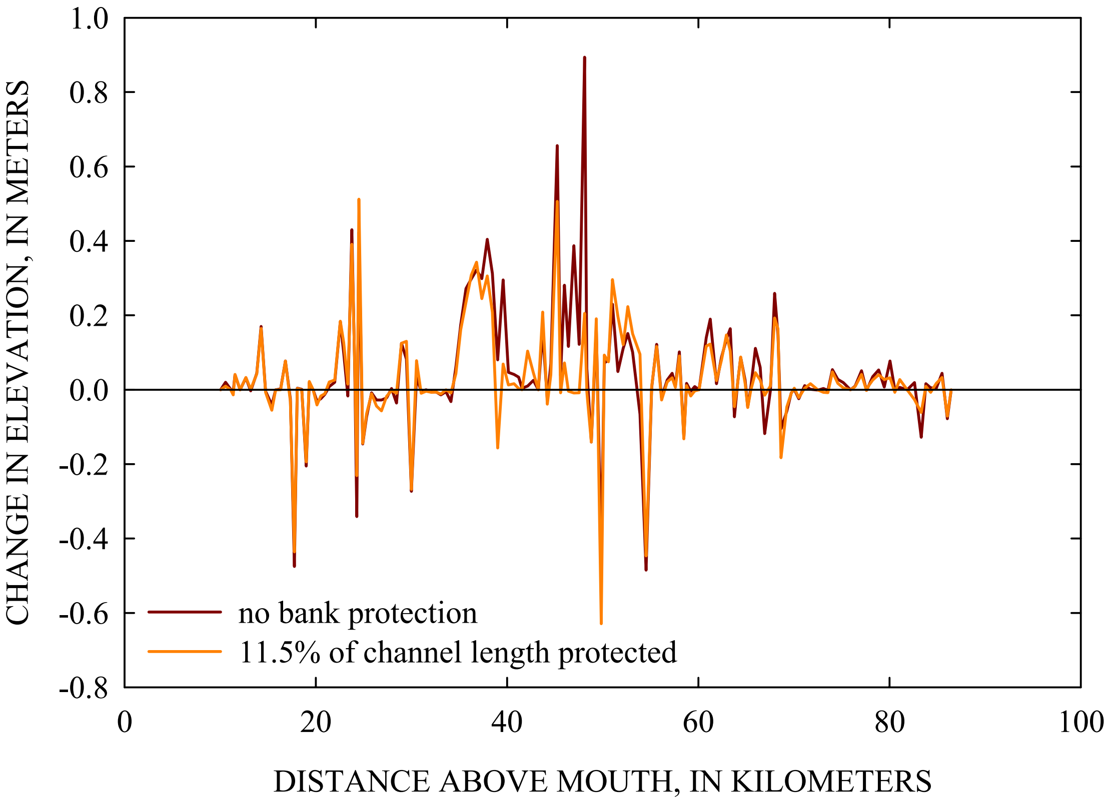


Figure 4-40. Comparison of simulated changes in bed elevation on December 2028 for the 2001 Landuse Scenario with and without bank protection.

Sediment Load

Figure 4-42 shows the simulated annual runoff and sediment loads at gaging station 02423630 of Shades Creek and at the CONCEPTS downstream boundary (cross-section A). The average annual load of suspended sediment at the gaging station has decreased 4% to 6,680 T/y. This reduction is mainly in the fine fraction (clay and silt). The average annual load of fines has decreased from 4,530 T/y to 4,280 T/y. The average annual load of sands with bank protection, 2,400 T/y, is nearly the same as that without bank protection, 2,420 T/y.

The average-annual load of suspended sediment at the downstream boundary of CONCEPTS decreased marginally to 16,500 T/y with bank protection from 16,700 T/y without bank protection. Again, this reduction is due to a decrease in the fine fraction of the suspended load; from 11,200 T/y to 11,000 T/y. The average annual load of sands (5,500 T/y) did not change.

It can be concluded that streambank protection has only a minor effect on simulated sediment loads at the gaging station and the downstream boundary of CONCEPTS because most of the eroded bank material is deposited upstream of the gaging station between rkm 44 and rkm 50.

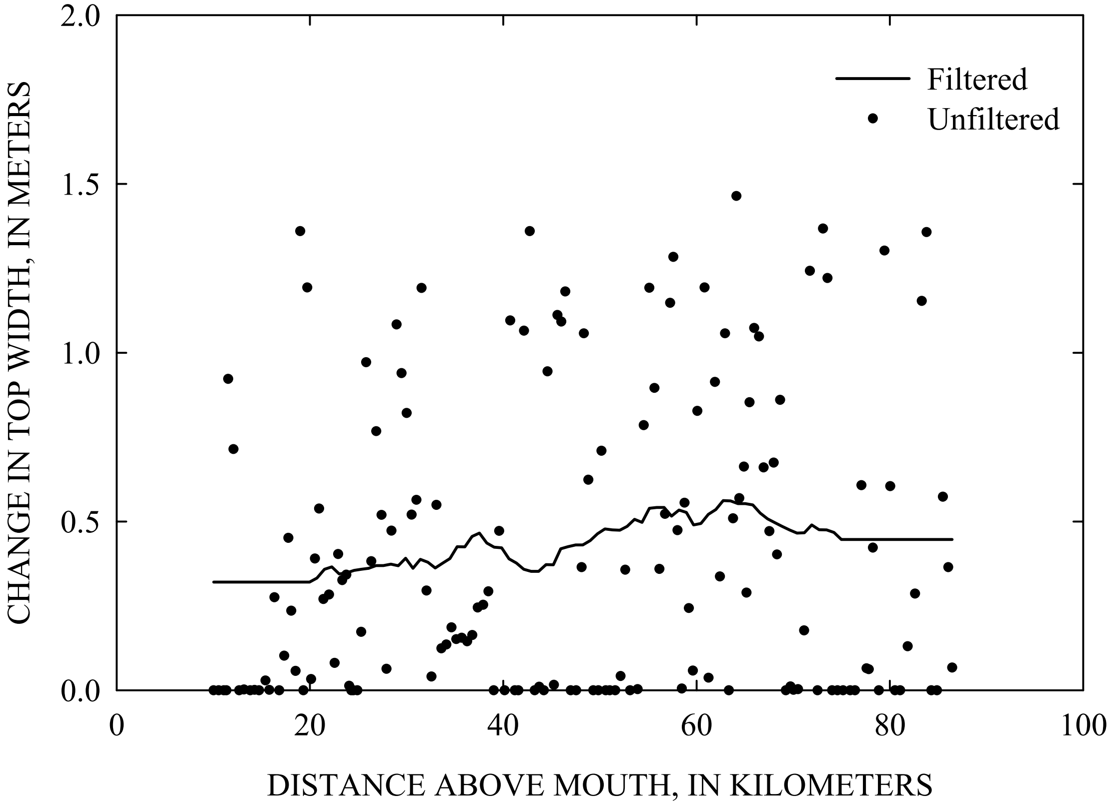
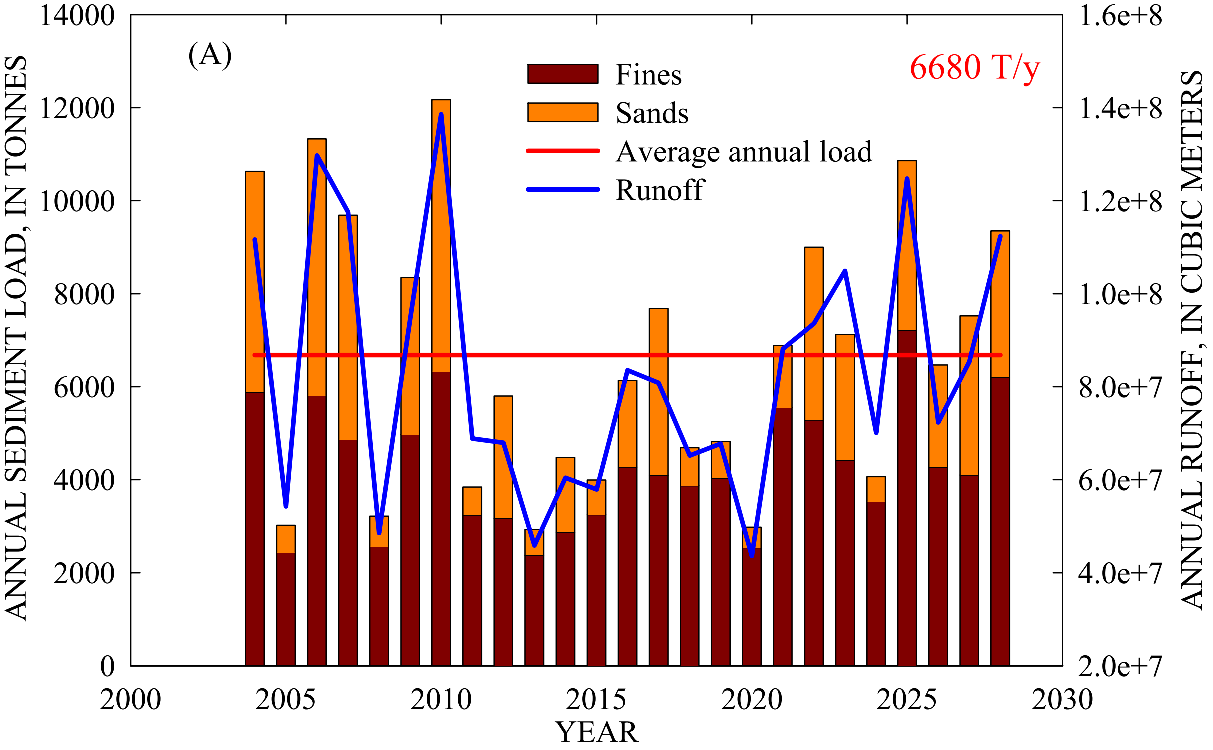


Figure 4-41. Simulated change in channel top width along Shades Creek on December 2028 for the 2001LURP scenario: •, unsmoothed data; and —, smoothed data using a running average of 45 data points.

Table 4-8. Relative source contributions of uplands and streambanks to suspended sediment integrated over the study reach for the 2001LURP scenario.

Sediment size	Uplands (%)	Streambanks (%)	Total (T/y)
Fines	88.7	11.3	8,500
Sands	33.8	66.2	7,390
Total suspended	63.2	36.8	15,900

Table 4-8 lists the sources of sediments delivered to the study reach. The amount of fines eroded from the streambanks has been greatly reduced by 10,200 T/y or 40%, because of bank protection; whereas, the amount of sands has been only reduced by 610 T/y or 7.6%. The bank material of the protected cross sections was mainly composed of fines. The uplands have become the main source of fines for the 2001LURP scenario as opposed to the 2001 landuse scenario.



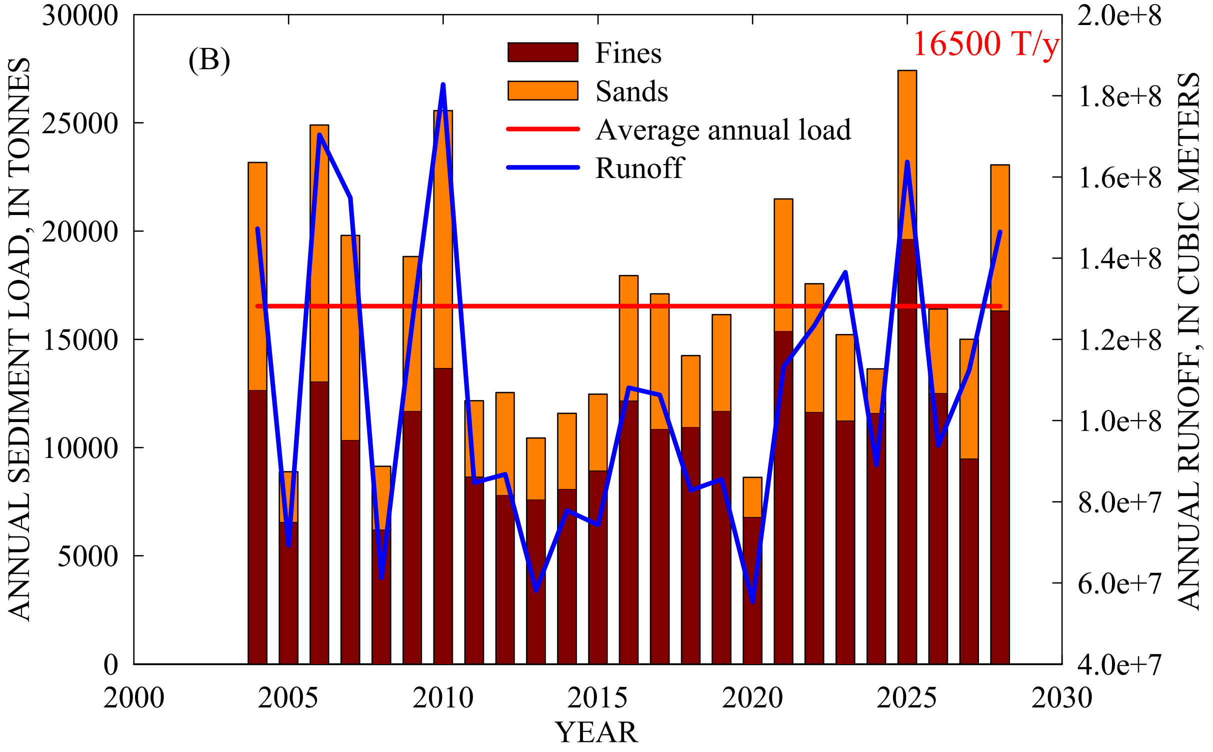


Figure 4-42. Simulated annual runoff and sediment loads at station 02423630 (A) and at the CONCEPTS downstream boundary (B) for the 2001LURP scenario.

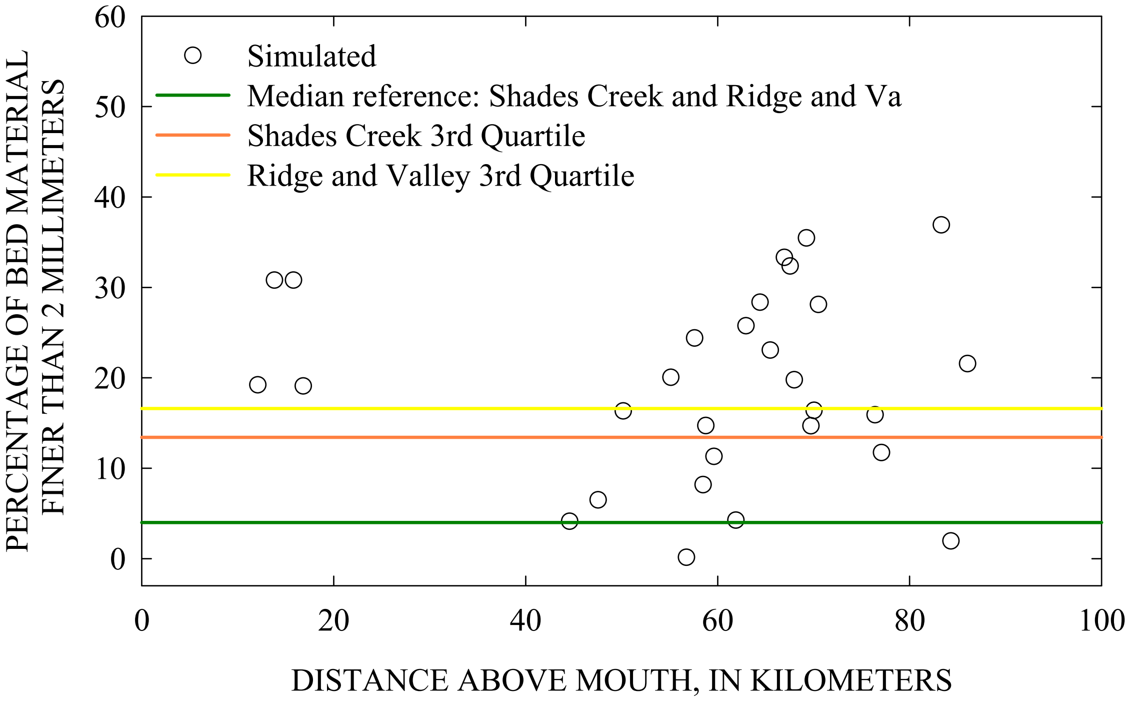


Figure 4-43. Percentage of fine-grained sediment within coarse-grained streambeds on December 2028 for the 2001LURP scenario. Colored lines refer to various reference levels determined for Shades Creek and the Ridge and Valley (see section 3.5).

Embeddedness

Figure 4-43 plots the simulated embeddedness along the study reach on December 2028 for the 2001LURP scenario. Compared to current conditions the number of coarse-grained cross sections has reduced to 29, however this is five more than for the 2001 landuse scenario. Only three sites have an embeddedness value smaller than the reference median of 4%: cross section DA at rkm 84.3, cross section BQ at rkm 61.9, and cross section BG at rkm 56.8. There are eight sites with an embeddedness value smaller than the reference third quartile of 13.4%. A comparison of Figures 4-38 and 4-43 shows that the distribution of coarse-grained cross sections is very similar for the 2001 landuse and 2001LURP scenarios. The average embeddedness is slightly smaller for the 2001LURP scenario than that for the 2001 landuse scenario.

4.4.6 2001 Landuse with All Forest Changed to Urban Scenario

A 25-year simulation was performed to determine trends in sediment loads due to possible future changes in landuse. The 2001 landuse coverage was altered by changing all the designated forest landuse to urban landuse. This scenario will be labeled 2001LUFU hereafter. Figure 4-28 shows the upland sediment contributions into the modeling reach as simulated by AnnAGNPS. The geometry and physical properties of the study reach at the start of the simulation are identical to those for the 2001 landuse scenario. Figures 4-44 through 4-48 show the simulation results.

Runoff

Average annual runoff at the mouth of Shades Creek with the Cahaba River increased 53.6% from 457 mm/y (2001 landuse scenario) to 702 mm/y, see section 4.3. Table 4-9 compares the simulated annual peak discharges at station 02423630 for the 2001 landuse and 2001LUFU scenarios. Annual peak discharges have increased by 22.6% on average.

Channel Geometry

Figure 4-44 shows the simulated changes in bed elevation and channel top width over the 25-year simulation period. The average change in bed elevation at the end of the simulation has increased to 0.07 m from 0.04 for the 2001 landuse scenario (Figure 4-34A). The increase is mainly due to increased deposition between cross sections X (rkm 22.9) and AV (rkm 48.3), see Figure 4-45. Differences in simulated bed elevation for 2001 Landuse and 2001LUFU scenarios upstream of rkm 48.3 and downstream of rkm 22.9 are negligible.

Table 4-9. Comparison of simulated annual peak discharge at station 02423630 for 2001 landuse and 2001LUFU scenarios.

	Annual peak discharge (m^3/s)			Annual peak discharge (m^3/s)	
Calendar year	2001 landuse	2001LUFU	Calendar year	2001 landuse	2001LUFU
2004			2017	148	173
2005	76.3	85.1	2018	94.1	115
2006	234	275	2019	84.9	112
2007	217	244	2020	90.7	104
2008	95.5	129	2021	104	128
2009	151	185	2022	288	418
2010	235	270	2023	292	318
2011	75.8	112	2024	71.7	93.0
2012	262	339	2025	192	215
2013	92	116	2026	163	208
2014	143	161	2027	239	288
2015	83.5	124	2028	224	262
2016	117	134			

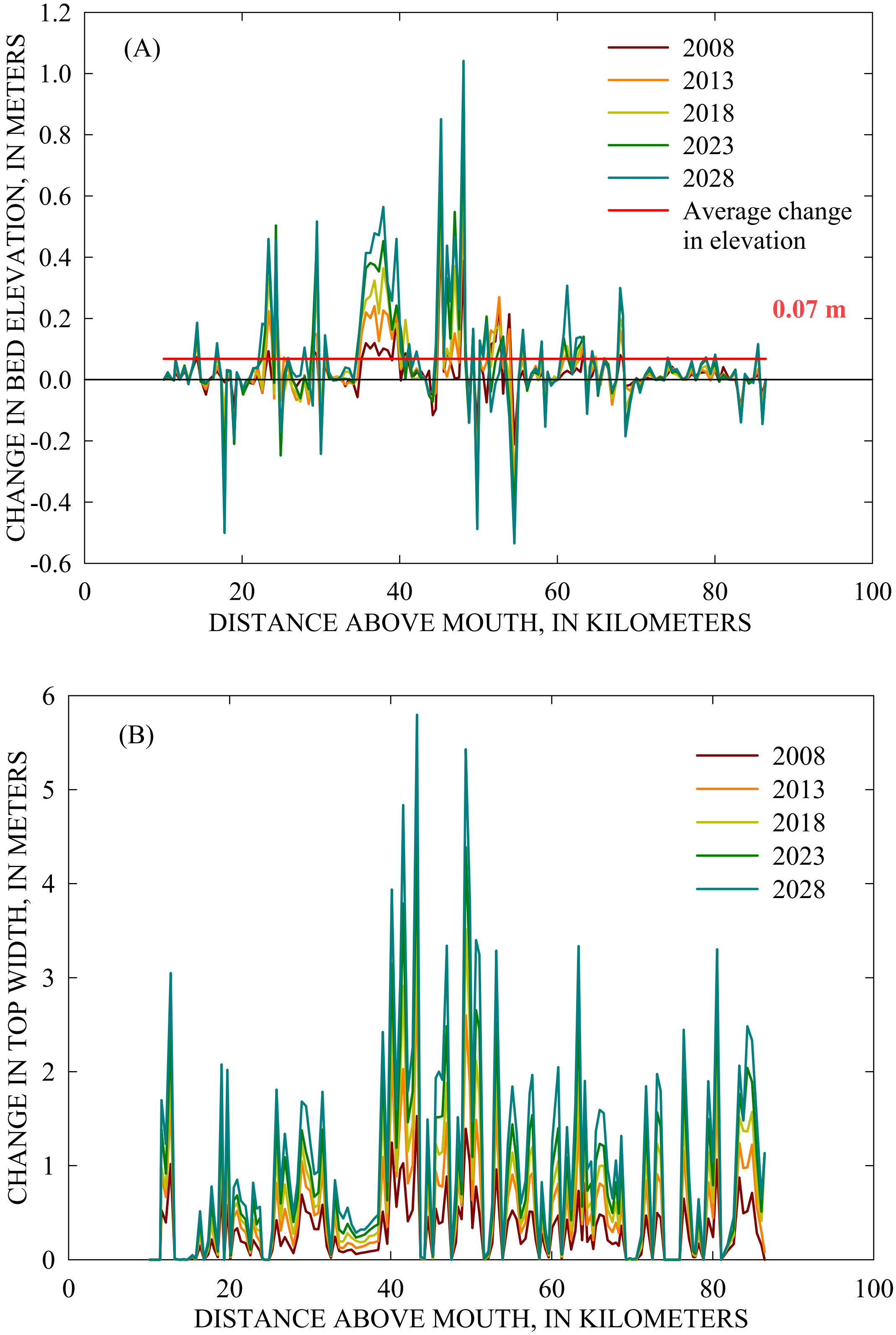


Figure 4-44. Simulated changes in bed elevation (A) and channel top-width (B) along Shades Creek over a 25-year period for the 2001LUFU scenario.

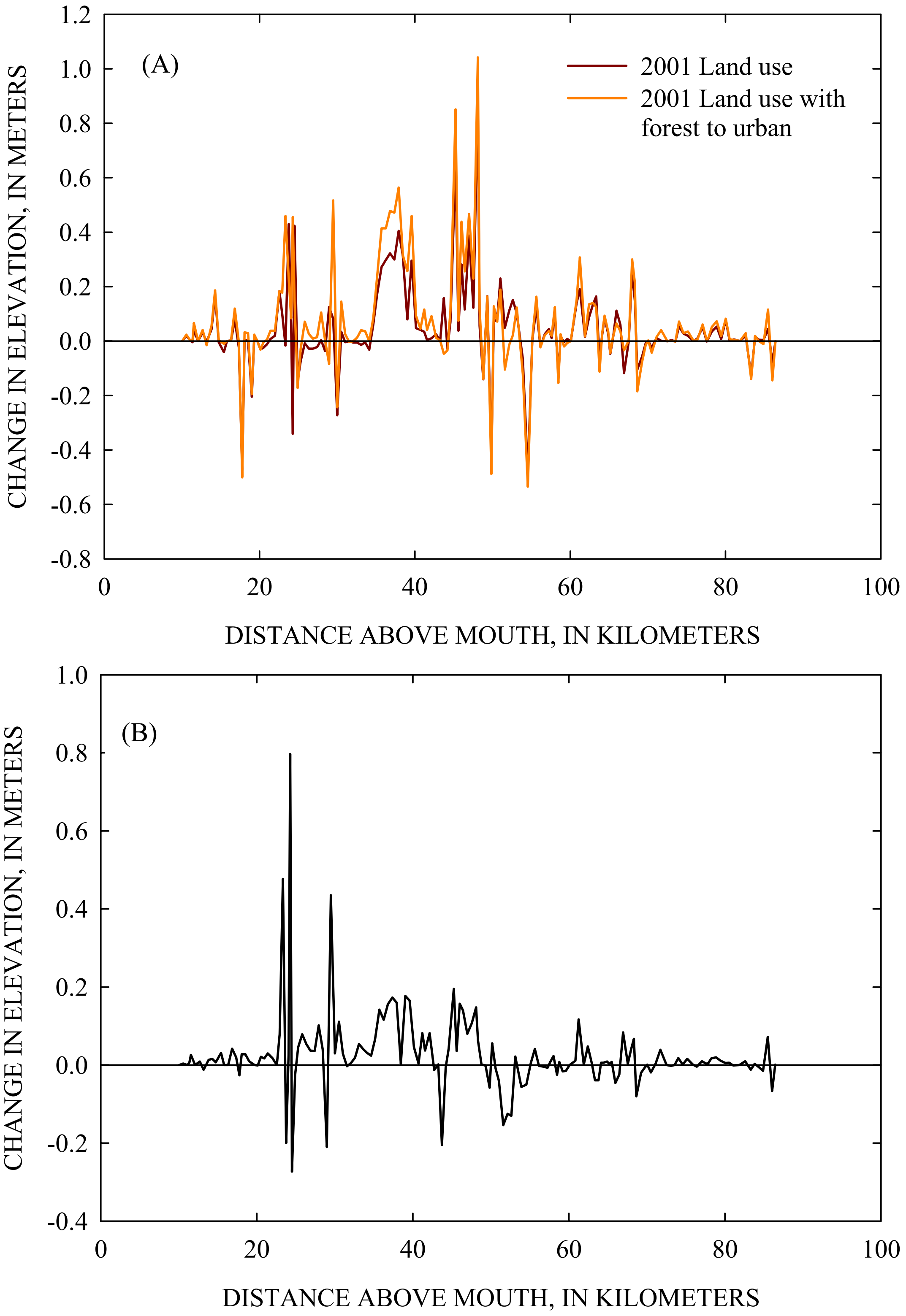


Figure 4-45. (A) Comparison of simulated changes in bed elevation on December 2028 for the 2001 Landuse and 2001LUFU scenarios, and (B) difference in simulated bed elevation on December 2028 between 2001 Landuse and 2001LUFU scenarios.

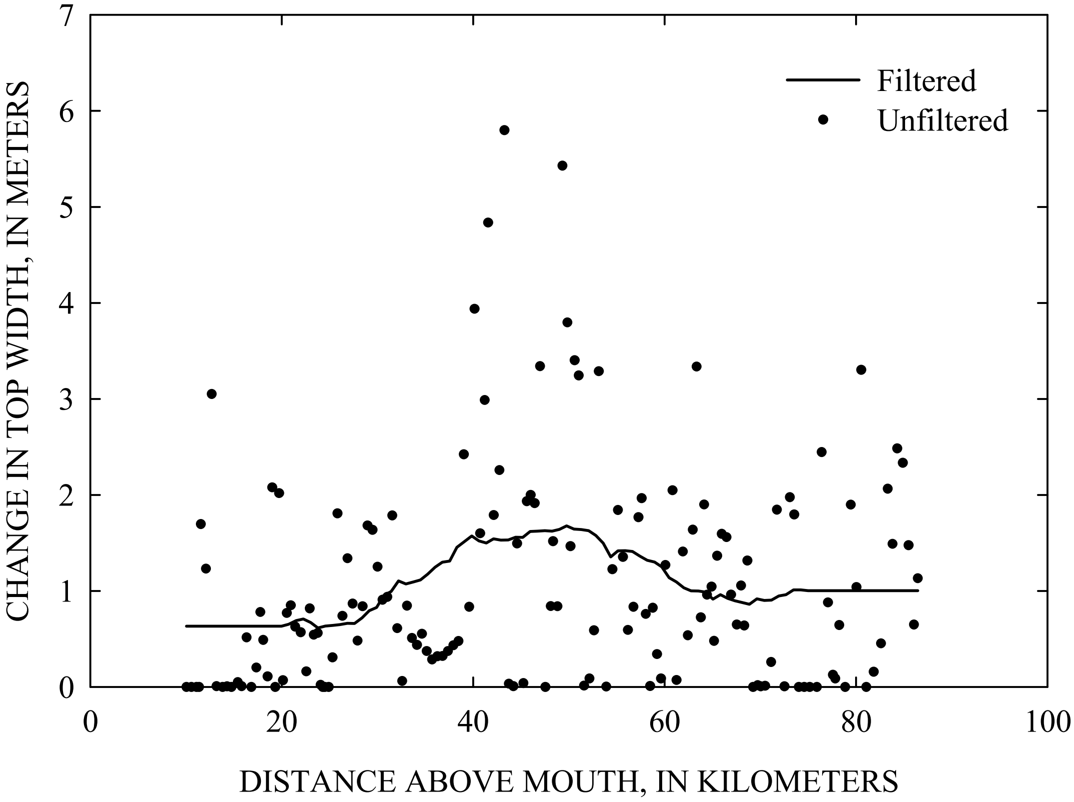


Figure 4-46. Simulated change in channel top width along Shades Creek on December 2028 for the 2001LUFU scenario: •, unsmoothed data; and —, smoothed data using a running average of 45 data points.

The trend of simulated changes in top width along the modeling reach can again be divided into the same three segments as that of the validation and 2001 landuse scenarios (Figure 4-46). The average increase in channel top width is approximately 0.6 m along the first segment, which is 0.2 m greater (50% increase) than in the 2001 landuse scenario. The maximum increase in top width along this segment is 3.0 m at rkm 12.7 (cross section F). The average increase in top width is approximately 1.0 m along the third segment, which is 0.3 m greater (43% increase) than in the 2001 landuse scenario. The maximum increase in top width along this segment is 3.3 m at rkm 80.5 (cross section CV). Along the second segment, the average change in channel top width gradually increases from 0.6 m at its downstream end and 1.0 m at its upstream end to a maximum of 1.7 m around rkm 49.5 (42% increase as compared to 2001 landuse scenario). Significant widening is modeled at rkm 40.2 (3.9 m, cross section AH1), rkm 41.2 (3.0 m, cross section AJ), rkm 41.6 (4.8 m, cross section AK), rkm 43.3 (5.8 m, cross section AM), rkm 49.3 (5.4 m, cross section AW1), rkm 49.9 (3.8 m, cross section AX), rkm 50.6 (3.4 m, cross section AY1), rkm 51.0 (3.2 m, cross section AZ), rkm 53.1 (3.3 m, cross section BB), and rkm 63.3 (3.3 m, cross section BS). The number of cross sections experiencing width adjustment greater than 2.0 m has increased from 11 for the 2001 landuse scenario to 23 for the 2001LUFU scenario.

Figure 4-47 compares the simulated change in channel top width on December 2028 for the 2001 landuse and 2001LUFU scenarios. The change in channel top width has increased along the entire study reach. The average increase along the study reach is 0.3 m. The increase in channel top width is caused by increased shear stresses on the bank toe, leading to greater bank toe erosion.

Sediment Load

Figure 4-48 shows simulated annual runoff and sediment loads at gaging station 02423630 of Shades Creek and at the CONCEPTS downstream boundary (cross-section A). Changing all forest landuse to urban landuse has increased the average-annual load of suspended sediment at the gaging station by 68% to 11,700 T/y from 6,950 T/y. The fine fraction (clay and silt) of the average annual suspended load increased 70% to 7,680 T/y. The sand fraction increased 67% to 4,030 T/y. The average-annual load of suspended sediment at the downstream boundary of CONCEPTS increased to 25,600 T/y from 16700 T/y for the 2001 landuse scenario, a 53% increase. The fine fraction has increased 53% to 17,100 T/y, and the sand fraction has increased 55% to 8,540 T/y.

Table 4-10 lists the sources of sediments delivered to the study reach and their relative contributions. The sediment loadings contributing to suspended load have increased 46.1% (12,300 T/y) compared to those for the 2001 landuse scenario. The loadings of fines and sands have increased similarly by 45.5% (8,500 T/y) and 47.5% (3,800 T/y), respectively. The increased loadings are originating mainly from the streambanks: 5,900 T/y (52.9%) increase in fines and 3,040 T/y (55.3%) increase in sands. The loadings from the uplands increased 2,670 T/y (34.0%) for fines and 794 T/y (30.5%) for sands, see Figure 4-28 for the spatial distribution.

Embeddedness

Figure 4-49 plots the simulated embeddedness along the study reach on December 2028 for the 2001LUFU scenario. Compared to current conditions the number of coarse-grained cross sections has reduced to 26, two more than for the 2001 landuse scenario. Only one site, cross section BG at rkm 56.8, has an embeddedness value smaller than the reference median of 4%. There are nine sites with an embeddedness value smaller than the reference third quartile of 13.4%. A comparison of Figures 4-38, 4-43, and 4-49 shows that the distribution of coarse-grained cross section is very similar for the 2001 landuse, 2001LURP and 2001LUFU scenarios.

Table 4-10. Relative source contributions of uplands and streambanks to suspended sediment integrated over the study reach for the 2001LUFU scenario.

Sediment size	Uplands (%)	Streambanks (%)	Total (T/y)
Fines	37.2	62.8	27,200
Sands	27.6	72.4	11,800
Total suspended	34.3	65.7	39,000

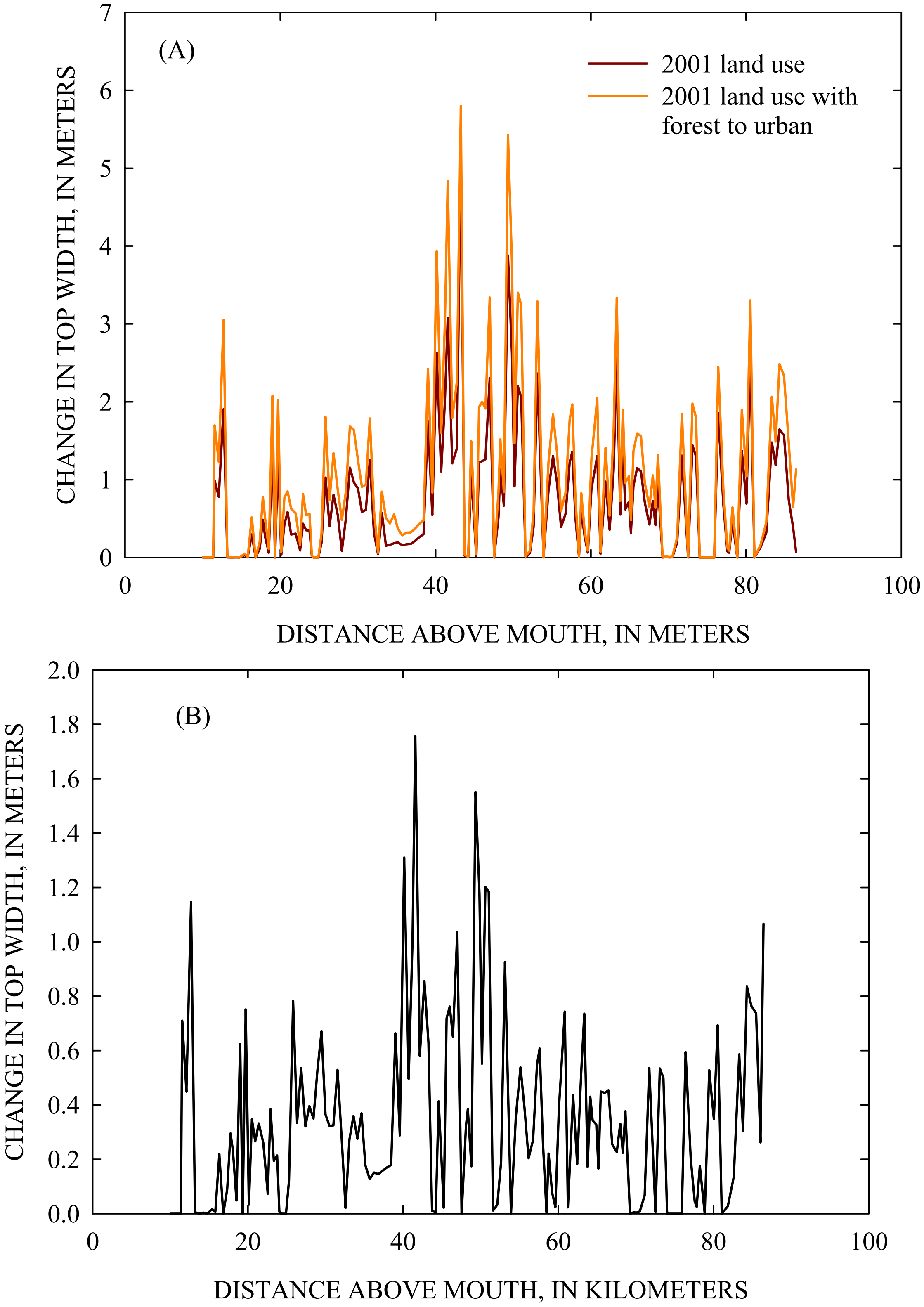


Figure 4-47. (A) Comparison of simulated changes in channel top width on December 2028 for the 2001 Landuse and 2001LUFU scenarios, and (B) difference in simulated channel top width on December 2028 between 2001 Landuse and 2001LUFU scenarios.

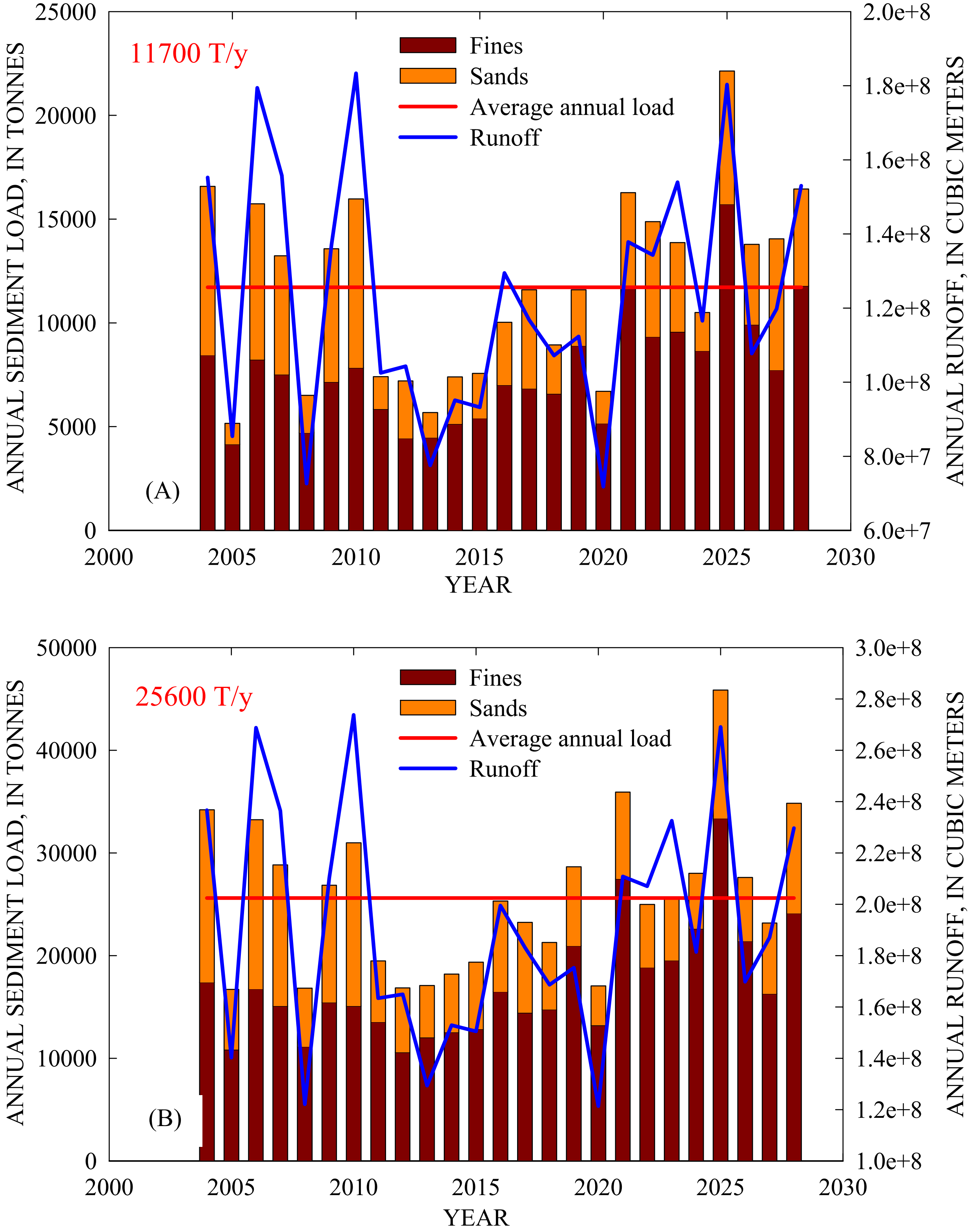


Figure 4-48. Simulated annual runoff and sediment loads at station 02423630 (A) and at the CONCEPTS downstream boundary (B) for the 2001LUFU scenario.

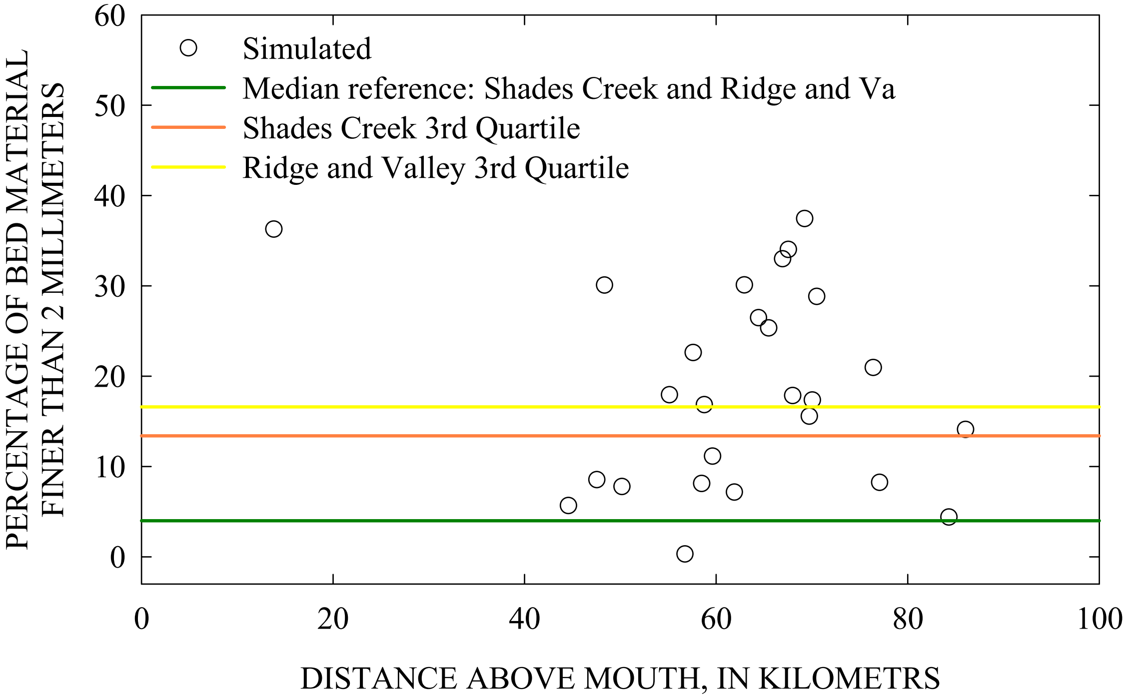


Figure 4-49. Percentage of fine-grained sediment within coarse-grained streambeds on December 2028 for the 2001LUFU scenario. Colored lines refer to various reference levels determined for Shades Creek and the Ridge and Valley (see section 3.5).

4.5 Little Shades Creek

To further illustrate the capabilities of AnnAGNPS to identify sources of runoff and sediment, the Little Shades Creek watershed simulation results were extracted from the complete Shades Creek simulation (Figure 4-50). The AnnAGNPS cells were comprised of the same cells as the entire Shades Creek simulation (Figure 4-51). The average annual runoff at the outlet of Little Shades Creek was 326 mm/y for the Validation scenario, was 337 mm/y for the 2001 landuse scenario (Figure 4-52), and was 662 mm/y for the 2001LUFU scenario (Figure 4-53).

Loadings to the CONCEPTS main channel, in this case Shades Creek, from the Little Shades Creek watershed for the Validation scenario was a result of sediment being eroded within the AnnAGNPS cells, transported to the edge of each AnnAGNPS cell (Figure 4-54) and then transported within the channel to the outlet of Little Shades Creek (Figure 4-55). This process produced 23 T/y/km^2 of sediment entering the CONCEPTS main channel from Little Shades Creek for the Validation scenario. For the 2001 landuse and the 2001LUFU scenarios, the average annual sediment loadings to Shades Creek were 36 T/y/km^2 and 50 T/y/km^2, respectively. This indicates that increased urbanization within Little Shades Creek Watershed between 1991 and 2001 resulted in higher sediment loads entering Shades Creek.

The amount of sediment from each AnnAGNPS cell that is eroded is transported to the edge of the AnnAGNPS cells and then enters the channel and flows through the Little Shades Creek tributary system to the outlet into Shades Creek. This information can be used to provide a sediment source accounting of where the sediments are coming from (Figure 4-55). Areas within the watershed can be targeted that are major sediment producing sites that contribute to the impact on downstream conditions especially along the ridges.

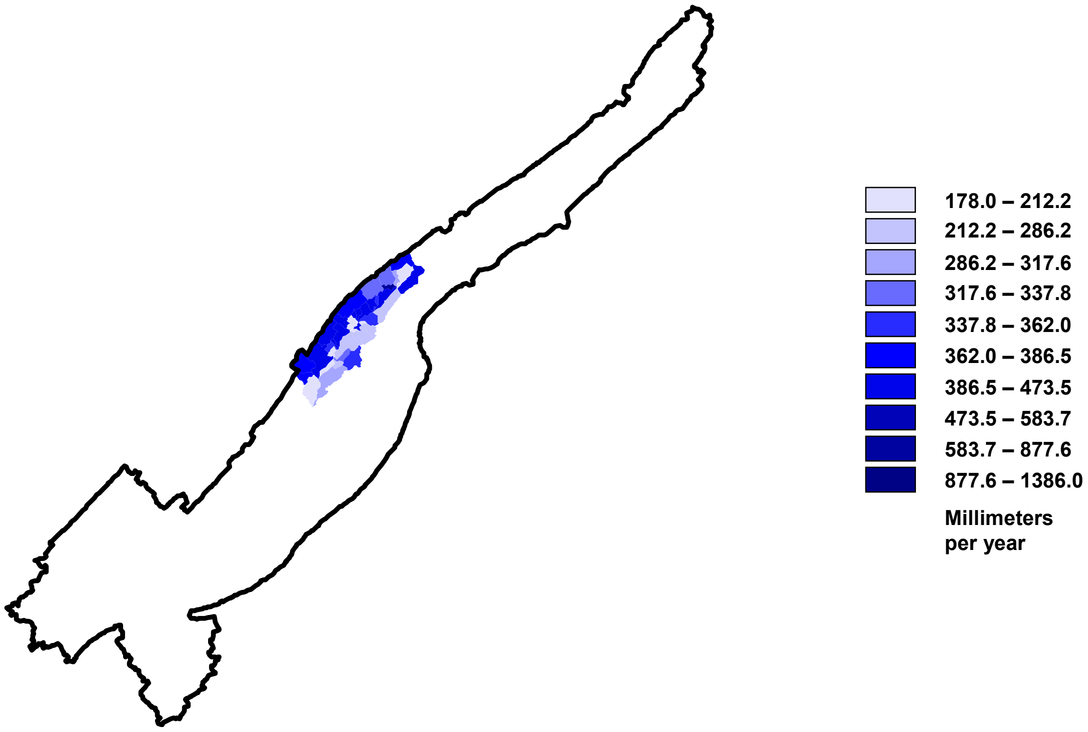


Figure 4-50. Average annual runoff simulated from AnnAGNPS for each cell on Little Shades Creek watershed for the validation period from 1978 to 2001.

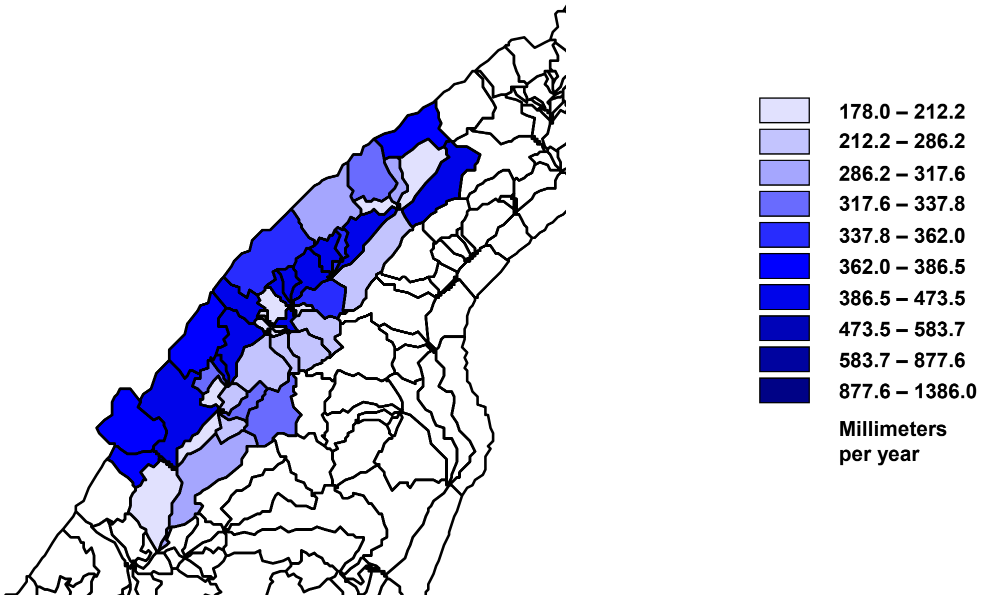


Figure 4-51. Average annual runoff simulated from AnnAGNPS for each cell on Little Shades Creek watershed for the validation period from 1978 to 2001 at a smaller scale.

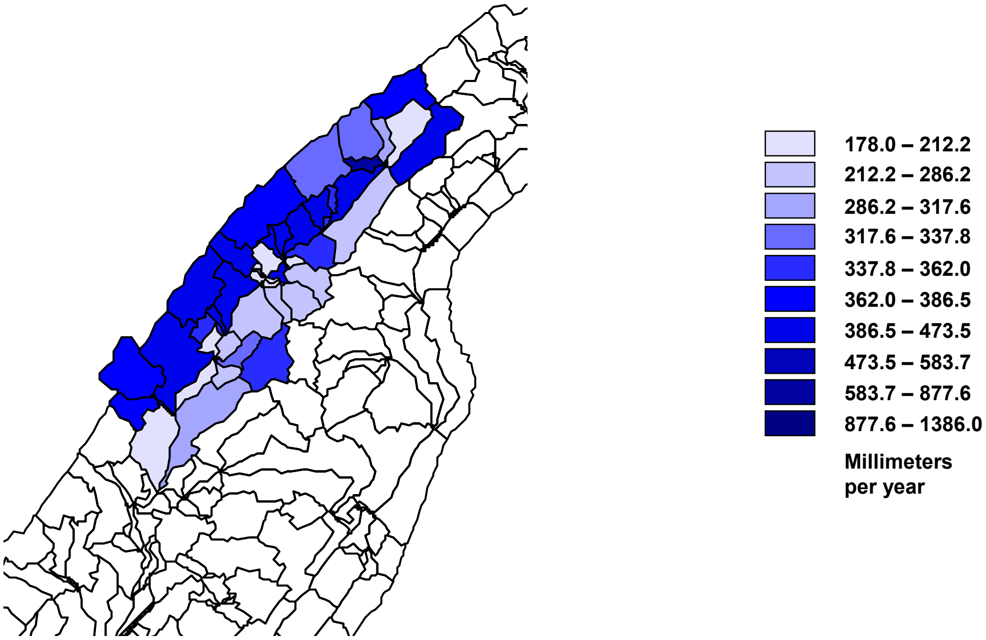


Figure 4-52. Average annual runoff simulated from AnnAGNPS for each cell on Little Shades Creek watershed for the future simulation using the 2001 landuse.

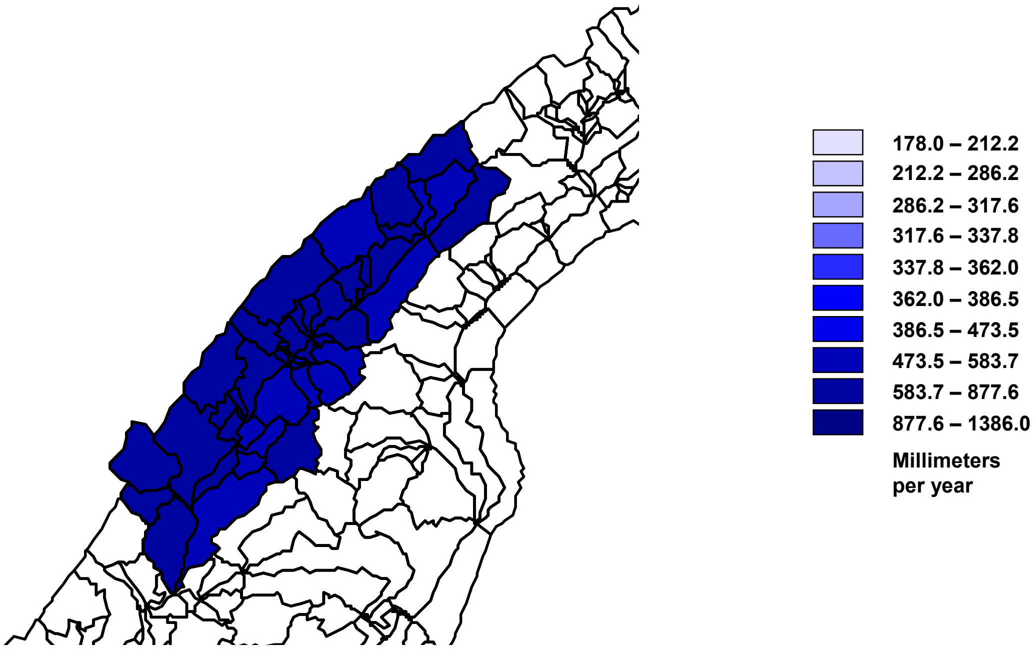


Figure 4-53. Average annual runoff simulated from AnnAGNPS for each cell on Little Shades Creek watershed for the future simulation using forest to urban conditions.

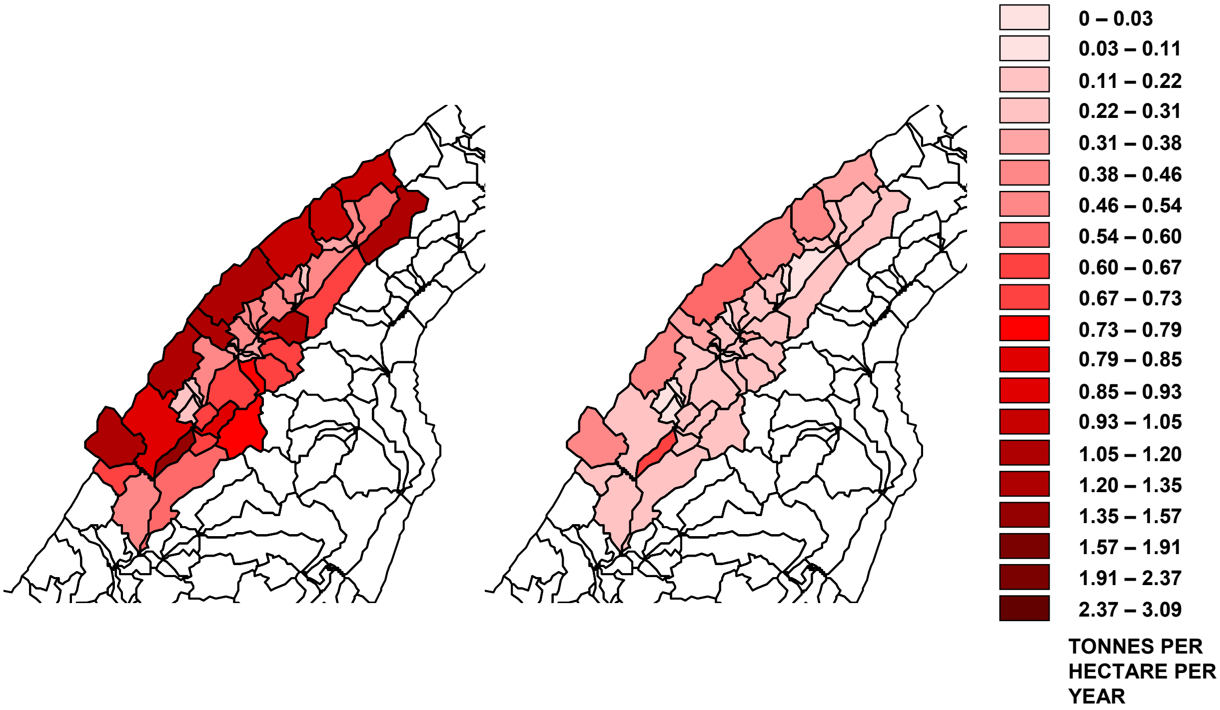


Figure 4-54. Average annual erosion (left) and sediment yield (right) simulated from AnnAGNPS for each cell on Little Shades Creek watershed for the validation period from 1978 to 2001.

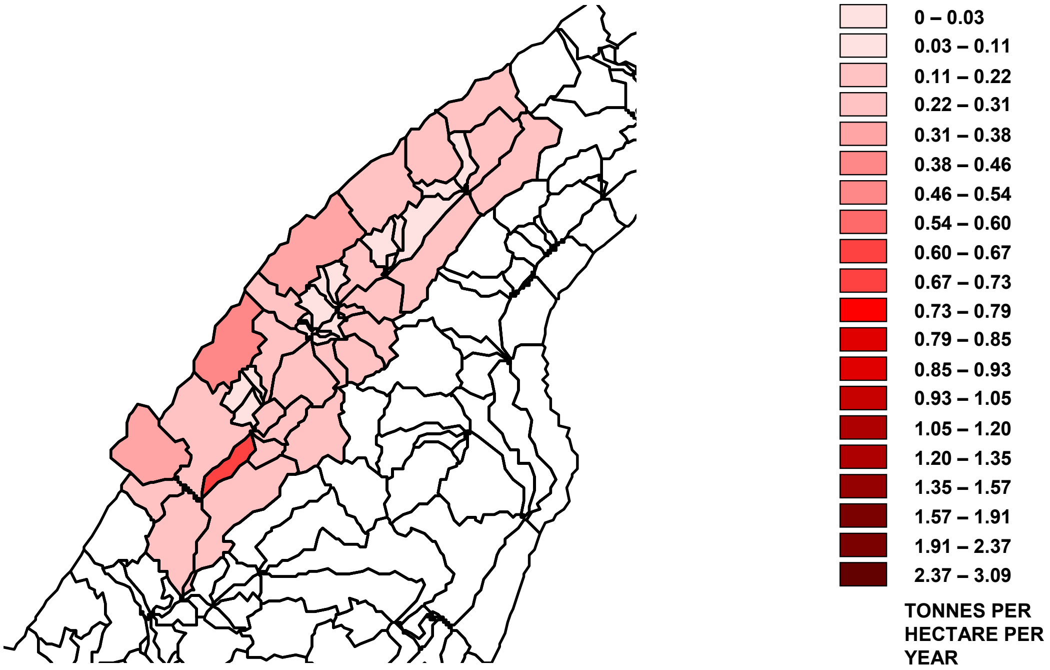


Figure 4-55. Average annual sediment load from AnnAGNPS for each cell on Little Shades Creek watershed for the validation period from 1978 to 2001.

4.6 Total Load at the Shades Creek Watershed Outlet

The suspended-sediment load at the confluence of Shades Creek with the Cahaba Creek was determined using the loading at the CONCEPTS downstream boundary plus the loadings produced by AnnAGNPS from the surrounding uplands downstream of this point (Table 4-11). This assumed that there was no channel erosion in the lower part of the watershed and can be justified by the relative stability of the downstream-most sections. For the Validation scenario, the load at the CONCEPTS downstream boundary was 18,900 T/y with an additional 2,100 T/y produced by AnnAGNPS from the uplands producing an annual suspended-sediment load of 21,000 T/y (Figure 4-56). Because channel contributions from the CONCEPTS downstream boundary to the confluence with the Cahaba River are neglected annual suspended-sediment yield between these points decreases from 73 T/y/km^2 to 58 T/y/km^2 (Figure 4-56).

For the 2001 landuse scenario, annual suspended-sediment load at the CONCEPTS downstream boundary was 16,700 T/y (64 T/y/km^2) with an additional 3,000 T/y from the uplands beyond this point to produce an annual suspended-sediment load at the outlet of Shades Creek of 19,700 T/y (55 T/y/km^2) (Figure 4-57; Table 4-11)). While the upland sediment contributions increased from the Validation scenario, improved channel conditions resulted in less sediment at the outlet. Using the 2001 landuse, annual suspended-sediment loads decreased only marginally (by 200 T/y; to 19,500 T/y) at the confluence with the Cahaba River for the simulations incorporating in-stream BMPs along reaches experiencing significant bank failures (Table 4-11).

The annual suspended-sediment load at the CONCEPTS downstream boundary and at the confluence with the Cahaba River for the 2001LUFU scenario was the greatest of all the modeled scenarios. At the downstream boundary of CONCEPTS, 25,600 T/y (99 T/y/km^2) was transported with an additional 3600 T/y from upland sources beyond this point, producing an annual suspended-sediment load at the Shades Creek outlet of 29,200 T/y (81 T/y/km^2) (Figure 4-58; Table 4-11). This represents a 48% increase over the 2001 landuse scenario reflecting the greater runoff rates associated with urban conditions.

Table 4-11. Summary of simulated annual, suspended-sediment loads for the four different modeling scenarios compared to measured values on Shades Creek (52.6 T/y/km^2) and the annual reference yield for the Ridge and Valley (24.7 T/y/km^2).

Scenario	Suspended-sediment load (T/y)	Suspended-sediment yield (T/y/km^2)	Difference from measured yield (%)	Difference from annual-reference yield (%)
Validation	21,000	58	10	135
2001 Landuse	19,700	55	4.6	123
2001LURP	19,500	54	2.7	119
2001LUFU	29,200	81	54	228

It is important to note that for all of the modeled scenarios, annual suspended-sediment loads are more than 100% greater than the annual-reference load determined from historical transport data analyzed from the Ridge and Valley (Table 4-11). Urbanization of the remaining forest land in the basin, simulated with the 2001LUFU modeling scenario, leads to annual suspended-sediment loads more than 200% greater than the annual reference.

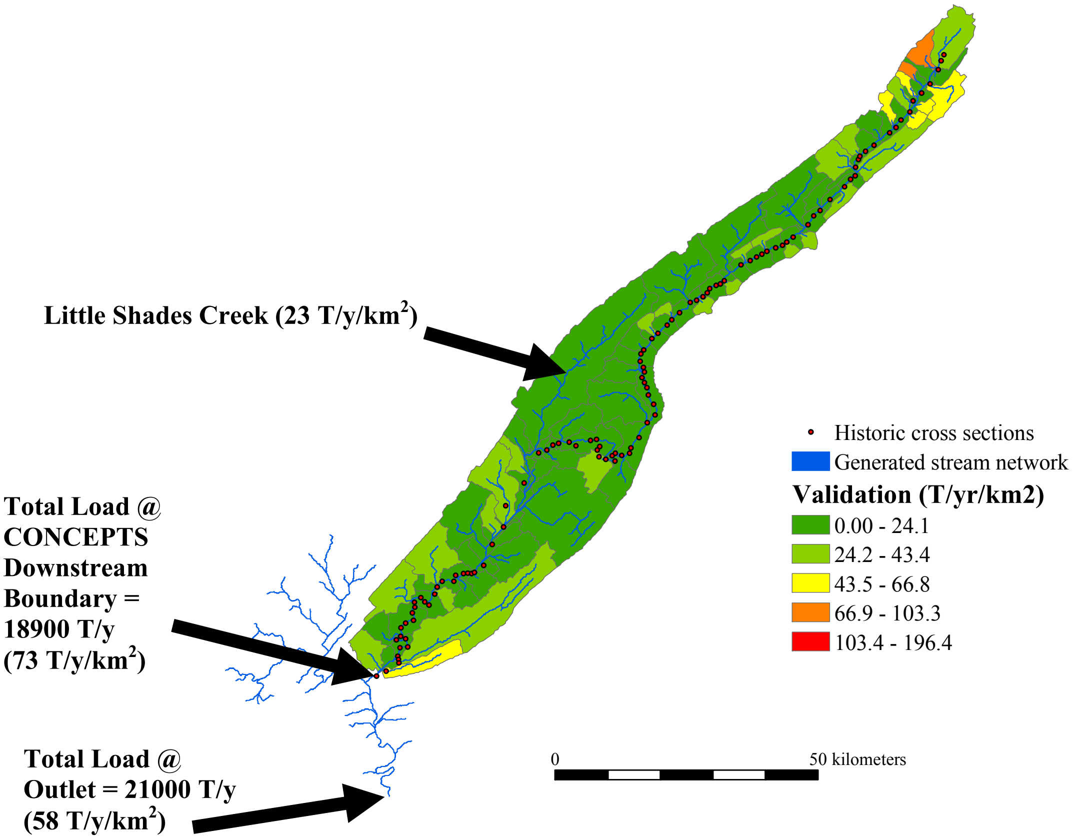
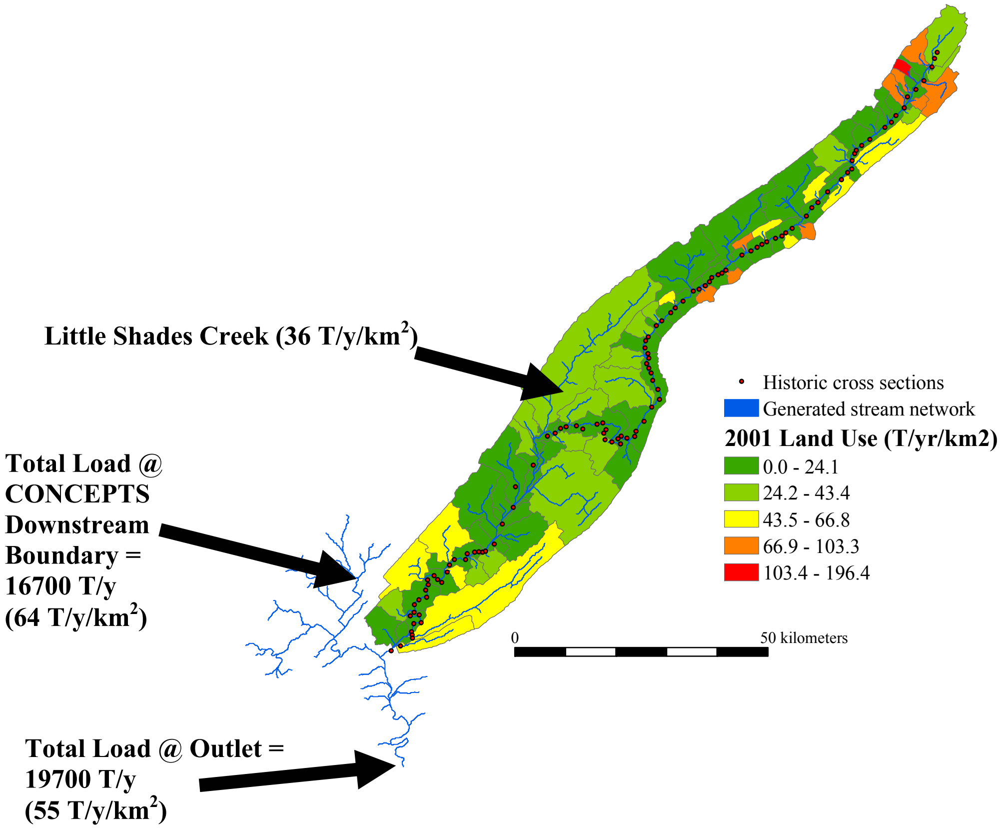


Figure 4-56. Simulated average-annual suspended load at the outlet of Shades Creek Watershed based on the upland load simulated by AnnAGNPS and the main channel load by CONCEPTS from the Validation scenario.


Little Shades Creek (36 T/y/km^2)

Total Load @ CONCEPTS Downstream Boundary = 16700 T/y (64 T/y/km^2)

Total Load @ Outlet = 19700 T/y (55 T/y/km^2)

Figure 4-57. Simulated average-annual suspended load at the outlet of Shades Creek Watershed based on the upland load simulated by AnnAGNPS and the main channel load by CONCEPTS from the 2001 landuse scenario.

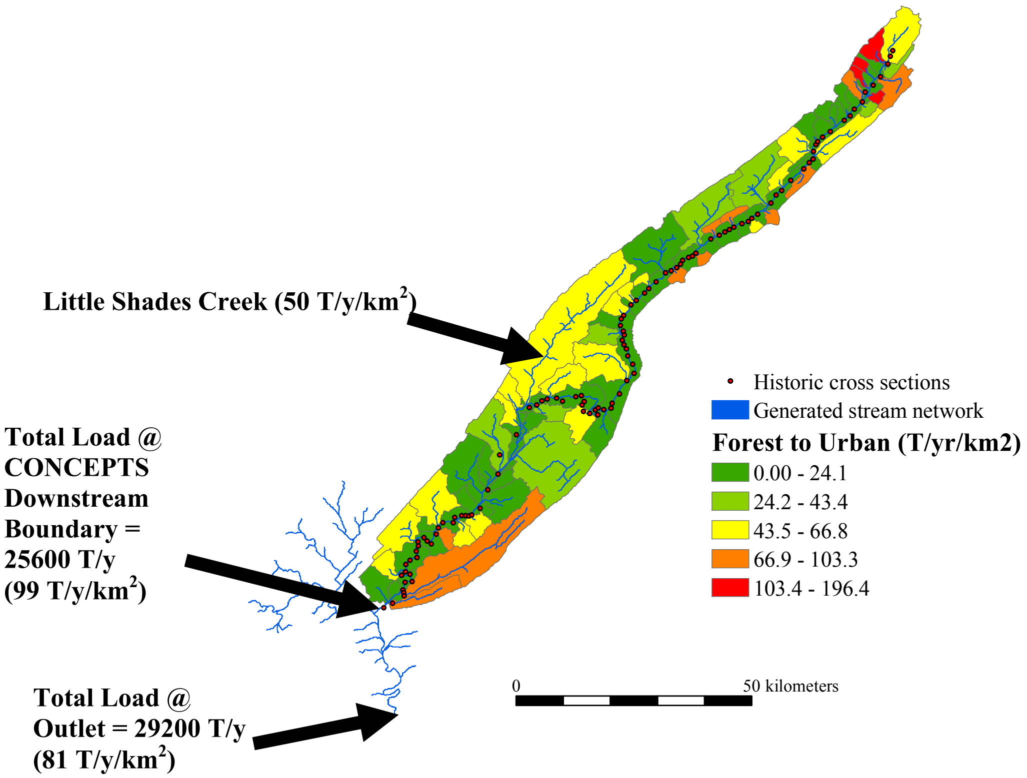


Figure 4-58. Simulated average-annual suspended load at the outlet of Shades Creek Watershed based on the upland load simulated by AnnAGNPS and the main channel load by CONCEPTS from the 2001LUFU scenario.

4.7 Summary

The watershed model AnnAGNPS and the channel evolution model CONCEPTS have been used to determine the:

1. Current distribution of sediment sources within the Shades Creek watershed (Validation scenario).
2. Effects of recent landuse changes on sediment loads and bed-material composition (2001 Landuse scenario).
3. Effects of future landuse changes on sediment loads and bed material composition (2001 Landuse with All Forest Changed to Urban (2001LUFU) scenario)
4. Effects of instream BMPs on sediment loads and bed material composition (2001 Landuse with Selected Reaches Protected (2001LURP) scenario).

The simulation period of the Validation scenario was 1964 to 2001. However, CONCEPTS was only run between 1978 and 2001, because historic cross sections were surveyed in 1978 and were used to construct the reach geometry at the beginning (January 1, 1978) of the simulation. Landuse in this scenario was based on a 1991 survey. The other three scenarios are 25-year simulations based on weather data from 1977 to 2001. The simulated channel geometry at the end of the Validation scenario is used as the initial channel geometry for the other three scenarios. Landuse in the 2001 Landuse and 2001LURP scenarios was based on a 2001 survey. Landuse in the 2001LUFU scenario was based on the 2001 survey in which all forest landuse was changed to urban landuse. In the 2001LURP scenario the streambanks of 17 cross sections experiencing widening greater than 1.5 m in the Validation scenario were protected against erosion. The total length of channel protected was 8.77 km or 11.5% of the model reach length.

Table 4-12 lists the major outcomes of the four modeling scenarios regarding simulated runoff, suspended-sediment load, reach-averaged widening and bed-elevation change.

Table 4-12. Simulated annual runoff, suspended sediment load, average widening, and average change in bed elevation for the four scenarios.

Scenario	Average annual runoff[1] mm/y	Average annual sediment load[1] T/y	$\overline{\Delta T}$ [2] cm/y	$\overline{\Delta z_b}$ [3] cm/y
Validation	462	21,000	3.37	0.338
2001 Landuse	457	19,700	2.83	0.172
2001LURP	457	19,500	1.62	0.117
2001LUFU	702	29,200	4.20	0.276

[1] Numbers are given at the mouth of Shades Creek with the Cahaba River
[2] Average annual change in top width along the modeling reach
[3] Average annual change in bed elevation along the modeling reach

Simulated annual runoff for the Validation scenario was 22% less than that measured (Figure 4-13). Simulated bankfull discharge, commonly assumed to be the peak discharge that occurs once every 1 to 2 years, agrees well with that observed (Table 4-4). The 5-year, 10-year, and 100-year peak discharges are slightly overpredicted; between 17 and 24%. Total annual runoff at the mouth of Shades Creek with the Cahaba River is 1% smaller for the 2001 Landuse scenario than that for the Validation scenario (Table 4-12). However, the higher runoff producing areas are slightly different; see Figures 4-18 and 4-19. Peak discharges at the gaging station are approximately 9.3% larger for the 2001 Landuse scenario than those for the Validation scenario (Table 4-6). The 2001LUFU scenario shows almost all areas producing high runoff amounts, as one would expect for an urban landscape (Figure 4-20). Average annual runoff at the mouth of Shades Creek with the Cahaba River increased 53.6% to 702 mm/y by changing forest landuse to urban landuse. Annual peak discharges at the gaging station increased 22.6% on average (Table 4-9).

Shades Creek is slightly aggradational (Table 4-12). The average depth of deposition along the modeling was reduced for the 2001 Landuse, 2001LURP and 2001LUFU scenarios because of channel bed adjustment simulated in the Validation scenario. Significant decreases in deposition were simulated between rkm 22 and rkm 24, and between rkm 50 and rkm 54 (e.g., compare Figures 4-30 and 4-35). Protecting streambanks (2001LURP scenario) further reduced the amount of deposition between rkm 44 and 50 (Figure 4-40). For the 2001LUFU scenario, deposition increased between cross sections X (rkm 22.9) and AV (rkm 48.3), see Figure 4-45.

Trends of simulated changes in top width along the modeling reach can be divided into three segments (Table 4-13): 1) segment from rkm 10.0 to approximately rkm 27.5; 2) segment from rkm 27.5 to rkm 68.0; and 3) segment from rkm 68.0 to rkm 86.5. Simulated channel adjustment in the Validation scenario generally yielded reduced widening rates in the 2001 Landuse, 2001LURP and 2001LUFU scenarios. Usually, the same cross sections as in the Validation scenario experience the greatest widening. Protecting streambanks of cross sections experiencing widening rates greater than 1.5 m (2001LURP scenario) significantly reduced the average widening of the modeling reach. Increased runoff in the 2001LUFU scenario greatly increased widening rates with respect to the 2001 Landuse scenario. The number of cross sections experiencing width adjustment greater than 2.0 m has increased from 11 for the 2001 landuse scenario to 23 for the 2001LUFU scenario.

Table 4-13. Average widening rates (m) of three distinct segments along Shades Creek.

Scenario	Segment 1 (rkm 10.0-27.5)	Segment 2 (rkm 27.5-68.0)	Segment 3 (rkm 68.0-86.5)
Validation	0.5	1.4	0.6
2001 Landuse	0.4	0.9	0.7
2001LURP	0.3	0.4	0.4
2001LUFU	0.6	1.3	1.0

Simulated average-annual suspended sediment load at the Greenwood gaging station (02423630) is slightly overpredicted, 10,400 T/y versus 9,850 T/y (Figure 4-33B). For the Validation scenario, the simulated average-annual suspended sediment load at the mouth of Shades Creek with the Cahaba River is 21,000 T/y (Table 4-12). For the 2001 Landuse scenario the average annual suspended load at the mouth (19,700 T/y) is 6.2% smaller than that for the validation scenario. Reduced rates of channel adjustment compared to the 1978-2001 period (Validation scenario) led to the reduction in suspended sediment loads. Protecting those cross sections experiencing the greatest widening had little effect on suspended sediment loads along the lower end of Shades Creek due to simulated deposition of the eroded streambank materials between cross sections AN (rkm 44.2) and AY (rkm 50.2). The sand fraction was the same for the 2001 landuse and the 2001LURP scenarios. The clay and silt fraction at the gaging station were smaller with bank protection than that without bank protection, 4,280 T/y versus 4,530 T/y. Changing all forest landuse to urban landuse (2001LUFU scenario) increased the average annual suspended sediment load at the mouth by 48% (Table 4-12). At the gaging station, the fine fraction (clay and silt) of the average annual suspended load increased 70% to 7,680 T/y, whereas the sand fraction increased 67% to 4,030 T/y.

Streambanks are the greatest source of sediments to suspended load, except for the 2001LURP scenario (Table 4-14). Streambank contributions are relatively smaller for the 2001 Landuse, 2001LURP and 2001LUFU scenarios than for the Validation scenario because of simulated channel adjustment in the Validation scenario. Uplands have become the main source of fines for the 2001LURP scenario. The amount of fines eroded from the streambanks has been greatly reduced (by 10,200 T/y or 40%) because of bank protection. For the 2001LUFU scenario, sediment loadings into the modeling reach increased 46.1% (12,300 T/y) compared to the 2001 Landuse scenario. The increased loadings are originating mainly from the streambanks (8,950 T/y) as opposed to uplands (3,460 T/y).

Table 4-14. Relative source contributions of uplands and streambanks to suspended sediment integrated over the study reach for the four scenarios.

	Uplands (%)		Streambanks (%)		Total (T/y)	
Scenario	Fines	Sands	Fines	Sands	Fines	Sands
Validation	29.2	17.8	70.8	82.2	20,700	5,190
2001 Landuse	40.3	31.2	59.7	68.8	18,700	8,000
2001LURP	88.7	33.8	11.3	66.2	8,500	7,390
2001LUFU	37.2	27.6	62.8	72.4	27,200	11,800

Due to fine-grained aggradation the number of coarse-grained cross sections was reduced significantly for the 2001 Landuse, 2001LURP and 2001LUFU scenarios. A comparison of Figures 4-38, 4-43 and 4-49 shows that the distribution of coarse-grained cross sections is very similar for the three scenarios. Three sites have an embeddedness value smaller than the reference median embeddedness of 4% for the 2001 Landuse and 2001LURP scenarios. For the 2001LUFU scenario, only one site, cross section BG at rkm 56.8, has an embeddedness value smaller than the reference median embeddedness of 4%. For the 2001 Landuse, 2001LURP and 2001LUFU scenarios there are respectively seven, eight and nine sites with an embeddedness value smaller than the reference third quartile embeddedness of 13.4%. Figures 4-30 and 4-35 showed significant deposition between rkm 45 and 55 for all scenarios. The number of sites with coarse-grained streambeds along this segment has reduced from ten to only one.

5 SUMMARY AND CONCLUSIONS

Combinations of field-based geomorphic assessments and sampling, analysis of historical flow and sediment-transport data and numerical simulation of upland and channel processes have been used to quantify "reference" and actual, sediment transport and bed-material characteristics in the Shades Creek Watershed, Alabama. Quantifiable "reference" conditions for suspended-sediment transport were developed using a technique documented in other ecoregions of the United States (Simon *et al.*, 2003). This procedure entailed quantifying rates of suspended-sediment transport for stable ("reference") and unstable streams throughout the ecoregion (Ridge and Valley) that encompasses the Shades Creek Watershed. Stable sites in the Ridge and Valley were determined by conducting Rapid Geomorphic Assessments (RGAs) and identifying the stage of channel evolution. Histograms, showing the distribution of suspended-sediment yields at the $Q_{1.5}$ and on an annual basis were then developed for stable sites. Both the median value and the central 50% of the distribution, represented by the range of yields between the 25th and 75th percentiles were assigned as the "reference" suspended-sediment transport yield. These values were then compared to a limited data set obtained for the gage on Shades Creek near Greenwood. The median "reference" yield at the $Q_{1.5}$ was 2.8 $T/d/km^2$ compared to a value of 7.3 $T/d/km^2$ for the gage at Greenwood. The median, annual suspended-sediment yield for "reference" conditions was 24.7 $T/d/km^2$ compared to a value of 52.6 $T/d/km^2$ at the Greenwood gage.

A similar technique was used to develop "reference" conditions for bed material using an embeddedness parameter. For this study, embeddedness was defined as the percentage of particles 2 mm or finer in a streambed composed of 50%, or more of coarser materials. "Reference" conditions were established for both the Ridge and Valley and for the Shades Creek watershed based on samples collected during the study. Results at both the regional and watershed levels were identical with a median value for stable sites of 4%. In comparison with literature values, the 4% level of embeddedness appears restrictive with the 75th percentile values of 16.6% (for the Ridge and Valley) and 13.4% (for Shades Creek), more reasonable.

The watershed model AnnAGNPS and the channel-evolution model CONCEPTS were used in this study to determine the magnitude and relative contributions of sediment emanating from the land surface and from channel sources. Four modeling scenarios were conducted to investigate a range of past, current and potential, future conditions in the watershed. They were:

1. Current distribution of sediment sources within the Shades Creek watershed using 1991 landuse (Validation scenario);
2. Effects of recent landuse changes on sediment loads and bed-material composition (2001 Landuse scenario);
3. Effects of future landuse changes on sediment loads and bed material composition (2001 Landuse with All Forest Changed to Urban (2001LUFU) scenario); and
4. Effects of generic bank stabilization along actively widening reaches on sediment loads and bed-material composition (2001 Landuse with Selected Reaches Protected (2001LURP) scenario).

Results from the Validation scenario were compared to measured values for the stream gage at Greenwood. Simulated annual runoff for the Validation scenario was 22% less than that measured while the simulated Q1.5 was within 5% of that measured. Suspended-sediment loads were within 10% of those calculated for the Greenwood gage.

A summary of the simulation results are re-printed from Table 4-12. Both runoff and average annual suspended-sediment load showed only minor differences except for the modeling scenario where all forest land was changed to urban (2001LUFU). Increases in sediment load are a direct result of greater runoff rates. This is manifest in the number of cross sections experiencing width adjustment greater than 2.0 m, which increased from 11 for the 2001 Landuse scenario to 23 for the 2001LUFU scenario.

Table 4-12. Simulated annual runoff, suspended sediment load, average widening, and average change in bed elevation for the four scenarios.

Scenario	Average annual runoff[1] mm/y	Average annual suspended-sediment load[1] T/y	$\overline{\Delta T}^{2}$ cm/y	$\overline{\Delta z_b}^{3}$ cm/y
Validation	462	21,000	3.37	0.338
2001 Landuse	457	19,700	2.83	0.172
2001LURP	457	19,500	1.62	0.117
2001LUFU	702	29,200	4.20	0.276

[1] Numbers are given at the mouth of Shades Creek with the Cahaba River

[2] Average annual change in top width along the modeling reach

[3] Average annual change in bed elevation along the modeling reach

Streambanks are the greatest source of sediments to suspended load, except for the 2001LURP scenario which simulated protected banks (see reprinted Table 4-14). Uplands became the main source of fines for the 2001LURP scenario because of the 10,200 T/y or 40% reduction in contributions from the banks. This 40% reduction was the result of protecting 11% of the stream length. The 46% (12,300 T/y) increase in loads for the 2001LUFU originated mainly from the streambanks (8,950 T/y) as opposed to uplands (3,460 T/y).

Table 4-14. Relative source contributions of uplands and streambanks to suspended sediment integrated over the study reach for the four scenarios.

	Uplands (%)		Streambanks (%)		Total (T/y)	
Scenario	Fines	Sands	Fines	Sands	Fines	Sands
Validation	29.2	17.8	70.8	82.2	20,700	5,190
2001 Landuse	40.3	31.2	59.7	68.8	18,700	8,000
2001LURP	88.7	33.8	11.3	66.2	8,500	7,390
2001LUFU	37.2	27.6	62.8	72.4	27,200	11,800

Average, annual suspended-sediment loads simulated by AnnAGNPS and CONCEPTS were converted to yields and used to compare with "reference" conditions (see reprinted Table 4-11). Because simulated values of suspended-sediment load were close to those measured, differences between simulated loads and the annual reference are similar to the difference between measured loads and the annual reference for the first three scenarios. Only the 2001LUFU showed a significant change, again because of vastly different runoff characteristics.

Table 4-11. Summary of simulated annual, suspended-sediment loads for the four different modeling scenarios compared to measured values on Shades Creek (52.6 T/y/km^2) and the annual-reference yield for the Ridge and Valley (24.7 T/y/km^2).

Scenario	Suspended-sediment load (T/y)	Suspended-sediment yield (T/y/km^2)	Difference from measured yield (through 2003) (%)	Difference from annual-reference yield (%)
Validation	21,000	58	10	135
2001 Landuse	19,700	55	4.6	123
2001LURP	19,500	54	2.7	119
2001LUFU	29,200	81	54	228

Shades Creek is a moderately disturbed system with the majority of its sediments emanating from streambank erosion. Geomorphic and numerical-simulation analyses have shown that suspended-sediment loads are greater than "reference" loads calculated with historical data from the Ridge and Valley ecoregion. "Reference" conditions for bed material (embeddedness) are strikingly similar when calculated for the Ridge and Valley ecoregion and for the Shades Creek watershed.

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