REGIONAL CHANNEL CHARACTERISTICS FOR MAINTAINING NATURAL FLUVIAL GEOMORPHOLOGY IN FLORIDA STREAMS

Prepared for:

FLORIDA DEPARTMENT OF TRANSPORTATION

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1 INTRODUCTION & BACKGROUND

1.1 Purpose

This study was conducted by the U.S. Fish and Wildlife Service (USFWS) for the Florida Department of Transportation (FDOT) to develop regional curves in two hydro-physiographic regions of the Florida Panhandle Coastal Plain: the Northwest Florida Coastal Plain and the North Florida Coastal Plain. For the purpose of this study, the Florida Panhandle was loosely defined as the region from the Suwannee River basin west, to the border of Alabama. Due to a limited number of survey sites in the region, the Northwest Florida Coastal Plain curves were augmented with two sites from the Alabama Middle Coastal Plain, and the North Florida Coastal Plain curves were augmented with six sites from the Georgia Middle Coastal Plain (described as Lower Coastal Plain by the Georgia Department of Transportation, GDOT).

The regional curves were developed by studying naturally stable stream channels that have been formed by existing rainfall, stream flow, geology, soils, and vegetation. Detailed stream information was collected through surveys of the channels. The survey data were then used to create the mathematical relationships of the regional curves.

1.2 Hydraulic Geometry Relationships versus Regional Curves

Stream channel hydraulic geometry theory, developed by Leopold and Maddock (1953), describes the relationships between dependent variables, such as channel width, depth, and area, as functions of an independent variable, such as discharge. These relationships can be developed at a single cross-section (station) or across many stations along a reach. Hydraulic geometry relationships are empirically derived and can be developed for a specific river or watershed in the same physiographic region with similar rainfall/runoff relationships.

Regional curves were first developed by Dunne and Leopold (1978) and relate bankfull channel dimensions to drainage area. Gage station analyses throughout the United States have shown that the bankfull discharge has an average return interval of approximately 1.5 years, or 66.7% annual exceedence probability, and a return interval range of 1 to 2 years. The primary purposes for developing regional curves are to aid in identifying bankfull stage and dimension in un-gaged watersheds and to help estimate the bankfull dimension and discharge for natural channel designs.

1.3 Bankfull Discharge and Other Channel-Forming Flows

Bankfull, effective, and dominant discharge are three common terms used to describe channel-forming flows in streams that are free to adjust their dimension, pattern, and profile. All of these flows are considered to be the channel-forming agent that maintains dimension, pattern, and profile and transports the bulk of sediment over time (Wolman and Leopold, 1957; Wolman and Miller, 1960), but their definitions vary by degree of quantification. Dominant discharge is a qualitative term that means channel-forming flow; it is rarely used in scientific investigations. Effective discharge is the most quantitative measure of a channel-forming flow and is the product of a sediment transport rating curve and the flow duration curve (Wolman and Miller, 1960); it is literally the discharge that transports the most sediment over time (Andrews, 1980). The calculation of effective discharge is difficult, because it requires field data of bedload and total suspended sediment, coupled with discharge, over a wide range of flows. Even if these parameters are modeled, some field data must be collected to calibrate the model.

The method most often used for estimating the channel-forming flow is field identification of the bankfull stage. There are numerous definitions of bankfull stage as well as numerous methods for its identification in the field (Wolman and Leopold, 1957; Nixon, 1959; Schumm, 1960; Kilpatrick and Barnes, 1964; Williams, 1978; and Knighton, 1998). It is generally accepted that bankfull stage is the discharge that fills a natural, stable channel to the elevation of the active floodplain and represents the break between erosion and depositional processes. Field indicators include the back of point bars, significant breaks in slope, changes in vegetation, the highest scour line, and the top of the bank (Leopold, 1994). In the field, the correct identification of the bankfull stage can be difficult and subjective (Williams, 1978; Knighton, 1998; and Johnson and Heil, 1996). It is especially difficult in the humid southeast because of dense, understory vegetation, a long history of channel modification, and subsequent adjustment in channel morphology. Regional curves, such as the ones developed in this report, remove much of the subjectivity by providing an empirical method for checking the bankfull indicator in the field. The check is most often done by measuring the bankfull cross-sectional area on the study reach and overlaying it on the regional curve for the site's drainage area. Under most circumstances, the project cross-sectional area should plot close to the predicted value as described by the confidence and prediction intervals of the regional curve.

1.4 Sand Bed Stream Morphology

The majority of regional curves have been developed for gravel bed streams in alluvial valleys. These gravel bed streams have riffle/pool sequences, where the riffles are composed of gravel-size particles and located in crossover reaches, between pools. Sand bed channels are defined by bed materials of median size, less than 2 millimeters (mm) along the intermediate axis (Bunte and Abt, 2001). Bed material features, such as ripples, dunes, planebeds, and antidunes, characterize the sand bedform. Although sand bed streams technically do not have riffles, the term is often used to describe the crossover reach between pools, and it was used in this report to represent the channel characteristics.

Sediment transport in sand bed streams is usually assessed in terms of capacity, or a stream's ability to move a mass of sediment past a cross-section within a unit of time, typically expressed as pounds per second or tons per year. Using actual data from monitored bankfull events, sediment transport capacity can be assessed directly, if a sediment transport rating curve has been developed for the project site. Since this curve development process is time consuming and costly, other empirical relationships are commonly used to assess sediment transport capacity. The most common capacity indicator is stream power. Stream power can be calculated a number of ways, but the most common is:

$\omega = \gamma QS/W$, where (Equation 1)
ω = unit stream power in W/m^2
γ = specific weight of water (9810 N/m^3). $\gamma = \rho g$ where ρ is the density of the water-sediment mixture (1,000 kg/m^3) and g is the acceleration due to gravity (9.81 m/s^2)
Q = bankfull discharge in m^3/s
S = channel slope (dimensionless)
W = bankfull channel width in meters

Note: 1 ft-lb/sec/ft^2 = 14.56 W/m^2

The size, stage, and variation of sand bedforms are formed by changes in unit stream power, as shown in Figure 1.1 and as described below (Knighton, 1998). Sand bedforms are related to local variations in stream power and sediment transport rate, which cause minor to major variations in aggradation and degradation (Gomez, 1991).

Sand bedforms can be divided between low-flow and high-flow regimes, with a transitional zone between the two. Ripples occur at low flows, where the unit stream power is just high enough to entrain sand-sized particles. This entrainment creates small wavelets from random accumulation of sediment that are triangular in profile, with gentle upstream slopes and steep downstream slopes. The ripple dimensions are independent of flow depth, and heights are less than 0.02 meters.

As unit stream power increases, dunes eventually replace ripples. Dunes are the most common type of sand bedform and have a larger height and wavelength than ripples. Unlike ripples, dune height and wavelength are proportional to flow depth. The movement of dunes is the major cause of variability in bed-load transport rates in sand bed streams. Dunes are eventually washed out, to leave an upper-flow plane bed characterized by intense bedload transport, preventing the patterns of erosion and deposition required for dune development. This stage of bedform development is called the transitional flow regime, between the low-flow and the high-flow regime features (Knighton, 1998).

As flow continues to increase, standing waves develop at the water surface, and the bed develops a train of sediment waves (antidunes) which mirror the surface forms. Antidunes migrate upstream as a result of scouring on the downstream face and deposition on the upstream face, in a reversal of the formation process of ripples and dunes. Antidunes can also move downstream or remain stationary for short periods (Knighton, 1998).

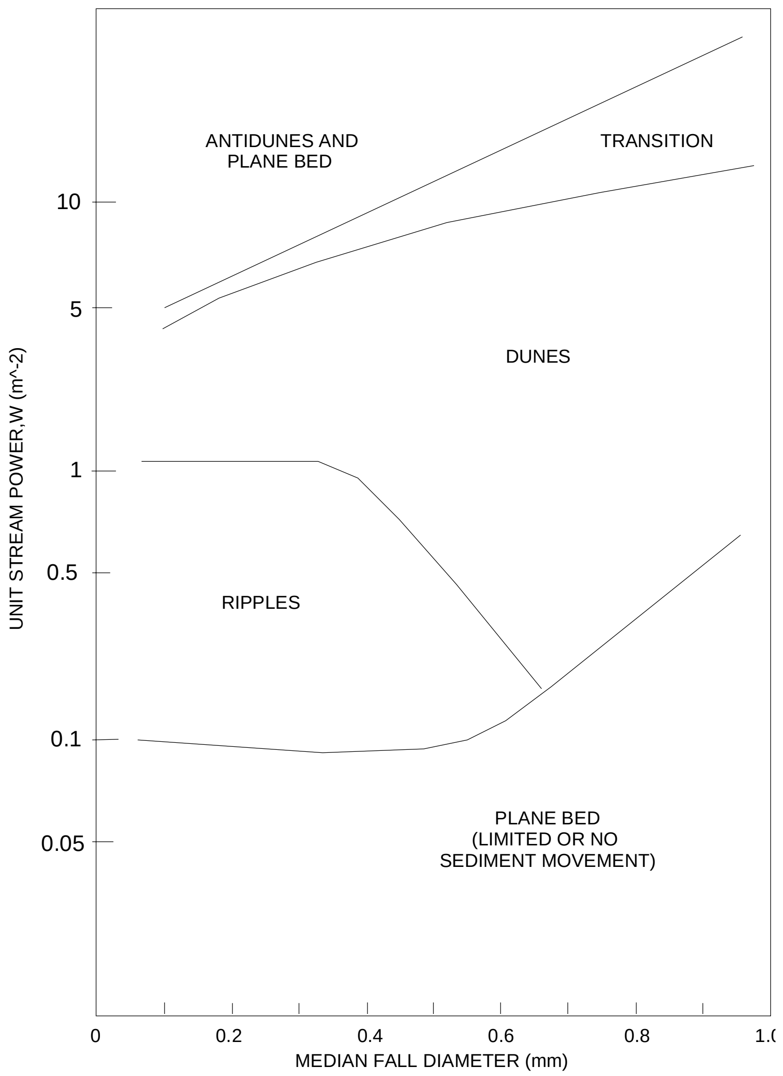

Figure 1.1 Median Fall Diameter versus Unit Stream Power for Sand Bed Forms (after Knighton ,1998, and Simons and Richardson, 1966).

2 SITE SELECTION AND ASSESSMENT

2.1 Characterization of the Study Area

The Florida Panhandle is entirely contained within the Coastal Plain physiographic province, which is characterized by the broad valleys, low topographic relief, and gentle slopes shown in Figure 2.1. Within the Panhandle region, there is a significant distinction in precipitation, and more specifically, in runoff between the western Panhandle of Florida and the remainder of the state (Gerbert et al., 1987). By evaluating these rainfall/runoff relationships, this study delineated two hydro-physiographic regions for the Florida Panhandle Coastal Plain. At a broad level, two hydro-physiographic regions that intersect the Florida Panhandle were developed: the Southeast Coastal Plain and the Gulf Coastal Plain (Figure 2.1). For the purpose of this study, the Panhandle was divided at the Aucilla River, approximately, with the Northwest Florida Coastal Plain hydro-physiographic region to the west, and the North Florida Coastal Plain hydro-physiographic region to the east (Figure 2.2).

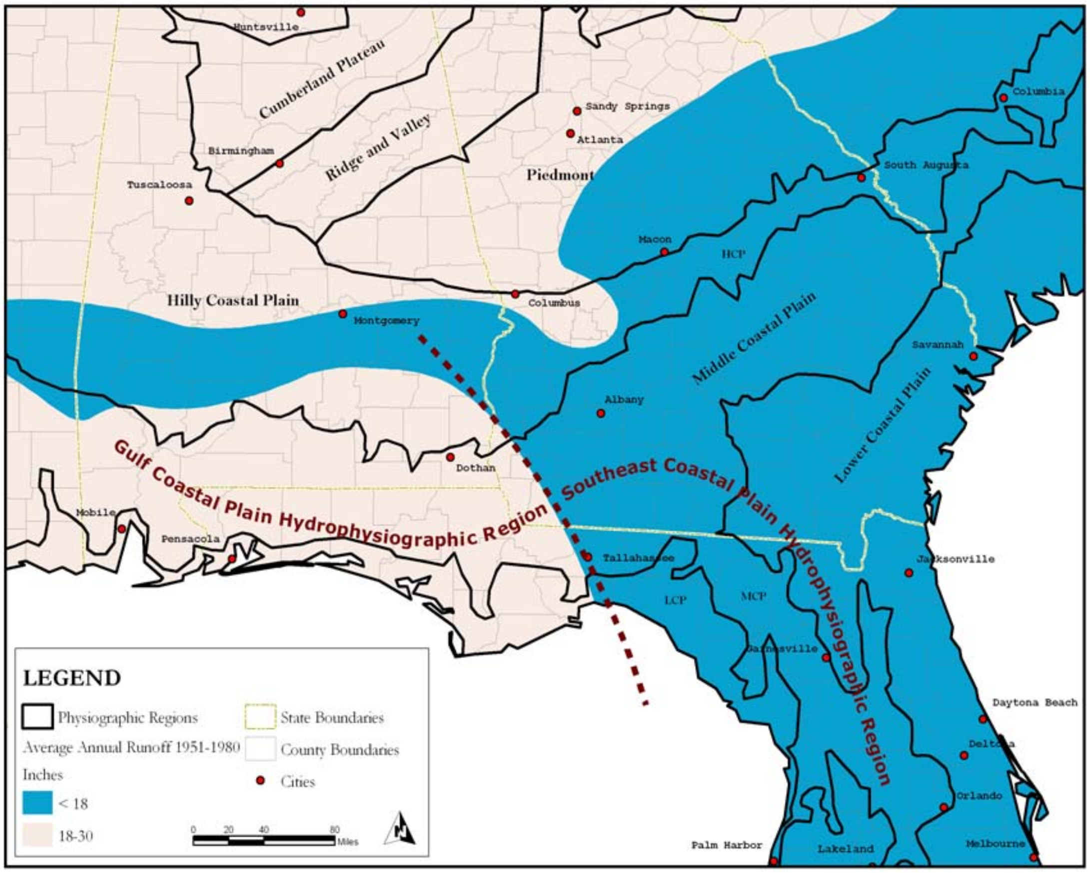

Figure 2.1 Intersection of the Southeast and Gulf Coastal Plains with Average Annual Rainfall Runoff from 1951 – 1980 along the Florida Panhandle (modified from Gerbert et al., 1987, and Miller and Robinson, 1994)

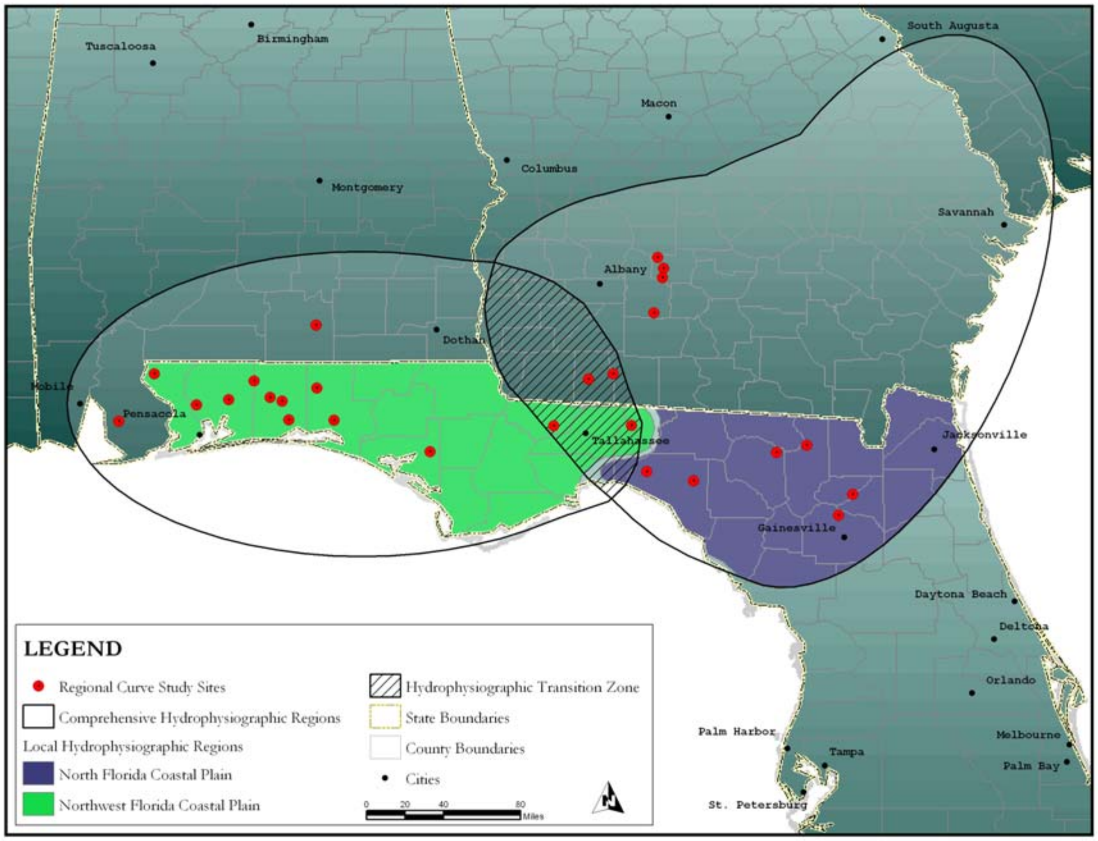

Figure 2.2 North and Northwest Florida Coastal Plain Hydro-physiographic Regions

2.1.1 Northwest Florida Coastal Plain

The majority of the Northwest Florida Coastal Plain is comprised of the middle Coastal Plain physiographic province, characterized by greater topographic relief (elevations ranging from 75 to 600 feet above sea level) than the lower Coastal Plain. Precipitation averages between 52 and 64 inches annually. Rainfall runoff values range from 18 to 40 inches annually (Gerbert et al., 1987). Coarse-textured soils are prominent throughout the province, due to prolonged exposure of marine terrace sediments. The drainage density of the middle Coastal Plain is higher and more well-established than that of the lower Coastal Plain (Miller and Robinson, 1994). The underlying geology is primarily composed of sands, clays, and organics from the Pleistocene, Holocene, and Pliocene eras. Major drainage basins include the Ochlockonee, Apalachicola, Choctawatchee, Escambia, and Perdido.

2.1.2 North Florida Coastal Plain

Less relief is evident within the North Florida Coastal Plain. The lower Coastal Plain comprises a larger extent of the province, where elevations generally remain less than 100 feet above sea level, and water tables are typically high. Precipitation averages between 52 and 56 inches annually and results in rainfall runoff averages between 8 and 18 inches annually (Gerbert et al., 1987). Coarse, sandy soils are predominant, but organic soils tend to coincide with topographic depressions and swamp lands. These lower-lying areas are common, as a result of repeated inundation by coastal waters during receding periods of northern glaciation, less than 20,000 years ago (Miller and Robinson, 1994). Several limestone geologic units lie along the Gulf coast of this province, dating from the Oligocene and Eocene eras. Major drainage basins include the Suwannee, Steinhatchee, Econfina, and Aucilla.

2.2 Site Selection

Twenty-three (23) United States Geologic Survey (USGS) gage stations were identified, with at least ten years of continuous or peak discharge measurements, no major watershed impoundments, no significant change in land use during or since the gaging period, and less than 10% impervious cover over the watershed area. These sites appeared to be geomorphically stable, with minimal recent human impacts. The study population was also limited to drainage areas of between 1 and 500 square miles. To supplement data collected in gaged watersheds, three stable, un-gaged watersheds were also selected. These reaches had no major watershed impoundments, no significant change in land use over the past ten years, less than 10% impervious cover over the watershed area, and stream bank heights that equaled the bankfull stage.

A total of 14 sites were selected for the Northwest Florida Coastal Plain Region, while 12 sites were selected for the North Florida Coastal Plain Region. Six of the sites used for the North Florida Coastal Plain regional curve are from data previously collected in the Georgia Coastal Plain by Buck Engineering (Georgia DOT, 2003). Due to the similar topography, geology, and rainfall/runoff relationships, the Georgia Coastal Plain and the North Florida Coastal Plain are treated as one hydro-physiographic region for this study.

The watershed area for each gage station was delineated based on digitized USGS 7.5 minute topographic maps, using ArcMap™ GIS and National Geographic Topo!$^{©}$ software. An assessment of the watershed was made to determine if the gage station met the study criteria described above. The percent impervious cover was assessed for each watershed using the topographic maps and aerial photography. A detailed, quantitative analysis of impervious cover was not completed. The following gage station records were obtained from the USGS: 9-207 forms (discharge summary notes), stage/discharge rating tables, annual peak discharges, established reference marks, and flood frequency analyses results.

2.2.1 Gage Selection

All currently and recently active, rural, and non-tidal USGS gages in the Florida Panhandle Coastal Plain with a drainage area of less than 500 square miles were considered for inclusion in the study. Gages were identified using the USGS site inventory (http://ga.waterdata.usgs.gov/nwis/) and with consultation from the USGS and USFWS staff. Gages were prioritized by the length, currency, and continuity of their discharge record. Forty-six gages meeting the criteria were visited during preliminary field visits. Since only fifteen of these sites we deemed to be suitable reaches for the study, potential reference reach quality streams were also considered for inclusion. Two gages from Alabama and 6 gages from Georgia were later identified for inclusion, based on their respective hydro-physiographic characteristics.

A total of 46 USGS gaged and 34 un-gaged streams were visited during the field assessment portion of the project. The majority of these sites did not meet the study inclusion criteria discussed below. Most sites were rejected due to one of three factors that prevented an accurate determination of bankfull stage and/or dimensions: 1) the site was characterized by an anastomosed channel or was simply swampland with no defined channel; 2) the site was characterized by incision and unstable banks; or 3) the site consisted of a limestone or gravel bed stream.

2.2.2 Inclusion Criteria

Once the inventory of gage sites and potential reference reaches was completed, a field reconnaissance visit was conducted. The purpose of the field reconnaissance was to make the following observations and determinations:

1. The stream reach must be a single-thread channel and not a Rosgen DA (anastomosed) stream type (Rosgen, 1994). The DA stream type is discussed in more detail in the following section.
2. Beaver dams must not hydraulically impact the site. This process did not rule out beaver activity in the watershed, just at the project reach.
3. The channel must be free to naturally adjust its dimension; e.g., the channel must not be armored by riprap.
4. Sites with recent dredging and/or bank vegetation removal were eliminated.
5. The bank height ratio (lowest bank height divided by the bankfull maximum depth) must be less than 1.5 for gage stations and 1.2 for reference reaches. Rosgen (1996) reported that a bank height ratio of 1.3 or greater is indicative of an unstable reach. A higher bank height ratio was allowed for gage stations because of the value in obtaining accurate discharge and flood frequency information.
6. For most sites, particularly the reference reaches, a drive-through survey was completed throughout the watershed to verify that land use was not rapidly changing.

Many potential sites were rejected due to the presence of braided channels and the lack of sediment transport through swamp systems. Many of the USGS gages visited had extensive wetland and bottomland forest areas upstream of the gaged road crossing, with no clear, single-thread channel present. These swampy systems often extended for thousands of feet upstream and downstream from the gage. Braided channels were found below the gages, but more often, deeply-incised streams were the cause for elimination of potential study reaches below gages. The incised channels were unstable in many cases and provided few, if any, reliable bankfull indicators. In many cases, incision continued downstream, eliminating reaches from consideration. Gravel bed or limestone bed streams were not included in this study.

2.2.3 Study Sites

Twelve sites in the Northwest Florida Coastal Plain, six sites in the North Florida Coastal Plain, six sites in the Georgia Coastal Plain, and two sites in the Alabama Coastal Plain were selected. Elevations of study sites ranged from 8 to 405 feet above sea level. Further descriptions of study reaches are provided in Section 4 and in Appendix I.

Of the twenty-three USGS gages selected, only ten are active, continuous discharge gages. Five other gages are discontinued but have collected continuous discharge data. Eight sites were discontinued and only measured annual peak discharge. The data for these gages are useful for estimation of bankfull discharge and flood frequency statistics. Two sites included in the study, Muddy Branch and Baggett Creek, had new bridges installed with reference marks not yet tied to the gage datum, so gage discharge estimates could not be developed. Gage data and flood-frequency analysis is located in Appendix II.

Every attempt was made to locate the study site such that the hydraulic influence of a bridge or culvert would be minimized. The study reach was at least twenty bankfull widths or, at least, one meander wavelength. Once a site was accepted, a stable, representative segment was selected, and the following features were flagged: the study reach beginning and end, two riffle cross-sections, one pool cross-section, and bankfull indicators. This information was used for survey work along the reach, as described in the methodology section. The final study sites are shown in Figure 2.2 and include twenty-three gage stations and three un-gaged sites.

2.3 DA versus C and E Stream Types

One of the most complex aspects of this project was determining if a potential site was functioning as a system with single or multiple-thread channels. Multiple-thread channels are also called anastomosing streams and are classified by Rosgen (1994, 1996) as D and DA stream types. The DA stream type is considered stable, with width/depth ratios generally less than 40 and sinuosities generally ranging from 1.2 to 1.5; however, both values may vary considerably within that range. Channel slopes are usually at or less than 0.05 (Rosgen 1994, 1996).

Nanson and Knighton (1996) characterized anastomosed streams by low gradients, very small stream powers (usually ≤ 10 W m^{-2}), and cohesive banks that produce laterally stable channels of low width/depth ratios. These channels are typically aggradational systems, which are controlled through either basin subsidence or a rising base level downstream (Smith, 1983); however, these controls are not the only influences and are not universal (Knighton, 1998). Vertical accretion is the primary mechanism of floodplain construction. Due to limited sediment transport capacity, aggradation can lead to in-channel deposition and reduced cross-sectional area, which locally forces flow out of the channel and onto a floodplain, increasing the potential for new channel erosion. Channel shifting or relocation occurs on a larger scale and over longer time periods, with avulsions causing the dominant process (Knighton, 1998). A large, wide valley with anastomosing channels provides a means of distributing sediment across the floodplain, as well as accommodating infrequent but high-magnitude floods, where channel capacity is constrained by the small bankfull cross-sectional area (Schumann, 1989).

Rosgen stream types C and E are common, single-thread channels in wide alluvial valleys with low to moderate gradients, and they can exist in the same valley types as the anastomosing rivers (Rosgen 1994, 1996 and Nanson and Croke, 1992). The primary difference between the C and E stream types is that the bankfull width/depth ratio is greater than 12 for C streams and less than 12 for E streams. Sinuosity is generally greater for E stream types as well; however, sinuosity varies greatly in Southeastern stream types.

The field determination of multiple versus single-thread channels was made by visual observation of the adjacent floodplain. Floodplain features such as sloughs, meander scars, vernal pools, and oxbow lakes were common in all stream types, and floodplain widths were expansive. Entrenchment ratios were typically greater than 10. The primary difference between the DA and C / E stream types was the presence of connected channels. If the sloughs, old channels, and oxbows were not connected to the active channel, the reach was classified as single thread. This decision was made because bankfull sediment transport only occurs in the active channel. The other floodplain features act as water and sediment sinks and thus could not convey part of the effective bankfull or channel-forming discharge.

3 METHODOLOGY

A series of field measurements was collected at each selected site to classify the stream and determine key features for the development of the regional curve. Cross-sectional and longitudinal surveys were conducted at each stream to determine the channel dimension, pattern, and profile. Bankfull elevation determination was based on consistent bankfull indicators, including top of bank, inner channel benches, and the back of point bars (Leopold, 1994). For a majority of the larger streams, aerial photos were used to develop pattern statistics for the channel. Bed material analyses were conducted to assist in stream classification and characterization; in addition, bankfull discharge was estimated for each reach. A plan view sketch of each site and the results of all the field surveys are shown in Appendix I.

3.1 Dimension, Profile, and Pattern Measurements

At each site, a Topcon 211D Total Station and Hewlett Packard (HP) 48GX with a Tripod Data System survey card were used to complete a longitudinal profile and three cross-sections, along a minimum reach length of 20 times the bankfull width (or at least one meander wavelength). For gage stations, the survey was tied to the USGS reference marks. Elevations for USGS benchmarks are included in Appendix II.

Cross-sections were surveyed at two representative riffles, or crossover sections, and one pool. Morphological features were surveyed moving left to right, looking downstream, including top of bank, bankfull stage, edge of channel, edge of water/water surface, thalweg, and channel bottom (Harrelson et al., 1994; USGS, 1969). Permanent pins were not established; however, the cross-sections were tied to the longitudinal profile station. The data were downloaded from the HP, and the following bankfull dimensions were calculated: width, cross-sectional area, maximum depth, mean depth, ratio of width/mean depth, bank height ratio, and entrenchment ratio (riffles only). The data were then entered into Microsoft Excel for graphing and regional curve development.

Longitudinal survey measurements were generally collected at the beginning of each bed feature (heads of riffles and pools) and included: thalweg, water surface, bankfull stage, and top of low bank. The slope of a line developed using bankfull indicators was compared to a best fit line through the water surface points. Leopold (1994) used this technique to verify the feature as bankfull if the two lines were generally parallel and consistent over a long reach. At gaged stream sites, the longitudinal survey was carried through the gage plate to obtain the bankfull stage and corresponding discharge. The data were processed the same as discussed for the cross-sectional data, and valley slope and average water surface slope were calculated.

Channel pattern was determined from the survey points and from aerial photographs, as necessary. More extensive surveys would have been needed to depict pattern statistics on many of the large streams. For that reason, aerial photos were often used to measure those parameters; however, it was not possible to determine the exact location of the stream channel on the aerials (as it was on many of the smaller reaches) because the surrounding vegetation was quite dense. In those cases, pattern measurements were based solely on the survey points.

3.2 Bed Material Measurements

Since all of the project sites had sand-dominated bed material, the Wolman pebble count procedure did not apply (Bunte and Abt, 2001); instead, three bulk samples were taken across the wetted bed at a riffle and pool cross-section. The samples were returned to the soils lab, dried and sieved on American Society for Testing and Materials (ASTM) standard sieves. Grain size distributions were developed and plotted.

3.3 Stream Classification

Each project reach was classified using the Rosgen (1994, 1996) method. The width of the floodprone area was measured from survey data or topographic maps (where survey data were insufficient due to wide, heavily vegetated floodplains). In cases where the clear survey shots could be collected across the valley, a complete cross-section was surveyed across the floodplain, and the floodprone area width was taken from the cross-section.

3.4 Bankfull Discharge and Flood Frequency for Gaged Streams

For gaged streams, the bankfull discharge was determined using the USGS stage-discharge rating table and the longitudinal survey of bankfull stage (discussed above). The return interval was determined through Log-Pearson Type III distributions of annual peak discharge data. Procedures are outlined in USGS Bulletin #17B, “Guidelines for Determining Flood Flow Frequency,” (1982). The recurrence interval was calculated as the inverse of the annual exceedence probability. The bankfull discharge recurrence interval was then estimated as an interpolation of the data.

3.5 Estimating Bankfull Discharge for Un-gaged Streams Using Manning’s Equation

We developed estimates for bankfull discharge at each of the project sites using the geometry data for cross-sectional surveys, estimated Manning’s ‘n’ values, and water surface slope data from longitudinal surveys. For gaged sites, Manning’s ‘n’ values were estimated using methods discussed by Chow (1959). A sensitivity analysis was performed by comparing the Manning’s estimated discharge at USGS gage sites to the gaged discharge. Since a good correlation between the gage discharges and Manning’s estimated discharges was established, as discussion in section 4.3, Manning’s ‘n’ values were also selected using Chow’s methods for un-gaged sites, and discharges were calculated.

4 RESULTS AND DISCUSSION

Detailed survey results, site sketches, and stream bed material analyses for each study site are presented in Appendix I. Gage data and flood frequency analyses for each gage site are presented in Appendix II. A summary of general site conditions is presented in Table 4.1. Drainage areas ranged from 1.0 to 474 square miles, with a median value of 38.3 square miles; values were broadly distributed throughout this range (Figure 4.1). Water surface slopes ranged from a very flat 0.01% to a high of 0.4% in one of the headwater streams. Generally, sites with smaller drainage areas had steeper slopes than the larger streams (Figure 4.2). All sites were on sand bed streams; median particle size ranged from 0.15 mm (fine sand) to 2.0 mm (very coarse sand). In most cases, riffles were only slightly coarser than pools.

Table 4.1 Summary of General Site Conditions

Stream Name	Drainage Area (mi^2)	Water Slope (ft/ft)	Channel Material (D50 mm)	Return Interval (years)	Hydro-Physiographic Region
Newell Branch near Worth, GA	1.0	0.00400	0.48	1.0	North Florida
Muddy Creek near Beaver Creek, FL	1.5	0.00197	1.31	N/A	Northwest Florida
UT to Warrior Creek near Norman Park, GA	1.6	0.00120	0.45	1.0	North Florida
UT to Rocky Creek, near Gainesville, FL*	2.6	0.00120	0.86	N/A	North Florida
Seven Mile Creek near Milton, FL*	2.6	0.00305	0.57	1.0	Northwest Florida
Caney Creek near Monticello, FL	2.6	0.00047	0.40	N/A	Northwest Florida
Newell Branch near Ashburn, GA	6.5	0.00100	0.41	1.0	North Florida
Baggett Creek near Milligan, FL	7.7	0.00220	0.75	N/A	Northwest Florida
Little River near Ashburn, GA	8.5	0.00040	0.34	1.0	North Florida
Barnetts Creek near Thomasville, GA	15.0	0.00260	1.21	1.0	North Florida
Little Double Bridges Creek near Enterprise, AL	21.4	0.00128	0.43	1.1	Northwest Florida
Rocky Creek near Live Oak, FL*	26.6	0.00050	0.36	N/A	North Florida
Juniper Creek near Niceville, FL	27.6	0.00056	0.81	1.1	Northwest Florida
Brushy Creek near Walnut Hill, FL	49.0	0.00078	1.99	1.0	Northwest Florida
Fish River near Silverhill, AL	55.3	0.00058	0.15	1.1	Northwest Florida
Fenholloway River near Foley, FL	60.0	0.00080	0.59	1.4	North Florida

Stream Name	Drainage Area (mi^2)	Water Slope (ft/ft)	Channel Material (D50 mm)	Return Interval (years)	Hydro-Physiographic Region
Tired Creek near Cairo, GA	60.0	0.00060	0.30	1.0	North Florida
Bear Creek near Youngstown, FL	67.2	0.00023	1.32	1.0	Northwest Florida
Alaqua Creek near Portland, FL	83.7	0.00011	0.71	1.0	Northwest Florida
Deep Creek near Suwannee Valley, FL	88.6	0.00021	0.65	1.2	North Florida
Shoal River Near Mossy Head, FL	123.0	0.00051	1.35	1.2	Northwest Florida
New River near Lake Butler, FL	191.0	0.00017	0.55	1.0	North Florida
Econfina River near Perry, FL	198.0	0.00020	0.61	1.4	North Florida
Big Coldwater Creek near Milton, FL	237.0	0.00037	0.50	1.0	Northwest Florida
Little River near Midway, FL	305.0	0.00018	0.38	1.0	Northwest Florida
Shoal River Near Crestview, FL	474.0	0.00038	0.22	1.0	Northwest Florida
Maximum	474.0	0.00400	1.99	1.4	
Minimum	1.0	0.00011	0.15	1.0	
Mean	81.4	0.00098	0.68	1.1	
Median	38.3	0.00057	0.56	1.0	

* Un-gaged streams

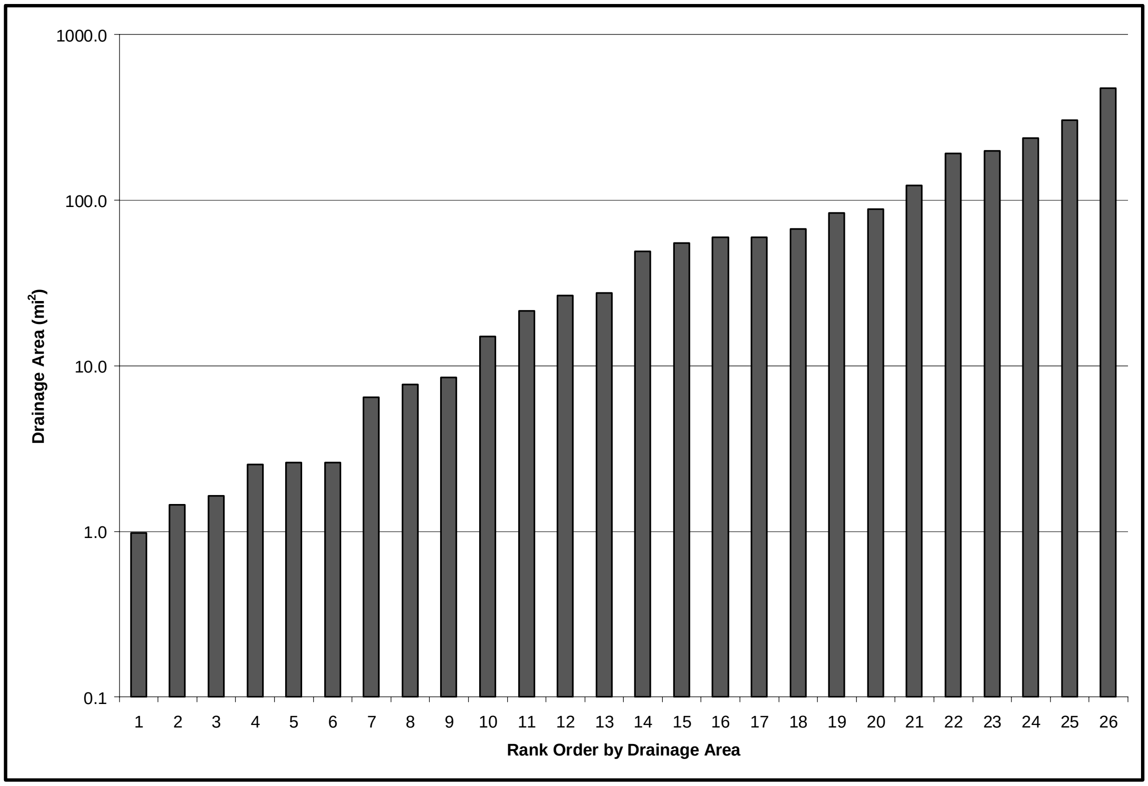

Figure 4.1 Distribution of Study Site Drainage Areas

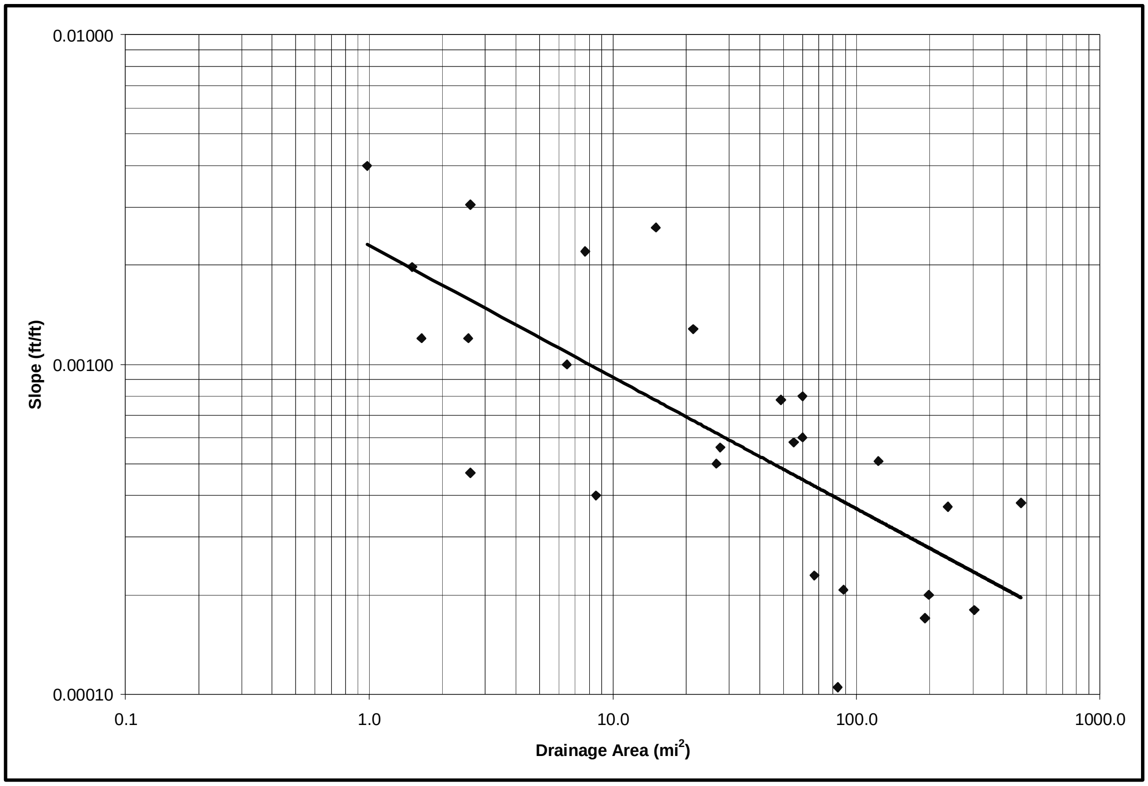

Figure 4.2 Water Surface Slope versus Drainage Area for Study Sites

4.1 Return Intervals

Estimated return intervals for bankfull events ranged from approximately 1.0 to 1.4 years, using the Annual Maximum Series from a Log Pearson Type III distribution. The majority of gage sites had return intervals of just over 1 year, resulting in a median return interval for the 23 gaged sites of just 1.1 years. This median value is noticeably lower than the average 1.5 year return interval observed in Piedmont and other higher gradient systems, but is within the one- to two-year range described by other researchers (Leopold, 1994; Harman et al., 2000; and Doll et al., 2000). These findings are consistent with other coastal plain regional curve data from Georgia, North Carolina, and Maryland (Georgia DOT, 2003; Sweet, 2003; McCandless, 2003). Partially duration analysis was not performed due to the limited amount of daily peak discharge data available.

Given the short return intervals discovered in this study, care was taken to ensure that the appropriate bankfull indicators had been selected and that higher channel features (that could represent a larger bankfull flow) were not present. Because many of the best gage sites had bankfull indicators only at the tops of the banks, it was clear that less frequent flood events would involve discharges that would be out of the channel and onto the floodplains.

4.2 Stream Classification

Stream classification data are presented in Table 4.2. The 26 sites fell into two Rosgen Level II stream types. There are seventeen E5 type streams and nine C5 type streams (four are C5c stream types). Both Northwest Florida and North Florida have C5 and E5 stream types. Entrenchment ratios for all streams were very large; the smallest measured entrenchment ratio was 3.7, and the largest was 35.9. Width / depth ratios were typical for E and C stream types. Some of the C5 stream types have very low slopes (less than 0.1%) and are therefore classified as C5c stream types. Sinuosity was low for some reaches, especially considering the generally flat slopes of the streams, which may indicate that the streams were channelized in the past. Based on the age of the riparian forest cover, this channelization likely took place over 50 years ago, and channels now appear to functioning in a stable regime.

Table 4.2 Bankfull Classification Characteristics of Study Reaches

Stream Name	Entrench-ment Ratio	Width/ Depth Ratio	Sinuosity	Water Surface Slope (ft/ft)	Channel Material (D50 mm)	Bank Height Ratio	Rosgen Stream Type
Alaqua Creek near Portland, FL	33.1	6.2	1.58	0.00011	0.71	1.0	E5
Baggett Creek near Milligan, FL	33.0	7.0	2.42	0.00220	0.75	1.0	E5
Barnetts Creek near Thomasville, GA	26.0	7.4	1.1	0.00260	1.21	1.1	C5
Bear Creek near Youngstown, FL	20.6	8.9	1.36	0.00023	1.32	1.0	E5
Big Coldwater Creek near Milton, FL	9.4	24.3	1.18	0.00037	0.50	1.0	C5c
Brushy Creek near Walnut Hill, FL	10.5	8.2	1.57	0.00078	1.99	1.1	E5
Caney Creek near Monticello, FL	3.8	6.1	1.12	0.00047	0.40	1.1	E5
Deep Creek near Suwannee Valley, FL	10.6	6.0	1.31	0.00021	0.65	1.0	E5
Econfina River near Perry, FL	>50	5.3	1.32	0.00020	0.61	1.0	E5
Fenholloway River near Foley, FL	6.8	4.2	1.11	0.00080	0.59	1.5	E5
Fish River near Silverhill, AL	6.6	9.7	1.51	0.00058	0.15	1.0	E5
Juniper Creek near Niceville, FL	21.5	11.7	1.34	0.00056	0.81	1.0	C5c
Little Double Bridges Creek near Enterprise, AL	6.5	10.1	1.25	0.00128	0.43	1.0	C5
Little River near Ashburn, GA	10.0	19.4	1.1	0.00040	0.34	1.0	E5
Little River near Midway, FL	18.3	12.7	1.68	0.00018	0.38	1.0	C5c
Muddy Creek near Beaver Creek, FL	8.1	9.3	2.73	0.00197	1.31	1.0	E5
New River near Lake Butler, FL	21.3	10.3	1.23	0.00017	0.55	1.1	E5
Newell Branch near Ashburn, GA	23.0	24.2	1.4	0.00100	0.41	1.2	C5
Newell Branch near Worth, GA	10.0	20.5	1.1	0.00400	0.48	1.5	C5
Rocky Creek near Live Oak, FL	27.6	5.1	1.43	0.00050	0.36	1.2	E5
Seven Mile Creek near Milton, FL	18.6	11.0	2.0	0.00305	0.57	1.0	E5
Shoal River Near Crestview, FL	19.0	20.2	1.76	0.00038	0.22	1.0	C5c
Shoal River Near Mossy Head, FL	5.3	9.4	1.54	0.00051	1.35	1.4	E5
Tired Creek near Cairo, GA	30.0	10.2	1.7	0.00060	0.30	1.3	E5

Stream Name	Entrench-ment Ratio	Width/ Depth Ratio	Sinuosity	Water Surface Slope (ft/ft)	Channel Material (D50 mm)	Bank Height Ratio	Rosgen Stream Type
UT to Rocky Creek, near Gainesville, FL	17.8	5.8	1.38	0.00120	0.86	1	E5
Warrior Creek near Sumner, GA	22	10.7	1.1	0.00120	0.45	1.2	C5

4.3 Bankfull Indicators and Discharge

Bankfull indicators on the study reaches were most often the top of the bank or sometimes a lower bench/bar feature. The width of the floodplain was not considered bankfull because of the thick vegetation and signs of water storage. The majority of sediment transport only occurs within the main channel of the study reaches.

Table 4.3 shows the bankfull discharge, estimated using Manning’s equation for the three un-gaged streams, along with the corresponding cross-sectional areas. The table also shows the Manning’s ‘n’ values used in the analysis. For these un-gaged sites, the ‘n’ values were estimated by evaluating the stream reach’s vegetation, sinuosity, and bedform and using best professional judgment.

Table 4.3 Bankfull Discharge and Manning’s ‘n’ of Un-gaged Study Reaches

Stream Name	Drainage Area (mi^2)	Cross-Sectional Area (sf)	Channel Manning’s ‘n’	Estimated Velocity (fps)	Estimated Discharge (cfs)
Rocky Creek near Live Oak	26.6	74.8	0.04	1.79	134
UT to Rocky Creek near Gainesville	2.6	11.7	0.04	1.38	16.2
Seven Mile Creek near Milton, FL	2.6	33.2	0.045	2.18	72.4
Baggett Creek near Milligan, FL	7.7	63.7	0.045	2.99	190.8
Muddy Creek near Beaver Creek, FL	1.5	23.7	0.05	1.72	40.8

Manning’s equation was also used to estimate bankfull discharge for the 23 gaged sites. A sensitivity analysis comparing the two discharge values was conducted, and the results are shown in Table 4.4. The general agreement of the results (the mean of the absolute value of the error was 10.9%) supports both the estimations of discharge and Manning’s ‘n’ values for the un-gaged sites.

Table 4.4 Bankfull Discharge Sensitivity Analysis for Gaged Study Reaches

Stream Name	**Drainage Area (mi^2)**	**Manning's 'n' used**	**USGS Gage Discharge (cfs)**	**Manning's Discharge (cfs)**	**Percent Error**
Newell Branch near Worth, GA	1.0	0.032	7	7	0.0%
UT to Warrior Creek near Norman Park, GA	1.6	0.055	21	21	0.0%
Caney Creek near Monticello, FL	2.6	0.04	30.5	38.2	25.1%
Newell Branch near Ashburn, GA	6.5	0.038	12	17	41.7%
Little River near Ashburn, GA	8.5	0.051	23	23	0.0%
Barnetts Creek near Thomasville, GA	15.0	0.05	45	45	0.0%
Little Double Bridges Creek near Enterprise, AL	21.4	0.04	217	245	12.9%
Juniper Creek near Niceville, FL	27.6	0.035	254	225	-11.4%
Brushy Creek near Walnut Hill, FL	49.0	0.04	352	473	34.3%
Fish River near Silverhill, AL	55.3	0.04	528	559	5.9%
Tired Creek near Cairo, GA	60.0	0.051	260	260	0.0%
Fenholloway River near Foley, FL	60.0	0.04	248	236	-4.9%
Bear Creek near Youngstown, FL	67.2	0.045	439	383	-12.8%
Alaqua Creek near Portland, FL	83.7	0.04	592	542	-8.4%
Deep Creek near Suwannee Valley, FL	88.6	0.035	398	310	-22.1%
Shoal River Near Mossy Head, FL	123.0	0.035	1310	1138	-13.1%
New River near Lake Butler, FL	191.0	0.035	311	303	-2.6%
Econfina River near Perry, FL	198.0	0.04	375	474	26.4%
Big Coldwater Creek near Milton, FL	237.0	0.035	1330	1311	-1.4%
Little River near Midway, FL	305.0	0.04	1260	1321	4.8%
Shoal River Near Crestview, FL	474.0	0.035	2650	2703	2.0%

4.4 Regional Curves

Table 4.5 summarizes the data used in the Northwest Florida Coastal Plain Regional Curve (Northwest Florida Regional Curve) and the North Florida Coastal Plain Regional Curve (North Florida Regional Curve). For the un-gaged sites, bankfull discharge estimates are from the Manning's analysis. For the gaged sites, bankfull discharge estimates were estimated using the USGS stage-discharge rating table and the longitudinal survey of bankfull stage. The other bankfull measurements were collected during the field surveys. Stream power was calculated using Equation 1.

Table 4.5 Bankfull Summary Data for the Florida Panhandle Coastal Plain Regional Curve Sites

Stream Name	Gaged Site	Drainage Area (mi^2)	Cross-Sectional Area (ft^2)	Discharge (cfs)	Width (ft)	Mean Depth (ft)	Stream Power (W/m^2)
Newell Branch near Worth, GA	Y	1.0	7	7.0	12.3	0.6	2.1
Muddy Creek near Beaver Creek, FL	Y*	1.5	23.7	40.8	14.8	1.6	5.0
UT to Warrior Creek near Norman Park, GA	Y	1.6	10.6	21.0	10.7	1.0	2.1
UT to Rocky Creek, near Gainesville, FL	N	2.6	11.7	16.2	8.3	1.4	2.2
Seven Mile Creek near Milton, FL	N	2.6	35.5	72.4	19.8	1.8	1.0
Caney Creek near Monticello, FL	Y	2.6	31.6	30.5	13.7	2.3	10.2
Newell Branch near Ashburn, GA	Y	6.5	19.9	17.0	21.8	0.9	0.7
Baggett Creek near Milligan, FL	Y*	7.7	63.7	190.8	21.1	3.0	18.1
Little River near Ashburn, GA	Y	8.5	27.0	23.0	23.3	1.2	0.4
Barnetts Creek near Thomasville, GA	Y	15.0	30.0	45.0	14.8	2.0	7.2
Little Double Bridges Creek near Enterprise, AL	Y	21.4	116	217	34.2	3.4	7.4
Rocky Creek near Live Oak, FL	N	26.6	74.8	134.0	19.6	3.8	3.1
Juniper Creek near Niceville, FL	Y	27.6	110.6	254.0	36.2	3.1	3.6
Brushy Creek near Walnut Hill, FL	Y	49.0	180.2	352.0	38.4	4.7	6.5
Fish River near Silverhill, AL	Y	55.3	235.9	528	47.7	4.9	5.9
Fenholloway River near Foley, FL	Y	60.0	96.0	248	20.0	4.8	9.0
Tired Creek near Cairo, GA	Y	60.0	126.7	260.0	35.8	3.5	4.0
Bear Creek near Youngstown, FL	Y	67.2	249.1	439.0	47.4	5.3	1.9
Alaqua Creek near Portland, FL	Y	83.7	396.9	592.0	49.8	8.0	1.1
Deep Creek near Suwannee Valley, FL	Y	88.6	183	398.0	33.1	5.5	2.3

Stream Name	**Gaged Site**	**Drainage Area (mi^2)**	**Cross-Sectional Area (ft^2)**	**Discharge (cfs)**	**Width (ft)**	**Mean Depth (ft)**	**Stream Power (W/m^2)**
Shoal River Near Mossy Head, FL	Y	123.0	374.1	1310.0	59.2	6.3	10.3
New River near Lake Butler, FL	Y	191.0	208.7	311.0	46.5	4.5	1.0
Econfina River near Perry, FL	Y	198.0	281.8	375.0	38.4	7.3	1.8
Big Coldwater Creek near Milton, FL	Y	237.0	564.2	1330	116.6	4.8	3.8
Little River near Midway, FL	Y	305.0	718.1	1260.0	95.4	7.5	2.2
Shoal River Near Crestview, FL	Y	474.0	882	2650.0	133.3	6.6	6.9

*Gage sites with reference marks not tied to gage datum.

For each stream included in the study, the bankfull discharge, cross-sectional area, width, and mean depth were plotted versus drainage area. These relationships were found to be linear on a log-log scale; therefore, a power function was fit to the raw data. This power function regression was used based on hydraulic theory and previous experience with regional curves (Leopold and Maddock, 1953). The 95% confidence interval was also calculated for the regression equation and plotted with the data.

4.4.1 Bankfull Discharge

Originally, the relationship for bankfull discharge as a function of watershed area was plotted with data from all the study sites to confirm the difference in hydro-physiographic regions (Figure 4.3). The power function regression equation and corresponding coefficient of determination are:

$$Q_{bkf} = 12.6\, A_w^{0.79} \qquad r^2 = 0.83 \qquad \text{(Equation 2)}$$

where Q_{bkf} = bankfull discharge in cubic feet per second (cfs) and A_w = watershed drainage area in square miles (mi^2)

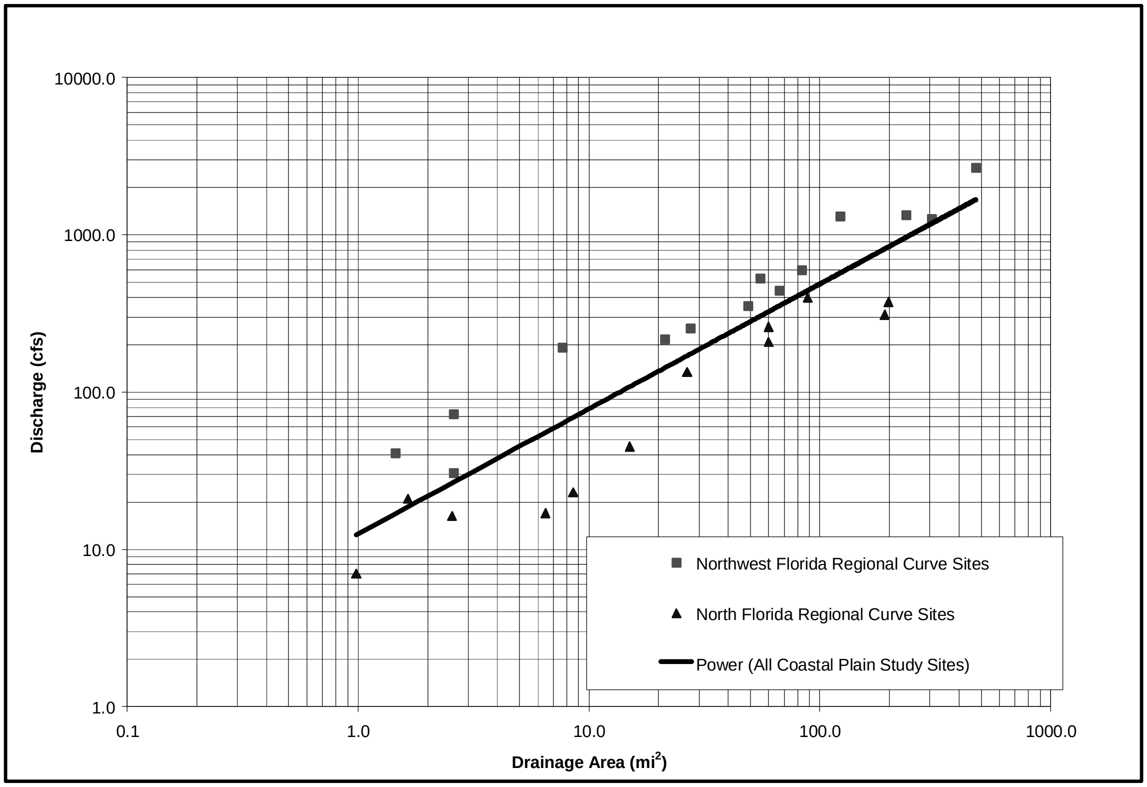

Figure 4.3 Bankfull Discharge versus Drainage Area for all Study Sites

Bankfull discharge is related to drainage area, with 83% of the variability in discharge across the entire study area explained by drainage area, but a distinct difference in the Northwest Florida Regional Curve (NWFCP) sites and the North Florida Regional Curve (NFCP) sites is evident. Bankfull discharge is generally higher for a given drainage area for Northwest Florida sites than that for the North Florida sites (Figure 4.4). The power function regression equations and corresponding coefficient of determinations are:

$Q_{bkf\text{-}NWFCP} = 27.7A_w^{\ 0.71}$ $r^2 = 0.95$ (Equation 3)
$Q_{bkf\text{-}NFCP} = 7.54A_w^{0.77}$ $r^2 = 0.92$ (Equation 4)

The two regional curves converge as drainage area increases, with Northwest Florida Regional Curve predicting about 3 to 4 times the discharge of the North Florida Regional Curve at smaller drainage areas and about 2 to 3 times the discharge at larger drainage areas. A regression on the 14 Northwest Florida Region Curve sites reveals a strong relationship between bankfull discharge and drainage area, with 95% of the variability in discharge across the region explained by drainage area. Regression on the 12 North Florida Regional Curve sites also reveals a strong relationship between bankfull discharge and drainage area, with 92% of the variability in discharge across the region explained by drainage area.

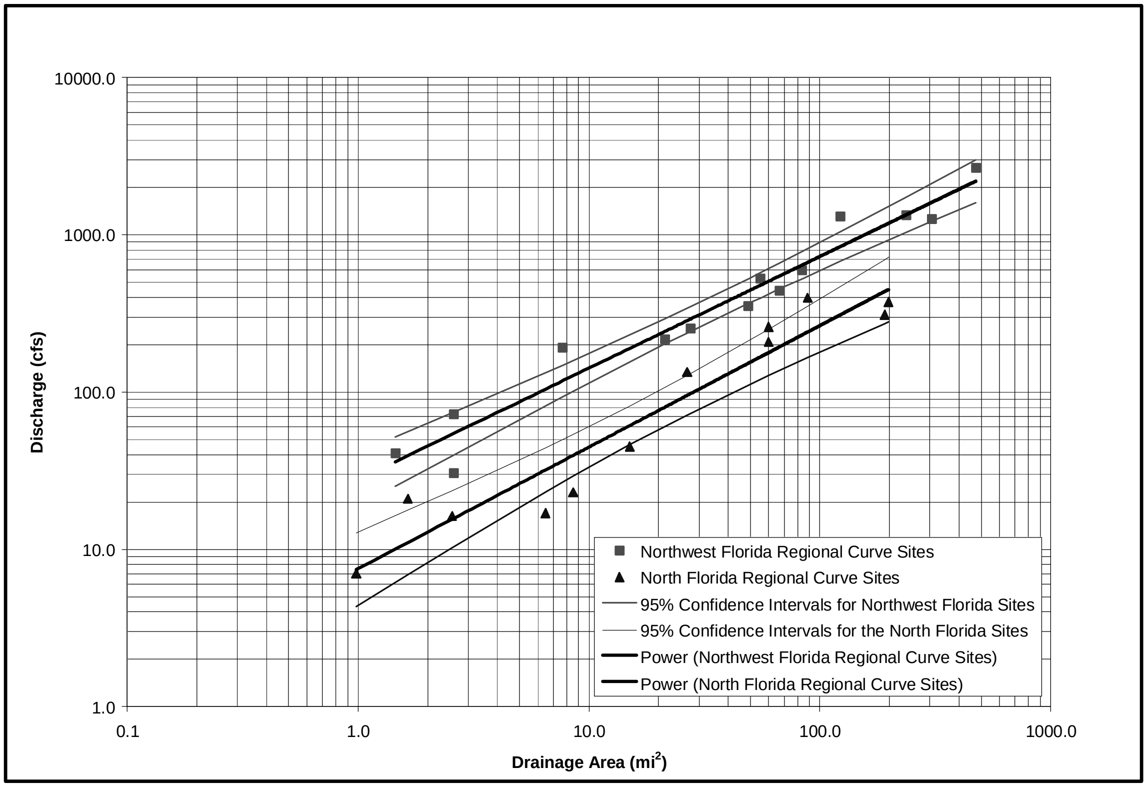

Figure 4.4 Bankfull Discharge versus Drainage Area for the North and Northwest Florida Coastal Plains

4.4.2 Bankfull Cross-Sectional Area

The relationships for bankfull cross-sectional area as a function of watershed area for Northwest Florida and North Florida are shown in Figure 4.5. The power function regression equations and corresponding coefficients of determination for the regional curves are:

$A_{\text{bkf-NWCP}} = 17.1A_{w}^{\;0.64}$ $r^2 = 0.99$ (Equation 5)
$A_{\text{bkf-NFCP}} = 6.1\ A_{w}^{\;0.71}$ $r^2 = 0.98$ (Equation 6)

where A_{bkf} = bankfull cross-sectional area in square feet (ft^2) and A_w = watershed drainage area in square miles (mi^2).

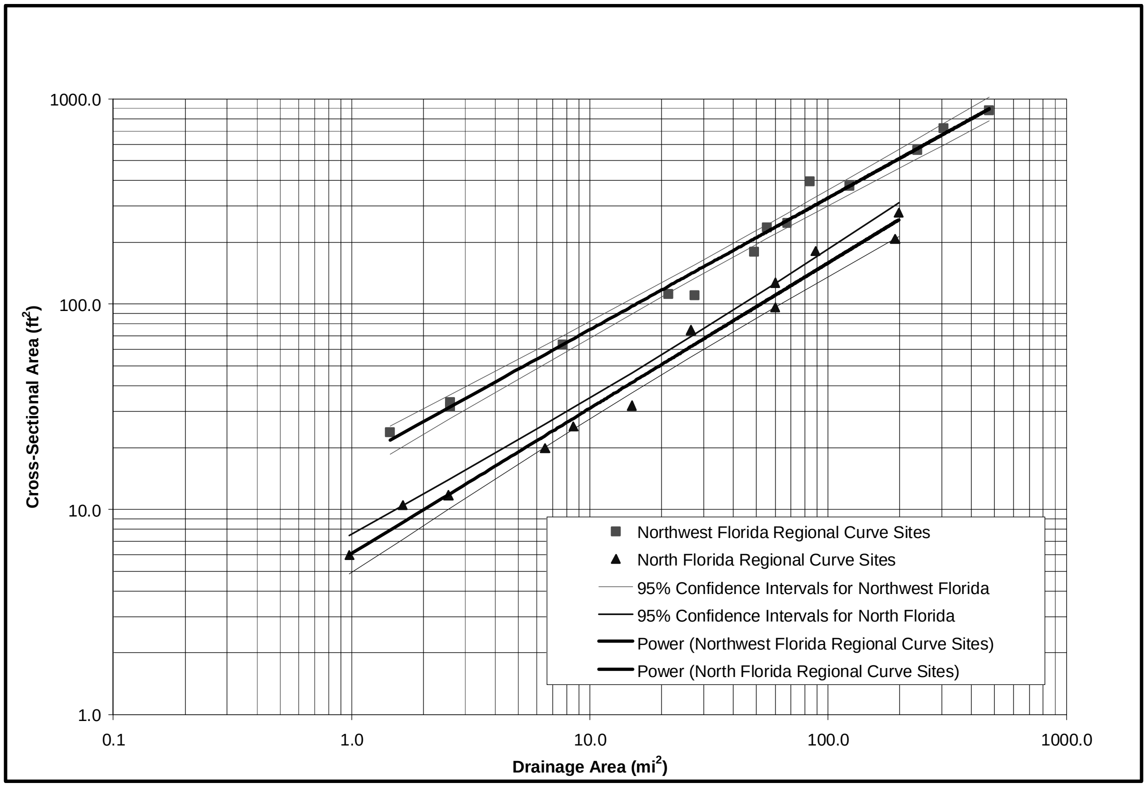

Figure 4.5 Bankfull Cross-Sectional Area versus Drainage Area

Bankfull cross-sectional area is related to drainage area, with 99% and 98% of the variability in cross-sectional area explained by drainage area for Northwest Florida and North Florida, respectively. The confidence intervals plotted in Figure 4.5 describe the area where the true relationship between bankfull cross-sectional area and drainage area can be described with 95% confidence, assuming that the empirical model selected is appropriate and that all the data points are from the same general population of events.

Bankfull cross-sectional area is substantially larger for a given drainage area for sites in Northwest Florida compared to North Florida. The Northwest Florida Regional Curve predicts bankfull channels approximately 2 to 3 times larger than the North Florida Regional Curve.

4.4.3 Bankfull Width and Depth

The relationships for bankfull width and depth as a function of watershed area are shown in Figures 4.6 and 4.7, respectively. The power function regression equations and corresponding coefficients of determination for the regional curves are:

$W_{bkf\text{-}NWFCP} = 10.4\ A_w^{\ 0.39}$ $r^2 = 0.96$ (Equation 7)
$W_{bkf\text{-}NFCP} = 9.2\ A_w^{\ 0.28}$ $r^2 = 0.85$ (Equation 8)
$D_{bkf\text{-}NWFCP} = 1.64\ A_w^{\ 0.25}$ $r^2 = 0.86$ (Equation 9)
$D_{bkf\text{-}NFCP} = 0.67\ A_w^{\ 0.43}$ $r^2 = 0.84$ (Equation 10)

where W_{bkf} = bankfull width in feet (ft), D_{bkf} = bankfull mean depth in feet (ft), and A_w = watershed drainage area in square miles (mi^2).

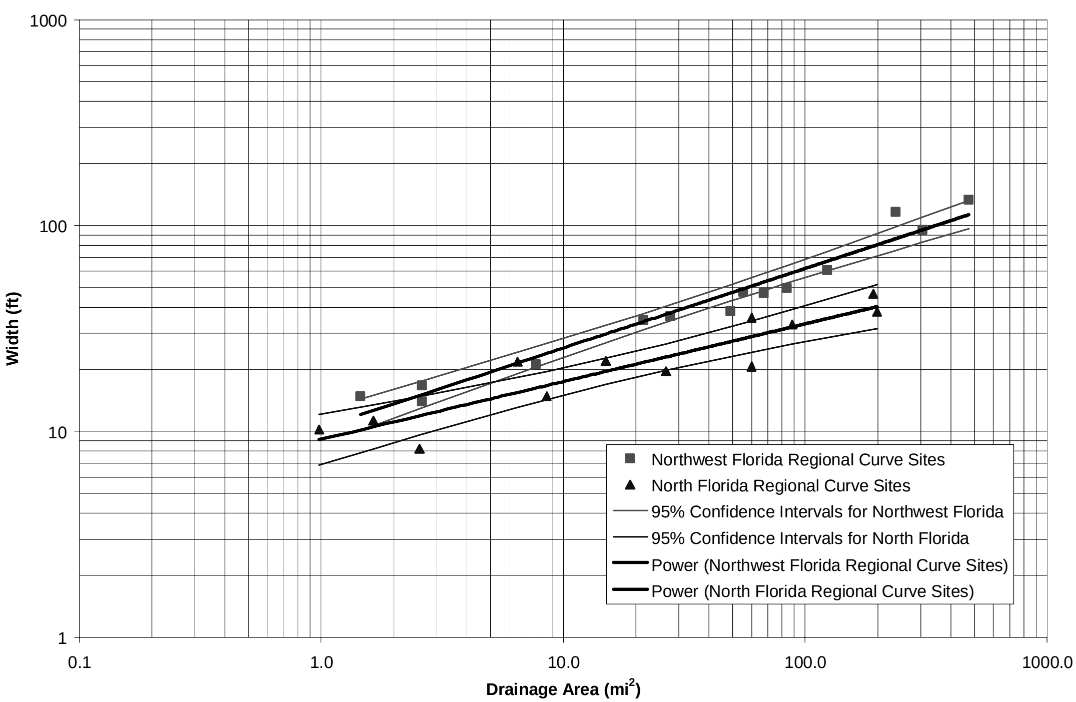

Figure 4.6 Bankfull Width versus Drainage Area

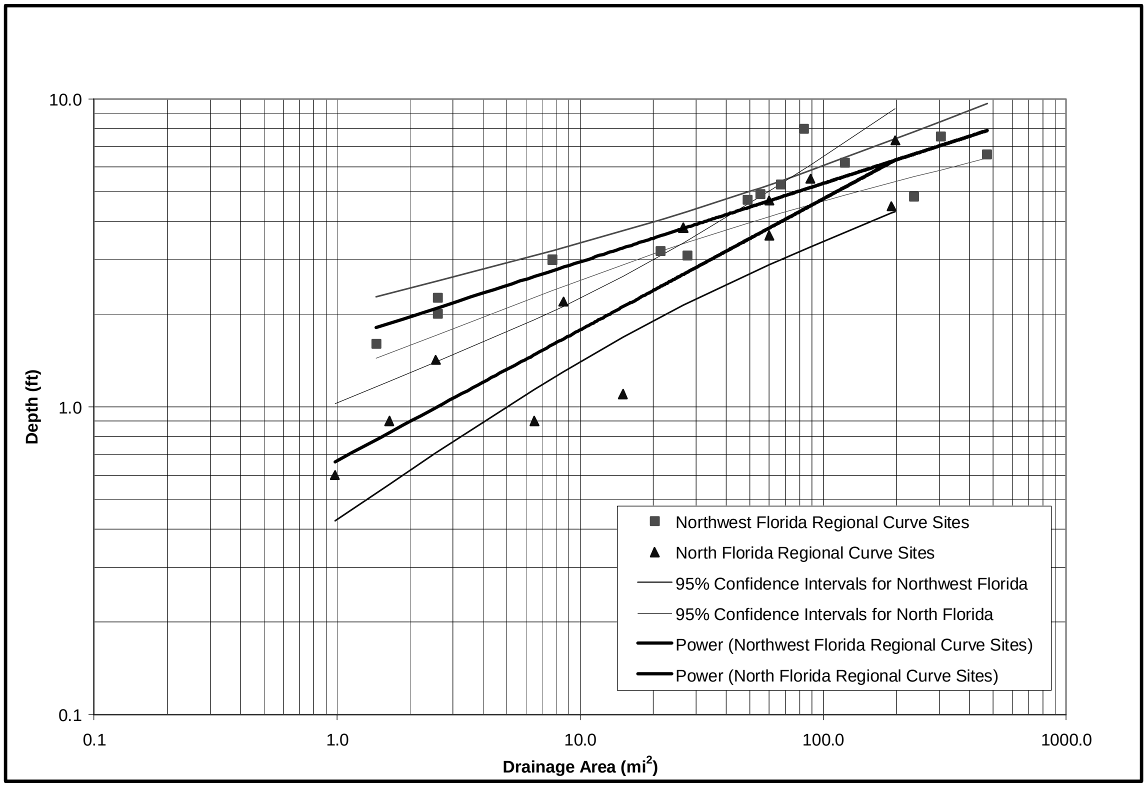

Figure 4.7 Bankfull Mean Depth versus Drainage Area

Bankfull width and depth are also both related to drainage area. Bankfull width in the Northwest Florida region is especially related to drainage area, with 96% of the variation explained by drainage area. In most cases, for both bankfull width and bankfull mean depth, the predictive ability of the regional curves can be improved by stratifying sites between those with E and C stream types (Figures 4.8, 4.9, 4.10, and 4.11). The power function regression equations and corresponding coefficient of determinations for bankfull width are:

$W_{\text{bkf-C Type NWFCP}} = 8.66\ A_w^{0.44}$ $r^2 = 0.97$ (Equation 11)
$W_{\text{bkf-E Type NWFCP}} = 11.59\ A_w^{0.33}$ $r^2 = 0.98$ (Equation 12)
$W_{\text{bkf-C Type NFCP}} = 10.26\ A_w^{0.32}$ $r^2 = 0.92$ (Equation 13)
$W_{\text{bkf-E Type NFCP}} = 6.14\ A_w^{0.37}$ $r^2 = 0.92$ (Equation 14)

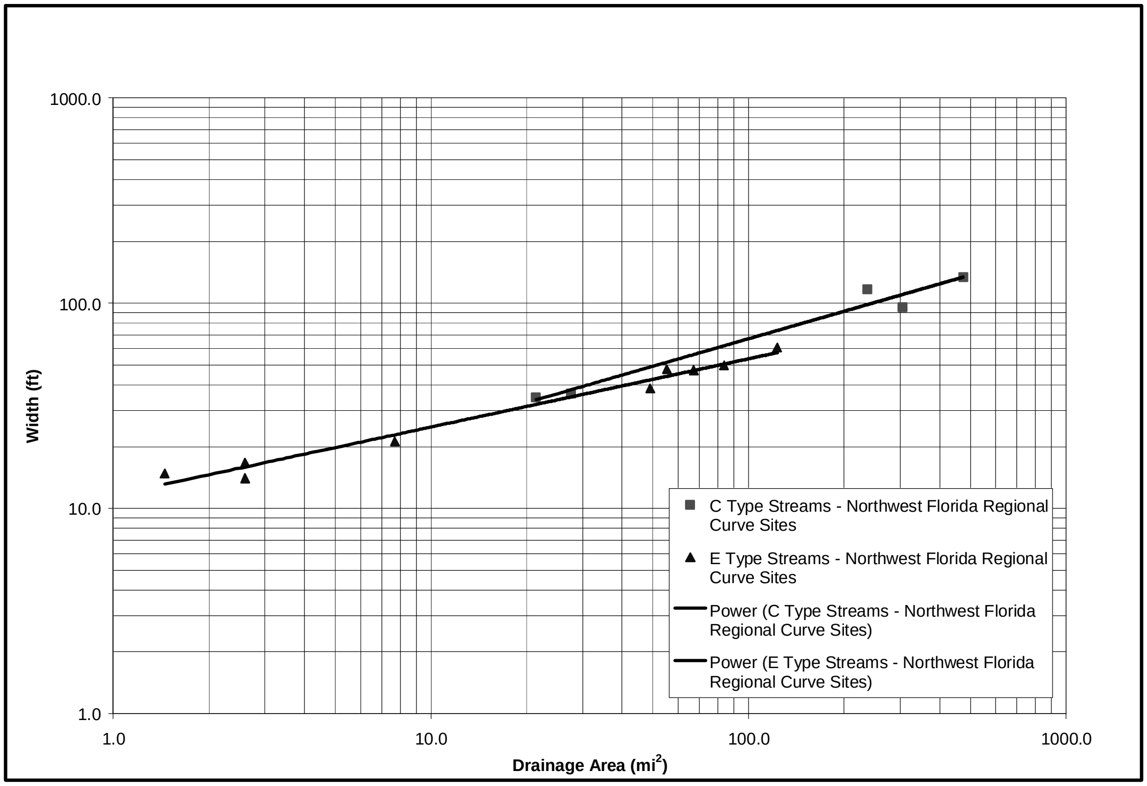

Figure 4.8 Bankfull Width versus Drainage Area for C and E Stream Types of the Northwest Florida Regional Curve Sites

Predictability of bankfull width and depth as a function of watershed area improved on all sites upon stratification of E and C stream types, except for the bankfull depth among C stream types from the North Florida Coastal Plain (Figure 4.11). The variation in bankfull depth explained by drainage area for these streams decreased from 84% to 72% (Equations 17 and 10 respectively). This decrease is most likely attributable to the small sample size of 4 data points, spanning a short range of (smaller) drainage areas. A larger sample size, spanning a larger range of drainage areas, such as the E type stream stratification for bankfull depth, would most likely improve the correlation.

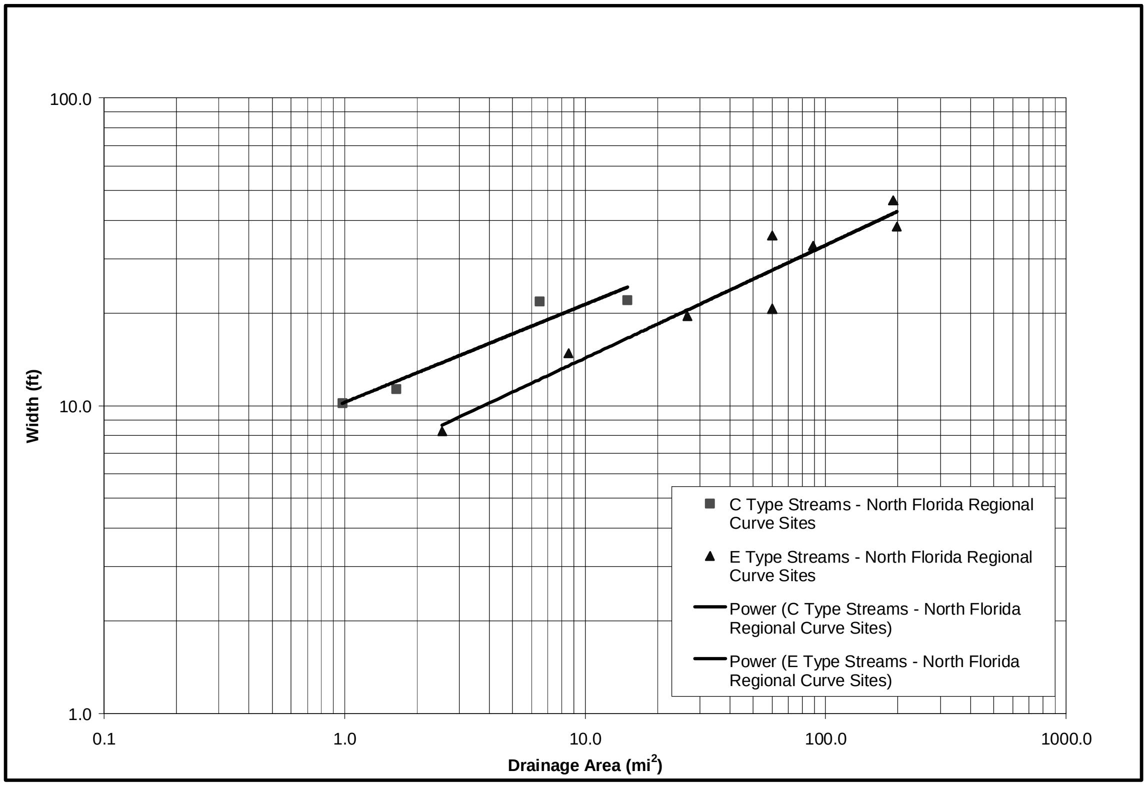

Figure 4.9 Bankfull Width versus Drainage Area for C and E Stream Types of the North Florida Regional Curve Sites

The power function regression equations and corresponding coefficient of determinations for bankfull mean depth are:

$D_{\text{bkf-C Type NWFCP}} = 1.36\ A_w^{0.26}$ $r^2 = 0.88$ (Equation 15)
$D_{\text{bkf-E Type NWFCP}} = 1.53\ A_w^{0.31}$ $r^2 = 0.95$ (Equation 16)
$D_{\text{bkf-C Type NFCP}} = 0.69\ A_w^{0.17}$ $r^2 = 0.72$ (Equation 17)
$D_{\text{bkf-E Type NFCP}} = 1.12\ A_w^{0.32}$ $r^2 = 0.89$ (Equation 18)

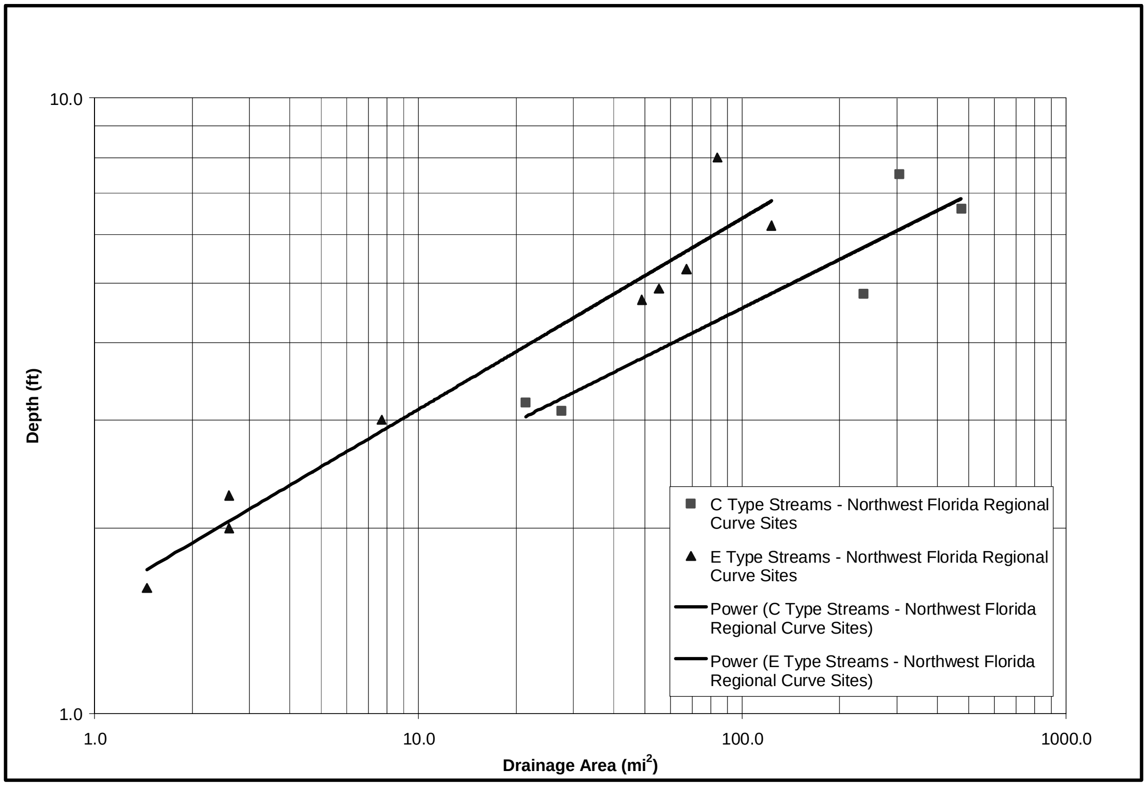

Figure 4.10 Bankfull Depth versus Drainage Area for C and E Stream Types of the Northwest Florida Regional Curve Sites

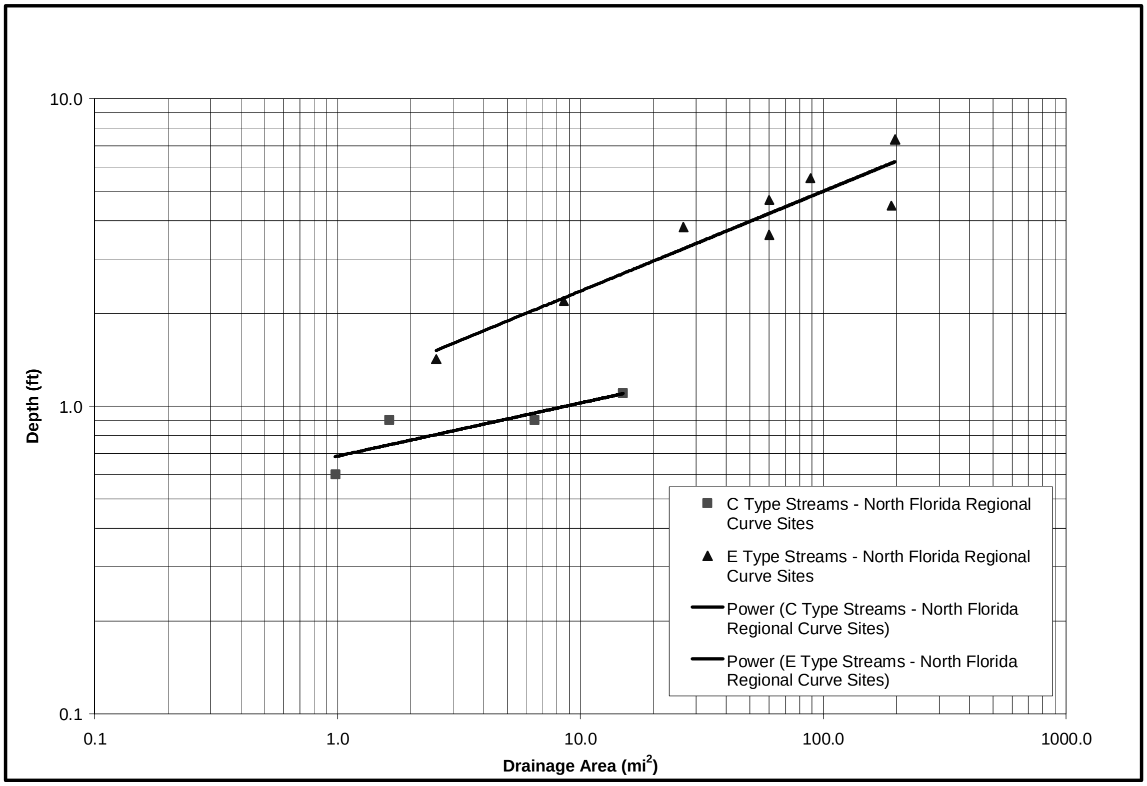

Figure 4.11 Bankfull Depth versus Drainage Area for C and E Stream Types of the North Florida Regional Curve Sites

Table 4.6 Summary of Regional Curve Equations

Hydro-physiographic Region	Regional Curve	Power Function Regression Equation	Coefficient of Determination
North Florida Coastal Plain	Bankfull Width (all)	$W_{bkf\text{-}NFCP} = 9.2\ A_w^{0.28}$	$r^2 = 0.85$
	Bankfull Width (C type)	$W_{bkf\text{-}C\ Type\ NFCP} = 10.26\ A_w^{0.32}$	$r^2 = 0.92$
	Bankfull Width (E type)	$W_{bkf\text{-}E\ Type\ NFCP} = 6.14\ A_w^{0.37}$	$r^2 = 0.92$
	Bankfull Depth (all)	$D_{bkf\text{-}NFCP} = 0.67\ A_w^{0.43}$	$r^2 = 0.84$
	Bankfull Depth (C type)	$D_{bkf\text{-}C\ Type\ NFCP} = 0.69\ A_w^{0.17}$	$r^2 = 0.72$
	Bankfull Depth (E type)	$D_{bkf\text{-}E\ Type\ NFCP} = 1.12\ A_w^{0.32}$	$r^2 = 0.89$
	Bankfull Cross-Sectional Area	$A_{bkf\text{-}NFCP} = 6.1\ A_w^{0.71}$	$r^2 = 0.98$
	Bankfull Discharge	$Q_{bkf\text{-}NFCP} = 7.54A_w^{0.77}$	$r^2 = 0.92$
Northwest Florida Coastal Plain	Bankfull Width (all)	$W_{bkf\text{-}NWFCP} = 10.4\ A_w^{0.39}$	$r^2 = 0.96$
	Bankfull Width (C type)	$W_{bkf\text{-}C\ Type\ NWFCP} = 8.66\ A_w^{0.44}$	$r^2 = 0.97$
	Bankfull Width (E type)	$W_{bkf\text{-}E\ Type\ NWFCP} = 11.59\ A_w^{0.33}$	$r^2 = 0.98$
	Bankfull Depth (all)	$D_{bkf\text{-}\ NWFCP} = 1.64\ A_w^{0.25}$	$r^2 = 0.86$
	Bankfull Depth (C type)	$D_{bkf\text{-}C\ Type\ NWFCP} = 1.36\ A_w^{0.26}$	$r^2 = 0.88$
	Bankfull Depth (E type)	$D_{bkf\text{-}E\ Type\ NWFCP} = 1.53\ A_w^{0.31}$	$r^2 = 0.95$
	Bankfull Cross-Sectional Area	$A_{bkf\text{-}NWCP} = 17.1A_w^{0.64}$	$r^2 = 0.99$
	Bankfull Discharge	$Q_{bkf\text{-}NWFCP} = 27.7A_w^{0.71}$	$r^2 = 0.95$

4.5 Comparison to Other Coastal Plain Regional Curves

Coastal Plain regional curves have also been developed for Georgia, North Carolina, and Maryland (Georgia DOT, 2003; Sweet and Geratz, 2003; USFWS, 2003). The North Florida Coastal Plain Regional Curve and the Georgia Coastal Plain Regional Curves show minimal differences in predicted discharge and will, therefore, be treated as one curve for the purposes of this comparison. The Northwest Florida Coastal Plain Regional Curve predicts a larger discharge than any of the other coastal plain curves, as shown in Figure 4.12.

The mean annual runoff for the North Florida/Georgia Coastal Plain, the North Carolina Coastal Plain, the Maryland Coastal Plain, and the Northwest Florida Coastal Plain are approximately 12, 15, 18, and 25 inches, respectively (from Gebert et al., 1987). This trend of increasing mean annual runoff correlates well with the increase in predicted bankfull discharge moving from the Georgia/North Florida Regional Curve up to the Northwest Florida Regional Curve.

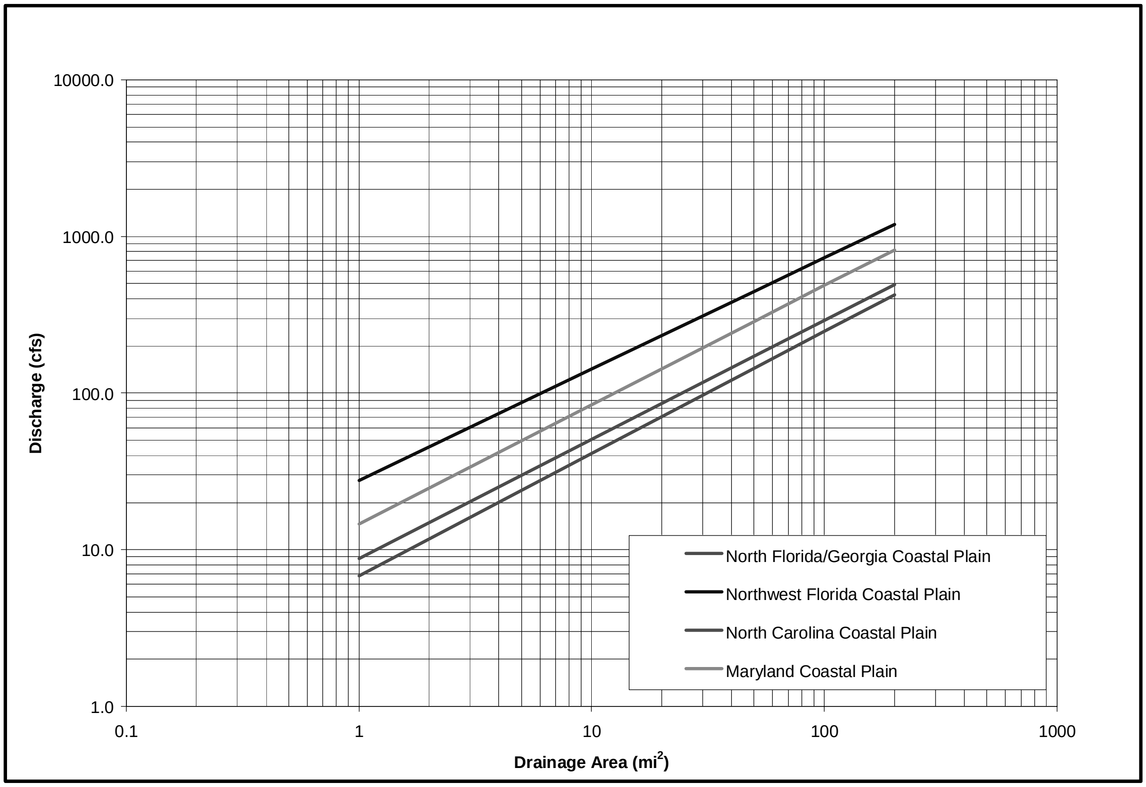

Figure 4.12 Bankfull Discharge Comparison for Coastal Plain Streams

4.6 Study Site Pattern Statistics

Table 4.6 summarizes pattern statistics for selected study reaches, as available data permitted, using a combination of aerial photography and survey data. The pattern statistics are reported as dimensionless ratios for meander width, radius of curvature, and meander length as a function of bankfull width for each study reach. As these statistics tend to vary throughout a single study reach, ranges and averages are presented to capture the continuum of plan form character. Sinuosity is also a measure of plan form character and is reported collectively with bankfull classification characteristics in Table 4.2 for convenience.

Table 4.7 Pattern Summary Statistics for Selected Study Reaches

	Meander Width Ratio (MWR = Wblt/Wr)			**Radius of Curvature / Bkf Width (Rc/Wr)**			**Meander Length / Bkf Width (Lm/Wr)**		
Stream Name	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**
Alaqua Creek near Portland, FL	3.4	2.6	4.2	1.2	1.1	1.2	5.1	3.2	6.5
Baggett Creek near Milligan, FL	1.5	1.2	1.9	1.3	1.3	1.3	4.4	3.5	5.4
Bear Creek near Youngstown, FL	2.5	1.4	3.4	1.4	0.9	1.9	5.6	4.2	6.3

	Meander Width Ratio (MWR = Wblt/Wr)			**Radius of Curvature / Bkf Width (Rc/Wr)**			**Meander Length / Bkf Width (Lm/Wr)**		
Stream Name	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**
Big Coldwater Creek near Milton, FL	1.8	1.4	2.4	2	1.4	3.1	6.6	5.7	8.1
Brushy Creek near Walnut Hill, FL	1.2	1.0	1.3	1.0	0.8	1.3	3.2	3.7	3.7
Deep Creek near Suwannee Valley, FL	3.3	3.3	3.3	1.9	1.9	1.9	9.5	9.5	9.5
Econfina River near Perry, FL	3.1	1.2	4.4	3.6	2.1	5.9	9.1	5.6	15.5
Fenholloway River near Foley, FL	3.3	3.3	3.4	4.4	2.9	6	12.3	10.5	14.1
Juniper Creek near Niceville, FL	3.1	2.6	3.8	1.3	5.1	2.6	7.2	4.5	10.2
Little River near Midway, FL	2.9	1.6	4.6	1.2	0.9	1.9	5.9	3.4	10.2
Muddy Creek near Beaver Creek, FL	4.7	2.2	7.2	1.6	0.9	2.3	8.4	7.1	9.8
New River near Lake Butler, FL	1.6	1.4	1.9	1.5	1.0	2.3	4.5	4.0	5.5
Shoal River Near Crestview, FL	3.6	2.0	5	1.8	1.2	2.4	5.7	2.4	8.9
Shoal River Near Mossy Head, FL	4.6	2.8	6.8	1.3	2.1	1.6	9	3.7	14.4
UT to Rocky Creek, near Gainesville, FL	3.8	2.4	5.2	2.3	2.1	2.6	8.7	8.6	8.8
All Sites Summary	3.0	1.0	7.2	1.9	0.8	5.9	7.0	2.4	15.5

4.7 Application of the Regional Curves

As with all empirical relationships, the regional curve equations can only be applied to streams that have characteristics similar to those at the study sites. In stable transport streams, downstream transport of both the stream discharge and sediment load occurs without aggrading or degrading while maintaining stream dimension, pattern, and profile (Rosgen, 1996). In low gradient Coastal Plain streams, stability is defined as the balance of the rate of vertical accretion with the rate of subsidence and floodplain development (Nanson, 1996).

Vegetated stream banks and riparian areas are major keys to stability in these sand bed systems. Each of the study reaches had well-vegetated riparian areas with multiple layers of canopy and thick ground cover. Streambanks contained significant root mass, and in many of the smaller streams, roots on the stream bed appear to contribute to grade control. By minimizing streambank erosion and colonizing depositional areas, the robust riparian vegetation found in the Florida Panhandle Coastal Plain may contribute to the maintenance of relatively small stream channels.

Another factor in the stability of the study streams is the availability of expansive floodplains. The majority of the study sites had a floodplain area far wider than the stream's width, making available significant areas for the distribution of flood energy.

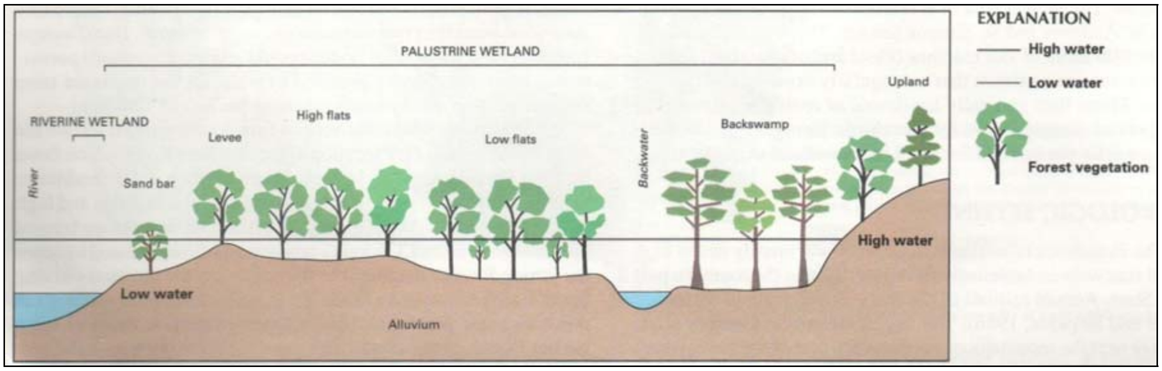

Figure 4.13 Typical Broad Floodplain of Florida Panhandle Coastal Plain (after USGS Water-Supply Paper 2425)

These regional curves should only be used in the rural Coastal Plain of the Panhandle of Florida on streams with the following characteristics:

1. A wide, alluvial valley with entrenchment ratios greater than 5.0.
2. Well-vegetated floodplains functioning as water and sediment storage areas.
3. Bank height ratios less than 1.5 and preferably less than 1.3.
4. Single-thread channels that have the potential to evolve into anastomosing or DA stream types.
5. Streams with stream powers generally less than 10 W/m^2.
6. Rosgen C5, C5c, and E5 stream types.

5 CONCLUSIONS

This study found significant relationships between drainage area and bankfull area, width, mean depth, and discharge in both the Northwest Florida Coastal Plain Region and the North Florida Coastal Plain Region. When used with appropriate caution and supported by other data, these regional curves can support stream assessment and restoration design.

The division of the Panhandle of Florida into two hydro-physiographic regions was driven by rainfall/runoff relationships more than by physiographic province; in fact, the two provinces (middle and lower coastal plain) showed no differences in bankfull discharge relationships under similar rainfall/runoff regimes. Due to similar physiographic characteristics and mean annual runoff, the North Florida Coastal Plain streams have a drainage area/bankfull discharge relationship similar to that of Georgia Coastal Plain streams, while Northwest Florida Coastal Plain streams have a drainage area/bankfull discharge relationship similar to that of Alabama Coastal Plain streams.

Compared to Coastal Plain regional curves developed in Maryland, North Carolina, and Georgia, Northwest Florida Coastal Plain streams exhibit greater bankfull discharge and dimensions. This increased bankfull discharge is probably due to the higher precipitation and increased runoff in the region; in fact, when looking at mean annual runoff for the four regions and the corresponding bankfull discharges, a direct relationship is apparent.

The break between the North Florida/Georgia Coastal Plain region and the Northwest Florida Coastal Plain region appears to occur around 20 inches of mean annual runoff. There is a quick transition between 15 and 20 inches of runoff around the Tallahassee area. Without further study, it seems as if this is a transitional area between the two hydro-physiographic regions, where streams may exhibit characteristics of either region or may fall somewhere in between.

Many sites were discarded during the study because the channels were braided. Many single thread systems showed some characteristics of braided channels. It is possible that the streams in this study are single-threaded due to past land use and channel modification and they are now slowly evolving back to multi-channel systems. This conclusion is supported by the low bankfull stream powers, cross-sectional areas, discharge, and frequent return intervals. These results match well with other research that describes Coastal Plain channels as aggradational with ample floodplain storage and frequent avulsions. These avulsions occur as the small main channel slowly fills with sediment or is jammed with debris, spilling more flood waters onto the floodplain more often and eventually forming new active channels. Since stream power is so low, this evolution from C and E to DA stream types will likely take centuries to complete. Nevertheless, this research provides a guide for designers to create stable Coastal Plain streams that can improve in form and function with time.

Further work is necessary to reduce the variability and improve the statistical strength of the regional curves. The twenty-six study sites fall within two hydro-physiographic regions, spread over an area of more than 30,000 square miles. Additional data points would be useful in identifying a more definitive break between the two regions or possibly in defining a third region. Additional points would also be useful in further determining the effect of stratifying site data by stream type. More discharge data are needed, especially in the North Florida Coastal Plain. Additional data into Alabama, Mississippi and South Carolina would help to define the outer edges of larger hydro-physiographic provinces not restricted by state boundaries.

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REFERENCES

Andrews, E. D., 1980. Effective and bankfull discharges of streams in the Yampa river basin, Colorado and Wyoming. Journal of Hydrology 46, 311-330.

Bunte, K., and Abt, S., 2001. Sampling surface and subsurface particle-size distributions in wadable gravel- and cobble-bed streams for analyses in sediment transport, hydraulics, and streambed monitoring. General Technical Report. RMRS-GTR-74. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 428 pp.

Chow, V. T. 1959. Open Channel Hydraulics. McGraw Hill Book Company. New York, NY. 680 pp.

Doll, B.A., Wise-Frederick, D.E., Buckner, C.M., Wilkerson, S.D., Harman, W.A., and Smith, R.E., 2000. Hydraulic Geometry Relationships for Urban Streams Throughout the Piedmont of North Carolina. Riparian Ecology and Management in Multi-Land Use Watersheds. American Water Resources Association Summer Symposium. Portland, Oregon. September 28-31, 2000. 299-304.

Dunne, T., and Leopold, L.B., 1978. Water in Environmental Planning. W.H. Freeman Co. San Francisco, CA.

Georgia Department of Transportation (Georgia DOT). 2003 Final Report: Bankfull Regional Curve Development for the Coastal Plain of Georgia. Prepared by Buck Engineering.

Georgia State Climate Office (GSCO), 1998. Climatology of the Georgia Coastal Plain. University of Georgia. Athens, GA.

Gerbert, W.A., Graczyk, D.J., and Krug, W.R., 1987. Average annual runoff in the United States, 1951-1980: U.S. Geological Survey Hydrologic Atlas, HA-710, scale 1:7,500,000.

Gomez, B., 1991. Bedload transport. Earth-Science Reviews 31:89-132.

Harman, W.A., Jennings, G.D., Patterson, J.M., Clinton, D.R., Slate, L.O., Jessup, A.G., Everhart, J.R., and Smith, R.E., 1999. Bankfull Hydraulic Geometry Relationships for North Carolina Streams. Proceedings of the American Water Resources Association (AWRA): Wildland Hydrology, D.S. Olsen and J.P. Potyondy, eds.) June 30-July 2, 1999. Bozeman, MT.

Harman, W.A., Wise, D.E., Walker, M.A., Morris, R., Cantrell, M.A., Clemmons, M., Jennings, G.D., Clinton, D., and Patterson, J., 2000. Bankfull Regional Curves for North Carolina Mountain Streams. AWRA Proceedings: Water Resources in Extreme Environments, D.L. Kane, ed. May 1-3, 2000. 185-190.

Harrelson, C.C., Potyondy, J.P., Rawlings, C.L., 1994. Stream Channel Reference Sites: An Illustrated Guide to Field Technique. General Technical Report RM-245. U.S. Department of Agriculture, Forest Service. Fort Collins, Colorado.

Johnson, P.A., and Heil, T.M., 1996. Uncertainty in Estimating Bankfull Conditions. Water Resources Bulletin. JAWRA 32(6):1283-1292.

Kilpatrick, F.A., and Barnes, H.H., Jr., 1964. Channel Geometry of Piedmont Streams as Related to Frequency of Floods. Professional Paper 422-E. U.S. Geological Survey, Washington, DC.

Knighton, David, 1998. Fluvial Forms and Processes. Rutledge, Chapman, and Hall, Inc. New York, NY.

Leopold, L.B., 1994. A View of the River. Harvard University Press, Cambridge, Mass.

Leopold, L.B. and Maddock, T., 1953. The hydraulic geometry of stream channels and some physiographic implications. United States Geological Survey Professional Paper 252.

Miller, J.H., and Robinson, K.S. Robinson, 1994. Proceedings of the Eighth Biennial Southern Silvicultural Research Conference. Auburn, AL. General Technical Report SRS-1. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station, 581-591.

Nixon, M., 1959. A study of bankfull discharges of rivers in England and Wales. Proceedings of the Institution of Civil Engineers, 12:157-175.

Nanson, G.C. and Croke, J.C., 1992. A genetic classification of floodplains. Geomorphology 4: 459-486.

Nanson, G.C. and Knighton, A.D., 1996. Anabranching rivers: their cause, character and classification. Earth Surface Processes and Landforms 21: 217-239.

Rosgen, D.L., 1994. A classification of natural rivers. Catena 22: 169-199.

Rosgen, D.L., 1996. Applied River Morphology. Wildland Hydrology Books, Pagosa Springs, CO.

Schumann, R.R., 1989. Morphology of Red Creek, Wyoming, an arid-region anastomosing channel system. Earth Surface Process and Landforms 14: 277-288.

Schumm, S.A. 1960. The shape of alluvial channels in relation to sediment type. U.S. Geological Survey Professional Paper 352-B. U.S. Geological Survey, Washington, DC.

Simons, D.B., and Richardson, E.V., 1966. Resistance to flow in alluvial channels. U.S. Geological Survey Professional Paper 422J.

Smith, D.G. 1983. Anastomosed fluvial deposits: modern examples from western Canada. Modern and ancient fluvial systems, J.D. Collins and J. Lewin, eds. Oxford: Blackwell, Special Publication of the International Association of Sedimentologists 6:155-168.

Sweet, W. V. and Geratz, J. W., 2003. Bankfull Hydraulic Geometry Relationships and Recurrence Intervals for North Carolina's Coastal Plain. Journal of the American Water Resources Association. 39: 861-871.

U. S. Fish and Wildlife Service (USFWS), 2003. Maryland Stream Survey: Bankfull Discharge and Channel Characteristics in the Coastal Plain Hydrologic Region. CBFO-SO3-02, Chesapeake Bay Field Office.

U. S. Geological Survey (USGS), 1969. Techniques of Water-Resources Investigations of the United States Geological Survey: Discharge Measurements at Gaging Stations. Book 3, Chapter A8. U.S. Geological Survey, Washington, DC.

USGS, 1982. Guidelines for Determining Flood Flow Frequency. Bulletin #17B of the Hydrology Subcommittee. Interagency Advisory Committee on Water Data. U.S. Geological Survey, Reston, VA.

USGS, 1996. Water-Supply Paper 2425. National Water Summary on Wetland Resources. Available on-line at http://water.usgs.gov/nwsum/WSP2425/ cited on December 9, 2004.

Williams, G.P., 1978. Bankfull Discharge of Rivers. Water Resources Research 14(6):1141-1154.

Wolman, M.G., and Leopold, L.B., 1957. River Floodplains: Some Observations on their Formation. USGS Professional Paper 282-C. U.S. Geological Survey, Washington, DC.

Wolman, M.G. and Miller, J. P., 1960. Magnitude and frequency of forces in geomorphic processes. Journal of Geology 68: 54-74.

APPENDIX I

Study Site Data and Descriptions

Under separate cover. Available by request.

Includes the following:

Alaqua Creek
Baggett Creek
Barnetts Creek near Thomasboro
Bear Creek
Big Coldwater Creek
Brushy Creek
Caney Creek near Monticello
Deep Creek near Suwannee Valley
Econfina River near Perry
Fenholloway River near Foley
Fish River
Juniper Creek
Little Double Bridges Creek
Little River near Ashburn
Little River near Midway
Muddy Creek
New River near Lake Butler
Newell Branch near Ashburn
Newell Branch near Worth
Rocky Creek near Live Oak
Seven Mile Creek
Shoal River near Crestview
Shoal River near Mossy Head
Tired Creek near Cairo
UT to Rocky Creek
UT to Warrior Creek

APPENDIX II

USGS Gage Information and Flood Frequency Analysis

Under separate cover. Available by request.

Includes the following:

Alaqua Creek near Portland
Baggett Creek near Milligan
Barnetts Creek near Meigs
Bear Creek near Youngtown
Big Coldwater Creek near Milton
Brushy Creek near Walnut Hill
Caney Creek near Monticello
Deep Creek near Suwannee Valley
Econfina River near Perry
Fenholloway River near Foley
Fish River near Silverhill, AL
Juniper Creek at State Hwy 85 near Niceville
Little Double Bridges Creek near Enterprise
Little River near Ashburn
Little River near Midway
Muddy Branch near Beaver Creek
New River near Lake Butler
Newell Branch near Ashburn
Newell Branch near Worth
Shoal River near Crestview
Shoal River near Mossy Head
Tired Creek near Cairo
Warrior Creek Tributary at Sylvester