

Western Tennessee Fluvial Geomorphic Regional Curves

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Note 1: Figure one was a hand-drawn figure in the original report. It is not included here.

Note 2: Part of this work was published as:

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Introduction

The following report is respectfully submitted to the U.S. Environmental Protection Agency (EPA), Region IV, in fulfillment of the reporting requirements for the fiscal year 1997 104B(3) grant, agreement #CP984142-97-4. This final report pertains to one of four sub-grants included in the FY97 104(b)3 grant between Tennessee Department of Environment and Conservation, and EPA, Region IV, Water Management Division. The sub-grant is titled “Development of Fluvial Geomorphic Regional Curves for West Tennessee”.

The sub-grant proposes to develop fluvial geomorphic regional curves for western Tennessee by identifying appropriate reference reaches, and performing geomorphic stream surveys. The project involves measuring bankfull width, depth, cross-sectional area, and dominant substrate. Those data are used to develop a set of relationships between drainage area and river geometry as an aid to river restoration and resource management. Each survey site is also classified using the Rosgen Stream Classification system (Rosgen, 1994).

A companion report titled, “Cross-Sectional and Planform Geometry of Selected, Unmodified, Low-Gradient Rivers of Western Tennessee,” was submitted to the Wetlands Section of the United States Environmental Protection Agency, Region IV (Smith and Turrini-Smith, 1999; contract number X984228-97-0). In that report we provided initial values for the regional curve, and provided a detailed analysis of planform geometry of rivers in western Tennessee. Although the data for the regional curves provided in the current report differs slightly from that provided in the previous report, the results do not differ significantly. That report is appended (Appendix B).

Background

Bankfull dimensions of width, depth, and channel cross-sectional area are key parameters used in fluvial geomorphology. Fluvial geomorphic regional curves graphically emphasize the consistent mathematical relationships between drainage area and bankfull dimensions of width, depth, and cross-sectional area, and between bankfull dimensions and bankfull discharge of stream systems in dynamic equilibrium. Fluvial geomorphic regional curves are very powerful tools for evaluating and predicting the physical impacts of channel modifications, flow alterations, and other watershed changes, as well as determining appropriate physical parameters for stream and associated wetland restoration. Regional curves have been developed and applied in various regions of the country since the mid-1970's (Dunne and Leopold, 1978; Emmett, 1975). No previous fluvial geomorphic regional curves exist for west Tennessee, where channel instability is pervasive and extensive channelization has been done (e.g., Simon and Hupp, 1992; Simon, 1989).

Western Tennessee fluvial geomorphic regional curves are the final product of this 104(b)3 sub-grant. These regional curves are essential for natural stream restoration projects in the western plains of Tennessee bordered by the Lower Tennessee and the Mississippi Rivers. The curves are also useful for watershed management and state

Aquatic Resource Alteration Permit decision-making, and documenting existing stream conditions. Another important benefit is that the geomorphic surveys establish a geomorphic baseline database of reference reaches in the region. This database can be used in conjunction with future cross-section resurveys to determine long-term geomorphic trends and quantify channel stability of relatively unmodified stream reaches. Specifically, the west Tennessee geomorphic regional curve for channel dimensions was essential for the development of the channel restoration design for Stokes Creek Restoration Demonstration project funded by EPA (cooperative agreement #CP984142-97-4; Turrini-Smith and Smith, 1999). The preliminary curves were also critical to evaluation of the West Tennessee Tributaries restoration demonstration project design proposed for the Middle Fork Forked Deer River (Smith and Rosgen, 1998). And, the curves were central to the field guide and fieldwork portion of a fluvial geomorphic short course taught by Dave Rosgen (Smith and Turrini-Smith, 1998).

This project involves collaborative work between TN Department of Environment and Conservation, Vanderbilt University, and the U.S. Geological Survey (USGS). The majority of the field work and data analysis was conducted by the principal investigators: Leslie Turrini-Smith with TN Department of Environment and Conservation, Dr. Douglas Smith with Vanderbilt University, and Dr. Timothy Diehl with the U.S.G.S. We greatly appreciate the assistance of Dr. Peter Kalla, Bruce Pruitt, and Morris Flexner, all with U.S. Environmental Protection Agency, Region IV during an early phase of the project.

Methodology

Site Selection

Regional curves should be based upon on as many high-quality stream sites as possible, and upon a wide range of drainage basin sizes. Far more information can be derived from sites that also have operating discharge gages with a long-term hydrologic record. These criteria defined our site selection process. High quality streams are those streams that have no indication of direct human modification (e.g., channelization) and no indication of alteration due to human modification of the watershed (e.g., excessive deforestation). Site selection was the most time consuming portion of the project because of the paucity of undisturbed stream reaches in western Tennessee. Even fewer are the unmodified sites that have hydrologic records.

A set of potential survey sites was developed based upon the following four criteria:

- Personal knowledge of the condition of the stream, or interviews with local resource managers,
- Selection of a site in the State of Tennessee Ecoregion Project (e.g., Griffith et al., 1997),
- Apparent presence of an unchannelized river reach (i.e., presence of sinuous channel) and unmodified upper watershed, based upon U.S. Geological Survey quadrangles or other maps and aerial photographs,
- Presence of a suitable discharge record

The list of potential sites was then further reduced based upon a site visit and automobile tour of the watershed. The remaining stream reaches were then reconnoitered by canoe and on foot to further evaluate the stream reach and condition of upstream and downstream reaches. We looked for geomorphic clues that the river/floodplain system was in a relatively natural state (self-formed), and that the system was not rapidly evolving (e.g., excessive recent widening or recent base-level changes). Many sites were dropped from further consideration owing to evidence of instability or direct human modification. Much of the western Tennessee landscape has been severely modified by watershed development. Channelization for agriculture and flood control is particularly pervasive. Channelization in the upper watersheds typically unleashes a very high sand bedload, which commonly leads to downstream channel blockages and avulsion. Even some of the ecoregion sites were not appropriate sites because they exhibited evidence of geomorphic instability or human modification (e.g., eroding banks, leaning trees, incised channel, aggraded channel). Final site selection was made during field reconnaissance of the watershed and the site to determine the extent of watershed modification, to evaluate impact of land use, and to assess geomorphic stability.

Field Surveying Protocol

Geomorphic surveys were generally conducted with a minimum of three field people. We found three field people to be the most efficient number for surveying. Usually all three principal investigators were present, with occasional additional field assistance from interested volunteers from TN Environment and Conservation, Division of Water Pollution Control, or, in one case, from volunteers from University of Memphis. Personnel from EPA Region IV and Water Pollution Control assisted with data collection on the larger rivers for one week in May 1997.

Data collection protocol generally followed the procedures described in "Stream Channel Reference Sites: An Illustrated Guide to Field Technique" (Harrelson et al., 1994). The field equipment included a Topcon self-leveling rotating laser level, model RL-H, metric Mound City survey rods and rod levels, measuring tapes, Brunton pocket transit, and Western Hydrology cross-section stake kit. Quality assurance and quality control of data collection was done in the field by the measuring person calling out the reading, and the notetaker verbally repeating the reading for verification, and inspecting the data for consistency with previous readings. Survey data was normally plotted the same day as a means of identifying and reducing survey errors. Although some of the streams were small enough to wade, the majority of cross sections included either sonar bathymetry or rod surveying from boat or canoe.

For the few sites that remained on the list following the initial site visit, a detailed "representative" cross section was surveyed. The surveys were located within a straight reach of channel, with a broad floodplain, where bankfull indicators were present, and the geometry was not complicated by excess woody debris or apparently anomalous morphology. The cross-section surveys commonly included between 50 and 75 survey points that are tied to at least two long-term benchmarks. Survey benchmarks are four foot-long iron rods driven vertically into the ground and capped by an orange plastic cap.

The surveys typically include the bankfull channel, the natural levee system and a significant length of floodplain on at least one side of the channel. Although the depth of the channels precluded a rigorous particle-size determination, the dominant particle size (e.g. silt/clay, sand, gravel) was easy to record, and is sufficient for a Rosgen stream classification. A site map showing the locations of benchmarks was sketched for each cross section, and several documentary photographs were taken. Additionally, we estimated or measured the lateral extent of the floodplain or other low, frequently-flooded surfaces adjacent to the river. Where it was technically feasible, the water surface slope was also surveyed. The surveyed rivers typically have slopes of approximately 0.0002, which is difficult to detect in a short horizontal distance. The forested floodplains made longitudinal surveys difficult to achieve.

At surveyed sites with a discharge gage station, the bankfull elevation was surveyed from the cross section to the staff gage plate. The recurrence interval of the bankfull stage was then determined by computing the annual flood frequency series from the discharge record.

Survey Sites Included in the Regional Curve Analysis

We surveyed twenty cross sections, but eliminated six sites because of channel alteration, excessive aggradation, proximity to a beaver dam, or insufficient data. Figure 1 shows the regional distribution of the fourteen selected sites. The fourteen sites we ultimately included in the regional curve regression analysis are provided in Table 1. The sites range in drainage area from 6 mi² to 2309 mi² (15 km² to 5911 km²), providing a significant range of channel sizes for streams that do not appear to be significantly affected by either local or regional modification. Appendix A (Figs. A1 to A14) provides annotated, graphical representations of the fourteen surveyed cross sections and a data summary for each site. Detailed site maps and original survey data are available from the authors.

TABLE 1
Surveyed Sites Used in Regression Analysis for
West Tennessee Fluvial Geomorphic Regional Curves

Surveyed Stream Reach	Drainage Area (mi ²)	Cross-sectional Area (ft ²)	Bankfull Width (ft)	Mean Depth (ft)	Width/Depth Ratio	Bed Material	Rosgen Stream Type
1) Marshall Creek at Van Buren Rd.	6	23.0	16.2	1.4	11	sand	E5
2) West Fork Spring Creek at Van Buren Rd.	14	104.1	30.1	3.4	9	sand	E5
3) Cypress Creek at Howell Buntin Rd.	17	72.4	18.4	3.9	5	silt/clay	E6
4) Spencer Creek at Hammett Rd.	18	87.3	28.9	3.0	10	silt/clay	E6
5) Harris Creek above Potts Chapel Rd.	18	123.0	33.3	3.7	9	sand	E5
6) Cypress Creek at Lower Brownsville Rd.	22	149.1	35.2	4.2	8	silt/clay	E6
7) Lagoon Creek near Estes Rd.	38	158.3	32.1	4.9	6	silt/clay	E6
8) Little Hatchie Creek above Powell Chapel Rd.	84	342.5	58.4	5.9	10	sand	E5
9) Spring Creek at Sain Rd.	117	161.3	43.3	3.7	11.6	sand	E5
10) Wolf River at LaGrange	200	264.4	49.3	5.4	9	sand	E5
11) South Fork Obion River at Jarrell Bottoms	300	235.0	61.8	3.8	16	silt/clay	C6
12) Hatchie River at Pocahontas	839	988.9	100.1	9.9	10	silt/clay	E6
13) Hatchie River below Bolivar	1480	1281.0	197.6	6.5	30	sand	C5
14) Hatchie River at Rialto	2309	1416.5	130.5	10.9	12	sand	C5

Definitions for Table 1:

Drainage area is the land surface area contributing flow to the reference reach.

Cross-sectional area is the bankfull cross-sectional area of the reference reach channel.

Bankfull width is the width of the reference reach channel at the bankfull elevation.

Mean depth is the bankfull cross-sectional area divided by the bankfull width.

Width/Depth ratio is the bankfull width divided by the mean depth.

Bed material is the dominant particle size on the channel bottom at the cross section.

Rosgen Stream Type refers to the stream classification system published by Rosgen (1994).

The fourteen sites were analyzed in several ways. For each site, the following steps were performed.

- Plot cross-sectional data to compare with observations and to eliminate clerical errors.
- Choose bankfull elevation using as many criteria as possible. See discussion below.
- Calculate bankfull dimensions from survey data. (cross-sectional area, width, mean depth).
- Calculate width/depth ratio, and entrenchment ratio (Rosgen, 1994), and water-surface slope.
- Determine Rosgen (1994) stream type

In general, "bankfull" stage is the stage of incipient flooding on rivers that are in equilibrium with their watersheds. The tops of natural levees in western Tennessee do not represent the stage height of incipient flooding because these levees are discontinuous features that stand well above the general floodplain elevation. After conducting several surveys, we adopted the following, internally consistent, way of choosing bankfull geometry in the field. Because the natural levees are discontinuous, the general elevation of the floodplain behind the levees ("backswamp") is approximately the same as the local river stage at the onset of flooding. Therefore, we adopted the backswamp elevation as the bankfull elevation. In all cases, there are other local geomorphic features, such as a point bar, channel depositional bench, or a break-in-slope on the riverbank that corroborate our choice of bankfull elevation (see Appendix A). A cross section of Little Hatchie Creek (Fig. A8, Appendix A) provides an example of the backswamp elevation corresponding to the elevation of a depositional bench. Note that the levees at this site stand approximately one meter above what we consider to be the "bankfull" elevation. Downstream from the cross section, the top of a point bar is at approximately the same elevation as the backswamp, lending further evidence that this discharge stage is important in shaping and sizing the channel.

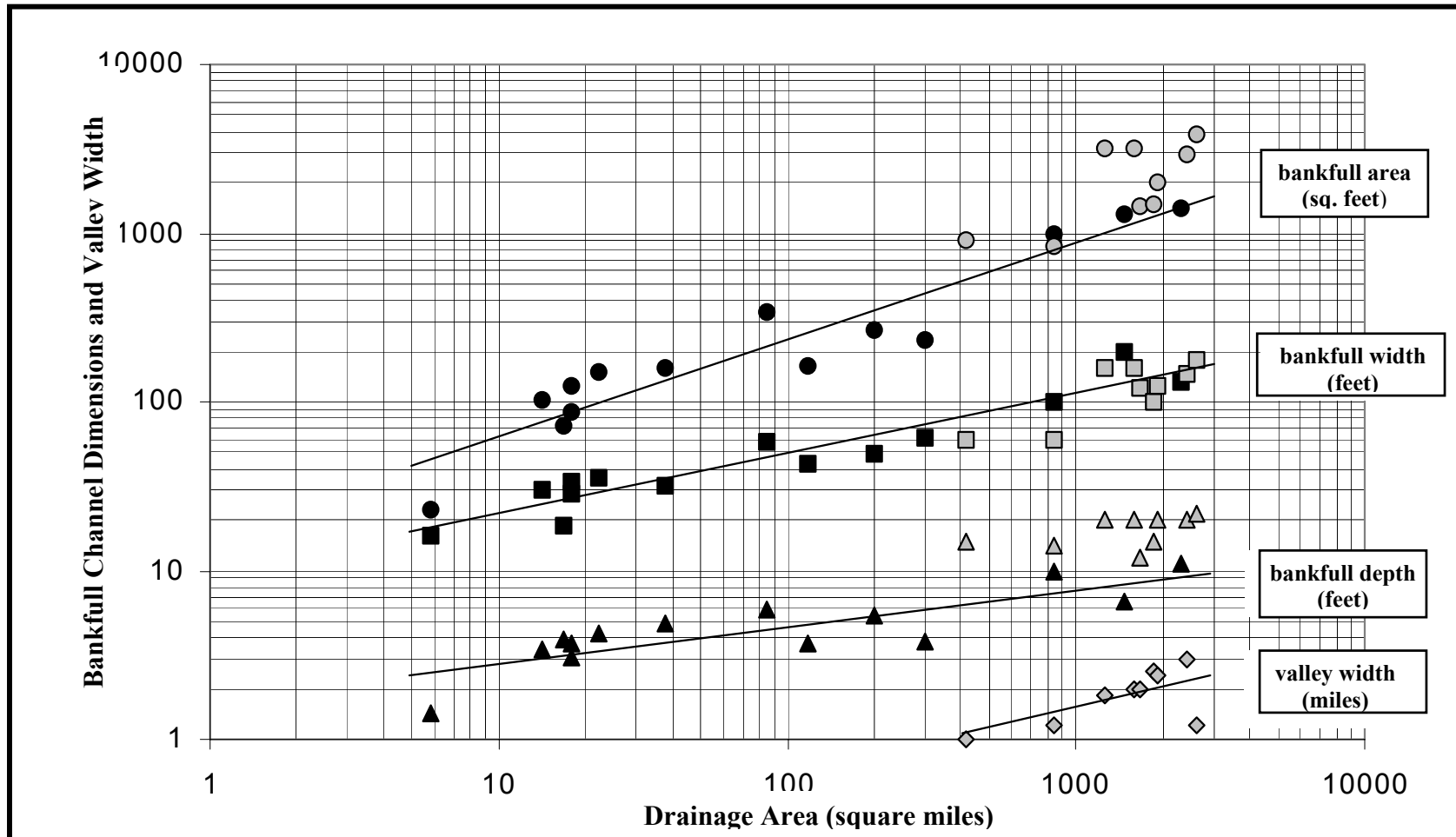
Data Analysis and Regional Curves

Bankfull Dimensions vs. Drainage Area Regression Analysis

The logarithm (base 10) values of the bankfull dimensions were regressed against the logarithm (base 10) values of the drainage area, to develop the power functions relating drainage area to cross-sectional area, width and mean depth (Fig. 2). These data were then plotted on log-log paper to linearize the relationships (Fig. 2). The R^2 values for drainage area versus cross-sectional area ($R^2= 0.89$), width ($R^2= 0.90$), and mean depth ($R^2= 0.68$), show a significant correlation among the variables. The authors caution against extrapolating the regression results beyond the range of the data presented.

FIGURE 2

Fluvial Geomorphic Regional Curves for Western Tennessee
Showing Bankfull Dimensions and Valley Width vs Drainage Area



Black symbols are 1997 - 1998 data (this study). Gray symbols are 1911 - 1912 data (Hidinger and Morgan, 1912). Bankfull channel dimension regression formulae and regression lines are calculated using only 1997 - 1998 data.

Bankfull area = $16.4 \times DA^{0.57}$ $R^2 = 0.89$
 Bankfull depth = $1.7 \times DA^{0.22}$ $R^2 = 0.68$

Bankfull width = $9.6 \times DA^{0.36}$ $R^2 = 0.90$
 Valley width = $0.07 \times DA^{0.44}$ $R^2 = 0.44$

In addition to the 1997 - 1998 surveys (black symbols in Fig. 2), we plotted historic survey data from the Hatchie River (gray symbols in Fig. 2). The historic data (Table 2) are from Hidinger and Morgan (1912).

TABLE 2

Historic Hatchie River Survey Data from Hidinger and Morgan (1912)

Drainage Area (mi²)	Cross-sectional Area (ft²)	Channel Width (ft)	Channel Depth (ft)	Valley Width (miles)	Miles above mouth	Comments
2620	3850	175	22	1.2	21	I.C. Railroad
2403	2900	145	20	3.0	39	L&N Railroad
1916	2000	125	20	2.4	44	levee
1847	1500	100	15	2.5	55	NC&St. L Railroad
1660	1440	120	12	2.0	66	Pirtle's Ferry
1600	3200	160	20	2.0	73	I.C. Railroad
1260	3200	160	20	1.8	84	Henline Landing
839*	840	60	14	1.2	97	Pocahontas
414	900	60	15	1.0	100	Southern Railroad

Bankfull width is one of the most repeatable measurements in the field because it is not very sensitive to different interpretations of "bankfull" stage. Thus, it should be the most robust parameter to compare among surveys performed by different personnel and for different purposes. We see the strong correlation between recent and historic channel width data as a strong indication that the (unmodified) planform geometry of the Hatchie River has not changed markedly for nearly 100 years, and likely for much longer. Of note is the clear difference between recent and historic measures of mean bankfull depth and cross-sectional area. We ascribe that difference to our choice of bankfull depth. We chose the stage of incipient flooding (backswamp elevation) as the primary marker of geomorphic bankfull. Although we do not have their original survey data or notes, we suggest the Hidinger and Morgan (1912) likely chose the levee tops as the bankfull stage, and may have recorded maximum depth, rather than calculated a mean depth. An alternative explanation is that the Hatchie River was 50% to 100% deeper in the early part of the century than it is today, but without a significant change in top width. We have also plotted the measurements of valley width published in Hidinger and Morgan (1912). Although the data appear to have a significant relationship with drainage area, outliers reduce the R^2 value to 0.44 (Fig. 2).

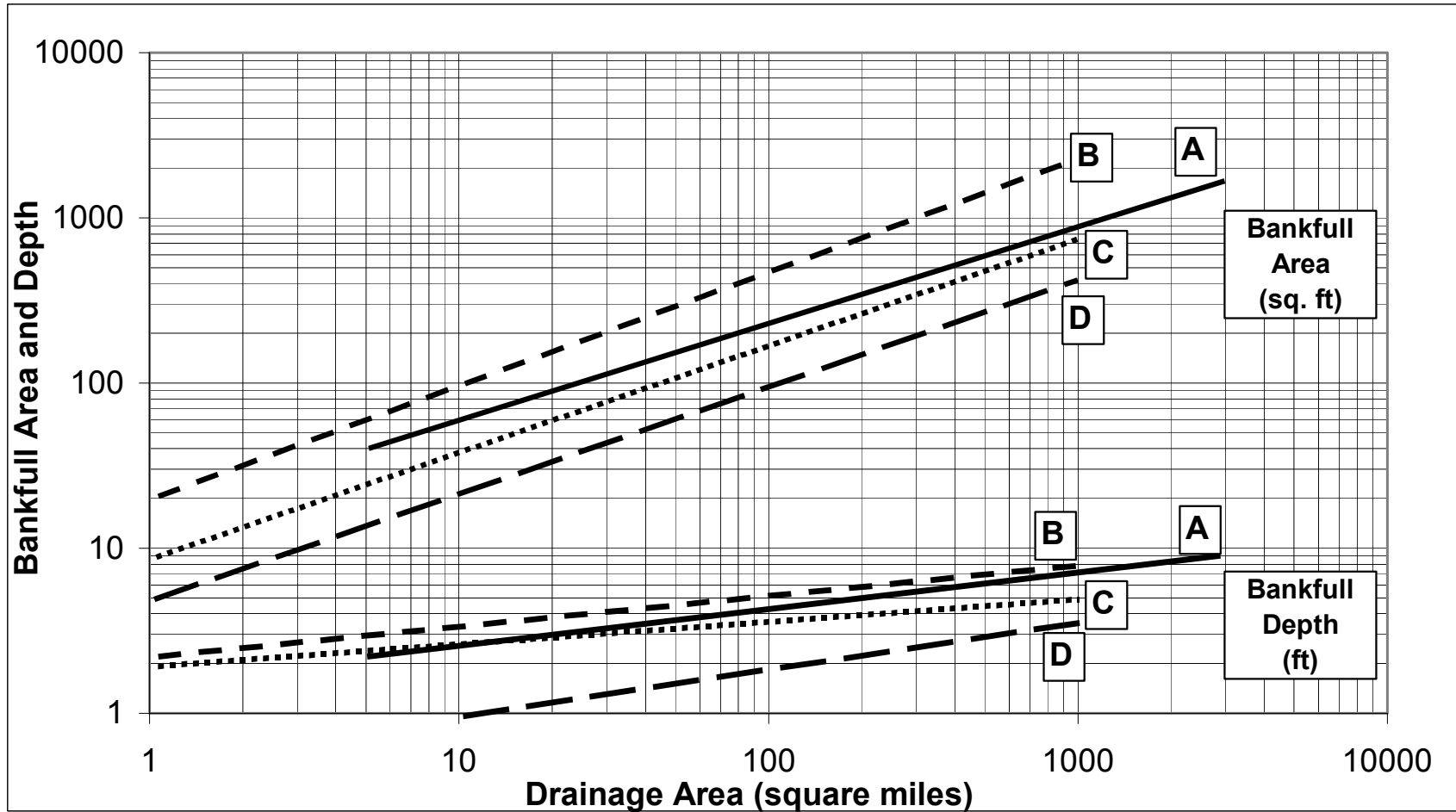
Comparison with Other Regional Curves

The shape of any given river, at a particular reach, is integration of all physical factors acting upon the reach. Individual factors are many, including climate history, recent weather, geological substrate, tectonic setting, physiographic setting, and watershed condition. The rivers within a given, restricted, region of the world generally have the same basic appearance because the physical factors that govern their geometry are

similar. Therefore, to reduce data scatter, and improve local knowledge of river morphology, “regional curves” relating bankfull geometry and drainage area should be derived from rivers within the same physiographic province.

The literature (Dunne and Leopold, 1978; Emmett, 1975) provides regional curves for three other physiographic provinces in North America. It is instructive to compare the new results from western Tennessee to those other regions of North America (Figs. 3 and 4). For any specific drainage area, the average bankfull cross-sectional area of western Tennessee rivers is larger than certain rivers in Wyoming and Idaho, but 50% smaller than other rivers studied in the “Eastern U.S.” (Fig. 3). The Eastern U.S. data came primarily from the Pennsylvania piedmont (Dunne and Leopold, 1978). It is important to note that channel design in western Tennessee, using the “Eastern U.S.” data, would result in a channel cross-sectional area that is 100% oversized. It is clear that the “Eastern U.S.” regional curves should have a more regionally restrictive title. The bankfull depths of western Tennessee rivers are comparable to other “Eastern U.S.” and Wyoming rivers, but are significantly deeper than those of Idaho (Fig. 3). Figure 4 shows that the bankfull widths of western Tennessee rivers are not very different from those of Wyoming or Idaho, but are 50% narrower than those of other “Eastern U.S.” rivers. In summary, undisturbed western Tennessee rivers have a significantly lower width/depth ratio than rivers of the other three regions of the U.S., especially those of the Pennsylvania piedmont. A lower width/depth ratio is common among rivers with cohesive (muddy) banks, like those in much of western Tennessee. Lower width/depth rivers are more efficient hydraulic conduits because there is less surface contact with the water, so the Pennsylvania Piedmont rivers require twice the cross-sectional area of western Tennessee rivers to drain any given watershed size, despite the lower annual precipitation in Pennsylvania.

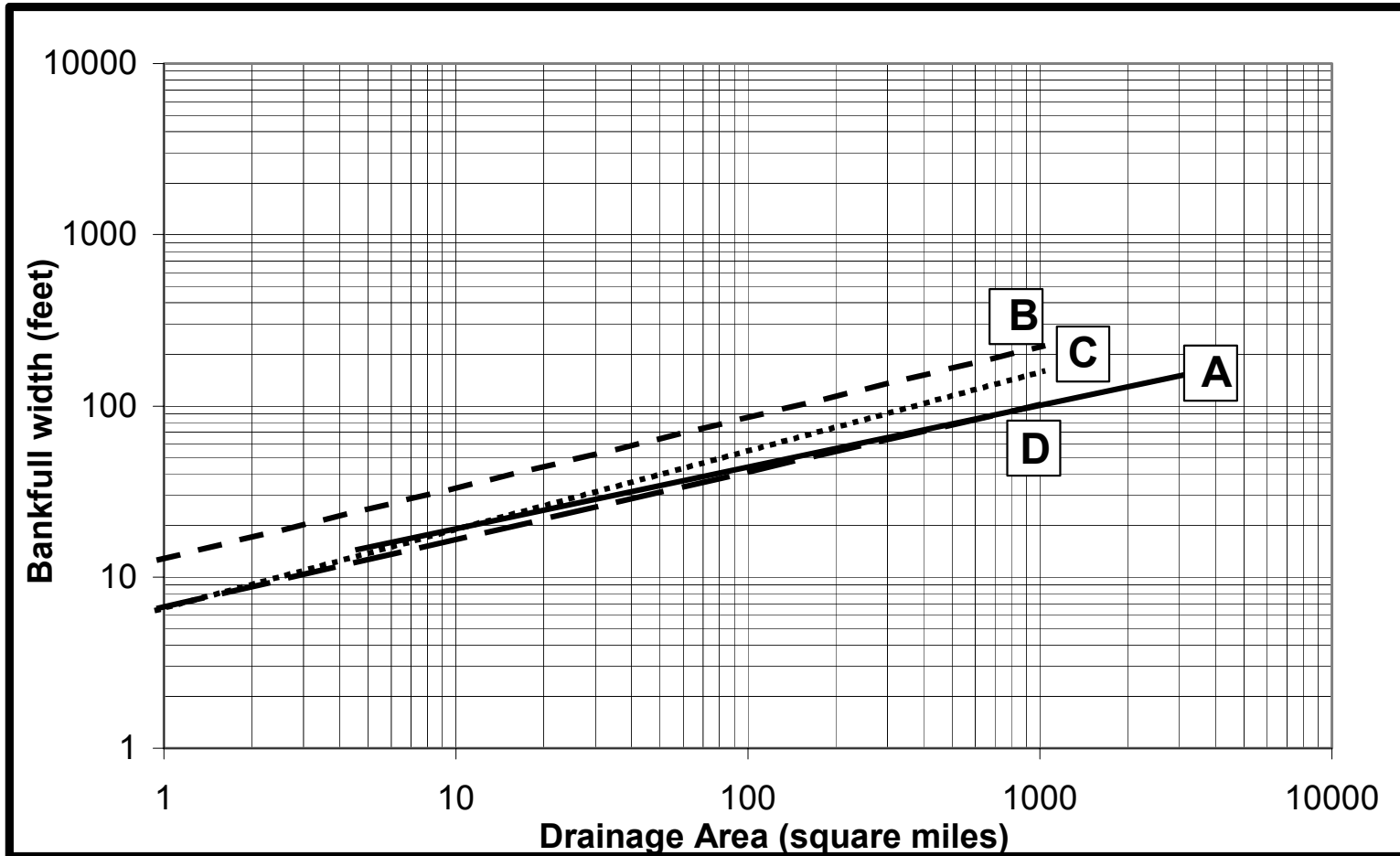
Figure 3: Comparison with various regional curves



A: Western Tennessee (present study)
 B: Eastern U.S. (Dunne and Leopold, 1978)

C: Upper Green River Wyoming (Dunne and Leopold, 1978)
 D: Upper Salmon river, Idaho (Emmett, 1975)

Figure 4: Comparison of various published regional curves



A: Western Tennessee (present study)
 B: Eastern U.S. (Dunne and Leopold, 1978)

C: Upper Green River Wyoming (Dunne and Leopold, 1978)
 D: Upper Salmon river, Idaho (Emmett, 1975)

Bankfull Discharge vs. Drainage Area Analysis

There are several obstacles to generating a bankfull discharge vs. drainage area regional curve in western Tennessee. The best data come from natural channels with greater than ten years of discharge data and representing a wide range of drainage areas. There are only five sites in western Tennessee that meet those requirements. There are also no appropriate gage sites with drainage areas less than 300 square miles. We surveyed four gaged sites, and only three sites were considered appropriate for inclusion in a bankfull discharge vs. drainage area regional curve database without significantly more work. Three data points are not a sufficient sample size for a meaningful regression analysis. Three surveyed sites are from Hatchie River gages; thus, the data points are interdependent, further compromising the "regional" aspect of the resulting discharge regional curve. Further development of a discharge vs. drainage area regional curve will require direct measurement of discharge during bankfull conditions at sites with relatively unmodified channels. Therefore, a bankfull discharge vs. drainage area regional curve is beyond the scope of this grant. The bankfull discharge calculations from our surveys at gaged sites are reported in Table 3 below.

TABLE 3

Calculated Bankfull Discharge Values from Surveyed Gage Sites

Stream Reach	Bankfull Discharge (cfs)	Drainage Area (sq. mi.)	Recurrence Interval of Exceedence* (years)	Comments
Wolf River at LaGrange	330	210	n/a	Insufficient length record USGS gage site
Hatchie River near Pochahontas	n/a	311	n/a	In-channel staff gage plate missing US Army Corps gage site
Hatchie River at Pochahontas	1300	837	1.0	US Army Corps gage site
Hatchie River at Bolivar	4900	1480	1.02	Long discharge record USGS gage site
Hatchie River at Rialto	n/a	2309	n/a	Constriction at bridge alters bankfull stage from cross section to gage US Army Corps gage site

*Based on annual flood series

Acknowledgments

We thank the U.S. Environmental Protection Agency for funding this project. Early field work for the project was greatly facilitated by the collaboration of U.S. Environmental Protection Agency researchers (Dr. Peter Kalla, Bruce Pruitt, and Morris Flexner). We wish to thank Dr. Timothy Diehl, with the U.S. Geological Survey in Nashville, TN, for his strong collaboration on every aspect of this project.

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APPENDIX A

Annotated Cross Sections of Fourteen River Reaches Used in Regression Analysis

The following pages show the cross-sections and summarize data for the 14 surveys used in the regression of the regional curves. The following notes apply to all cross sections.

Definitions for Appendix A:

Drainage area is the land surface area contributing flow to the reference reach.

Cross-sectional area is the bankfull cross-sectional area of the reference reach channel.

Bankfull width is the width of the reference reach channel at the bankfull elevation.

Mean depth is the bankfull cross-sectional area divided by the bankfull width.

Width/Depth ratio is the bankfull width divided by the mean depth.

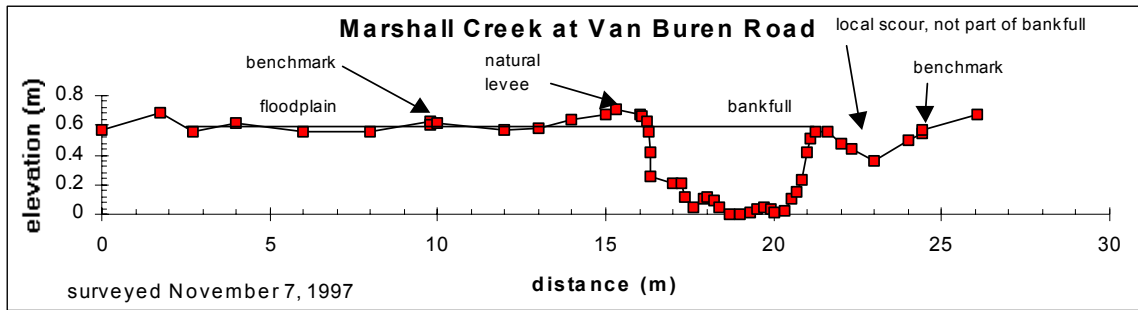
Floodprone width is the cross-sectional width at the water stage twice as high as the maximum bankfull depth

Entrenchment is the floodprone width divided by the bankfull width

Bed material is the dominant particle size on the channel bottom at the cross section.

Rosgen Stream Type refers to the stream classification system published by Rosgen (1994).

FIGURE A1



Bankfull Channel Dimensions		
Drainage Area	15 sq. km	6 sq. mi
Area	2.14 sq. m	23.1 sq. ft
Width	4.95 m	16.2 ft
Mean Depth	0.43 m	1.4 ft
Maximum Depth	0.56 m	1.8 ft
Floodprone Width	80 m	262 ft
Width/Mean Depth Ratio	11	
Entrenchment	16	
Slope	0.0014	
Substrate	sand	
Rosgen Stream Type	E5	

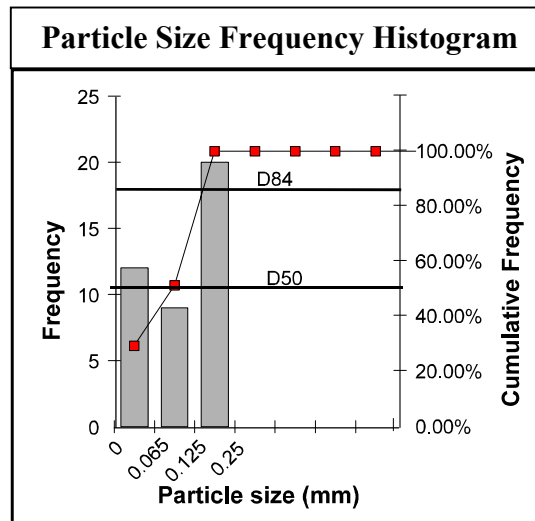
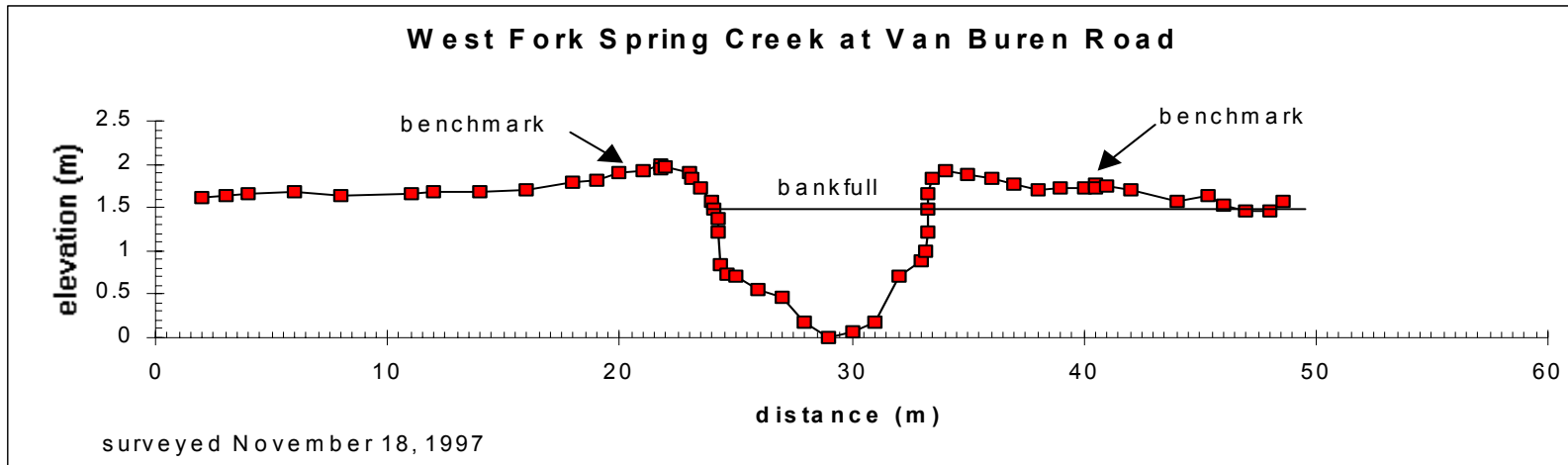
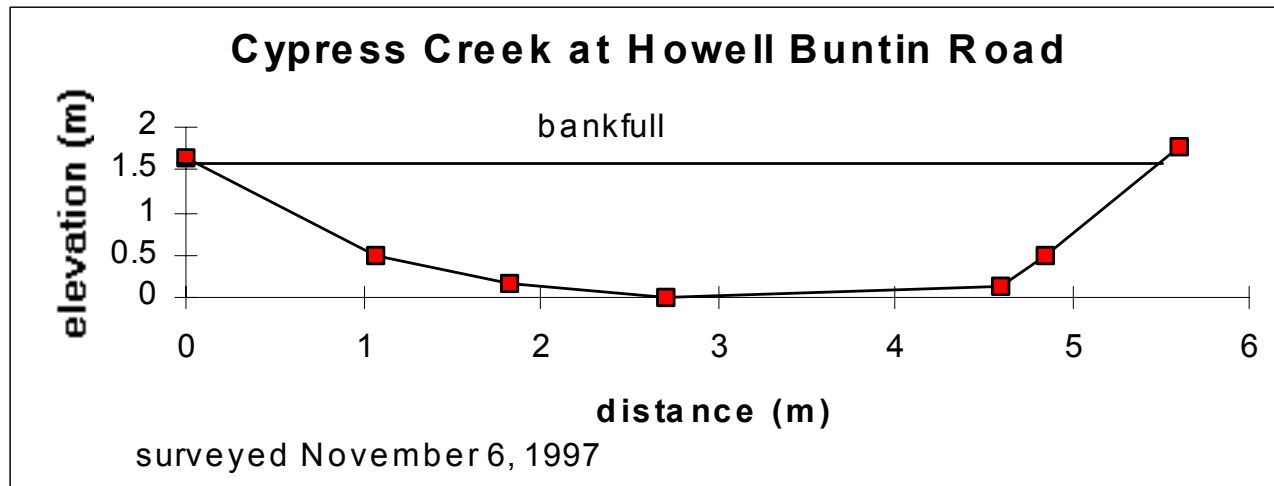


FIGURE A2



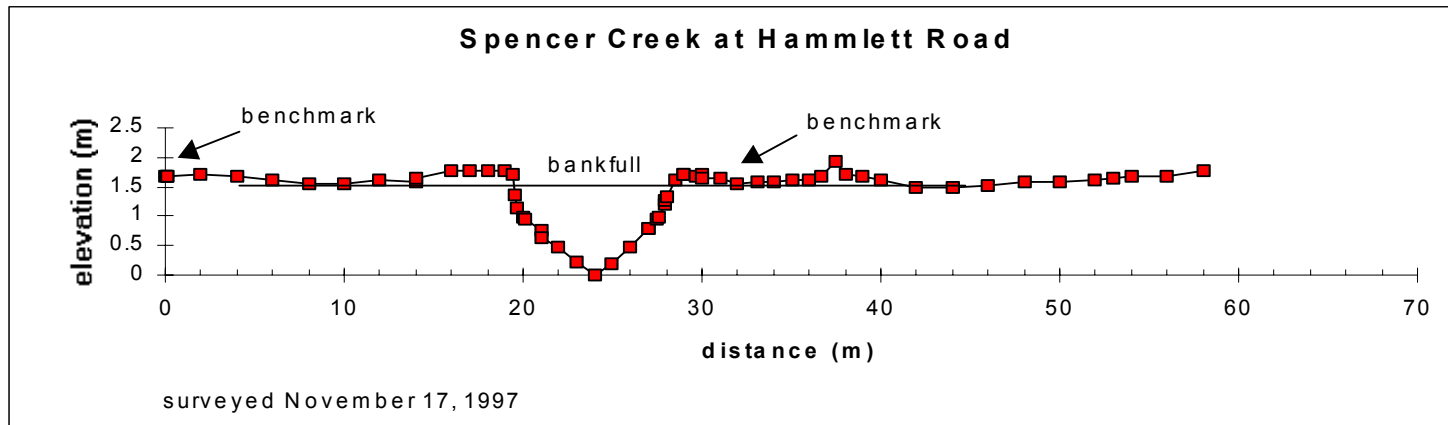
Bankfull Channel Dimensions		
Drainage Area	36 sq. km	14 sq. mi
Area	9.68 sq. m	104.1 sq. ft
Width	9.18 m	30.1 ft
Mean Depth	1.05 m	3.5 ft
Maximum Depth	1.49 m	4.9 ft
Floodprone Width	250 m	820 ft
Width/Mean Depth Ratio	9	
Entrenchment	27	
Slope	0.00015	
Substrate	med. sand	
Rosgen Stream Type	E5	

FIGURE A3



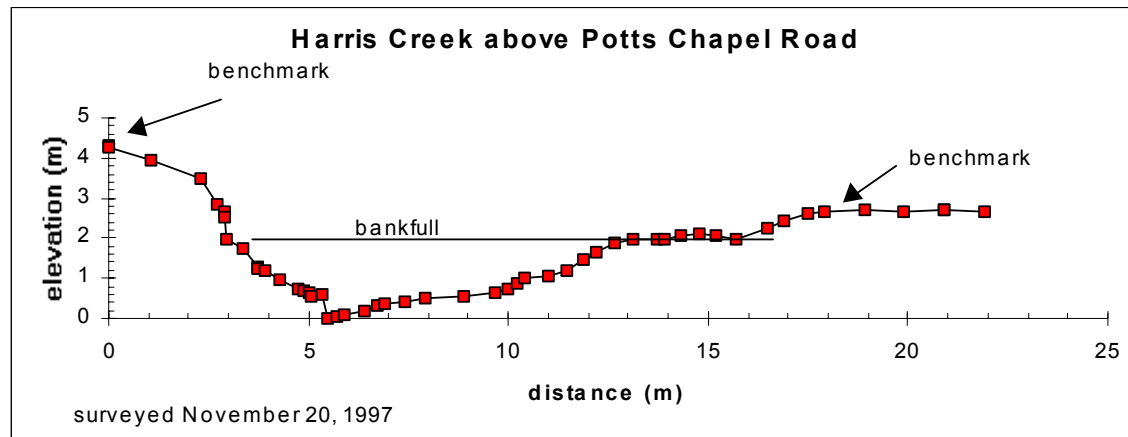
Bankfull Channel Dimensions		
Drainage Area	43 sq. km	17 sq. mi
Area	6.73 sq. m	72 sq. ft
Width	5.61 m	18.4 ft
Mean Depth	1.2 m	3.9 ft
Maximum Depth	1.65 m	5.4 ft
Floodprone Width	>100 m	>328 ft
Width/Mean Depth Ratio	5	
Entrenchment	>18	
Slope	low	
Substrate	mud	
Rosgen Stream Type	E6	

FIGURE A4



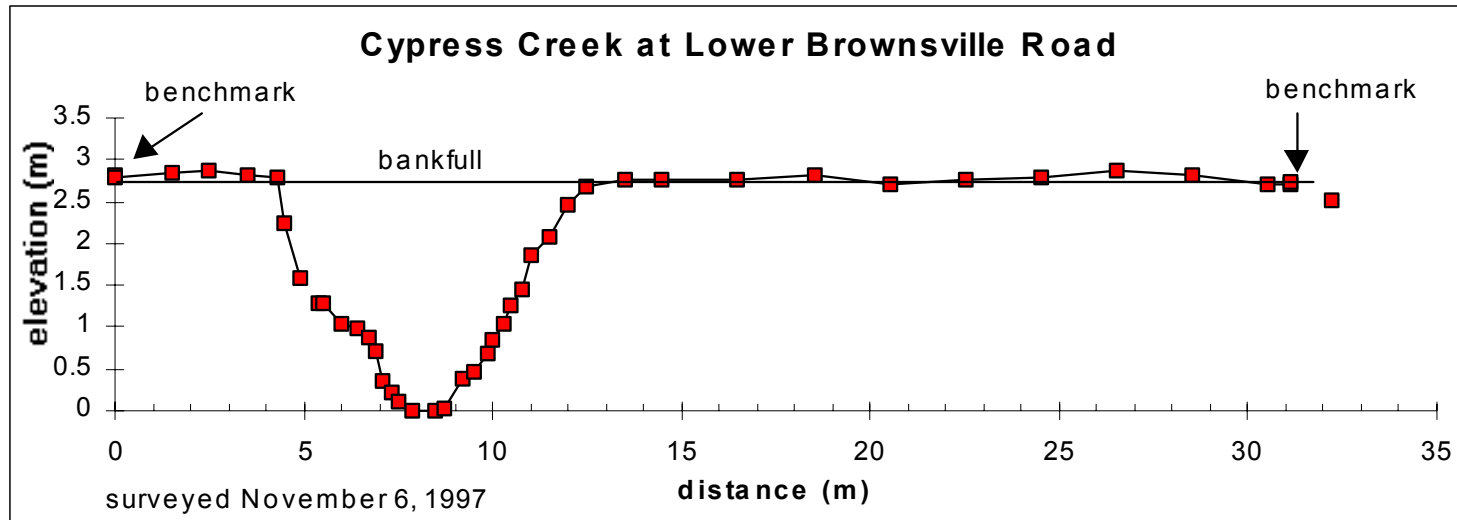
Bankfull Channel Dimensions		
Drainage Area	46 sq. km	18 sq. mi
Area	8.11 sq. m	75.6 sq. ft
Width	8.8 m	28 ft
Mean Depth	0.92 m	2.7 ft
Maximum Depth	1.47 m	4.4 ft
Floodprone Width	200 m	660 ft
Width/Mean Depth Ratio	10	
Entrenchment	23	
Slope	0.0002	
Substrate	mud	
Rosgen Stream Type	E6	

FIGURE A5



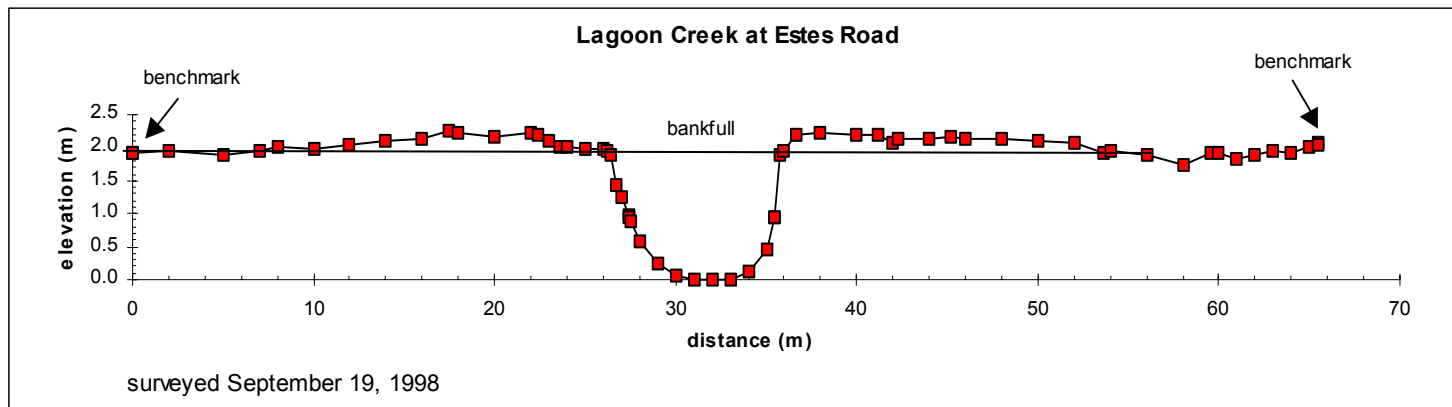
Bankfull Channel Dimensions		
Drainage Area	46 sq. km	18 sq. mi
Area	11.43 sq. m	123.0 sq. ft
Width	10.15 m	33.3 ft
Mean Depth	1.13 m	3.7 ft
Maximum Depth	2.00 m	6.5 ft
Floodprone Width	225 m	82 ft
Width/Mean Depth Ratio	9	
Entrenchment	2.46	
Slope	0.0016	
Substrate	sand	
Rosgen Stream Type	E5	

FIGURE A6



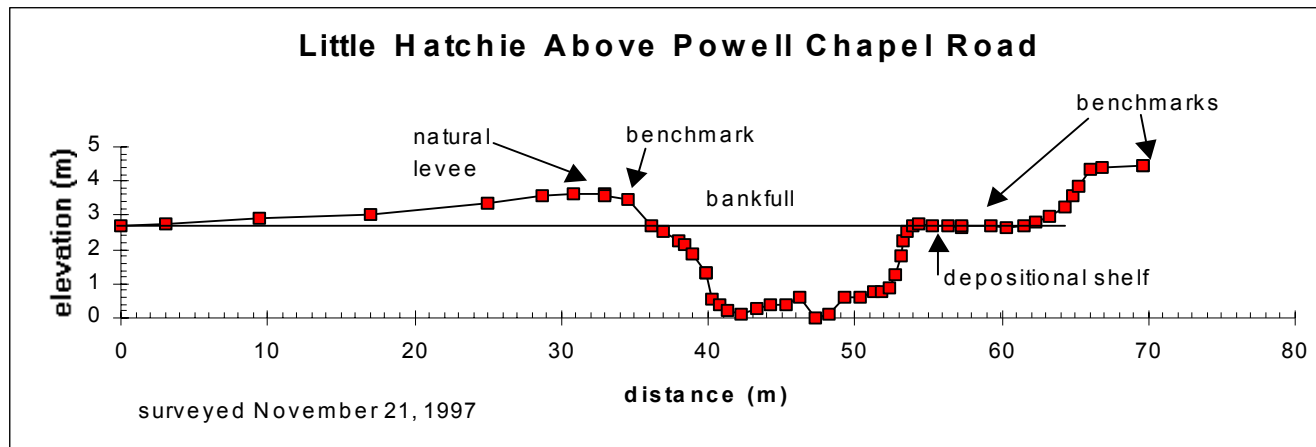
Bankfull Channel Dimensions		
Drainage Area	57 sq. km	22 sq. mi
Area	13.86 sq. m	149.1 sq. ft
Width	10.72 m	35.2 ft
Mean Depth	1.29 m	4.2 ft
Maximum Depth	2.78 m	9.1 ft
Floodprone Width	>150 m	>490 ft
Width/Mean Depth Ratio	8	
Entrenchment	>14	
Slope	low	
Substrate	mud	
Rosgen Stream Type	E6	

FIGURE A7



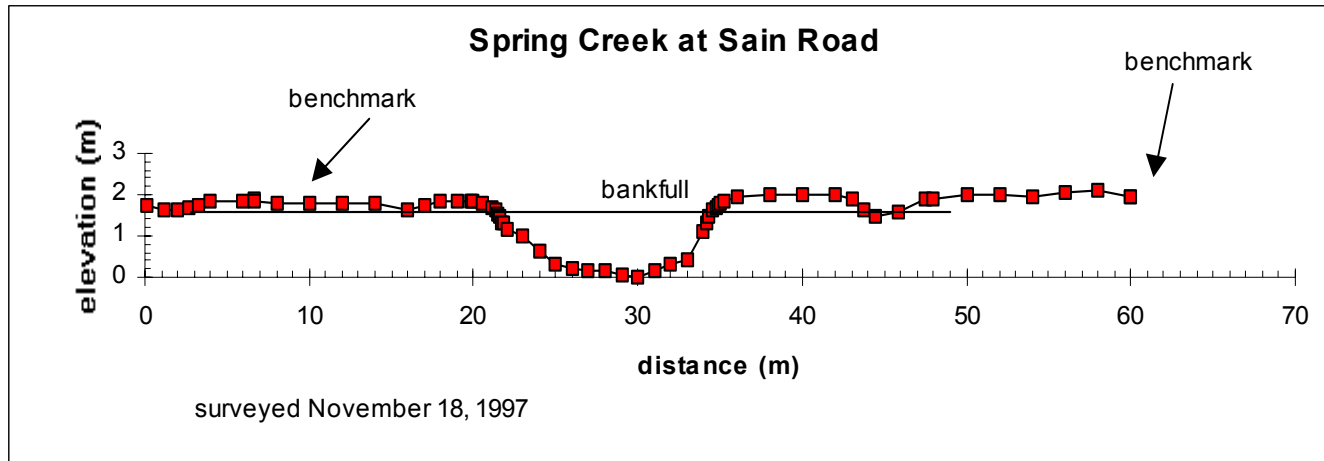
Bankfull Channel Dimensions		
Drainage Area	96 sq. km	37.5 sq. mi
Area	14.71 sq. m	158.2 sq. ft
Width	9.80 m	32.1 ft
Mean Depth	1.50 m	4.9 ft
Maximum Depth	1.94 m	6.4 ft
Floodprone Width	550 m	1800 ft
Width/Mean Depth Ratio	6.00	
Entrenchment	56	
Slope	0.0003	
Substrate	mud	
Rosgen Stream Type	E6	

FIGURE A8



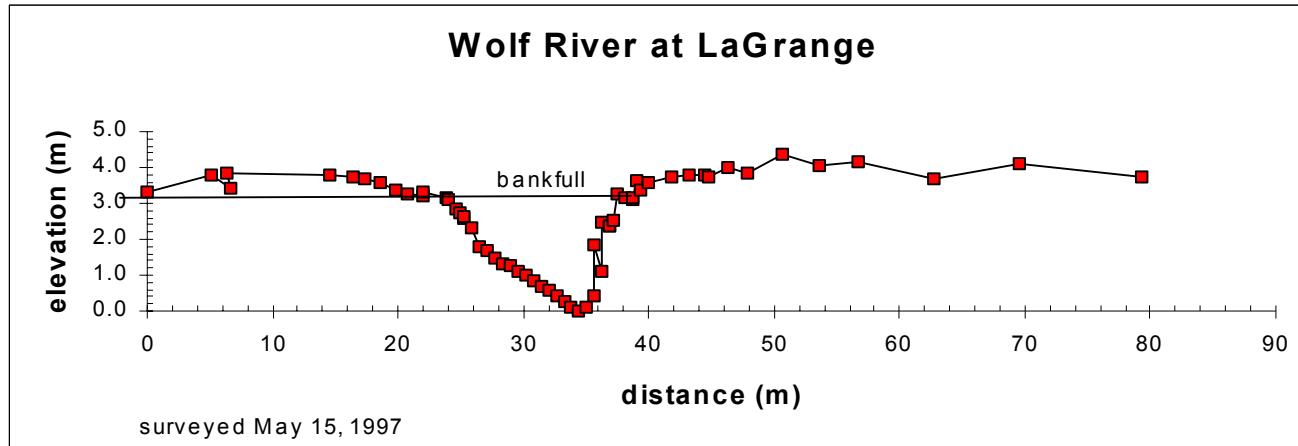
Bankfull Channel Dimensions		
Drainage Area	216 sq. km	84 sq. mi
Area	31.84 sq. m	343 sq. ft
Width	17.8 m	58.4 ft
Mean Depth	1.8 m	5.9 ft
Maximum Depth	2.71 m	8.9 ft
Floodprone Width	120 m	390 ft
Width/Mean Depth Ratio	10	
Entrenchment	6.7	
Slope	0.0007	
Substrate	sand	
Rosgen Stream Type	E5	

FIGURE A9



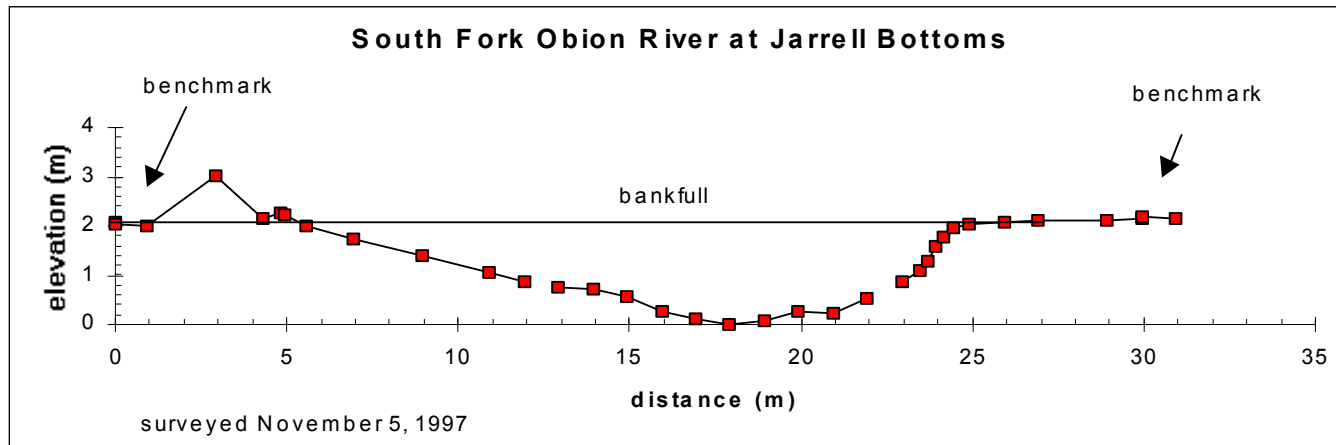
Bankfull Channel Dimensions		
Drainage Area	300 sq. km	117 sq. mi
Area	14.99 sq. m	161.3 sq. ft
Width	13.2 m	43.3 ft
Mean Depth	1.14 m	3.7 ft
Maximum Depth	1.61 m	5.3 ft
Floodprone Width	>150 m	>490 ft
Width/Mean Depth Ratio	11.6	
Entrenchment	11.4	
Slope	0.0003	
Substrate	sand	
Rosgen Stream Type	E5	

FIGURE A10



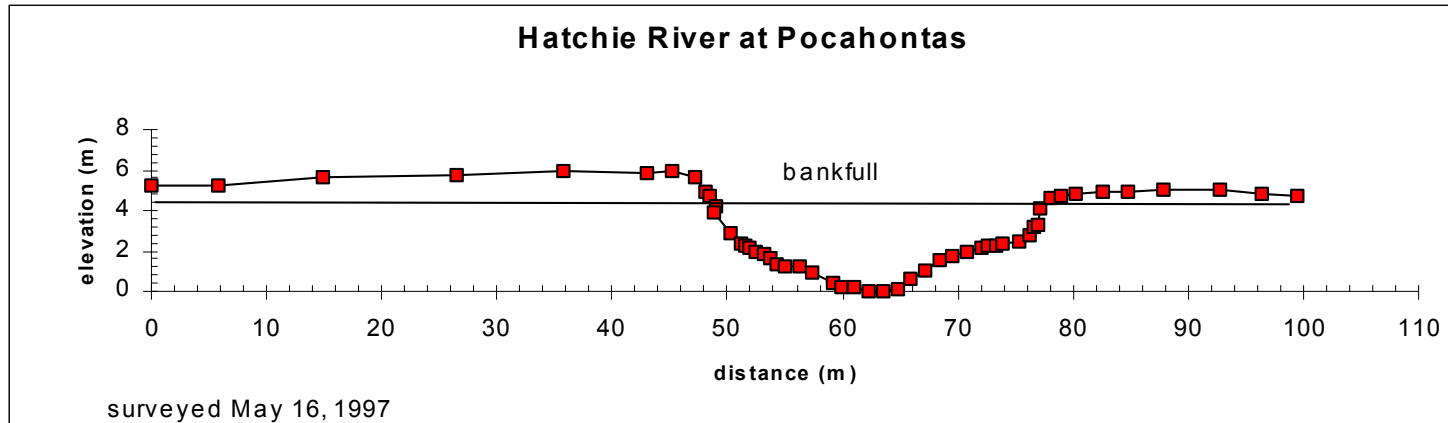
Bankfull Channel Dimensions		
Drainage Area	512 sq. km	200 sq. mi
Area	24.58 sq. m	264.5 sq. ft
Width	15.02 m	49.2 ft
Mean Depth	1.64 m	5.4 ft
Maximum Depth	3.14 m	10.3 ft
Floodprone Width	90 m	300 ft
Width/Mean Depth Ratio	9	
Entrenchment	6	
Slope	very low	
Substrate	sand	
Rosgen Stream Type	E5	

FIGURE A11



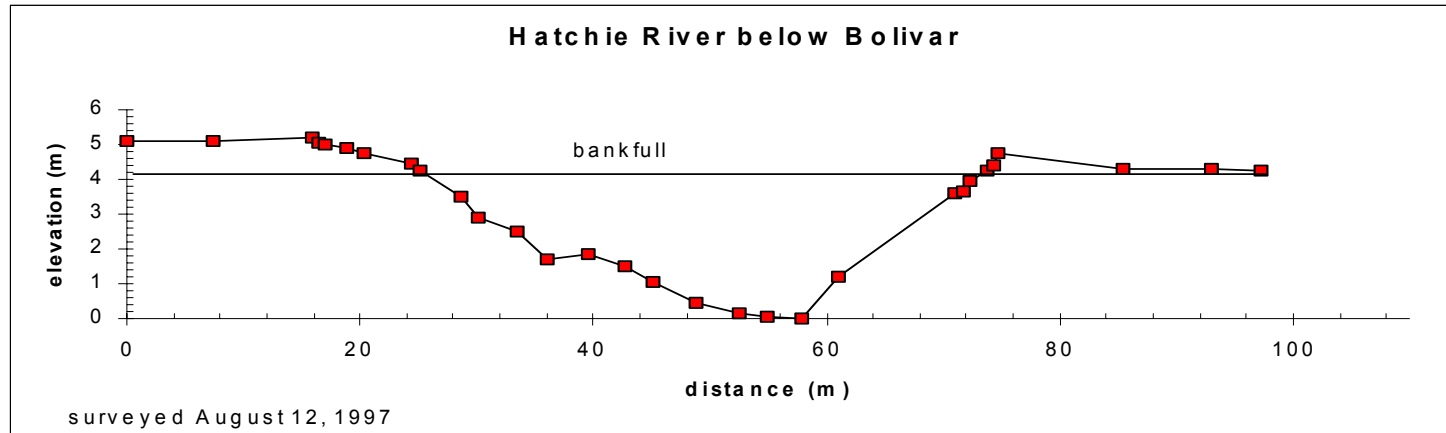
Bankfull Channel Dimensions		
Drainage Area	768 sq. km	300 sq. mi
Area	21.84 sq. m	235.1 sq. ft
Width	18.85 m	61.8 ft
Mean Depth	1.16 m	3.8 ft
Maximum Depth	1.98 m	6.5 ft
Floodprone Width	>200 m	>660 ft
Width/Mean Depth Ratio	16	
Entrenchment	>11	
Slope	very low	
Substrate	mud	
Rosgen Stream Type	C6	

FIGURE A12



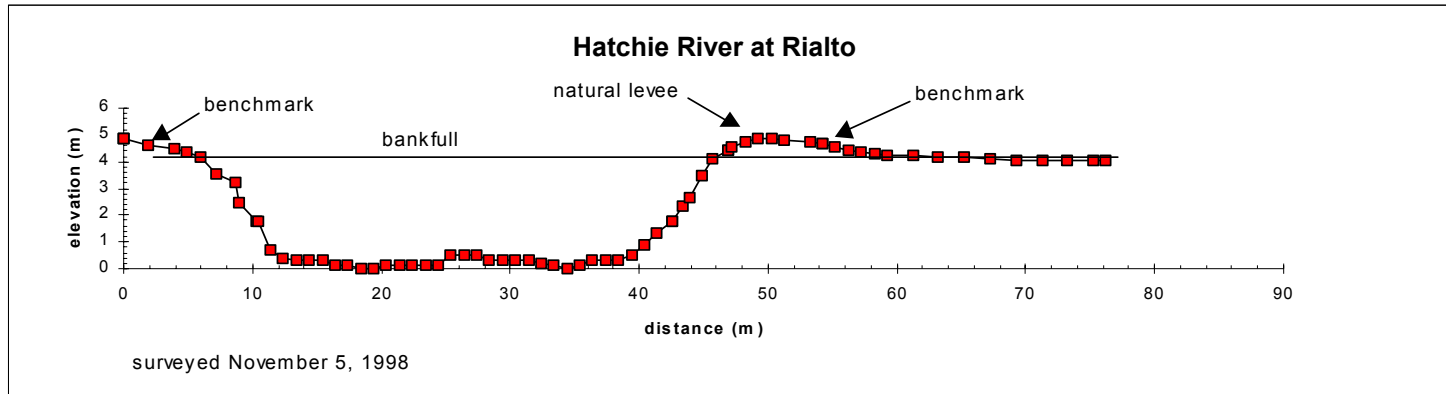
Bankfull Channel Dimensions		
Drainage Area	2148 sq. km	839 sq. mi
Area	91.92 sq m	988.9 sq. ft
Width	30.52 m	100.1 ft
Mean Depth	3.01 m	9.9 ft
Maximum Depth	4.7 m	15.4 ft
Floodprone Width	540 m	1770 ft
Width/Mean Depth Ratio	10	
Entrenchment	18	
Slope	0.0002	
Substrate	mud	
Rosgen Stream Type	E6	

FIGURE A13



Bankfull Channel Dimensions		
Drainage Area	3789 sq. km	1480 sq. mi
Area	119.01 sq. m	1281.1 sq. ft
Width	60.25 m	197.6 ft
Mean Depth	1.98 m	6.48 ft
Maximum Depth	4.27 m	14 ft
Floodprone Width	>600 m	>2000 ft
Width/Mean Depth Ratio	30	
Entrenchment	>10	
Slope	0.0002	
Substrate	sand	
Rosgen Stream Type	C5	

FIGURE A14



Bankfull Channel Dimensions		
Drainage Area	5911 sq. km	2309 sq. mi
Area	131.66 sq. m	1416.5 sq. ft
Width	39.8 m	130.5 ft
Mean Depth	3.31 m	10.9 ft
Maximum Depth	4.17 m	13.7 ft
Floodprone Width	>840 m	>2750 ft
Width/Mean Depth Ratio	12	
Entrenchment	21	
Slope	0.0001	
Substrate	sand	
Rosgen Stream Type	C5	

APPENDIX B

**Cross-Sectional and Planform Geometry of Selected,
Unmodified, Low-Gradient Rivers of Western Tennessee**

submitted to

**Wetlands Section
United States Environmental Protection Agency
Region IV**

April 29, 1999

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INTRODUCTION

The following report is respectfully submitted to the Wetlands Section of the United States Environmental Protection Agency (USEPA). In 1997, personnel with the TN Department of Environment and Conservation, Vanderbilt University, and U.S. Geological Survey proposed a three-agency, collaborative project to develop high quality fluvial geomorphic regional curves specific to western Tennessee. The collaborative final report that includes the regional curves is still forthcoming; the present report serves two purposes.

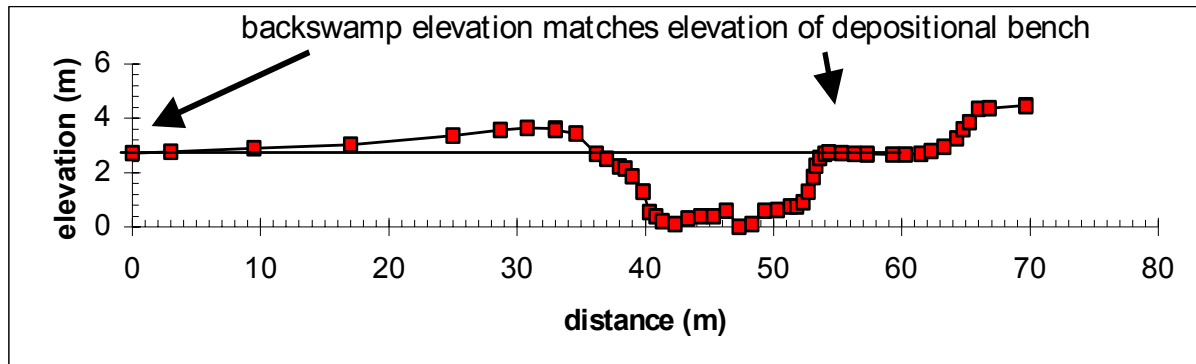
- We introduce most of the cross-sectional data that will be used in the production of the fluvial geomorphic western Tennessee regional curves.
- We provide planform data derived from aerial photographs and topographic maps.

Our report is based upon fieldwork in western Tennessee, analysis of aerial photographs, and interpretation of 1:24,000 scale U.S. Geological Survey topographic maps. The data presented here include cross-sectional geometry and elements of planform geometry for several low-gradient river reaches of western Tennessee that apparently have not been adversely impacted by channelization or broader watershed alteration.

CROSS-SECTIONAL GEOMETRY

"Bankfull" cross-sectional geometry is commonly used in stream restoration design. However, the definition and meaning of "bankfull" in the literature, is as hotly debated as is its field recognition. Particularly troubling is the recognition of "bankfull" dimensions in streams that are out of equilibrium (degrading or aggrading), channelized, or that have naturally high levees. All three of these field conditions exist in western Tennessee. Because we have limited our work to stream reaches that we judge to be naturally-formed and in equilibrium with watershed conditions, our concern was with high, natural levees.

In general, "bankfull" stage is the stage of incipient flooding on rivers that are in equilibrium with their watersheds. The tops of natural levees in western Tennessee do not represent the stage height of incipient flooding because these levees are discontinuous features. We adopted the following, internally-consistent, way of choosing bankfull geometry in the field. Because the natural levees are discontinuous, the general elevation of the floodplain behind the levees ("backswamp") is approximately the same as the local river stage at the onset of flooding. Therefore, we adopted the backswamp elevation as the bankfull elevation. In most cases, there are other local geomorphic features, such as a point bar, channel depositional bench, or a break-in-slope on the riverbank that corroborate our choice of bankfull elevation. A cross-section of the Little Hatchie Creek provides an example of the backswamp elevation corresponding to the elevation of a depositional bench (Fig. 1). Note that the levees at this site stand approximately one meter above what we consider to be "bankfull" elevation. Downstream from the cross-section, the top of a point bar is at approximately the same elevation as the backswamp.

FIGURE 1: Cross-section of Little Hatchie Creek above Powell Chapel Road

Of nineteen cross-sections that were surveyed, we regressed only fifteen cross-sections for the regional curve. The four that were not retained were not in equilibrium because of the influence of excess sedimentation, beaver dams, or nearby channelization. Table 1 provides bankfull channel geometry for the fifteen cross-sections we retain for the regional curve analysis.

TABLE 1: Bankfull Dimensions of Selected Unmodified Streams in Western Tennessee

	Reference Reach Location	Drainage Area (km²)	Area (m²)	Width (m)	Mean Depth (m)	Width/ Mean Depth	Bed Material	Rosgen Stream Class
1	Marshall Creek at Van Buren Rd.	15	2.14	4.94	0.43	12	sand	E5/C5
2	West Fork Spring Creek at Van Buren Rd.	36	9.68	9.18	1.07	9	sand	E5
3	Cypress Creek at Howell Buntin Rd.	43	6.74	5.61	1.19	5	silt/clay	E6
4	Spencer Creek at Hammett Rd.	46	7.06	8.54	0.79	11	silt/clay	E6
5	Harris Creek above Potts Chapel Rd.	46	11.43	10.15	1.13	9	sand	E5
6	Cypress Creek at Lower Brownsville Rd.	57	13.86	10.70	1.28	8	silt/clay	E6
7	Lagoon Creek near Estes Rd.	96	14.69	9.76	1.52	6	silt/clay	E6
8	Little Hatchie Creek above Powell Chapel Rd.	216	31.84	17.80	1.80	10	sand	E5
9	Spring Creek at Sain Rd.	300	14.99	13.20	1.13	12	sand	E5/C5
10	Wolf River at La Grange	512	24.63	13.72	1.80	8	sand	E5
11	South Fork Obion River at Jarrell Bottoms	768	21.85	18.84	1.16	16	--	C
12	South Fork Obion River at Jarrell Bottoms	768	22.31	9.15	2.44	4	--	E
13	Hatchie River at Pocahontas	2148	95.90	32.01	2.99	11	silt/clay	E6
14	Hatchie River at Bolivar	3789	119.07	60.37	1.98	30	sand	C5
15	Hatchie River at Rialto	5911	131.62	39.79	3.29	12	sand	C5

Definitions for Table 1:

Drainage Area - land surface area within watershed contributing flow to the reference reach in square kilometers

Area - bankfull cross-sectional area of the reference reach channel in square meters

Width - bankfull top width of the reference reach channel in meters

Mean Depth - Area / Width

Width / Mean Depth - aspect ratio of bankfull channel

Bed Material - the dominant particle size on the channel bottom at the cross-section

Rosgen Stream Class - stream type as published by Rosgen (1994)

PLANFORM GEOMETRY

Large-scale, "natural" restoration of river systems requires knowledge of stable planform geometry. The vertical stability of a river is in part a function of the average channel slope (S_c), or gradient. The channel slope, in turn, is a function of sinuosity (K) and average valley slope (V_s). Among naturally stable rivers there is a clear relationship between bankfull width and meander length (L_m), the down-valley distance between meander loops. The radius of curvature (R_c) in a bend will control the average stress imparted on the outer bank of the river, and is one factor influencing large-scale roughness. Both the amplitude and meander belt width (W_b) provide a minimum measure of how much valley width, or floodplain, is available to accommodate frequent flood events. Table 2 gives the planform geometry of nine reference reaches selected in western Tennessee.

Dimensionless ratios allow one to scale certain geometry parameters from reference reaches so that they are appropriately sized for a given restoration reach. The most commonly used denominator for these dimensionless ratios is the bankfull width. Under the current funding, it was not possible to field check bankfull width at six of the nine sites used for the planform study. For the sites lacking field data, we have derived approximate bankfull channel widths using the preliminary western Tennessee regional curves for bankfull geometry. The regression equation is $W_{b_{kf}}(DA) = 9.85 \times D.A.^{0.34}$, where D.A. is the drainage area for the reach in mi^2 , and the bankfull width is in feet. The three sites in Table 3 where bankfull geometry was surveyed in the field (Lagoon Creek, Hatchie River at Pocahtontas, and Hatchie River at Rialto) show that field observations ($W_{b_{kf}}$) agree well with the calculated values ($W_{b_{kf}}(DA)$). We note that this measure of reliability is somewhat circular since those three sites were among the fifteen that we regressed to derive the $W_{b_{kf}}(DA)$ formula. An independent measure of the accuracy of the $W_{b_{kf}}$ term is to calculate $W_{b_{kf}}$ as a function of R_c , based upon the formula given by Williams (1986). Williams (1986) found that $W_{b_{kf}}(R_c) = 0.71 \times R_c^{0.89}$. We used the R_c values from Table 2 to recalculate bankfull width for each reach. These values are labeled $W_{b_{kf}}(R_c)$ in Table 3. Table 3 shows that there is reasonable agreement between the two independent methods-- $W_{b_{kf}}(DA)$ and $W_{b_{kf}}(R_c)$ --of deriving bankfull width, and that both are corroborated by field surveys where available. We have chosen to use the surveyed bankfull width, where available, as the denominator in the dimensionless ratios of Table 3. Where field data are not available, we have used the bankfull width derived from the preliminary regional curve for the ratios in Table 3.

TABLE 2: Planform Geometry of Selected Unmodified Streams in Western Tennessee

River	Location	K	Sv	Sc	Lm (m)	Rc (m)	Amplitude (m)	Wb (m)
Lagoon Creek (tributary to Hatchie R.)	near Estes Road	1.7	0.0006	0.0003	120	20 (10-50)		210
Cypress Creek (tributary to Tusculmbia R.)	below Muddy Creek	1.9	0.00025	0.0001	210	50 (25-115)	200 (70-340)	300
Hatchie River	at Wolfpen Road	2.1	0.0005	0.0002	340	30	240 (170-360)	410
Middle Fork Forked Deer River	above Eaton, TN	1.8	0.0004	0.0002	220	50 (25-70)	250 (130-470)	500
Wolf River	at Rossville	1.9	0.0008	0.0004	310	90 (40-170)	170 (100-480)	450
Hatchie River	at Pocahontas	2.3	0.0003	0.0002	410	65 (50-215)	260 (190-310)	540 (360-720)
Hatchie River	Hatchie, TN	2.1	0.0004	0.0002	330	90 (30-290)	400 (50-1000)	800
Hatchie River	Hatchie Bottom Wildlife Refuge near I-40	2.3	0.0004	0.0002	460	110 (85-170)	370 (190-570)	780 (720-840)
Hatchie River	at Rialto	2.3	0.0002	0.0001	400	130	590 (480-720)	840

Note: Some entries have average values followed by the range of values observed listed in parantheses. Calculations involving these parameters use the average value. Remnant meanders were analyzed for Middle Fork Forked Deer River and Cypress Creek.

Definitions for Table 2:

K - Sinuosity is (channel length) / (valley length) as measured from 1:24000 scale U.S.G.S. quadrangle, 1:25,000 scale infrared aerial photographs, or 1:10,000 scale black-and-white aerial photographs.

Sv - Valley Slope is the (valley rise) / (valley length) as measured from 1:24000 scale U.S.G.S. quadrangles.

Sc - Channel Slope is Sv / K

Lm - Meander Length is (valley length) / (number of full meander waves), where both were measured from same sources as K.

Rc - Radius of Curvature is the radius of the circle that best fits a meander loop between inflection points, along the centerline of the channel. Rc was measured by fitting a circular drafting template or dividers to meander loops on the sources listed for K.

Amplitude - Amplitude is the wave height of individual meander loops, as measured from the centerline of the channel, measured from the same sources as K.

Wb - Meander Belt Width is the average width of a corridor drawn to encompass the full meander pattern across a floodplain, measured from the same sources as K.

TABLE 3: Dimensionless Ratios for Planform Geometry of Selected Unmodified Streams in Western Tennessee

River	Location	D.A. (km ²)	W _{bkf} (m)	W _{bkf} (DA) (m)	W _{bkf} (Rc) (m)	WbR	RcR	LmR
Lagoon Creek (tributary to Hatchie R.)	near Estes Road	96	11	10	10	19	1.8	11
Cypress Creek (tributary to Tuscumbia R.)	below Muddy Creek	379	--	16	23	18	3.0	13
Hatchie River	At Wolfpen Road	794	--	21	15	19	1.4	16
Middle Fork Forked Deer River	above Eaton, TN	896	--	22	23	23	2.3	10
Wolf River	at Rossville	1287	--	25	39	18	3.6	12
Hatchie River	at Pocahontas	2148	32	30	29	19	2.2	14
Hatchie River	Hatchie, TN	4400	--	38	39	21	2.4	9
Hatchie River	Hatchie Bottom Wildlife Refuge, near I-40	4756	--	39	46	20	2.8	12
Hatchie River	Rialto	5911	40	42	54	21	3.3	10
AVERAGE VALUES						20	3	12

Definitions for Table 3:

D.A. is the drainage area above the study reach.

W_{bkf} is the bankfull width surveyed in the field.

W_{bkf} (DA) is the bankfull width calculated from the preliminary regional curve as a function of drainage area.

W_{bkf} (Rc) is the bankfull width calculated as a function of radius of curvature.

WbR is the ratio of meander belt width to bankfull width.

RcR is the ratio of radius of curvature to bankfull width.

LmR is the ratio of meander length to bankfull width

The average meander belt width ratio (WbR) is 20 in low gradient rivers of western Tennessee (Table 3). All of the streams surveyed for the western Tennessee regional curve fall into either the C or E Rosgen (1994) stream categories, or are on the border between the two categories, as indicated by a width/average depth value of about 12 (Table 1). Class C streams typically have a WbR ranging from 4 to 20, whereas class E streams typically have a WbR ranging from 20 to 40 (Rosgen, 1994). Thus an average WbR value of 20 in the streams of western Tennessee is a further indication that they typically have characteristics of both C and E stream types.

There is little published data available for evaluating the RcR values we obtained from western Tennessee rivers (Table 3). According to data in Williams (1986), RcR typically ranges between two to three, consistent with the values of Table 3. Although we report an average value of 3 for RcR, there is great variability in this parameter in natural streams of western Tennessee. For example, there are exceptionally long, broadly-arching reaches with high Rc values, as well as much tighter, "hairpin" turns. The temporal stability of a wide range of planform geometries arises in part from the presence of wooded, cohesive banks that apparently resist erosion very well.

It has been widely published that the typical pool-pool spacing in rivers ranges from 10 to 14 times the bankfull width (e.g., Leopold, 1994). The average value among the streams measured in western Tennessee is 12, with a range from 9 to 16. The values that fall significantly outside the published range (10-14) may be from reaches that are out of equilibrium. Conversely, the higher variability may be a feature of natural streams of western Tennessee.

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Williams, G.P., 1986, River meanders and channel size: Journal of Hydrology, v. 88, p. 147-164.

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