HYDROBIOGEOMORPHOLOGY OF FLUVIAL SYSTEMS IN PENINSULAR FLORIDA: IMPLICATIONS TO CLASSIFICATION, CONSERVATION, AND RESTORATION

By

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To Mom, Sarah, and Nolan

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I thank Kristen Blanton for her diligence, leadership and outstanding common sense, Jacque Levine for her MacGyver-like ability to make things work, and Jessie Taft and Kory Baxley for all their help whenever called upon. I thank stream team member Aziza Khan for her assistance with GIS analyses and her amazing ability to always meet last-minute requests with a smile. This study was successful on the merits of those five people, which is not always easy in the wet sub-tropics given the sudden electrical storms, jet-black waters with lurking alligators, thick vine-tangled vegetation sheltering various vipers, and other unmentionables. We surveyed streams often more by feel than by sight and the team seemed to fall in love with Florida’s wonderful array of fluvial forms while doing so. We learned some valuable scientific lessons together, especially the importance of humor to sanity.

TABLE OF CONTENTS

APPENDIX

LIST OF TABLES

LIST OF FIGURES

Abstract of Dissertation Presented to the Graduate School
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Florida has a unique combination of a wet sub-tropical climate and a geologic history that involved comparatively recent marine processes on what is now the terrestrial landscape of the peninsula. This combination has led to three distinctly different water delivery systems to Florida streams, copious and steady groundwater emitted through limestone springs under pressure, unconfined lateral groundwater seepage through thick columns of sand through relict dunes, and surface water runoff coursing through and over combinations of shallow organic and sandy soils. These sources substantially impact the character of flow regimes.

Florida stream valleys generally have modest relief, but changes in grade appear to be associated with substantial differences in channel shape. Florida streams often course through complex valleys that can repeatedly alternate between confining sandy bluffs and broad flat swamps. In-line lakes and wetlands are common.

Existing stream classification schemes in Florida focus either generically on stream channel shape or on associations of water quality with aquatic biota. There existed a pressing need for systematic and quantitative study of the fluvial

geomorphology of Florida streams and their associations with their watersheds. Such information is vital for the conservation, restoration and management of this resource.

This study provides a first attempt at describing an array of Florida fluvial forms based not only on their channel shape and water quality, but also on important thresholds concerning their landscape associations at the watershed and valley scales. These descriptions of Florida stream types are based on quantified channel and floodplain characteristics, valley shape, watershed soil characteristics and potential functional associations concerning stream hydrology, sediment transport, riparian vegetation, and aquatic habitat. Streams chosen for study were of a “near-to-natural” character and represented some of the healthiest stream settings in the peninsula. The main purpose of the study was to determine how a stream fits its landscape and how a restorationist tasked with recreating a damaged system would determine restoration objectives. At least 15 types of Florida streams can be systematically described based on metrics related to flow variability and flow source, power to transport sediment, conveyance shape and size, and position in the drainage network.

CHAPTER 1
INTRODUCTION

Need for Research

Despite having a variety of fluvial forms, some of which are comparatively rare in other regions of North America, no physical classification system based on modern concepts of fluvial geomorphology has been developed for the Florida peninsula. This is important because stream classifications developed elsewhere may not apply very well to Florida's unique combination of humid sub-tropical climate, carbonate geology, sandy soils, and low relief.

Across humid temperate regions, streams are often classified and evaluated based predominantly on their shape at the reach scale, generally covering distances of less than a few hundred feet (Rosgen, 1996; Harrelson *et al*., 1994; Barbour *et al*., 1999). This approach to fluvial geomorphic classification rests on assumptions that channel shape at that particular scale is associated rather strongly with processes of interest to stream restoration designers and riparian systems managers tasked with protecting streams. Those assumptions are probably most valid for streams that are relatively deformable under dominant alluvial control. In other words, streams whose shape is a strongly dictated as a function of sediment transport.

Peninsular Florida has fluvial forms that are under variable degrees of alluvial control, raising questions concerning the indiscriminate applicability of shape-based classification at the reach scale. The proposed research is intended to determine the merits of classifying peninsular Florida streams based on metrics collected at multiple scales, including the reach. The premise of this research is to test the concept that not all Florida streams lend themselves to the types of reach-scale, form-based classification now widely used across much of the rest of North America and that classification will improve by incorporating basin-scale forms and process-based factors.

In other words, this assessment of different classification approaches and the use of classification for improved understanding of associations among independent and dependant variables is anticipated to facilitate restoration activities that allow practitioners to better restore damaged streams to their watershed, or to guide watershed management plans for the protection of relatively intact riparian systems.

Existing stream classification schemes in Florida focus either generically on stream channel shape or on associations of water quality with aquatic biota. No systematic and quantitative study of the fluvial geomorphology of Florida streams and their associations with their watersheds and valleys has been conducted. Such information is vital for the conservation, restoration and management of this resource. The lack of current information holds especially true of small wadable streams draining headwater positions in the landscape (low-order streams) and the streams formed downstream of low-order channel junctions (mid-order streams). In comparison, the geomorphology, hydrology, floodplain habitats, and aquatic habitats of higher-order systems comprised of rivers located downstream of two or more mid-order catchments are fairly well studied (Inter-Fluve, 1997; Warne *et al*., 2000; and Darst, *et al*., 2002). There are many more low-order and mid-order streams than higher-order rivers. For these reasons our team focused on low- and mid-order systems.

This study provides a first attempt at describing an array of Florida fluvial forms based not only on their channel shape and source of water, but also on important thresholds concerning their landscape associations at the watershed and valley scales. These descriptions of Florida stream types are based on quantified channel and floodplain characteristics, valley shape, watershed soil characteristics and potential functional associations concerning stream hydrology, sediment transport, riparian vegetation, and aquatic habitat. The main purpose of the study was to determine how a stream fits its landscape and how a restorationist tasked with recreating a damaged system would determine the appropriate restoration objectives.

General Approach

Streams were sampled from several types of natural kinds ranging across distinctly different hydrologic regimes and physiographic settings within peninsular Florida. Variables commonly associated with important forms in fluvial geomorphology were measured across a hierarchy of scales including the catchment, valley, reach, and in-stream patch. Process variables related to hydrology and hydraulics, including tractive forces important for sediment transport, were determined as well.

Study Area Description

Compared to most of North America, Florida has a unique combination of a seasonally wet and dry sub-tropical climate and a geologic history that involved Neogene marine processes on what is now the terrestrial landscape of the peninsula. This combination has led to three distinctly different water delivery systems to Florida streams, copious and steady groundwater emitted through limestone springs under pressure, unconfined lateral groundwater seepage through thick columns of sand through relict dunes, and surface water runoff seasonally coursing through and over combinations of flat shallow organic and sandy soils.

The climate varies across the state, especially in terms of the timing and annual volume of precipitation and in the magnitude of monthly potential evapotranspiration. Most of the peninsula exhibits a fairly pronounced wet and dry season pattern, with intense and frequent summer rains. The panhandle and northern Florida are more affected by the continental land mass than the peninsula and the seasonal pattern is different as a result (Henry *et al*., 1994). Although most Florida peninsular streams exhibit pronounced seasonal flow patterns with higher pulses during the wet season (June through October) versus the dry (November through May), the three basin physiographies substantially impact the variability of flow. Chapter 2 provides more detail concerning this characteristic of Florida landscapes.

Florida stream valleys generally have modest relief, but changes in grade can be associated with substantial differences in channel shape. The stream channels often course through complex valleys that can repeatedly alternate between confining sandy bluffs and broad flat swamps. In-line lakes and wetlands are common. These valley forms reflect the marine history of the peninsula and its interaction with more modern fluvial forces.

Continental streams are comparatively well-studied versus those of peninsular Florida. Our team was interested in the potentially unique attributes of peninsular, seasonally wet, sub-tropical streams. From this point forward, when the term Florida is used, generally the context is the peninsula and not the panhandle or areas close to Georgia.

Site Selection

Site selections were limited to streams located roughly between the Santa Fe River watershed and Lake Okeechobee to assure that the stream population was peninsular rather than continental. All sites were surveyed at positions above the 5-foot contour line (National Geodetic Vertical Datum), as mapped on USGS 1:24,000 7.5 Minute Series Topographic Maps, to assure they were non-tidal. First, the USGS Florida site inventory was used to select as many gaged sites as possible that met the initial inclusionary criteria:

- At least ten years of continuous or peak discharge measurements
- No direct alteration to the reach with water control structures, ditches, or canals
- Less than 20% of basin is impervious cover
- Less than 20% of basin is ditched or has induced discharge (for example, agricultural tail water)
- Less than 10% of basin is mined
- No significant land use changes during or since the gaging period, which was determined by examining historical aerial photographs at the University of Florida's Map and Imagery Library.

Twenty-seven candidate sites reported with gages were initially selected using this method. To supplement the gaged sites, areas defined by the Cadastral Sectional grid were randomly selected to fill the roster with ungaged sites. If the selected Section contained more than one stream segment, it was successively quartered, and one of the quarters was then randomly selected until the selected polygon contained just one stream. A stream was then rejected if it did not meet the above inclusionary criteria (minus the minimum gage record criterion). Of the first 100 ungaged sites selected in this fashion, 75 streams were rejected and a clear trend emerged when it became apparent that all but four of the pre-selected sites were draining large tracts of public conservation lands. Therefore, to select sites more efficiently, Cadastral Sections were restricted to public landholdings, such as state parks, state and national forests, water management district lands, state wildlife lands, military bases, and county preserves, and to large private landholdings not subject to future development, such as those owned by the Nature Conservancy and those under conservation easement. Once 70% of the sites had been selected, these were graphically plotted based on their drainage area and valley slope to ensure that the sample was not skewed towards a clustered regression. Sites continued to be selected randomly, but were rejected if they fit a redundant drainage area to valley slope bin. Eighty-three sites were selected in this manner.

Once site access permission was obtained, initial field investigations were conducted. Sites were ultimately excluded from the study if they had negative local effects (such as cattle grazing, ditching, evidence of logging, bridge or road effects, altered hydrology), were not single-threaded channels or had poorly defined channels (such as braided or anastomosed stream types, sloughs, strands), or had uncooperative landowners. Twenty-seven of the originally selected sites were rejected, including Warm Mineral Springs Run (artificial weirs and bank clearing), Bugg Spring Run (stage declining since 1960’s), Otter Spring Run (uncooperative landowner), Camp-La-No-Che Run (drowned or embayed by Lake Norris at time of visit), Gopher Bank Gully (slough), Spoil Bank Tributary (uncooperative landowner), Myakka River Tributary (local ditching), Oak Creek Tributary (uncooperative landowner), Wolf Creek (slough), Bull Creek Tributary (anastomosed), Big Jones Creek (anastomosed), Alexander Springs Tributary 1 (road eroded and impassable), Lake Arbuckle Tributary (strand), Hog Branch (wastewater plant discharge), Mud Prairie Distributary (strand), Gobbler Lake Distributary (strand), Cow Creek Tributary (banks impacted by logging), Charlie Creek near Gardner (uncooperative landowner), Little Charlie Bowlegs Creek (slough), Fort Drum Creek (anastomosed and with large fearless alligator), Jane Creek (slough), Anclote River (potential dewatering from wellfield), New River near Zephyrhills (recent urbanization and unstable banks), Little Withlacoochee River near Tarrytown (slough), Lake Placid Tributary (tree falls from hurricanes precluded access), South Fork of Blackwater Creek near Penney Farms (uncooperative landowner), and Hickory Creek (local ditching). Fifty-six of the originally selected sites were surveyed and included in the study (Figure 1-1), 18 of which were gaged with reliable long-term records (Figure 1-2).

Metrics and Hierarchy of Scale

The hierarchical considerations behind the sampling classes included aspects of the physical catchment (basin capture and dominant delivery of water as runoff or groundwater), hydrology (water volume and flow frequency patterns in the stream), hydraulics and reach boundaries (potential relationships among valley and channel form, substrate, and processes), and physical habitat (patch scale features important to aquatic fauna that derive from the fluvial geomorphology of the system and, in some cases, reinforce it).

This construct embodied key concepts in applied fluvial geomorphology, some of which were assumptions explored further by this research:

- Humans can impact various stream component variables across multiple scales.
- Channel shape alone may not be sufficiently delineative to classify streams in Florida to facilitate proper restoration or management activities because form may be convergent with multiple processes.
- Climate, catchment and hydrology components are “downhill” relationships. They are independent variables that affect the lower hierarchy components without

feedback loops. Such loops, if they occur, operate on very long timescales that are unimportant to stream restorationists or watershed managers.

- Basin/catchment components deliver water to a valley. Once in the valley, interactions among hydraulics, sediments, vegetation, and channel form reach a dynamic equilibrium that is impacted or maintained on a time scale relevant to human activities.

- Channel and floodplain form are maintained by processes and complex feedback loops operating at the patch, valley, and reach scales.

Given the construct of interest, the sample selection was designed to capture differences across three physical-scale hierarchies, 1) basin/catchment, 2) valley and reach, and 3) patch/sub-reach. It also captured process variability by means of hydrology and hydraulics data across flow regimes ranging from intermittent to perennial and from low to high energy pulses. Morphology surveys at the reach scale were expected to capture virtually all of the common and uncommon channel and valley forms given the large number of sites in the study. In addition to channel shape and hydraulic relationships, this included the range of normal conditions exhibited by the important boundary quality of substrate type (sand, rock/clay, and detritus). Different dominant controls on fluvial form boundaries such as alluvial (transport), bedrock (geological), imposed (vegetation and snags), and colluvial (hillslope) were captured. The main physical habitat types recognized by limnologists as most important to Florida's aquatic macroinvertebrate and fish fauna were captured as well.

A reference reach survey was conducted at each site according to Harrelson *et al.* (1994). Cross-sectional and longitudinal surveys were completed along a minimum reach length of 20 times the channel width (top-of-bank to top-of-bank) to determine bankfull width, mean bankfull depth, maximum bankfull depth, bankfull cross-sectional area, slope, and sinuosity of the channel. A Leica Total Station and a handheld data collector running Carlson SurvCE (Carlson) were used to record measurements to 100th of a foot, as per accuracy of the equipment. Depth of water at the thalweg was recorded to the nearest 10th of a foot. Plan, longitudinal, and cross-section profiles were derived from the survey data using RiverMorph 4.0.1 Stream Restoration Software.

General Use of Exploratory Statistics

The research questions boiled down to interests concerning the prediction of group membership, structure of the data, and relationships among variables. Basic *a priori* decisions included whether to proceed using controlled versus uncontrolled multivariate analyses, features (discrete data) in addition to properties (continuous data), and simple random sampling versus structured sampling.

Simple random sampling of roughly 50 sites from the population of all Florida streams was unlikely to lead to a sufficient representation of all major stream types, some of which are clearly not random in their distribution and have much more limited distributions than others. Plus, much can be inferred from examination of the sensitivity of the association between independent variables and their potential effects on a dependent variable using regression, within and among classes. Regression works best when samples cover a range of variables of interest across as much of the population as possible. Therefore a more structured site selection approach was required to assure that the limited number of samples covered the potential fluvial forms and also would cover a relatively wide range of potential independent variables for use in regression.

Some statistical analyses of multivariate datasets are more sensitive to outliers, and more reliant on normality, linearity, and homoscedastcity than others. Data screening started with looking for missing or mis-entered data and proceeded to screening for the aforementioned conditions. Decisions related to treatments for outliers favored use of techniques less sensitive to them rather than eliminating them from the dataset when feasible. Transformations of non-normal data were utilized to overcome some parametric limitations in the raw data. Inflated correlation is a real and somewhat unavoidable issue in fluvial geomorphology. Use of composite variables was carefully considered and alternatives were used as deemed allowable. Data centering was used to address collinearity in regressions. Deflated correlation was unlikely given the sampling design.

The research plan was designed with several different statistical techniques to be invoked on various components of the dataset, including principal components analysis (PCA) for exploration, linear regression for exploration and prediction, multiple regression for prediction and class comparisons, and hierarchical cluster analysis for exploring classification (Tabachnick and Fidell, 2007).

Document Organization

This document provides three special purpose chapters in addition to the introduction and summary. Chapter 2 focuses on the watershed scale, with particular emphasis on comparing the geomorphic differences between streams fed by two different aquifer types versus streams fed mostly by rainfall runoff.

Chapter 3 focuses on the valley scale, with emphasis on describing the clinal and patchy patterns of Florida’s riparian corridor morphology within the drainage networks of different physiographic regions of the state. It overviews Florida’s deranged drainage networks, which are frequently punctuated with in-line wetlands and lakes. This chapter also discusses applications of functional process zone (FPZ) concepts. FPZ concepts are used to describe and classify rivers as habitat patches with abrupt lateral and longitudinal edges that can repeat along the drainage network. The habitat patches are not completely random or static, however, and they are usually organized at a landscape level (Thorp *et al.*, 2008).

FPZ concepts are further explored as part of Chapter 4, which provides descriptions of latent variables suggesting associations between fluvial form, in-stream habitat patches and fluvial processes that seem to depend on hierarchical interactions of the watershed scale and its hydrogeology, valley confinement characteristics, and bankfull channel hydraulics. This chapter provides descriptions of the apparent natural kinds of streams in Florida, as partially evidenced by a series of hierarchical cluster analyses on all the available metrics for 56 sites.

Chapter 5 briefly summarizes the findings while placing them in the context of potential management decisions to promote enhanced stream protection, better restoration strategies, and proper mitigation approaches. The need for future multi-disciplinary research is also emphasized.

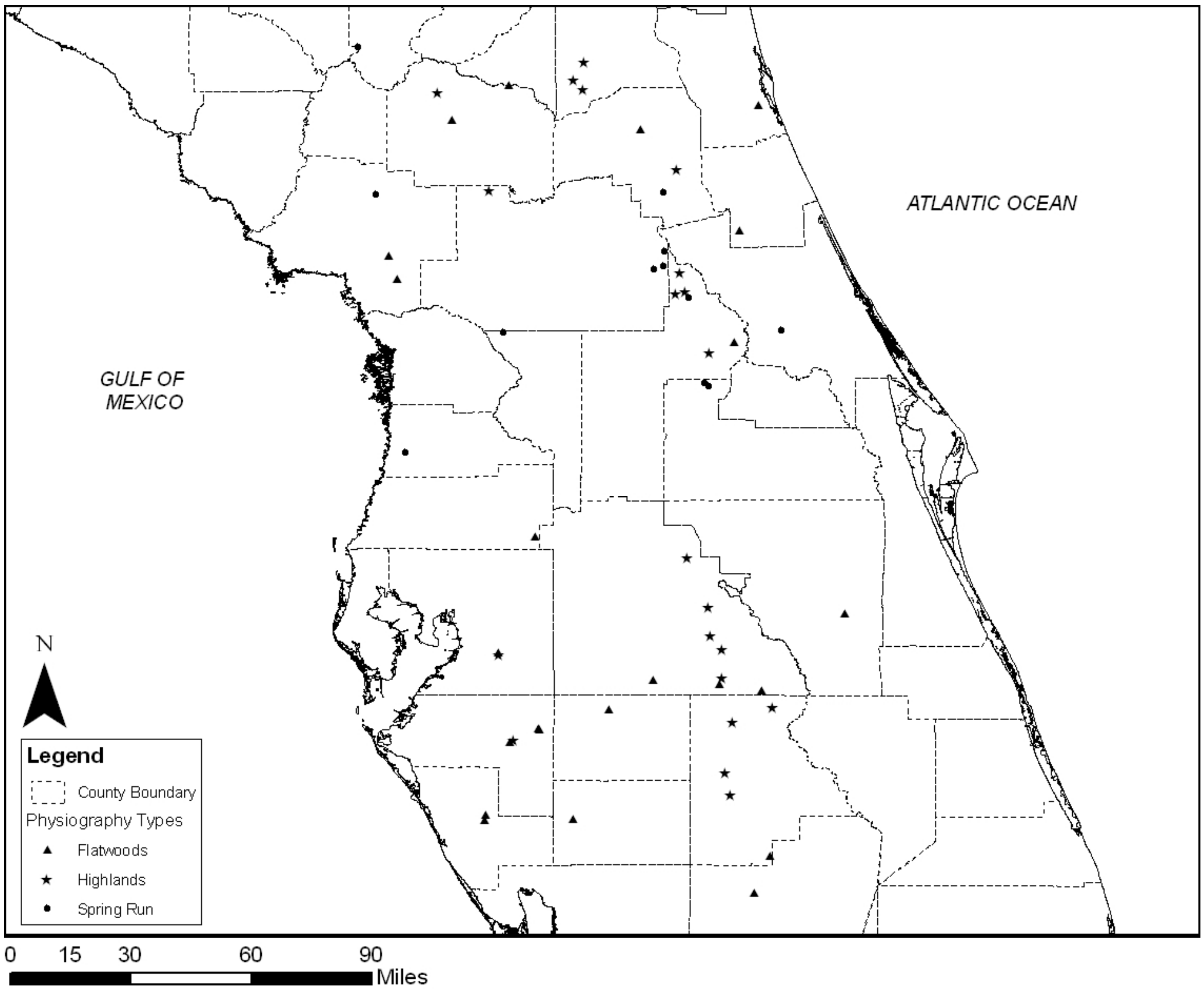


Figure 1-1. Reference reach study site locations (56 streams).

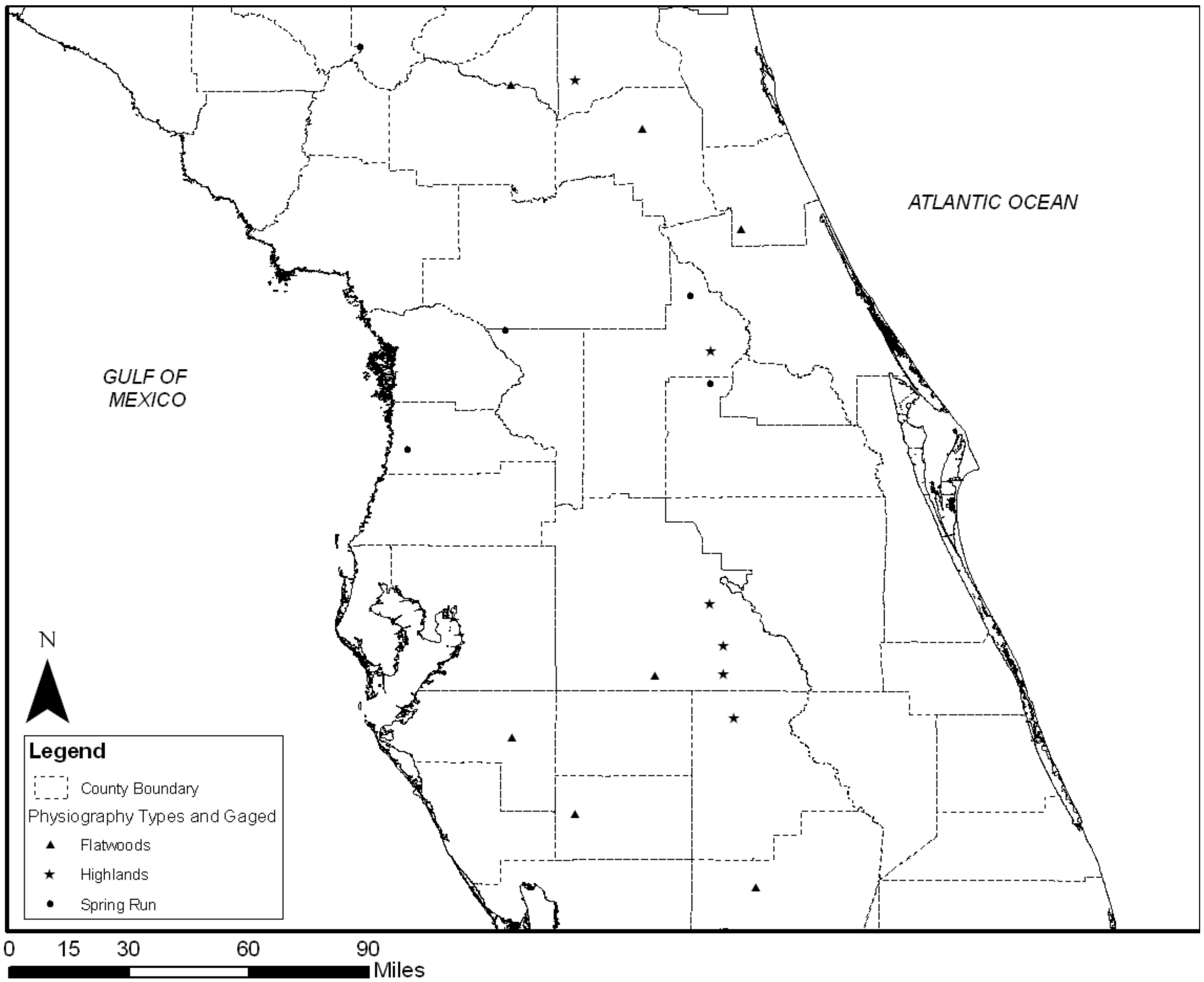


Figure 1-2. Gaged study site locations (18 streams).

CHAPTER 2
HYDROBIOGEOMORPHOLOGY OF BLACKWATER STREAMS AND SPRING RUNS IN SUB-TROPICAL FLORIDA

Introduction

Purpose

Streams belong to their watersheds. The purpose of this chapter is to further describe this association in the wadable perennial streams of peninsular Florida by comparing the hydropatterns and basin characteristics among streams draining three different kinds of water supply systems commonly found in the state. These include two types of groundwater dominated systems, one that provides perennial discharge from a confined aquifer consisting of carbonate rock in karst terrains and the other which provides baseflow discharge predominately via lateral seepage from a deep sandy unconfined aquifer with high infiltration capacity. The seepage basins typically have some internal drainage and often have large lakes (Myers and Ewel, 1990; FNAI, 1990). We observed that seepage stream watersheds also provided runoff during intense, high volume rain events. The seepage basins occurred on high sandy ridges consisting of relict dunes (White, 1970). These areas, when undisturbed, support upland habitats consisting of xeric plant communities that have special adaptations to droughty sands with low groundwater tables (Myers and Ewel, 1990; FNAI, 1990). The third water supply system consists of comparatively flat basins that have low infiltration capacity during the wet season with very high water tables (Myers and Ewel, 1990). They routinely deliver most of their total discharge volume via surface water runoff events, often through a series of wetland depressions and sloughs (FNAI, 1990). These landscapes support pine savannas and woodlands, grasslands with palmettos, and prairies adapted to seasonally wet conditions, often referred to as “flatwoods” (Myers and Ewel, 1990; FNAI, 1990).

The fundamental question is, “Should we consider water source as part of a hierarchical classification system of Florida streams and, if so, why?” The second question centers on what hydrologic and watershed variables are important to consider based on their association with channel and floodplain morphology. This is an important question related to stream management and restoration because hydrologic variability is complex and many restoration and management approaches seek simplifications.

One common simplification rests on the concept of effective discharge, which states that channel dimension and pattern result mainly from the actions of the single discharge that does the most overall work transporting sediment (Andrews, 1980). The theory of dominant discharge states that if a stream were to flow only at its most effective discharge rate, it would achieve the same overall cross-section dimension and planform pattern that it exhibited under its naturally variable flow regime (Harvey, 1969). This is not as simple a concept as it appears and it is also potentially misleading if taken too literally by stream managers because biological systems can influence morphology and the associated plant communities respond to different flooding regimes in riparian corridors. Furthermore, comparatively rare events may provide important pulsed disturbances that breakup channel evolution trends by establishing a hierarchical component to “equilibrium” conditions akin to pressing a reset button. Uncommon floods also do work in the floodplain at thresholds that the effective discharge does not attain.

Because Florida's karst spring runs provide as close to a constant discharge as one can find in nature, they offer the potential to explore the literal truth of dominant discharge concepts. Or put another way, "What would happen in nature to a stream channel and its floodplain geomorphology if it only modestly deviates from its dominant discharge rate?"

Streams draining flatwoods basins have much more variable flow regimes and serve as an excellent comparison within the same climate. However, this comparison is potentially confounded by differences in the water quality of these two types of streams important to aquatic biota, especially hardness and color. Therefore, seepage streams draining Florida's sandy highlands were included to determine if they provide an intermediate degree of flow variability and could offer an opportunity to explore the intermediate effects between the highly variable flatwoods flows and the very steady karst flows but with a smaller degree of confounding water quality issues. This is because the highlands streams are usually blackwater streams with wet-season water quality more similar to flatwoods streams than to the spring runs.

Study Area and General Site Descriptions

The geomorphology of Florida has been described and mapped based largely on its marine-derived geology and variable submergence history due to sea-level fluctuations. The peninsula consists of a relatively thin veneer of reworked sand and clay of varying thicknesses over a thick mantle of porous limestone bedrock. Sea level changes have led to the formation of several relect marine terraces and a distinct sandy central ridge running down the interior of the peninsula. Large portions of the state are pocked with lakes and wetland depressions originating from the solution of carbonate rock—generally referred to as karst terrain. The areas with the most obvious karst features tend to be along the highest ridges and are internally drained with relatively few streams compared to areas with more limited karst-derived lakes. The areas with limited karst expressions tend to have fewer lakes and more streams. This has led to two basic physiographies in the state supporting streams: 1) highlands (generally with lots of lakes, relict sand dunes, low water tables, rolling topography and few streams) and 2) flatwoods (generally with lots of wetlands, high water tables, flat topography and many streams). Although the highlands have lower overall drainage densities, a patchy distribution of streams occur on these ridges and some of those patches can provide localized drainage densities similar to those of the flatwoods. This is discussed in more detail in Chapter 3.

Most geomorphic classifications used in the state are based on the work of William White (White, 1958; White, 1970). Understanding the geological/geomorphic setting of streams in Florida is important because the lithology exerts significant controls on the distribution of flow among surface water and groundwater systems. The major geomorphic divisions exhibit a variety of watershed sizes, valley slopes, valley lengths, stream network patterns, and groundwater/surface water interactions. Griffith *et al.* (1994) mapped 20 ecoregions in the state based on a combination of the effects of geomorphology, climate, soils, and ecological communities with some significant deference to the natural vegetation (Figure 2-1). The NRCS has produced land form classes and maps resulting in four Florida peninsula categories based on soils, geomorphology, and climate (NRCS, 2006). These classifications inherently reflect Florida’s marine geological history, which has left a complex milieu of geological exposures and shallow lithological layers across the state comprised of unconsolidated sands, stiff clay, and limestone (Figure 2-2). The scale of these deposits and their frequent re-working due to sea level changes, as recently as the Pleistocene and early Holocene, means that long Florida stream valleys typically flow through multiple exposures.

Also, more than one ecoregion can occur in a watershed (surface drainage basin) or springshed (area of recharge and potentiometric influence to a spring run). Inclusions of the vegetation and soils assemblages common to one ecoregion can be found in the broad areas mapped as a different ecoregion. For example, it is pretty common to have up to 40% of a watershed in a xeric highland ecoregion comprised of flatwoods plant communities or to have small watersheds almost completely dominated by xeric highland communities within a flatwoods ecoregion. Ecoregions likely warrant careful consideration for Florida fluvial geomorphology, mainly because they have a strong association with geomorphic history of the landscape, but ecoregions alone are not likely to be robust predictors of stream types or functions as typically mapped at a statewide scale.

Existing Limnological Classification of Florida Streams

There have been limited attempts to derive a comprehensive physical classification of Florida's freshwater streams. Ecologists interested in stream limnology and aquatic fauna developed the only attempts at general stream classifications in Florida. These were based primarily on faunal metrics, water quality, and in some instances sediment type. Rogers (1933) offered one of the earliest classifications based on his crane-fly research in northern Florida, describing five classes of streams based on their water quality, sediment type, size, and position along the drainage network. These included 1) "small streams" defined by the presence of alluvial bed forms of rolling sand, 2) “larger calcareous streams” with water derived from huge springs and calcareous lakes with clean swept limestone beds and ranks of submerged aquatic vegetation, 3) “swamp and bog streams” with sluggish flow through swamps with poorly defined banks and organic bottoms, 4) “lower streams” were generally rivers with highly variable seasonal flow and bottomland floodplains, and 5) “seepage areas and small rills” typically were small seepage outlets from the surficial aquifer, often less than a few square yards in size. Occurring along most “small streams” these seepage areas exhibited concentrations of unique crane-flies, perhaps warranting special consideration from this particular researcher. Rogers stated that the “small streams” were the most common type.

Building on the work of Rogers, Beck (1965) provided perhaps the most influential of the attempts at developing a statewide stream classification in Florida, resulting in five limnological classes of streams based on their chemical, physical, and biological characteristics and matters of convenience. Beck, perhaps unfortunately, reduced Rogers’ attention to stream size and landscape position and added two nominal classes as matters of convenience (“Large Rivers” and “Canals”). Beck largely validated certain “natural kinds” of classes by statistically significant differences in faunal distribution. Beck described natural kind classes for Sand-Bottomed Streams, Calcareous Streams, and Swamp-and-Bog Streams, which corresponded rather similarly to those described by Rogers.

The characteristics separating the three natural kinds of streams in Beck’s classification were mainly pH, hardness, color, velocity, substrate, and aquatic fauna (especially rheophilic macroinvertebrates, mollusks, and fishes). Sand-bottomed streams had low to neutral pH, moderate to high color, low to moderate hardness, moderate to swift velocity, beds dominated by fine sand, and rheophilic/rheobiontic macroinvertebrate fauna. Calcareous streams had neutral to slightly alkaline pH, were colorless, had moderate hardness, low to swift velocities, sand, clay, limestone and organic beds, mollusk fauna, and submerged aquatic vegetation. Swamp-and-Bog streams had low pH, high color, low hardness, low velocity, organic silt beds, no rheophiles, almost no mollusks, and fish fauna with sunfish and darters.

Scientists working for the Florida Natural Areas Inventory (FNAI, 1990) refined Beck's classification by adding descriptions of landscape settings and water sources. They also categorized vegetated Swamp-and-Bog conveyances as wetlands rather than streams (as strands, sloughs, swales). FNAI listed four riverine ecosystem types: Alluvial Streams, Blackwater Streams, Spring-Run Streams, and Seepage Streams.

Alluvial Streams originate in high uplands and carry high sediment loads. They have intermittent to perennial flow. They are generally confined to large streams and rivers originating from the continental landmass. This name is potentially misleading, because it implies that all other stream channels in Florida are non-alluvial which is not true. It would be more accurate to think of them as “Wash-Load” streams given their perennial turbidity or “Continental River” given their origin.

Blackwater Streams, the most common type in the state, originate from sandy lowlands with wetland reservoirs discharging tannic waters to the channel. They can be intermittent or perennial and often, but not always, are characterized by acidic waters. FNAI makes no reference to their practically ubiquitous sandy alluvial bed forms and seems to be lumping quite a number of different types of entrenched and non-entrenched forms with very different floodplain configurations. In fact, contrary to FNAI's descriptions, most larger blackwater rivers in Florida do have strong alluvial indictors such as natural levees (for example, the Peace River) and anastomosing plan-forms (for example, the Kissimmee River). Streams ranging across a fantastic array of basin sizes and hydrologic regimes are also lumped. For example, this class would include both of the following streams:

- An unnamed headwater tributary six feet wide, 900 feet long, that flows for four months a year, drains a 0.8 square mile watershed, lacks a wetland floodplain, its banks consist of upland soils held tightly by palmettos, and bankfull flow is two cubic feet per second (cfs)
- An open channel 50 feet wide that is part of a valley more than 40 miles long, flows perennially, drains more than 200 square miles, has banks of alluvium held tightly by wetland tree and shrub species across a wetland floodplain more than 500 wide, and bankfull flow is about 200 cfs.

This comparison illustrates systems with some key limnological similarities that differ substantially in their fluvial form and processes. They have different protective management requirements and, if damaged by human activities, would have far different restoration designs.

FNAI's Seepage Streams originate from shallow ground waters that have percolated through deep, sandy upland soils. They can be intermittent or perennial with either clear or tannic waters. They are usually short, shallow and narrow or they may form the headwaters of Alluvial and Blackwater Streams. Based on these descriptors it is difficult to separate quite a few streams with different fluvial forms and processes between the Blackwater and Seepage classes using FNAIs qualitative descriptions, especially some of the larger streams draining sandy highlands associated with the Lake Wales Ridge and many small headwater streams in the sandier flatwoods with slight xeric upland inclusions. Furthermore, the Seepage Stream class also fails to distinguish between “sapping streams” (steepheads) with sandy bottoms and “bayhead runs” with organic beds, two generally small stream systems with fundamentally different valley formations and sediment transport mechanisms.

FNAI’s Spring-Run Streams are perennial water courses deriving most of their flow from artesian vents. Water is clear with neutral to slightly alkaline pH. They have sand bottoms, sometimes with exposed limestone. This characterization of the bottom sediment is incomplete as it ignores one of the most common bed materials in these runs, referred to by Odum (1957) as gyttja. Gyttja is an organic sediment derived from biota within the spring run.

The FNAI classification seems reasonable for certain nominal purposes and does adequately describe many streams in the state. The main delineative criteria are based on water quality (especially suspended solids, pH, color) and on the dominant source of water and the media through which it passes before reaching the channel. Blackwater Streams get their water via wetlands, Alluvial Streams from continental runoff, Seepage Streams from thick upland sands, and Spring-Runs from the artesian limestone aquifer. While they were conceived based on importance to aquatic flora and fauna, these could also be very important distinctions related to the fluvial functions of Florida streams. Figures 2-3 through 2-7 depict photographs comparing perennial spring runs, flatwoods and highlands streams under varying flow conditions.

Methods

Data Availability and Site Selection

In addition to on-line queries of USGS records, data managers at the South, Southwest, Suwannee, and St. Johns River Water Management Districts were contacted to identify which of the 56 streams selected for this study had reliable long-term discharge records. We also queried these sources for additional sites draining small watersheds, but identified a rather consistent bias toward mid-order and larger streams. For example, 1.9% of the USGS gage sites with at least 10 years of daily records in Florida were from streams with less than two square mile watersheds, despite the fact that the majority of streams drain such watersheds. Only one of the eight available gaged low-order streams identified met the inclusionary criteria of the study, usually because of urban landscapes or direct alteration by channelization or with a hydraulic control structure. The nature of the available data restricted long-term hydrologic assessments to a subset of the perennial streams in our study. A total of 18 of the 56 reference reach sites (32%) had useful records. This included five karst streams, six highlands streams, and seven flatwoods streams.

Field and Desktop Measures

Drainage area was calculated for each site in the study. This analysis used local surface topography to delineate watersheds for the highlands and flatwoods streams. Surface divides in some of the lowest-relief areas of Florida can be subtle and can even be crossed by wet-season sheet flow after extreme rainfall events. Furthermore, groundwater divides providing baseflow can shift seasonally. Therefore, basin divides should be viewed as approximate in Florida. This is further complicated for spring runs which can have a local topographic basin that is very different in location and size from the main source of water to the run, its springshed.

Springsheds are the land areas that catch the rainfall infiltration which discharges to spring runs. Their location can be poorly associated with topographic divides and usually varies spatially on a seasonal basis depending on the geometry of the potentiometric surface of the Floridan aquifer. Springsheds are necessarily a rough approximation of the actual extent of the groundwater catchment and are often estimated using a combination of well data and numerical modeling. Publications aimed at delineating springsheds or calculating recharge for specific springs or spring clusters were used to assign springshed dimension for the spring runs studied.

Shoemaker *et al*. (2004) delineated Alexander Spring Run's springshed using particle-tracking models and their value was adopted directly in this study. In most other cases, the springshed consisted of a recharge zone that distributed groundwater flow to multiple spring runs and the authors provided a recharge rate (usually expressed in inches/year) as part of the water budget. When the spring run mean discharge is known in addition to the springshed's average annual recharge rate, the average size of the springshed can be calculated for a given run. For the purposes of this study, spring runs belonging to springsheds feeding multiple runs were simply assigned an area directly proportional to the relative discharge of the run studied versus the total discharge of all the runs sourced from the common recharge area. Shoemaker *et al*. (2004) provided relevant data for Silver Glen Springs, of which the Silver Glen Unnamed Tributary (UT) run was a tributary, enabling this method to be used for that site. Shoemaker *et al*.'s (2004) data for the northern part of the St. John's River Water Management District (SJRWMD) were used to estimate the springshed size for Forest Spring Run. Knochemus and Yobbi (2001) provided data used to calculate the springshed size for the Weeki Wachee River. Wanielista *et al*. (2005) provided data used to calculate springsheds for Rock and Kittridge Runs. Hirth's (1995) recharge study and water balance for the Ichetucknee River was used to derive a proportional springshed for its tributary in this study, Cedar Head Run. Knowles *et al*. (2002) study of the recharge areas of Lake County and the Ocala National Forest was used to estimate the springshed size for Morman Branch UT. Phelps (1994) provided a recharge map and potentiometric surface that was used to delineate the springshed for Juniper Run. SWFWMD (1993) provided data used to calculate the springshed sizes for the Gum Slough and Alligator Runs. Little Levy Blue Spring Run's springshed was estimated from recharge rates reported for the Suwannee River Water Management District (SRWMD) (Grubbs, 1998).

Detailed field surveys were made at the reach scale to map the stream channel topography, in-stream habitat patches, and bankfull indicators using a two- or three-person crew and Leica total station. See Blanton (2008) for additional method details. Each of the 56 sites was visited twice, some multiple times during a three-year period. The survey point files and rendering results were reviewed prior to the follow-up visits to verify their reliability and interpretation. During the follow-up visits shallow sediment cores were extracted to determine the alluvial history of the floodplain, the dominant bank and floodplain plant species were inventoried, as were the alluvial channel features and alluvial floodplain features. The width of the wetland, relative elevation of biological flood indicators, connecting upstream and downstream waterbody junctions, channel grade and channel bank controls, and potential transport mechanisms (such as scour versus sapping) were explored and documented. This suite of multi-disciplinary observations (soils, vegetation, geomorphology, hydroecology) enabled an improved understanding of potential site processes associated with geomorphology compared to what the geomorphic survey data alone could provide.

Bankfull discharges were calculated by relating field indicators at the surveyed reference reaches to the gage height data in the manner described by Blanton (2008). This method was applicable to all gaged sites except two (Gum Slough and Lowry Lake UT). These two streams required different treatments because their gage records were disjunct from the reference reach and their flow data required adjustment to be more applicable to the conditions in the reach due to intervening sources of discharge between the research site and the gage.

The Gum Slough Spring Run's bankfull discharge was determined by conducting standard USGS velocity-area measurements using a Sontek Acoustic Doppler Velocimeter (ADV) at a near bankfull condition (within 0.1 feet). Manning's n was calculated from this event and then Manning's equation was used to calculate the bankfull discharge at the surveyed bankfull stage and hydraulic grade line.

The Gum Slough gage was located a few hundred feet downstream of the reference reach, shortly after the stream entered an anastomosing zone with numerous mature tree islands. Our study was devoted to single thread reaches, so this was not an appropriate area to survey. A cluster of high volume spring vents added flow to the run between the surveyed reach and the gage. Therefore the available record had to be adjusted. Based on several measurements taken in 1932, 1972 and in 1999 (as referenced in Champion and Starks, 2001), and a single measurement made in 2008 by our team, the flow from the springs upstream of the reference reach averaged 33.5% of the flow at the gage (range of 31 to 38%). Therefore, the measured daily flow record was multiplied by 0.335 to provide a simulated record for the reference reach.

Lowry Lake UT was the smallest tributary in the hydrologic analyses. It was a four foot wide seepage stream that drained a sandhill community. The channel had significant bed roughness from a series of steps and pools cascading over live root systems that completely spanned the channel. Bankfull discharge was estimated at Lowry Lake UT using Manning's equation in a slope-area solution. The slope was based on the average water surface profile through the surveyed reference reach at the field indicators for bankfull stage. Cross-section dimensions were derived from the same survey at a riffle and the flow was calculated from bankfull stage using a value of n (0.25) estimated from values that were taken from flows measured at two very similarly narrow root-step streams (Lake June-In-Winter UT and Ninemile Creek) taken during bankfull conditions.

Lowry Lake UT's gage was located about one mile downstream of the reference reach and two seepage streams contributed flow to the gage downstream of the survey reach. The reference reach basin was about 22% of the total gage drainage area. Physiography, land use, and channel incision were nearly identical for the gage and reference reach basins, so the available record was adjusted by simply multiplying it by 0.22 to simulate a long-term record for the surveyed area. The adjustments made to these two sites to capture their records are likely to be imperfect approximations of actual daily flow conditions, but based on the commonalities of the source areas, are likely to provide good indication of properly scaled, long-term flow variability of these sites. Given the small number of sites in the study with long-term flow records, these were justifiable inclusions.

For all sites in the study, indicators of biologically relevant overbank flow levels were used to define flood discharge stages. Typically, these were the lower limits of lichen and/or water stain lines on trees on the bank and in the floodplain. In most cases these indicators coincided within a few vertical inches of the wetland edge, typically extending at least a few feet laterally into the dense palmettos lining the wetland corridor. For many streams with entrenched channels and rare overbank flooding, the lichen line was at the base of trees and thick moss collars replaced the lichens below the top of bank, so other indicators were used. They usually were the upper limits of thick moss collars, the upper limits of wetland vegetation on the bank at a pronounced inflection, or simply the top of bank in the absence of these indicators.

For sites with gage height records applicable to the surveyed reach, flood discharge was determined from the stage-discharge curve using techniques analogous to those deployed to calculate bankfull discharge. This could not be done for Lowry Lake UT and Gum Slough Run and their flood discharges were calculated using Manning's equation and literature values for the floodplain friction factor based on the type and density of floodplain vegetation (Arcement and Schneider, 1989).

The long term gage records were evaluated, in part, with GeoTools Version 4 software (Raff *et al*., 2007). The software was used to calculate the available 105 hydropattern metrics to assess five key components of the flow regime: magnitude, frequency, duration, timing, and rate of change (Poff *et al*., 1997). Appendix B provides a list and brief description of each metric, plus some additional metrics calculated independently of the software.

GeoTools was also used to calculate flood frequencies. Partial duration series were used instead of annual maximum series because bankfull flood frequencies are typically more frequent than once a year in Florida (Metcalf *et al*., 2009; Warne *et al*., 2000; Blanton, 2008) and also in other blackwater streams of the southeastern coastal plain of the United States (Sweet and Geratz, 2003; Hupp, 2000). The method was standardized by specifying minimum discharge at one-half bankfull flow, the Cunane empirical distribution function, and a minimum inter-event duration of seven days for each site. The flood frequency was then determined from the output table for the bankfull and seasonal flood discharges.

The gage data were prepared for use in the evaluation software first by careful examination for missing records. Few occurred and these were substituted by inserting values that were an average of the adjacent values in the record. The spring runs had records from five to 11 years long, while some of the blackwater streams had continuous records dating back to the 1950s. Because the main interest was to compare metrics related to flow variability among basin classes, the longer records were truncated to their most recent available 11 year period through calendar year 2008 to reduce potential bias from the longest terms all being in large blackwater streams. Flow duration exceedance curves were developed in MS Excel 2003 and then were plotted using SigmaPlot Version 11. These data were used to calculate the median discharge and to determine the percent of time the bankfull and flood discharges were equaled or exceeded.

GIS layers were developed for LiDAR-derived topography where available to delineate watersheds and develop large-scale transects bigger than the reference reach surveys. Most of these data were from the Southwest Florida Water Management District (SWFWMD) and some was available from the SJRWMD and Alachua County. For areas without LiDAR topo, the USGS 1:24000 orthoquads maps were used. Drainage densities were calculated from the National Hydrologic Database as digitized for Florida from the 1:24000 USGS quads. NRCS (2007a) hydrologic soils groups were determined for each basin using the shapefiles available from the Florida Geographic Digital Library (FGDL), as were land use distributions (such as percent lakes and wetlands) from Florida Land and Cover Classification Codes (FLUCCS).

Bankfull discharges were derived from field measurements of flow at or near bankfull stage for 35 of the 56 study sites (Table 2-1). For 14 of these sites with USGS or SJRWMD gages, the agency field measurements and their stage-discharge records were used to calculate the average long-term discharge reported at bankfull stage. Our team developed stage-discharge relationships for an additional eight low-order streams in the study from 2007-2009 and used these data to help verify bankfull discharge. For 27 sites, our team was able to measure the discharge during a single event within 75% of bankfull stage using the USGS velocity-area method and these discharge values were adjusted to bankfull stage using Manning’s equation and the same hydraulic slope and n taken during the measurement.

For the 21 of 56 sites without measured bankfull conditions, the discharge was calculated using Manning’s equation, field indicators of dominant discharge (flood and bankfull stages), and topographic survey data (cross-sections and profiles). The Manning’s n values calculated for 35 the 56 study sites using measured discharges and surveyed hydraulic grade lines (or field indicators of bankfull grade line) close to bankfull conditions provided a library of reference conditions for sites where those data could not be measured but were with similar bed and bank dimensions, reach slope, vegetation and debris loads.

Manning's n for flood flows was calculated from gage record stage-discharge relationships using an assumed hydraulic slope equivalent to the valley slope along the segment encompassing the reference reach. The values calculated in this manner typically met expected literature values for the floodplain depths and vegetation. Data from similar sites in the study were again used to assign floodplain n values to ungaged sites to calculate flood discharges based on field indicators of flood stage and valley slope topography as a surrogate for hydraulic slope at flood condition. The approaches taken are expected to provide an order of magnitude estimate of flood flows, while typically providing much better estimates of bankfull discharge for each site.

Exploratory Statistics

The hydropattern metrics from GeoTools were reduced and examined for potential latent variables using principal components analysis (PCA). The sites were hierarchically clustered on the z-scores of the raw data for all hydropattern metrics using Ward's method.

Box plots and one-way analysis of variance (ANOVA) were used to explore potential differences in several metrics hypothesized to differ among physiographies (mean alluvial features, flood power to bankfull power ratios, and channel resistance as Manning's n). Regressions are useful to detect differences that tests of means like ANOVA may fail to illustrate. Therefore power function regressions were performed on data that were normally expected to be highly dependant on scale of the drainage area or volume of dominant discharge. These data were typically linearized by log-log transformations, which were plotted to examine different trends in geomorphic variables associated with drainage area or discharge, corrected for physiography. The regression and ANOVA explorations used metrics that were available from all 56 sites in the study enabling evaluation of sites draining a wide array of basin sizes, many of which are not perennial, but was necessarily limited to dominant discharges in the absence of long term flow records. The PCA and cluster analyses were applied to the metrics available from the 18 sites with perennial discharge records enabling a more detailed look at flow variability on a more limited number of sites and smaller range of flow regimes.

Results and Discussion

Basin Types and Flow Exceedance Curves

The 18 streams with perennial flow data were grouped based on their physiographic region prior to statistical testing. This grouping consisted of three basin classes consistent with their perceived dominant water sources (karst springs, xeric highlands, and flatwoods). The groupings were vetted based on the soils, vegetation, and hydrogeomorphology of the drainage basin of each site. This was necessary because these water sources can intergrade. The study design focused on the upper part of spring runs, close to their vents but in areas with hydraulically adjustable bed features, to minimize confounding factors related to surface drainage contributions far downstream of the headspring and to avoid reaches clearly dominated by geologic controls.

Highlands and flatwoods water sources within basins, especially for mid-order sites, were unavoidably mixed. So a means for separating these two groups was devised by plotting a simple index of flow variability based on data from flow exceedance probability curves versus a simple index for basin characteristics likely to be highly associated with basin infiltration capacity. The basin soil index was the sum of two NRCS soil hydrologic groupings associated with sandy xeric uplands that allow very high to moderately high wet season infiltration and modest to little runoff (A and C soils). This sum was calculated as the percentage of the total drainage area covered by those soil classes. NRCS did not map any B soils in the study areas. Based upon examination of 2004 true-color one-meter aerials available from the Florida Department of Environmental Protection (FDEP) and groundtruthing during the various site visits, areas mapped by the NRCS with A soils appeared to be associated with longleaf pine sandhill, xeric oak scrub, and sand pine scrubs while C soils appeared to correspond to scrubby flatwoods and xeric oak scrubs for the study areas. Therefore, the A+C soil percentage of the basin was considered to be a good index for the drainage area's groundwater flow delivery capacity versus surface runoff.

Flow exceedance curves offer a visual interpretation of the discharge variability. Curves with steep slopes and wide vertical ranges represent flashy streams with more variable flow regimes. Systems with very steady flow have relatively flat curves. To facilitate comparison among sites, the average daily flows were divided by the site's median discharge. The information was presented in the conventional USGS fashion with a horizontal exceedance probability axis and vertical discharge logarithmic axis. A simple metric was calculated as a flashiness index from the data used to produce these curves. In various wetlands throughout the state, the upland ecotone often occurs at a seasonal high water elevation that has at least a two-month hydroperiod (Myers and Ewel, 1990). This is slightly more than a 15% exceedance, which in the author's experience as a professional wetland scientist, is a convenient starting point for defining seasonal high water levels in Florida wetlands. Median flow could be considered the "normal" value and, by analogy, the 85% exceedance could be considered the "seasonal low" water. Therefore, the slope of the unit discharge between the 15^{th} and 85^{th} flow percentiles represents an index of the routine interannual or seasonal flow differences for Florida waters.

This seasonal flow slope (SFS) was calculated for the 18 gaged sites and was plotted against the A+C soil index in their watersheds (Figure 2-8). This plot is linear when plotted as an exponential function suggesting that highlands and flatwoods streams were part of a nonlinear continuum, but one that had a transition at about 40% to 45% A+C soils when raw data were plotted. Streams above that threshold behaved mostly like groundwater-dominated systems with comparatively steady flow and streams below it were increasingly surface water dominated and more seasonally flashy.

As expected, the spring runs provided flatter flow exceedance curves in association with their comparatively constant discharge regimes than the flatwoods streams and the highlands streams, which receive baseflow from a different aquifer and flood flows from basin runoff are indeed intermediate in pattern between the karst-fed and flatwoods streams (Figures 2-9 through 2-11). Therefore, it appears that flatwoods, highlands, and karst basin types are useful distinctions but that they do not necessarily offer completely disjunct hydrologic classes and also could be viewed to merely represent some useful distinctions along a natural gradient of groundwater influence.

Partial Duration Frequency of Discharge

Bankfull flow is a frequent occurrence in Florida. Blanton (2008) confirmed that it routinely occurs more frequently than an annual return interval (ARI) of 1.5 years, in perennial and non-perennial streams, based on an annual maximum series (AMS). This is an important threshold because it means that Florida streams do not fit norms reported for most, but by no means all, perennial streams in temperate humid climates (Williams, 1978; Leopold *et al*., 1964). Many Florida streams have very low bankfull ARIs (approaching 1.01 years). Such low ARI numbers are difficult to interpret, because the ARI is the inverse of the number of times the flow threshold is exceeded per year (annual flow frequency), and by using the AMS to calculate the ARI one cannot derive values corresponding to multiple floods within a year. For that reason, and also because the AMS often starts to distort the flow distribution for many flow regimes below even a 10-year return interval, a partial duration series was used to more accurately calculate the annual bankfull and flood flow frequencies for the 18 gaged study sites.

The 18 perennial study sites met or exceeded bankfull discharge conditions at least eight times per year (Table 2-2). ANOVA indicated average bankfull frequencies differed significantly ($p<0.05$) between karst streams versus the other basin types (Table 2-3). Mean bankfull frequencies were 19 events/year for flatwoods streams, 21 events per year for highlands, and 33 for spring runs. Perhaps karst streams retain more in-channel volume through the year due to their steady flow and are able to more routinely pulse above the bankfull stage versus blackwater streams (highland and karst) that have a lot more water level variability and further to rise and fall between events. It should also be noted that bankfull flow in karst streams is often entrenched; meaning bankfull discharge is not necessarily exceeding the elevation of the valley floor. These are not runoff streams with alluvial floodplains.

Upon reaching bankfull discharge, spring fed streams tended to stay above it longer than the perennial streams of other basin types as suggested by statistically significant ($p<0.05$) ANOVA tests on the flow exceedance percentiles (Table 2-3). Karst streams discharged at or above bankfull flow nearly 41% of the year on average versus 23% and 28% for the flatwoods and highlands streams. In this case, highlands and flatwoods streams were indistinguishable.

There were no statistically significant differences among basin groups for either their flood flow frequencies or flood flow durations (Table 2-3). The flood discharge was not a rare event because it was defined in a manner to approximate the lateral limits of the heavily vegetated wet season channel using a combination of hydroecological and geomorphic indicators to delineate such channels where they occur. Not all Florida streams had such features above the top-of-bank, while others had readily observable bankfull channels embedded within a flood channel that existed above the top of the bankfull channel. Such dual-tier conveyances with an open alluvial channel embedded within a wider heavily vegetated wet season channel are common in the seasonal tropics (Mossa *et al.*, 2002; Junk *et al.*, 1989; Gupta, 1995). Tockner *et al.* (2000) found that aspects of flood-pulse hydrology apply to some large unregulated rivers outside the tropics as well. This raises an interesting question for Florida, which has a distinct wet and dry season, but does not have annual average precipitation volumes as high as much of the humid tropics, “Do Florida’s perennial streams behave more like temperate humid streams with an alluvial channel and floodplain that is rarely flooded, or do they behave more like seasonal tropical streams that have a routinely flooded vegetated upper channel and an open alluvial transport channel?”

Basin Flashiness and the Hydraulics of Open Channels and Floodplains

The answer to the question posed above would seem to be, “It depends on basin physiography and basin scale.” First the flashiness of the flow duration data of the 18 perennial streams are discussed, followed by event hydraulics data from all 56 sites. As previously mentioned, seasonal flow slope was calculated as an index of the overall slope of the unit flow duration curve between the 15th and 85th discharge percentiles. Flow is within this range, on average, for 70% of the year and the endpoints nominally represent the seasonal high and seasonal low flow limits. SFS scores are higher for systems with comparatively greater seasonal flow variability. To eliminate scale effects, flows were rendered dimensionless by dividing each daily value by the median discharge of the site’s full record and, rather than analyze the raw differences in unit seasonal discharge magnitude, the SFS was indexed as a slope of the curve by simply dividing the difference in unit seasonal flows by 70 (the seasonal percentile range). Greater SFS values correspond to greater seasonal range, implying greater seasonal pulses or flashiness. The seasonal pulses of perennial Florida streams differed by substantial magnitude among basin types and in a statistically significant manner. Each basin type differed from the other two (ANOVA, $p<0.05$) (Table 2-3, Figure 2-12). Flatwoods sites averaged seasonal flow variability roughly three times greater than that of the highlands, which in turn averaged about three times more seasonal fluctuation than the spring runs.

To put this into perspective, the total flow fluctuation for perennial flatwoods streams typically ranged across four or five orders of magnitude (Figures 2-11). A site with a median discharge of 20 cfs would experience flows ranging from a trickle at 0.02 cfs to flood pulses with 2,000 cfs (Figure 2-11). Spring runs fluctuated a lot less, typically within a single order of magnitude (Figure 2-9). So, a spring run with the same median discharge of 20 cfs would typically experience a range of flows from 15 to 40 cfs.

Regression lines on scatter plots of bankfull and flood flows versus drainage area were compared among physiographic classes. Tests of bankfull discharge coefficients (regression constant and slope) between flatwoods and highlands were not statistically significant ($p>0.05$). The karst systems differed from the other two physiographies for slope and from the flatwoods for intercept (Table 2-4, Figure 2-13). This implies that highlands and flatwoods basins differ little in their capacity to deliver bankfull discharge thresholds, but that karst systems differ, especially from the flatwoods. The data scatter suggested that the karst differences mainly occurred for the smaller contributing areas. For larger systems it does not matter much whether the water is sourced via temporally long underground pathways or short surface paths. This implies that bankfull discharge is a routine and sustained occurrence for most Florida streams, but that it may be less routine and more peaked for runoff dominated low-order streams.

Flood flows were different and appeared to show a consistent trend of flatwoods basins delivering greater floods per basin area than the highlands streams, which in turn produced greater flood yields than the spring runs (Table 2-4, Figure 2-14). These facts suggested that, while drainage area played a functionally significant role in flood pulse delivery, it was significantly moderated by the groundwater infiltration capacity of the landscape.

Flood pulses were not only more pronounced in the runoff dominated systems; they also produced disproportionately large increases in flood power compared to bankfull power. For example, the average flood/bankfull power ratio of flatwoods streams was almost twice that of highlands streams, and this ratio for highlands streams was almost three times higher than spring runs (Table 2-3, Figure 2-15). This implies that more alluvial work can typically be done in the wet season channels of perennial flatwoods streams than other basin types and that the least amount of such work capacity occurs in association with karst basins.

Greater similarities among basin types for bankfull flow versus drainage area suggested that in-stream hydraulics may be more similar than it is for flood flows. However, regression lines through scatter plots of channel width versus bankfull discharge indicated that the spring runs tended to be wider than highlands or flatwoods streams versus bankfull discharge. This suggests that different in-channel processes are at work at sub-bankfull levels for the karst systems as well (Table 2-4, Figure 2-16). The channel planform of spring runs also differed from the other stream types with a wider range of radius of curvature/width ratios that were skewed toward the highest such ratios in the study (Figure 2-17). In general, but by no means universally, spring runs were wider and more gradually sinuous than the other two stream basin types, which did not differ much from each other regarding bankfull channel dimension or shape.

Comparatively broad, straight and shallow channels were consistent features of spring runs in at least one other setting, the volcanic soils of the Pacific northwestern United States (Whiting and Moog, 2001; Whiting and Stamm, 1995). The scientists working in that region attributed such geomorphic differences versus the region's runoff streams to the effects of biologically mediated processes, including the anchoring of otherwise mobile sediments by vegetative islands and submerged aquatic vegetation (SAV) and to the comparatively large loads of snags in the runs. The spring runs lacked big spates to flush the vegetation and woody debris and the flow simply eroded broad channels around the obstructions instead. Florida spring runs appear to have a general convergence of form with spring fed streams in the Pacific Northwest. While the mechanisms of this convergence may also be biologically mediated, they appear to differ in some important ways. For example, differences in mean snag densities (pieces of large woody debris per 100 linear feet of channel) were statistically non-significant (P = 0.556) among the gaged perennial streams studied in Florida. Snag densities were highly variable with means of 1.9 snags/100 LF for flatwoods, 2.9 snags/LF for highlands, and 2.7 snags/LF for karst sites (Table 2-3). More detail concerning Florida biogeomorphology, including that of spring runs, is provided in the next section.

Overall, statistically indistinguishable fractions of annual rainfall were captured as discharge to Florida stream channels among the three basin types (Table 2-3). An average of 22% of rainfall became discharge in flatwoods streams with values of 23% and 28% for the highlands and karst streams. So the total amount of water reaching these streams did not differ nearly as much as the timing and variability of that delivery within the year. Keep in mind that while bankfull discharge does not differ much as a function of basin size among physiographies, that the bankfull flow frequency and bankfull flow duration of karst streams did differ significantly from flatwoods streams. This means that it is likely a more consistent and more highly effective threshold for providing a specific level of work on the channel.

That steady concentration of comparatively invariable work seemed to carve and maintain a bankfull channel forms that were wider (especially relative to hydraulic depth) and straighter than streams draining more variable flow regimes. Variability in flow appeared to lead to narrower channel cross-sections with tighter bends, perhaps so they can carry a wider range of flows without mean velocity changing too much as a function of channel stage.

Not all spring fed streams are as steady as Florida's and wide, gradually meandering conditions are by no means universal to spring runs worldwide. For example, small spring runs in a semi-arid climate in Arizona were found to be narrower than their runoff dominated counterparts (Griffiths *et al*., 2008). The reason cited for this was that the valley flats of the runs were extensively re-worked by alluviation during occasional flash-floods and that the smaller constant spring flows subsequently headcut through the newly deposited material as it was quickly re-vegetated and stabilized given the moist conditions of the valley. Interestingly, these sites also exhibited significant and rapid biological-groundwater flow interactions, but with a different outcome on channel morphology seemingly associated with an inherent variability in the frequency and intensity of sediment and water discharge operating on two different times scales.

Variable flow could also be associated with tighter bends due to differences in sediment yields that are correlated with flow variability. Greater amounts of alluvial sediment can enhance bends by building point bars and some theories of bend formation follow a premise that streams meander in response to the competing efficiencies of channel form related to sediment transport versus clear water transport (Langbein and Leopold, 1966; Leopold and Wolman, 1957). The spring runs tend to carry less total and variable solids loads and have less associated point bar formation with a lower sinuosity planform.

Biologically Mediated Morphology and Groundwater Regimes

The pulsed disturbances created by flow variability appear to have physical and biological ramifications that can affect channel geomorphology. One of the working hypotheses was that biological systems in Florida's virtually year round growing season could offer substantial resistance to changes normally wrought by erosive forces. If this hypothesis is correct, one would expect to see increasing evidence of biological control as a function of the steadying influence of groundwater discharge. If true, this raises the question regarding what thresholds in the flow regime may trigger biological versus alluvial control of various components of geomorphology and how these thresholds might differ among basin types.

Larger spring runs in Florida, generally at least 30 feet wide with typically less than 70% of the channel canopied (as measured using a spherical densitometer), normally supported varying amounts of SAV meadows on their bed (Figure 2-18). SAV meadows were not ubiquitous in spring runs because they require lots of light penetration and are sensitive to a variety of human impacts. Light penetration requirements, and perhaps other factors, tended to reduce SAV cover in the blackwater stream types versus spring runs (Figure 2-19). SAV meadows greatly reduce flow velocities, setting up a two tiered velocity regime in the channel, the layer within the tape grasses and the one above them (Odum, 1957). Manning's friction factors (n) averaged about 0.14 in karst streams at least 30 feet wide (which are those most likely to have pronounced SAV patches). This was statistically and functionally greater than the n-values of similarly wide blackwater streams, which averaged about 0.07 (Table 2-3, Figure 2-20).

The seepage dominated headwater streams of the highlands developed very high friction factors (mean 0.23). These seepage streams were typically narrow, less than 10 feet wide. They had significantly higher n values than the spring runs and flatwoods (collective mean 0.07) of similar widths because they form living root weirs across the entire stream channel bed that create a resistant series of steps and pools (Figure 2-21). To avoid confusion with the more physically derived and uniformly organized clast weirs of step-pool channels in mountainous regions, we refer to Florida's biologically derived analogues as "root-step" streams. These fascinating little streams are discussed in more detail in Chapters 3 and 4.

For now it is important to note that friction factors are higher in groundwater dominated systems than in runoff dominated systems for the largest and smallest streams in this study. One key aspect of this is that highly variable flow regimes seem to shift geomorphic controls toward physical processes related to alluvial transport and deposition. For example, boxplots of the total alluvial features inventoried for flatwoods, highlands, and karst streams displayed decreasing alluvial inventories with basin types of increasing dominance of groundwater flow process (Table 2-3, Figure 2-22). It appears to take a significant dominance of groundwater flow source to reduce flow variability at thresholds necessary to allow for living biological systems to remain established at sufficient scales to directly control the main channel flow resistance.

Fundamentally different biological mechanisms are responsible for increasing friction factors in the groundwater dominated flow systems, dependant on channel width, valley slope, and shade. The physical template that determines which species can provide the increased friction depends on the general fluvial geomorphic association of greater channel width as a function of greater dominant discharge and relative channel depth as a function of valley relief. This is part of the reason why narrow headwater seeps with low flow volumes and steep slopes have different friction generating plant species than wide spring runs with comparatively copious groundwater discharge flowing through relatively flat valleys.

The fundamentally different growth habits of the plant species occurring in these two extremes of light limitation indicate that if the physics allow, biology will find a way to exert its self-serving will on channel shape. For example, SAV meadows require light rich environments unshaded by competing tree canopies growing on the banks. The SAV species hold shallow sediments in place, perhaps forcing wider planforms than what would have formed without their presence that in turn provide more substrate for SAV meadows. In virtually all ecosystems, this genetically self-serving positive feedback loop is limited by competing species. In this case, the competitors include a panoply of shade producing wetland tree and shrub species that grow on the channel banks. When channels are sufficiently narrow, these woody species preclude the establishment of SAV by shade, limiting the establishment of competing agents that may otherwise widen the channel at the trees' expense.

When the channels are very narrow with small seepage volumes, the trees prevent further bed erosion and downcutting by creating intense grade controls in the form of living root weirs across the entire channel bed. This occurs in areas with the steepest channel slopes in Florida, typically between 1.0% and 2.5% grade. Grade control by root weirs may serve as a defense mechanism by the wetland trees to prevent excessive bed erosion and subsequent dewatering of seepage wetlands flanking the stream channel. It is a self-reinforcing habit by tree species associated strongly with saturated seepage conditions. Most root steps were observed to be formed by sweet bay trees (*Magnolia virginiana*) and blackgum (*Nyssa silvatica* var. *biflora*), and less frequently by loblolly bay (*Gordonia lasianthus*) and dahoon holly (*Ilex cassine*). All of these species are dominant or common associates of seepage swamps and frequent channel bank associates. This assemblage of wetland trees maintain and perhaps enhance the lateral and longitudinal extent of saturated soil conditions by creating living dams.

In Florida's groundwater dominated streams of all widths, the channel banks become living boundaries that are fundamentally different from the wooded banks of channels under more intense alluvial controls. To understand this distinction, first note that vegetation, particularly woody vegetation, is well documented for adding shear strength to stream channel banks that can greatly resist erosion in humid climates around the world with channel forms that are otherwise dominated by alluvial controls (Ikeda and Izumi, 1990; Andrews, 1984; Hey and Thorne, 1986; Ebisemiju, 1994). These roots systems help to hold the bank together, resisting mass wasting and gravitational failure. That benefits the plants by giving them great access to a source of water at a light gap and their root structures assure the stability of their own growing medium. Some riparian bank plants also help to deflect flow forces reducing erosion. Florida is no exception. For example, saw palmetto roots provide significant shear strength to sandy stream embankments and their long thick rhizomes often drape over the bank crests, armoring many Florida stream banks. Florida has numerous woody riparian tree species that fix banks in a very conventional manner. An important distinction of this general and very common type of stream bank condition is that these banks are built by alluvial process and their subsequent erosion by fluvial forces is resisted by biological agents growing in the inorganic alluvium, which consists mainly of sandy deposits in most Florida streams.

However, some stream banks in Florida are not comprised of alluvial mineral materials being held together by roots. Instead, the banks themselves consist of dense masses of thick, intertwined roots holding together decaying leaf litter and older peaty parent materials (Figure 2-23). These living or “biological banks” build themselves up and smother the inorganic sub-layer, raising the bank height from a few inches to a few feet higher than it might otherwise achieve. The biological bank also extends laterally over alluvium, narrowing the channel. Such banks were usually dominant to ubiquitous along spring runs and root-step seeps, were often found along portions of highlands stream banks, and were generally rare along flatwoods stream banks (Table 2-3, Figure 2-24). They appear to be strongly associated with groundwater flow.

The stream channels appeared to hydraulically prune their roots at the base and as a result some larger biological banks formed overhanging ledges that water flowed beneath for up to several feet beyond the apparent bank edge. Natural tree falls can leave persistent gaps along the embankment that are gradually filled by living bank growth rather than rapid fill from copious sediment transport. The comparatively sediment-starved groundwater systems simply do not have enough inorganic material available to mechanically rebuild the banks with alluvium. This lack of a rapid bank recovery mechanism may contribute to channel widening in spring runs and to the rough edges commonly observed along the root-step channel margins.

Although the woody biological banks could shrink the channels of large spring runs by enlargement of their own growing platforms into and over the channel, the SAV meadows stabilize the bed and increase friction which could counter this and result in channel widening. Wider channels offer more growth media in shallow clear water for SAV species. Some of the variability among spring run geomorphology may be due to the unique ways these two assemblages compete for a share of the steady supply of water and sunlight provided by the run. In contrast to the steady spring runs, highly variable flow regimes of blackwater systems appear to disrupt this competition and the channels are able to overcome biological controls to achieve hydraulically more efficient flow and sediment transport regimes. As a result, their bed and banks were dominated by inorganic substrates, especially sand.

Effect of Basin Water Source on Stream Sediment Origins

Drainage basins of spring runs are unique in that the area receiving recharge to the artesian aquifer may be a long linear distance from the local surface water basin. As a result many, but not all, spring runs have remote or disjunct springsheds that are much larger than their local surface basins. This was true for 10 of the 12 runs studied. Such an arrangement means that spring runs receive water yield disproportionately larger than their external sediment yield.

Recalling that alluvial features were most common in the more highly pulsed flatwoods systems, it is important to understand that spring runs generally lacked alluvial floodplains, but did routinely exhibit alluvial bed forms such as sediment shoals and sandy ripples, and occasionally bend pools and point bars. They obviously must have some sediment yield or they would all eventually degrade to resistant lithological layers or would achieve relatively level-bottomed grade as linear embayments of their receiving waters. So where does their sediment come from?

Some of it likely does come from sporadic erosion in their sandy local basins. Sand is commonly found as part of the alluvial bed materials and some of this can be washed into the runs at points where high sandy bluffs border the run channel. Often a thin veneer of sand covered finer bed materials giving the misleading appearance of a ubiquitous sand bed along the run.

In reality, much of the bed material of most spring runs in our study was comprised of deposits of organic sediment several inches to several feet thick that Odum (1957) referred to as “gyttja” in his landmark ecosystem study of the Silver River. The Silver River is widely believed to be the largest karst spring river in the world. Its dominant bed material, particularly in its upper reaches is fine organic sediment with very high water content, usually derived from algae and other detritus. Prugh (1969) described and mapped similar sediments in surveyed cross-sections of another 1st magnitude spring run, the Ichetucknee River. All but two of the smallest of the 12 spring runs in this study had substantial amounts of similar fine organic sediments on the bed and seven sites had bed materials either dominated by it or co-dominant with sand. Because the term “gyttja” is more generally used to describe a particular kind of lake sediment, the term “detrital floc” was adopted for the purposes of this study to describe these common organic sediments in Florida spring runs. In streams where the detrital floc was found in association with substantial amounts of sand bed material, the organic sediments were typically found away from the channel center closer to the bank margins. This suggests hydraulic sorting of these materials of variable density. In some cases, the detrital floc margins formed shallow channel shelves with dense SAV meadows that the deeper sandy channel center lacked.

To give a sense of the characteristics of these materials, during the survey it was easy to walk downstream on the firmly-packed center bed sands and one could easily feel the stream power of the flow walking upstream in this zone. A wader would sink deeply into the detrital floc layer however, sending plumes of turbid brown organics downstream. Little force of flow would be felt in the shallow channel margin. The detrital floc is slightly cohesive and, despite very high water content, holds its shape well and can easily be grabbed and partially molded (Figure 2-25). For comparison, Figure 2-26 shows a typical sandy alluvium from a flatwoods stream channel.

Mollusk shells and shell fragments, particularly from snails, were variably significant components of the bed materials of the seven largest runs studied. Many Florida spring runs, probably because of high carbonate levels, support abundant and diverse mollusk populations (Shelton, 2005). Light levels in the clear water allow periphyton growth on the SAV and other substrates that are grazed by an abundant and diverse array of snail species. As these animals die, their shells become sediment load. In essence the spring run mollusks convert dissolved minerals to solids that form some part of the internal sediment yield to spring runs. Much of the internal yield comes from periphyton and other plant material detritus. Shelly detrital floc was quite common on the beds of larger spring runs, suggesting that much of their fluvial form depends on internal (autochthonous), biologically-mediated sediment yields that at least partially offset the reduced external (allochthonous) yields from their comparatively small local surface basins. In essence, larger spring runs course over valley fills of their own making.

Conclusions

Ramifications for Dominant Discharge Concepts

The primary ramification is not to take the concept of dominant discharge too literally. In Florida, streams with steady groundwater flow and very rare spates had fundamentally different open channel and wet-season channel geomorphology than streams with similar bankfull discharge draining flatwoods basins with flashy flow regimes. Within the region, the overall channel pattern and dimension was highly dependent not only upon the dominant discharge and the total annual volume of discharge, but also on flow variability and the associated flow delivery medium. Sediment sources were different in association with flow regime and, in general, biological mechanisms grew in importance versus physical controls as flow variability decreased. The concept of dominant discharge is a very useful restoration design tool, but it is only part of the complete kit, which must necessarily also account for flow variability.

Biota as a Groundwater Dependant Geomorphic Agent

Florida’s sub-tropical climate, virtually year-long growing season, ample moisture and high groundwater tables provide a setting that is ideal for the growth of dense luxuriant vegetation within its fluvial corridors. The nearly constant saturation promoted formation of rich organic soil layers. In systems with comparatively steady flow, particularly systems dominated by groundwater discharge such as large spring runs and diminutive seeps, biology exerted geomorphic controls that were at least as important as alluvial control. In the flashier systems dominated by surface water runoff in the flatwoods and the larger streams of the highlands basins, physics exerted a greater degree of control and alluvial features were more abundant and diverse. In the battle between biology and physics, steady groundwater flow in the absence of routine powerful floods can tip the scale toward biology.

Populations of Florida Streams as a Function of Water Source

A hierarchical cluster analysis of sites using 108 flow metrics properly assigned 89% (16 of 18) of perennial streams to their respective physiographic settings (Figure 2-27). One exception, the flatwoods stream Little Haw Creek, clustered as a closer associate of the highlands streams than its flatwoods counterparts. The other exception, Lowry Lake UT, was a tiny root-step seepage stream draining a highlands landscape that clustered with the artesian spring runs. It had a fundamentally different geomorphology and water source.

While the cluster generally confirms that flow variability and associated physiographic settings can provide valuable information for classifying Florida's perennial streams, the necessary long-term discharge record is not available for very many non-perennial (intermittent or ephemeral) streams. Also, the fact that 11% of the perennial sites with long-term records clustered inconsistently with their physiographic setting suggests factors other than groundwater influence and basin physiography are important for proper stream classification. For example, some geologic controls related to valley form are discussed in Chapter 3 and an approach that integrates geomorphic features existing at the watershed, valley, reach, and in-stream patch scales is discussed in Chapter 4.

Research Needed

The fact that Florida spring runs have morphology that in some key respects is more similar to the morphology of spring runs in the Pacific Northwest than they are to runoff dominated streams close by is intriguing. In both regions biological mechanisms seemed to be important, but they differed. Snags played a key role in Washington and Oregon, but not among perennial streams in Florida. Sub-tropical snails and periphyton species played important roles in generating internal sediment yields in Florida, but this mechanism has not been reported elsewhere. SAV appeared to play a role in both regions. This convergence of fluvial form and basic process raises the question, “Do spring runs in other settings around the world have similar form factors with biological control agents and why or why not?”

This study explicitly measured short reaches of 12 different spring runs, deliberately sampling single thread portions of these runs with alluvial bed materials as opposed to channel segments with geologic controls or portions of runs with multi-threaded channels and islands. Even casual observation of the longer runs in our study, such as Alexander Spring Run, Juniper Spring Run, Gum Slough Spring Run, Weeki Wachee River, and Rock Springs Run (and others we are familiar with that were not included in our study such as the Silver River and Ichetucknee River) suggests common occurrences of repeating channel forms with deep segments under geologic controls and very broad multi-threaded channels with shoals and tree islands that were not included in our surveys. These features often repeat and alternate with single thread sections under alluvial bed controls along the run. Furthermore, some runs such as Alexander and Juniper are so long that they pick up substantial amounts of surface drainage and flow with high volumes of blackwater during the wet season at their midreach and lower sections. Perhaps higher degrees of flow variability and greater yields of external inorganic sediments explain the rather sinuous middle and lower sections of these two runs. Full-length fluvial geomorphic studies of all Florida’s longer spring runs are necessary to systematically learn more about the longitudinal patterns in channel form and their associated controls in these uniquely complex fluvial systems.

Florida scientific and regulatory programs need to support the development of more systematic long-term records from reasonably intact low-order and mid-order streams in rural areas in all physiographic categories. More such gages have been established in urban basins by the USGS, but there is little baseline information to compare those with intact rural streams. As Florida continues to urbanize, intact lower-order streams could likely continue to be functionally diminished and we may never quite know what we are losing until it is too late and the effects start compounding in ways that are evident in the larger rivers that are routinely gaged. Many kinds of stress phenomena in fluvial geomorphology have long lag times followed by periods of intense change when the gradual alterations eventually reach a critical threshold. For example, sudden and rapid periods of channel widening unfold after decades of gradual channel deepening over-steepens the banks to a point where they can no longer support their own mass. This is a common example of lags and thresholds in channel evolution in eroding urban streams. In our site selection process, more than 75% of streams randomly selected were rejected from inclusion in the study because of substantial human impacts in their watershed or due to direct modification of the channel. Establishing long-term gaging stations on more of the remaining intact small streams in Florida is a pressing need that could form the hydrologic basis for a lot of applied research related to natural resources, water supply, and fisheries management of Florida’s stream networks. The amount of flow data from the most common and perhaps most vulnerable streams are arrestingly small. Small streams are in more direct intimate contact with their watersheds than large rivers and can serve as faster harbingers of undesirable changes in hydrology, habitat, or water quality.

Table 2-1. Discharge calculation methods by location

Site name	Phys.	DA (sq.mi)	Gage I.D.	Bankfull method	Bankfull Manning's n	Flood method	Flood Mannings n
Bell Creek UT	FW	0.2	None	SAM	0.13	SAM	0.13
Lower Myakka River UT 3	FW	0.4	None	VAM	0.05	SAM	0.05
East Fork Manatee UT 2	FW	0.4	None	VAM	0.21	SAM	0.21
Wekiva Forest UT	FW	0.5	None	SAM	0.10	SAM	0.18
Coons Bay Branch	FW	0.5	None	SAM	0.13	SAM	0.13
Grassy Creek UT	FW	0.8	None	VAM	0.14	SAM	0.14
East Fork Manatee UT 1	FW	0.9	None	VAM	0.10	SAM	0.10
Hillsborough River UT	FW	1.0	None	SAM	0.12	SAM	0.12
Lower Myakka River UT 2	FW	2.7	None	VAM	0.05	SAM	0.08
Blues Creek near Gainesville	FW	3.2	None	SAM	0.06	SAM	0.06
Cow Creek	FW	5.6	None	SAM	0.07	SAM	0.07
Moses Creek near Moultrie	FW	7.8	USGS 02247027	LTR	0.08	LTR	0.07
Grasshopper Slough Run	FW	8.7	None	VAM	0.07	VAM	0.08
Morgan Hole Creek	FW	11.0	None	VAM	0.06	VAM	0.08
Tenmile Creek	FW	16.8	None	SAM	0.07	SAM	0.11
Tyson Creek	FW	20.7	None	VAM	0.06	VAM	0.13
Rice Creek near Springside	FW	45.8	USGS 02244473	LTR	0.08	LTR	0.17
Bowlegs Creek near Ft Meade	FW	50.9	USGS 02295013	LTR, VAM	0.07	LTR	0.35
Manatee River near Myakka Head	FW	65.7	USGS 02299950	LTR	0.04	LTR	0.06
Santa Fe River near Graham	FW	94.1	USGS 02320700	LTR	0.05	LTR	0.03
Little Haw Creek near Seville	FW	106.2	USGS 02244420	LTR	0.03	LTR	0.23
Horse Creek near Arcadia	FW	219.0	USGS 02297310	LTR	0.06	LTR	0.08
Fisheating Creek at Palmdale	FW	313.0	USGS 02256500	LTR, VAM	0.05	LTR	0.20
Manatee River UT	HL	0.3	None	SAM	0.27	SAM	0.27
Lowry Lake UT	HL	0.3	SJR 72051622	SAM	0.25	SAM	0.25
Tuscawilla Lake UT	HL	0.3	None	SAM	0.27	SAM	0.27
Shiloh Run near Alachua	HL	0.4	None	SAM	0.05	SAM	0.05
Cypress Slash UT	HL	0.4	None	VAM	0.17	SAM	0.17
Lake June-In-Winter UT	HL	0.6	None	VAM	0.34	SAM	0.34
Tiger Creek UT	HL	0.9	None	VAM	0.08	SAM	0.08
Snell Creek	HL	1.7	None	SAM	0.09	SAM	0.09
Bell Creek	HL	1.9	None	SAM	0.08	SAM	0.08
Alexander UT 2	HL	2.3	None	SAM	0.10	SAM	0.10
Jack Creek	HL	2.7	None	VAM	0.08	VAM	0.09
Gold Head Branch	HL	2.8	None	SAM	0.27	SAM	0.27
Hammock Branch	HL	3.0	None	SAM	0.07	SAM	0.07
Jumping Gully	HL	4.2	None	SAM	0.12	SAM	0.12
Ninemile Creek	HL	6.8	None	SAM	0.30	SAM	0.30
South Fork Black Creek	HL	26.5	None	SAM	0.06	SAM	0.15
Carter Creek near Sebring	HL	36.0	USGS 02270000	SAM	0.04	SAM	0.16
Tiger Creek near Babson Park	HL	53.2	USGS 02268390	LTR, VAM	0.11	LTR	0.10
Catfish Creek near Lake Wales	HL	57.5	USGS 02267000	LTR, VAM	0.20	LTR	0.16
Blackwater Creek near Cassia	HL	118.4	USGS 02235200	LTR	0.03	LTR	0.04
Livingston Creek near Frostproof	HL	119.8	USGS 02269520	LTR	0.05	LTR	0.24
Morman Branch UT Spring Run	K	0.5	None	VAM	0.10	SAM	0.10
Silver Glen UT Spring Run	K	1.0	None	VAM	0.16	SAM	0.16
Forest Spring Run	K	1.7	None	VAM	0.26	SAM	0.26
Little Levy Blue Spring Run	K	2.1	None	SAM	0.19	SAM	0.23
Kittridge Spring Run	K	3.1	None	VAM	0.08	SAM	0.08
Cedar Head Spring Run	K	5.2	None	VAM	0.07	SAM	0.07
Alligator Spring Run	K	8.7	None	VAM	0.25	SAM	0.25
Gum Slough Spring Run	K	27.0	USGS 02312764	VAM	0.15	SAM	0.15
Juniper Spring Run	K	33.7	None	VAM	0.10	SAM	0.15
Weeki Wachee River	K	85.9	USGS 02310525	LTR, VAM	0.09	LTR	0.09
Rock Spring Run	K	100.0	USGS 02234610	LTR, VAM	0.04	LTR	0.04
Alexander Spring Run	K	110.0	SJR 18523784	LTR, VAM	0.21	LTR	0.21

Phys. = basin physiography: FW = flatwoods, HL = highlands, K = karst. DA = drainage basin area.
LTR = long term discharge record coupled with field indicators of stage. VAM = direct velocity-area measurement.
SAM = slope-area method using field indicators of slope & Manning's equation.
Manning's n from sites using VAM or LTR were calculated, all others were estimated from observed channel conditions.

Table 2-2. Bankfull and flood channel discharge summaries

Site name	Phys.	Drainage basin area (sq. mi.)	Bankfull channel flow (cfs)	Average number of bankfull flow exceedances per year*	Percent of time bankfull flow exceeded for the period of record	Flood channel flow (cfs)	Average number of flood flow exceedances per year*	Percent of time flood flow exceeded for the period of record
Bowlegs Creek near Ft Meade	FW	50.9	59.1	13	14	234.1	3.25	2.0
Fisheating Creek at Palmdale	FW	313.0	81.9	28	40	1,018.5	8.20	6.2
Horse Creek near Arcadia	FW	219.0	230.0	19	21	1,330.8	3.90	2.4
Little Haw Creek near Seville	FW	106.2	109.2	17	25	580.5	1.40	1.5
Manatee River near Myakka Head	FW	65.7	139.9	17	12	1,246.6	1.65	0.5
Moses Creek near Moultrie	FW	7.8	20.9	8	7	138.4	1.10	0.8
Rice Creek near Springside	FW	45.8	23.2	32	34	521.9	1.50	0.5
Santa Fe River near Graham	FW	94.1	109.6	8	13	516.4	0.53	0.7
Blackwater Creek near Cassia	HL	118.4	128.7	10	13	885.1	0.03	0.0
Carter Creek near Sebring	HL	36.0	31.5	16	23	94.8	1.93	2.5
Catfish Creek near Lake Wales	HL	57.5	45.1	22	35	162.8	0.05	0.4
Livingston Creek near Frostproof	HL	119.8	58.8	26	34	335.1	1.10	0.6
Lowry Lake UT	HL	0.3	0.6	34	48	1.9	0.06	0.0
Tiger Creek near Babson Park	HL	53.2	60.9	16	17	189.7	1.50	0.8
South Fork Black	HL	26.5	52.3	29	26	89.0	14.40	9.2
Alexander Spring Run	K	110.0	121.9	34	38	247.3	1.43	1.0
Cedar Head Spring Run	K	5.2	7.4	42	43	20.4	0.10	0.0
Gum Slough Spring Run	K	27.0	36.4	26	35	56.0	9.60	10.6
Rock Spring Run	K	100.0	48.0	32	54	68.3	0.18	0.1
Weeki Wachee River	K	164.0	163.6	30	36	183.5	18.40	19.2

Phys. = basin physiography.

FW = flatwoods, HL = highlands, K = karst.

*Based on partial duration series with minimum 7 days between indpendant flow peaks.

Table 2-3. ANOVA summaries

Variable	Phys.	N	Mean	SE	Sig.	ANOVA test, pairwise procedure
Bankfull events	FW	7	19.00	3.08	A	One-way ANOVA, Holm-Sidak
	HL	6	20.50	3.44	A	
	K	5	32.88	2.73	B	
Bankfull duration	FW	7	22.64	4.04	A	One-way ANOVA, Holm-Sidak
	HL	6	28.08	5.34	A	
	K	5	41.36	3.52	B	
Flood events	FW	7	2.92	0.98	A	Kruskal-Wallis ranks, Dunn
	HL	6	0.78	0.34	A	
	K	5	5.94	3.56	A	
Flood duration	FW	7	1.97	0.76	A	Kruskal-Wallis ranks, Dunn
	HL	6	0.72	0.38	A	
	K	5	6.18	3.18	A	
SFS/70[a]	FW	7	0.10	0.01	A	One-way ANOVA, Holm-Sidak
	HL	6	0.03	0.01	B	
	K	5	0.01	0.00	C	
Flood/bkf power[a]	FW	7	9.89	2.51	A	One-way ANOVA, Holm-Sidak
	HL	6	4.92	0.80	B	
	K	5	1.78	0.28	C	
Rc/W	FW	7	1.19	0.17	A	One-way ANOVA, Holm-Sidak
	HL	6	0.96	0.15	A	
	K	5	2.60	0.74	B	
LWD/100'	FW	7	1.87	0.47	A	One-way ANOVA, Holm-Sidak
	HL	6	2.88	0.93	A	
	K	5	2.77	0.73	A	
%Discharge	FW	7	21.60	0.03	A	Kruskal-Wallis ranks, Dunn
	HL	6	22.80	0.07	A	
	K	5	27.80	0.04	A	
%SAV[b]	FW	7	0.19	0.19	A	One-way ANOVA, Holm-Sidak
	HL	6	7.26	2.29	A	
	K	5	30.64	10.38	B	
n (W < 10')	GW	5	0.23	0.04	A	T-test
	BW	4	0.07	0.02	B	
n (W > 30')	GW	6	0.14	0.03	A	T-test
	BW	8	0.07	0.02	B	
Total alluv.	FW	7	7.12	0.72	A	One-way ANOVA, Holm-Sidak
	HL	6	5.60	0.51	A	
	K	5	1.60	0.68	B	
BioBanks	FW	7	1.00	0.00	A	Kruskal-Wallis ranks, Dunn
	HL	6	1.67	0.33	AB	
	K	5	3.60	0.25	B	

Sig. = significant differences between physiographies with different letters ($p < 0.05$).
SE = standard error. FW = flatwoods, HL = highlands, K = karst.
[a]Log-10 transformation was used to meet assumptions for normality & equal variance.
[b]Ignored normality and variance assumptions.
SFS/70 = seasonal flow slope, Rc = radius of curvature, W = channel width.
%Discharge = amount of rain on catchment that becomes streamflow.
LWD/100' = snags per 100 linear feet of channel, SAV = submerged aquatic vegetation.
n = Manning's friction factor, Total Alluv = no. alluvial features in the stream and floodplain.
BioBanks = dominance of biological banks (1 rare, 2 present, 3 common, 4 ubiquitous).
GW = groundwater stream, BW = blackwater stream.

Table 2-4. Regression summaries

Variables		B constant			p > F			B slope			p > F		
IV	DV	FW	HL	K	FW HL	K HL	K FW	FW	HL	K	FW HL	K HL	K FW
Log(DA) ctr	Log(Qbkf)	1.085	0.949	0.750	0.154	0.086	0.004	0.652	0.718	1.072	0.477	0.006	0.001
	SE------->	0.094	0.068	0.113	NS	NS	Sig	0.093	0.070	0.119	NS	Sig	Sig
Log(DA) ctr	Log(Qflood)	1.698	1.355	1.047	0.000	0.007	0.000	0.857	0.806	0.898	0.609	0.710	0.751
	SE------->	0.063	0.092	0.109	Sig	Sig	Sig	0.065	0.099	0.127	NS	NS	NS
Log(Qbkf) ctr	Log(W)	1.122	1.114	1.485	0.890	0.000	0.000	0.314	0.470	0.417	0.058	0.531	0.223
	SE------->	0.039	0.057	0.066	NS	Sig	Sig	0.057	0.080	0.084	NS	NS	NS

Log = log10 transform, ctr = variable centered, NS = $p > 0.05$, Sig = $p < 0.05$, SE = standard error.

FW = flatwoods, HL = highlands, K = karst.

DA = drainage area, Qbkf = bankfull flow, Qflood = flood flow, W = bankfull channel width.

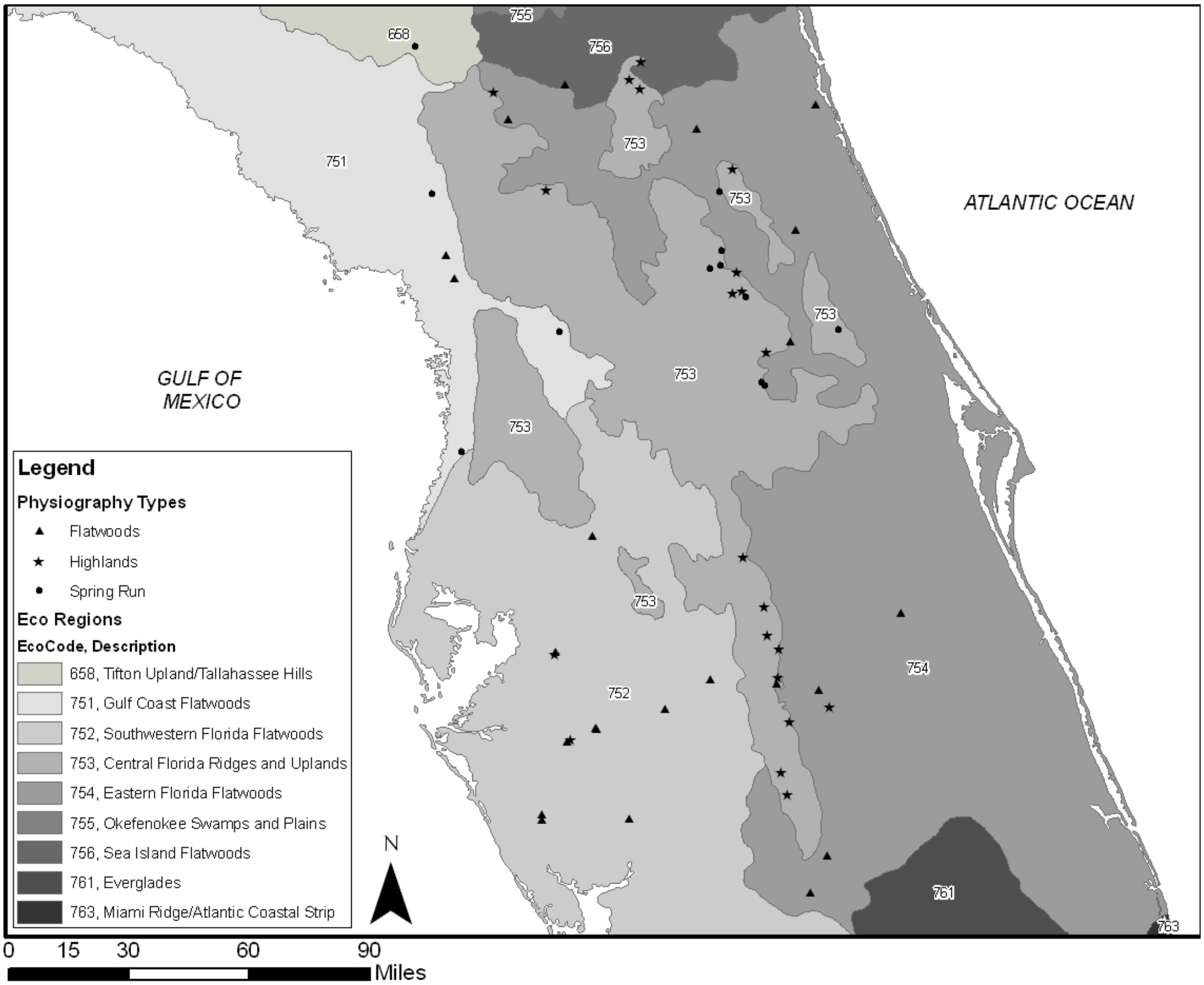


Figure 2-1. Florida Department of Environmental Protection ecoregions in the study area (FGDL 2009).

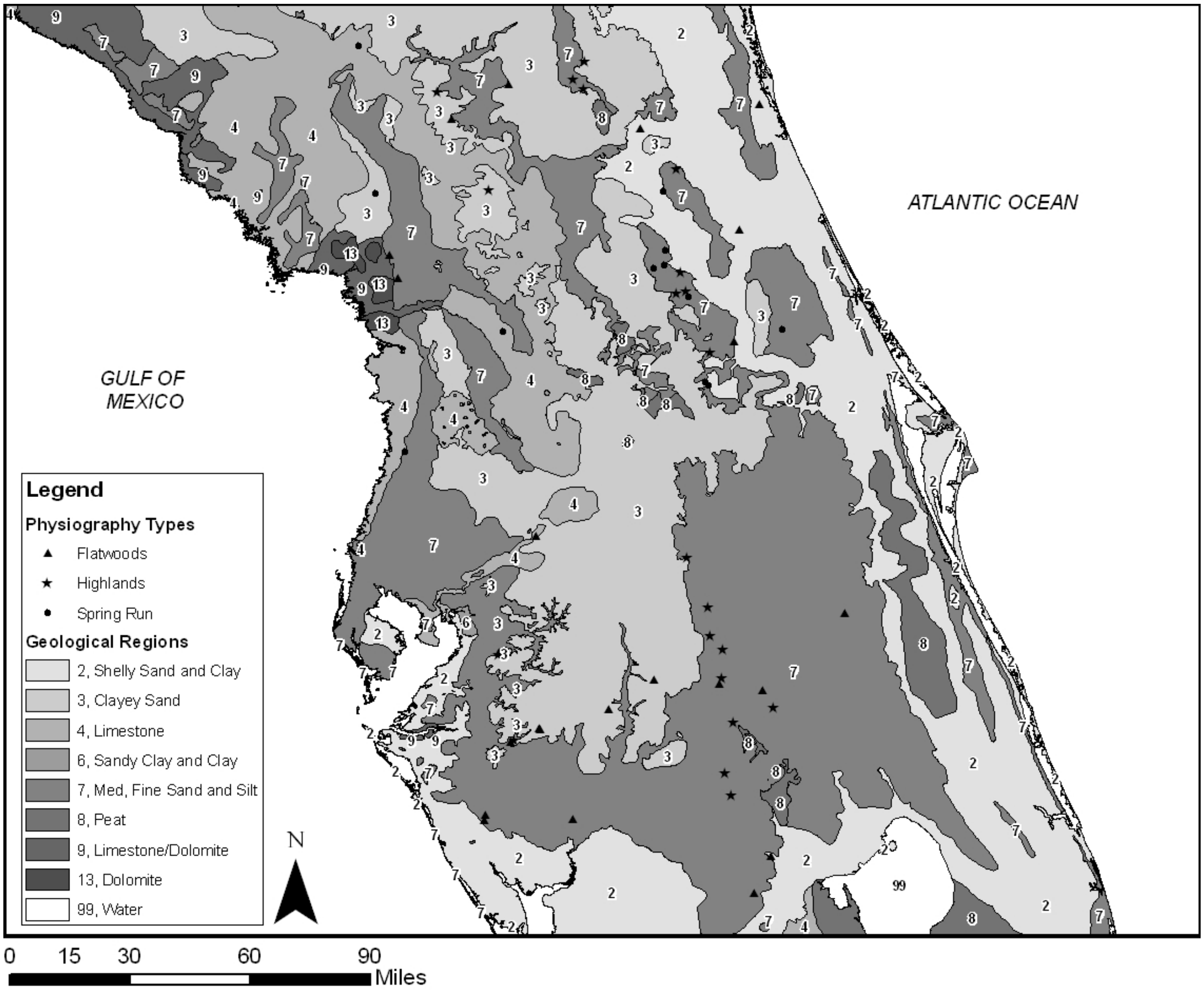


Figure 2-2. Florida Geological Survey geologic regions in the study area (FGDL 2009).

Figure 2-3. Example of a karst spring run at bankfull stage (Alligator Spring Run, September 7, 2008).

Figure 2-4. Example of a blackwater stream at wet season flood stage (Little Haw Creek, September 8, 2008).

Figure 2-5. Example of a flatwoods stream near bankfull stage (Rice Creek, July 2, 2008).

Figure 2-6. Example of a highlands stream at bankfull stage (Tiger Creek, June 9, 2009).

Figure 2-7. Example of a highlands stream at baseflow stage (South Fork Black Creek, June 19, 2008).

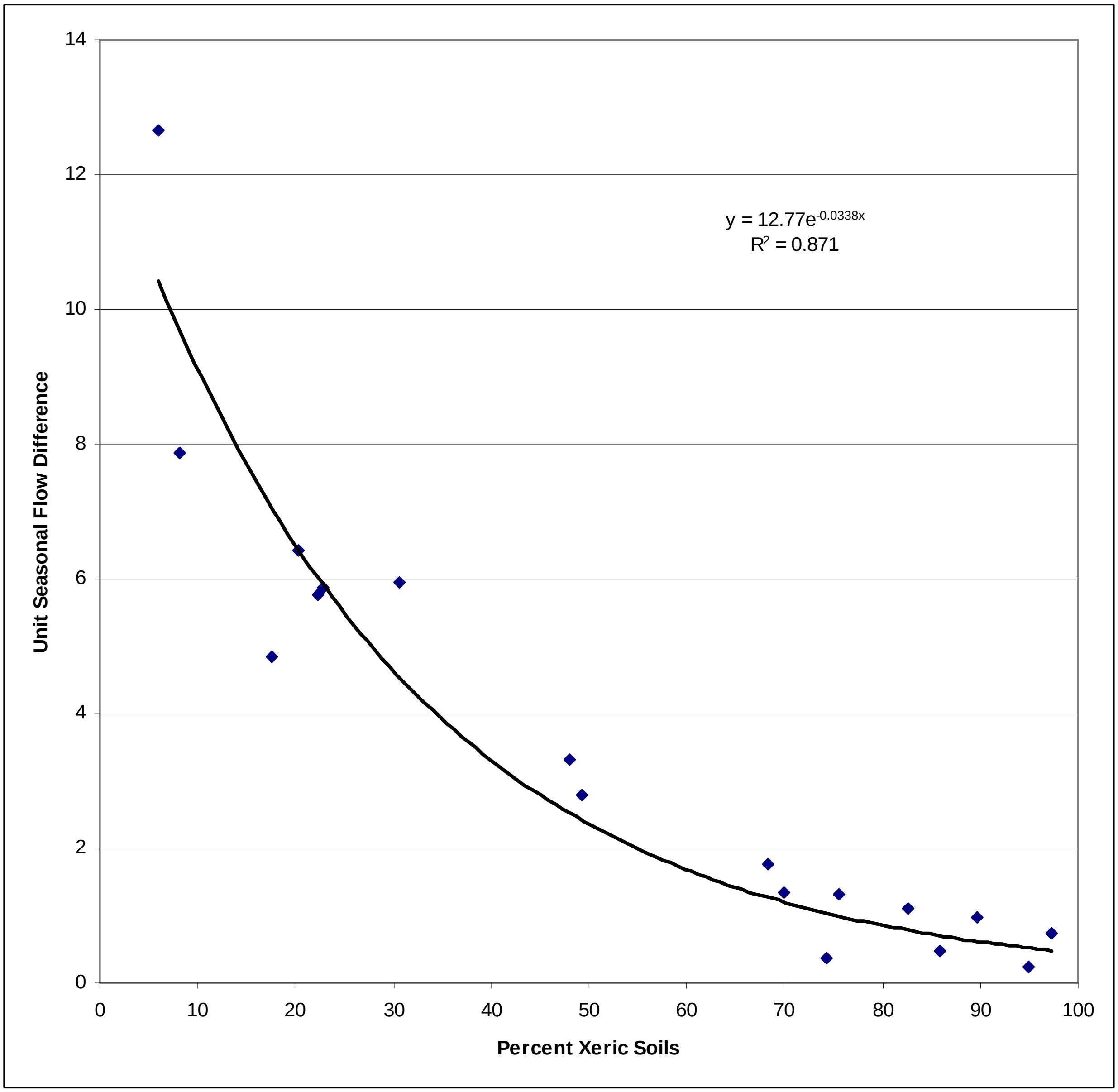


Figure 2-8. Seasonal flow flashiness versus xeric soils in the drainage area. Xeric soils are defined as NRCS hydrologic soil groups A + C. Unit seasonal flow difference is the range between the 15% and 85% flow exceedance divided by the median flow.

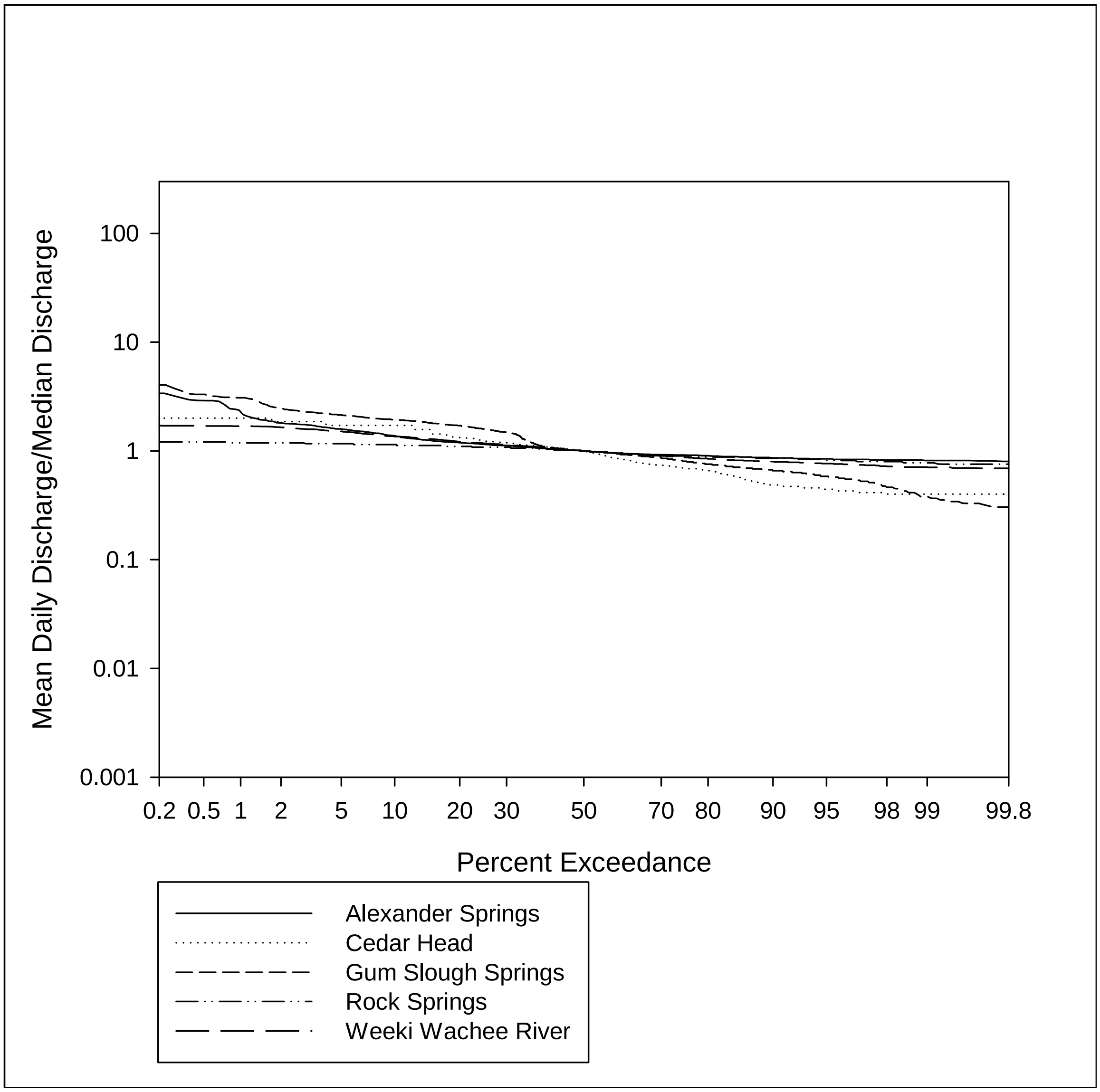


Figure 2-9. Karst spring run flow duration curves.

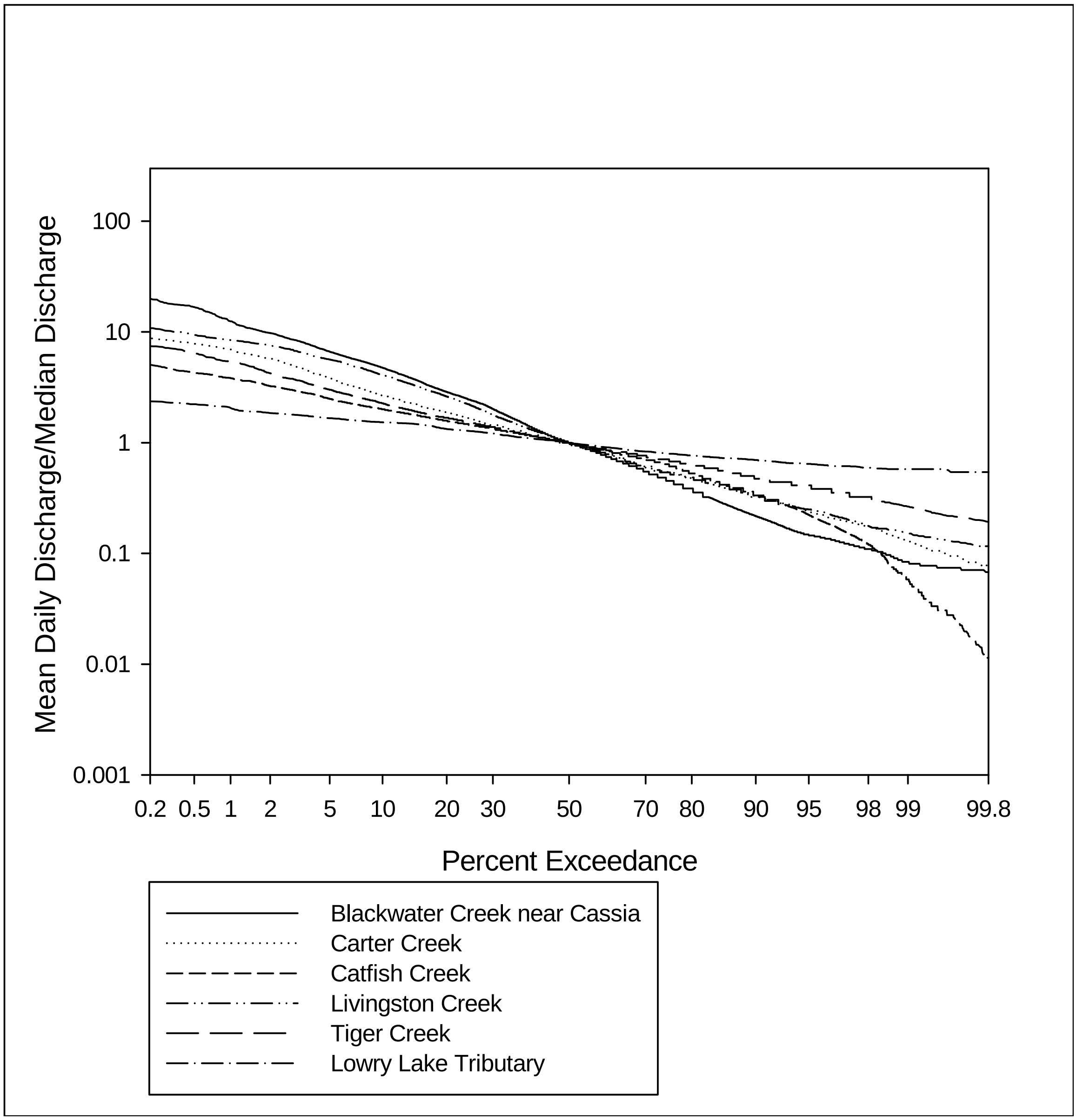


Figure 2-10. Highland stream flow duration curves.

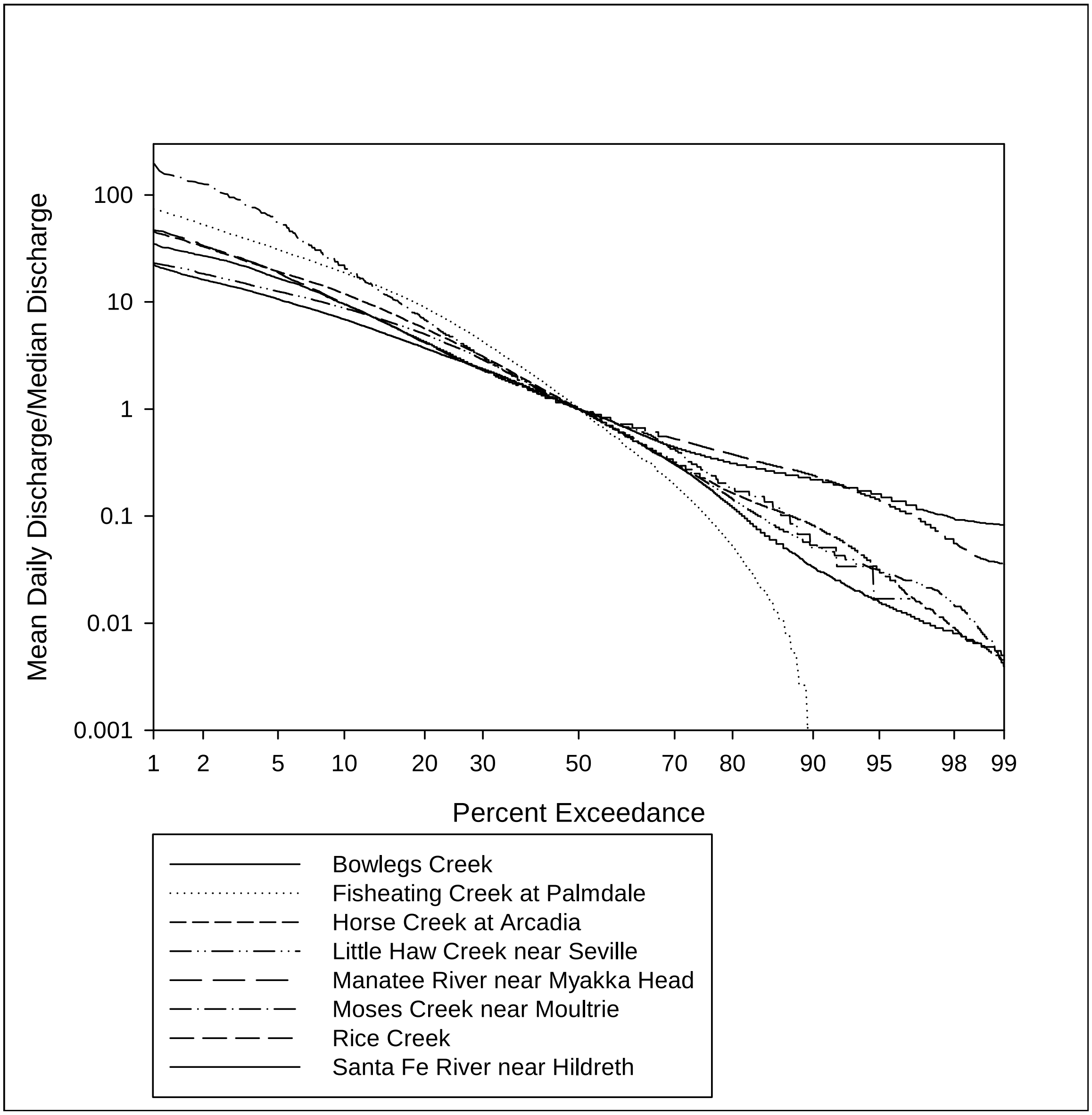


Figure 2-11. Flatwoods stream flow duration curves.

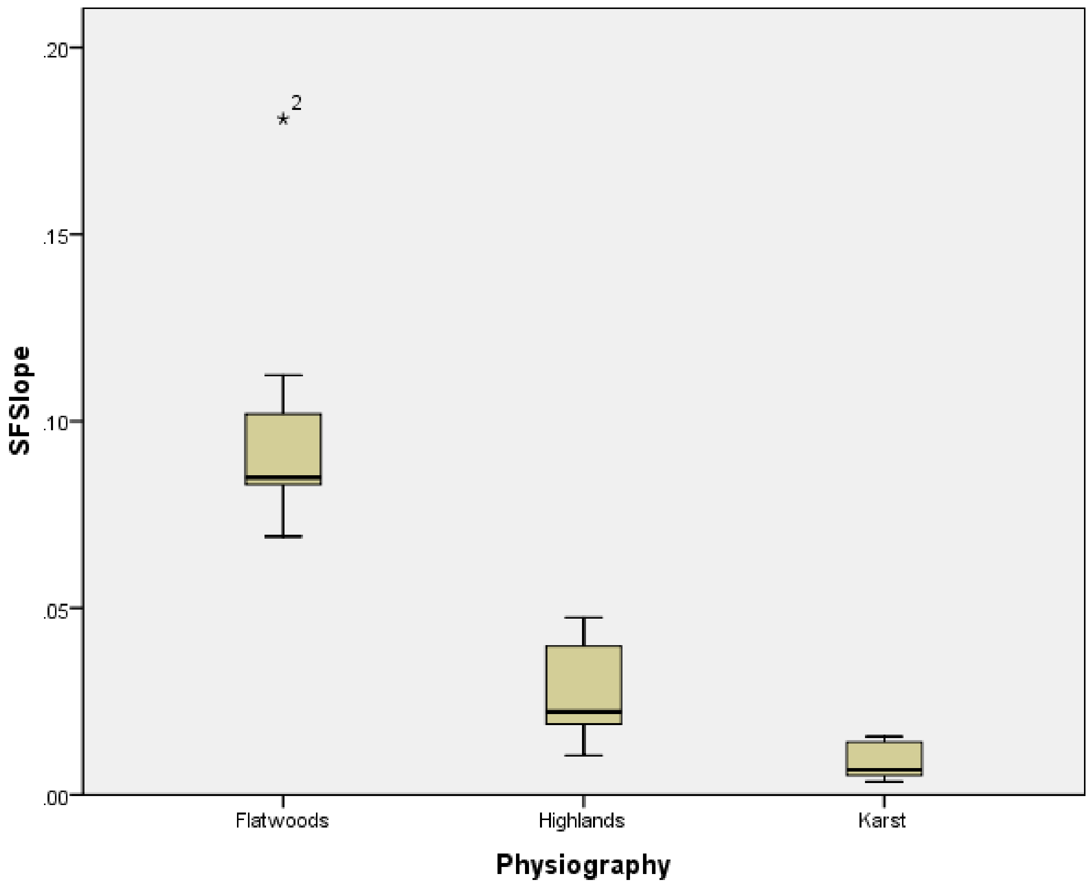


Figure 2-12. Seasonal flow slope (SFS) of different basin types. SFS is the difference between the 15% and 85% unit flow exceedance values divided by 70. It provides an approximation of the variability of the flow regime between the wet and dry seasons.

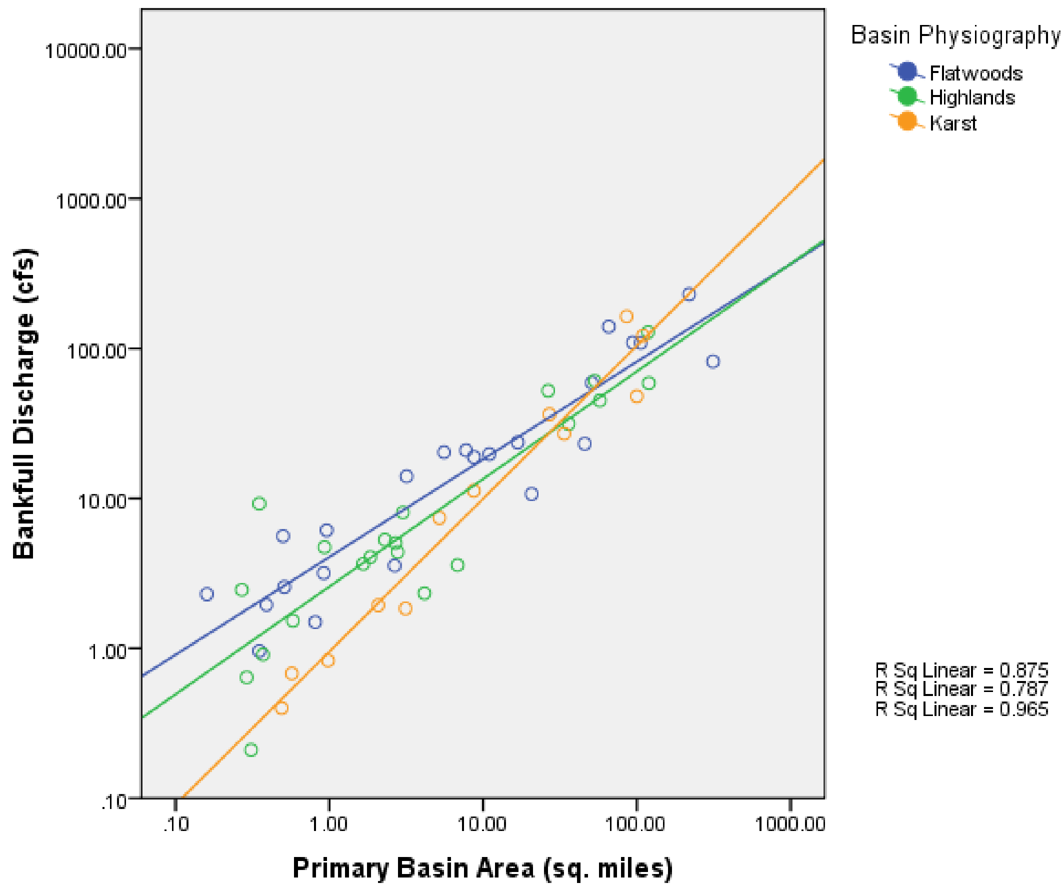


Figure 2-13. Bankfull discharge versus the dominant catchment area (springshed for karst streams or surface basin for highlands and flatwoods streams). Springsheds were derived from literature values and surface basins were delineated from topographic maps.

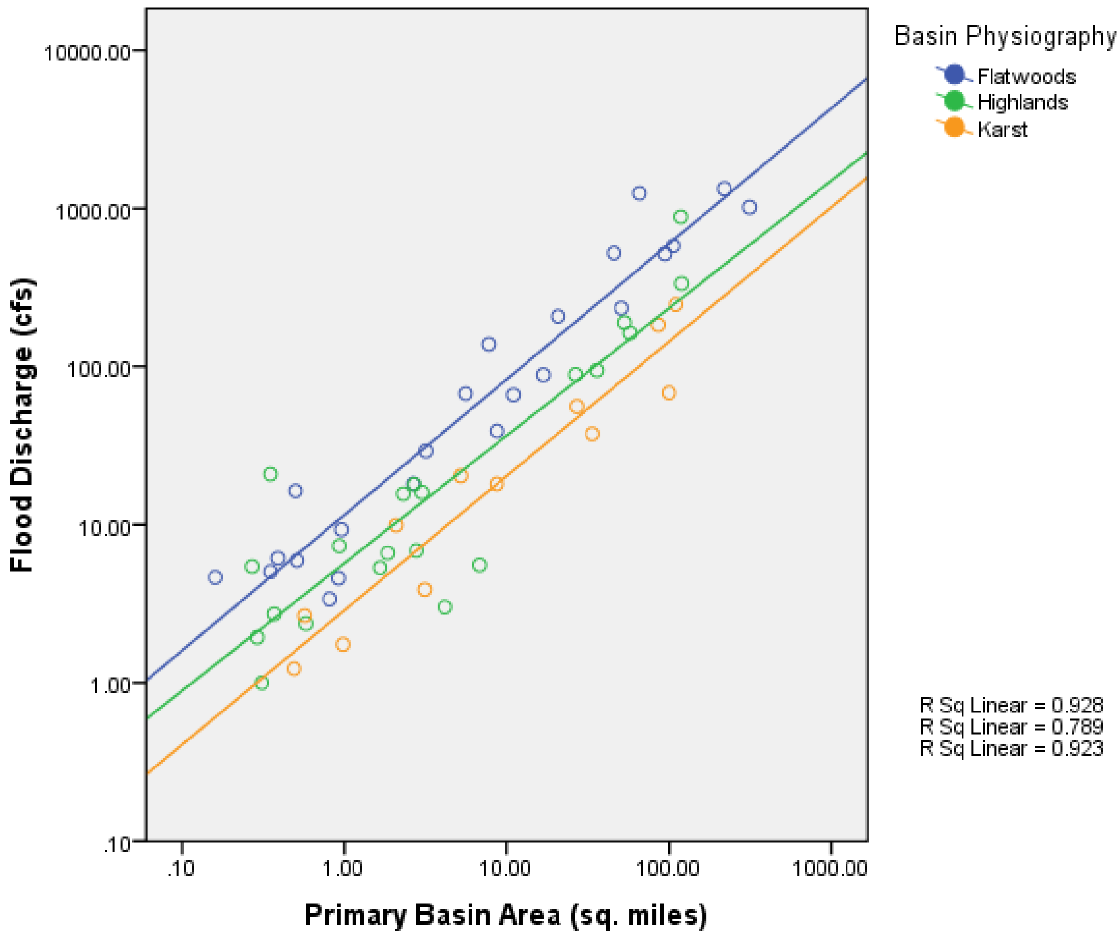


Figure 2-14. Flood discharge versus the dominant catchment area (springshed for karst streams or surface basin for highlands and flatwoods streams).

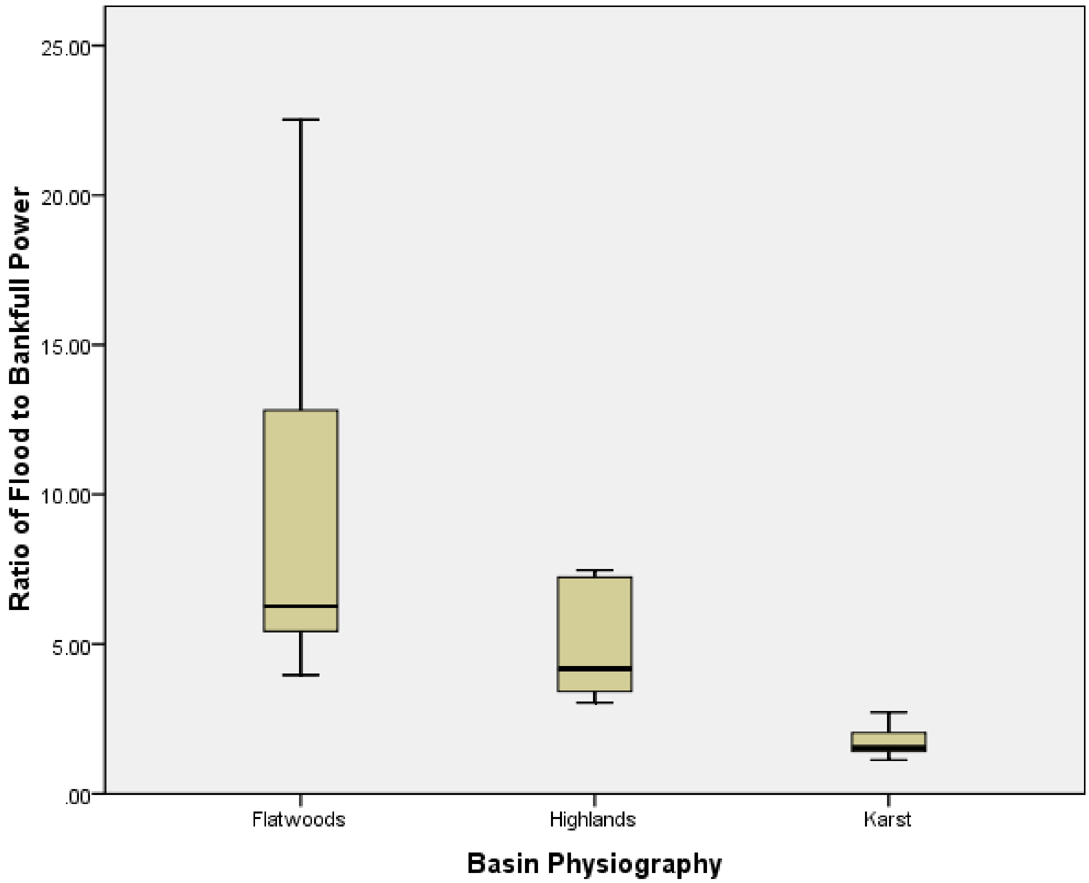


Figure 2-15. Flood/bankfull discharge power ratios for perennial streams in different basin types.

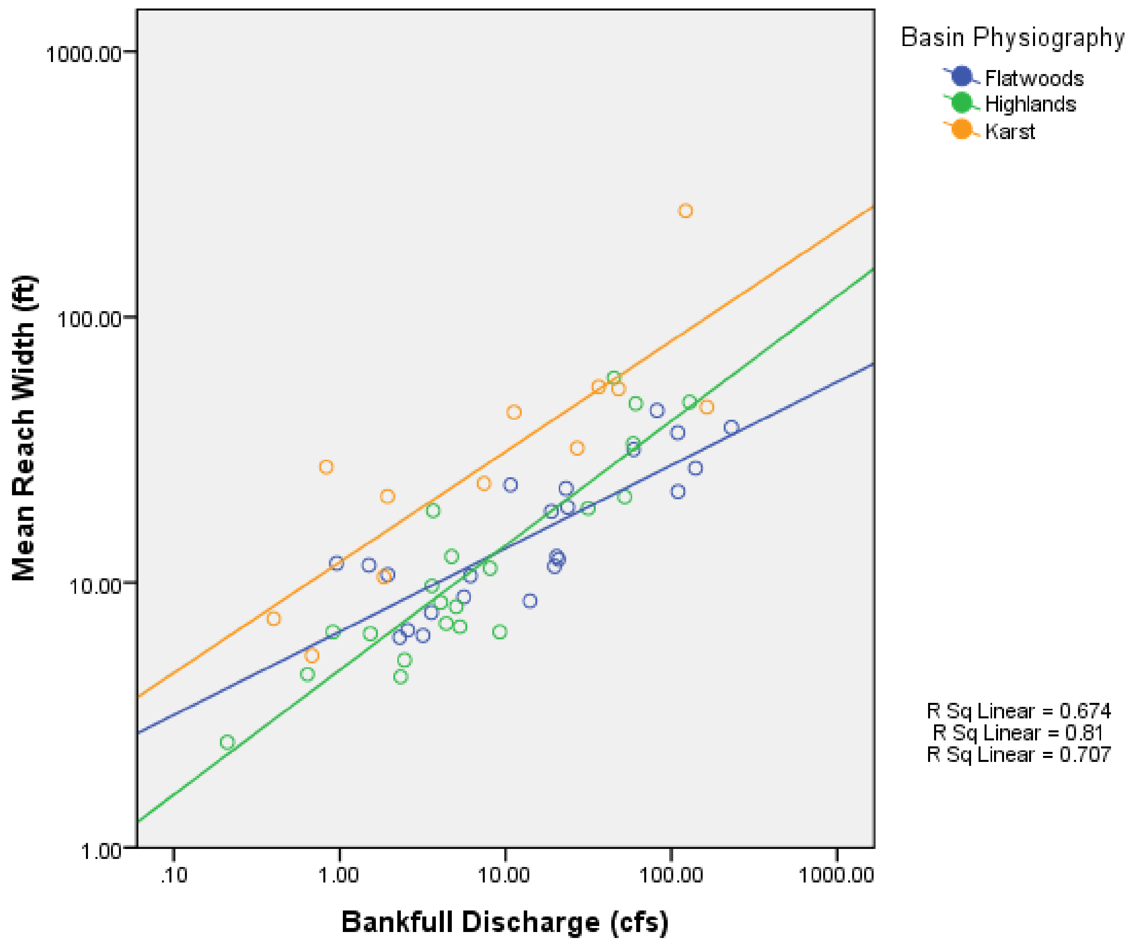


Figure 2-16. Channel width versus bankfull discharge in different basin types.

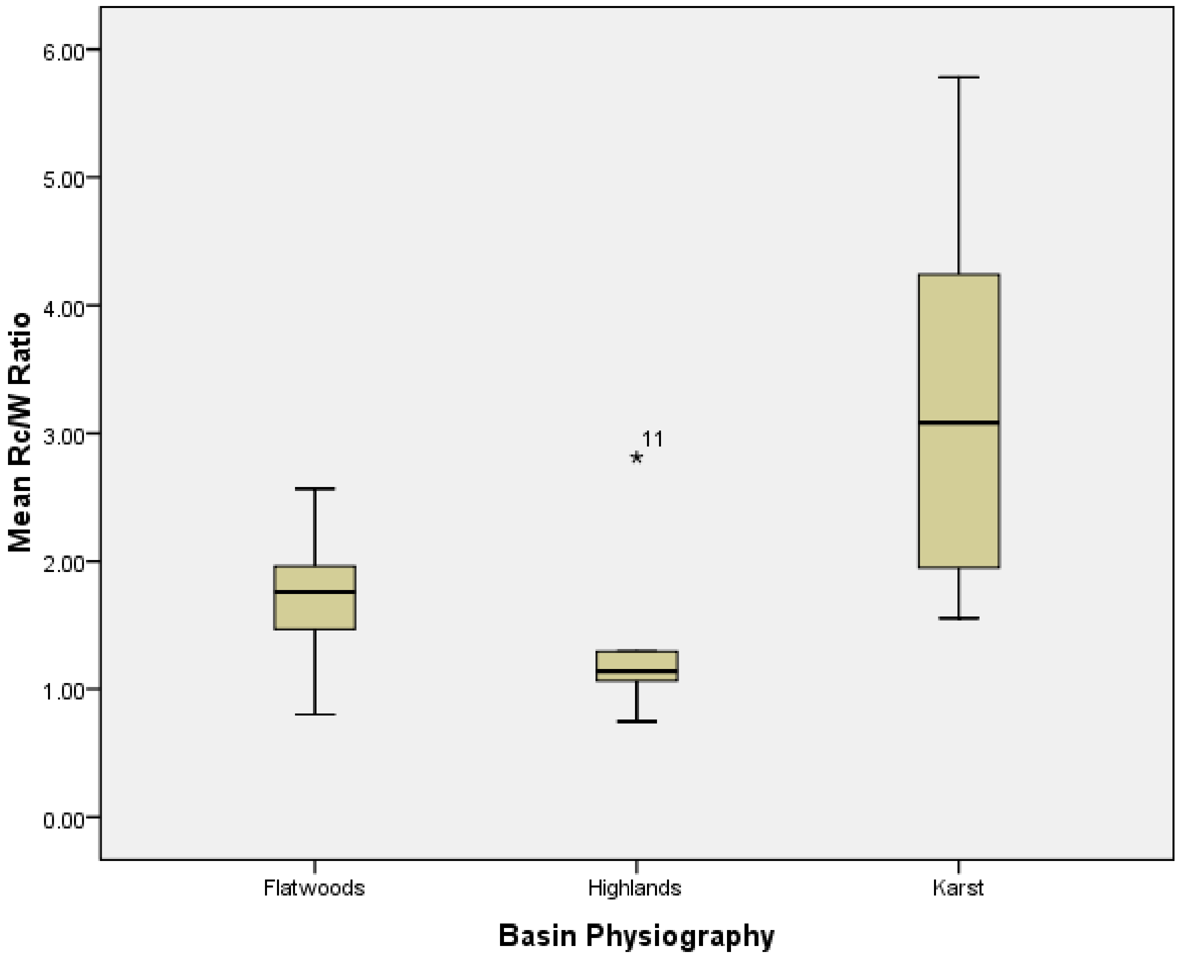


Figure 2-17. Radius of curvature/channel width ratio for perennial streams in different basin types.

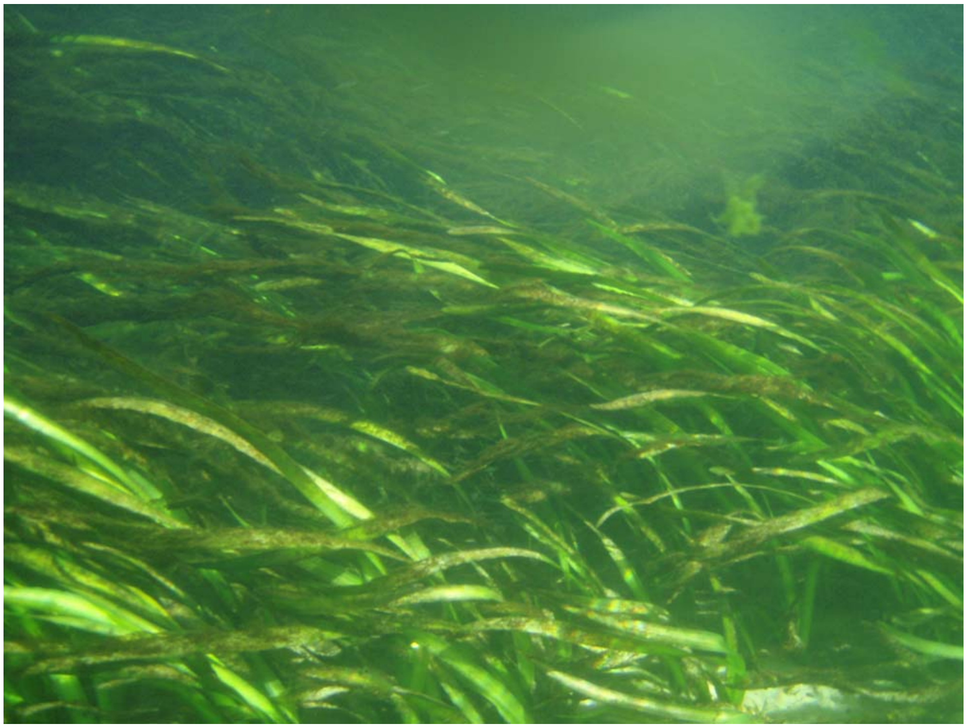


Figure 2-18. Submerged aquatic vegetation. Note the flow bending the plants.

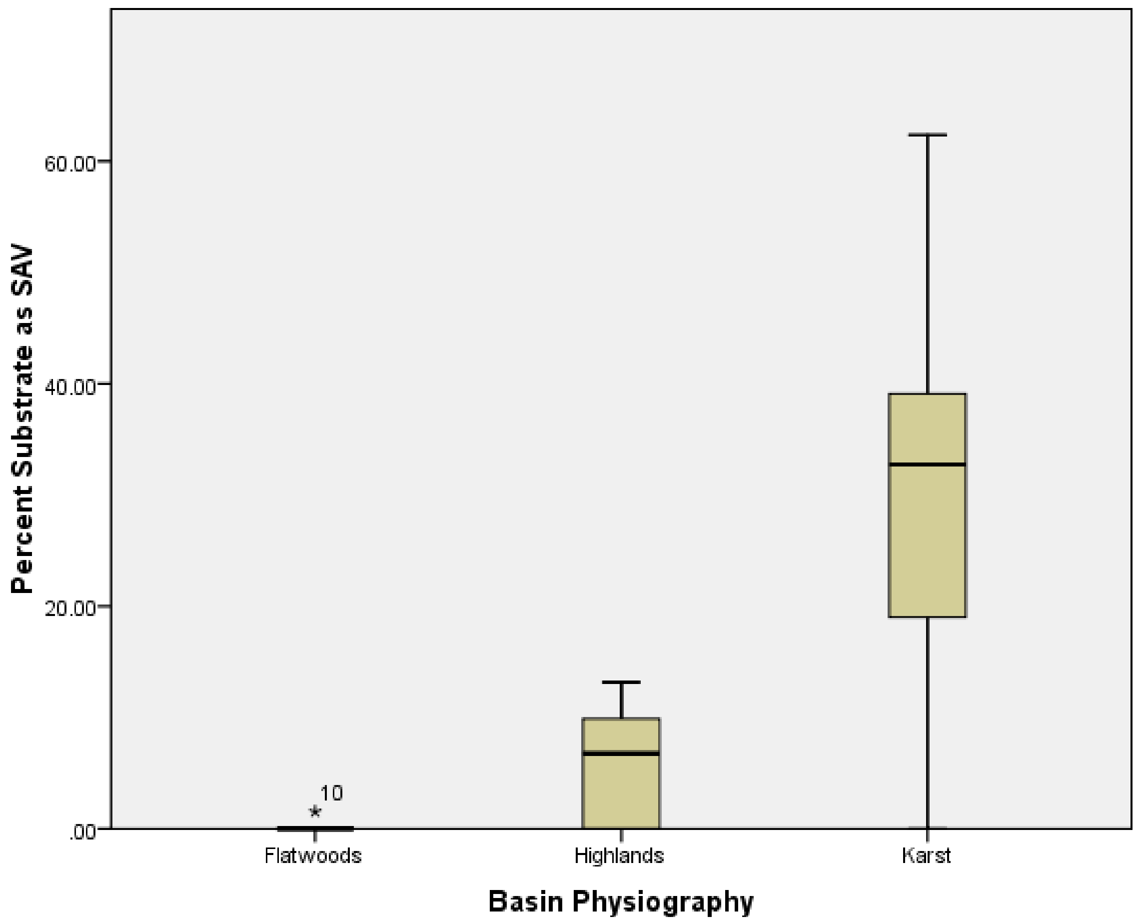


Figure 2-19. Frequency percentage of in-stream submerged aquatic vegetation for perennial streams in different basin types.

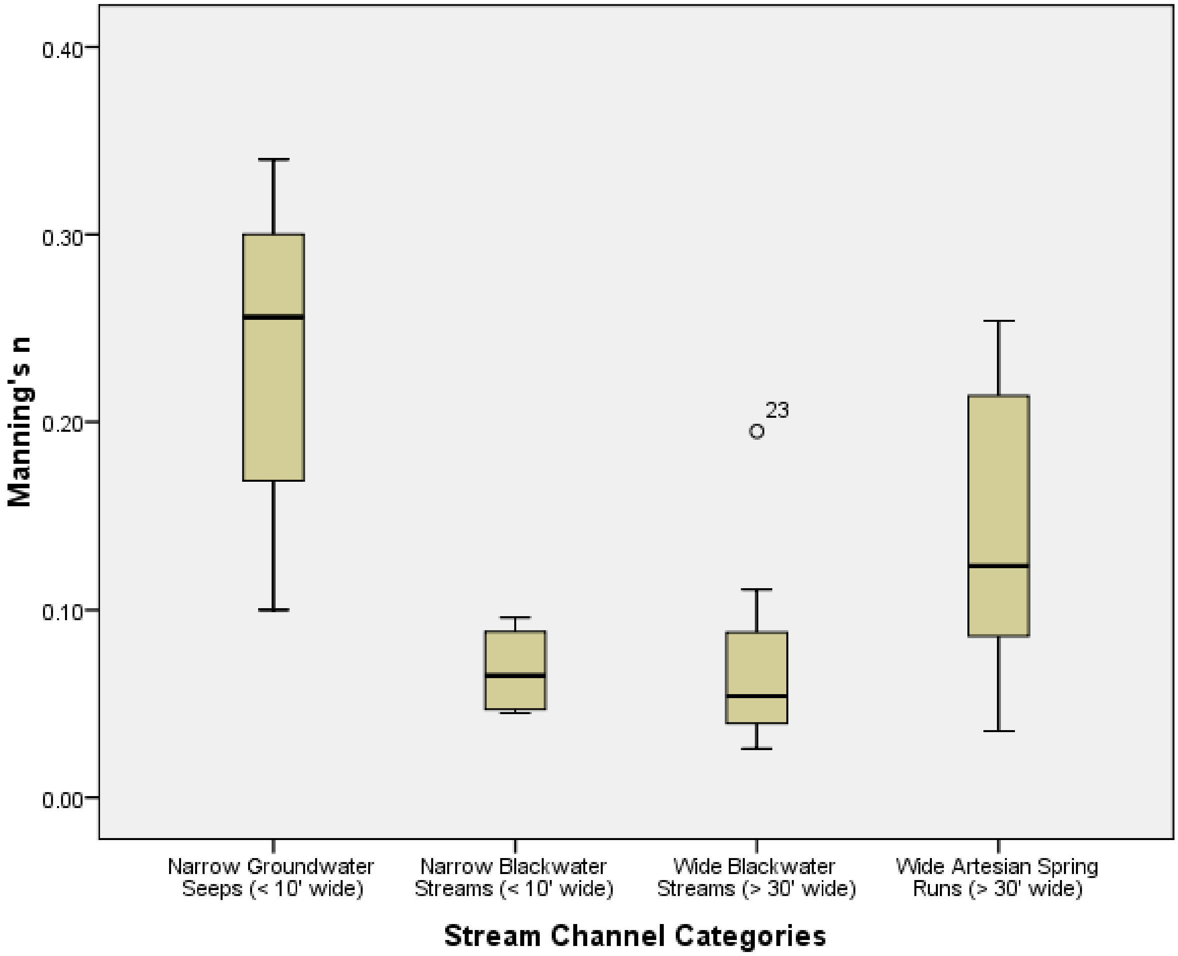


Figure 2-20. Channel resistance (n) comparisons for narrow and wide streams fed mainly by groundwater versus surface water runoff (blackwater).

Figure 2-21. Root step channel. Note the shallow flow over the step and the deep pools upstream and downstream of the living weir.

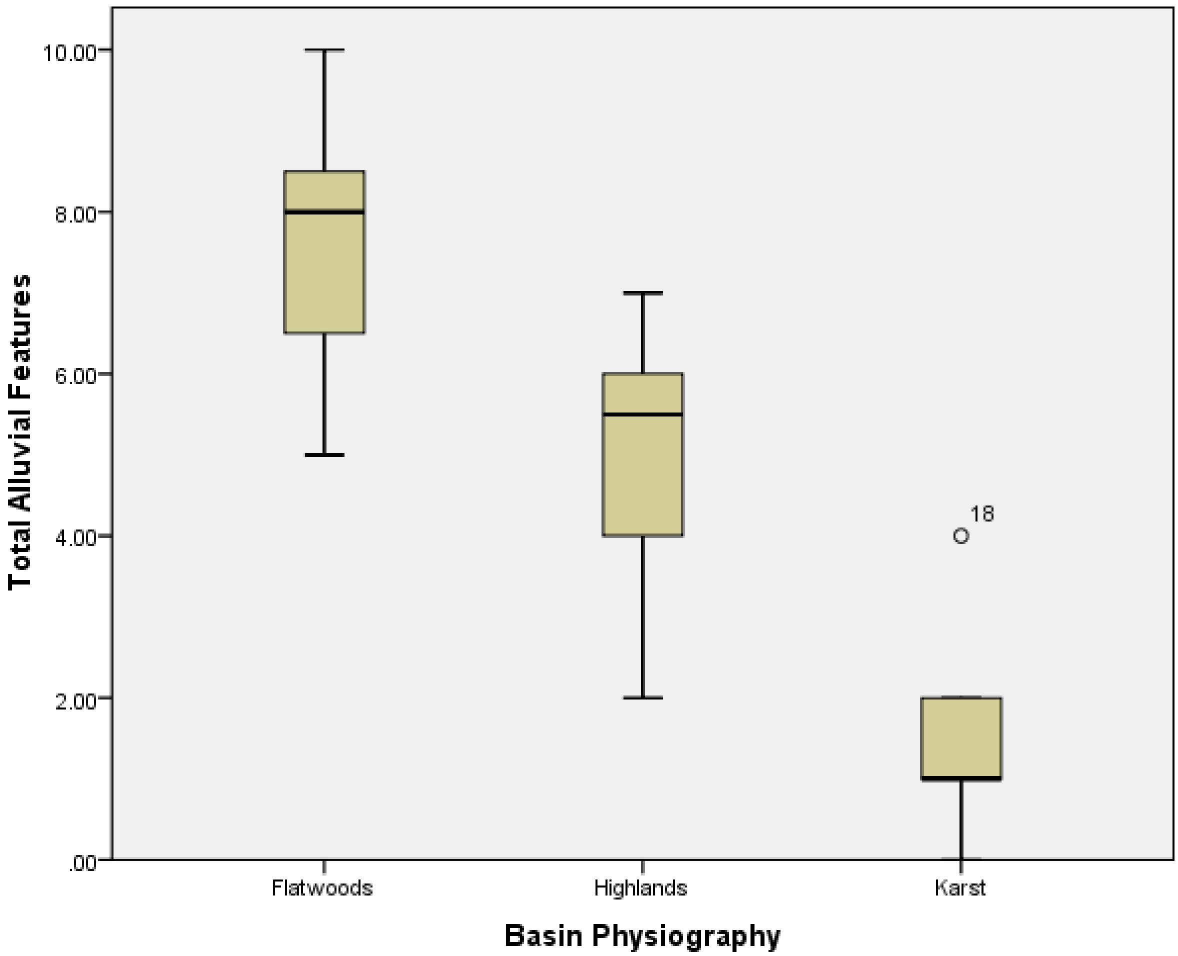


Figure 2-22. Alluvial features of the channel and floodplain for perennial streams in different basin types. Alluvial features are formed via sediment transport. Examples include natural levees, linear backswamps, point bars, oxbow lakes, stratified sediment layers, bend pools.

Figure 2-23. Biological banks. Note the live shrubs and trees are not only layered over the inorganic soil base but are growing over a hollow palm snag as well. This suggests long-term and aggressive self-organization of the living embankment.

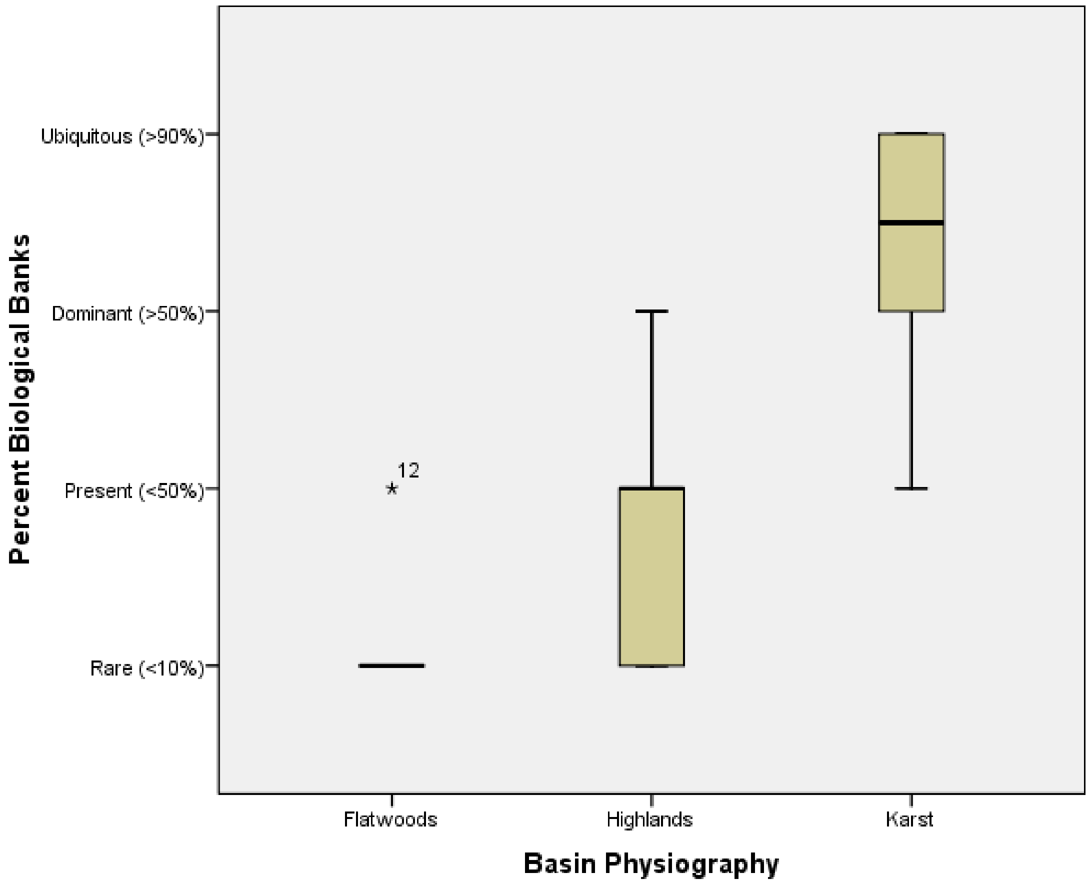


Figure 2-24. Percent dominance of biological banks for perennial streams in different basin types.

Figure 2-25. Shell and detrital floc sediment under a thin veneer of sand. Most of the sediment yield in many spring runs is autochthonous and has a biological origin.

Figure 2-26. Sandy alluvium with thin organic layers from a flatwoods stream point bar. Most of the sediment yield in flatwoods and highlands streams is allochthonous and has an erosional origin.

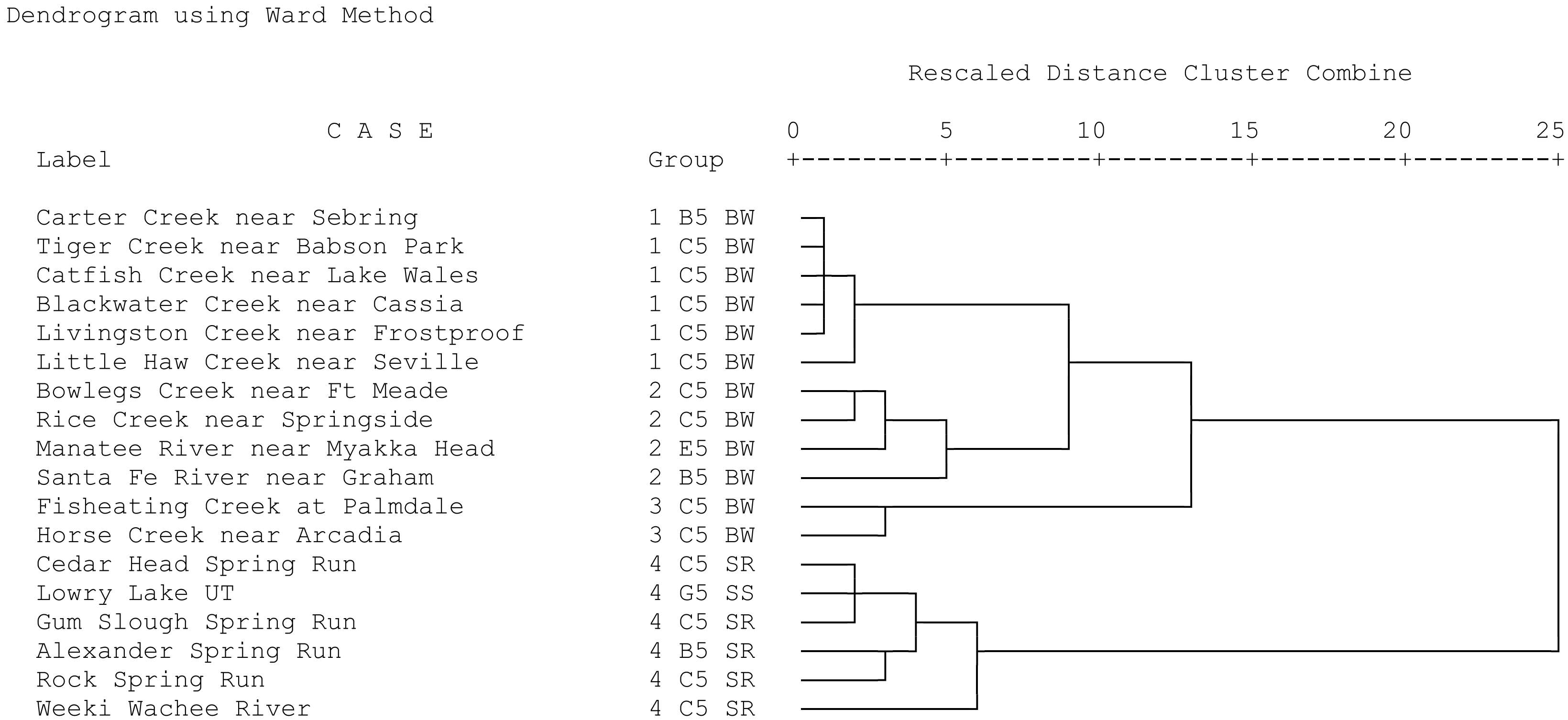


Figure 2-27. Dendogram of hydrologic clusters of streams. Cluster groups include; Group 1 = high baseflow with runoff spates, Group 2 = flashy intermediate discharge, Group 3 = flashy high discharge, Group 4 = steady groundwater flow. B5, C5, and E5 are Rosgen Level II channel classifications (Rosgen, 1996). FNAI (1990) stream classes include; BW = blackwater streams, SR = spring runs, SS = seepage streams. Note that the Rosgen and FNAI classes are poorly associated with the hydrologic clusters.

CHAPTER 3
ALLUVIAL AND GEOLOGICAL CONTROL THRESHOLDS IN FLORIDA'S DERANGED STREAM VALLEYS

Introduction

Purpose

Florida's drainage networks consist of complex valleys that offer highly varying degrees of lateral confinement, routinely have discontinuous open channels punctuated by in-line lakes and wetlands, and occur within three different hydrogeological settings that vary significantly in their surface water and groundwater discharge capacities. This all occurs within in a lowland, seasonally-wet sub-tropical landscape with potential for significant vegetative controls. The geomorphology of these deranged valley complexes has not been systematically described, except for case studies for the larger rivers such as the Kissimmee, St. Johns, Suwannee, and Ocklawaha (Warne *et al*., 2000; Interfluve, 1997). The main purpose of this investigation was to determine the following:

- How do valley form and dimension change along the drainage network?
- What associations of riparian sediment type and vegetation communities seem to occur with valley geomorphology?
- What physical indicators and floodplain hydraulic thresholds exist at the basin scale for alluvial control on floodplain form?
- What are the typical stream valley lengths and widths between in-line waterbodies and how might these vary spatially within the drainage network?
- How do valley patterns differ among the peninsula's three major hydrogeomorphic settings (sandy highlands, flatwoods, and karst) in potential association with their runoff versus groundwater flow dominance?

Answers to these questions are likely to provide managers of Florida's riparian corridors and watersheds with much-needed baseline knowledge and should assist with future restoration endeavors, especially those where it is important to restore functions related to the interaction of streams with their floodplains.

General Classification of Drainage Networks and Valley Forms

Drainage networks tend to exist in patterns related to their history of interaction of climate with geology. Several qualitative morphologic patterns are widely described in modern textbooks with increasing emphasis on channel network evolution (for example Knighton, 1998). Common network morphologies include dendritic, rectangular, radial, centripetal, trellised, parallel, annular, and deranged configurations (Zernitz, 1932). In watersheds with rather uniform valley tilt and poorly sorted distribution of geological exposures, dendritic networks are the norm. Dendritic networks consist of streams connected in a tree-like pattern (Figure 3-1). They could be considered the prototypical morphology (Zernitz, 1932) and it seems like most of the natural and laboratory stream network evolution studies in the literature are primarily dendritic in form, especially those summarized in textbooks (Knighton, 1998; Schumm, 1977; Leopold *et al*., 1964; Gregory and Walling, 1973).

Rectangular, radial, centripetal, trellised, parallel and annular networks could be viewed as dendritic networks where the underlying geology imposed some degree of repeated order on the pattern and dimension of the network. For example, a radial network consists of a series of otherwise dendritic drainage complexes emanating outward from a point centered on a pronounced conical rise (for example, from the cone of a volcano). Centripetal networks are the opposite, draining inward to a sinkhole, inland lake valley, or eroded dome. Rectangular, annular, and trellised networks follow rock fracture patterns existing on large scales. Parallel networks are series of long linear dendritic drainages that are confined by parallel interfluves in folded mountain ranges or along linear dunes where the crests are largely parallel. Deranged networks can also be ordered in a quasi-dendritic fashion, but the stream valleys are frequently punctuated or interrupted by un-channelized features such as lakes and wetlands (Figure 3-1). This means that more than two low order streams can join at a single node, a situation that is highly improbable in a dendritic network (or at any other network type except centripetal).

While geology greatly affects and constrains drainage patterns, interactions of climate on soil and vegetation appear to be major driving forces behind the density and long-term dynamics of channel network evolution. Drainage density (total stream length per drainage area) appears to be non-linearly correlated with precipitation with intermediate amounts of annual rainfall or precipitation effectiveness (P-E) resulting in the lowest average drainage densities (Madduma Bandara, 1974). Although global drainage densities are quite variable as an associate of annual rainfall, the maximum drainage densities, as high as 32 miles per square mile (20 km/km^2), occur in semi-arid climates with rainfall between six to 30 inches per year (150 to 800 mm/yr) (Gregory, 1976). Most of these areas are sparsely vegetated or are grasslands offering limited protection from erosion. Ignoring areas with virtually no rainfall, the lowest maximum drainage densities occur in regions with about 39 to 55 inches per year (1,000 to 1,400 mm/yr) at about five to eight miles/mi^2 (3 to 5 km/km^2). Most of the world's tropical and sub-tropical savannas fall in that range of precipitation (Bourliere, 1983). Gregory (1976) also showed that maximum drainage density increases to about 10 miles/mi^2 (six km/km^2) in more humid climates with at least 59 inches per year (1,500 mm/yr). This perhaps over-generalized pattern suggests that the lowest drainage densities occur in regions of intermediate rainfall. At lower levels of effective rainfall, the drier climate reduces stabilizing vegetation allowing for the most erosion while high levels of effective rain can overcome the effects of dense vegetation. Savannas occupy an interesting pivot point with the lowest capacity for maximum dissection, between the most highly dissected semi-arid regions and humid forest landscapes. It should be pointed out that minimum drainage densities appear to be similar among all climates, except in semi-arid regions where they may be higher. Gregory (1976) reported minimum drainage densities typically less than two miles/mi^2 worldwide.

Peninsular Florida's Geomorphology and Quaternary Climate Fluctuations

Florida has a complex biogeographic and associated climactic history because it straddles the northern edge of the tropics and sea-level fluctuations have led to wide variation in exposure and relief relative to marine base-levels during the last 25 million years (Webb, 1990). Marine forces shaped Florida's predominant land surface features as the Florida Platform exposure has changed repeatedly. Subaerial peninsular Florida comprises about one-third of the Platform. All three of the major hydrogeologic physiographies reflect different aspects of marine process associated with long-term fluctuations in global climate. Much of the existing physiography greatly reflects genesis from the past 25 million years of variable exposures, and especially the repetitive sea-level fluctuations that occurred during Pliocene and Pleistocene glacial and inter-glacial periods, during the last four or five million years. The establishment of Florida's carbonate lithology began during the Jurassic Period some 200 million years ago when Florida was under a shallow sea (Webb, 1990).

The extensive flatwoods ecoregions of the peninsula were once the shallow floors of ancient sea beds and several different marine terraces cross these plains along the scarps of relict shorelines. At least six such shorelines formed during the last 2.5 million years are currently exposed at elevations ranging from roughly seven to 115 feet above existing mean sea level (MSL) (Webb, 1990). Doline features, likely associated with solution weathering of underlying carbonate bedrock, are common in the flatwoods, forming numerous round or oval wetland depressions. Some of these depressions form in-line lakes and wetlands that interrupt the stream channel network. Most of the wetlands and lakes in Florida are less than several thousand years old (Webb, 1990). The spodosol catenas of the flatwoods typically consist of a relatively thin veneer of leached fine sand, generally one to four feet thick, over a loamy clay layer or a sandy-organic layer partially cemented by aluminum or iron referred to as a “fragipan” or “hardpan.” The sub-layers have low hydraulic conductivity so this catena aids in maintaining groundwater tables at or near most of the land surface during the wet season in the flatwoods. Runoff coefficients are accordingly high and wetlands abound. Subtle changes in grade, less than a foot, can determine upland-wetland ecotones in the flatwoods. Organic soils are often well-developed in surface depressions ranging from a few inches to more than 10 feet in thickness. These histosols are often sapric, sometimes with fibric material. Streams in the flatwoods typically have high color from dissolved organic compounds picked up from the organic wetland soils and decaying matter in the uplands and the water tends to be acidic and soft.

Florida’s sandy highlands consist of relict aeolian and coastal dunes that formed and were re-worked not only as sea-levels rose and fell, but also as the climate fluctuated from moist to dry. Dry phases allowed for aeolian work and wet phases for pluvial work. These sequences formed catenas consisting of greater than five feet of well-leached fine sand over clay or bedrock. The sand depths can exceed 20 feet. The term “highlands” is relative, as these areas are typically only 150 to 250 feet above sea level. Those forming the spine along the central part of the state owe a large fraction of their total elevation to isostatic rebound that occurred after submergence and subsequent exposure and limestone weathering created the Ocala Arch (Webb, 1990). The water table is generally several feet below the highlands land surface, allowing significant infiltration through the thick sands and subsequent seepage discharge to low-lying undulations in this landscape. Many wetlands and streams within the highlands are supported mainly from lateral seepage from the unconfined sandy aquifer. Ancient sinkhole lakes abound in many portions of the highlands, adding to the propensity toward internal drainage inherent to their thick columns of sand. Although large areas of the highlands are internally drained, most have some inclusions of soil catenas similar to flatwoods that support higher groundwater tables and produce significant wet season runoff. Furthermore, low-lying depressions and valleys filled with organic soils are common and some of these punctuate and derange the drainage network as in-line waterbodies. Water quality in highlands streams is typically acidic and soft. Water is often colorless in the dry season and highly tannic in the wet as contact with wetland soils increases with the rising water table.

The peninsula’s bedrock consists of carbonate rocks or ancient shell beds, some of which are near the land surface providing a milieu of paleo- and active karst features. Sinkholes, massive submerged karst conduits, and artesian springs are common features in much of the state. Florida has more than 700 karst springs (Scott *et al*., 2004). Thirty-three of them have median discharge greater than 100 cfs, reportedly forming the highest concentration of 1st magnitude springs in the world (Rosenau *et al*., 1977). Most of the artesian springs emerge in the highlands or along scarps at the edge of the flatwoods, often forming perennial stream channels of clear, hard water. The importance of weathering and other erosion of Florida's karst have left an indelible stamp of active and paleokarst features on the landscape, associated with much of the present deranged drainage patterns. During the last glacial (Wisconsonian, circa 20,000 years ago) sea level was about 330 feet below the present elevation. This means that maximum relief for erosion was roughly more than twice that present today. This is important because it gave an opportunity for very different valley erosion regimes than present. Some of those regimes have likely affected the alignment of present spring runs and other rivers. Lower sea-levels may have allowed the formation of deep valley cuts with attendant widely spaced interfluve crests. Therefore, some modern streams are likely flowing through thick accumulations of valley fill that has occurred as subsequent seas levels and associated base levels have risen. This may account for another aspect of apparent geologic control on the modern drainage network concerning numerous areas with wide valleys that are over-dimensioned for the existing stream's meander belt.

Florida's existing drainage networks are influenced or even largely controlled by other aspects of their ancient marine history. For example, many of the rivers originating on the central peninsula (Peace, Withlacoochee, Kissimmee, St. Johns, and Ocklawaha) have north-south alignments reflecting the long-axis of the various barrier islands, dunes and swales, and lagoons formed along former near-shore marine environments. North-south alignments are not universal, however, with the Suwannee, Caloosahatchee, and Hillsborough Rivers providing examples of exceptions.

All of the existing exposures have been repeatedly re-worked to varying degrees and are subject to being shaped by Holocene forces. The oldest continuous exposures on the peninsula consist of the ancient dunes of the Lake Wales Ridge, portions of which have generally been above sea level during at least the last two million years. The Lake Wales Ridge supports numerous endemic species of plants and animals uniquely adapted to the hot, wet climate with very droughty and seasonally dry sandy soils. Most of Florida’s stream networks have likely been substantially altered during the last 20,000 years as sea levels have risen more than 300 feet and the climate has become increasingly wet. As a result, most of Florida’s freshwater ecosystems are less than several thousand years old (Webb, 1990).

Florida’s complex climatogenetic history and resulting deranged drainage networks raise a compelling question, “Are Florida streams predominantly under geological control and what, if any, Holocene alluvial forces are at work and where?”

General Longitudinal Concepts: Clinal versus Zonal

Questions concerning the relative degree of importance of modern fluvial forces versus resistance to change by older geological features in river valleys have been increasingly raised, with at least three textbooks centered on the subject during the last 10 years or so (Thorp *et al*., 2008; Miller and Gupta, 1999; and Schumm, 2005). These texts provide contrast to valley process classifications that view drainage networks as longitudinally self-organizing systems at equilibrium for sediment transport and deposition (Leopold *et al*., 1964). Such deterministic concepts for longitudinal and lateral alluvial channel and floodplain self-organization revolutionized and injected new life into the disciplines of fluvial geomorphology and stream ecology from the 1950s through the present. Since that time a classic set of continuum principles have become textbook viewpoints concerning stream form and function along the valley network. Chief among these are that typical stream networks self-organize with gradual and predictable changes downgradient related to their hydrology and channel dimension (Leopold and Maddock, 1953; Wolman, 1955), sediment transport regimes (Wolman and Miller, 1960; Montgomery and Buffington, 1997), meander dimension (Williams 1986), floodplain dimension and thickness of alluvium (Wolman and Leopold, 1957), longitudinal gradient or valley slope (Mackin, 1948; Leopold and Langbein, 1962), and macroinvertebrate trophic strategies (Vannote *et al*., 1980).

Montgomery and Buffington's (1997) stream classification system was based on the underlying principle that process linkages along the drainage network would have systematic influence on any given stream reach. They found that the common fluvial bedforms associated with mountain stream channels (cascades, step-pool, plane-bed, pool-riffle, and dune-ripple) were related to thresholds of sediment transport capacity relative to sediment supply and that the bedforms and their associated bed material size and organization was primarily a response of the system to offer greater frictional resistance in parts of the drainage network with the greatest transport capacity. They described their stream types as generally sorting along a continuum of drainage basin size and valley slope, but clearly illustrated that it was the processes, not the positions that mattered most. They recognized that assessments of channels should also carefully consider disturbance history, local influences on channel morphology, and local external constraints within the context of the continuum of excess transport capacity and resistance forms they described.

In fact, it is probably the norm that clinal processes along a continuum of form are in reality often disrupted or punctuated by local geological controls along many riverine valley systems. Anyone who has rafted down a river that alternates between multiple stretches of placid runs punctuated with wild rapids, with an occasional cascade portage has experienced this. Knighton (1998), using examples, describes how inputs from tributaries with differing geologic conditions and associated differences in sediment caliber and volumes can break up the "normal" sediment transport continuum of the mainstem river and greatly affect its channel dimensions and planform in a manner that would cause a traveler to hardly view the river as having a gradual continuum of form progressing downstream.

Many rivers appear to have sudden, rather than clinal, changes to their channel and valley form and dimension along their length and these changes are often repeated as opposed to unfolding in a strictly progressive manner. Such systems are far from the exception and, as a result, Thorp *et al.* (2008) attempted to improve description, understanding, and management of riverine systems by recommending descretization into series of longitudinal functional process zones (FPZ). FPZs are fluvial geomorphic units typically occupying valleys at a scale larger than the reach. The functions are related to fundamental hydrogeomorphic processes, especially those associated with differing channel and floodplain formations. Such formations are often the defining physical template for complex ecological gradients and community structure development and linkages within the terrestrial and aquatic portions of the riparian corridor. The lateral sorting and linkages of different physical habitat patches repeat within FPZs, but differ among them. A valley can consist of more than one longitudinally linked FPZ. In fact, most Florida valleys appear to consist of multiple sequences of different FPZs.

Clinal or gradualistic processes certainly influence the development of FPZs, but they do not completely rely upon them and often repeat along the valley and are frequently defined not only by modern alluvial factors, but also by more chaotic relicts of their geological past or by some history of episodic events. The beauty of the FPZ concept is that it allows retention of clinal concepts related to modern alluvial and hydraulic processes along the drainage network without having to neglect the variety of fluvial forms and functions that are under alternate geological or biological controls that are largely independent of (or at least resistant to) such gradients.

Florida drainage networks, deranged by numerous in-line wetlands and lakes and with many abrupt transitions in lateral valley confinement, may be among the most quintessential systems where FPZ concepts are necessary for properly characterizing and managing fluvial systems. Therefore, it seems important to explore reach data for patterns related to fluvial form with position in the drainage network and for any continua that may exist and also for patterns likely to be repeated or punctuated within the clinal progression that warrant description as FPZ's. While it is important to tease out the zonal patterns intrinsic to gradients of fluvial adjustment intrinsic to the scale of the watershed or present magnitude of the flow regime, it is just as important to recognize the less predictably structured spatial heterogeneity somewhat extrinsic to the effects of the modern climate.

Methods

All 56 streams selected for this study were utilized in this analysis. Field methods and at-a-station hydraulic calculations were conducted as described in Chapter 2 for bankfull and flood conditions. GIS layers were developed for LiDAR-derived topography where available to delineate watersheds and develop large-scale transects bigger than the reference reach surveys. Drainage networks were described for each reach's basin using the topographic data in the GIS, USGS digital 1:24,000 quad maps, and georeferenced 2004 true-color aerial photography available at one-meter resolution. Box plots, one-way analysis of variance (ANOVA), cross-tabulation comparisons of categorical data, and regression of continuous variables were used to explore the data.

Results and Discussion

Valleys and their streams can be measured and described from three two-dimensional viewpoints; longitudinal, planform, and lateral. Longitudinal patterns are those that occur along transects parallel to the centerline of a valley. Lateral patterns are those that occur along transects oriented across the valley, perpendicular to the longitudinal axis. Planform patterns can be described as "map views," looking straight down on the valley like a roadmap so one can determine where it exists in the landscape. All three viewpoints are related to each other in three-dimensional space, collectively providing a complete description of the fluvial system morphology. This section is organized to evaluate and describe Florida's fluvial systems in terms of each of these standard viewpoints.

A wide range of valley widths and lengths were measured between the in-line waterbodies for this study. Variability in valley patterns such as hillslope relief, longitudinal relief, meander belt confinement by hillslopes, occurrence of alluvial features, and longitudinal concavity were observed and recorded between the in-line waterbodies during the extensive field reconnaissance conducted for this study. Various types of riparian, headwater, and in-line waterbody community types were recorded. Numerous soil associations were observed and recorded along potential longitudinal and lateral gradients. These measurements and observations were sorted into their appropriate lateral, longitudinal and planform perspectives and were examined for patterns in association with increasing drainage area size and increasing drainage order to determine potential associations with their position in the drainage network. Sites were segregated based on their landscape physiography to compare the associations of valley form and patterns among Florida landscape types (flatwoods, highlands, and karst).

Planview Valley Network Patterns and Landscape Associations

In general, stream drainage area should increase with stream order but the magnitude may differ among various physiographic settings. Because a small number of 3rd through 5th Order streams occurred in the study compared with 1st and 2nd order systems, the three higher-order categories were lumped into a mid-order category to facilitate a more equitable comparison. Mean drainage basin size increased with Strahler's stream order for flatwoods and highlands landscapes with each successive order (Figure 3-2) and the results were statistically significant for post-hoc pairwise comparisons of the log transformed drainage area values among orders (Table 3-1).

Headwater systems of highlands landscapes may warrant additional considerations because internal drainage can lead to delineations of very high watershed areas that would be unlikely for flatwoods (which generally lack internal drainage). For example, of the seven 1st order flatwoods streams in the study, the largest drainage area measured was 2.7 square miles (for Lower Myakka UT 2). The two largest 1st Order drainages out of the 10 highlands streams studied were 57.5 square miles (Catfish Creek) and 6.8 square miles (Ninemile Creek). Catfish Creek drains a large headwater lake with no influent streams on the Lake Wales Ridge and Ninemile Creek drains seepage from a high sandy scrub and sandhill complex with internally drained wetlands and ponds located on the Ocala Ridge. Neither of these areas have the capacity to develop surface water drainage because rainfall is quickly captured by a large lacustrine depression or a thick sandy surficial aquifer. Such areas are not exceptional in the highlands and are rare to nonexistent in the flatwoods.

Drainage area was not strongly associated with Strahler order for karst landscapes (Figure 3-2). This is not surprising considering that the drainage area used in this comparison is often remote from the karst stream. Therefore, an alternate comparison was made substituting the local surface water basin for the recharge basin area for the karst systems. This also failed to produce increases in mean drainage area in association with increasing order for the karst systems studied. The experimental design deliberately selected karst systems from a population likely to be independent of surface water controls (in areas located close to the headspring). As some spring runs are joined by surface water streams along their length, it seems likely that long runs should increase their local drainage area along their length and so will stream order. Whether this occurs to the same magnitude as in highlands or flatwoods landscapes was not assessed by this study.

Drainage network magnitude based on Shreve’s ordering system is a measure of drainage complexity. Unlike Strahler orders, Shreve’s magnitude cumulatively adds each branch in a downstream progression (Shreve, 1966). Figure 3-3 illustrates that more streams entered the drainage system as basin size increases and that these trends were particularly strong for flatwoods and highlands systems. Flatwoods appeared to support greater drainage network complexity than highlands streams with apparent increases in regression slope and constant versus drainage area (Table 3-2). Generally, karst systems differed at statistically significant levels ($p < 0.05$) for all pairwise comparisons of slope and regression constant with the other two physiographies, except that karst slope was statistically indistinguishable from that of highlands (Table 3-2). It appears that the sensitivity of the association of drainage magnitude with drainage area increases with the surface water influence in the hydrologic regime versus groundwater dominance.

Drainage density is the total stream length divided by drainage area. For this study, it was computed using the perennial and intermittent streams delineated in the National Hydrographic Database, expressed as linear feet per square mile. No substantial differences were apparent between flatwoods and highlands physiography or the highlands and karst sites based on Dunn post-hoc tests of Kruskal-Wallace ANOVA on ranks, but karst and flatwoods were different with the flatwoods averaging twice the drainage density of karst basins (Table 3-1, Figure 3-4). This suggests that as surface water processes increasingly dominate over groundwater processes, drainage density tends to increase. Florida’s drainage densities are among the lowest in the world for humid climates, given that densities mapped at the 1:24,000 to 1:50,000 scales are typically in excess of one mile per square mile (Gregory, 1976). This may be due to a combination of factors in addition to groundwater capture of rainfall, including the simple fact that much of the drainage network is encumbered by in-line lakes and wetlands which directly reduce the total stream length.

In-line waterbodies types located immediately downstream of the stream segments studied differed in their distribution by physiography (Pearson Chi-Square, $p = 0.005$). For example, most flatwoods downstream junctions consisted of streams followed by various forms of in-line surface water wetlands (depressional marshes, swamps and quasi-depressional sloughs) (Figure 3-5). Highlands downstream waterbodies consisted primarily of stream junctions, in-line lakes, depressional swamps and seepage swamps. Comparing flatwoods and highlands regions, lakes and seepage swamps appeared to be more common in the highlands while stream junctions appeared to be more common in the flatwoods. Various forms of in-line surface water wetlands (sloughs, marshes, and swamps) appeared to be in overall similar proportion. Karst streams mainly differed from the other landscapes by joining more springs downstream and by having proportionally fewer in-line depressional wetlands. Karst regions appeared to support the lowest overall proportion of in-line waterbodies and were the least deranged, while highlands had the greatest proportion. This suggests fundamentally different geology/genesis of highlands and karst valley structure.

Upstream waterbody types also differed significantly by physiography (Pearson Chi-Square, $p = 0.002$). Karst systems were not included in the cross-tabs comparisons because the experimental design called for all of their upstream junctions to occur as springs or spring runs and they clearly differ on that respect. Most flatwoods upstream junctions consisted of various forms of surface water wetlands (depressional marshes, swamps and quasi-depressional sloughs) followed by influent streams (Figure 3-6).

Waterbodies in the highlands upstream of the studied channels consisted primarily of seepage swamps, followed by in-line lakes, depressional swamps, and stream junctions which were found in nearly equal proportions to each other. Comparing flatwoods and highlands regions, lakes and seepage swamps appeared to be more common in the highlands while stream junctions, depressional marshes, and sloughs appeared to be more common in the flatwoods. Much of these differences may exist based on the relative occurrences of different headwater wetlands in each landscape. Marshes are more common in the flatwoods, while lakes and seepage swamps are more common in the highlands (Myers and Ewel, 1990).

The distribution of dominant riparian community types within stream meander belt also varied by physiography (Pearson Chi-Square, $p = 0.003$) (Figure 3-6). The meander belt is the generally flat part of the valley that the stream meanders across. Streams in the flatwoods coursed mainly through valleys occupied by cypress bottomland swamps, hydric hammocks and mesic hammocks. Streams in the highlands were predominantly flanked by seepage swamps, bottomland hardwoods and bottomland cypress swamps. Most spring runs coursed through valleys consisting of seepage swamps or mixed swamps (with hardwoods, pines, palms, and some cypress). By definition, mixed swamps have less propensity for overbank flooding than bottomland swamps. In addition to karst systems which generally lacked bottomland swamps, the biggest differences among the landscapes were that bottomland cypress was the largest single category in the flatwoods while the riparian zones of the highlands and karst systems were most likely to consist of lateral seepage swamps. This suggests that the landscape groundwater regime not only interacts with the fluvial geomorphology of the streams, but also has pronounced association with the riparian zone plant communities.

The relative distribution of riparian communities also appears to be associated with Strahler's stream order (Pearson Chi-Square, p = 0.039) (Figure 3-7). First and second order streams meandered in contact with a rich array of upland and wetland plant communities ranging from narrow valleys of xeric sandhills to wide bottomland cypress swamps. Mid-order systems (3^{rd} through 5^{th} order) rarely were in much direct contact with uplands and generally flowed through wetland valleys. These comparative differences likely reflect the fact that mid-order and higher order stream valleys tend to be formed and maintained by fluvial forces that operate at much greater magnitude and frequency than those found in the headwater portions of the landscape. The comparative reduction in the sheer volume of water available in low order systems likely allows a wider variety of upland and mesic communities to persist within the meander belt. Blanton (2008) reported that cypress trees were most common on flat, floodprone floodplains. Systems with that kind of hydromorphology tend to be located in mid-order and higher positions along the drainage network in Florida.

Meander belt width increased significantly in association with drainage area for all landscape classes (Figure 3-9). This is common in humid regions worldwide (Williams, 1986). Basically, as stream discharge volumes increase, meander geometry increases. Therefore, streams draining larger watersheds require more lateral space to accommodate their stable meander pattern. Streams of the flatwoods exhibited statistically significantly higher intercepts and than those of the highlands or karst regions, while highlands and karst streams differed little in that regard (Table 3-2).

Regression slopes for highlands streams did not differ in a statistically significant fashion from those of karst or flatwoods, but karst streams differed from flatwoods. The differences did not appear to have a very large practical effect, with significant overlap between all three landscapes. However, it did appear that surface water systems exhibited greater meander widths than the groundwater dependent systems for small streams and that the difference diminished with increasing basin size. Medium and larger systems appeared to meander more similarly among the landscape types. This may indicate that somewhat geographically universal fluvial forces in the larger basins consistently overcome colluvial controls that can resist such forces more effectively in the headwaters. In other words, meander geometry is influenced more by biological and geological controls that appear to be sorted differently among physiographic settings in the headwaters, but that the physics of water and sediment transport overcome these differential controls irrespective of physiography at some threshold of basin scale represented by the higher-order systems. Inspection of the data scatter suggests convergence of the dominance of alluvial control of meander pattern occurred at drainage area equal to or greater than 10 square miles (Figure 3-9).

Stream meander belts can be confined or constrained by geology. In such cases where the hillslope materials are erodible, the stream channel will cut into and flatten the slope edges over time, leading to a meander belt that is rather uniform in width and well-adjusted to its valley. In cases where the flow regime is greatly resisted by the valley slopes, the stream cannot cut a valley flat that matches its meander belt width and it is said to be laterally confined. This can occur in Florida in areas where dense vegetation provides shear strength that endures even the most severe of floods, perhaps typically closer to the headwaters. Unconfined streams course through valleys that are wider than their meander belt. All three arrangements, unconfined, well-adjusted, and confined stream valleys occur in Florida and were routinely encountered in this study. Figure 3-10 depicts an alternating sequence of two types (unconfined and well-adjusted). Valley confinement and its landscape associations are discussed in more detail in the Lateral Valley Pattern section, but the concepts were introduced here because they need to be illustrated in plan view as well as cross-section to be fully understood.

Longitudinal Valley Patterns and Landscape Associations

When viewed on a sufficiently large scale, drainage networks tend to exhibit a generally concave longitudinal profile (Mackin, 1948; Montgomery and Buffington, 1997). This means that the streams draining the small watersheds in headwater positions of the longitudinal profile tend to occur within valleys exhibiting steeper longitudinal slopes than those streams draining larger watersheds at lower positions in the landscape. This pattern results from differential effects of sediment transport regimes and energy efficiency that are altered by the ever increasing discharge of water and sediment as one moves down the valley. A well-organized concave profile is referred to as a graded profile. Graded profiles are consistent with sustained differences in sediment supply versus transport capacity whereby headwater streams have more capacity than supply and supply progressively increases downstream, eventually overcoming capacity. Where that occurs, sediment fills the valley, reducing its grade (Montgomery and Buffington 1997). Systems can be characterized as existing in three zones along the graded profiles; export, transitional, and depositional (Schumm, 1977). Export zones occur in the colluvially controlled valleys of the headwaters, while depositional zones occur in higher order systems with alluvially controlled floodplains. Therefore, transitional areas can exist with a variety of alluvial and colluvial influences.

Florida, in a very general sense, tends toward graded profiles within all three physiographies as evidenced by the fact that valley slope decreases in association with increased drainage area (Figure 3-11). The most notable difference among the landscape types occurred between the intercepts of the highlands streams versus those of the karst and flatwoods regions. This is due to the fact that headwater streams in the highlands had the steepest stable slopes measured in the study. These seepage and sapping streams are the previously mentioned “root-step” channels that seem to maintain their steep profiles by substantial vegetative controls. The higher valley relief of low-order highlands streams probably also occurs due to the fact that these regions have greater overall available relief than flatwoods in general and also because spring runs are more likely to emerge in comparatively low spots in the landscape (Walker, 2006). Streams further down the valley and draining larger watersheds appeared to differ little by physiography once drainage area reaches about 10 square miles. Regression slopes were statistically similar among all comparisons except for highlands and flatwoods (Table 3-2).

Although Florida exhibits a tendency to develop graded profiles in a general way, lots of local exceptions occur, consistent with the wide scatter in valley slope versus drainage area. Grade inflections were measured along valley profiles for each study reach from the reach upstream to the headwaters of that valley. Four classes of inflections were observed. Concave profiles bow downward, convex profiles bow upward, flat or linear profiles represent relatively constant gradient and exhibit no obvious inflection, while mixed profiles have convex and concave segments.

All four types of profile inflections commonly occurred in each physiographic region, without any clear differences in their distribution among the landscape types (Pearson Chi Square, $p = 0.558$). Statistically significant differences occurred among Strahler stream orders (Pearson Chi Square, $p = 0.041$). All four types occurred for each order, but flat profiles were most common at headwater streams, concave profiles at second order systems, and mixed profiles along mid-order valleys (Figure 3-12). So, even though on average the valley profiles tend toward a graded (concave) profile in Florida as evidenced by the negative regression of valley slope versus drainage area (Figure 3-11), site-specific profiles can be highly variable and may actually have a slight overall bias towards mixed mid-order shapes that include relatively flat headwater reaches followed by concave second order segments. This probably stems from the fact that the vast majority of headwater streams drain either seepage wetlands or depressional wetlands, which to remain saturated require flat or depressed lands. The system picks up more energy downstream and the profile begins to grade toward concavity in many 2nd order segments. Since this process is usually driven by headward erosion of the bed, it obviously must be resisted in the headwater reaches to some degree to maintain their predominantly flat or convex profiles. This means that grade controls in 1st order streams and at their upstream junction with their headwater waterbodies are critical to maintaining their valley grade. Therefore, headwater waterbody to stream channel transitions are part of an ongoing study. Preliminary results show that most of these transitions unfold over distances of a few hundred feet with poorly defined or anastomosed channels that serve to dissipate hydraulic forces.

It is important not to overstate these general patterns in valley grade morphology because virtually every combination can be found at all orders. The diversity of Florida's valley profile shapes likely reflect the effects of intense vegetative controls that can resist grading in a low-relief landscape and the complex climatogenetics of the peninsula which have left behind a deranged network with lots of old marine scarps and dune lines to cross.

Valley segment length was defined as the distance along the valley centerline with an uninterrupted alluvial stream channel between two in-line waterbodies and/or stream junctions for each study reach. This variable represents the stream linkage length of the valley for chains-of-waterbodies formed by Florida's deranged stream networks. Valley segment length increased in association with drainage area for all three physiographies (Figure 3-13). This pattern is analogous to that of dendritic networks where stream segment lengths generally increase with drainage area as well (Strahler, 1957). In Florida, the frequency (and length) of punctuation by in-line waterbodies appeared to be inherently scale dependant on drainage basin area, perhaps because large-deep depressions, which are presumably less frequent than small-shallow depressions, are necessary to interrupt the continuity of larger stream channels. For example, derangement of headwater reaches was often provided by shallow seepage swamps and marshes a few acres in size, while derangement of Florida's major rivers was not caused by such wetlands, which the riverine hydraulic and sediment transport regimes can simply overwhelm. Therefore, riverine derangement was usually caused by large lakes a few thousand acres in size and several feet deep.

Valley segment length regressions versus drainage area did not differ in a statistically significant manner between flatwoods and highlands landscapes suggesting that their stream lengths are somewhat similarly organized in association with drainage area (Table 3-2). Conversely, karst systems exhibited statistically significant differences in slope from flatwoods systems and in intercept from highlands systems, suggesting that the artesian stream valley lengths may be organized differently.

The number of transitions within a valley per unit valley length (number per mile) was calculated for each reference reach. A transition was inventoried wherever a stream junction was formed, at in-line waterbodies, and at breaks between well-adjusted and unconfined valleys. Therefore, this variable could be viewed as an index of longitudinal valley complexity per unit length. The number of transitions per mile declined in association with drainage area for all three physiographies, but was not nearly as sensitive in highlands landscapes (Figure 3-14). This scale dependency is consistent with observations that streams draining larger watersheds receive sufficient quantities of water and sediment to re-work and grade their valleys more significantly than headwater systems which receive lower inputs of water and sediment. This means that colluvial factors remain more pronounced in the headwater positions.

This suggests that the complex climatogenetic history of the landscape may remain less altered by modern fluvial systems near their headwaters leading to longitudinally less graded and more complex valley forms. The regression slope for highlands valley transitions per mile versus drainage area was significantly different from those of karst and flatwoods landscapes (Table 3-2). Flatwoods and karst regions appeared to have similar regression slopes but statistically significant different intercepts. The consistently greater longitudinal complexity of spring run valleys implies that they are subject to more pronounced influences from colluvial geomorphology versus streams in the flatwoods.

The very different and more gradual regression slope for highland stream valleys, and its low R^2 of 0.14, suggests that colluvial factors may wield a heavier influence on their valley structure than fluvial and alluvial processes normally associated with increasing drainage area. Part this likely to be due to varying degrees of valley confinement caused by the relict dunescapes common in the highlands, as evidenced at several sites like Catfish Creek (illustrated on Figure 3-10). However, it appeared that the regression slope difference was influenced most heavily by the low order streams in the highlands having less longitudinal complexity than their counterparts in other landscapes. Most of these headwater highlands streams were greatly influenced by groundwater sapping, a powerful land-forming process that was absent from the karst and flatwoods headwater streams studied. Sapping leads to relatively straight, deep, and typically narrow seepage valleys that are confined to a narrow set of hydrogeologic conditions (including thick columns of sand in areas of high relief and copious groundwater seepage) (Schumm *et al*., 1995). They simply rarely, if ever, occur in flatter areas associated with complex in-line depressions. Highlands and karst streams draining larger watersheds seem to co-exist with more longitudinal valley complexity than their flatwoods counterparts, suggesting that colluvial influences may persist further along their drainage networks.

Lateral Valley Patterns and Landscape Associations

Valley bottom width generally increases with drainage area because larger streams require wider meander belts to accommodate their bigger migrating bends (Williams, 1986). Florida stream systems weakly comported with this general pattern, exhibiting much scatter across a regression of mean valley width versus drainage area for all three physiographies (Figure 3-15). This is consistent with the fact that deranged networks frequently create wide depressed valleys that sometimes streams can maintain their continuity through, depending on the relative depth of the deranging feature versus the magnitude of sediment and stream power available. The geologically mediated scatter is so great that no statistically significant differences in regression slope or intercept were detected among the three landscape classes for valley width versus drainage area (Table 3-2).

Four primary types of lateral valley configurations were observed among the sites studied and the dominant form was inventoried for each reach. The valley forms included seepage ravines, confined, well-adjusted and unconfined forms (Figure 3-16). Seepage ravines consist of relatively narrow sapping valleys. They were typically V-shaped and the meander belt was confined by either sandy upland hillslopes or mucky seepage swamp slopes. Overbank flooding is seemingly too rare to create a floodprone bench or floodplain.

Upland confined streams exhibited upland communities within a large fraction of the meander belt width. Much of the bankline and virtually every outer bend was in contact with or very close proximity to upland hillslopes. These systems exhibited limited signs of overbank flooding and often consisted of streams meandering through dense palmettos, with some wetland species occupying sporadic low-lying benches within the meander belt. Although Figure 3-16 illustrates an example with upland bluffs several feet high, the confining uplands often consisted of much lower hillslopes, especially in the flatwoods. Even a couple of feet increase in elevation can make for an upland confined channel in Florida.

In well-adjusted valley systems the majority of the meander belt was occupied by wetland communities generally subject to seasonal overbank floods that at least partially structure the valley floor. Many, but not all outer bends contacted or approached upland hillslopes, but most of the total bank length was bordered by wetlands. Essentially, well-adjusted valleys had meander belts coursing through wetland valley-flats that were typically bounded by upland hillslopes, although in some cases the hillslopes consisted of seepage wetlands. Well-adjusted streams often included textbook examples of fluvial systems predominantly under alluvial control as opposed to colluvial or geologic factors.

Unconfined meander belts occupied very wide flat valley flats that were much wider than the belt width. They tended to represent systems under significant geologic control or paleo-valleys where perhaps fluvial systems previously had much greater flow and sedimentation regimes than present. One type of unconfined stream valley included systems that were largely encompassed by low-lying colluvial wetlands that flood, not so much in response to overbank stream flow, but due to seasonally fluctuating local groundwater tables. The other type of unconfined valley included systems encompassed by alluvial wetlands with comparatively routine overbank flow and associated floodplain sedimentation from the stream discharge.

Significant differences in the distribution of valley confinement classes were observed among different Strahler stream orders (Pearson Chi-Square, p = 0.069; Likelihood Ratio, p = 0.025) (Figure 3-17). All four types of confinement were present along 1st and 2nd order streams, but only those with wetland flats subject to overbank flooding (well-adjusted and unconfined) were present in 3rd order and higher systems. Seepage ravines were most common in 1st order systems.

Significant differences in the distribution of valley confinement classes were observed among the different physiographic regions (Pearson Chi-Square, p = 0.062; Likelihood Ratio, p = 0.010) (Figure 3-18). Flatwoods systems lacked seepage regimes which were common in highlands and karst systems. Karst systems lacked upland confined streams, rather ubiquitously being flanked by extensive wetlands. This suggests that the karst valleys are more likely to have a history as infilled paleo-depressions as opposed to scoured colluvium. Highlands landscapes were the only physiographic division that exhibited all four types of valley confinement. This adds to the impression that highlands valley forms reflect a complex intersection of modern alluvial and relict geologic controls.

Significant differences in the distribution of dominant meander belt sediment or soil classes were observed among Strahler stream orders (Pearson Chi-Square, p = 0.016) (Figure 3-19). First order systems had the greatest overall diversity of sediment types reflecting their common contact with a variety of colluvial soils. Alluvial soil layers such as those consisting of finely stratified organic and inorganic layers were only present in the mid-order streams, implying that 1st and 2nd order systems have lower overall alluvial characteristics than higher order systems.

Significant differences in the distribution of dominant meander belt sediment or soil classes were observed among the different physiographies (Pearson Chi-Square, $p = 0.164$; Likelihood Ratio, $p = 0.029$) (Figure 3-20). Stratified layers were only present in flatwoods streams, suggesting that the less flashy groundwater fed systems less commonly generate sufficient power to deposit sand in their floodplains. Peat and mucky peat were largely absent from flatwoods valleys but were quite common for highlands and karst systems. This suggests that peat development requires rather constant seepage in Florida's riparian corridors with limited overall hydrologic flood and drawdown pulses. Muck (cohesive sapric histosols) and mucky sand were the only two classes found in all three physiographies, reflecting the rather widespread distribution of non-perennial wetlands in the riparian corridors of Florida.

Channel and Floodplain Hydraulics and Alluvial Features

In Florida's humid sub-tropical climate, year-round bioturbation, dry season oxidation of organic layers, a landscape dominance of fine sandy soils, and a lack of Fall leaf litter pulses can combine to obscure alluvial-organic soil layers that are commonly developed in temperate regions and that can serve as excellent verification of alluvial floodplain construction. Therefore, in addition to looking for such sediment lamellae, a variety of other alluvial features were inventoried within the stream channels and their floodplains to improve understanding of landscape characteristics associated with active alluvial processes. Features inventoried included sand bed ripples, induced scour pools, bend pools, point bars, sand shoals or riffles, natural bank levees, linear backswamps with fine textured sediments, floodplain chutes and secondary channels indicative of past avulsions, a ubiquitous valley flat with fine textured soils, sandy benches between bends, and oxbow lakes or ponds in the floodplain.

The number of alluvial features increased with drainage area substantially for flatwoods and highlands areas and rather modestly for karst systems (Figure 3-21). Differences among the regression constants were statistically significant among all pairwise comparisons of physiography (Table 3-2). Flatwoods and highlands regression slopes could not be statistically segregated, but karst differed significantly from both. The regression comparison suggests that alluvial features increase steadily with increased drainage area (perhaps in response to associated increases in water and sediment yields). The regression comparisons further suggest that the number of alluvial features were consistently higher for systems dominated by surface water flows versus those under the influence of groundwater flow regimes. The karst systems, clearly dominated by steady groundwater flow regimes, have comparatively limited alluvial features.

Flood and bankfull channels were determined at each reach using the best available and most reliable field indicators. The non-karst perennial streams studied were routinely overbank, often in excess of 25% of the year and generally fluctuated above bankfull stage at least several times during the year (Table 2-2). This situation is similar to many areas in the seasonal tropics which exhibit a channel-within-a-channel configuration and the wet-season or flood channel is typically heavily vegetated (Junk, *et al*., 1989). Flood channels were delineated in the field using a combination of biological and physical indicators including persistent stain lines, lichen lines on mature trees, moss collars on trees close to the bank, sharp palmetto lines at wetland boundaries, and the horizontal limits of finely textured soils on a valley flat. The flood channels identified in this manner generally flowed every year and the upper stage of the channel was reached typically once every 1.5 to 5 years (based on annual maximum series calculated by Blanton, 2008). The upper stage of the flood channels showed a lot more variability among sites when a partial duration series was used to calculate the exceedance frequency, but the most typical exceedance frequencies were right around once per year (Table 2-2). Basically, the flood channel represents the routine wet season channel with hydropattern thresholds associated with at least some of the sorting of the ecological communities in the floodscape. The flood channel hydraulics are expected to serve as a good indication of the capacity of the system to conduct relatively routine geomorphic work in the floodplain.

The ratio of flood channel to bankfull channel stream power provides a dimensionless index of the capacity for work that can be conducted in the floodplain versus that which the system more routinely provides within the main channel. Karst systems exhibited no trend in association with drainage area on this index, but highlands and flatwoods streams did and were accordingly depicted on Figure 3-22. The regression constant was statistically different but the regression slope was not. This implies that flatwoods systems produce consistently larger flood flow work compared to highlands streams draining similarly dimensioned watersheds.

Flatwoods landscapes were also associated with proportionally wider floodplains versus those draining the highlands in a regression comparing the width of the flood channel to the width of the bankfull channel versus drainage area (Figure 3-23). The regression constant was statistically significantly different but the regression slope was not (Table 3-2). This association does not necessarily demonstrate cause and effect in a deranged network, but when viewed together with other factors such as the increased number of alluvial features for flatwoods systems over highlands and the increased flood to bankfull power ratio, it seems to add credence to the concept that flatwoods systems generate more routine floods that conduct more work in their floodplains than their highlands counterparts draining watersheds of similar size. The flatwoods sites exhibit disproportionately large flood channels compared to their bankfull channels versus those of the highlands. This is because bankfull discharges are similar in both types of watersheds, but that the larger spates of the flatwoods are necessarily accommodated by larger (wider) flood channels.

Montgomery and Buffington (1997) characterized mountain streams as self-adjusting systems that achieved channel dimensions and roughness conditions necessary to balance sediment transport capacity with supply under a variety of valley slope conditions. To achieve this balance, channel resistance (roughness) was necessarily higher in areas with steeper valley slopes and low sediment supply. In the mountainous regions studied, roughness coefficients were associated with the size of rocky bed materials. Even in comparatively flat, sandy Florida, convergent principles seem to apply. The roughness mechanisms differ as they are largely induced by living vegetation and logs in Florida in lieu of rocks, but nevertheless, increased roughness occurs in association with increased valley slope (Figure 3-24). No statistically significant differences were detected on the regression constant or slope between flatwoods and highlands streams (Table 3-2). Manning's n in karst streams exhibited no association with valley slope.

Conclusions

Application of Clinal and Functional Process Zone Concepts

Florida's deranged stream networks appeared to have an underlying self-adjusting and clinal structure similar to that of many dendritic and alluvial watersheds around the world with tendencies toward development of graded profiles, increasing stream order and magnitude with drainage area, increasing channel and floodplain dimensions with drainage area, increased meander belt widths with drainage area, increasing alluviation with drainage area, greater colluvial contact in the headwaters, and the development of more channel resistance with increasing valley slope. It is important to be aware of these patterns. Some forms of floodplains simply cannot be supported in the headwater reaches, especially those dependent on alluvial deposition.

However, these general patterns often exhibited many local exceptions and lots of scatter due to Florida's intense sub-tropical vegetative controls and how they interact with groundwater flow regimes (see Chapter 2). Complexities also arose due to a long history of differential solution weathering that has formed many doline depressions in the landscape, some of which interrupt the continuity of channel systems leading to description of the network as being deranged. Furthermore, the multiple partial inundations of the peninsula by sea water have created a complex array of relict marine terraces and dune lines that collectively break up clinal patterns toward concavely graded profiles and increasingly wider floodplains with increased drainage size. Numerous punctuations in the drainage network occurred due to in-line depressions and sudden and repeated transitions in valley width and slope inflections occurred frequently. The geologic controls were not completely chaotic as evidenced by the fact that channeled valley lengths between interrupting waterbodies increased with drainage size.

Any useful characterization of Florida’s stream systems must take into account fluvial and vegetation controls operating under the modern climate which are nominally clinal processes and must also consider the geologically-oriented punctuations that add seemingly chaotic elements to the valley structure. To ignore either kind of control would lead to oversimplified solutions for conserving, managing, or restoring small streams in the Florida. For that reason, use of FPZ concepts are strongly encouraged, because these readily and naturally accommodate repeated and punctuated conditions without abandoning important clinal considerations. Which dominates is a matter of spatial scale. Clinal patterns are unlikely to be obvious except if one were to rapidly travel long distances along any given drainage network. Sudden changes in grade, valley width, and in-line waterbodies form ecotonal boundaries that are rather obvious when traversing even a short distance along the network. Under such short distances any overall graded pattern along the valley is obscured. It seems likely that most stream restoration practitioners will end up working on local scales. To prescribe appropriate earthwork and vegetation, they will want to know what palette of valley and channel associations to draw from and to do so will need to know their position along the fluvial system’s clinal gradient. Even though Florida’s complex stream system genesis allows for a fair amount of abrupt change, some combinations of geomorphology and vegetation just do not make much sense and are unlikely to be self-sustaining. The position of the stream in the drainage network is associated with its likelihood to be in a zone of excess sediment transport capacity and net export (most headwater streams), mixed transport/deposition zones (most mid-order well-adjusted streams), or a predominantly depositional floodscape (most mid- to higher order well-adjusted or unconfined streams).

Descriptions of Valley Types and Their Landscape Associations

Several combinations of valley processes and form associations can be inferred from the data. The relative amount of groundwater and surface water dominance appeared to greatly associate with valley process and related form. Although there was overlap in valley types among flatwoods, highlands, and karst landscapes, some types were less common or even absent from particular physiographies. Furthermore, the scale dependencies of common processes and associated valley forms differed among these three physiographies. It is probably a good idea to view these hydrogeomorphic landscapes as the first hierarchy of consideration.

The second consideration is a matter of position along the drainage network as it relates to sediment and water yields that are sensitive to drainage area. These factors directly affected the scale and form of the stream channel and its floodplain. Different processes dominated along this gradient as well. Riparian soil and vegetation community patches were associated with the different hydrology zones that these scale-dependant processes formed, such as sandy bank levees, mucky linear backswamps, sandy chutes or secondary channels with detritus, oxbow lakes, sandy islands, and silty mucky valley flats. Each of these alluvial features tends to support niche requirements of different groups of vegetation and, presumably, different meta-populations of aquatic and terrestrial fauna (Thorpe *et al*., 2008). For example, Blanton (2008) observed that cypress dominated bottomlands occupied valleys with extensive alluvial flats or linear backswamps and cypress trees were largely absent from the more entrenched (colluvial) stream valleys in the landscape. Palmettos and live oaks were generally only encountered on systems with confined upland meander belts or on natural sandy levees or islands. The third consideration is local lateral valley confinement. Confinement can influence local hydraulics and allows for spatially variable contact with colluvial inputs of sediment and chemicals with the stream. Some types of valley confinement are also scale dependant. The various apparent scale dependencies and their interactions with physiography led to several common types of valley Functional Process Zones that were observed during this study and that became even more apparent after evaluation of these data.

These types of observations revealed several basic types of colluvial versus alluvial valleys occupied by Florida streams. The positions of these systems in the drainage network (in association with drainage area) seemed to differ among the physiographic regions (Figure 3-25). For example, Tiger Creek drained a 53 square mile highlands watershed and had created an alluvial valley flat about 150 feet wide, while Tenmile Creek drained a flatwoods basin three times smaller and had created a similarly dimensioned alluvial valley flat. The Manatee River drained a flatwoods watershed more similar in size to that of Tiger Creek and had a substantially more complex, wider and deeper floodscape. Note that even the 86 square mile watershed of the Weeki Wachee River spring run failed to produce an alluvial valley rivaling that of the 17 square mile Tenmile Creek of the flatwoods. These examples illustrate the normal propensity of runoff dominated watersheds to produce more alluvial work and complexity in bigger flood channels for a given basin size versus those of the less flashy groundwater systems. Note also the comparatively high bluffs present in all three highlands valley examples. These did not occur for all highlands stream segments, but most highlands valleys included at least portions of their shoreline with such geomorphic features, while such bluffs were comparatively rare in the flatwoods, generally only occurring where larger streams cross old marine terrace lines.

Valleys where alluvial processes and forms were almost completely limited to the stream channel bed and their meander belt were dominated by soils and landscape features not created by modern alluviation were deemed to be colluvial valleys. Colluvial valleys included seepage ravines, upland-confined channels, and wetland-confined channels. Seepage ravines are V-shaped or U-shaped valley cross-sections that promote lateral seepage to the stream channel and the groundwater discharge is sufficient to support sloped wetland communities such as bay swamps (Figure 3-26). No alluvial floodplain is present. In some cases, the lateral extent of the seepage slope wetland can be several hundred feet wide, but in many cases it is much smaller, as little as 20 feet.

Upland-confined channels meander through upland valleys where the wetland boundary closely corresponds to the channel banks. A common setting for this arrangement includes the headwater and low-order positions of streams of the flatwoods that form chains of wetlands (Figure 3-27). These systems are bordered by either pine and palmetto savannas or by mesic hardwood gallery forests that lack a floodplain, but sometimes have small bankfull benches along the inner portions of bends with shrubby or forested wetland species inclusions.

Wetland-confined channels meander through shallow depressed areas subject to flooding or prolonged saturation where it occurs long enough to support a variety of wetland types, usually hardwood swamps or hydric palm/pine hammocks and less commonly freshwater marshes, wet prairies, or cutthroat grass swales (Figure 3-27). These wetlands do not include alluvial features or soils and therefore appear likely to be receiving most of their water from non-fluvial sources. In other words, these colluvial areas would be wetlands irrespective of the presence of the stream and the stream network serves primarily as a downhill exporter of water from the wetland rather than an overbank source to it.

Valleys where alluvial processes and forms appeared to directly influence soils and landscape features within the meander belt were deemed to be alluvial. These valleys included well-adjusted floodplains and unconfined floodplains. Well-adjusted floodplain valleys have a channel meander belt that is very close in typical width to the width of the valley flat, and the meander belt is confined by upland hillslopes, or sometimes by seepage slopes (Figure 3-28). These streams are well-adjusted to their valleys, generally meandering across the entire valley floor. As a result of channel migration and overbank deposition of sediments, the valley floor is populated by alluvial features. The outer channel bends frequently are bordered by uplands on the valley slope and wetlands border most of the channel elsewhere. The floodplain is almost always a wetland. Some systems have large portions of their outer bends flanked by upland bluffs rather than just the apex of the bend. This represents a condition intermediate between upland confined and well-adjusted systems that may warrant its own designation, but for now these systems were categorized as well-adjusted. Most well-adjusted alluvial bottomlands present more than one alluvial feature type and can be vegetated by a variety of plant communities, mostly hardwood or cypress bottomland swamps, with inclusions of hydric or mesic palm, pine or oak hammocks. Sediments can consist of various combinations of sandy alluvium, fine-textured alluvium, and cohesive black muck. These sediments can sometimes occur in layers, often with detrital inclusions, but they generally sort into features roughly parallel to the valley's long axis such as channel levees, linear backswamps, and oxbow lakes.

Unconfined channels meander through very wide valley flats compared to their meander belt width (Figure 3-29). These are essentially portions of streams unconfined by the geologic history of the segment. Unconfined valleys can be alluvial or non-alluvial depending on their position in the landscape and its associated sediment yield. Where they were colluvial, they were referred to as the "wetland confined channels" described earlier and where they were alluvial, they were called "unconfined floodplains." Unconfined floodplains can be dominated by a single alluvial feature such as a flat valley fill canopied by mixed cypress and bottomland hardwood swamp species growing on a fine-textured (silty) and mucky alluvial soil, or they can be occupied by a diverse array of sandy versus mucky alluvial features forming a comparatively rough bottomland that presents a variety of relatively dry and deep water habitats.

These five valley types (seepage ravines, upland-confined channels with colluvial valleys, wetland-confined channels with colluvial valleys, well-adjusted alluvial valleys, and unconfined alluvial valleys) represent landscape level sorting of sediment transport regimes and resultant geomorphic features. Cluster analysis and principal components analysis were used to further interpret the valley variables to determine how to best use them in a stream classification system in Chapter 4. Although some valley types alternated with each other in various combinations along the drainage network, they appeared to have strong associations with particular positions in the drainage network. For example, the V-shaped seepage valleys of most root-step streams were confined to the colluvial hillslopes of headwater seepage areas in highlands physiography. The alluvial floodplain characteristics increased with drainage area for blackwater streams, seemingly because more sediment is available for transport and there is more water available to carry and deposit it in a downstream direction along the drainage network.

Research Needed

Very little systematic and detailed studies of the fluvial geomorphology of low- to mid-order components of warm-climate deranged drainage systems have been made. As a result, preliminary studies of tropical deranged networks are underway using high-resolution aerial photography. Initial results suggest a relatively high presence of derangement of savanna drainage networks compared to those in tropical arid zones and rainforests. The fluvial geomorphology and related hydroecology of warm-climate deranged networks likely warrants systematic research to determine if any common processes are involved or if this is merely an example of convergence of form.

Comparative hydrobiological studies should be made to determine the ecological relevance of various valley forms, if any, to the aquatic fauna and flora of Florida's riparian corridors. Studies emphasizing fish and phytoplankton are especially needed given the paucity of data on the occurrence, seasonality, and spatial distribution of such biota along Florida riparian corridors. The FDEP has extensively studied macroinvertebrates in Florida streams, going to great lengths to develop what they believe is a scale-independent index of biological integrity (Fore *et al*., 2007). Further research is needed in the opposite vein to determine what, if any, factors related to macroinvertebrate species composition and productivity differ among FPZs. It seems that differences in the magnitude and frequency of longitudinal and lateral hydraulic connections among different FPZs should affect the aquatic fauna.

Related nutrient fluxes or spiraling also warrant further research to help identify potential differences in water quality and trophic functions among FPZ's. Such fluxes may provide clues related to the natural buffering capacity of groundwater versus surface water dominated systems and the widely varying organic content of their floodscape soils. For example, it could be hypothesized that in the headwaters, organic-rich seepage valleys would process nitrogen compounds differently from flatwoods valleys with sandy soils right up to the channel banks. If such differences in nutrient assimilative capacity exist, agricultural and development buffers would necessarily differ as a function of which type of headwater stream corridor is present to assure similar levels of protection for stream water quality and associated trophic status.

Table 3-1. ANOVA summaries

Variable	Factor	N	Mean	SE	Sig.	ANOVA test, pairwise procedure
Flatwoods DA*	1st order	7	0.8	17.8	A	Two-way ANOVA, Holm-Sidak
	2nd order	9	17.9	15.7	B	
	Mid-order	7	115.6	17.8	C	
Highlands DA*	1st order	10	7.0	14.9	A	Two-way ANOVA, Holm-Sidak
	2nd order	8	13.2	16.6	B	
	Mid-order	3	88.2	27.1	C	
DA*	FW	23	44.8	9.9	A	Two-way ANOVA, Holm-Sidak
	HL	21	36.1	11.7	A	
	K	12	54.5	19.9	A	
Drainage density	FW	23	2863.1	313.8	A	Kruskal-Wallis ranks, Dunn
	HL	21	2459.7	418.5	AB	
	K	12	1381.8	511.5	B	

Sig. = significant differences between physiographies with different letters ($p < 0.05$).
SE = standard error. FW = flatwoods, HL = highlands, K = karst.
*Log-10 transformation was used to meet assumptions for normality & equal variance.
DA = drainage area (square miles).
Drainage density = feet of stream per square mile.
Orders based on Strahler method (Mid-order is 3rd, 4th and 5th orders).

Table 3-2. Regression summaries

Variables		B constant			p > F			B slope			p > F		
IV	DV	FW	HL	K	FW HL	K HL	K FW	FW	HL	K	FW HL	K HL	K FW
Log(DA) ctr	Log(Magn)	0.597	0.418	0.096	0.054	0.005	0.000	0.553	0.373	0.189	0.071	0.166	0.006
	SE------->	0.062	0.091	0.108	NS	SIG	SIG	0.064	0.098	0.125	NS	NS	SIG
Log(DA) ctr	Log(MBW)	1.952	1.844	1.790	0.045	0.394	0.012	0.280	0.354	0.493	0.197	0.070	0.005
	SE------->	0.036	0.052	0.062	SIG	NS	SIG	0.037	0.056	0.072	NS	NS	SIG
Log(DA) ctr	Log(VSS)	-0.754	-0.546	-0.884	0.005	0.000	0.131	-0.364	-0.536	-0.444	0.029	0.371	0.421
	SE------->	0.071	0.052	0.086	SIG	SIG	NS	0.076	0.058	0.102	SIG	NS	NS
Log(DA) ctr	Log(LVS)	3.524	3.661	3.272	0.207	0.004	0.053	0.322	0.464	0.701	0.225	0.130	0.014
	SE------->	0.073	0.107	0.127	NS	SIG	NS	0.075	0.115	0.148	NS	NS	SIG
Log(DA) ctr	Log(Trans)	0.154	0.194	0.550	0.713	0.010	0.004	-0.569	-0.153	-0.499	0.001	0.033	0.647
	SE------->	0.109	0.080	0.133	NS	SIG	SIG	0.118	0.089	0.158	SIG	SIG	NS
Log(DA) ctr	Log(VW)	2.583	2.485	2.360	0.429	0.860	0.399	0.331	0.362	0.563	0.085	0.262	0.856
	SE------->	0.084	0.123	0.146	NS	NS	NS	0.086	0.170	0.132	NS	NS	NS
Log(DA) ctr	(TAlluv)	4.805	3.664	1.023	0.006	0.000	0.000	2.101	1.954	0.718	0.735	0.038	0.016
	SE------->	0.401	0.293	0.488	SIG	SIG	SIG	0.432	0.327	0.579	NS	SIG	SIG
Log(DA) ctr	Log(RPower)	0.648	0.439	--	0.007	--	--	0.220	0.117	--	0.197	--	--
	SE------->	0.050	0.073	--	SIG	--	--	0.051	0.078	--	NS	--	--
Log(DA) ctr	Log(RWidth)	0.950	0.436	--	0.000	--	--	0.359	0.300	--	0.617	--	--
	SE------->	0.074	0.108	--	SIG	--	--	0.076	0.116	--	NS	--	--
Log(VS) ctr	Log(n)	-1.080	-1.013	--	0.322	--	--	0.390	0.352	--	0.795	--	--
	SE------->	0.047	0.067	--	NS	--	--	0.123	0.147	--	NS	--	--

Log = log10 transform, ctr = variable centered, NS = $p > 0.05$, Sig = $p < 0.05$, SE = standard error.
FW = flatwoods, HL = highlands, K = karst.
DA = drainage area, Magn = Shreve's order, MBW = meander belt width, VSS = valley segment slope%.
LVS = length of the valley segment (ft), Trans = no. of transitions per valley mile, VW = valley width (ft).
TAlluv = total alluvial features, RPower = ratio of flood/bankfull stream power.
RWidth = ratio of flood/bankfull channel width, n = Manning's friction factor, VS = reach valley slope%.

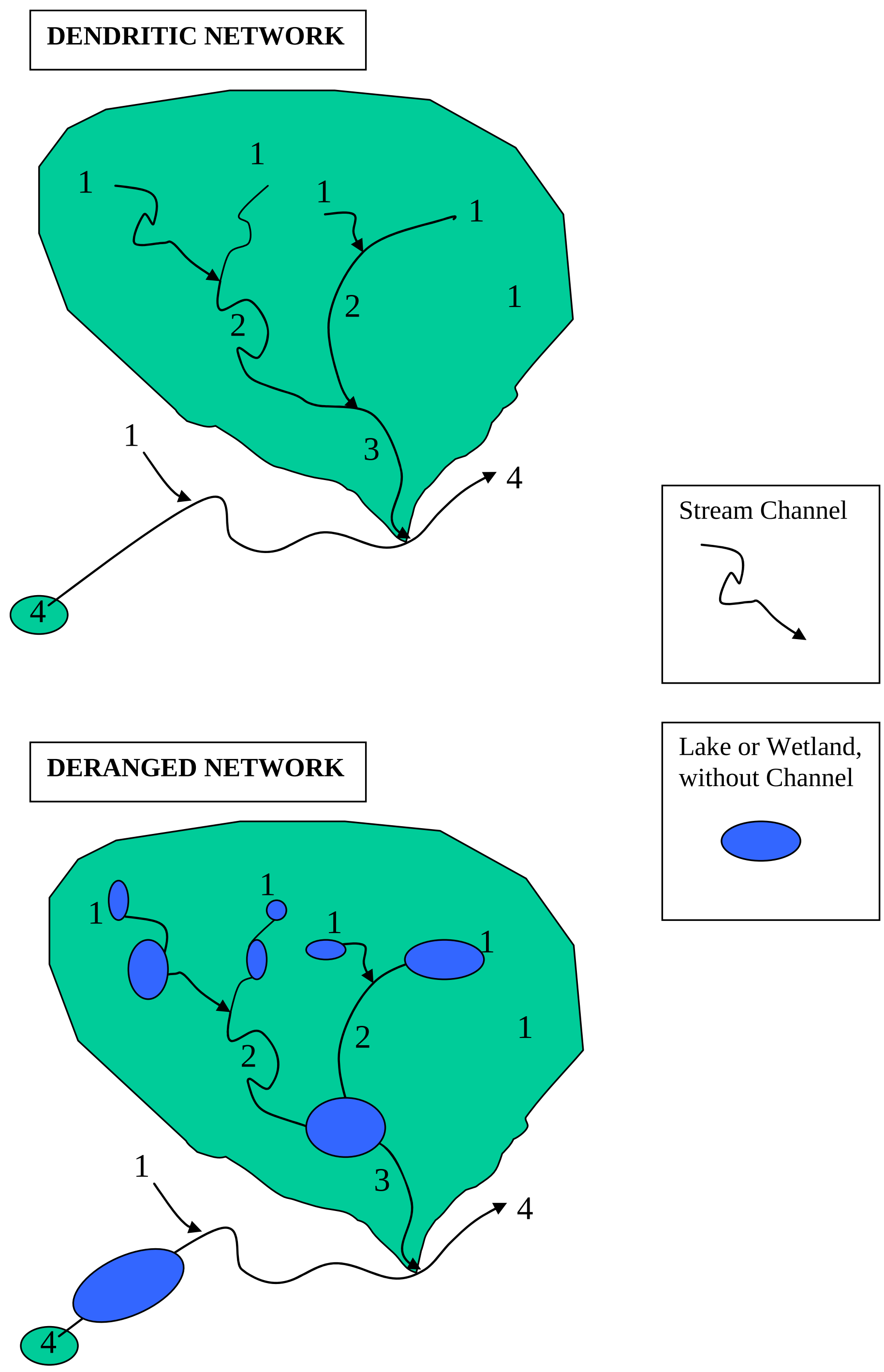


Figure 3-1. Dendritic and deranged drainage networks with example of Strahler's (1957) ordering system.

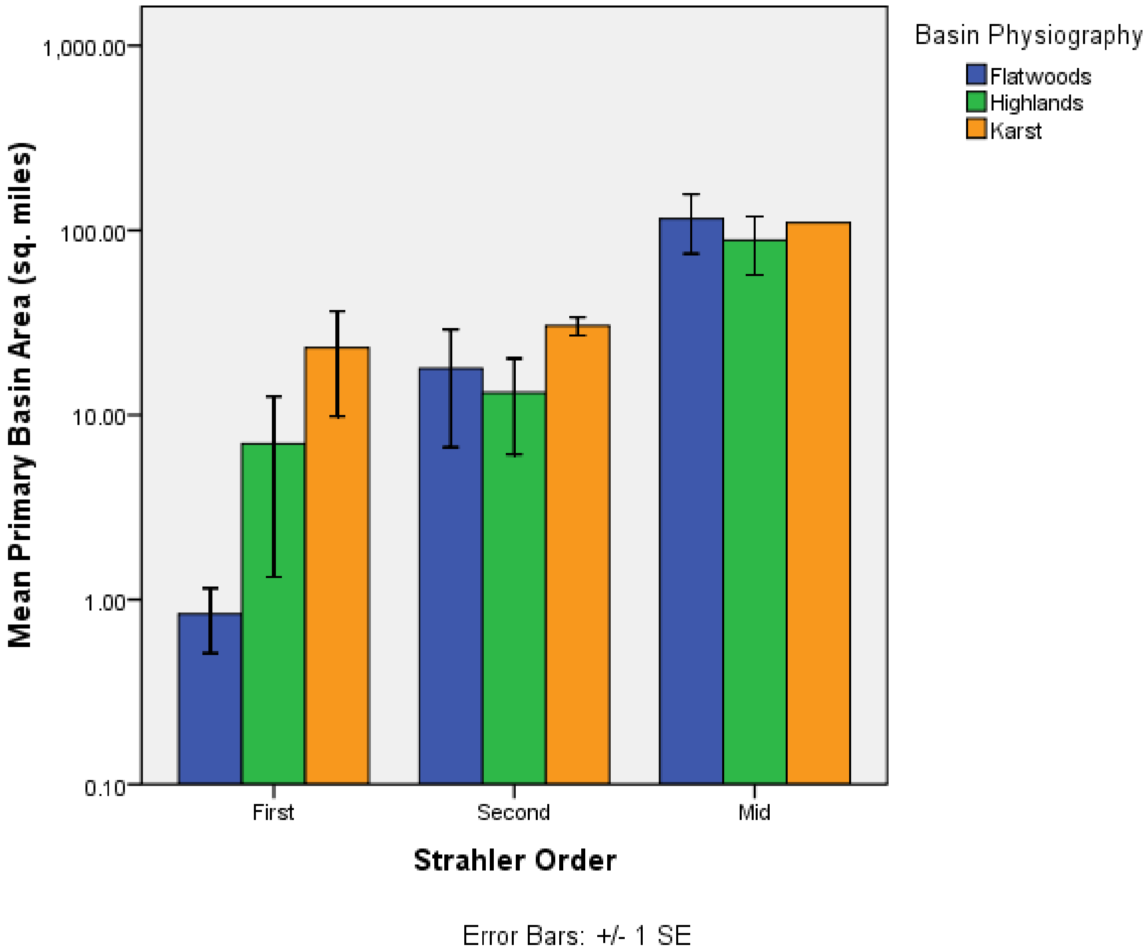


Figure 3-2. Drainage area associated with stream order for three physiographic regions.

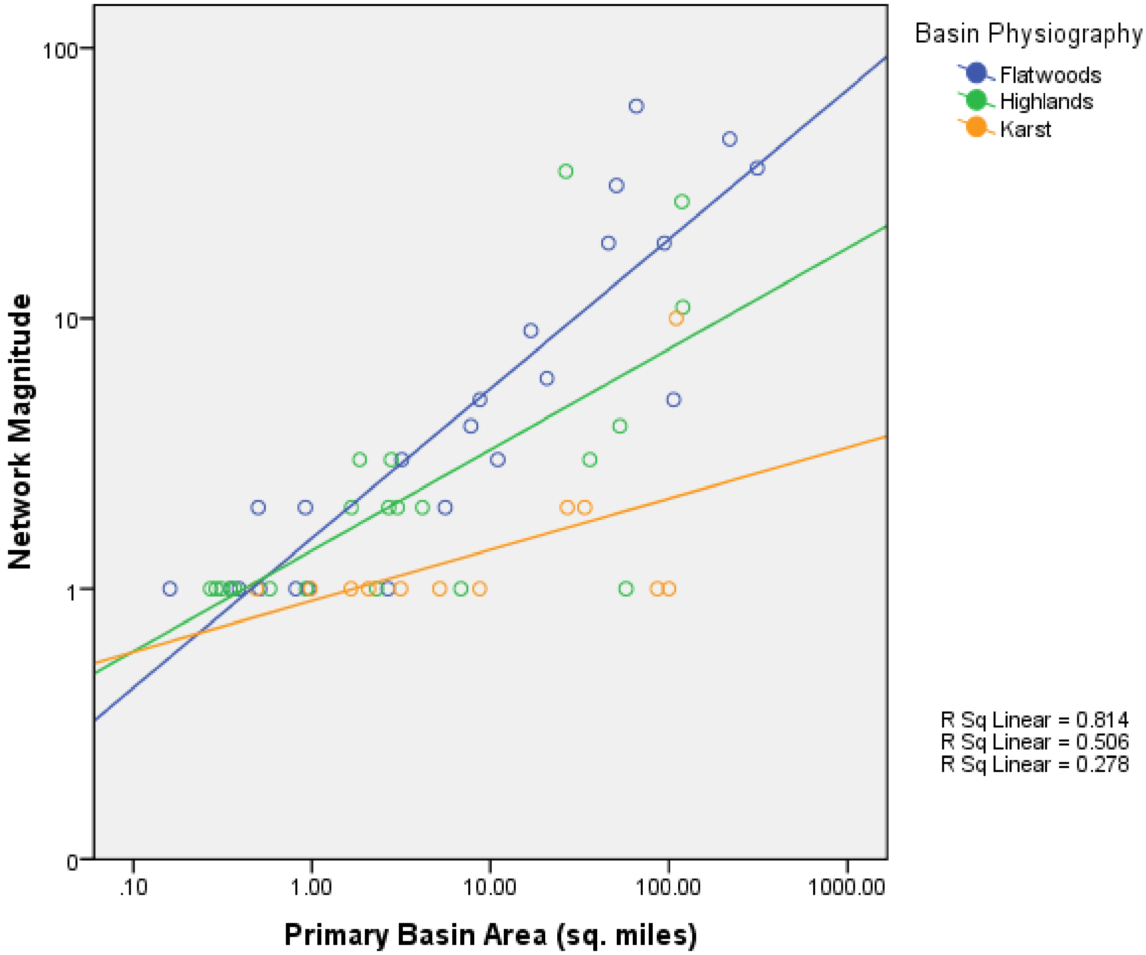


Figure 3-3. Shreve (1966) cumulative network magnitude versus drainage area for three physiographic regions.

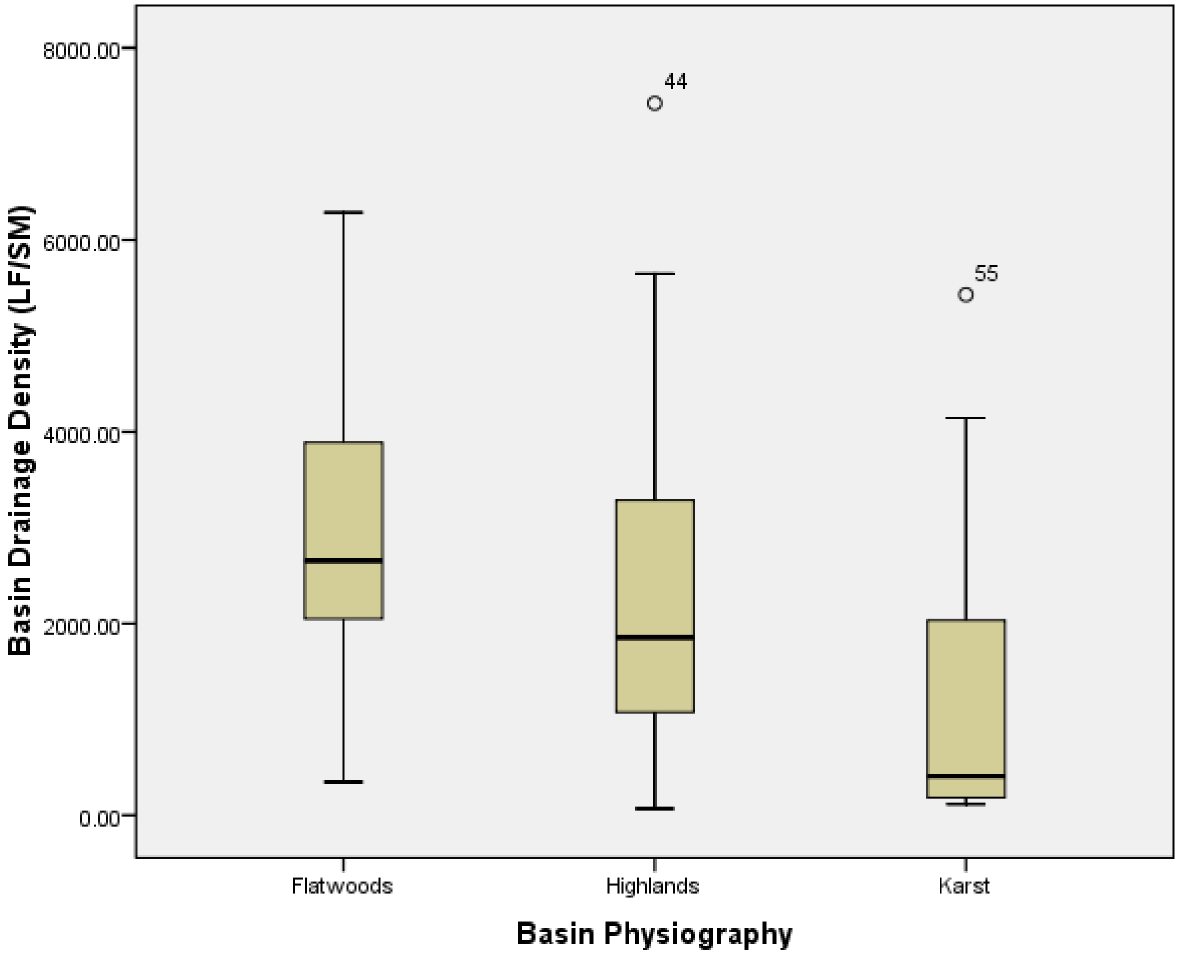


Figure 3-4. Drainage density associated with stream order for three physiographic regions. Drainage density calculated from the National Hydrographic Database of perennial and intermittent streams.

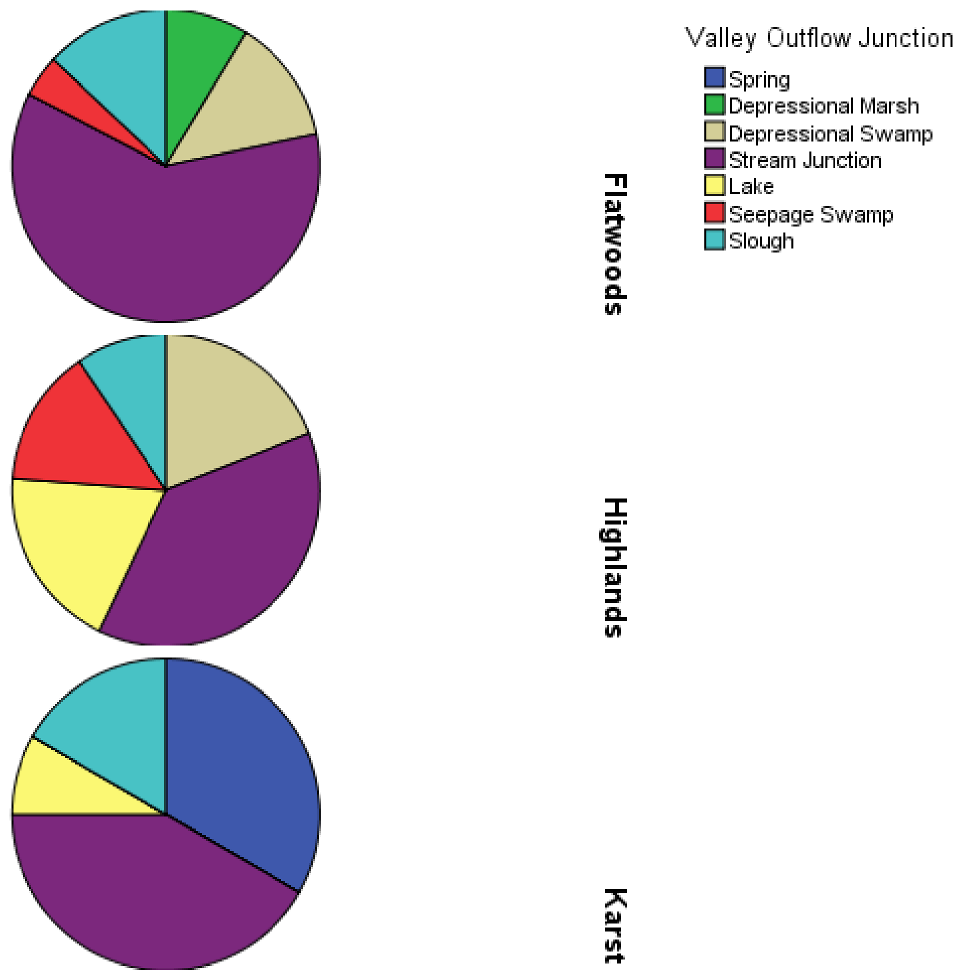


Figure 3-5. Proportions of waterbody type occurring downstream of the channel reach for three physiographic regions.

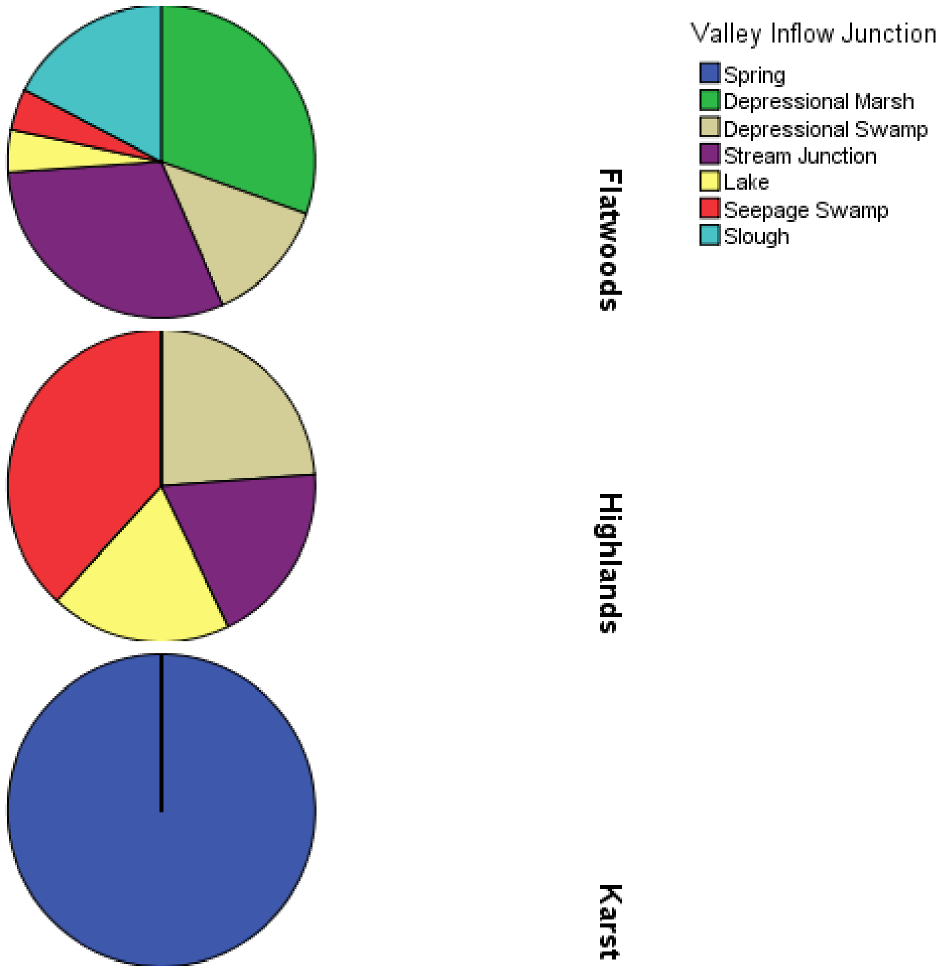


Figure 3-6. Proportions of waterbody type occurring upstream of the channel reach for three physiographic regions.

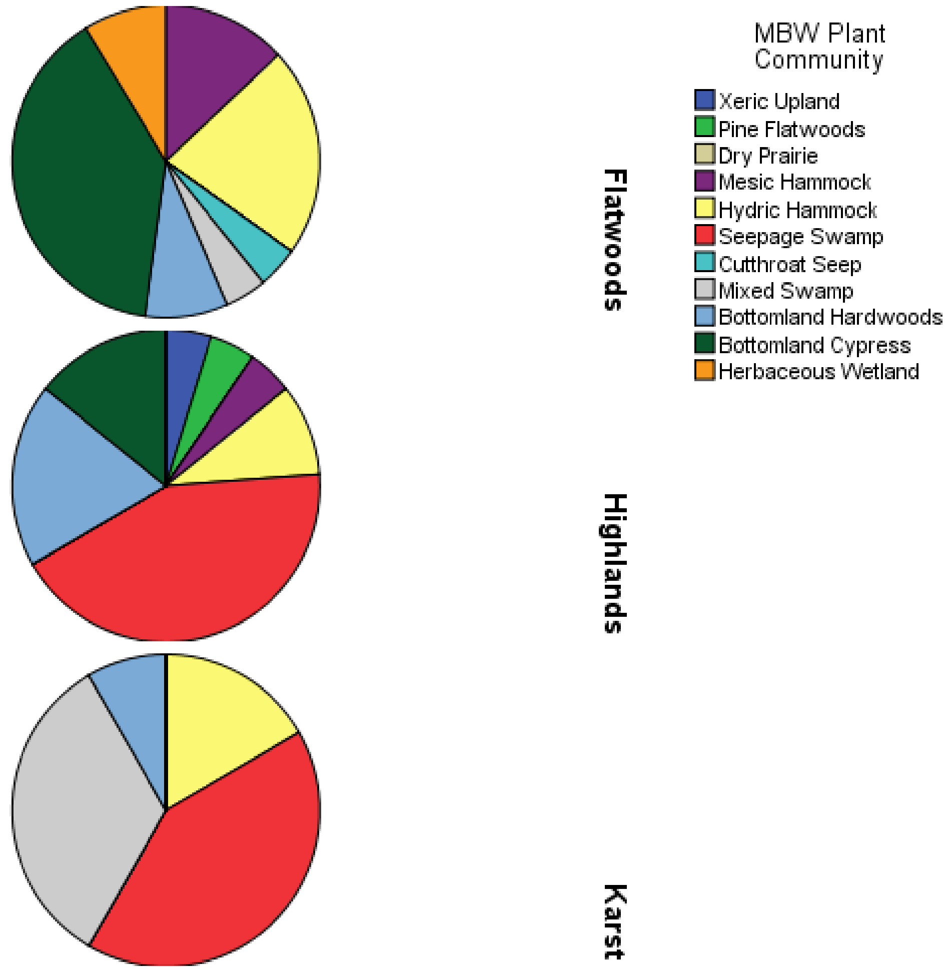


Figure 3-7. Proportions of riparian wetland type dominant in the channel meander belt for three physiographic regions.

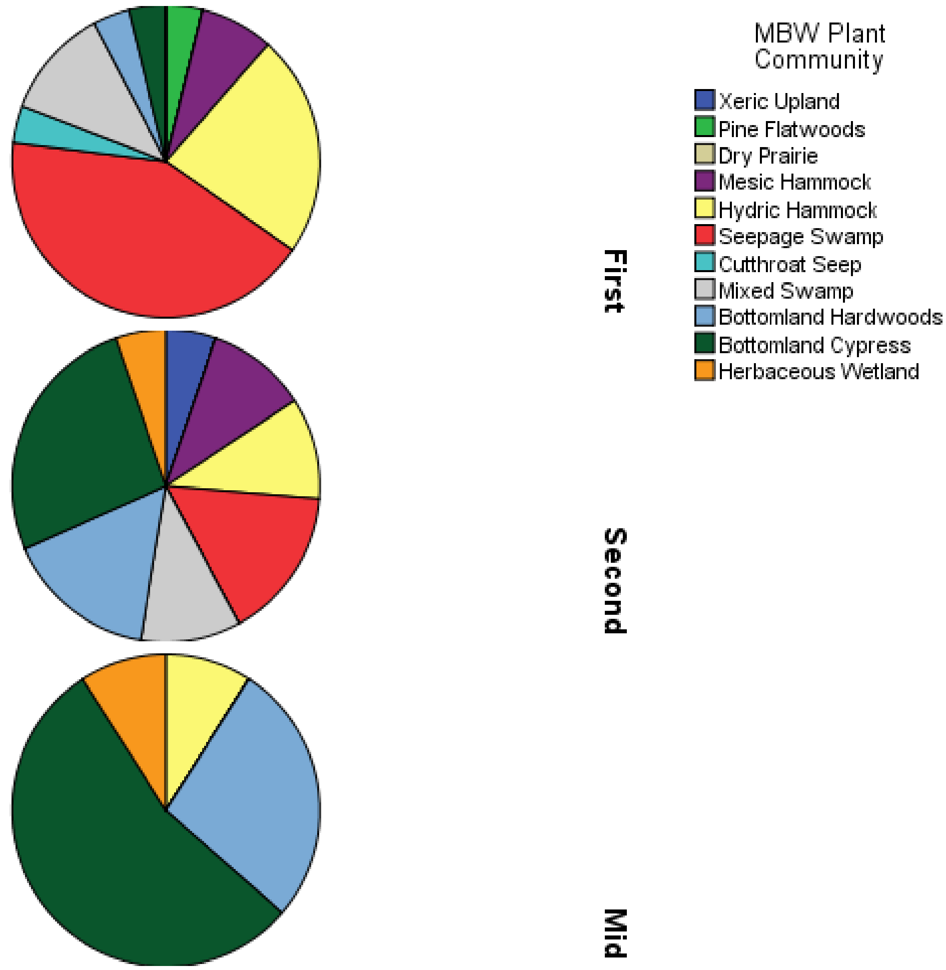


Figure 3-8. Proportions of riparian plant communities dominant in the channel meander belt by Strahler stream order.

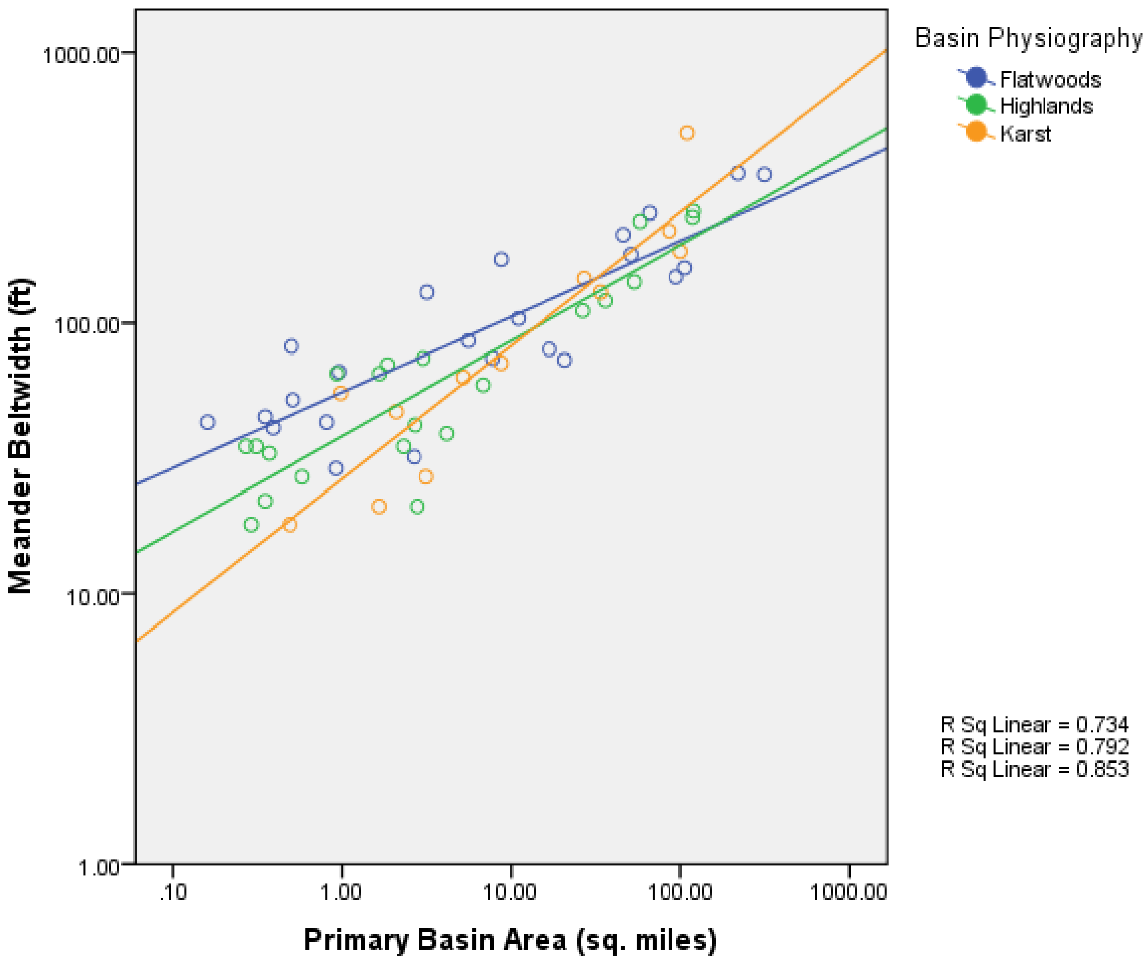


Figure 3-9. Meander belt width versus catchment area for three physiographic regions.

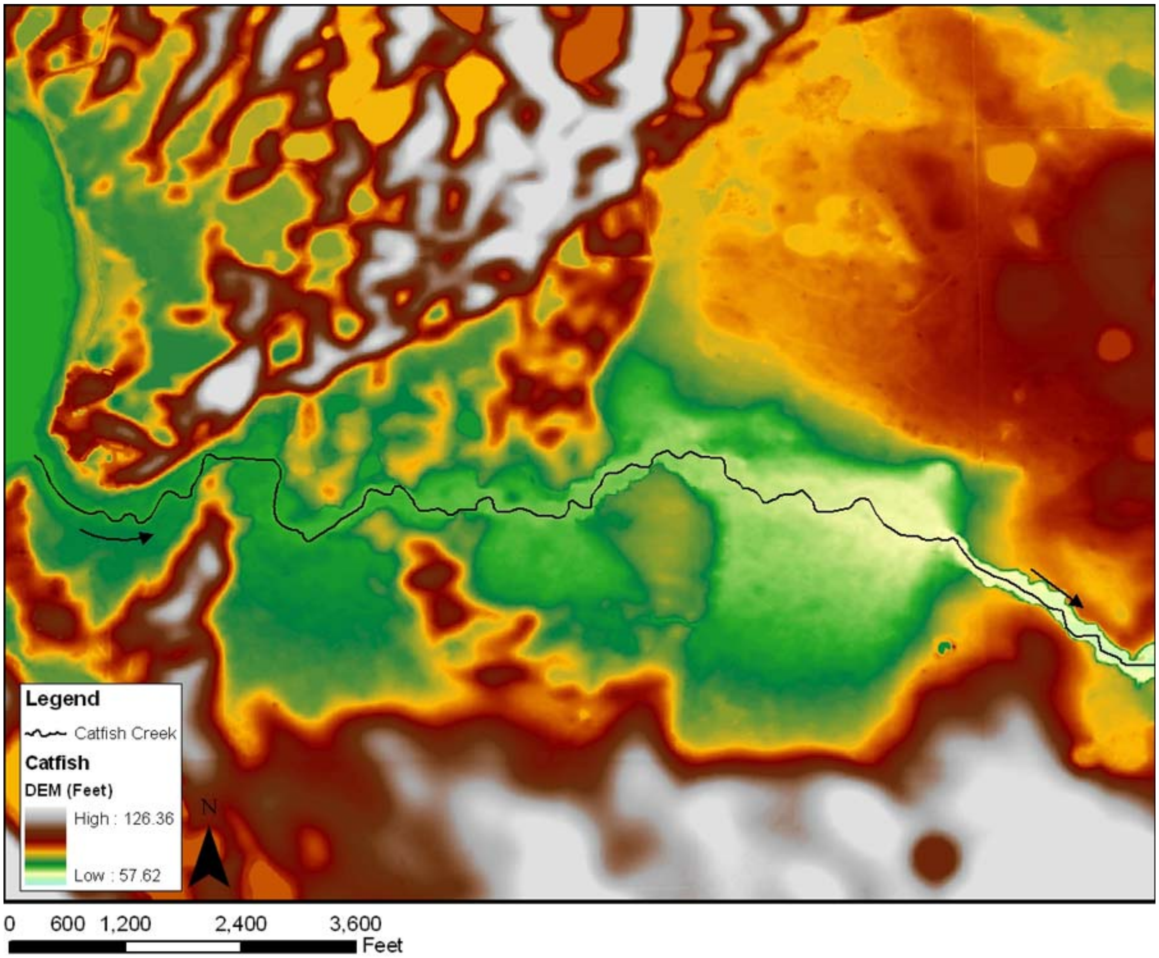


Figure 3-10. Catfish Creek stream channel with alternating unconfined and well-adjusted meander belts.

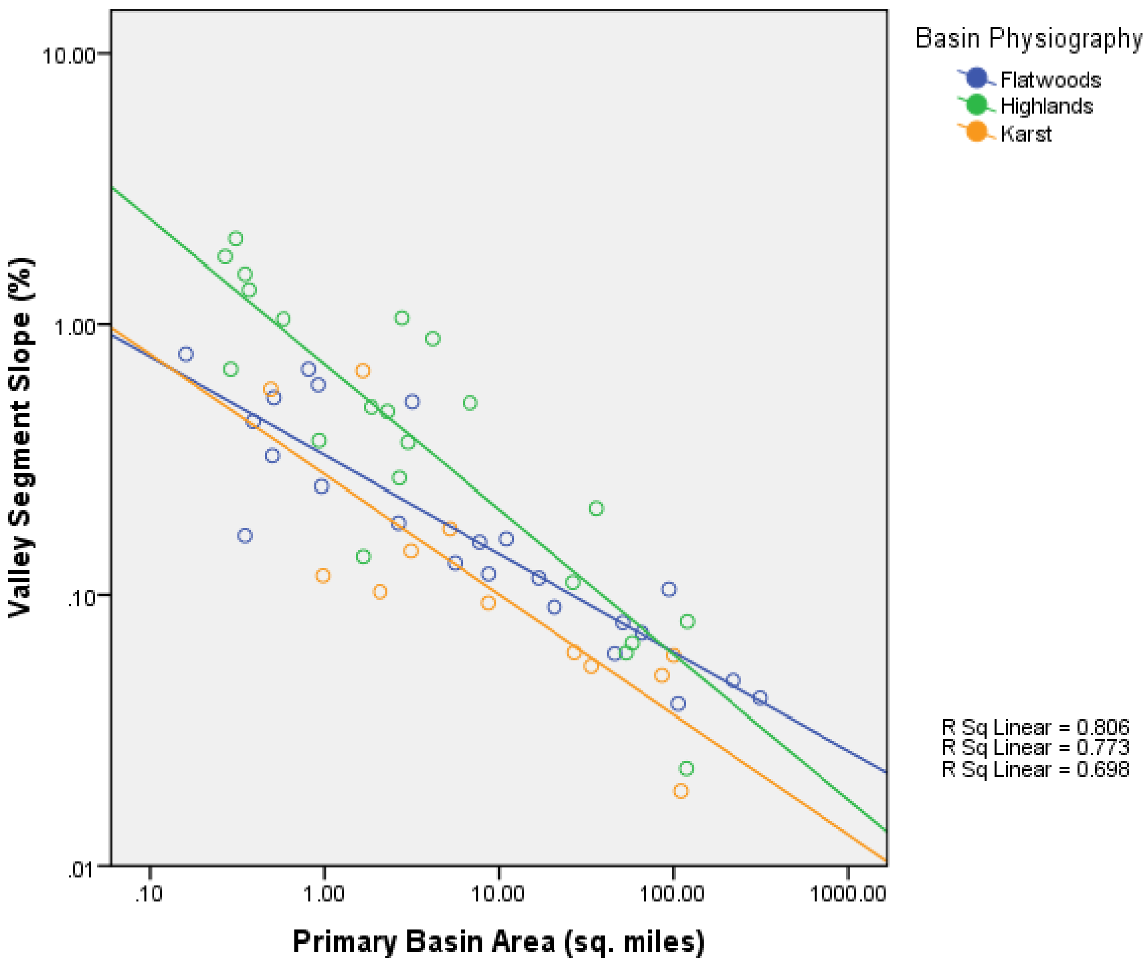


Figure 3-11. Valley slope versus drainage area for three physiographic regions.

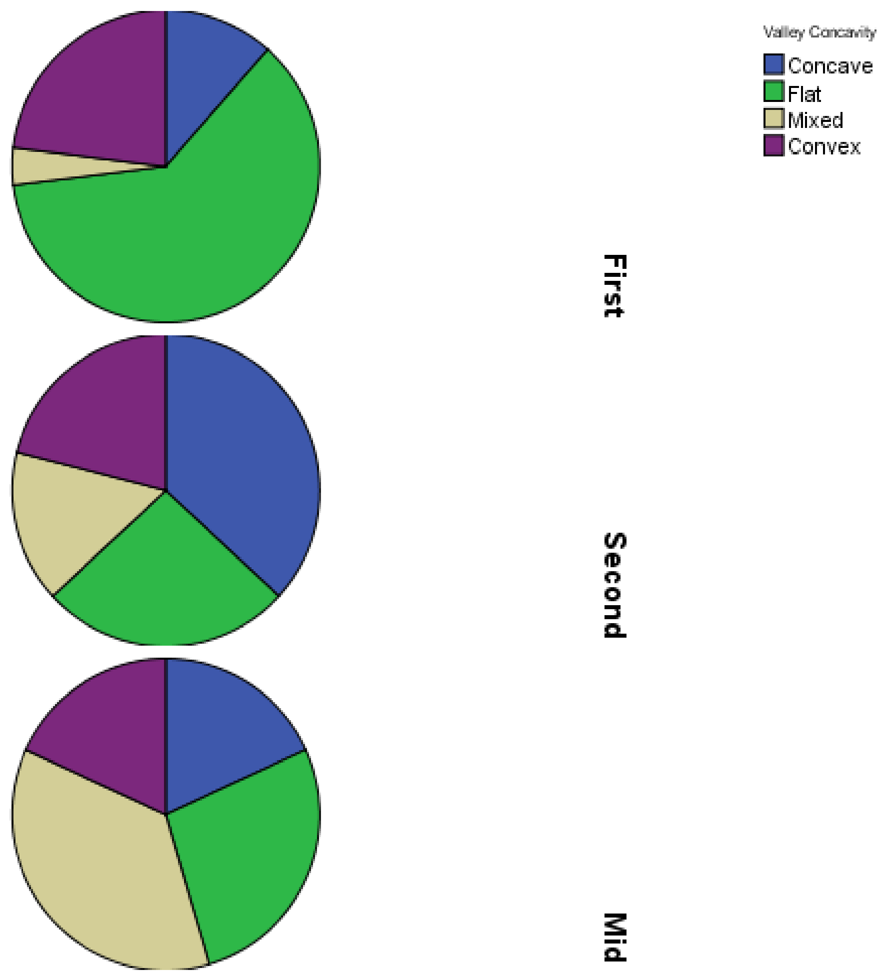


Figure 3-12. Longitudinal valley shape distribution by Strahler stream order.

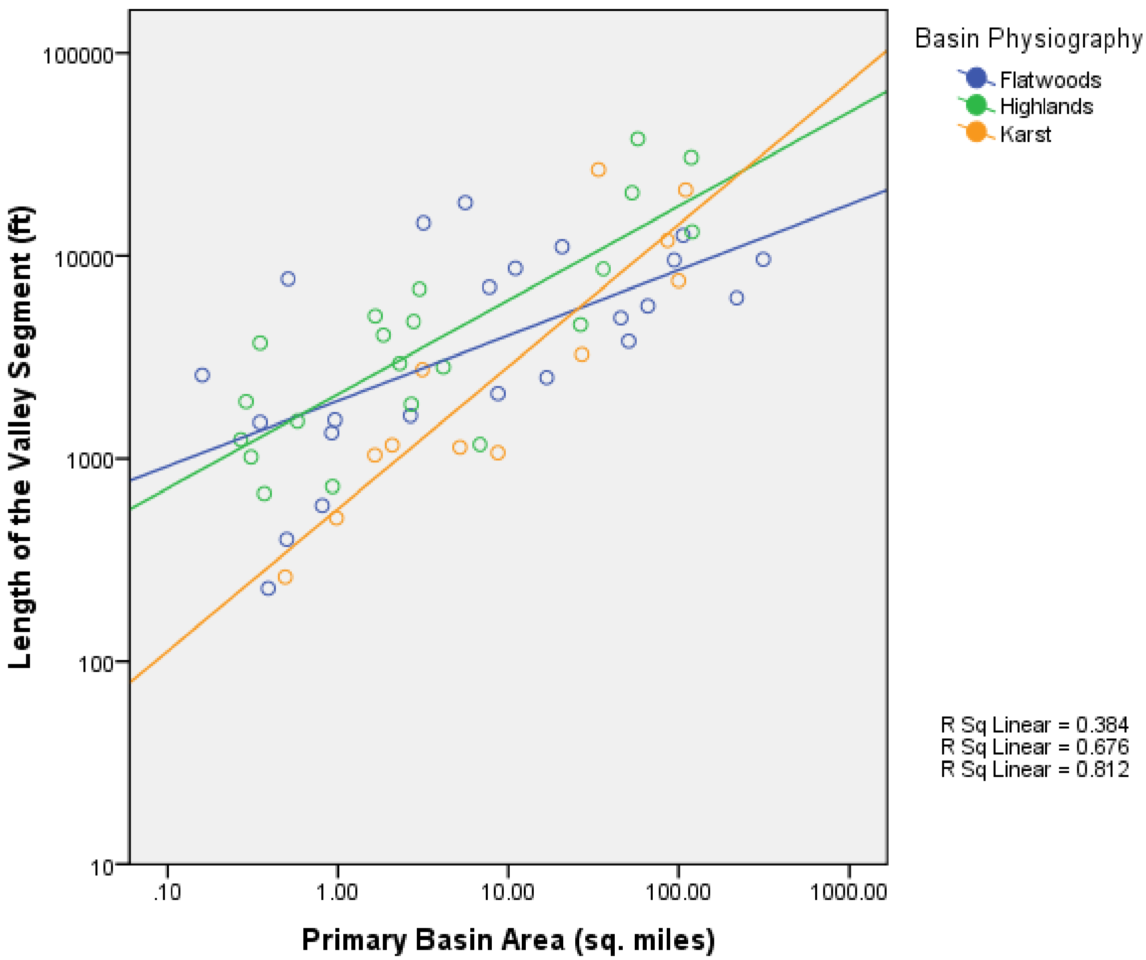


Figure 3-13. Valley segment lengths between in-line waterbodies or stream junctions versus drainage area for three physiographic regions.

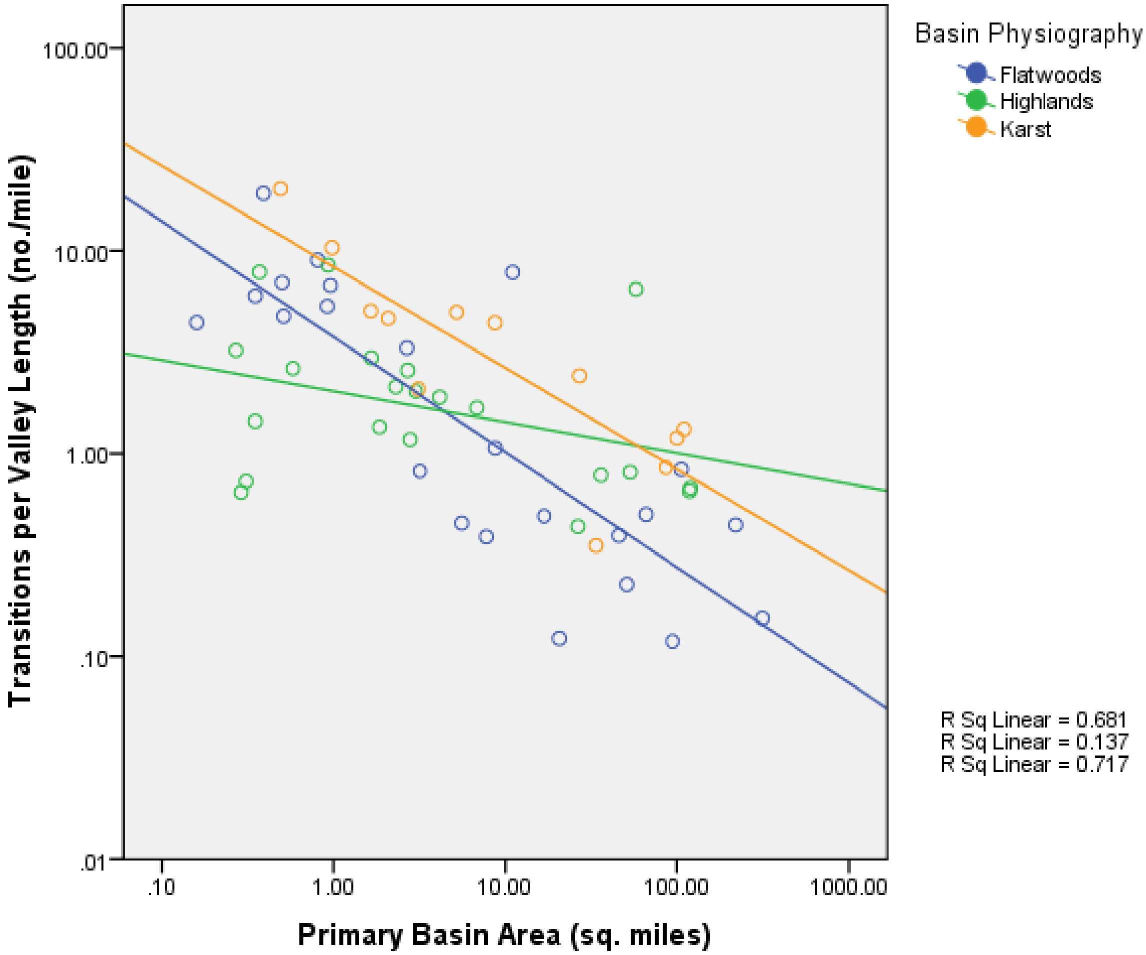


Figure 3-14. Number of valley segment transitions per valley mile versus drainage area for three physiographic regions.

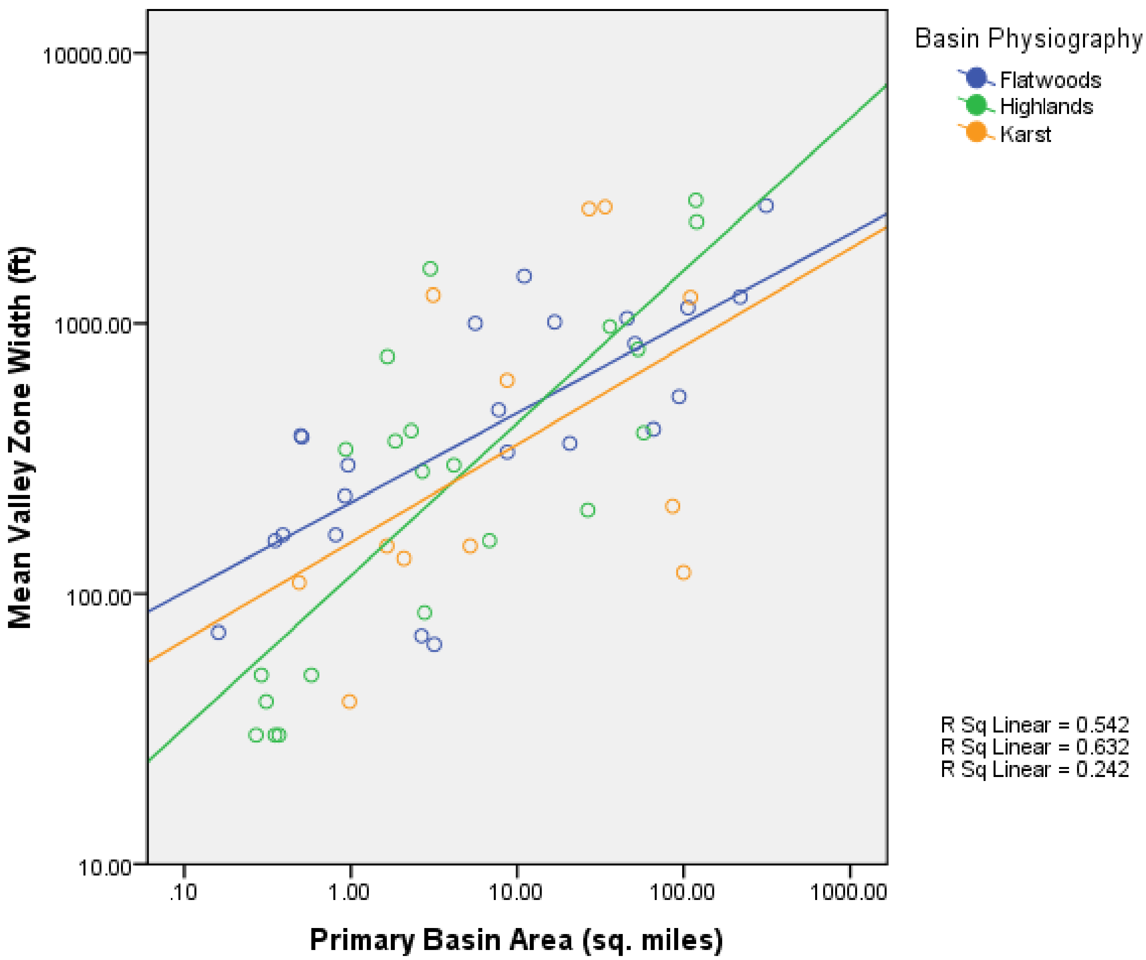


Figure 3-15. Valley width versus catchment area for three physiographic regions.

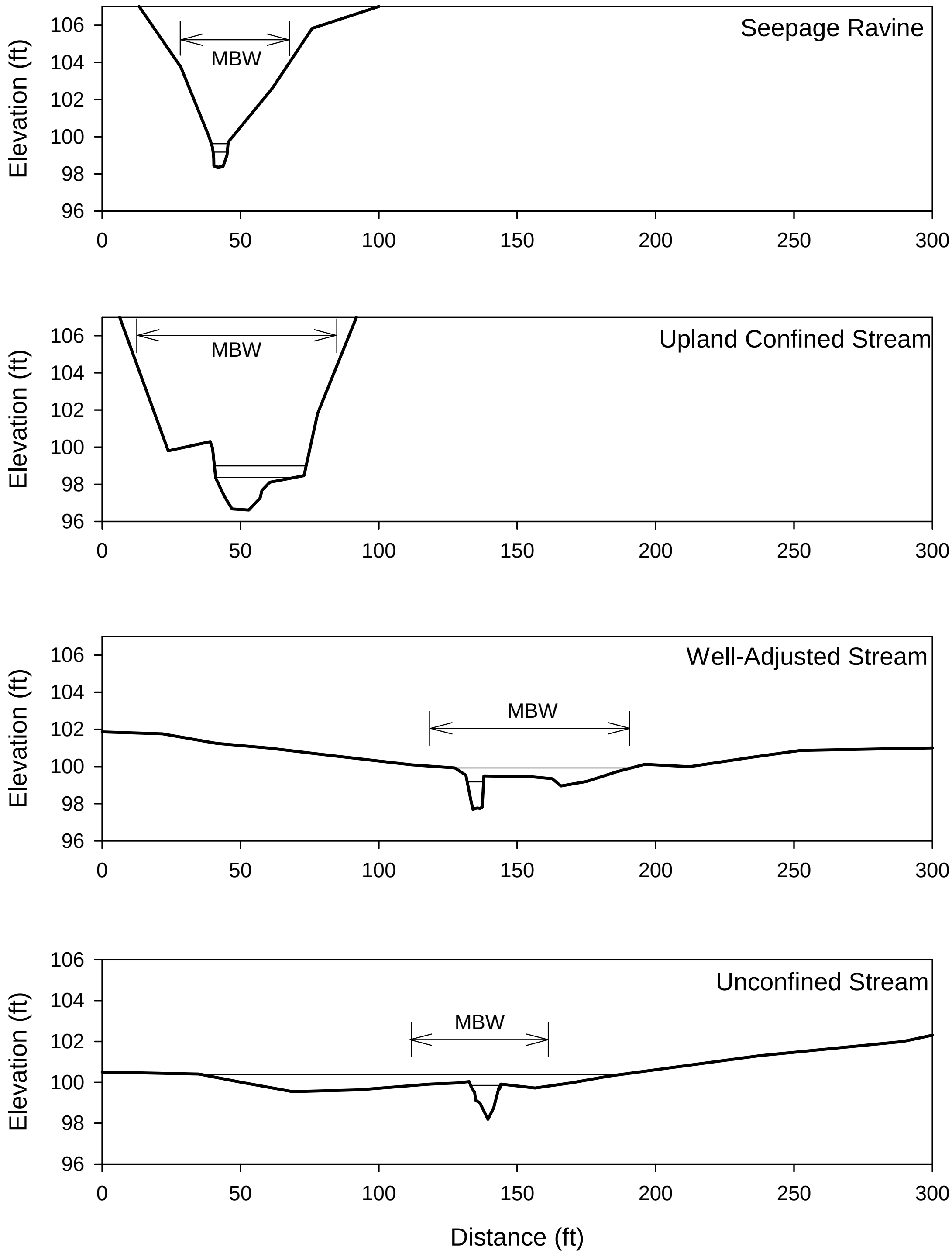


Figure 3-16. Types of valley confinement. MBW = meander belt. Confinement depends on the relative width of the meander belt to the seasonal flood width line. The flood width corresponds to the uppermost of the two thin horizontal lines. The lower line is the bankfull stage.

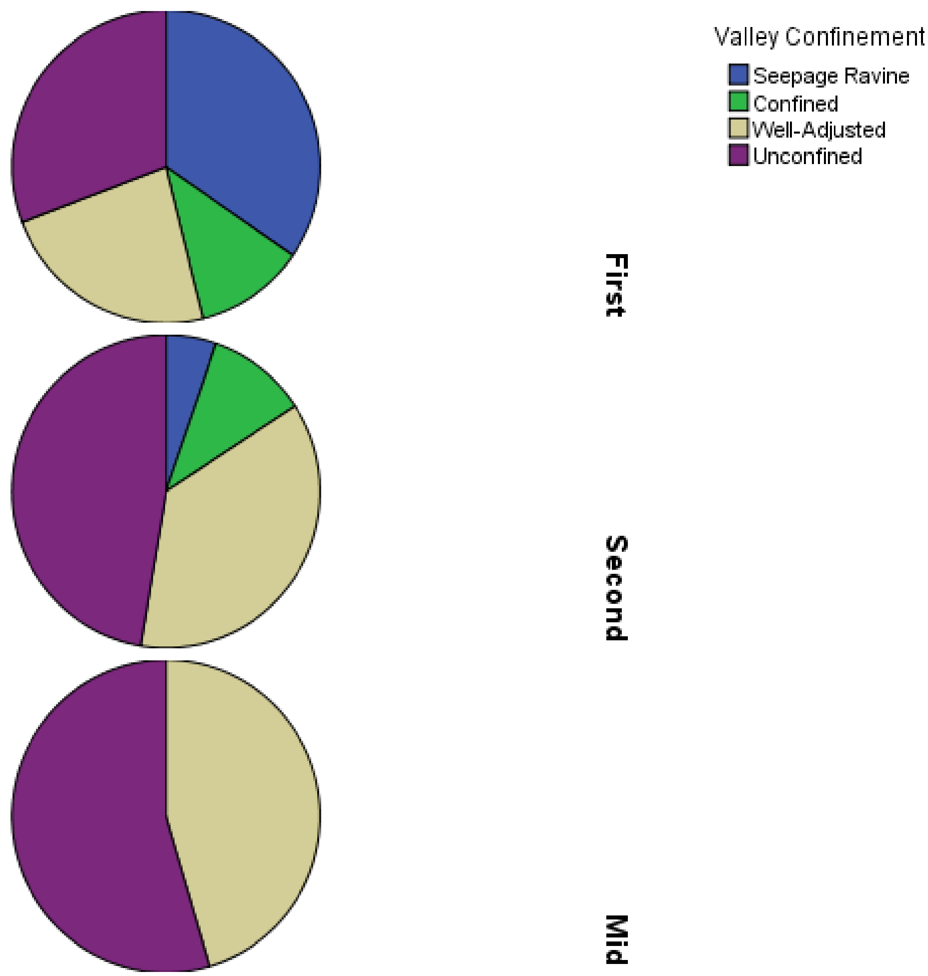


Figure 3-17. Valley confinement distribution by Strahler stream order.

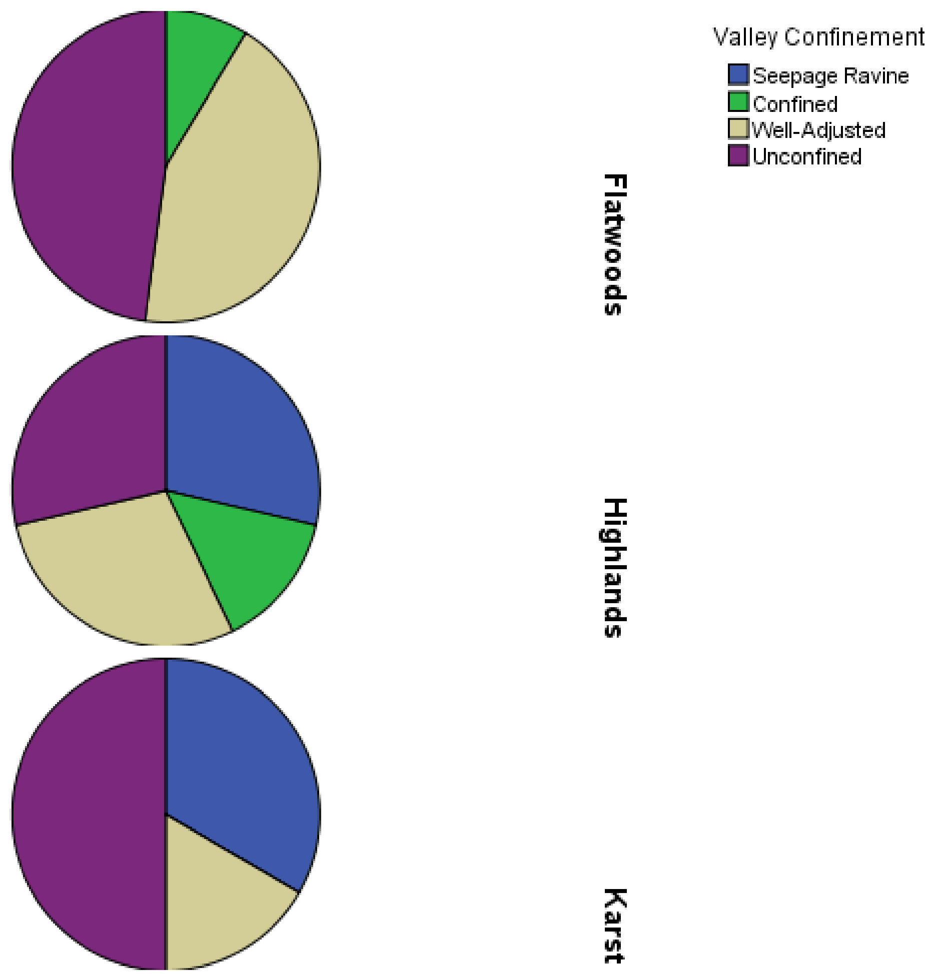


Figure 3-18. Valley confinement distribution by physiography.

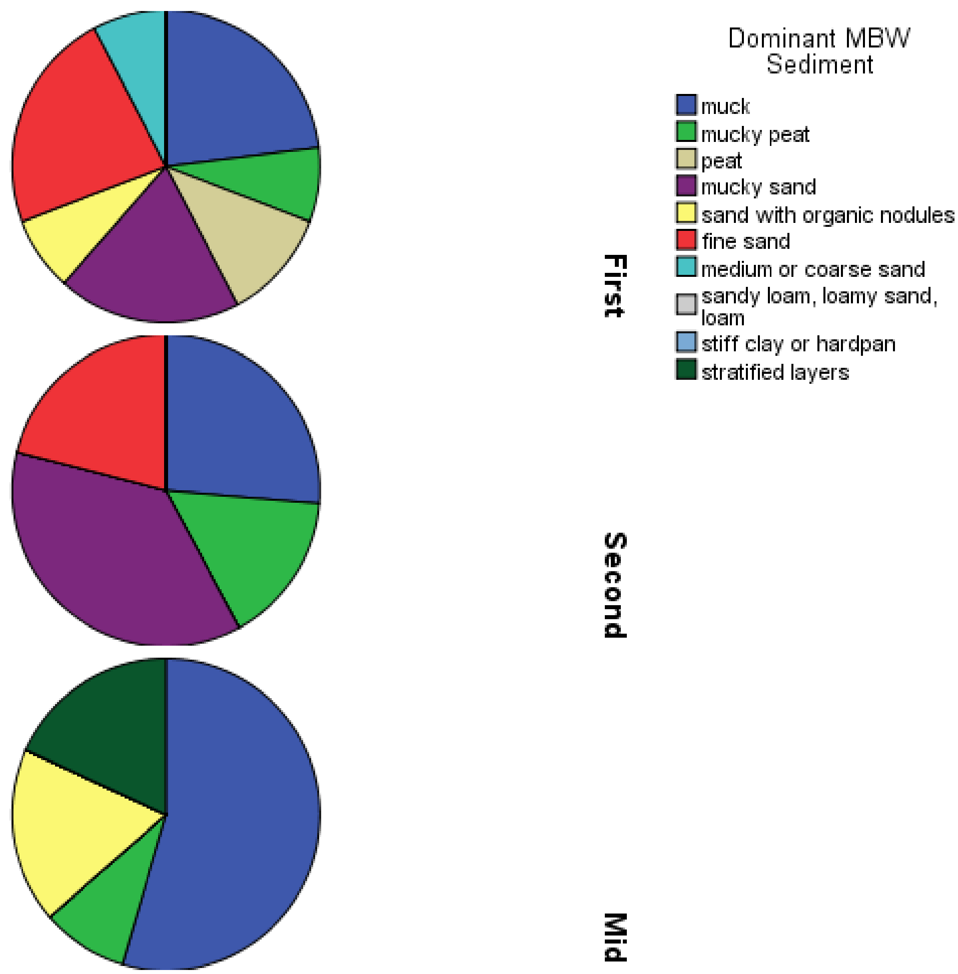


Figure 3-19. Dominant meander belt sediment distribution by Strahler stream order.

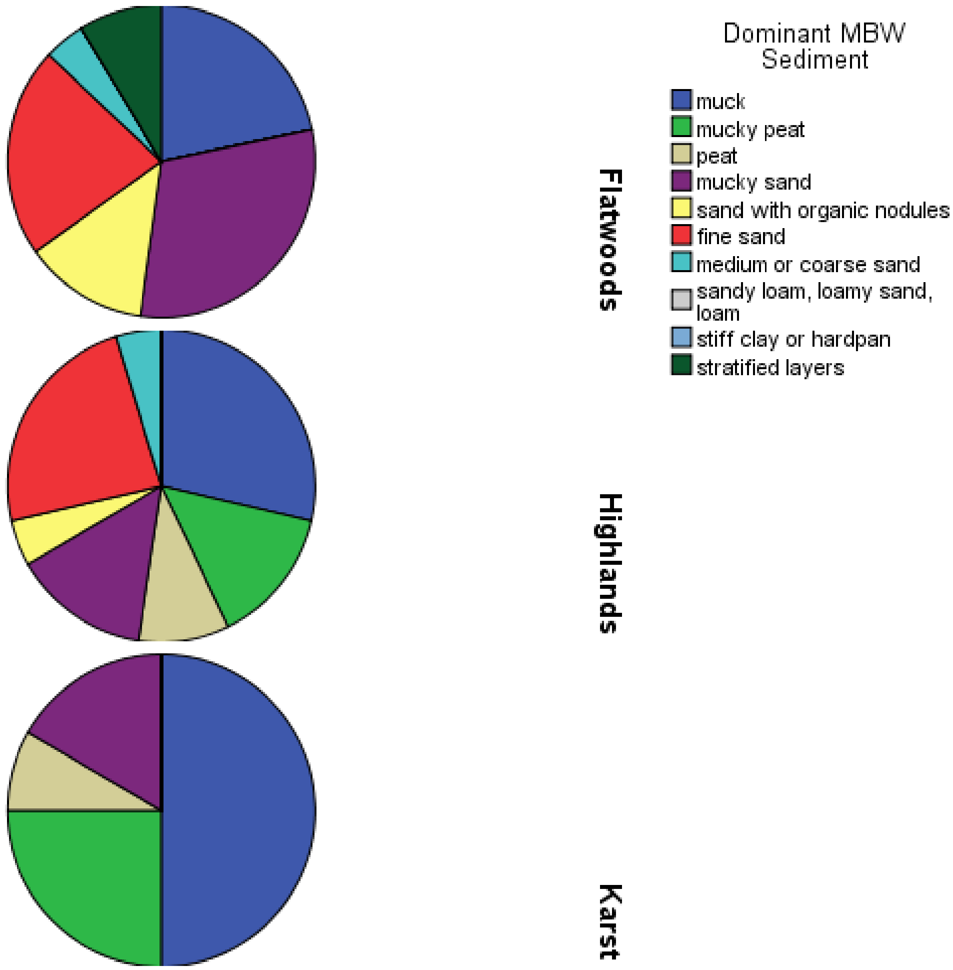


Figure 3-20. Valley confinement distribution by physiography.

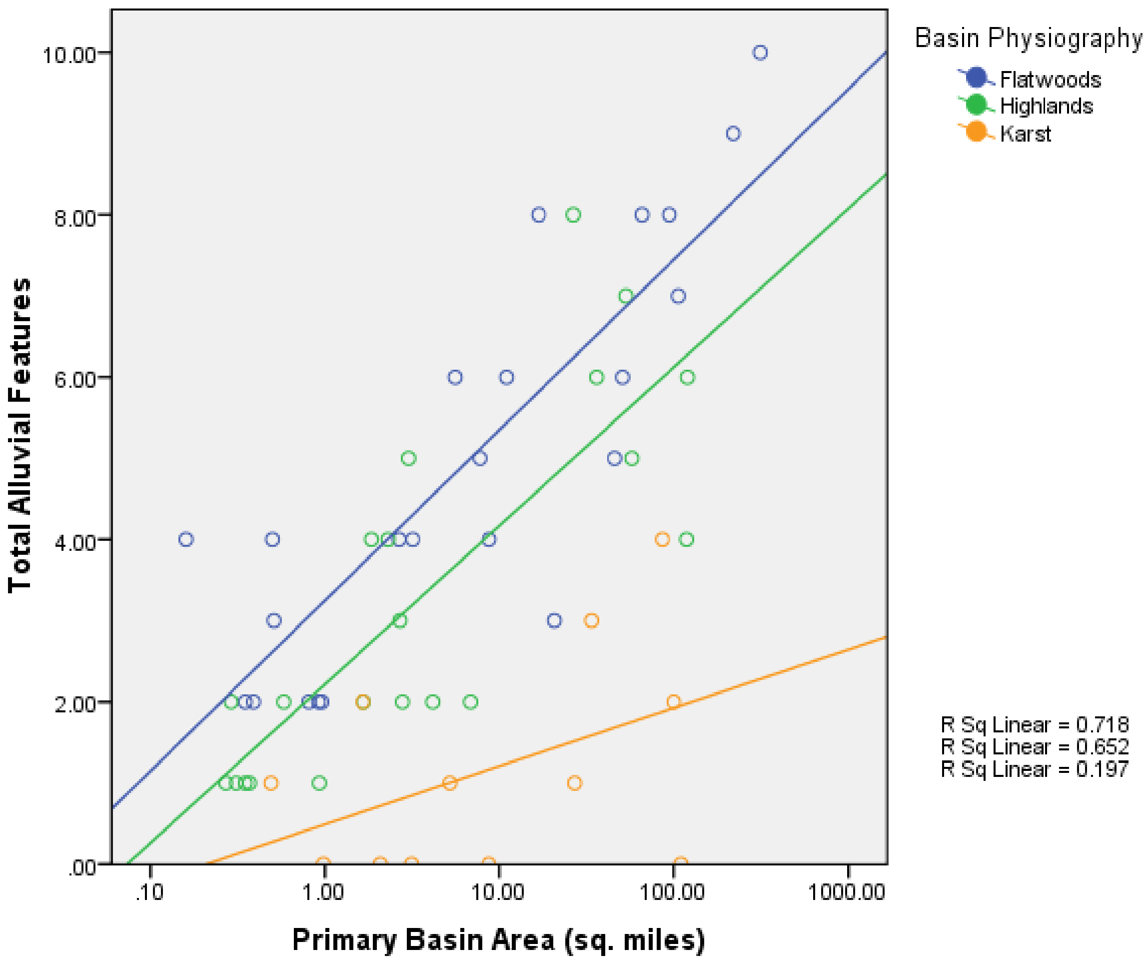


Figure 3-21. Total alluvial features versus catchment area for three physiographic regions. Alluvial features are formed via sediment transport. Examples include natural levees, linear backswamps, point bars, oxbow lakes, stratified sediment layers, bend pools. See Appendix A for full listing.

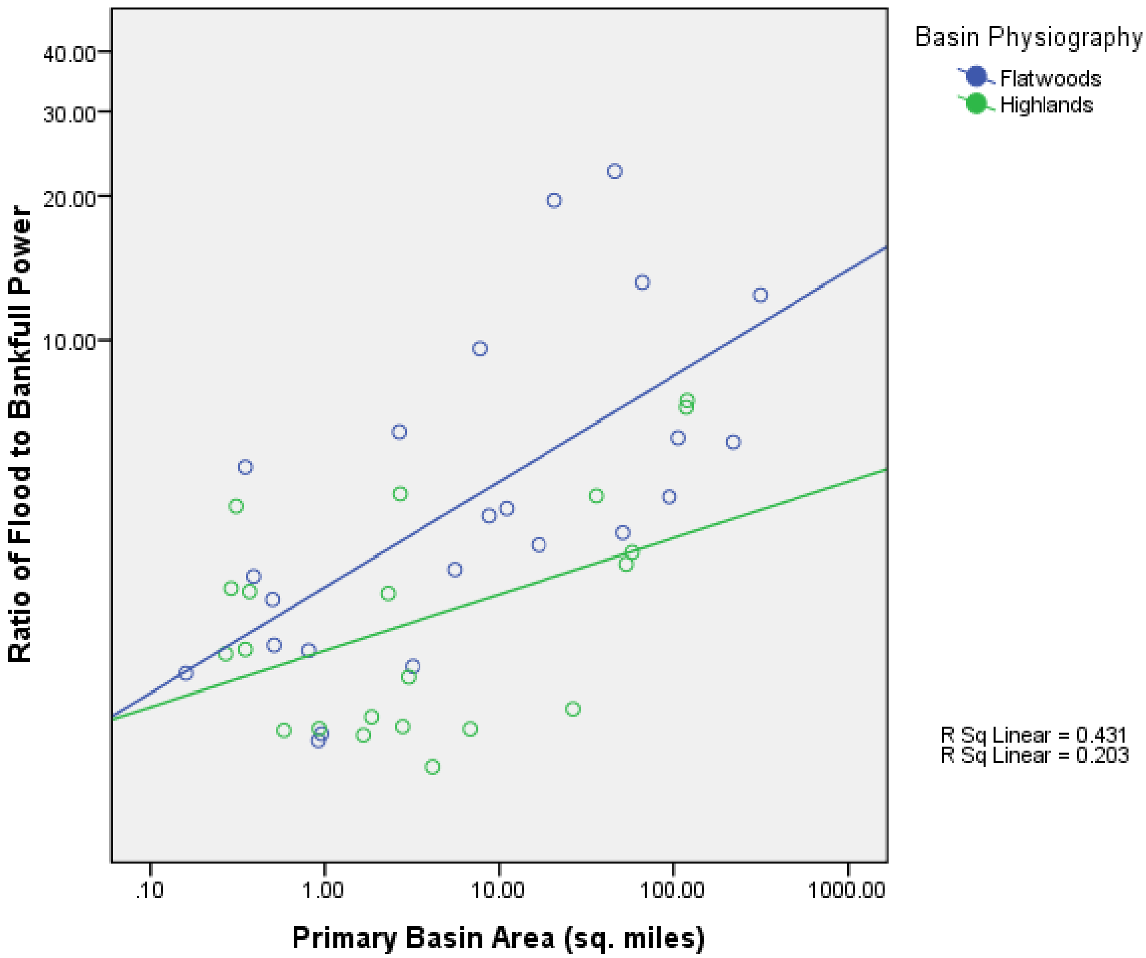


Figure 3-22. Ratio of flood channel to bankfull channel stream power versus catchment area for two physiographic regions.

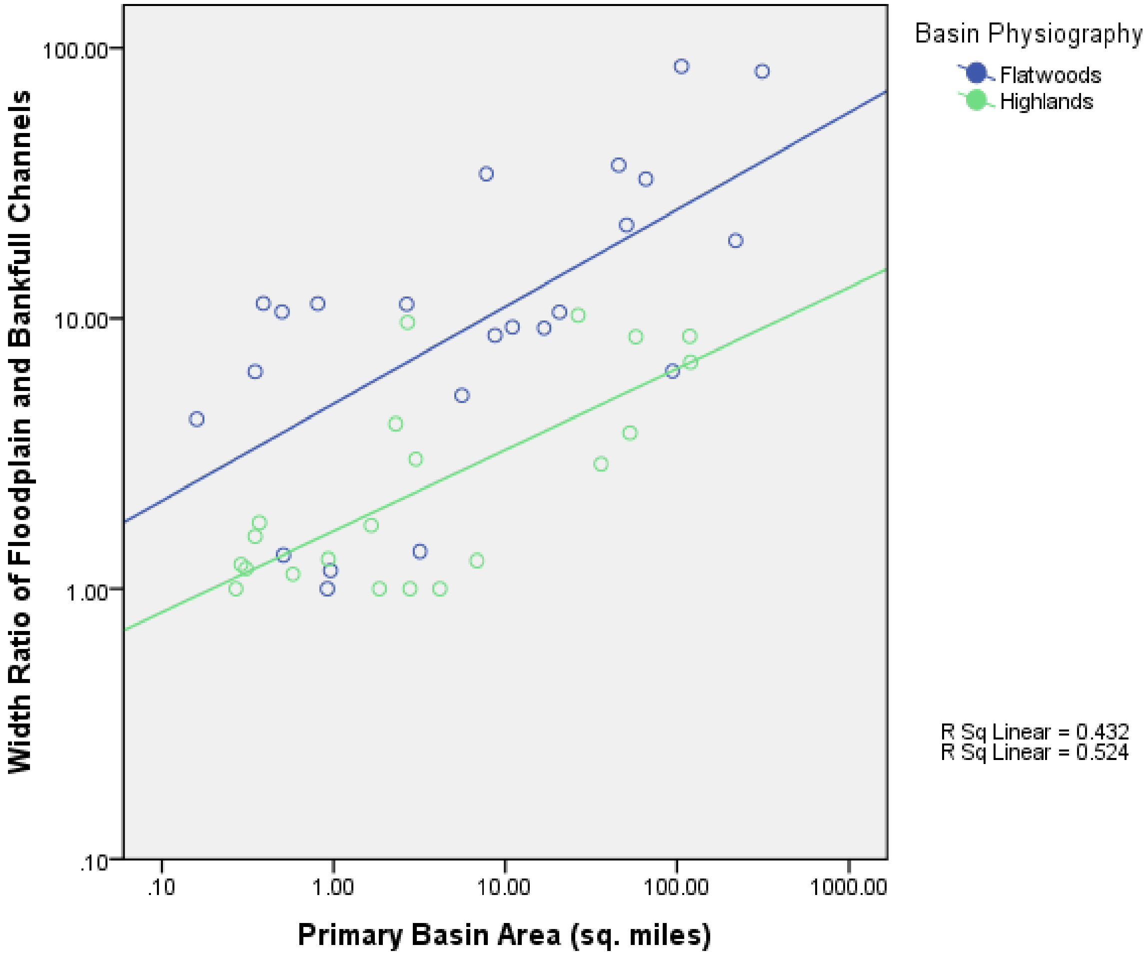


Figure 3-23. Ratio of flood channel to bankfull channel width versus catchment area for two physiographic regions.

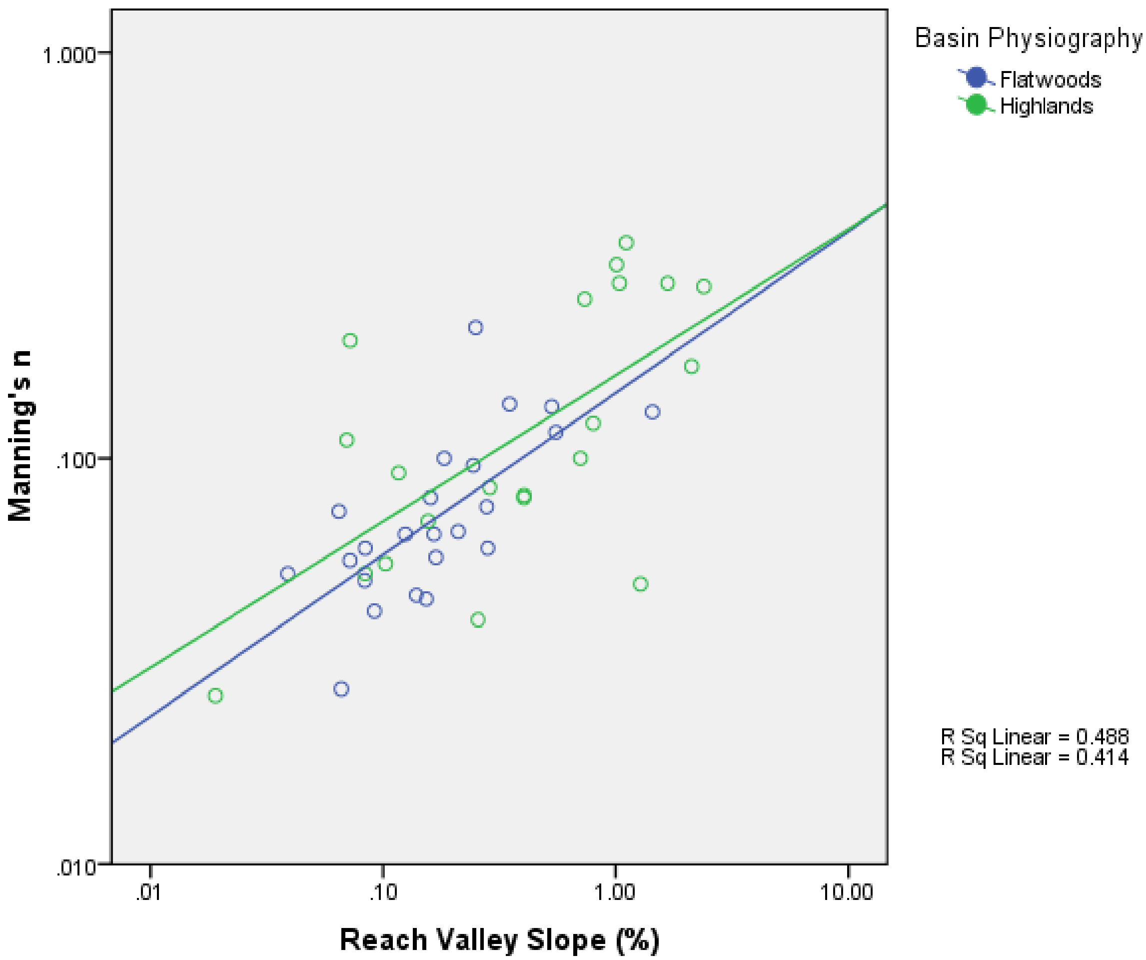


Figure 3-24. Bankfull channel friction factor versus local valley slope for two physiographic regions.

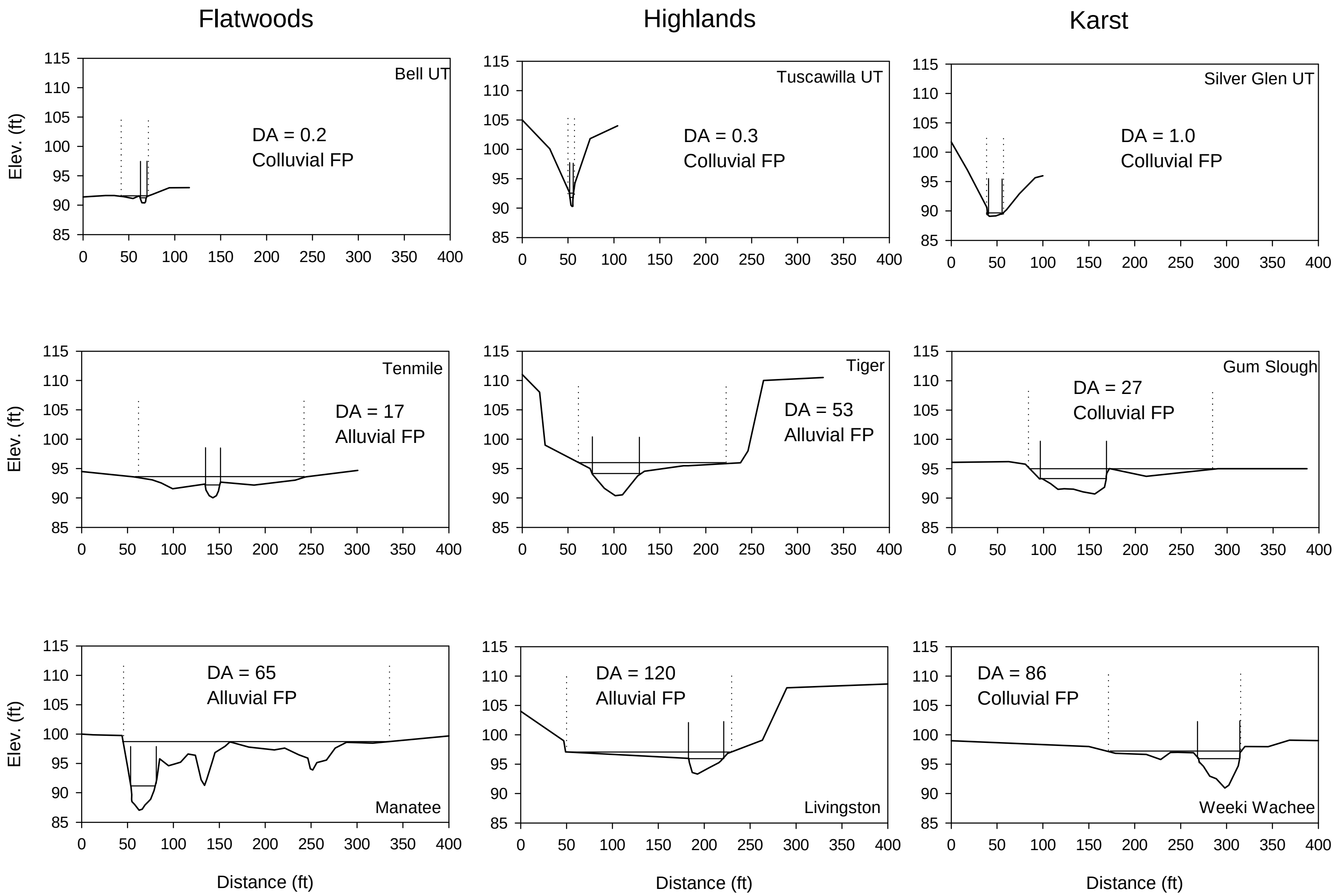
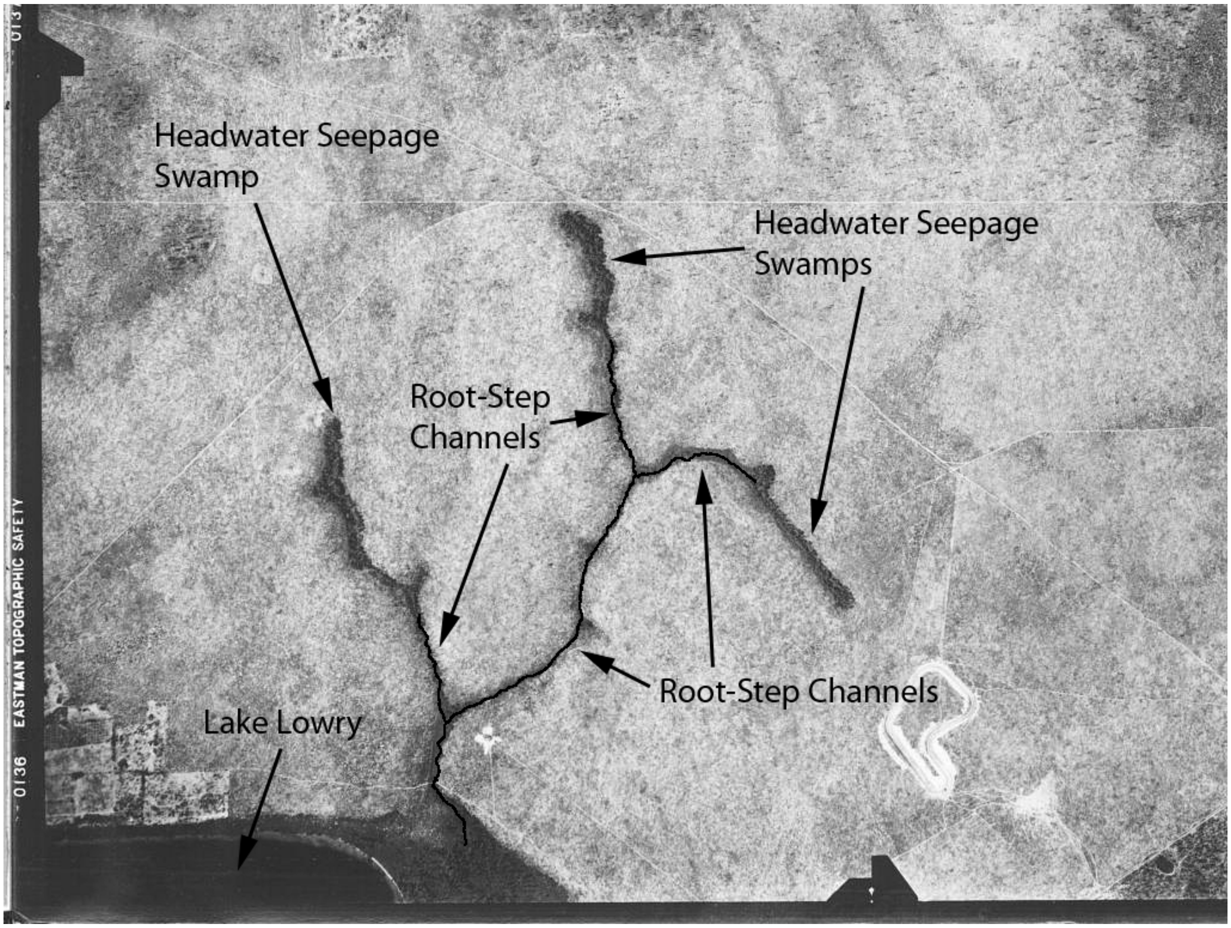
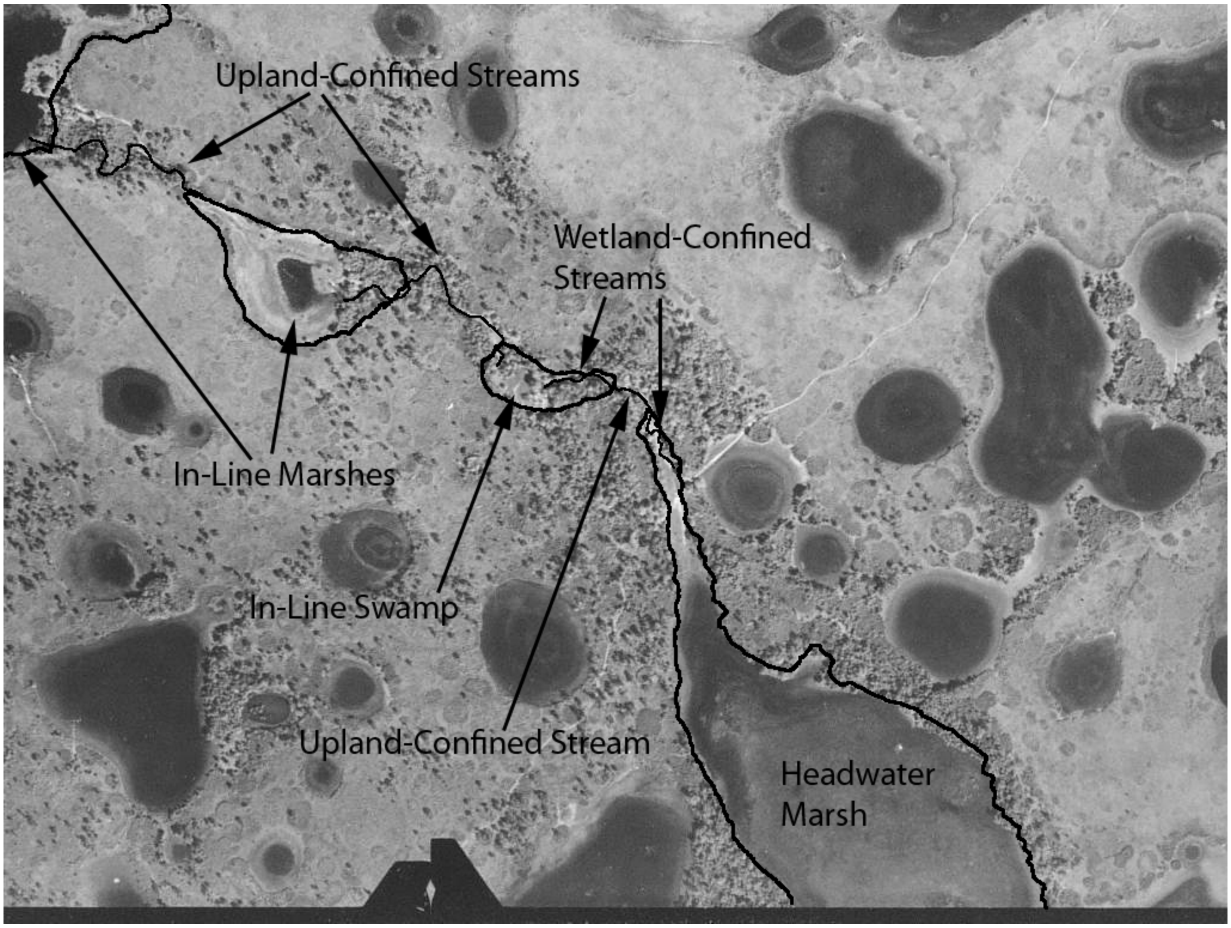


Figure 3-25. Valley bankfull and floodscape channel comparisons by drainage area (DA, sq. miles) and physiography Dotted vertical lines delineate flood channel and solid lines mark the bankfull. Vertical datum normalized.



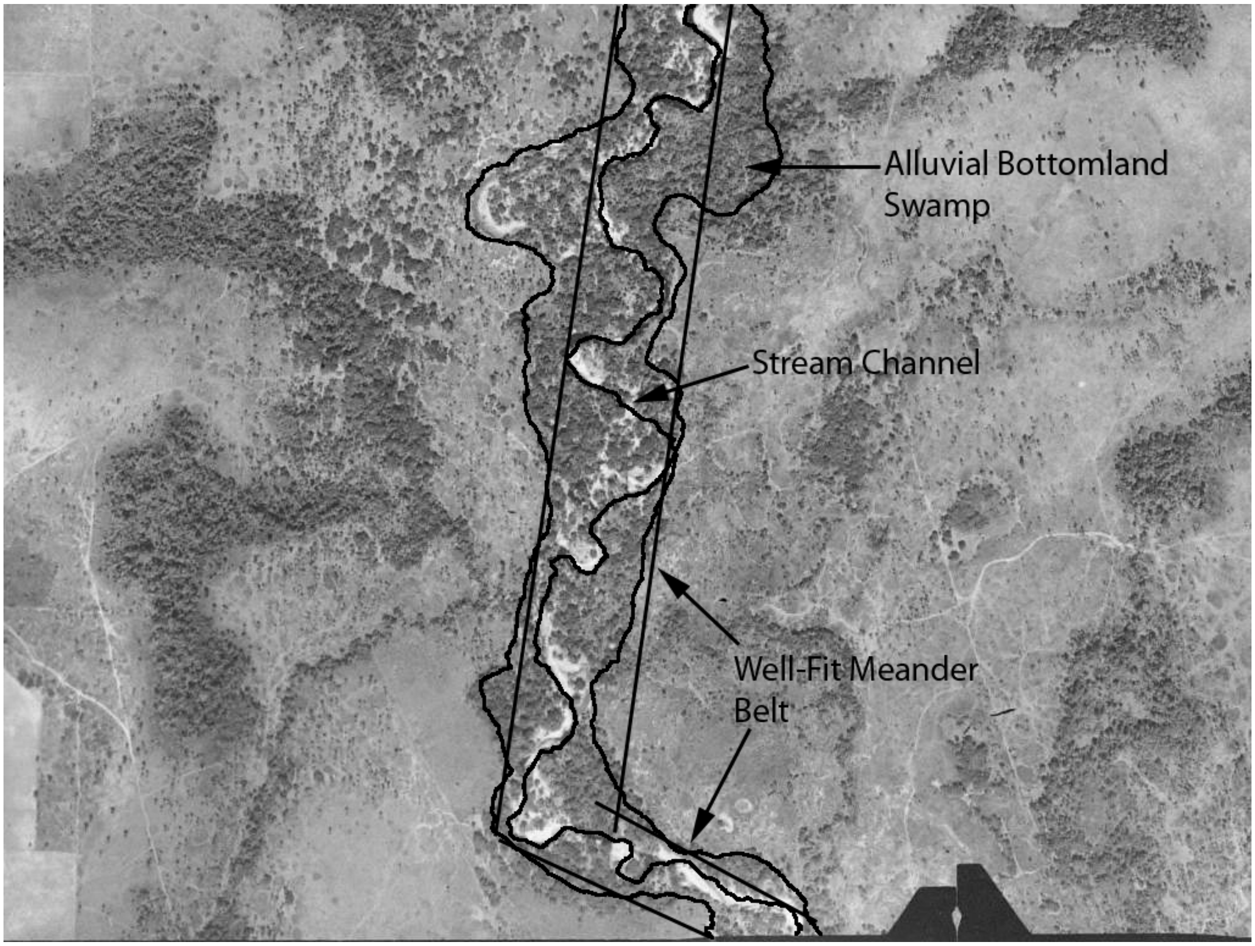
Scale is approximately 1 inch = 2,000 feet. Flow direction is toward the lake.

Figure 3-26. Sapping valleys with seepage ravines. Lake Lowry Unnamed Tributary (UT) (USDA 1943a)



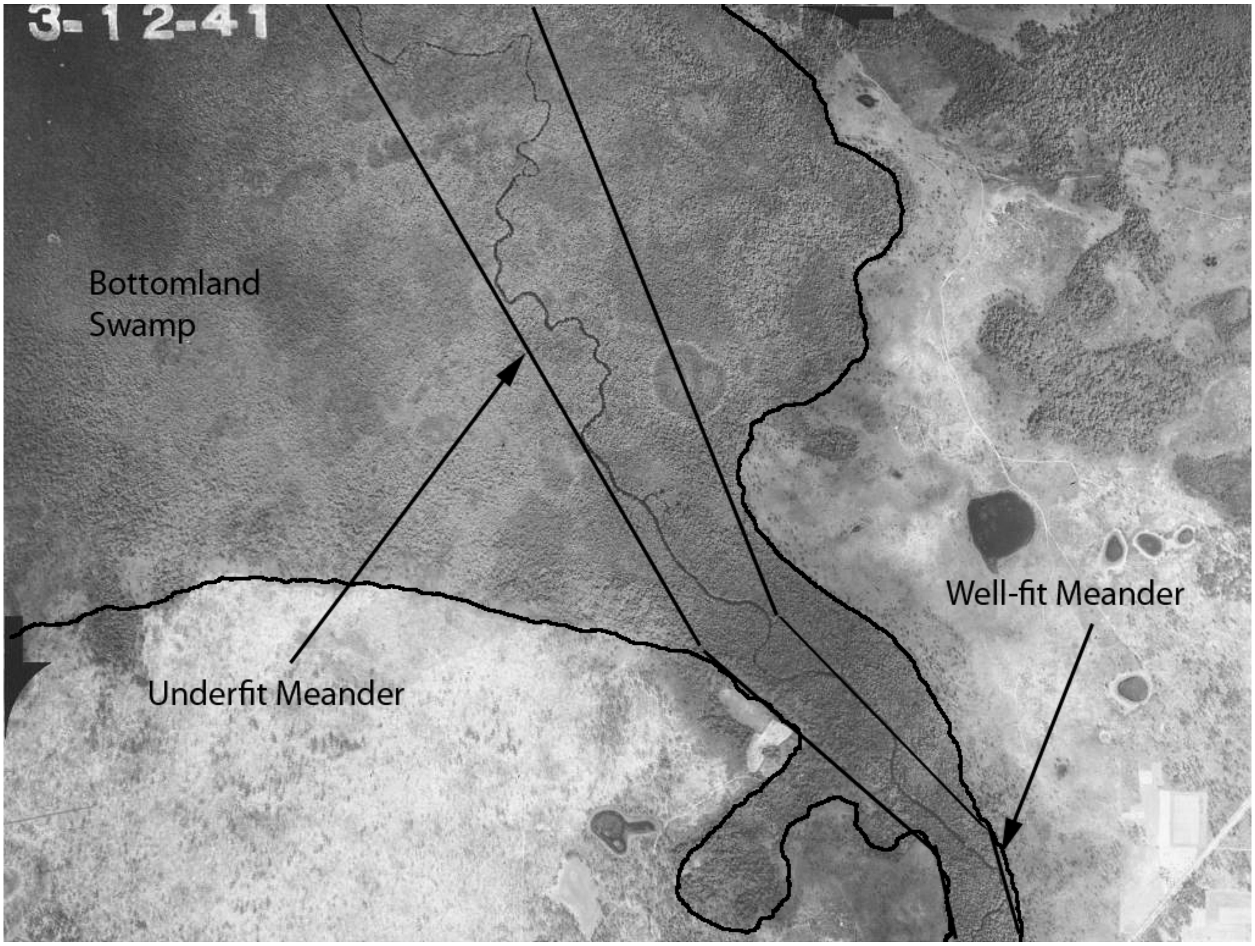
Scale is approximately 1 inch = 1,000 feet. Flow direction is to the northwest.

Figure 3-27. Chain-of-wetlands with upland and wetland confined channels. Lower Myakka Unnamed Tributary (UT) 2 (USDA 1948).



Scale is approximately 1 inch = 1,000 feet. Flow direction is to the south.

Figure 3-28. Well-adjusted channel within a high-gradient alluvial bottomland forest. Horse Creek near Arcadia (USDA 1943b).



Scale is approximately 1 inch = 2,000 feet. Flow direction is to the southeast.

Figure 3-29. Unconfined channel within an immense bottomland forest. Blackwater Creek near Cassia (USDA 1941).

CHAPTER 4
A CLASSIFICATION SYSTEM FOR THE CONSERVATION AND RESTORATION OF FLORIDA'S FLUVIAL SYSTEMS

Introduction

About $10 billion has been spent on 30,000 river restoration projects in the United States and the industry is growing rapidly (Malakoff, 2004). Florida has been behind the national trend in awareness of protecting streams from disruptions to fluvial geomorphic processes, but this is expected to change. In fact, it is possible that the findings of this proposed research topic will help to promote awareness in the state regarding stream protection and restoration. During the site selection for this study, 75 of the first 100 randomly-selected stream sites were rejected because they were likely to be impacted by their basin-scale land use alterations, drainage ditches, land clearing, filling or other human activities.

The prioritization of stream restoration projects and the design approaches to fix damaged streams (or arrest further damage) often starts with a regionally applicable fluvial geomorphic classification for intact, properly functioning stream systems. Streams with measurements departing from the desired classification are sometimes identified as those in need of restoration. Furthermore, the awareness, conservation, and management of intact stream segments are also often based on how well a system fits natural channel classification schemes.

Florida currently lacks a systematic fluvial geomorphic classification for freshwater streams useful for management and restoration. This is unfortunate, because Florida has unique fluvial forms that likely depart from "national" norms. This distinction is likely because the classification norms being used to guide restoration activities in the United States are derived largely from studies of perennial streams in temperate climates under alluvial control. Alluvial control means the stream shape is controlled largely by sediment transport. In contrast to the rest of the U.S., Florida has a mostly sub-tropical climate with a major stochastic presence of powerful tropical storms, most of Florida's streams flow intermittently (seasonally) rather than perennially, and the stream corridors appear to be only partially under alluvial control. While existing alluvial-based stream classifications are likely to apply to streams in Florida originating from the temperate continental land mass (such as the Apalachicola River), they could be more limited or even incorrectly applied to the population of streams originating in the unique climate and physiography of the Florida peninsula. Fluvial geomorphologists working in non-temperate, non-perennial, or non-alluvial systems, especially in deserts and the seasonal tropics, are finding streams in such settings do not fit prevailing reach-scale shape-based classification approaches very well. Miller and Gupta (1999) provide a compilation of case studies of unique fluvial forms that do not fit alluvial control norms developed from north, temperate regions. Thorp *et al*. (2008) are also questioning some of the fundamental clinal concepts of stream self-organization even for the regions in which they were first derived, suggesting that patch dynamics are the norm for most systems worldwide.

Purpose

The seasonally wet Florida peninsula, poised between the seasonal tropics and a humid temperate landmass, offers an intriguing possibility to test concepts related to the limits of alluvial and clinal classification systems based on humid temperate norms. From a practical standpoint, applied stream morphologists working in Florida should want to know, "Can we be comfortable relying on classifications developed under potentially different circumstances than those in Florida?” and “If not, then what should we be using?”

Therefore, the main objective is to derive at least a tentative classification scheme tailored to facilitate improved understanding, management, and restoration of freshwater streams on the Florida peninsula that are unique or otherwise poorly classified through the lens of norms developed for streams elsewhere.

General Approaches to Stream Classification

Most modern stream classifications depend, at least in part, on “regime theory.” Under regime theory, stream morphology can be viewed as a product of a generally constant set of long-term environmental forcing functions of climate, physiography, and alluvial sediment characteristics. This set of relatively constant forcing functions is the system’s “regime.” Streams that react to these forcing functions on a time scale that is short enough to prevent a confounding series of lag effects from previous environmental regimes are said to be “in-regime” for their region. Lag is best reduced to the point of favoring equilibrium concepts when there is a lot of water delivered to the channel at high frequencies which provides energy resulting in work that routinely transports readily available sediments.

Perhaps regime theory is therefore best applied to streams under routine alluvial control rather than those under more stochastically determined features related to bedrock controls or colluvial control. Regime theory presumes that streams enter a relatively predictable equilibrium of channel form as an associate of basin characteristics within a relatively homogenous region. Regions must be sufficiently homogenous and correctly delineated to properly apply regime theory. Examples of streams fitting such conditions have been described in the humid northeast, humid midwest, and various non-desert areas of the western United States, in humid New Zealand, in humid Great Britain and Europe. Knighton (1998) provides a good summary. Regime-based classification and restoration practices are commonly applied to gravel and sand bed streams in humid temperate climates around the world.

For systems where regime theory is applicable, one can often apply regression equations to carefully defined regions relating independent form variables (such as drainage basin area) to dependent form variables in the channel (such as bankfull channel cross-section area). Because these regressions are limited by region, they are referred to as “regional curves.” Regional curves are encountered often in applied stream restoration practices. Regions and stream classifications within regions are often segregated based on visual inspections of slope and intercept differences in the regression line among samples drawn from *a priori* populations.

Rosgen (1994) developed what is perhaps the most prevalent general classification method using a regime theory framework. The Rosgen stream classification focuses primarily on stream channel shape, classifying streams by measurements taken at a reach scale typically a few hundred feet long (Rosgen, 1996). Rosgen based his physical form-based classification largely on the works of fluvial geomorphologists working in perennial alluvially-controlled channels who were interested in predicting the associations between channel form and processes (Leopold and Maddock, 1953; Leopold *et al.* 1964; Williams, 1986). One of the central tenants of Rosgen’s shape-based classification is that changing any one of the dimensional variables in his classification at the reach scale will cause shifts in the others for the stream to regain equilibrium status.

Rosgen picked relatively easy to measure forms that had been identified as sensitive indicators of channel process in alluvial streams. For this reason, it is often assumed to be sufficiently process-based to be used to guide stream restoration designs, sometimes including major riparian engineering works. Such use of Rosgen's approach has been the topic of several peer-review journal articles and even more conference proceedings debating the merits of widespread application of its technology. Critics or cautionaries include Montgomery and Buffington (1997), Juracek and Fitzpatrick (2003), Harmel *et al*. (1999), and Caratti *et al*. 2004. Some have found Rosgen's system was readily adaptable to their region of interest (Epstein, 2002; Doll *et al*., 2003; Savery *et al*., 2001; Hey, 2006).

An earlier regime-theory based classification was offered by Leopold and Wolman (1957). That system also relied on observations of channel shape at the reach scale, with less standardization of measurements and a more visual approach to define channel shape as opposed to Rosgen's rather quantitative methods. Channels were classified as a continuum of forms including braiding, meandering, and straight. This classification was largely conceptual.

If streams under alluvial control best fit classifications systems developed under a regime theory framework, then streams under varying degrees of non-alluvial control could be expected to be outliers to such a classification system or they could fit the classification by mere coincidence and simply have similar shapes as a matter of unrelated convergence of form. Streams with significant non-alluvial controls likely belong to a different population of streams than alluvial systems and it becomes important to understand how and why they differ if one is interested in managing, restoring, or otherwise protecting such riparian systems.

Systems with low-frequency flow events that do the most work moving channel materials, systems with low availability of transportable sediments, systems with non-hydraulic controls imposed on sediment movement, and systems with rapidly changing climate or physiography are less likely to fit regime theory classifications. Desert streams, streams of the seasonal tropics with monsoons, streams with bedrock (non-alluvial) controls, and streams forming on newly volcanic soils or areas of recent glacial retreat do not seem to fit regime theory very neatly (Miller and Gupta, 1999; Gupta, 1995; McCarthy *et al*., 1992; Sidle and Milner, 1989).

The dimensions of non-regime channel systems are sometimes controlled largely by rare, somewhat unpredictable events (for example, colluvial processes like landslides, or unusual hydraulic events such as megafloods). Non-regime streams may also be controlled by non-alluvial processes related to valley geology or biology that greatly restrict or preclude the movement of transportable alluvium such as exposed bedrock, subsidence/collapse features, massive log jams, or incredibly dense vegetative controls. The basic difference is that regime channels are best viewed as a product of existing climate and physiographic conditions in a region and non-regime channels reflect relict or heavily constrained physical conditions resistant to change under the existing climate. One responds and one resists.

Most workers noting exceptions to the regime-theory model probably assume they are dealing with unique cases, and many are perhaps correct, so no universal classification system for non-alluvial, non-equilibrium channels has emerged. Workers in regions with non-regime channels probably must develop special geographically-limited classifications, although potential exceptions are emerging. For example, Gupta (1995), based on observations in South America, the Caribbean, and India, has offered that streams in the seasonal wet tropics exhibit a channel-within-a-channel geometry. Evidence suggests that rare, extremely high rainfall events form the mega-channel within a valley. The mega-channel, or a portion of it, also conveys the wet season flows, but is not necessarily formed or maintained by these. A dry-season channel cuts into the mega-channel, formed under locally varying degrees of alluvial and bedrock control. The mega-channel is probably not a regime system, getting “reset” every so often by rare storms, while the dry season channel is likely to be under sufficient alluvial control to be in-regime with its watershed’s routine delivery of water and sediment.

This dual channel concept for the seasonal tropics extends beyond fluvial geomorphology into ecological-based stream classification, further enhancing its utility. Ecologists now recognize one key difference between temperate streams and those of the seasonal tropics is that tropical stream flora and fauna are more closely adapted to seasonal flood pulses. A heavily vegetated outer channel (part of the mega-channel) receives a wet-season flood pulse that is sustained for months, then the water levels retreat during the dry season (sometimes dropping more than 40 feet in elevation) where flow is confined to a much smaller interior channel. The seasonal flood pulse, coupled with the dual channel structure is a major force of nature with some tropical tree species so in tune with it that their seeds only germinate after dispersal through the guts of fishes which are adapted to eat their seeds. The trees only drop seeds when the wet season channel is flooded and the fish are likely to be present.

Approaches not presuming applicability of regime theory require process-based classification with knowledge of the system at more than one spatial dimension. They may also require recognition of the temporal history and trajectory of the system if it is not in a period of relative stasis since the last threshold-shifting pulsed disturbance. Some literature has emerged openly questioning the regimes that are assumed even in temperate humid climates. Given the pervasive degree of logging, farming, grazing, mining, and development one may prefer to use classifications that are strengthened by investigations into the processes behind channel dimension as opposed to simple measurement of seemingly associated forms. This outlook is often referred to as a "classification of natural kinds" or "process-based classification."

One of the best-described and oft-cited examples of such a process-based classification is that of Montgomery and Buffington (1997). They classified streams in mountainous terrain of the Pacific Northwest of the United States. They found some cause to invoke regime theory for that setting, but could not find cause to simply adopt shape-based reach-scale classifications such as that of Rosgen. They coupled reach level processes to reach shapes and also found justification to link these to hillslope processes, valley shapes, vegetation, and woody debris to achieve a useful classification system.

Montgomery and Buffington (1997) based their classification on the differing relationships between sediment transport capacity and sediment supply along the channel network, which in mountainous regions typically leads to a graded profile exhibiting steeper slopes at the highest elevations and more gentle slopes at lower elevations. The differences also manifest themselves with rather distinct segregation among stream classes in their associations between channel slope and grain size relative to channel depth, between drainage area and bankfull shear stress, and between channel slope and drainage area. Convergence of form can exist among functionally differing streams types in this type of setting, perhaps rendering shape-based classification insufficiently diagnostic.

Fluvial geomorphologists and stream ecologists working in Australia have devised “River Styles” concepts using a hierarchy of scale starting with the catchment and its associated valley settings based on their degree of confinement and then incorporating distinctions related to different process-form associations within the riparian corridor. After determining the position in the drainage network and the type of valley confinement, which in Australia are generally associated with the degree of floodplain alluviation, the delineative criteria then segregate the river styles based on hierarchical combinations of geomorphic units located within the valley, including the valley bed materials, channel planform type, channel bedforms, and floodplain alluvial forms present (Brierley and Fryirs, 2000). Which set of riparian delineators is utilized is nested within the valley confinement class. This hierarchical classification approach was developed to improve understanding of processes and form associations and to describe streams more holistically as laterally and longitudinally organized floodscapes, as opposed to merely linear channel systems, to guide better management decisions regarding the protection and restoration of Australian riparian corridors. A total of 18 river styles were proposed.

Erskine *et al*. (2005) adopted a similar approach for Australia’s tropical rivers, originally identifying nine river types. Saynor *et al*. (2008) later expanded this to 12 classes including certain fluvial forms with discontinuous channels. They called for additional research concerning two of the partially channelized systems to first make distinctions among various “chains-of-ponds,” which included a diverse array of spatially extensive in-line wetlands down to large in-line pools that remain wet well into the dry season long after the river links have ceased flowing. Second, they encouraged further exploration of conditions leading to “non-channelized valley floors” associated with seepage percolines, alluvial fans, and hillslope hollows. The authors also described “floodouts” as channel discontinuities derived from differential bedload deposits and “lakes, swamps, and billabongs” as including “backflow billabongs” and “channel billabongs” which seem to be similar to deep in-line sloughs using North American terminology. This classification is important as it was the only classification system encountered for streams that explicitly recognized discontinuities in the channelized drainage network and some of the forms described appear to have Florida analogues.

Streams are very much place-based ecosystems, and those in settings not particularly consistent with regime theory will warrant unique, rather than generic approaches to classification. Conversely, some generic classification approaches appear to be well conceived, broadly applicable, and quite useful to stream managers in a variety of settings. It would be foolhardy to misapply a generic classification to an inappropriate setting and it would be a waste of resources to derive new classification approaches for each area where previously developed broad or generic approaches apply. Which of these two approaches is warranted for Florida, especially in the state’s non-continental watersheds?

Florida Fluvial Geomorphology and Stream Classification

Goodwin (1999) recommends that fluvial classifications be based on "natural kinds" of streams as opposed to "nominal kinds." Natural kind classes are based on a desire to understand complex phenomena and are ideally based on the relationships between processes and form. Nominal kind classifications are based on very specific purpose or convenience and do not necessarily relate to natural laws. The only published fluvial classifications for Florida appear to be closer to nominal rather than natural kinds. The purpose of this proposed research is to move closer to a natural kinds classification, while retaining the practical advantages of a nominal (useful) system.

Although not technically a classification, some workers have derived stream regions in the state. This could be important, because regime theory relies on correct delineation of a region. The Florida Department of Environmental Protection defined three stream regions outside of the Everglades/South Florida region, based on an extensive database of macroinvertebrate species and related metrics (Barbour *et al*. 1996). The purpose of their work was to develop biological criteria as a means of understanding stream water quality and for defining the ecological "health" or degree of ecological integrity or impairment of a stream.

The USGS delineated three stream regions in the state outside of the Everglades based on flood-flow regressions relating annual peak flows with various return intervals between 2 and 100 years to basin characteristics including basin size, lake area, and basin relief (Bridges, 1982). These regions were empirically derived to establish a basis for providing a parsimonious set of flood-prediction regression equations for ungaged stream segments throughout the state. The regression differences are likely due to the state's north to south climactic gradient superimposed on areas with broad physiographic differences. These regressions have been refined and additional sub-regions have been mapped in west-central Florida, one of the state's most abundant stream regions (Hammett and DelCharco, 2005). The sub-regions, while also empirically derived, correspond reasonably well to White's physiographies.

Kelly (2004) examined the daily median flow records of Florida streams with long-term gage records and noted that the seasonal flow patterns differ rather distinctly across the state. He identified three geographic stream regions based largely on the relative influence of continental versus tropical weather patterns and the associated seasonal distribution of flow. Panhandle streams, influenced heavily by continental weather patterns, receive much rainfall from winter and spring frontal storms resulting in a pulse of increased flow in the winter and spring. Fronts push south less effectively down the peninsula while the humid sub-tropical climate provides increased summer convective storms. Summer and fall tropical storms provide ample rain as well on the peninsula. These factors combine to create a distinct flow pulse during the summer-fall wet season. This pattern is generally more pronounced as one progresses south. Therefore, a transitional area exists with streams exhibiting bimodal wet seasons between the panhandle in an area roughly between Tallahassee in the panhandle and peninsular Florida north of Gainesville.

An examination of Kelly's data also suggests differences in wet season unit flow (stream discharge per basin area) among the hydrologic regions. This is probably not only related to climate, but to basin soils and relief. In fact, Kelly (2004) also notes that streams with substantial groundwater inputs from springs and seeps have very limited seasonal pulses compared to streams receiving most of their water from overland flow (runoff). This means that stream hydrology in Florida is very much a function of regional climate and of geomorphology. The question remains, “Do these fundamental differences in hydrology translate to differences in fluvial form in Florida streams, and if so, how much and in what manner?”

Some examination of Florida fluvial geomorphology has occurred. Gross (1987) described two shape-based classes founded on her measurements of reach scale channel and floodplain cross-sections of palustrine streams in peninsular Florida. She described one type as narrow channels deeply incised in small floodplains and the other as wide-shallow channels meandering through broad floodplains. Tighe (1988) described selected geomorphic characteristics of Florida drainage networks at the basin scale, but made no attempt to classify streams or map stream regions based on geographic differences.

Metcalf (2009) applied Rosgen’s shape-based classification to streams largely confined to extreme north Florida and the panhandle, identifying two major physical classes of streams (C5—broad and shallow versus E5—deep and narrow). Distinct regional differences were noted with panhandle streams exhibiting larger channel cross-sections and higher bankfull flow versus basin size when compared to those of north-central Florida and south-central Georgia. This is not surprising given that the panhandle averages about 10 more inches of rain per year than north-central Florida.

Blanton (2008) measured bankfull channel dimensions in blackwater streams on peninsular Florida as part of this Dissertation’s project and compared regressions of bankfull channel dimension versus drainage area for the northern and southern half of the study area. She found that bankfull dimension was not sensitive to latitude within the peninsula. This suggests that the climactic variation of the peninsula is not significant enough to do more or less work on maintaining open channel dimensions that vary more than the combined other sources of variation in channel size. Peninsular Florida streams have regional curves distinctly different from the continentally influenced regions of Florida measured by Metcalf (2009).

However, work on the peninsula has been consistent with Metcalf's inventory of streams dominated by Rosgen C5 and E5 classes. Kiefer and Durbin (2004) determined that all 14 headwater streams they measured in north-western Hardee County classified as Rosgen C5 and E5 types. Kiefer and Mossa (2004) noted statistically significant differences in valley slope for two Rosgen channel shape types (C5 versus E5) of small headwater streams in west-central Florida. Streams with cross-sections of low width-to-depth ratios occurred in steeper valleys than those with high width/depth ratios. Anecdotal evidence suggests that the occurrence of sloughs and strands (very broad, shallow streams with largely organic sediments and almost fully vegetated beds) is also related to valley slope, with these systems occupying valleys with the lowest gradients. Valley slope appears to be associated with stream channel shape in Florida.

The low topographic gradient of many Florida valleys, coupled with high water tables and numerous wet depressions and lakes sometimes means that the receiving waterbody establishes seasonally variable backwater or embayment effects that change the effective base level of the stream outlet, keeping it high and shifting it upstream during the wet season when most flow is available to work on the stream. This effect was rather well-documented as occurring on the pre-channelized Kissimmee River as a result of interactions between the river and Lake Okeechobee (Warne *et al*., 2000).

Vegetation also probably exerts significant confinement on channel cross-section morphology and planform patterns in Florida compared to other regions due to low relief, mild humid climate, and nearly year-round growing season. For example, the Ocklawaha River did not conform to “normal” planform associations and patterns established by Williams (1986) for more than 400 temperate climate alluvial streams (Inter-Fluve, 1997). This was attributed to substantial vegetative controls exerted by the trees along its bank and in its floodplain. Many Florida headwater streams appear to take rather random walks through their heavily canopied valleys, exhibiting little of the predictable planform and profile periodicities found in regions without nearly continuous growing seasons. Other researchers have described vegetation-imposed pool-riffle and planform morphologies in headwater streams among a variety of climates that disrupt or trump alluvial controls, but this is less commonly reported for rivers (Montgomery and Buffington, 1997; McCarthy *et al*., 1992).

Beck (1965) and Kelly (2004) suggest classifications that also distinguish between streams dominated by groundwater versus surface water inputs. Florida has among the world’s greatest occurrences of streams fed mainly by artesian springs (vents that discharge flow to the land surface from a confined aquifer) (Meinzer, 1927). No systematic comparisons are currently available between palustrine (runoff) and artesian (spring run) stream morphologies or potential process-associations in Florida. Comparisons have been made in spring runs and runoff streams on volcanic regions of the Pacific Northwest, noting substantial differences in channel and floodplain morphology, soils, sediment transport capacities, large woody debris, and vegetation between these two basic types of stream valleys in that region (Whiting and Moog, 2001; Whiting and Stamm, 1995).

Sapping (or piping) has also been suggested to be an important process for stream network formation in parts of Florida, especially in the panhandle (Schumm *et al.*, 1995). This is a relatively rare form of stream network. Sapping is the gradual movement of non-cohesive soils by groundwater flow. Sapping valleys appear to form in Florida sites with rather high hydraulic groundwater gradients and deep sand layers. This process can lead to a relatively straight valley that abruptly terminates at its upstream end at a steep hillslope shaped like an amphitheatre. A seep feeding the stream channel typically emanates from close to the base of the amphitheatre. A seep differs from a spring as it is sourced from the surrounding surficial (unconfined) aquifer versus a confined aquifer. Seep flow is generally laminar emerging diffusely through an unconsolidated porous media as opposed to the concentrated turbulent flow of a spring which gushes through a macroporous rock medium. The FNAI's "steepheads" are a type of sapping stream. Steepheads often create microclimactic conditions which support vegetation unique to their region, including some of the rarest plant species in Florida.

Sapping valleys may have been more prevalent in Florida than they are today given that groundwater gradients are currently suppressed by the higher sea levels of the Holocene compared to the Pleistocene. Sporadic occurrences of sapping streams occur on the peninsula. Examples include Gold Head Branch in Clay County and Hidden Waters Ravine in Lake County. The highland sand-scrubs and sandhills of the

Lake Wales Ridge, the Ocala Ridge, and Brooksville Ridge and even some localized inclusions of seeps in flatwoods physiography elsewhere in the peninsula, especially in areas where stream valleys cross terraces (relict marine, lacustrine, or floodplain) may also have conditions conducive for sapping or at least exhibit sapping as one of the processes important to their channel and valley morphology.

Florida has an assemblage of apparent stream types including some unusual fluvial forms, but no one has assessed the boundaries of association between basin and reach scale forms and processes that lead to distinctions between sloughs and alluvial channels, between steepheads and spring runs, between spring runs and alluvial channels, etc. No systematic classification of Florida freshwater streams based on principals of fluvial geomorphology exists.

This is necessary to remedy because the existing nominal classifications of Florida streams largely ignore physics in perhaps the most physically-driven of aquatic ecosystem types, fluvial channels. Furthermore, the existing physically-based classifications used elsewhere in North America should be used with caution in Florida given that their underlying theory was developed in climates and physiographies that differ from seasonally humid, sub-tropical, sandy-soil, low-gradient peninsulas on limestone.

It is possible that fundamentally different stream types in the state are likely to have convergent shape factors when applying shape-based classification schemes. However, these streams may require consideration of their unique source of water (groundwater versus runoff), valley shape (slope and width), position within a basin and basin size, basin soil drainage classification (and depth to groundwater), lithology, and other factors to predict their stable channel and floodplain morphologies and to be properly managed or restored. If so, a regionally-specific, process-based, and multi-scale classification may be warranted and shape-based reach-scale classifications, such as the internationally popular Rosgen technique, may be limited to use in only a subset of Florida stream types. A better classification approach then we currently have is likely to be essential to moving the practice of stream restoration and management forward in Florida.

Methods

Site Inclusion, Field and Desktop Measures

All 56 sites selected by the methods described in Chapter 1 are included in the classification analysis. Field measures taken at the reach scale are summarized in Chapter 1 and Blanton (2008) provides very detailed descriptions. Valley scale metrics were measured as part of a desktop GIS analysis. This analysis used the best available topographic data for each study site location surrounding its reference reach. Data ranged in quality from one-foot LiDAR-derived contours to five-foot USGS quads. All measurements were made using ESRI ArcGIS 9.3 software. Appendix A provides descriptions of all measured and derived variables.

Exploratory Statistics

The variables fall into classes based on their derivation including: measured continuous data, dimensionless variables derived from the raw data by dividing one measured variable by another of the same units of measure, factor variables derived by dividing two variables of different units of measure (usually, these were metrics commonly used by fluvial geomorphologists to differentiate shapes independent of scale), and categorical data derived from simple measurements parsed into classes or from observational data. Some of the categorical data was ordinal and was used in statistical tests requiring numerical as opposed to strictly categorical data.

The primary statistical tests were exploratory. Hierarchical cluster analyses (CA) was used to examine how sites grouped on various combinations of these variables. The clusters were made using Ward’s method to calculate distance measures and agglomerate the sites. All variables were centered by clustering on their z-scores to eliminate the scale effects among variables with different units.

CA was invoked in a systematic approach. First, all sites were clustered based on all 123 non-categorical variables. Then, each site was assigned a group variable based on the first two clusters and each group of sites was separately clustered on the 123 variable set. This was done because the first split sometimes hides meaningful clusters.

Given the results from Chapter 2, which suggest that groupings of stream sites based on three watershed types are useful, separate clusters were examined on based on group categories (flatwoods, highlands, and karst). Separate factors using PCA were also derived from all 123 variables for each of these three groups.

Because one of the major hypotheses of this study is that Florida stream classification may work best if it is based on variables at multiple scales (watershed, valley, reach, and habitat patch), separate clusterings were produced for all sites based on groups of variables for each scale. Separate factors were derived using PCA for each of these variable groupings to aid in understanding why sites grouped the way they did.

Clusters were also ran on just the 45 dimensionless variables for all sites and then also for the dimensionless and shape-factor variables (56 total). These two analyses remove the direct effects of scale, but not necessarily its indirect effects. This can lead to more interesting interpretations than just observing that something clusters as “big” because it is large. Some shapes and dimensionless ratios are almost undoubtedly correlated with scale variables such as drainage area. Valley slope for example is a well known inverse associate of basin size. Comparing clusters derived when scale variables are not directly included with those that are can provide clues concerning the nature of scale effects. The CA dendograms from all assessments are provided in Appendix D.

Examination for latent variables was performed using PCA to simplify the description of how sites differ concerning the 123 non-categorical variables in the study. PCA was performed on the same combinations of sites and variables used in the suite of CA assessments. For each evaluation, an initial extraction was made of five factors from the correlation matrix. Variable communalities scoring less than 0.4 were winnowed. The analysis was re-run on the reduced variable set with varimax rotation. Coefficients were sorted by size and display of scores less than 0.5 were suppressed to aid in the visual examination of the results. Tabulations from each of the rotated component matrices are included in Appendix E.

The results from the various CA groupings and some of their PCA factors were assessed and interpreted to form a conceptual basis for a classification system. The explorations enabled judgment concerning the value of including certain types of variables for Florida stream classification as well as suggesting ways that Florida streams naturally are grouped, at least based on the variables included in the study.

PCA and CA calculations were made using SPSS 16.0 Graduate Pack statistical software.

Results and Discussion

A spectrum of watershed sizes and slopes were represented in the study for each physiographic class. Table 4-1 provides the roster of study sites and information on their dominant physiography, drainage area, basin soils, basin wetlands, basin lakes, and local valley longitudinal slope. Florida stream channels and their valleys also present various combinations of valley and channel form related to their degree of confinement and flood channel dimension. Table 4-2 provides data related to the bankfull channel and Table 4-3 provides information comparing the flood channel and bankfull channel dimensions for each site.

Florida drainage networks can best be described as “deranged’ rather than “dendritic.” This means that the stream channels are often interrupted by in-line lakes and wetlands. Table 4-4 provides descriptions of the valley segment configuration for each reference reach. Metrics include the meander belt vegetative community, its form of valley confinement, the types of waterbodies brooked by the stream segment, ratio of the riparian wetland’s total width versus the stream channel’s meander belt width, and the number of alluvial floodplain features present. For the purposes of this study, a valley segment was defined as a length of valley between the two waterbody junctions encompassing the reference reach.

Keep in mind that a reach is a small-scale detailed survey area, typically 20 times the bankfull width. While it is meant to represent typical conditions within a somewhat uniform, but typically much longer valley segment, the rapid and frequent transitions of valley confinement in many of Florida’s streams complicate claims that a reach survey represents anything than perhaps a subset of the valley conditions within a segment.

Clusters of Streams in Two Size Classes

The initial cluster was performed using all non-categorical variables on all sites. This resulted in primary branches clearly related to channel flow capacity and drainage basin size. Alexander Spring Run had the biggest and widest channel in the study, (cross-section of about 560 square feet and bankfull width of 250 feet) and one of the largest bankfull discharges (122 cfs). It split off first. The next two major branches split the sites into large and small capacity systems. The division occurred for watersheds of several square miles in size. “Big Capacity” systems ranged from drainage areas of approximately three to more than 300 square miles and “Small Capacity” systems typically drained less than three square miles.

The next hierarchy of branches split the Big Capacity sites into those with the highest capacity floodplains versus those with lower floodplain capacity. Divisions beyond that are largely uninterpretable, including various seemingly jumbled combinations of spring runs and blackwater streams.

The Small Capacity branch split into groups that seemed to cluster based primarily on valley slope, with a group of eight sites including the highest slopes in the study splitting off from the rest. After that, no obvious common themes were readily interpretable from the smaller branches in either of the two size capacity groups. In other words, branches splitting at less than five distance units on the rescaled cluster combine line were deemed largely uninterpretable or of limited utility. These lower-level groupings variably represented quite a wide variety of channel shapes, valley categories, and physiography.

The main interpretation of this initial cluster is that it suggests variables related to stream magnitude such as basin size and bankfull discharge are of primary importance. The floodplain capacity, groundwater physiography, and reach valley slope area also are likely to be essential and primary components of any peninsular Florida stream classification. PCA was conducted to explore potential latent variables. The five factors potentially explained 71.1% of the variance in all 123 variables. The 1st component accounted for 30.6% of the total variance alone. Measures of channel depth, bankfull discharge, flood channel discharge, alluvial features in the floodplain and in the channel, channel and floodplain stream power, drainage area, and drainage network magnitude all loaded high on that component. It seems to be a measure of the scale-dependant capacity to deliver powerful flow regimes capable of maintaining deep channels and alluvial floodplains. This component is the “Big, Powerful, and Alluvial Basin” variable.

The 2nd component accounted for 17.4% of the variance and loaded positively on measures of channel width, wetted perimeter, width to depth ratio, radius of curvature, channel cross-section area, percent substrate as submerged aquatic vegetation (SAV), meander belt width, and distance between bends. It appears to be a measure of wide channels with large gradual bends and substantial presence of SAV on the bed that do not correlate with major flood pulses. Such systems generally are spring runs that provide steady flow and usually lack major flood pulses. This component could be called the “Wide and Steady Flow” variable.

The 3rd component explained 8.4% of the variance, loading positively on the percentage of D soils in the watershed, ratio of flood to bankfull power, width ratio of the flood to bankfull channels, valley width at the flood limits, and percent wetlands in the watershed. It loaded negatively on percent A soils. This component describes an association between watershed soil and wetland conditions sufficient to generate seasonal overbank flood pulses to the stream corridor. While the 1st component also deals in part with flood pulses it seems to be oriented on the sheer size of the watershed and valley system at thresholds necessary for alluvial work, and this 3rd component is oriented on the qualities of the watershed soils and vegetation that typically support seasonal flood pulses without consideration of alluvial work. It could be called the “Flatwoods Flood-Pulse” variable because it positively associates with characteristics common in that kind of ecoregion.

The 4th component accounted for 7.8% of the overall variance. It was positively associated with longitudinal slopes down the valley and along the stream channel, channel shear stress, overbank and in-channel unit power, thalweg depth, and presence of root steps in the channel. This component could be called the “Steep Slope” variable. The 5th component explained 6.0% of the variance and had solely to do with the overall width of the riparian wetland and its relative width compared to the bankfull channel and its meander belt. It is essentially a measure of a lack of valley confinement. Systems with related characteristics were referred to as “unconfined” streams because geological controls on the valley led to a width greater than what is necessary to accommodate the stream meander corridor. Therefore, this component serves as the “Geologic Valley Control” variable.

As hypothesized, it is clearly not sufficient to describe sites based only their limnological characteristics without directly considering scale. The clusters were clearly split based on system scale and the five principal components explaining 71.1% of the variance appeared to be associated with processes related to forces sufficient to shape alluvial floodplains, maintain wide channels, produce wet season floods, or with physical controls on valley shape (slope and width). Notably, channel shape at the reach scale did not emerge as an important latent variable in this most fundamental phase of the analysis. It may turn out to be an important refining variable within certain categories of physiography and scale, but it was not the primary classifier for peninsular Florida streams.

To explore potential cluster masking from initial effects, the sites were subdivided into two groups based on the first three branches. Alexander Run split out on its own and was added to the rest of Big Capacity group. That cluster was also checked without inclusion of Alexander, and with the exception of Alexander itself, the same clusters appeared. The rest of the sites were separately clustered as the Small Capacity group.

The Big Capacity group cluster provided branching patterns different from the smaller branches of the same sites in the All Sites cluster. The biggest difference is that most of the fine branches in the Big Capacity group (less than five units on the rescaled distance cluster combine) were readily interpretable. Nine interpretable clusters were apparent for the 27 sites included in this group, plus two sites that seemed to be miscellaneous outliers. These two sites, Alexander UT 2 and Blues Creek drain basins on the cusp of large and small thresholds, 2.3 and 3.2 square miles respectively.

Subgroup 1 consisted of a single site, Alexander Spring Run that was a very wide, high capacity spring run without an alluvial floodplain and with a low valley slope. It was the only such site in the study, but other similar streams occur in Florida including Rainbow Spring Run and the Chassohowitzka River, for example. Subgroup 2 consisted of the Weeki Wachee River, the only other 1st Magnitude spring run in the study but one with a deep and sinuous channel.

Subgroup 3 consisted of three deeply entrenched channels draining large flatwoods basins that produced routine overbank floods with sufficient power to create some of the most alluvially complex floodplains in the study, namely Horse Creek, the Little Manatee River and the Santa Fe River. Subgroup 4 consisted of the two largest highlands drainages in the study, both of which had modest alluvial floodplain features, Blackwater Creek near Cassia and Livingston Creek. Subgroup 5 consisted of two unconfined channels coursing through wide alluvial cypress bottomlands, Fisheating Creek and Little Haw Creek. Both drained large watersheds. Subgroups 3 through 5 comprised the largest and most powerful streams in the study, all with significant alluvial controls in their floodplains. Their drainage areas ranged from 65.7 to 313 square miles.

Subgroup 6 consisted of a miscellaneous assortment of mid-sized streams from both highlands and flatwoods areas, all with floodprone valley flats and at least one alluvial floodplain feature. These comprised the smallest group of streams with recognizable alluvial floodplain controls in the study. The smallest site in this subgroup was Hammock Branch which drained three square miles and the largest was Carter Creek draining 36.0 square miles.

Subgroups 7 and 8 consisted of streams which drained watersheds ranging from 20.7 to 50.9 square miles, placing this subgroup generally intermediate in size between most systems in either Subgroup 6 or Subgroups 3 through 5. All four streams in Subgroups 7 and 8 had valley flats with finely textured organic-rich alluvium. Subgroups 7 and 8 differed mainly in their degree of valley confinement and longitudinal valley slope. Subgroup 7 included two well-adjusted streams with moderate slopes, Bowlegs Creek and the South Fork Black Creek. Subgroup 8 consisted of two unconfined streams, Tyson Creek and Rice Creek, in areas where they meandered through very low gradient and wide valley segments.

Subgroup 9 consisted of an assortment of perennial streams fed by copious groundwater discharge, none with alluvial floodplain features. Five of the seven sites in this group were artesian spring runs and the other two drained highlands landscapes.

A potential deficiency of this group is that spring runs, which from Chapter 2 we learned have some fundamental differences from the other stream physiographic settings, especially the flatwoods streams, did not consistently form any independent group. This may be because the flood and bankfull flow metrics are a poor substitute for other metrics such as the seasonal flow slope and the partial duration series flood frequencies, that require a long term daily flow record to develop. Neither did highlands and flatwoods streams segregate very well, which was unexpected given their rather systematic differences in sensitivity of alluvial processes with basin area (see Chapter 3).

PCA results for this group of “Large” sites produced five components that cumulatively explained 73.0% of the variance. The components suggested latent variables representing stream power and depth (20.3%), stream width (19.7%), alluvial floodplain processes (15.2%), valley slope and shear stresses (9.1%), and channel roughness or riffle-pool heterogeneity (8.7%). These variables seemed to collectively represent hydraulic processes and associated hydraulic geometry, which is understandable for a collection of mostly perennial mid-order streams. This set of latent variables and clusters failed to make important distinctions related to source of water and its medium of delivery, but did provide evidence of the general importance of gradients related to scale of the delivery system and magnitude of hydraulic forces.

The Small Capacity streams when assessed without the Big Capacity sites clustered into four groups at about 10 to 20 rescaled distance cluster units. The clusters were not interpretable beyond that. Subgroup 1 consisted a single site, Shiloh Branch, which was a small intermittent channel with high clay content in its banks and clay a few inches below the sand on its bed. It drained a V-shaped valley among a landscape of gently rolling hills in a region with Hawthorne formation (clay) outcroppings. The only other site in the study that had a similar setting was Blues Creek, which clustered independently of all of the other sites in the Large Capacity group.

Subgroup 2 consisted of six of the seven root-step sites in the study, plus one site, Jumping Gully, which exhibited sparse root-steps immediately downstream of the study reach. These sites occupied the steepest valley slopes in the study. Subgroup 3 consisted of the smallest spring runs studied plus a small sapping stream, Lowry Lake UT, with copious seepage. Lowry Lake UT has root steps and was the only such site not to be split into Subgroup 2.

Subgroup 4 forms a group of 15 sites at a cluster distance of about 16 units that consisted of an uninterpretable mix of seepage streams, intermittent runoff sites, and a couple of spring runs of various channel shapes and valley slopes. The most to be said is that these sites generally consisted of those generic low-order streams that are neither among the smallest spring runs nor root-step sapping ravines.

PCA results for this group of “Small” sites produced five components that cumulatively explained 67.7% of the variance. The components suggested latent variables representing channel depth features (19.6%), stream width (13.5%), seepage potential of the watershed (12.5%), channel uniformity (12.3%), and channel sediment transport capacity (9.9%). These variables seem to collectively represent in-channel hydraulic processes and associated hydraulic geometry, with one representing the seepage flow delivery system of the watershed. This set of latent variables and clusters failed to distinguish many dissimilar low-order streams, but did rather cleanly delineate steep-sloped sapping streams with root-step morphology and very small artesian spring runs.

The drainage area threshold between the first split among all sites into Large and Small clusters was a bit blurred at somewhere between three to seven square miles. Large and Small clusters appeared to differ rather sharply concerning the presence of alluvial floodplain features. Twenty-six of the 29 Large sites had at least one alluvial floodplain feature, while only two of 27 Small sites did. The two smallest sites in the Large group were clearly mis-assigned and neither had an alluvial floodplain.

The remaining Large site with a non-alluvial floodplain was Grasshopper Slough which drained an 8.7 square mile catchment. This site was unique and warrants some discussion because it consisted of a chain of five in-line sloughs alternating with four deep and sinuous sand-bed channels in quick succession over a valley length of 4.4 miles. The sloughs occurred on more gradual longitudinal valley slopes versus the channel segments. The sloughs immediately upstream and downstream of the study reach were carefully inspected from the ground and had multi-threaded (anastomosing) channels with discontinuous sandy or mucky beds and collections of small bars often with roughly two-inch bands of alternating white sand and muck. In effect, alluviation was occurring extensively in this system in zones located between the single-thread channels. Since the materials were being deposited in broad flats along the valley, it seems that they were not routinely available for lateral overbank deposition along the steeper channel stream linkages. The steeper segments formed deep hydraulically efficient channels with sand beds that can maintain continuity of sediment transport, but that had limited material available for overbank work because it was more readily trapped by the sloughs. This is an interesting outcome of a deranged network. Similar arrangements are described for streams in the seasonally wet-dry tropics of Australia and South Africa where they are referred to as “floodouts’ (Erskine *et al*., 2005).

Two Small sites were ascribed with one alluvial floodplain feature. Wekiva UT drained a small (0.5 square mile) basin with a varied input of runoff and seepage from its watershed. It was unconfined through a very wide and flat valley floor vegetated with cabbage palms and bottomland hardwood species with sandy organic soils. The striking flatness of the valley led to its assignment as a “valley flat” but it appears this may be erroneous, especially since the sediments were not dominantly fine-textured, and the system was more likely a colluvial wetland. Jack Creek was the remaining site ascribed as having an alluvial floodplain feature in this group. It drained a 2.7 square mile watershed of sandy scrub and some large bay swamps and appeared to have perennial seepage flow. During the study, the system also experienced at least two large spates, one of which completely blew out the culverted dirt road crossing located about 100 feet downstream of the study reach. The site had sporadic bankfull benches consisting of sandy-organic lamellae situated between sections of moss-covered biological banks. This site seems to be a transitional one, existing between gentle seepage sites lacking alluvial floodplains and those with more routine spate-dominated controls that transport and deposit sand in floodplains.

Based on the overall cluster divisions and attributes of alluvial floodplains, it would appear that a scale-dependent threshold for floodplain alluviation occurred at approximately six square miles, with an indefinite range occurring from about 2.5 to nine square miles. The indeterminate range suggests that the potential for alluviation is not strictly dependent on basin size and can be moderated by a variety of factors. The cluster and PCA results suggested that these modifiers could include variations in longitudinal valley slope and valley width, and the watershed's capacity for groundwater infiltration versus runoff generation from rainfall. Streams draining watersheds ranging from 2.5 to 9 square miles should be carefully examined for these modifiers before assuming their proper alluvial floodplain condition. True floodplain alluviation was absent from all 22 streams studied with watersheds less than 2.5 square miles in any peninsular Florida landscape setting, while all 17 non-karst streams draining watersheds in excess of nine square miles included alluvial floodplain features. The spring runs studied rarely had alluvial floodplain features, the only exception being the Weeki Wachee River which had built some bankfull benches with alternating sand and organic layers. This may not be a natural condition, as for many years the run was fed an artificial sediment load in terms of "beach" building at the mermaid attraction at the headspring. However, it does point out that areas of large spring runs receiving allochthonous sand yields have the capacity to develop at least modest alluvial features in their floodscapes.

Clusters of Streams Among Physiographic Settings

Sites were split into groups based on their physiography and then separately clustered using all non-categorical variables. Clustering of the 23 sites in the Flatwoods Group resulted in seven subgroups, readily interpretable at splits below five distance cluster units. Subgroup 1 included Fisheating and Little Haw Creeks, both with seasonally flashy, very large capacity floodscapes with sandy bed shoals in the channel and large, wide alluvial cypress bottomland floodplains with mixed organic and sandy sediments rich in alluvial features. The meander belts were well-adjusted to unconfined versus the valley flat. Subgroup 2 was closely related, but the streams were more entrenched with higher banks in association with larger valley slopes for their drainage area. They also occupied extensive flashy alluvial valleys, usually with some cypress trees mixed in with hardwood bottomland species on topographically complex floodplains rich in alluvial features. However, their floodplains were cut through otherwise confining upland bluffs, generally well-adjusted to the meander belt. This group included Horse Creek, the Manatee River, and the upper Santa Fe River. Subgroups 1 and 2 consisted of high-power, large-capacity systems draining watersheds in excess of 65 square miles.

Subgroup 3 also included systems with large alluvial bottomlands, but these systems were less flashy, less confined than Subgroup 2 and their floodplains were very flat and featureless with finely-textured mucky sediments when compared with Subgroups 1 or 2. Two of the three sites in this subgroup, Rice Creek and Tyson Creek, had bottomlands dominated by cypress trees, while Bowlegs Creek had an emergent marsh floodscape. These streams drained watersheds ranging from 20 to 50 square miles.

Subgroups 4 and 5 included sites draining smaller watersheds than the first three subgroups (5 to 17 square miles), with smaller alluvial meander belts that were variably confined and unconfined along the valley. Subgroup 4 consisted of Cow, Tenmile and Moses Creeks, all of which have small linear backswamps of mixed cypress and hardwoods with lenses of finely textured mucky sediments or sand and muck layers. Subgroup 5 included two sites, Morgan Hole and Grasshopper Slough that were transitional between alluvial and non-alluvial floodscapes. Grasshopper Slough, as previously discussed, had in-line slough segments receiving alluvial deposition. Morgan Hole has a flat valley cross-section with an occasional avulsion pool in the floodplain and fairly well-developed natural sandy levees along the banks. This places it barely into the alluvial floodplain category.

Subgroup 6 included four low-order streams without alluvial floodplains with drainage basins ranging from 0.5 to 3.2 square miles. Subgroup 6 included a single site, Blues Creek, that was fundamentally different from the rest of the sites in at least two key respects. It was bordered by high upland bluffs that extend to the bankfull stage on both banks and it was a disappearing stream that discharged into a sinkhole. The stream had cut down to a resistant clay and rock layer and, although it had some sandy alluvium on the bed with point bars, the site had obvious and abundant geologic controls too. Subgroup 7 also included six low-order streams with colluvial corridors draining small watersheds ranging from 0.2 to 2.7 square miles. Subgroups 6 and 7 were distinguishable based on channel shape (bankfull width-to-depth ratio as defined by Rosgen (1996)). Subgroup 6 W/D ratios ranged from 3.6 to 10.3 compared to Subgroup 7 which ranged from 10.4 to 86.0. Rosgen uses a W/D cut-off of 12 to distinguish his C (wide) versus E (narrow) channel forms. On this basis, all but one of the Subgroup 7 sites classified as C's and all of the Subgroup 6 sites as E's. The streams partitioned into these two Subgroups occurred across a wide array of valley confinement and associated riparian vegetation communities, including uplands and wetlands.

PCA results for this group of Flatwoods sites produced four interpretable components that cumulatively explained 65.5% of the variance. The components suggested latent variables representing channel and floodscape power and alluviation (38.3%), valley confinement (9.7%), drainage aspects of flatly-sloped wetland dominated riparian corridors (9.1%), and drainage aspects of the landscape associated with large lakes (8.3%). These variables seem to collectively represent hydraulic processes, potential for sediment transport, and their association with landscape conditions.

The latent variables and clusters suggested the dimension of the flow delivery system (watershed) and its capacity to produce flood flows that can transport and deposit alluvium in the floodplain was the main point of segregation, followed by the valley form with respect to stream entrenchment and lateral confinement. Smaller headwater channels with non-alluvial floodplains clustered separately from those with alluvial features. Colluvial stream systems appeared to further segregate based on their channel morphology.

None of the streams in the flatwoods group appeared to be erroneously clustered. However, one potential short-coming of this clustering reflects the fact that the riparian vegetative metrics in the study are categorical and therefore were excluded. This resulted in some systems with very different riparian communities being lumped together in Subgroups 6 and 7, the headwater channels. For example, 6 of the 10 small colluvial sites had much if not most of their embankments bordered by palmetto and other upland species of the flatwoods. These steeply banked, but shallow streams drain depressional wetland systems, providing wet season flow linkages across the upland plain. The other four sites were flanked by colluvial wetlands. At least for ecological purposes, these two types of bank conditions should probably be distinguished.

Clustering of sites restricted to those of the Highlands Group resulted in three interpretable subgroups of the 21 sites included. These clusters appeared to primarily split into three main groups based primarily on the inverse association of valley slope with basin size. Subgroup 1 included low-gradient streams draining the largest highlands basins, which ranged from 26 to 120 square miles. All six of these sites have at least one alluvial component in their floodplain. Subgroup 1 systems reflected different degrees of geologic confinement on their alluvial floodplains with the confined meander belts tending to develop slightly more roughness in the floodplain. Well-adjusted and unconfined forms frequently alternated along highlands valleys.

Subgroup 2 consisted of eight streams with comparatively smaller drainage systems (one to seven square miles) than the first subgroup and with generally steeper valley profiles. Most of these systems received copious, perennial groundwater seepage, but did not appear to exhibit runoff spates sufficient to develop alluvial floodplains although they had sandy shoals and other alluvial bed features. Most were flanked by lateral seepage wetlands of varying widths. Subgroup 2 also included three streams that appeared to receive occasional wet-season spates. Two of these, Hammock Branch (3.0 square miles) and Jack Creek (2.7 square miles), exhibited some floodscape alluviation.

Subgroup 3 consisted of six streams draining relatively steep headwater valleys with root-step channel morphology. Watersheds ranged from 0.3 to almost 3.0 square miles. Most of these systems tended to receive water rather directly from their adjacent uplands or sloped wetlands as well as their headwater bay swamps. The copious lateral drainage supported virtually ubiquitous biological banks and the longitudinal drainage usually commenced from a sudden, amphitheatre-like seepage escarpment in the uplands at the head of the stream. Groundwater sapping is the dominant mechanism that forms and maintains these types of valleys. One root-step variant, found only at Cypress Slash UT, differed from the others in that it had limited signs of lateral seepage and its root-steps were formed from palmettos as opposed to the more typical formations from seepage swamp hardwoods (for example, bay trees and dahoon holly). This site sat high on a ridge complex and appeared to receive its water mainly from a small headwater lake ringed by bay swamp during the wet season only.

Subgroup 3 also contained a seventh site that was incongruent with the others, Shiloh Creek, that occurred in a valley slope and landscape position similar to that of the root-step systems. Shiloh, however, lacked root-steps and was not flanked by sandy seepage slopes either longitudinally or laterally. In fact, it was flanked by upland soils with a clay sub-layer and had cut to bed clay, with a thin layer of sand up to a few inches thick above the clay. This site may be under some degree of geologic control and the high clay content in the near surface soil layers probably precluded sapping effects and groundwater seepage necessary to develop root-step morphology.

PCA results for these Highlands sites produced five components that cumulatively explained 75.0% of the variance. The components suggested latent variables representing floodplain dimension and alluviation (30.5%), stream width and associated light-loving habitats (18.2%), channel uniformity (10.6%), runoff producing soils in the watershed (8.4%), and associations of steep valley slopes and channel hydraulics (7.4%). These variables seemed to collectively represent hydraulic processes, potential for sediment transport, and their association with landscape conditions.

Much like their counterparts in the flatwoods, the dimension of the flow delivery system (watershed) and its capacity to produce flood flows that can transport and deposit alluvium in the floodplain appeared to be the main point of segregation, followed by the valley form with respect to longitudinal slope. Smaller headwater channels with non-alluvial floodplains clustered separately from those with alluvial features. The Highlands cluster revealed potential differences among steep-sloped headwater streams with root-step morphology that the cluster with all the streams from other physiographic groups failed to illicit. Clustering appeared to be rather clean, with only two sites out of 21 seemingly misplaced. In addition to the previously mentioned Shiloh Run, Ninemile Creek was a root-step seepage channel that failed to cluster with the other six root-step systems. Its watershed, at six square miles, was twice the size of the next largest root-step channel's basin. Perhaps the biggest deficiency of this Highland cluster was that lateral confinement (and the different vegetation communities associated with higher hillslopes) alternate frequently and over comparatively short distances in many highlands valleys and the clusters generally failed to distinguish streams on that basis.

Clustering of sites restricted to those of the Karst Group resulted in four interpretable subgroups of the 12 sites included. Subgroup 1A included a very wide and shallow 1st magnitude run in a low-gradient valley with dense meadows of submerged aquatic vegetation (SAV) carpeting the streambed, represented by a single site Alexander Run. Subgroup 1B also included a single site, the Weeki Wachee River, which was deep with strong current, patchy SAV and a firm sandy bed at the thalweg with detrital floc patches along the channel margins. Alexander Spring Run and the Weeki Wachee River were the only 1st Magnitude runs in the study, providing a dominant (bankfull) discharge of 122 cfs and 164 cfs respectively.

Subgroup 2 included three 2nd magnitude runs, Gum Slough, Rock, and Juniper, with deep sandy channel thalwegs of moderate resistance alternating with shallow patches of SAV meadows offering higher resistance. Light gaps were generally available and the SAV meadows often grew on lateral accumulations of detrital floc near the channel margins. Two sites, Alligator Run and Cedar Head Run, comprised Subgroup 3. These sites were closed canopied with detrital floc providing the dominant sediment substrate and very limited SAV.

Subgroup 4 consisted of the five smallest runs in the study, of 3rd or 4th magnitude. These sites were fully canopied and all but one completely lacked SAV. They generally had relatively uniform flat, broad, and shallow sandy beds with steady but gentle flow. One 3rd magnitude run in Subgroup 4, Little Levy Blue Run, differed in that it had a peat bed reflecting the fact that the run had cut through a quasi-depressional peat-filled swamp basin. The swamp trees had water stain lines indicating fairly routine “drowning” of the run by surface waters. This system was generally non-alluvial. None of the spring runs had alluvial floodplains, except for the previously discussed Weeki Wachee River.

PCA results for this group of Karst sites produced five components that cumulatively explained 83.0% of the variance. The components suggested latent variables representing channel width and associated SAV (28.2%), channel depth and related hydraulics (25.2%), potential for local allochthonous input of sand to the channel (11.5%), channel bed complexity and roughness (10.3%), and associations of steep valley slopes, channel hydraulics, and in-stream habitats (7.8%). These variables seem to collectively represent hydraulic processes, potential for sediment transport, and associations with in-stream habitats.

Splitting the Karst systems away from other stream physiographic categories was quite useful as it revealed several clusters masked by the comprehensive inventory of streams. In a common thread with the other physiographies, the spring runs clustered primarily based on the magnitude of their flow delivery system. The interactions of channel width and discharge hydraulics, sediment type, and shade appeared to be the most important considerations for classifying spring runs.

Meinzer’s (1927) spring magnitude categories (1^{st} magnitude greater than 100 cfs, 2^{nd} magnitude between 10 and 100 cfs, 3^{rd} magnitude between 1 and 10 cfs, and 4^{th} magnitude less than 1 cfs) did not appear to be directly representing flow thresholds of geomorphic significance in spring runs. The dominant discharge data and cluster analysis from this study suggested approximate alternate thresholds of greater association with run geomorphology. For example runs in the largest capacity groups (1A and 1B) had bankfull discharge from 122 to 164 cfs, while the Subgroup 2 sites ranged from 27 to 73 cfs, Subgroup 3 included sites with 7.4 and 11.3 cfs, and Subgroup 4 ranged from 0.4 to 1.9 cfs. These data cannot be used to set very precise divisions, but it is clear that most would straddle Meinzer's. The division between very large and large runs is likely to be somewhere between 73 and 122 cfs, nominally 100 cfs (plus or minus 20 cfs). The division between large and medium runs is likely to fall somewhere between 11 and 27 cfs, nominally 20 cfs (plus or minus six cfs) which falls well within the 2nd Magnitude range. The division between medium and small runs is likely to occur between 1.9 to 7.4 cfs, nominally five cfs (plus or minus two cfs).

Clusters of Streams Based on Variables from Four Scales

In the approaches discussed to this point, sites were segregated into a series of logical groups and then clustered on all variables to explore the sensitivity of the types of clusters developed without potential interference from fundamentally different sites "diluting" the analyses. The approach in this section differs in that all study sites are simultaneously considered, but logical subsets of variables are used to determine the clusters. This was done for variables associated with four different scales, in declining order; Watershed, Valley, Reach, Patch.

Watershed variables offered initial branching that segregated sites into big delivery systems versus other systems. Beyond that, these variables failed to consistently segregate sites into their alluvial floodplain characteristics, failed to distinguish root-step systems from other headwater streams, and generally lumped and split a wide variety of the small streams in no compelling fashion. Three Watershed classes were apparent. Subgroup 1 included 12 large scale systems from all three physiographies. Subgroup 2 included 19 mid-sized to small systems, all from either karst or highlands landscapes. Subgroup 3 included 25 mid-sized to small sites, mostly flatwoods systems (16), but also included four root-step systems plus four other highlands streams, and one spring run. Watershed variables provided important structure to classification data, but are by no means complete and they failed to consistently partition streams by their physiographic settings. This hierarchy of data failed to stand alone.

PCA results for the Watershed variables produced four components that cumulatively explained 74.3% of the variance. The components suggested latent variables representing watershed size (31.2%), watershed groundwater infiltration capacity (21.4%), basin slopes and magnitude of drainage dissection (10.9%), and wetland influence in the landscape (10.8%). These variables seemed to collectively represent common landscape processes important to stream sediment and water budgets. The PCA and the fundamental importance of hydrology and sediment processes suggests that Watershed variables should be included in any Florida stream classification and the CA suggests that they are far from being the only important class of variables.

Valley scale variables provided a consistently interpretable set of nine clusters. The last cluster consisted of Alexander Run. The first multi-site branch split off based on its characteristics related to large, powerful flood channels with strong alluvial floodplain features forming Subgroup 1. These valleys were typically in the higher order, downstream portions of the drainage network. All nine sites in this subgroup were either unconfined or well-adjusted within broad wetland floodscapes. Subgroup 2 consisted of two large, unconfined spring runs (Gum Slough and Juniper Run) within very wide wetlands (without alluvial floodplains).

Subgroup 3 was comprised entirely of mid-order channels with alluvial floodplains and unconfined meanders including Bowlegs Creek, South Fork of Black Creek and Tenmile Creek. Subgroup 4 consisted entirely of eight mid-order channels, seven with well-adjusted meanders in alluvial floodplains. This suggests confinement categories should be considered as a fundamentally important classifying variable for mid-order stream valleys. This makes sense because well-adjusted alluvial channels imply a high level of fluvial work was necessary to form and maintain the valley flat, while in unconfined systems less such work was required by the fluvial system to structure the valley floor.

Subgroup 5 consisted of four spring runs with little in common among their valley form other than being non-alluvial. Subgroup 6 properly captured all six groundwater-dependant root-step systems located in seepage ravines, plus one spring run in a similar ravine, Forest Spring Run. Forest Run had a single pronounced root step about 200 feet upstream of the study reach in an unusually steep part of the valley. The study reach did not have any such features as it was located in a less steeply sloped part of the valley.

Subgroup 7 consisted of two stream gullies with high clay content in their bed and banks, Shiloh Run and Blues Creek. Neither had a floodplain. Twenty low-order sites comprised Subgroup 8, only one of which (Jack Creek) had any alluvial floodplain features. As previously mentioned, Jack Creek was barely alluvial in that regard. A variety of confinement classes were represented by the 19 colluvial systems. This suggests that valley confinement should be viewed as a modifier, rather than a primary classifier for low-order streams.

PCA results for the Valley variables produced five components that cumulatively explained 70.1% of the variance. The components suggested latent variables representing floodscape flow and power and its alluviation potential (20.9%), valley dimension and its geologically-influenced complexity (19.8%), degree of dominance by wetlands in the riparian zone (13.3%), valley slope and related floodscape hydraulics (8.6%), and degree of valley confinement (7.5%). These variables seemed to represent key characteristics at the interface between stream valley bottoms and their hillslopes very well. Dimension and form associated with alluviation appeared to be well-represented too.

The PCA and CA results imply that the valley variables offer a lot of useful information for classifying streams. However, valley scale variables sometimes failed to distinguish spring runs from non-artesian systems and failed to satisfactorily distinguish sites within a large group of 20 low-order streams beyond recognizing their fundamentally colluvial valley slopes.

Reach scale variables produced seven interpretable subgroups. The clusters formed on major branches dependant mainly on channel size. The large capacity channels branch provided four subgroups. Subgroup 1 consisted of Alexander Run. Subgroup 2 consisted of the six largest blackwater streams in the study plus the Weeki Wachee River. All have deep powerful main channels with large cross-sectional areas. Subgroup 3 consisted of six wide channels draining mostly mid-sized basins including four spring runs and two highlands streams. Nine streams draining mostly mid-sized basins with comparatively narrow channel dimension comprised Subgroup 4. Three highlands streams and six flatwoods streams comprised this subgroup. The mid-sized channels seemed to mainly segregate based on channel width, with about 30 feet being the threshold.

The small capacity channels branch provided three subgroups. Subgroup 5 included five of the steepest sloped headwater streams, including four root-step systems. Subgroup 6 included four small low-gradient streams with very high width-to-depth ratios in excess of 35. Twenty-four low-order streams were lumped in Subgroup 7 with generally unremarkable depths, widths, or slopes.

The reach scale variables provided a good general framework for segregating sites based on their channel capacity and dimension. Channel conditions add value for stream classification, but no pattern emerged giving confidence that variables at this scale alone offered a complete picture. Classification schemes relying solely on reach scale variables are apt to miss key considerations of fluvial process that occur at different hierarchies of scale. Channel condition was not fully associated with important conditions occurring in the floodscape or watershed.

PCA results for the Reach variables produced five components that cumulatively explained 82.8% of the variance. The components suggested latent variables representing stream depth and associated concentrations of bankfull discharge, stream power and velocity (30.8%), channel width and its association with bend curvature (28.2%), reach valley slope and shear stress (9.5%), amount of channel complexity (horizontal and vertical channel roughness) (9.1%), and planform geometry (5.2%). These variables seemed to represent key associations in hydraulic geometry quite well.

Habitat Patch variables included mostly aquatic features such as pools and substrates deemed important for various assemblages of aquatic fauna (submerged vegetation, rocks, logs, pools, leaf packs, undercut roots, etc.) within the channel. Canopy closure was also included as it can affect in-stream habitat. Pools were divided into three categories; deep (greater than four feet deep at bankfull condition), medium (two to four feet deep), and shallow (one to two feet). Habitat variable clusters suggested eight Subgroups.

Subgroups 1 and 2 had the lowest canopy densities among the clusters. Subgroup1 consisted of spring runs with deep and medium pools that were also wide enough to reduce canopy cover to less than 39% and allow for SAV growth. Subgroup 2 consisted of a wide array of small to large blackwater streams with low canopy cover (less than 47%), a dominance of medium pools, and generally high diversity of alluvial bed features (typically four to five).

Eight of the largest channels in the study comprised Subgroup 3. These sites featured a dominance by deep pools and had abundant alluvial bed features. This subgroup included representatives from all three landscape types. A wide range of canopy cover occurred (nine to 88%).

Subgroup 4 consisted of a combination of medium sized spring runs and blackwater streams with intermediate to dense canopy closure (56% to 94%) and was mainly distinguished from other groups by having the highest large woody debris load (2.5 to 8.8 logs per 100 linear feet of channel) among the clusters. Interestingly these sites also had low to modest alluvial bed feature counts (zero to three), suggesting that the debris loads were not resulting in high levels of induced bed morphology.

Subgroup 5 was comprised of 17 sites with intermediate levels of canopy closure (most typically 65% to 85%). These sites also had a generally even distribution of pools among shallow, medium, and deep categories. They consistently presented the highest range of root habitats (19% to 63% of the total bed habitat) among groups. All other groups had less than 26% roots. This subgroup included a highly diverse array of streams ranging from small seepage-fed root-step channels to the large, deep and flashy Santa Fe River. Most of these channels were from well-adjusted or confined valleys, suggesting that confinement may promote root scour and development of root habitats.

Subgroups 6, 7, and 8 may be representing a cline of progressive canopy cover within 16 of the smallest streams in the study. These three subgroups averaged canopy cover of 74%, 85%, and 95% respectively. The subgroups also showed a potential cline of their average large woody debris loads, perhaps in direct relation to the canopy trend, of 1.6, 3.2, and 4.3 logs per 100 linear feet. The number of alluvial bed features averaged 2.7, 2.7, and 1.2 respectively. Shallow pools dominated within Subgroups 6 and 8, with medium pools dominant in Subgroup 7. Large woody debris can induce morphologic complexity in the bed, but it requires interaction with water at sufficiently high velocity to do so. The greatest bed complexity in this potential cline occurred within the intermediate Subgroup 7. The smallest streams occurred in Subgroup 8, and almost all of them were dominated by gentle groundwater flow regimes. Therefore, it seems plausible that the optimum combination of wood availability and flow capacity for inducing alluvial bed forms and creating medium pools occurred in the middle subgroup.

Habitat patches alone were poor predictors of channel type. Habitat patch variables were important for segregating spring runs and root-step systems when used in concert with variables from other scale categories. PCA results for the Habitat variables produced five components that cumulatively explained 76.3% of the variance. The components suggested latent variables representing canopy closure and suppression of SAV (21.5%), woody debris and detritus (15.8%), varied bed forms and the presence of deep pools (15.3%), root habitats and associated pools (12.5%), and simple systems with shallow pool dominance (11.1%). These variables seemed to represent key associations between bank and bed habitat components important to stream fauna. Thresholds of interaction between tree canopy and light availability in the water column, water scour and pruning of root interfaces along the banks and bed, and woody debris loads from the tree canopy to the stream bed are all examples covered by this suite of latent variables.

Each hierarchy of scale seemed to offer something unique to classification and each fell short of providing a sufficient classification alone. One important and consistent thread among all four scale groups of variables is that, in different ways, they sorted sites based on dimension. Sites formed groups related to big, medium, and small dimensionality irrespective of whether it was watershed, valley, reach, or patch variables being used. Of all the sets, valley variables provided the most consistent and complete predictions of stream classes, while reach variables offered the least consistency. Watershed scale clusters were not very interpretable beyond the earliest clusters.

Clusters of Streams on Dimensionless Variables

Size drove the development of major cluster groups in all analyses using the entire continuous variable set. Because of the important influence of dimension, it would be interesting to assess metrics where the direct affects of scale have been removed by using dimensionless variables. Such variables in fluvial geomorphology often describe shapes or forms that in some cases imply process. For example, one of the key metrics in the Rosgen classification system and other descriptive schemes for open channels is the width to depth ratio (W/D). Narrow and deep channels have low W/D ratios and broad, shallow channels have high W/D ratios. This metric does not directly correlate with the size of the channel. It is dimensionless.

All sites were clustered on the dimensionless variables, resulting in eight interpretable groupings. Interpretation was aided by examination of PCA results from the same variable set, which produced five components that cumulatively explained 62.9% of the total variance. The components suggested latent variables representing landscape infiltration potential (14.3%), flood forces relative to bankfull forces (13.9%), valley slope and associated channel shape factors (11.9%), channel canopy closure and associated bend ratios and aquatic plant distributions (11.5%), and channel roughness factors (11.3%). All of the latent variables seemed to relate to important processes and process-form associations commonly described in fluvial systems.

The “Landscape Infiltration” variable positively loaded on percent A+C soils, percent A soils, percent uplands, basin gradient, and valley hillslope gradient and negatively on percent D soil and percent wetlands in the watershed (Table 4-5). This clearly reflected the capacity of the catchment to allow for groundwater infiltration versus direct runoff. The positive association with basin and valley grades simply reflects the fact the Florida's sandy xeric uplands that allow for high infiltration rates consist of rolling relict dune complexes. This component also loaded positively on a ratio of top-of-bank height to bankfull stage. High numbers on that ratio indicate stream entrenchment or confinement. This implies that some landscape factors leading to seepage streams can also favor or associate with some forms of stream entrenchment or confinement. Root-step sapping streams are one example.

The "Relative Flood Forces" variable positively loaded on the watershed bifurcation ratio, flood/bankfull discharge ratio, flood/bankfull depth ratio, flood/bank height depth ratio, flood/bankfull power ratio, floodplain/bankfull channel width ratio, and percent pools greater than four feet deep. It loaded negatively on the flood/bankfull velocity ratio. The bifurcation ratio is a measure of how finely dissected the watershed is by its stream network. In this study, the highest bifurcation ratios generally, but not universally, occurred in the flatwoods landscapes. Finely dissected landscapes are associated with high runoff potential. That high runoff potential accentuates flow differences for the wet and dry seasons and it also suggests an overall flashier flow regime. This runoff characteristic leads to more pronounced flood flows for a given volume of rainfall and the fluvial system must be able to accommodate these flood pulses. It does so by building a floodplain. The floodplain serves to dissipate energy during flows, leading to a negative association of basin flashiness with flood/bankfull velocity ratios. The flashiness brings jet pulses to the channel leading to the formation of deep pools. Systems operating under the dominant influence of this latent variable are in direct contrast to those that tend to be buffered by watersheds favoring infiltration which is represented by the "Landscape Infiltration" variable.

The “Valley Slope Association” variable loaded positively with valley segment slope, reach valley slope, bankfull channel slope, the ratio of maximum/minimum channel depth in the study reach, the mean reach pool/riffle thalweg depth ratio, the meander belt to channel width ratio, and percent C-soil. The last two associations are hard to interpret and may be random associations, but the rest are more straightforward to discuss concerning process-form associations known to operate in fluvial systems. The component also loaded negatively with the bankfull channel width/depth ratio. Steeply sloped valleys tend to favor channels that downcut rather than widen, hence the negative association of this slope-oriented variable with the W/D ratio. Steeply sloped channels also tend to produce high levels of resistance, without which they would be planed flat by channel grading forces. That resistance was offered by root-steps and woody debris in Florida channels and these features created pronounced vertical roughness on the bed, leading to high pool/riffle depth ratios.

The “Channel Openness” variable is the inverse of the more commonly phrased “canopy closure” concept. Most streams in humid climates, but by no means all, are lined by trees. Wide channels in forested riparian zones are less fully shaded than narrow ones, permitting more light to penetrate the water surface. This latent variable loaded negatively on percent canopy closure along the stream centerline and on total closure (which is measured facing not only upstream and downstream, but also facing both banks). The variable also loaded positively on the percent aquatic substrate with SAV and on percent substrate with emergent aquatic vegetation. These two forms of aquatic herbaceous plants require ample light and are shaded out by tree canopy. The variable loaded negatively on shallow pools and positively on the mean radius-of-curvature/channel width ratio (Rc/W). The Rc/W ratio provides a sense of how tight the channel bends are compared to channel width. Rc/W ratios of 2 to 3 are considered to be the modal value that is inherently stable in alluvial channels with limited vegetative or geologic controls (Williams, 1986). Florida streams tended to support lower ratios in association with their intense strengthening of the bank with very dense sub-tropical vegetation. The negative association with shallow pools is also probably an artifact of channel dimension. Channel width is associated with discharge and higher discharge generally is also associated with increased channel depth, so wider streams are simply less likely to have shallow pools. In this case, “Channel Openess” provides process-form associations with channel dimension and pattern setting thresholds that shift the competitive balance between canopy and in-stream aquatic plants for light.

The final latent variable assessed, “Channel Roughness” loaded positively with the ratio of maximum/minimum channel cross-section area in the bankfull channel, a similar ratio comparing maximum and minimum bankfull depths in the reach, the ratio of mean pool depths versus mean riffle depths in the reach, and the ratio of the maximum to minimum channel widths measured in the reach. Channels scoring high on this variable are physically complex with high vertical and horizontal roughness. Such roughness appears to be associated with hydraulic interactions with large woody debris and live vegetation in the channel and on the banks. When vegetation and debris interact with water forces in this manner the resultant bed and bank forms are said to be “induced morphology.”

With that understanding of the latent variables, better informed discussion of the cluster analysis can proceed. The clusters appeared to divide primarily based on either basin infiltration capacity or on valley slope, with various refinements thereafter concerning channel form, canopy closure, aquatic vegetation, bend geometry, and channel complexity. Subgroup 1-A consisted of six sites with high percentages of infiltration soils (mean of 72% A+C soils) (Table 4-6). These sites had the steepest valley slopes of any group, averaging 1.4% and the lowest W/D ratios, averaging 6.6. They also had the roughest channels, averaging 3.0 on the cross-sectional area minimum/maximum ratio. All six sites had root-step channel morphology and drained small watersheds in the highlands.

Subgroup 1-B also had high watershed infiltration capacity, averaging 75% A+C soils. However, this subgroup had substantially lower average valley slopes than Subgroup 1-A at 0.2% (a factor of seven times less). The four streams in Subgroup 1-B all consisted of intermediate to large sized basins draining the highlands. They all had copious groundwater discharge with perennial flow. W/D ratios were high, averaging 26. Canopy closure was generally moderate, averaging 50% and this appeared to allow occasional patches of SAV or emergent vegetation in the channels (less than 10% of the bed). Rc/W ratios were low (mean = 1.1), mainly due to the wide channels. Channel complexity was generally low, with the min-max cross-section area ratio averaging 1.9.

Subgroup 2-A consisted of five of the six steepest sloped spring runs in the study (mean valley slope = 0.44%). These sites occurred within areas dominated by high infiltration capacity soils (mean = 95% A+C soils). Canopy closure was virtually complete, averaging 95%. SAV and emergent vegetation cover was low, both averaged less than 4%. The mean Rc/W ratio was the lowest among all subgroups at 0.9. These were the smallest spring runs in the study. Width to depth ratios were variable, and some of the bends of the more narrow channels were sometimes so tight that they simply wrapped part way around a single tree's root disk along the bank edge.

Subgroup 2-B consisted of four intermediate magnitude spring runs. These sites averaged valley slopes of 0.096%, more than four times less than that of subgroup 2-A and W/D ratios were consistently greater than 17 (mean = 27.8). Canopy closure was highly variable among the sites, averaging 63% with an associated average of 7.8% SAV and 18.6% emergent vegetation.

Subgroup 2-C had valley slopes that were about half those of Subgroup 2-B, averaging 0.043%. W/D ratios were correspondingly high, averaging 65.8, the highest among any subgroup. All three sites in this cluster were high magnitude spring runs. The wide channels allowed for sparse canopy (mean = 12%) that allowed for very high SAV (mean = 44.8%) and high emergent vegetation cover (mean = 12.1%). The 2-B and 2-C spring runs both averaged Rc/W ratios of a bit more than three, making them the highest scoring subgroups on that metric.

Subgroup 3-A consisted of six sites that averaged the lowest percentage of infiltration prone soils (6%). All were headwater streams draining wetlands in the Flatwoods, except a seeming outlier, Little Levy Spring Run. Valley slopes were variable ranging from 0.1 to almost 0.8% (mean 0.39%). Canopy closure was generally high (mean = 83%) and SAV was completely absent. Emergent vegetation, especially ferns, lizard's tail or other shade-tolerant wetland species, was present (mean bed coverage = 9%). These sites generally exhibited high bed roughness (mean channel cross-section ratio = 2.8).

Subgroup 3-B also consisted of sites with a wide range of valley slopes (range 0.11 to 0.88%, mean 0.41%). The 13 sites in this sub-group represented a catchall of large and small systems draining flatwoods and highlands basins. Percent A+C soils were variable, ranging from four to 73% (average = 38%). Some were headwater streams and others were mid-order. Gullies, perennial seepage streams, and one root-step sapping stream were in this group. These systems seemed to have small W/D ratios (mean = 9.4) and high canopy closure in common (mean = 74%). They could best be described as blackwater streams that are not wide enough to allow significant light penetration to the channel. SAV was completely absent and emergent vegetation only averaged 0.8% bed cover.

Subgroup 3-C differed from 3-A and 3-C primarily with consistently more gradual valley slopes, averaging less than 0.1%. Low slopes tended to be associated with wider and shallower channels and these sites accordingly averaged W/D of 18.5, although considerable scatter occurred. Canopy closure was quite variable, ranging from three to 91% with a mean of 50%. These were all blackwater streams and SAV was low to absent because the dark water attenuates light (mean SAV bed coverage = 1.3%), but the mix of channel widths in this subgroup apparently allowed for substantial light penetration that emergent plants could take advantage of (mean bed cover = 13.9%). Another distinguishing factor of these sites was that they averaged the greatest flood/bankfull depth ratio of among all the clusters (mean = 2.2). That suggests that the sites routinely received seasonal flood pulses with overbank water levels more than twice as high above the bed as the bankfull levels. Since this happens in most mid-order and larger streams draining flatwoods and highlands streams and such larger streams tended to occupy positions in the drainage network with gradual valley slopes, it is no surprise that this group of 15 sites consisted of 11 of the largest drainage systems in the study. However, it also included streams draining watersheds less than a few square miles.

The dimensionless variables provided clusters partially interpretable based on basin physiography, channel shape, and valley slope but did not follow this sequence along all cluster branches. Dimensionless ratios served quite well to expose some potentially important process-form associations and these kinds of variables would form an important component of any classifications system interested in representing process.

However, they served as incomplete predictors of factors related to system scale, sometimes lumping very small streams with very large ones. For example, Subgroup 3-C contained Jack Creek and Horse Creek which were spectacularly different kinds of streams that happened to have very similar flood/bankfull depth ratios (2.7 and 2.6 respectively). Jack Creek was predominantly a seepage fed stream which drained a 2.7 square mile basin in the highlands. It was eight feet wide and one foot deep at bankfull. Horse Creek drained a 219 square mile flatwoods watershed, was 38 feet wide and 4.5 feet deep under bankfull conditions. Jack Creek's bankfull discharge was five cfs and its wet-season flood channel carried 18 cfs, while Horse Creek's bankfull discharge was 230 cfs and its wet-season flood channel carried 1,330 cfs. During the wet season, one could stand in Jack's 2.7 feet of water in the channel and expect to live, but woe onto those who stand in Horse Creek's channel during the same time of year, when it would be almost 12 feet deep. So size does matter. Shape factors provided important insight concerning form-to-process considerations for stream classification, but convergence of form among different physiographic settings and frequently between streams of vastly different magnitude and alluvial processes means that other kinds of variables must also be considered.

Descriptions of Natural Kinds of Florida Streams with Delineative Criteria

The collective interpretations of the various cluster analyses strongly suggested that classification of peninsular Florida streams required variables from all four hierarchies of scale. However, perfect and seamless classification cannot be extracted from simply throwing a bunch of variables into a bin and expecting them to stratify on their own. Therefore, the classification is based on a strategic progression that starts with the physiographic setting at the watershed scale, then incorporates drainage area and valley slope in a concerted fashion, optionally followed by consideration of valley confinement, and completed using reach and patch variables as dependant variables in association with the larger hierarchies of watershed and valley scale. This approach not only takes the best of what was learned from the exploratory cluster analyses, it also allows for additional professional judgment to be incorporated based on categorical data and the some key concepts from the existing limnology-based classification schemes for Florida streams.

Highlands and flatwoods stream types are described starting with their largest riparian systems and moving upgradient. Spring runs start with those in the highest discharge magnitude categories. Thresholds were derived from the range of the apparent delineative variables within various reliable and interpretable cluster groupings. This study has identified general thresholds of alluvial controls in Florida floodplains, dependant on landscape-derived hydrology and drainage area. Based on this approach, there appears to be 15 natural kinds of low- to mid-order, alluvial-bed, single-thread stream systems in peninsular Florida. Most natural kinds were identified in the clusters conducted by assessing cases split into logical groups based on physiography and then running the analyses on all non-categorical variables. Refinements concerning the types of streams dominated by groundwater-biological interactions, such as seepage ravines with root-step morphology and larger spring runs became more apparent upon analysis using dimensionless variables.

Basin size and valley slope appear to be fundamentally important variables for understanding fluvial forms and some of the associated alluvial processes in Florida streams. They also provide easily measured or observed metrics, often with fairly clear thresholds for delineating classes of streams. Valley slope versus basin size and bankfull channel W/D ratio versus valley slope provide useful zones of confidence for determining the likely presence or absence of a single-thread alluvial channel in the landscape. Similar associations apply for flatwoods and highlands physiographies, so the cases from these two physiographies were combined to create a “blackwater” stream confidence chart applicable to streams in both physiographies (Figure 4-1). Karst systems were statistically different in those associations and so warranted separate consideration (Figure 4-2).

The basin size at which streams start to develop persistent and continuous (as opposed to small and patchy) alluvial floodplain features differs for all three basin physiographies (Table 4-4). Such features seemed to consistently appear in basins larger than five square miles in the flatwoods, while widespread alluvial floodplain features appear to typically require drainage areas of at least 20 square miles in highlands basins (Figure 4-3). Smaller localized exceptions can occur in both settings and were reliably observed in sites draining as little as 2.5 square miles. The fact that these floodplain process-form thresholds would differ between these two landscapes is consistent with findings related to statistically significant differences regarding floodplain hydraulics and floodplain dimensions of these two physiographies in association with sensitivity of regressions versus drainage area. However, the stated thresholds should be treated as tentative or nominal because no highlands basins between seven and 26 square miles were measured, so the alluvial floodplain threshold for highlands streams could be as low as seven square miles. Likewise, no flatwoods basins were measured between 3.5 and 5.5 square miles, so the threshold may be as low as 3.5 square miles for such landscape settings. Irrespective of the specific thresholds, the general comparative differences strongly suggest that flatwoods are more prone to develop alluvial floodplains at lower drainage area thresholds than their highlands counterparts, largely in association with higher wet-season flood pulses and associated capacity to transport sediments. These functional differences appear to be important, so the tentative drainage area thresholds are offered for consideration and use until such time as they can be refined. The largest local basin and largest springshed basin in the spring runs studied were 50 and 110 square miles respectively, but none supported an alluvial floodplain, providing further evidence that as landscapes shift from runoff to groundwater dominated flow delivery regimes, the drainage area thresholds and overall potential for alluvial controls in the floodplain is diminished.

Some stream types required further consideration of valley confinement or channel shape as supplementary measures, but typically those variables were not independently diagnostic. Valley confinement is highly variable across the landscape and should generally be considered as a modifier to more intrinsic classes of streams based on the three principal classifiers (physiography, valley slope, and drainage area). Valley confinement classes have been found to be of primary importance in some regions, especially Australia where associations of confinement were identified with in-stream habitats and fisheries utilization (Erskine *et al.*, 2005). We found no analogous form-form associations and the fisheries of low-order Florida streams are largely unstudied. Until evidence emerges that valley confinement should be used as a primary classifier in Florida, its use is suggested as a lower-hierarchy modifier instead.

Root-steps and biological banks are important in-stream habitat patches helpful to properly characterize some of the smallest headwater streams in highlands areas. Deep pools are associates of certain larger stream types. Dense SAV meadows also associate with particular stream settings and channel widths. However, these diagnostic in-stream habitats should probably be viewed as dependant variables rather than direct classifiers because they are associated with particular combinations of more universally determinable factors including basin physiography, valley slope, bankfull discharge, and seasonal flood discharge. Those latter factors can be determined even in altered landscapes, whereas if a stream has been cleared of its bank vegetation, channelized, or overgrazed, the habitat patches may be destroyed or unrecognizable. Habitat patch variables may therefore serve better as monitoring items to determine stream integrity or restoration success.

The first step in this delineation is to determine if the basin is draining a flatwoods, highlands, or karst physiography. The vast majority of karst spring runs and their headsprings are inventoried and mapped. Check Florida Department of Environmental Protection records if you suspect the site is a spring run. These systems have very clear water with high hardness and neutral to slightly alkaline pH. The water is typically a constant 72 degrees F. Flatwoods and highlands ecoregions can produce darkly stained water during the wet-season, usually soft with low to neutral pH. Flatwoods ecoregions generally consist of low-gradient landscapes with numerous wetlands depressions scattered within savanna-like grasslands with patches of variably dense shrubs and palmettos and usually with a scattered-open canopy of pines. Dry prairies are included in this definition. Xeric or scrubby flatwoods are not. For our purposes, a flatwoods is a system that delivers most stream flow by rainfall runoff generating wet-season pulses and extensive shallow flooding in the wetlands and riparian corridors. Highlands ecoregions generally consist of rolling sandy hills dotted with a variety of deep and shallow lakes, seepage wetlands, and some depressional wetlands. The uplands are very well-drained, resulting in a dominance of dense scrubby schlerophytic vegetation adapted to water stress. Highlands include long-leaf pine wiregrass sandhills, sand pine scrub, scrubby flatwoods, xeric oak communities and a variety of other xeric upland communities growing on thick sand layers with groundwater tables routinely several feet below the land surface.

Flatwoods hydrology is associated with the poorly drained NRCS Hydrologic Soil Group (HSG) D and not with a dominance of higher infiltration soils categorized as A and C. The delineative threshold occurs when HSG soils A+C collectively sum to less than 45% of the total soil cover in the catchment (Figure 2-8). If that is the case, then proceed to the “Streams draining the flatwoods” section. If the HSG A+C cover sums to greater than 45%, then the site should be classified in accordance with the "Streams draining the sandy highlands" section. Although an inflection in a seasonal flow flashiness index occurs near 45%, the reality is that streams draining HSG A+C soil cover close to that inflection (ranging from 40 to 50%) should be carefully considered from the perspectives of both flatwoods and highlands physiographies because they exist in a tension zone or transitional area. Low-order streams are probably less likely to differ much across that tension zones with respect to their floodplain forms and processes than the higher-order systems. Therefore, while prediction of flood-flow magnitude and discharge should be made to guide decisions related to what kind of floodplain restoration is necessary for all streams (NRCS, 2007b), this is especially important for streams draining five to 25 square mile watersheds with 40 to 50% A+C soils because that combination represents the zone of greatest uncertainty concerning the alluvial characteristics of the floodplains between highlands and flatwoods.

It is also important to consider alterations to the landscape. The apparent thresholds reported in this study were observed from data collected from some of the least altered watersheds remaining in Florida. Ditching, farming, and residential development can change the water delivery and must be considered. Altered watersheds will likely require some form of modeling to establish if their hydrologic performance has remained within the range of natural conditions. It is just as important to assess common bankfull flows, which in Florida can be equaled or exceeded frequently and for extended periods (up to 40% of the total record in perennial streams) as it is to assess basin response to comparatively uncommon storm events (with one-year, two-year and 25-year return intervals). When numerical hydrology studies would be required is a matter of site-specific engineering judgment and is beyond the scope of this research. The further a site differs from the conditions observed in this empirical study, the less applicable it becomes and the need for hydrology modeling increases. This research should not be applied to urban or suburban areas with substantial amounts of directly connected impervious area. Urban stream restoration and management simply has too many potentially confounding factors limiting the application of empirically-derived data from unpaved and un-sewered lands (Riley, 1998). This research is most applicable for rural sites or special conditions where altered watersheds can be manipulated or restored to function analogously to natural rural landscapes.

A shorthand nomenclature is provided to assist with an efficient understanding and communication of the basis for each stream class. These are basically acronyms that start with the physiography (FW = flatwoods, HL = highlands, K = karst), next add the valley type for flatwoods or highlands streams based on its degree of alluvial characteristics (for example, AFS = alluvial floodscape, CV = colluvial valley, MM = medium magnitude) or on the discharge class for karst systems, and closes with an optional channel modifier (for example, HG = high-gradient, WC = wide channel). So a FW-AFS-HG channel drains a flatwoods (FW) watershed through a highly alluvial floodscape (AFS) and the channel is a comparatively deep system associated with its high energy gradient (HG).

Some useful recurring terms have been adopted with specific definitions for this classification. First, an original term suggested by Thorpe *et al*. (2008) is the "floodscape." The floodscape is comprised of the aquatic and terrestrial components of the riparian corridor located at elevations greater than the limits of the main channel's bankfull threshold and that are connected to the main channel only when it is flowing overbank. The "flood channel" described in this dissertation provides one way to conceive of a useful kind of floodscape. Floodscapes can exist across colluvial or alluvial formations. For this study, the "alluvial floodscape" is a zone lateral to the stream channel with sufficiently routine and powerful flooding and sedimentation to create alluvial features including anabranches, levees, linear backswamps, etc.

Thorpe *et al*. (2008) also refer to the bankfull channel and all its internal components as the "riverscape," which can be used synonymously with "bankfull channel" or "alluvially-active open channel." Riverscape provides a convenient alternative terminology, as some riparian specialists refer to all open, active, bankfull channels as "rivers" with no implication of magnitude. Typically, small channels attributed with place names often include the terms Brook, Creek, Run, Branch, etc. while larger streams are often designated as Rivers. The term riverscape does not imply scale and means any active bankfull channel. The riverscape and floodscape form a "riverine landscape" which for the purposes of this research is used rather synonymously with "riparian corridor."

Nomographs are provided for each landscape class to aid in riparian system classification (for example, Figure 4-4). It should also be recognized that dashed lines were used to delineate the apparent thresholds among stream classes to symbolize the probabilistic or fuzzy nature of classification. The closer the system is to the line, the more likely it is to have shared or intermediate characteristics with the adjacent group. Furthermore, systems close to the line may occasionally be more properly classified in the adjacent group. These classes should be viewed as central tendencies more so than as absolute or rigid thresholds. They were derived to promote thought concerning common associations of fluvial form and process in Florida landscapes, not to stop it.

Streams draining flatwoods

The delineative threshold for applying this section occurs when HSG soils A+C collectively sum to less than 45% of the total soil cover in the catchment (Figure 2-8). Five of the six main classes proposed for flatwoods landscapes sort well along a plot of reach valley slope versus drainage area (Figure 4-4). While most of the classes sort neatly in association along this gradient, the two colluvial valley stream classes sort based on factors that do not strongly segregate within the range of these variables under which these stream types exist. The details are discussed under the appropriate category below, but channel shape (W/D) and drainage network positions seem to be associated with these two classes.

High-gradient alluvial floodscapes (FW-AFS-HG). FW-AFS-HG systems consist of stream corridors in comparatively high-gradient floodplains draining larger flatwoods basins. Their most notable features include a complex array of alluvial floodscape features and deep, strong-flowing blackwater riverscapes with numerous bends and deep pools (Figure 4-5). These systems typically drain watersheds in excess of 50 square miles, which evidently are large enough to routinely generate discharge volumes sufficient to transport, deposit, and otherwise rework alluvium in the vegetated floodscape. Recalling that flood power is a product of the discharge volume times the water surface slope, the comparatively high gradient of the valley slopes of these systems of at least 0.08% (or 4.2 ft/mile) helps to generate a lot of floodscape power. It is important to refer to the nomograph because the aforementioned thresholds are not as linear as a simple narrative description may imply (Figure 4-4). This is true of all of the riparian system classes among all landscape settings.

Riparian corridors with this combination of drainage area size and valley slope appear to be associated with mid-order systems crossing old marine terraces or other scarps and their valley flats are typically less than 1,000 feet wide, flanked by steep upland hillslopes. This combination of floodplain confinement and longitudinal slope promotes the deepest routine flood depths among the sites studied, in excess of nine feet. Examples from this study included Horse Creek near Arcadia, the Manatee River near Myakka Head, and the Santa Fe River near Gresham.

The combination of big floods generated from these mid-order watersheds through comparatively steep valley grades assures that the floodscapes of these systems are populated with a diverse array of alluvial floodplain features which sort into areas dominated by deposition or scour. As a result, the floodplain usually includes at least three of the following features; sandy natural levees, vegetated islands on mixed sand and detritus, anabranching channels with sandy or layered sandy and organic beds, linear backswamps with finely-textured organic soils, and oxbow pools/lakes. Most of these features run roughly parallel with the valley's main axis, so their lateral roughness does little to impede flood flows and consequently Manning's n is almost as low during flood discharge as during bankfull flow (about 0.05). Thalweg flood depths are nearly double the bankfull depths, often exceeding nine feet.

The riparian vegetation partially sorts in association with these alluvial features, increasing the plant community diversity within the riparian corridor. Common inclusions are hydric or mesic oak hammocks on islands or sandy bank levees, often with palmetto. Cypress, blackgum or popash variably occupy the linear backswamps. Valley flats can be occupied by virtually any wetland bottomland species common in Florida. The oxbow lakes sometimes have floating-leaf emergent communities. Anabranches can be vegetated by sedges or other emergent wetland plants but are usually unvegetated depending on depths and shade.

The crest of the bankfull channel is typically entrenched below the valley flat by at least half a foot and is often bordered by a pronounced sandy levee. The riverscape is several feet deep with mobile sandy shoals and a dominance of pools at least four feet deep at bankfull conditions. The channels are efficient with relatively low Manning's n values (approximately 0.05) and low W/D ratios. Depending on the amount of entrenchment below the floodplain, these riverscapes should typically classify as Rosgen E5, and sometimes B5 channels. The high stream power, ubiquitous sandy alluvium, and darkly stained waters generally preclude submerged aquatic vegetation. Habitat diversity is good and most systems offer an assortment of sandy riffles, deep pools, large woody debris, fine woody debris, leaf packs, and overhanging roots. Emergent aquatic vegetation can occur along the shallow channel margins and on point bars. Most of the channel length is bordered by wetland bottomland species (often including cypress or water hickory) or by palmettos and oaks on some of the higher sand levees.

These valley segments are typically joined by lateral stream junctions at their upstream and downstream ends, providing direct channel connections to other streams in the drainage network. Obviously, routine lateral connections between the floodscape and riverscape occur. Fauna benefitting from such combinations of lateral and longitudinal hydraulic connections would almost definitely include a wide variety of freshwater fish species from differing trophic guilds, including various aspects of their life cycles. Therefore, these systems should support diverse fisheries.

Where the reach has been directly altered, the probable occurrence of an FW-AFS-HG could be inferred from watersheds draining flatwoods landscapes within the valley slope-drainage area zone of confidence depicted on Figure 4-4. Valley flats less than 1,000 feet wide should be located between sandy bluffs at least several feet higher than the base of the floodplain. Intact reaches draining watershed-valley slope combinations in this range can be diagnosed or confirmed in the field by observation of bankfull channels with low W/D ratios (tentatively less than 15) and floodscapes with at least three kinds of alluvial floodscape features, creating a rough valley floor. Bankfull delineations in these systems require care as most appear to be variably entrenched at least a half-foot below the valley flat, which is rarely actually flat itself. This requires use of a bankfull inflection as the channel field indicator (Blanton, 2008). Banks are typically steep and more than one such “inflection” may be apparent. The lowest consistent inflection line at or above the tops of point bars is most likely to be correct. To reliably establish a bankfull profile using field indicators at these kinds of sites it is prudent to set and survey lots of pin flags and confirm bankfull stage with the lower limits of alluvial deposition at multiple points along the floodplain. Due to dense vegetation and rough topography it would be extremely tedious to properly conduct a bankfull assessment in this type of channel without use of a total station.

Low-gradient alluvial floodscapes (FW-AFS-LG). FW-AFS-LG systems are similar to FW-AFS-HG systems in terms of draining larger flatwoods basins. The main difference is that they consist of stream corridors in comparatively low-gradient valleys that are less confined by their flatter upland hillslopes, allowing for shallower flood depths. Their most notable features include a complex array of alluvial floodscape features with non-entrenched and wide meandering blackwater riverscapes with deep pools. These systems typically drain watersheds in excess of 50 square miles which routinely generate discharge volumes sufficient to transport, deposit, and otherwise rework alluvium in the vegetated floodscape. The comparatively low gradient of the valley slopes of these systems of between 0.03% to 0.07% is nevertheless sufficient to generate floodscape power necessary for alluvial sorting, but is gradual enough to promote relatively high W/D riverscapes and to retard channel entrenchment below the valley flat (Figure 4-6). These floodscapes can occur in wide valleys either under well-adjusted or unconfined conditions. Examples from this study included portions of Fisheating Creek near Palmdale and Little Haw Creek near Seville.

The big floods generated from these mid-order watersheds create floodscapes populated with a diverse and rough array of alluvial floodplain features which sort into areas dominated by deposition or scour. Friction factors are high in the floodplain (n is typically greater than 0.20) and the flood channels are much wider (typically more than 1,000 feet) and shallower than those of the FW-AFS-HG systems. The floodplain usually includes at least three of the following features; sandy natural levees, vegetated islands on mixed sand and detritus, anabranching channels with sandy, layered sandy or finely-textured organic beds, linear backswamps with finely-textured organic soils, and oxbow pools/lakes.

The riparian vegetation partially sorts in association with these alluvial features, increasing the plant community diversity within the riparian corridor. Common inclusions are hydric oak and cabbage palm hammocks on islands or sandy bank levees, sometimes with palmetto. Cypress, blackgum or popash variably occupy the linear backswamps. Valley flats can be occupied by virtually any wetland bottomland species common in Florida. The oxbow lakes often have floating-leaf emergent communities. Anabranches can be vegetated by sedges or other emergent wetland plants or unvegetated depending on depths and shade.

The bankfull channel is usually not entrenched and typically grades smoothly to the valley flat. Natural levees tend to be less pronounced and more sporadic than those of the FW-AFS-HG systems. Riverscapes are generally less than three feet deep with mobile sandy shoals and a dominance of pools at least four feet deep at bankfull conditions. The riverscape channels are much more efficient than the floodscape with relatively low Manning's n values (approximately 0.05 or less). The riverscape typically is greater than 50 feet wide with high W/D ratios (typically greater than 15). These riverscapes should classify as Rosgen C5s. Submerged aquatic vegetation can occur but will be rare or patchy and is unlikely to consist of long-lived species. Habitat diversity is good and most systems offer an assortment of sandy riffles, deep pools, large woody debris, fine woody debris, leaf packs, and overhanging roots. Emergent aquatic vegetation usually occurs along the shallow channel margins and on some point bars. Most of the channel length is bordered by wetland bottomland species, usually cypress. Some trees extend onto the active channel bed.

These low-gradient valley segments typically connect non-riverscape waterbodies such as in-line sloughs or lakes at their upstream and downstream ends, providing direct channel connections to other types of large waterbodies in the drainage network. Even lower gradient valleys in this range of drainage basin size will often take on anastomosing planforms or transition to deep sloughs with organic beds. Routine lateral connections between the floodscape and riverscape occur. Fauna benefitting from such combinations of lateral and longitudinal hydraulic connections would almost definitely include a wide variety of freshwater fish species from differing trophic guilds, including various aspects of their life cycles. Therefore, these systems should support diverse fisheries. Fauna also benefitting from combinations of lotic, paralotic, and lentic waterbodies would also benefit tremendously by these systems. Perhaps it is no coincidence that Fisheating Creek is one of the best riverine systems to observe dense aggregations of alligators and colonial wading birds in the state.

Where the reach has been directly altered, the probable occurrence of an FW-AFS-LG could be inferred from watersheds draining flatwoods landscapes in the valley slope-drainage area zone of confidence delineated on Figure 4-4. Valley flats should be well in excess of 1,000 feet wide, sometimes approaching 4,000 feet. Intact reaches draining watershed-valley slope combinations in this range can be diagnosed or confirmed in the field by observation of bankfull channels with high W/D ratios (tentatively greater than 15) that rather seamlessly grade into valley flats with floodscapes containing at least three kinds of alluvial floodscape features, creating some roughness on an otherwise flat valley floor. Unlike the FW-AFS-HG systems, bankfull field survey is uncomplicated, relying on delineation of the valley flat which occurs at the top-of-bank coincident with the bankfull stage.

Wide alluvial valley flats (FW-AF-WF). FW-AF-WF systems drain smaller flatwoods basins than the two FW-AFS classes. Their most notable features include a simple alluvial floodscape with non-entrenched and wide meandering blackwater riverscapes. These systems typically drain watersheds ranging roughly from 20 to 50 square miles which routinely generate discharge volumes sufficient to transport and deposit fine alluvium in the vegetated floodscape at valley slopes greater than 0.05%. These floodscapes can occur in wide valleys either under well-adjusted or unconfined conditions. Examples from this study included portions of Rice Creek near Springside, Tyson Creek, and Bowlegs Creek near Fort Meade.

The big floods generated from these mid-order watersheds create comparatively flat floodscapes dominated by depositional features usually several hundred feet wide (Figure 4-7). As a result, the floodplain typically is dominated by layered sandy or finely-textured organic beds and/or linear backswamps with finely-textured organic soils. Floodplain friction factors tend to be high (n greater than 0.15), with up to three feet of flooding above the bankfull stage.

The riparian vegetation can be virtually any wetland bottomland species common in Florida. Cypress is common, but not ubiquitous. Most sites are densely forested, but natural or unnatural catastrophic disturbances such as hurricanes or clear-cut logging can lead to areas vegetated by herbaceous emergent wetland plants.

The bankfull channel is usually not entrenched and typically grades smoothly to the valley flat. Natural levees tend to be less pronounced and more sporadic than those of the FW-AFS systems. Riverscapes are approximately two to three feet deep with mobile sandy shoals and a mixture of medium and deep pools. The channels are efficient with relatively low Manning's n values (approximately 0.07) and high W/D ratios (typically greater than 15). These riverscapes should classify as Rosgen C5s. Habitat diversity is good and most systems offer an assortment of sandy riffles, deep pools, large woody debris, fine woody debris, leaf packs, and overhanging roots. Emergent aquatic vegetation is present in light gaps, usually along the shallow channel margins and on some point bars. Most of the channel length is bordered by wetland bottomland species, often cypress.

These valley segments connected non-riverscape and riverscape waterbodies, providing direct channel connections to various types of flowing waterbodies in the drainage network. Lower gradient valleys in this range of drainage basin size will take on anastomosing planforms or transition to sloughs with organic beds. Routine lateral connections between the floodscape and riverscape occur. Fauna benefitting from such combinations of lateral and longitudinal hydraulic connections would almost definitely include a wide variety of freshwater fish species from differing trophic guilds, including various aspects of their life cycles. Therefore, these systems should support diverse fisheries.

Where the reach has been directly altered, the probable occurrence of an FW-AF-WF could be inferred from watersheds draining flatwoods landscapes in association with valley slope-drainage area zone of confidence depicted on Figure 4-4. Intact reaches draining watershed-valley slope combinations in this range can be diagnosed or confirmed in the field by observation of bankfull channels with high W/D ratios (tentatively greater than 15) that rather seamlessly grade into valley flats with floodscapes containing at least one kind of alluvial floodscape feature with predominantly depositional genesis. Bankfull field survey is uncomplicated, relying on delineation of the valley flat which occurs at the top-of-bank coincident with the bankfull stage.

Compact complex alluvial corridors (FW-AF-CC). FW-AF-CC systems drain smaller flatwoods basins than the FW-AF-WF class. They have alluvial floodplain features, but these may be more sporadically formed than those of the previously discussed stream types as this particular class is transitional between those rather fully-formed alluvial floodscapes and systems clearly dominated by colluvial floodscapes. FW-AF-CC systems include a variety of channel forms and dimensions meandering through partially alluvial valleys. This is a complex of small, variably alluvial systems. These systems typically drain watersheds ranging from three to 20 square miles which routinely generate discharge volumes sufficient to transport and deposit fine alluvium in the vegetated floodscape at valley slopes ranging from 0.05% to 0.5%. These floodscapes can occur in moderately wide valleys, typically less than 500 feet across, either under well-adjusted or unconfined conditions. Examples from this study included portions of Cow Creek, Moses Creek near Moultrie, Tenmile Creek, Grasshopper Slough, and Morgan Hole Creek (Figure 4-8).

The floods generated from these mostly mid-order watersheds create comparatively flat floodscapes dominated by depositional features. As a result, the floodplain usually is dominated by sandy or mixed sandy and organic soils. Floodplain friction factors tend to be low (n less than 0.10), with about one to two feet of flooding above bankfull. The most common alluvial features include small sandy levees and linear backswamps filled with either layered sandy and organic sediments or finely textured silty organic sediments.

The riparian vegetation can consist of virtually any wetland bottomland species common in Florida. Cypress is common in the backswamps, but not ubiquitous and hardwoods dominate most of the riparian corridor. Most sites are densely forested, but areas with high fire frequencies can have areas vegetated by herbaceous emergent wetland plants and pines.

The bankfull channel can be entrenched by up to a few inches, but also often grades smoothly to the valley flat. Natural levees tend to be less pronounced and more sporadic than those of the FW-AFS systems. Riverscapes are nominally two feet deep with mobile sandy shoals and a typical dominance of medium pools. The channels are efficient with relatively low Manning's n values (approximately 0.06) and variable W/D ratios. These riverscapes should typically classify as either Rosgen C5 or E5 types. Habitat diversity is good and most systems offer an assortment of sandy riffles, medium pools, large woody debris, fine woody debris, leaf packs, and overhanging roots. Emergent aquatic vegetation is present in light gaps, usually along the shallow channel margins and on some point bars. Most of the channel length is bordered by wetland bottomland species, often hardwoods.

These valley segments connected non-riverscape and riverscape waterbodies, providing direct channel connections to various types of flowing waterbodies in the drainage network. Lower gradient valleys in this range of drainage basin size will take on anastomosing planforms or transition to sloughs with organic beds. Routine lateral connections between the floodscape and riverscape occur. Fauna benefitting from such combinations of lateral and longitudinal hydraulic connections would almost definitely include a wide variety of freshwater fish species from differing trophic guilds, including various aspects of their life cycles. Therefore, these systems should support diverse fisheries.

Where the reach has been directly altered, the probable occurrence of an FW-AF-CC could be inferred from watersheds draining flatwoods landscapes in the appropriate zone of confidence depicted on Figure 4-4. Intact reaches draining watershed-valley slope combinations in this range can be diagnosed or confirmed in the field by observation of alluvial valley flats with wetland floodscapes variably and approximately between 100 and 500 feet wide containing natural levees or backswamps. Bankfull field survey is uncomplicated, relying on delineation of the valley flat or easily read bank inflections.

Narrow channels of colluvial valleys (FW-CV-NC). FW-CV-NC systems are characterized by low W/D channels that drain small flatwoods basins through colluvial floodscapes (Figure 4-9). Watersheds ranging from 0.1 to 3.0 square miles are typically large enough to create alluvial riverscapes, but rarely generate discharge volumes sufficient to transport and deposit fine alluvium in the vegetated floodscape at valley slopes ranging from 0.07% to 2%. These floodscapes can occur in a range of valley conditions, but are usually located in 2nd order positions with concave or convex profiles approaching downstream junctions with larger streams. Examples from this study included portions of Coons Bay Branch, East Fork Manatee UT 1, and Wekiva Forest UT.

The colluvial floodscapes can consist of either sand or mucky sand soils. Floodscape friction factors tend to be high (n greater than 0.10), with typically less than one foot of flooding above bankfull. The riparian vegetation usually consists of mesic or hydric hammocks or hardwood swamps. Pines and palmettos often flank most of the narrow unconfined or well-adjusted meander corridor, which is typically less than 100 feet wide and may only be a few feet wide. Most sites are densely forested, but areas with high fire frequencies can have areas vegetated by herbaceous plants and pines.

The bankfull channel is usually entrenched by up to a few inches, but also can grade smoothly to the colluvial valley flat. Riverscapes are nominally 1.5 feet deep with mobile sandy shoals often mixed with detritus. Pools tend to be a mix of shallow and medium depths. The channels have moderately high Manning's n values (typically close to 0.10) and narrow W/D ratios, typically less than 11. These riverscapes should typically classify as Rosgen E5 types. Habitat diversity varies and most systems offer an assortment of sandy riffles, shallow to medium pools, large woody debris, fine woody debris, leaf packs, and overhanging roots. Sporadic root steps or undercut large trunk roots can occur, but are usually not present. Emergent aquatic vegetation is present in light gaps, usually along the shallow channel margins. Most of the channel length is bordered by wetland bottomland species, often hardwoods and occasionally pines, cabbage palms, and palmettos. Cypress is typically absent.

These valley segments appear to provide seasonal connections among a variety of shallow non-riverscape and riverscape waterbodies upstream, providing direct channel connections to various wetlands types and streams in the upper parts of the drainage network. Downstream connections are more routinely made with larger streams as opposed to in-line waterbodies. Routine lateral connections between the floodscape and riverscape are modest. Fauna benefitting from such combinations of lateral and longitudinal hydraulic connections should include a variety of small freshwater fish species from differing trophic guilds, including various aspects of their life cycles, but the fisheries of these systems have been poorly studied.

Where the reach has been directly altered, the probable occurrence of an FW-CV-NC could be only partially inferred from watersheds draining flatwoods landscapes in the valley and drainage area zone of confidence depicted in Figure 4-4. It also is necessary to know if the stream occupies a convex or concave valley profile approaching a larger tributary. This is important because streams draining similar sized watersheds and valley slopes, but that drain headwater wetlands or that connect two wetland depressions with flat valley profiles (instead of crossing convex or concave valleys to join another stream), are inherently more likely to be FW-CV-WC channels instead of FW-CV-NC types. Intact FW-CV-NC reaches can be diagnosed or confirmed in the field by observation of narrow non-alluvial floodscapes typically much less than 100 wide, drained by tightly meandering riverscapes with W/D ratios less than 12 (Figure 4-10). Bankfull field survey is uncomplicated, relying on delineation of easily read bank inflections. To more fully understand the FW-CV-NC channels it is necessary to also understand the somewhat closely aligned FW-CV-WC channels described next.

Wide channels of colluvial valleys (FW-CV-WC). FW-CV-WC systems represent the fluvial forms most likely to be draining headwater wetlands or to be chaining together two wetland depressions along a low-order valley. They are characterized by high W/D channels that drain small flatwoods basins through colluvial floodscapes (Figure 4-11). Watersheds are similar to those of FW-VC-NC systems ranging from 0.1 to 3.0 square miles with valley slopes ranging from 0.07% to 2%. These floodscapes usually occupy 1st order positions with flat longitudinal valley profiles. Examples of FW-CV-WC systems from this study included portions of Bell UT, Lower Myakka UT 2, Lower Myakka UT 3, East Fork Manatee UT 2, Grassy UT, and Hillsborough UT.

While FW-CV-WC and FW-CV-NC riparian corridors cannot be distinguished solely on the basis of their valley slopes and basin areas, they appear to generally occupy different landscape positions along the colluvial valley portions of the watershed. The WC systems typically drain headwater wetlands in generally low gradient valleys exiting the wetland depression or they often occur between two wetland depressions in 1st order chains-of-wetlands. In contrast, the NC systems are typically further downstream, often picking up additional inflow from other small tributaries and becoming 2nd order systems. Furthermore, the NC systems tend to occupy convex or concave valleys because they often are the streams connecting chains of wetlands to a larger stream across its floodplain inflection (Figure 4-12). This means that they terminate at the relatively low base levels of larger magnitude stream channels and can therefore head cut more deeply up from the connecting junction. This head cutting process is evidently greatly resisted as the valley flattens closer to a depressional headwater or in-line wetland along a 1st order chain.

Without such head cutting, the channels near these kinds of wetlands tend to develop a wide and shallow form. It is common to probe shallow woody root disks extending all the way across the channel bed in the WC channels with dense mats of fine roots in the upper two to three inches of sandy sediment (Figure 4-13). Roots extending across the NC channels are unlikely to exhibit such shallow planar characteristics and generally lack shallow meshes of ubiquitous fine root mats across the entire bed. So in this case, bankfull W/D appears to be a functionally relevant associate of head cutting resistance in low-order colluvial valleys of the flatwoods, that functionally segregates the WC and NC channel types. That resistance appears to lose its dominance further downstream as at least one of three things occur; 1) additional 1st order streams join the network (adding flow volume energy), 2) the channel begins to cross the valley hillslope of a larger channel system and picks up slope (adding momentum energy), or 3) the channel enters the floodscape of a larger stream as it approaches its downstream junction and the larger channel system's lower base level allows or promotes headcutting (by allowing greater sediment export capacity).

The colluvial floodscapes of FW-CV-WC systems can consist of either sand or mucky sand soils with hillslopes that may or may not confine the meander belt. Floodscape friction factors tend to be high (n greater than 0.10), with typically less than one foot of flooding above bankfull. The riparian vegetation usually consists of mesic or hydric hammocks or shallow hardwood swamps (for example, those dominated by laurel oaks). Pines and palmettos often flank most of the narrow meander corridor, which is typically less than 150 feet wide and may only be a few feet wide. Most sites are densely forested, but narrow sites with high fire frequencies can be vegetated by herbaceous plants like Fakahatchee grass or sand cordgrass with copses of cabbage palms, slash pines, and often with dense wax myrtle thickets.

The bankfull channel can be entrenched by up to a few inches, but also often grades smoothly to the valley flat. Riverscapes are nominally one foot deep or less with well-rooted sandy beds often mixed with detritus. Pools tend to be shallow (less than two feet deep at bankfull). The channels have moderately high Manning's n values (typically close to 0.10) and large W/D ratios, typically greater than 11. These riverscapes should typically classify as Rosgen C5 types. Habitat diversity varies and most systems offer an assortment of sandy riffles, shallow pools, large woody debris, fine woody debris, leaf packs, and shallow root exposures. Emergent aquatic vegetation is present in light gaps, usually along the shallow channel margins. Most of the channel length is bordered by wetland bottomland species, often hardwoods and occasionally pines, cabbage palms, and palmettos. Cypress is typically absent.

These valley segments appear to provide seasonal connections between shallow depressional waterbodies, forming chains-of-wetlands in the upper parts of the drainage network. Routine lateral connections between the floodscape and riverscape are modest. Vertebrate fauna benefitting from such combinations of lateral and longitudinal hydraulic connections should include a variety of generalist freshwater fish or amphibian species from differing trophic guilds, including various aspects of their life cycles, but the aquatic fauna of these systems have been poorly studied. It is also possible that the mostly aquatic round-tailed muskrat would use such systems as travel corridors between denning populations in herbaceous wetlands.

Where the reach has been directly altered, the probable occurrence of an FW-CV-WC could be partially inferred from watersheds draining flatwoods landscapes in the range depicted on Figure 4-4. It is also necessary to verify that the valley slope is generally flat or perhaps slightly convex and that it is close to a wetland depression or is an interior link in a chain-of-wetlands. Intact reaches in the appropriate landscape and valley settings can be diagnosed or confirmed in the field by observation of narrow non-alluvial floodscapes typically less than 150 wide, drained by meandering riverscapes with W/D ratios greater than 11 (Figure 4-10). Bankfull field survey is uncomplicated, relying on delineation of the valley flat or easily read bank inflections.

Streams draining areas of sandy highlands

The delineative threshold for applying this section occurs when HSG soils A+C collectively sum to greater than 45% of the total soil cover in the catchment (Figure 2-8). All three of the main classes proposed for highlands landscapes sorted well along a plot of reach valley slope versus drainage area (Figure 4-14).

Sand ridge alluvial floodscapes (HL-AFS). HL-AFS systems drain large highlands watersheds. They have alluvial floodplain features, but these may be more sporadically formed than those of similarly large flatwoods drainage areas. HL-AFS systems include a variety of channel forms and dimensions meandering through highly varied hillslope morphologies that can rapidly and repeatedly alternate among large unconfined wetland flats, seepage slopes, and well-adjusted to partially confining sandy upland bluffs. Of all the stream systems described from this study, these seem to have the greatest overall longitudinal diversity in their valley hillslope morphology. These systems typically drain watersheds at least 15 square miles and probably more than 20, which routinely generate discharge volumes sufficient to transport and deposit fine alluvium in the vegetated floodscape at valley slopes ranging from 0.06% to 0.6%. Examples from this study included portions of Blackwater Creek near Cassia, Carter

Creek near Sebring, Catfish Creek near Lake Wales, Livingston Creek near Frostproof, the South Fork of Black Creek, and Tiger Creek near Babson Park (Figure 4-15).

The floods generated from these large watersheds create narrow floodplains which can be discontinuous and highly variable in width ranging from 50 to 500 feet wide. The floodplain usually is dominated by muck or mixed sandy and organic soils. Floodplain friction factors tend to be high (mostly greater than 0.15), with about two to three feet of flooding above bankfull stage. The most common alluvial features include small sandy benches and short backswamps filled with either layered sandy and organic sediments or finely textured silty organic sediments.

The riparian vegetation can consist of virtually any wetland bottomland species common in Florida. Cypress is common in the backswamps, but not ubiquitous and hardwoods dominate some of these riparian corridors. Most sites are densely forested, but areas with hurricane damage can have areas vegetated by herbaceous emergent wetland plants.

The bankfull channel can be entrenched by up to a few inches, but also often grades smoothly to the valley flat where it occurs. Natural levees tend to be sporadic where present. Riverscapes are variable, typically ranging from 1.5 to four feet deep with mobile sandy shoals and a typical dominance of deep pools, with some medium pools too. The channels are efficient with relatively low Manning's n values usually less than 0.06, but patches of submerged aquatic vegetation or dense debris fields are not uncommon, leading to friction factors up to 0.20. These channels tend to be at least 20 feet wide and with W/D ratios greater than 12. The riverscapes should typically classify as Rosgen C5 types, with occasional areas as B5's in highly confined valleys where the stream has created sporadic or narrow alluvial benches. Submerged aquatic vegetation was routinely encountered, covering up to 13% of the channel bed, but rarely at the densities found in karst systems of similar width. Habitat diversity is good and most systems offer an assortment of sandy riffles, large and medium pools, large woody debris, fine woody debris, and overhanging roots. Emergent aquatic vegetation is present in light gaps, usually along the shallow channel margins and on some point bars. Most of the channel length is bordered by wetland bottomland species, often hardwoods or cypress.

These valley segments connected non-riverscape and riverscape waterbodies, providing direct channel connections to various types of flowing waterbodies in the drainage network. Lakes and stream junctions were the most common. Some of these systems are best characterized as forming chains of lakes. Lateral hillslopes consist of a wide variety of vegetation zones including xeric uplands (scrub or sandhill) that meet the outer channel bends frequently, seepage swamps, or mesic oak hammocks. Routine lateral connections between the variably dimensioned floodscapes and riverscape occur. Fauna benefitting from such combinations of lateral and longitudinal hydraulic connections would almost definitely include a wide variety of freshwater fish species from differing trophic guilds, including various aspects of their life cycles. Therefore, these systems should support diverse fisheries. It appears that these riverscapes have the highest in-stream habitat diversity of any of the stream types studied along with the larger karst streams.

Where the reach has been directly altered, the probable occurrence of an HL-AFS system could be inferred from watersheds draining highlands landscapes in the zone of confidence depicted on Figure 4-14. Intact reaches draining watershed-valley slope combinations in this range can be diagnosed or confirmed in the field by observation of at least one alluvial valley feature within wetland floodscapes that vary between 50 and 500 feet wide. Bankfull field survey can be complicated, relying on delineation of the valley flat or bank inflections and requiring multiple moves to negotiate the variable and very densely vegetated bluffs constricting the narrow floodplain.

Baseflow corridors (HL-BFC). HL-BFC systems drain mid-sized highlands watersheds. They generally lack alluvial floodplain features and these systems include a variety of channel forms and dimensions meandering through highly varied hillslope morphologies that can rapidly and repeatedly alternate among large unconfined wetland flats, seepage slopes, and well-adjusted to partially confining sandy upland bluffs. These systems can be found draining a very wide range of watersheds ranging from 0.5 to perhaps 20 square miles which rarely generate discharge volumes sufficient to transport and deposit fine alluvium in the vegetated floodscape at valley slopes ranging from 0.1% to 0.7%. Examples from this study included portions of Alexander UT, Bell Creek, Hammock Branch, Jack Creek, Jumping Gully, Snell Creek, and Tiger UT. It should be noted that the study lacked sites between 10 to 20 square miles. All but the largest streams in the HL-AFS category barely exhibited consistent alluviation in their floodplains with few alluvial features. This suggests that the divide between those systems and HL-BFC without consistent floodplain alluviation is likely to be closer to 20 square miles than 10.

These systems are intermediate in form between systems which routinely receive alluvial flood pulses and those that practically never receive them. Systems within this category that drain the highest levels of A+C soils are clearly dominated by groundwater seepage, usually without any signs of floodplain alluviation. Examples include Snell Creek and Tiger UT (Figure 4-16). However, as increasing amounts of D soils and wetlands occur in the watershed, these systems can begin to pick up occasional spates that form sporadic alluvial benches at the bankfull stage. Good examples include Jack Creek and Hammock Branch (Figure 4-17). Systems with increasing influence from D soils begin to take on discontinuous floodscape forms akin to those more continuously present in the flatwoods AF-CC systems, while systems more completely dominated by baseflow regimes begin to take on wider channel forms with less alluvial floodplain work more akin to those of medium sized spring runs. The HL-BFC systems therefore seem to occupy an interesting transition that intersects important process thresholds concerning flow-regime and sediment transport gradients that exist along the groundwater versus surface water continuum and the continuum of basin scale.

The floods generated from these intermediate watersheds tend to course through narrow floodscapes less than 100 feet wide. The floodscape usually is dominated by muck, mucky sand, or mucky peat, reflecting the steady groundwater seepage and long-term saturation. Floodplain friction factors tend to be moderate (most around 0.10), with about 0.5 to one foot of flooding above bankfull stage. Alluvial features are generally absent and where present typically consist of discontinuous sandy benches or anabranches or backswamps filled with muck or mucky sands. The riparian vegetation can consist of a wide array of wetland or upland communities including pine forests, seepage swamps, mesic and hydric hammocks, and bottomland cypress. Most sites are densely forested.

The bankfull channel is usually entrenched by up to a few inches. Riverscapes are shallow, typically less than 1.5 feet deep at riffles with mobile sandy shoals and a typical dominance of medium and shallow pools. The channels have relatively high Manning's n values usually around 0.10. These channels tend to be less than 25 feet wide and the W/D ratios vary widely causing the riverscapes to typically classify as Rosgen C5 or E5 types. Submerged aquatic vegetation was absent. Habitat diversity is good and most systems offer an assortment of sandy riffles, large and medium pools, large woody debris, fine woody debris, leaf packs, and overhanging roots. Emergent aquatic vegetation is present in light gaps, usually along the shallow channel margins. Most of the channel length is bordered by wetland bottomland species, typically hardwoods or cabbage palm.

These valley segments connected non-riverscape and riverscape waterbodies, providing direct channel connections to various types of flowing waterbodies in the drainage network. Wetland and stream junctions were the most common. Almost all in-line wetlands were forested consisting of seepage slopes, depressional hardwood swamps, and cypress or hardwoods strands. Lateral hillslopes consist of a wide variety of vegetation zones including xeric uplands (scrub or sandhill) that meet the outer channel bends frequently, seepage swamps, or mesic oak hammocks. Routine to sporadic lateral connections between the variably dimensioned floodscapes and riverscape occur. Fauna benefitting from these systems probably take advantage of the perennial or nearly perennial longitudinal flow connections between waterbodies.

Where the reach has been directly altered, the probable occurrence of an HL-BFC system could be inferred from watersheds draining highlands landscapes within the zone of confidence depicted on Figure 4-14. Intact reaches draining watershed-valley slope combinations in this range can be diagnosed or confirmed in the field by observation of no more than one discontinuous alluvial valley feature within wetland floodscapes that vary between a few feet and 100 feet wide. Bankfull field survey relies on delineation of the bank inflections and is pretty straightforward.

Root-step channels (HL-RSC). HL-RSC systems drain small highlands watersheds. They lack alluvial floodplain features and are characterized by root-step morphology in valleys often formed by groundwater sapping. These systems typically drain very sandy watersheds ranging from 0.2 to 10 square miles which rarely generate discharge volumes sufficient to transport and deposit fine alluvium in the vegetated floodscape at valley slopes ranging from 0.6% to almost 3.0%. Examples from this study included portions of Cypress Slash UT, Gold Head Branch, Lake-June-In-Winter UT, Lowry Lake UT, Manatee River UT, Ninemile Creek UT, and Tuscawilla Lake UT (Figure 4-18).

These systems practically never receive alluvial spates and as a result their banks are typically constructed by biologically-mediated processes and include moss-covered live root masses growing in peat or peaty muck (Figure 4-19). These biological banks can be continuous or sporadic along the floodscape margins. The floodscape usually is dominated by narrow sapping valleys with muck, mucky sand, or mucky peat, reflecting the steady groundwater seepage and long-term saturation. Floodplain friction factors tend to be high (most around 0.25), with less than 0.5 feet of flooding above bankfull stage. Alluvial features are absent. The riparian vegetation community usually consists of seepage swamps and most sites are very densely forested thickets of vine-tied bay trees and their associates.

The bankfull channel is usually entrenched by up to a few inches. Riverscapes are shallow, typically less than 1.5 feet deep at riffles with some mobile sandy shoals mixed with detritus and a typical dominance of medium and shallow pools. The channels have very high Manning's n values usually around 0.25 caused by the presence of living root weirs that span the channel. These live weirs organize the channel into a series of irregularly spaced steps and pools. The channels tend to be less than 10 feet wide and with narrow W/D ratios usually less than 13. Rosgen C5, E5, B5, and G5.types could be encountered depending on how narrow the v-shaped sapping valley is at the surveyed cross-section. Rosgen classes are not particularly enlightening for these systems because they are not formed from alluvial processes, but rather from groundwater sapping.

Habitat diversity is good and most systems offer an assortment of large and medium pools, fine woody debris, leaf packs, and overhanging roots. Most of the channel length is bordered by seepage species (typically sweet bay, with loblolly bays, dahoon, and blackgum) and sometimes palmetto.

These valley segments generally connected headwater seepage swamps to other kinds of waterbodies, providing seepage conduits to them. Lakes and or large stream junctions were the most common downstream connections. Lateral hillslopes usually consist of seepage swamps, sometimes with mesic oak hammocks, and usually topped by scrub or sandhill communities. Very limited lateral connections occur between the riverscape and floodscape. Fauna benefitting from these systems probably take advantage of the perennial or nearly perennial longitudinal flow connections between waterbodies.

Where the reach has been directly altered, the probable occurrence of an HL-RSC system could be inferred from watersheds draining highlands landscapes within the zone of confidence depicted on Figure 4-14. Intact reaches draining watershed-valley slope combinations in this range can be verified by the presence of root-step morphology. Bankfull field survey relies on delineation of the bank inflections or root scour lines at the bottom of moss collars and is pretty straightforward for these small, steeply sloped sites.

Streams draining karst aquifers

The delineative threshold for applying this section occurs when the stream receives the majority of its normal annual discharge from an artesian karst aquifer. Spring runs not only receive water from the artesian aquifer, but that volume can be supplemented from runoff or phreatic seepage from local surface watersheds remote from the springshed. This study focused on sites likely to be dominated by their artesian discharge. Copeland (2003) describes a spring run as a stream "whose primary (>50%) source of water is from a spring, or spring group." The geomorphic relevance of this definition has not been thoroughly tested or reported in the available literature. Most of the streams in this study are likely to be receiving at least 65% of their water from springs based on the location and comparative size of their local watersheds versus their springsheds. Four of the five main classes of spring runs can be determined almost solely based on their dominant (bankfull) discharge (Figure 4-20). The only exception occurs for certain types of the largest runs.

Great magnitude, wide spring runs (K-GM-WC). K-GM-WC systems receive copious flow from large springsheds. They lack alluvial floodplain features. These systems include very wide, high capacity riverscapes that gradually meander through varied hillslope morphologies that can rapidly and repeatedly alternate among large unconfined wetland flats, seepage slopes, and well-adjusted to partially confining sandy upland bluffs. These systems typically drain springsheds delivering bankfull discharge greater than 40 cfs. The lone example from this study included part of Alexander Spring Run (Figure 4-21). Similar sites are known from other locations such as the Rainbow River and Chassahowitzka River.

The active floodscape is generally confined to a narrow band of vertical fluctuation below the top-of-bank, rarely resulting in overbank discharge to the valley floor. Flood stage is typically less than a foot above bankfull stage and the riverscape is generally entrenched by greater than a foot into its valley floor. Therefore, this run, like most other runs studied, could essentially be characterized as a special type of permanently inundated gully. The floodscape is narrow, about 20 feet wider than the riverscape, and the soils located near the surface water interface consist almost entirely of those constructed by biologically-mediated processes. These include moss-covered live root masses growing in peat or peaty muck. These biological banks tend to be rather continuous along the floodscape margins, sometimes forming hanging root-shelves protruding up to a few feet over the water surface. The floodscape usually is bordered by valley sediments with muck, mucky sand, or mucky peat, reflecting the steady groundwater seepage and long-term saturation of the riparian corridor. The riparian vegetation can consist of virtually any wetland bottomland species common in Florida.

Cypress is common along the banks, but is not ubiquitous and hardwoods dominate much of these riparian corridors. Most sites are densely forested hardwood swamps or hydric hammocks.

The bankfull channel is entrenched and is best recognized by water pruning that occurs at the vertical inflection of the roots and moss collars along the biological banks. Riverscapes typically average about two to three feet deep with mixed sand and shell beds on most of the bed and thick soft organic accumulations referred to as detrital floc along the channel margins. The channels are inefficient with high Manning's n values usually around 0.20, largely due to dense cover of submerged aquatic vegetation and emergent aquatic vegetation. These channels tend to be at least 200 feet wide with W/D ratios greater than 60, even exceeding 100. The riverscapes should typically classify as Rosgen C5 types, with occasional areas as B5's in portions of the stream valley with high sandhill or scrub bluffs. Submerged aquatic vegetation (SAV) was routinely encountered, covering approximately 60% of the channel bed, largely because canopy closure was close to zero. In addition to the SAV, habitat types include medium pools, large woody debris, fine woody debris, and overhanging roots. Emergent aquatic vegetation is present, usually along the shallow channel margins on about 20% of the bed. Most of the channel length is bordered by wetland bottomland species, often hardwoods, cypress, or cabbage palm.

These valley segments connect headwater springs to non-riverscape and riverscape waterbodies, providing direct channel connections to various types of flowing waterbodies in the drainage network. Lakes (or saltwater bays), stream junctions, or other spring clusters were the most common downstream connections. Lateral hillslopes consist of a wide variety of vegetation zones including xeric uplands (scrub or sandhill) that meet the outer channel bends occasionally, seepage swamps, or mesic oak hammocks. The fish and mollusk fauna benefitting from such runs have been well-studied and these systems support diverse fisheries and snail fauna.

The probable occurrence of a K-GM-WC system can only be partially inferred from spring runs with mean annual discharge in excess of 40 cfs (Figure 4-20). These systems differ from the other type of great magnitude system, K-GM-DC, based largely on geologic controls that are not well understood from this study. Presently, reaches draining watershed-valley slope combinations in the zone of confidence depicted on the nomograph must be confirmed in the field by observation of riverscapes with W/D ratios greater than 50 and channels at least 100 feet wide. Fortunately, not many of these stream types occur and they are all well-known. Bankfull field survey is straightforward and relies on root scour lines at bank inflections.

Great magnitude, deep spring runs (K-GM-DC). K-GM-DC systems receive copious flow from large springsheds. They generally lack alluvial floodplain features. These systems include deep, high capacity riverscapes that gradually meander through varied hillslope morphologies that can rapidly and repeatedly alternate among large unconfined wetland flats, seepage slopes, and well-adjusted to partially confining sandy upland bluffs. These systems typically drain springsheds at least 40 cfs of bankfull discharge. Examples from this study included portions of Rock Spring Run and the Weeki Wachee River (Figure 4-22). Similar sites are known from other locations such as the lower Silver River and portions of the Ichetucknee River.

The active floodscape is generally confined to a narrow band of vertical fluctuation below the top-of-bank, rarely resulting in overbank discharge to the valley floor, except at sporadic bankfull benches. Flood stage is typically less than a foot above bankfull stage and the riverscape is generally entrenched by greater than a foot into its valley floor. Therefore, these runs could essentially be characterized as a special type of permanently inundated gully. The floodscape is narrow, typically less than 20 feet wider than the riverscape except at the sporadic bankfull benches which can be as wide as 100 feet. The soils located near the surface water interface consist almost entirely of moss-covered live root masses growing in peat or peaty muck. These biological banks tend to be rather continuous along the floodscape margins, sometimes forming hanging root-shelves protruding slightly over the water surface. Bankfull benches, where they occur, usually consist of sediments with alternating bands of sand and muck, each a few inches thick. The floodscape usually is bordered by valley sediments with muck or peat, reflecting the steady groundwater seepage and long-term saturation of the riparian corridor. The riparian vegetation can consist of virtually any wetland bottomland species common in Florida. Cypress is common along the banks, but is not ubiquitous and hardwoods dominate much of these riparian corridors. Most sites are densely forested hardwood swamps or hydric hammocks.

The bankfull channel is entrenched and is best recognized by water pruning that occurs at the vertical inflection of the roots and moss collars along the biological banks. Riverscapes typically average about 2.5 to five feet deep with mixed sand and detritus on most of the bed and thick soft organic accumulations referred to as detrital floc along the channel margins. The channels are deep and efficient with Manning’s n values usually less than 0.09. These channels tend to be on the order of about 50 feet wide with W/D ratios less than 60. The riverscapes should typically classify as Rosgen C5 types, with occasional areas as E5’s or even B5’s in portions of the stream valley with high sandhill or scrub bluffs. Patches of SAV were routinely encountered, covering 30 to 40% of the channel bed. Canopy closure was less than 30%. In addition to the SAV, habitat types include deep pools, large woody debris, fine woody debris, overhanging roots, and sporadic limestone exposures. Emergent aquatic vegetation is sporadically present, usually along the shallow bankfull benches where they occur. Typical emergent vegetation includes sawgrass. Most of the channel length is bordered by wetland bottomland species, often hardwoods, cypress, or cabbage palm.

These valley segments connect headwater springs to non-riverscape and riverscape waterbodies, providing direct channel connections to various types of flowing waterbodies in the drainage network. Large swamps, stream junctions, or other spring clusters were the most common downstream connections. Lateral hillslopes consist of a wide variety of vegetation zones including xeric uplands (scrub or sandhill) that meet the outer channel bends occasionally, seepage swamps, or mesic oak hammocks. The fish and mollusk fauna benefitting from such runs have been well-studied and these systems support diverse fisheries and snail fauna.

The probable occurrence of a K-GM-DC system could be partially inferred from spring runs with mean annual discharge in excess of 40 cfs, but they differ from the other type of great magnitude system, K-GM-WC, based largely on geologic controls that are not well understood from this study. Presently, reaches draining watershed-valley slope combinations in the range depicted in Figure 4-20 must be confirmed in the field by observation of riverscapes with W/D ratios less than 60 and channels typically less than 100 feet wide (usually closer to 50 feet). Fortunately, not many of these stream types occur and they are all well-known and have large areas with apparent geomorphic integrity among local areas impacted by recreation activities, and in the case of the Weeki Wachee and Ichetucknee Rivers, by residential frontage. Bankfull field survey is straightforward and relies on root scour lines and/or bank inflections.

High magnitude spring runs (K-HM). K-HM systems receive copious flow from their springsheds, but less than the Great Magnitude sites. They generally lack alluvial floodplain features. These systems include a mix of deep and shallow, high capacity riverscapes that gradually meander through varied hillslope morphologies that can alternate among large unconfined wetland flats, seepage slopes, and well-adjusted to partially confining sandy upland bluffs. These systems typically drain springsheds delivering 20 to 40 cfs. Examples from this study included portions of Gum Slough Run and Juniper Springs Run (Figure 4-23).

The active floodscape is generally confined to a narrow band of vertical fluctuation below the top-of-bank, rarely resulting in overbank discharge to the valley floor, except at sporadic non-alluvial anabranches. Flood stage is typically less than two feet above bankfull stage and the riverscape is generally entrenched by greater than two feet into its valley floor. Therefore, these runs could essentially be characterized as a special type of permanently inundated gully. The floodscape is narrow, typically less than 20 feet wider than the riverscape except at the sporadic anabranches which can be as wide as 100 feet. The soils located near the surface water interface consist almost entirely of moss-covered live root masses growing in peat or peaty muck. These biological banks tend to be rather continuous along the floodscape margins. Anabranches, where they occur, usually consist of soft black sapric muck with very high water content. These are treeless areas not covered by the biological banks. If they are vegetated, a variety of emergent marsh vegetation is present, sometimes including sawgrass. The floodscape usually is bordered by valley sediments with muck or peat, reflecting the steady groundwater seepage and long-term saturation of the riparian corridor. The riparian vegetation can consist of virtually any wetland bottomland species common in Florida. Cypress is common along the banks, but is not ubiquitous and hardwoods dominate much of these riparian corridors. Most sites are densely forested hardwood swamps or hydric hammocks. Some of these swamps or hammocks can be spectacularly broad, measuring close to a mile wide.

The bankfull channel is entrenched and is best recognized by water pruning that occurs at the vertical inflection of the roots and moss collars along the biological banks. Riverscapes typically average about 1.5 to two feet deep with mixed sand and shell beds on most of the bed and thick soft organic accumulations referred to as detrital floc along the channel margins. The channels typically alternate repeatedly between deep and efficient zones with bare beds and shallow zones with denser SAV meadows. Manning’s n values are greater than 0.10. These channels are on the order of about 30 to 70 feet wide with W/D ratios from 20 to 50. The riverscapes should typically classify as Rosgen C5 types. Patches of SAV were routinely encountered, covering 10% to 20% of the channel bed. Canopy closure was less than 50%. In addition to the SAV, habitat types include mostly medium pools with some deep pools, large woody debris, fine woody debris, overhanging roots, some exposed limestone, and leaf packs. Emergent aquatic vegetation is sporadically present, usually along shallow bankfull benches where they occur. Typical emergent vegetation includes sawgrass. Most of the channel length is bordered by wetland bottomland species, often hardwoods, cypress, or cabbage palm. These channels exist just above the discharge threshold that tends to support runs with substantial amounts of SAV providing a clear functional distinction from systems with slightly lower discharge regimes (Figure 4-24).

These valley segments can connect headwater springs to non-riverscape and riverscape waterbodies, providing direct channel connections to various types of flowing waterbodies in the drainage network. Other spring clusters were the most common downstream connections for the sites in the study. Lateral hillslopes consist of a wide variety of vegetation zones including xeric uplands (scrub or sandhill) that meet the outer channel bends occasionally, seepage swamps, or mesic oak hammock. The fish and mollusk fauna benefitting from such runs have been well-studied and these systems support diverse fisheries and snail fauna.

The probable occurrence of a K-HM system could be inferred from spring runs within the zone of confidence depicted on Figure 4-20. Where intact, systems within this discharge regime can be confirmed in the field by observation of riverscapes with channels at least 30 feet wide, typically with at least 10% of their bed covered by SAV and a dominance of biological banks. Bankfull field survey is straightforward and relies on root scour lines and/or bank inflections.

Medium magnitude spring runs (K-MM). K-MM systems receive moderate flow from their springsheds. They lack alluvial floodplain features. These systems include closed canopy riverscapes that gradually meander through hillslope morphologies that can consist of large unconfined wetland flats, seepage slopes, or well-adjusted to partially confining upland sand or limestone bluffs. These systems typically drain springsheds delivering bankfull discharge ranging from five to 20 cfs. Examples from this study included portions of Alligator Run and Cedar Head Run (Figure 4-24).

The active floodscape is generally confined to a narrow band of vertical fluctuation below the top-of-bank, rarely resulting in overbank discharge to the valley floor. Flood stage is typically less than one foot above bankfull stage and the riverscape is generally entrenched by greater than a foot into its valley floor. Therefore, these runs could essentially be characterized as a special type of permanently inundated gully. The floodscape is narrow, typically 10 to 40 feet wider than the riverscape. The soils located near the surface water interface routinely consist of moss-covered live root masses growing in peat or peaty muck. These biological banks tend to be less continuous along the floodscape margins than the previously discussed spring run classes, alternating with areas of dense, cohesive sapric muck or mucky sand that lack the peat-filled root disks covered in moss. The floodscape usually is bordered by valley sediments with muck or peat, reflecting the steady groundwater seepage and long-term saturation of the riparian corridor. The riparian vegetation can consist of virtually any wetland bottomland species common in Florida. Cypress is uncommon along the banks, and hardwoods dominate much of these riparian corridors. Most sites are densely forested hardwood swamps or hydric hammocks..

The bankfull channel is entrenched and is best recognized by water pruning that occurs at the roots and moss collars along the biological banks and by an inflection at similar stage in the banks comprised of muck . Riverscapes typically average about 1.5

to 2.5 feet deep with mixed detrital floc and shell beds on most of the bed. Manning's n values can vary substantially (from 0.07 to 0.25) depending on the emergent aquatic vegetation and woody debris load in the channel. These channels are on the order of about 20 to 40 feet wide with W/D ratios les than 30. The riverscapes should typically classify as Rosgen C5 types. SAV was virtually absent, probably in response to canopy closures greater than 90%. Habitat types include medium pool, large woody debris, fine woody debris, overhanging roots, and leaf packs. Emergent aquatic vegetation is present, usually along the channel margins, sometimes in thick beds that comprise up to 40% of the riverscape bed. Typical emergent vegetation includes shade tolerant wetland species such as lizard's tail and never-wet. Most of the channel length is bordered by wetland bottomland species, often hardwoods, cypress, or cabbage palm. These channels exist just below the discharge threshold that tends to support runs with substantial amounts of SAV providing a clear functional distinction from systems with slightly higher discharge regimes (Figure 4-24).

These valley segments can connect headwater springs to non-riverscape and riverscape waterbodies, providing direct channel connections to various types of flowing waterbodies in the drainage network. Other spring clusters were the most common downstream connections for the sites in the study. Lateral hillslopes consist of a variety of vegetation zones including seepage swamps, mesic oak hammocks or xeric uplands. The fish and mollusk fauna of these closed canopy systems lacking SAV is less studied than those of the larger, wider runs with SAV.

The probable occurrence of a K-MM system could be inferred from spring runs within the zone of confidence depicted on Figure 4-20. Where intact, systems within this discharge regime can be confirmed in the field by observation of riverscapes with channels less than 40 feet wide, typically with less than 1.0% of their bed covered by SAV and a presence of biological banks. Bankfull field survey is straightforward and relies on root scour lines and/or bank inflections.

Low magnitude spring runs (K-LM). K-LM systems receive low flow from their springsheds. They lack alluvial floodplain features. These systems include closed canopy riverscapes that steadily trickle through seepage ravines in low-lying hammocks or swamps. These systems typically drain springsheds providing dominant discharge ranging from 0.2 to five cfs. Examples from this study included portions of Forest Spring Run, Kittridge Spring Run, Morman Branch UT, and Silver Glen UT (Figure 4-26).

The active floodscape is generally confined to a narrow band of vertical fluctuation below the top-of-bank, rarely resulting in overbank discharge to the valley floor. Flood stage is typically a few inches above bankfull stage and the riverscape is generally entrenched by greater than a foot into its valley floor. The floodscape is narrow, typically less than 30 feet wider than the riverscape and usually less than 80 feet wide, most often located at the base of much larger gradually-sloped seepage ravines. This suggests that most of these sites also receive flow input from the surficial aquifer. The soils located near the surface water interface routinely consist of moss-covered live root masses growing in peat or peaty muck. These biological banks tend to be less continuous along the floodscape margins than the previously discussed spring run classes, alternating with areas of dense, cohesive sapric muck or mucky sand that lack the peat-filled root disks covered in moss. The floodscape usually is bordered by valley sediments with muck or peat, reflecting the steady groundwater seepage and long-term saturation of the riparian corridor. The riparian vegetation usually consists of seepage slope hardwoods including bays, dahoon, and anise.

The bankfull channel is typically quite shallow, less than a foot deep at sandy riffles, and it is best recognized by water pruning that occurs at the roots and moss collars along the biological banks and by an inflection at similar stage on the banks comprised of muck. Riverscape bed materials tend to be either mixed or layered sand and detritus. Manning's n values can vary substantially but are typically greater than 0.10. These channels were generally less than 25 feet wide, with some approaching five feet. W/D ratios vary widely (seven to 50) as does the amount of confinement from the seepage ravine slopes leading to a wide array of probably rather meaningless Rosgen classifications including C5, E5, B5, G5, and F5 types. SAV was absent, probably in response to canopy closures greater than 90%. Habitat types include shallow pools, large woody debris, fine woody debris, overhanging roots, small patches of emergent vegetation, and leaf packs. Most of the channel length is bordered by wetland hardwoods and cabbage palms.

These valley segments can connect headwater springs to non-riverscape and riverscape waterbodies, providing direct channel connections to various types of flowing waterbodies in the drainage network. The fish and mollusk fauna of these low-flow closed canopy systems have been little studied.

The probable occurrence of a K-LM system could be inferred from spring runs existing within the zone of confidence depicted on Figure 4-20. Where intact, systems within this discharge regime can be confirmed in the field by observation of riverscapes with channels less than 25 feet wide, less than one foot deep, typically without SAV and with at least occasional presence of biological banks. Bankfull field survey is straightforward and relies on root scour lines and/or bank inflections.

Less common streams and unique situations

Shiloh Run and Blues Creek are functionally-confined and entrenched channels within well-drained rolling landscapes with mixed sand and clay outcroppings (Figure 4-27). These systems could be referred to as “clay gullies of colluvial valleys” (CV-CG). However, the form may be convergent from different landscape-level processes. In the case of Blues Creek, the system drains along 75 feet of relief from an in-line wetland-pond complex to an internally-drained sinkhole 2.7 miles downstream. That amount of raw valley relief was the greatest of any of the 56 sites studied. Blues Creek’s entrenchment is probably related to a period of pronounced base level lowering at the sink. The system has entrenched within its meander and thus has a highly sinuous valley with v-shaped hillslopes. Shiloh Run drains a small headwater swamp across 57 feet of relief to a junction with a larger stream valley about ¾ mile downstream. That amount of raw valley relief was second only to that of Blues Creek among the sites studied. Both of these systems appear to intersect mixed sand and clay outcrops. In addition to having some clay associated with the channel bed and hillslopes, these two streams also share share the characteristic that they drain two of the highest overall relief valleys in the study.

Little Levy Blue Spring Run created a sinuous channel with well-defined banks through an organic wetland sediment without inorganic alluvium. The channel is within the valley slope-drainage area regime and has a W/D ratio for its valley slope within the ranges that can support alluvial channels, so the bed is likely to be erosional in its genesis even though no inorganic alluvium was present. The system is also routinely “drowned” by the swamp it occupies, leading to water stain lines that have little to do with the spring flow. Another site intersecting a larger wetland bottomland, Hillsborough UT, also had a water-stain line from another waterbody (an upper terrace of the floodplain of the Hillsborough River) that was independent of the study reach’s flow regime. Hillsborough UT occupies an upland confined valley immediately upstream of the area where it enters the river terrace. So even though the system appears to be unconfined, it probably functions as a confined system in a wetland at that location. These two examples show that the interpretation of field indicators of hydrology and geomorphology require care and a diligent look upstream and downstream of the area of interest to more fully understand site conditions. What is learned from field assessments should be checked against the drainage area-valley slope regressions and other form-form factors associated with the presence or absence of alluvial channels for a give landscape class.

Conclusions

Using the thresholds and associations observed from this study, stream managers can make informed predictions of inherently self-sustaining channel and floodplain dimension and shape usually with little more than reliable knowledge concerning three site-specific variables; 1) the hydrogeologic region (or some measure of the capacity for rainfall infiltration versus runoff), 2) the stream’s drainage area, and 3) its local valley slope. It is important to understand the probabilistic nature of empirical process-form and form-form associations in fluvial systems. Nature provides for significant variability. The aim of this study was to identify recognizable thresholds and provide guidance for where the important transitions or tension zones are likely to occur. The study has identified several key threshold zones in the data including:

- Landscape Hydrologic Soil Group conditions where systems shift the balance from runoff controls to groundwater
- Threshold ranges where systems begin to form alluvial features in the floodplain associated with drainage basin area in different physiographic regions
- Channel width threshold ranges necessary to support submerged aquatic vegetation communities
- Combined valley slope and landscape characteristics associated with root-step seepage streams
- Appropriate drainage area and valley slope combinations for channels of different width-to-depth ratios
- The lower and upper limits of valley slope and drainage area beyond which the occurrence of natural stable streams with sandy beds become very unlikely.

While this classification appears to add value to our understanding of the fluvial forms found in peninsular Florida, it is not offered as the final word. It is hoped that it provides an excellent addition, building upon and refining the works of earlier Florida limnologists and geomorphologists working with streams in the peninsula, and it is expected to be refined over time.

General Benefits of Multi-Scale, Hierarchical Classification

The main benefit of a multi-scale approach is that it helped to delineate the scale-dependant limits and conditions of alluvial versus other kinds of stream channel and floodplain control processes operating in three different physiographic settings in Florida. It overcame issues related to the convergence of form that sometimes occur using shape-based classification, adding proper context for the application of Rosgen Level II classification as part of a broader hierarchy of classification metrics. It also built upon existing Florida stream classifications that are based mainly on limnological associations of water source, water quality and aquatic biota, by retaining much of the basic structure of these associations while adding a much-needed fluvial geomorphology component that takes scale seamlessly and directly into account. Large streams simply function differently than small ones and we can now attach certain meaningful and measurable physical thresholds for such scale dependencies.

The multi-scale approach to classification provides a more complete and finely-resolved characterization of the fluvial forms of Florida, providing 15 types as opposed to assigning more than 90% of streams into just two categories based only on channel shape (Rosgen C5 or E5) (Kiefer and Mossa, 2004) or four kinds based on scale-independent limnology (FNAI, 1990). This study has made it abundantly clear that stream channels and their floodplains belong to their watersheds. Stream classification in Florida is much more interesting and useful when floodscapes and their valley form are given as much emphasis as the open channels themselves. This is particularly true because certain floodscape types only occur in particular parts of the landscape. The multi-scale approach helped to discover and describe unique aspects of Florida streams, not solely as channels shaped or dimensioned in a particular way, but to identify them as whole fluvial systems with different water and sediment delivery systems, floodscapes, and channelscapes organized into self-sustaining functional process zones.

The blackwater streams occur within two main types of landscapes, highlands and flatwoods, resulting in similar dependencies of scale for bankfull channel process-form associations, but resulting in quite different floodscape forms and process thresholds associated with basin size. Nevertheless these systems can be viewed in a summary fashion as existing along a gradient of colluvial versus alluvial controls on their morphology, some of which are more greatly influenced by the amount of the annual discharge that is sourced via the surficial aquifer versus as overland runoff (Table 4-7). Karst systems differ substantially from blackwater systems because their main water delivery system is from deep underground and is typically independent of their local surface basins. The steady flow and clear water of these systems is associated with riverscape and floodscape process-form associations that consistently differ from the blackwater streams. Karst streams are perhaps best considered based on their position along gradients related to dominant discharge and associated channel width as it relates to light availability (Table 4-8). Systems dominated by groundwater flow, with limited seasonal flood spates, allow for biological controls that occur at thresholds simply not present in spate-driven systems. These biological controls lead to the formation of two of Florida's most interesting and unique fluvial forms, 1) narrow root-step sapping ravines of the highlands and 2) ultra-wide spring runs supporting SAV meadows growing on sediments created internally by the spring system itself.

Research Needed

While this classification appears to add much needed understanding of the fluvial systems and their forms found in peninsular Florida, it is not offered as the final word. The study was more exploratory rather than confirmatory in its scientific design and associated statistical methods. An ideal follow up study would involve predicting fluvial classification and dimension using the recommended metrics and conducting confirmatory measurements on a set of sites independent from the original sample.

The delineative criteria include some types of habitat patch variables thought to be associated with fluvial forces and understood to generally benefit fish and macroinvertebrates. However, it is not explicitly known what groups of aquatic fauna or particular species may associate with the suggested classes of streams or, as meta-populations, rely on specific groupings of these classes of streams and what temporal dynamics may be involved with their use. Much more study is warranted on these types of relationships. In fact, hydrobiology data may help to resolve if some of the proposed 15 fluvial forms suggested by geomorphology and hydrology should be expanded or lumped.

Some of the thresholds explored for spring runs in association with dominant discharge were necessarily fuzzy because only 12 runs were studied. These tolerance levels could likely be refined by studying sites within the ranges where gaps occurred in the dominant discharge continuum of this study. Also, this study did not attempt to identify at what basin size thresholds spring runs receiving combined runoff or surficial aquifer seepage begin to function more like blackwater streams.

This study focused on single-thread channels. It did not include multi-thread (anastomosed) channels which occur in Florida with some frequency, especially in low-gradient areas of long spring runs and in some broad, flat valleys that are parts of blackwater stream systems. Such streams, although generally outnumbered by single-thread forms, can be found virtually anywhere on the peninsula and they appear to be rather common in south Florida counties such as DeSoto, Glades, Highlands, and Okeechobee. Reference reach surveys and hierarchical study of anastomosed streams conducted in a manner similar to this one would provide an even more complete picture of the state’s fluvial forms. That concept could, of course, be fully extended to virtually all flowing waterbodies in the state, including non-alluvial channels such as sloughs, native swales, and strands. Anastomosed alluvial channels in Florida may be intermediate forms situated between more powerful alluvial single-thread channels and less powerful slough/strand/swale conveyances with fully non-alluvial beds.

The transitions between wetlands or lakes and their connecting stream channels are important in deranged networks. Our team has commenced research on such transitions to better define their properties. Several upstream and downstream connections have been surveyed and are being analyzed, but it is apparent that the low-order streams often attain a multithreaded form for up to a few hundred feet before entering or exiting a wetland. Large streams warrant further study in this regard.

This study only researched low to mid-order streams up to 330 square miles. It could be usefully expanded with study of larger rivers and spring runs. Such work would take some equipment that differs substantially from that used on wadable streams. Large streams are well-represented in Florida with long-term discharge records, but finding unaltered channels in unditched or non-urbanized watersheds could be challenging. The best that could be hoped for would be to find large stable stream channels without systematic hydrology regime changes during the last 25 years of so.

Unlike mid-order systems and higher, low-order stream gages are a relative rarity. Of the few gaged headwater streams in Florida, a large fraction are not on natural, unditched watersheds but are in urban areas. Our team has instrumented eight natural streams and a tremendous knowledge gap would be filled if those gages could be maintained for at least eight more years to obtain a 10 year discharge record. That would be a good start, but even more, perhaps 20 such sites, should be established to fully determine the flow regimes of low-order Florida streams in association with their landscape attributes.

Florida streams may have much in common with streams of the seasonal tropics, particularly those draining savannas, and other wet coastal plains or lowlands in the sub-tropics. Preliminary and ongoing research suggests that deranged networks are fairly common in tropical savannas and are significantly more common in such landscapes than in rainforests or deserts found on the same continents. This suggests a global context for Florida as one of many deranged landscapes found in strongly seasonal wet-dry, warm climates around the world. It is also possible that some lessons learned in Florida have application to temperate zones areas with large groundwater flow dominance or spatially differential surface water-groundwater interactions. Like Florida, such landscapes are often under intense agricultural or development pressure due to their moderate climate, abundance of water resources, and proximity to rivers or the coast. Areas worthy of comparative studies may include northern Australia and New Guinea savannas, sub-Saharan African lowlands, southern Brazil and adjacent areas, the Bolivian Moxos, the Venezuelan Llanos, various other savannas in South and Central America, portions of the southeastern coastal plain of the U.S. (especially the coastal plains of South Carolina, Georgia, Alabama, and Lousiana), and environments rich in karst springs wherever they occur.

Table 4-1. Site physiography, drainage area, and valley slope

Site name	Phys.	Drainage basin area (sq. mi.)	A+C soils (%)	D soils (%)	Wetlands (%)	Lakes (%)	Stream order	Reach slope (%)
Bell Creek UT	FW	0.2	0	100	3	0	1	1.437
Lower Myakka River UT 3	FW	0.4	0	100	29	0	1	0.139
East Fork Manatee UT 2	FW	0.4	15	85	10	0	1	0.250
Wekiva Forest UT	FW	0.5	44	56	24	0	2	0.183
Coons Bay Branch	FW	0.5	27	73	14	0	1	0.531
Grassy Creek UT	FW	0.8	14	82	13	4	1	0.350
East Fork Manatee UT 1	FW	0.9	17	83	11	0	2	0.244
Hillsborough River UT	FW	1.0	4	96	26	0	1	0.554
Lower Myakka River UT 2	FW	2.7	0	99	32	0	1	0.154
Blues Creek near Gainesville	FW	3.2	34	65	9	0	3	0.282
Cow Creek	FW	5.6	7	93	44	0	2	0.210
Moses Creek near Moultrie	FW	7.8	2	98	25	0	4	0.279
Grasshopper Slough Run	FW	8.7	11	89	12	0	5	0.065
Morgan Hole Creek	FW	11.0	8	92	7	0	3	0.169
Tenmile Creek	FW	16.8	7	93	30	0	9	0.124
Tyson Creek	FW	20.7	12	88	29	0	6	0.084
Rice Creek near Springside	FW	45.8	22	77	30	0	19	0.160
Bowlegs Creek near Ft Meade	FW	50.9	31	64	19	5	31	0.166
Manatee River near Myakka Head	FW	65.7	23	76	11	0	61	0.092
Santa Fe River near Graham	FW	94.1	18	70	27	12	19	0.084
Little Haw Creek near Seville	FW	106.2	20	71	33	6	5	0.066
Horse Creek near Arcadia	FW	219.0	8	91	18	0	46	0.072
Fisheating Creek at Palmdale	FW	313.0	6	94	22	0	36	0.039
Manatee River UT	HL	0.3	56	44	20	0	1	2.390
Lowry Lake UT	HL	0.3	97	3	3	0	1	0.735
Tuscawilla Lake UT	HL	0.3	51	49	13	0	1	1.039
Shiloh Run near Alachua	HL	0.4	88	11	3	0	1	1.278
Cypress Slash UT	HL	0.4	83	12	8	9	1	2.119
Lake June-In-Winter UT	HL	0.6	56	44	16	0	1	1.111
Tiger Creek UT	HL	0.9	87	8	7	6	1	0.288
Snell Creek	HL	1.7	73	26	20	0	2	0.117
Bell Creek	HL	1.9	41	59	7	0	3	0.403
Alexander UT 2	HL	2.3	52	47	15	5	1	0.705
Jack Creek	HL	2.7	55	45	20	0	2	0.403
Gold Head Branch	HL	2.8	97	2	3	1	3	1.671
Hammock Branch	HL	3.0	64	35	40	1	2	0.156
Jumping Gully	HL	4.2	63	23	14	16	2	0.799
Ninemile Creek	HL	6.8	55	22	18	18	1	1.010
South Fork Black Creek	HL	26.5	73	22	15	4	35	0.103
Carter Creek near Sebring	HL	36.0	70	15	5	14	3	0.256
Tiger Creek near Babson Park	HL	53.2	75	19	13	5	4	0.070
Catfish Creek near Lake Wales	HL	57.5	70	17	11	13	1	0.072
Blackwater Creek near Cassia	HL	118.4	48	46	26	6	27	0.019
Livingston Creek near Frostproof	HL	119.8	49	34	17	15	11	0.084
Morman Branch UT Spring Run	K	0.5	100	0	4	0	1	0.465
Silver Glen UT Spring Run	K	1.0	100	0	2	0	1	0.121
Forest Spring Run	K	1.7	90	9	2	0	1	0.335
Little Levy Blue Spring Run	K	2.1	8	92	45	0	1	0.094
Kittridge Spring Run	K	3.1	87	13	13	0	1	0.395
Cedar Head Spring Run	K	5.2	90	9	3	0	1	0.077
Alligator Spring Run	K	8.7	89	10	6	1	1	0.134
Gum Slough Spring Run	K	27.0	83	17	10	1	2	0.244
Juniper Spring Run	K	33.7	94	6	5	0	2	0.135
Weeki Wachee River	K	85.9	86	13	5	1	1	0.072
Rock Spring Run	K	100.0	95	3	3	1	1	0.050
Alexander Spring Run	K	110.0	74	22	13	4	10	0.055

Phys. = Basin physiography.
FW = flatwoods, HL = highlands K = karst.

Table 4-2. Bankfull channel dimensions

Site name	Phys.	Drainage basin area (sq. mi.)	Width (ft)	Bankfull flow (cfs)	Cross section area (sq. ft)	Mean thalweg depth (ft)	W/D ratio	Rc/W ratio
Bell Creek UT	FW	0.2	6.2	2.3	3.3	1.0	10.4	1.7
Lower Myakka River UT 3	FW	0.4	11.8	1.0	3.9	0.7	85.6	1.7
East Fork Manatee UT 2	FW	0.4	10.7	2.0	9.2	1.2	12.3	1.2
Wekiva Forest UT	FW	0.5	8.8	5.6	9.2	1.6	7.1	1.4
Coons Bay Branch	FW	0.5	6.6	2.6	5.0	1.2	10.3	2.5
Grassy Creek UT	FW	0.8	11.6	1.5	5.8	0.9	20.4	0.9
East Fork Manatee UT 1	FW	0.9	6.3	3.2	6.4	1.5	3.6	1.6
Hillsborough River UT	FW	1.0	10.6	6.1	10.2	1.6	12.6	1.5
Lower Myakka River UT 2	FW	2.7	7.7	3.6	4.0	1.0	20.0	1.3
Blues Creek near Gainesville	FW	3.2	8.5	14.0	14.0	2.5	7.5	3.0
Cow Creek	FW	5.6	12.5	20.3	15.5	1.9	13.3	2.7
Moses Creek near Moultrie	FW	7.8	12.2	20.9	25.9	3.2	6.6	1.4
Grasshopper Slough Run	FW	8.7	18.5	18.9	22.3	2.2	12.5	2.8
Morgan Hole Creek	FW	11.0	11.5	19.8	17.9	2.4	7.9	1.6
Tenmile Creek	FW	16.8	19.2	23.7	34.8	2.8	10.6	1.7
Tyson Creek	FW	20.7	23.3	10.7	28.0	1.8	24.2	1.0
Rice Creek near Springside	FW	45.8	22.6	23.2	43.5	3.3	20.1	2.0
Bowlegs Creek near Ft Meade	FW	50.9	31.7	59.1	55.9	3.3	27.5	1.9
Manatee River near Myakka Head	FW	65.7	26.9	139.9	72.9	4.1	9.6	1.8
Santa Fe River near Graham	FW	94.1	22.0	109.6	80.6	4.9	6.4	1.6
Little Haw Creek near Seville	FW	106.2	36.6	109.2	97.9	5.6	42.5	0.8
Horse Creek near Arcadia	FW	219.0	38.3	230.0	113.8	4.5	13.1	2.6
Fisheating Creek at Palmdale	FW	313.0	44.5	81.9	87.2	4.3	29.8	1.3
Manatee River UT	HL	0.3	5.1	2.5	6.2	1.5	2.4	1.1
Lowry Lake UT	HL	0.3	4.5	0.6	2.6	0.7	9.4	1.1
Tuscawilla Lake UT	HL	0.3	2.5	0.2	2.0	1.2	3.8	4.9
Shiloh Run near Alachua	HL	0.4	6.5	9.2	4.2	1.0	9.1	1.2
Cypress Slash UT	HL	0.4	6.5	0.9	1.7	0.7	10.5	1.6
Lake June-In-Winter UT	HL	0.6	6.4	1.5	5.7	1.3	7.8	1.2
Tiger Creek UT	HL	0.9	12.5	4.7	8.7	1.2	16.8	1.1
Snell Creek	HL	1.7	18.6	3.7	21.7	1.8	23.9	1.0
Bell Creek	HL	1.9	8.4	4.1	7.4	1.5	8.5	1.5
Alexander UT 2	HL	2.3	6.8	5.3	8.6	2.0	8.7	1.2
Jack Creek	HL	2.7	8.1	5.0	5.4	1.0	16.5	1.8
Gold Head Branch	HL	2.8	7.0	4.4	6.6	1.6	6.0	2.5
Hammock Branch	HL	3.0	11.3	8.1	14.3	2.2	8.4	1.8
Jumping Gully	HL	4.2	4.4	2.3	4.9	1.7	3.8	1.4
Ninemile Creek	HL	6.8	9.7	3.6	10.2	1.1	13.1	1.2
South Fork Black Creek	HL	26.5	21.0	52.3	44.4	3.4	12.9	0.9
Carter Creek near Sebring	HL	36.0	19.0	31.5	26.7	2.0	31.3	1.2
Tiger Creek near Babson Park	HL	53.2	47.2	60.9	95.4	3.8	24.3	0.7
Catfish Creek near Lake Wales	HL	57.5	59.0	45.1	66.9	2.1	32.4	1.3
Blackwater Creek near Cassia	HL	118.4	47.8	128.7	108.8	4.3	14.8	1.1
Livingston Creek near Frostproof	HL	119.8	33.3	58.8	64.1	3.6	23.3	2.8
Morman Branch UT Spring Run	K	0.5	7.3	0.4	1.4	0.3	35.0	0.8
Silver Glen UT Spring Run	K	1.0	27.2	0.8	10.1	0.6	50.0	0.6
Forest Spring Run	K	1.7	5.3	0.7	3.1	1.1	7.6	1.0
Little Levy Blue Spring Run	K	2.1	21.1	1.9	15.8	0.8	33.0	1.2
Kittridge Spring Run	K	3.1	10.5	1.8	3.5	0.6	37.0	1.0
Cedar Head Spring Run	K	5.2	23.6	7.4	25.6	1.8	17.0	3.1
Alligator Spring Run	K	8.7	43.8	11.3	61.0	2.5	30.2	4.4
Gum Slough Spring Run	K	27.0	54.5	36.4	106.8	2.8	43.0	4.2
Juniper Spring Run	K	33.7	32.1	27.1	52.7	3.0	21.0	1.2
Weeki Wachee River	K	85.9	45.8	163.6	161.2	5.7	14.5	1.9
Rock Spring Run	K	100.0	53.6	48.0	73.2	3.5	52.0	1.6
Alexander Spring Run	K	110.0	251.3	121.9	567.0	2.8	131.0	5.8

Phys. = basin physiography: FW = flatwoods, HL = highlands, K = karst.
W/D ratio based on reference reach width divided by the hydraulic depth.
Rc/W ratio is the mean radius of curvature to bankfull width for all bends in the reference reach.

Table 4-3. Flood channel dimensions and bankfull comparison ratios

Site name	Phys.	Drainage basin area (sq. mi.)	Flood width (ft)	Flood flow (cfs)	Flood/bkf depth ratio	Flood/bkf width ratio	Flood/bkf flow ratio	Flood/bkf power ratio
Bell Creek UT	FW	0.2	26	4.7	1.4	4.2	2.0	2.02
Lower Myakka River UT 3	FW	0.4	75	5.0	1.3	6.4	5.3	5.44
East Fork Manatee UT 2	FW	0.4	122	6.2	1.1	11.4	3.2	3.22
Wekiva Forest UT	FW	0.5	93	16.4	1.8	10.6	2.9	2.88
Coons Bay Branch	FW	0.5	9	5.9	1.3	1.3	2.3	2.31
Grassy Creek UT	FW	0.8	132	3.4	1.6	11.3	2.3	2.25
East Fork Manatee UT 1	FW	0.9	6	4.6	1.2	0.9	1.4	1.46
Hillsborough River UT	FW	1.0	12	9.3	1.1	1.2	1.5	1.51
Lower Myakka River UT 2	FW	2.7	87	18.2	1.8	11.3	5.1	6.44
Blues Creek near Gainesville	FW	3.2	12	29.3	1.2	1.4	2.1	2.08
Cow Creek	FW	5.6	65	67.5	1.4	5.2	3.3	3.33
Moses Creek near Moultrie	FW	7.8	418	138.4	1.9	34.3	6.6	9.60
Grasshopper Slough Run	FW	8.7	160	39.1	1.4	8.6	2.1	4.30
Morgan Hole Creek	FW	11.0	107	66.3	2.0	9.3	3.4	4.45
Tenmile Creek	FW	16.8	177	88.6	1.4	9.2	3.7	3.74
Tyson Creek	FW	20.7	246	207.7	3.3	10.5	19.4	19.57
Rice Creek near Springside	FW	45.8	834	521.9	2.4	36.9	22.5	22.53
Bowlegs Creek near Ft Meade	FW	50.9	703	234.1	1.8	22.2	4.0	3.96
Manatee River near Myakka Head	FW	65.7	882	1246.6	3.1	32.8	8.9	13.19
Santa Fe River near Graham	FW	94.1	141	516.4	2.1	6.4	4.7	4.71
Little Haw Creek near Seville	FW	106.2	3127	580.5	1.8	85.4	5.3	6.26
Horse Creek near Arcadia	FW	219.0	743	1330.8	2.6	19.4	5.8	6.14
Fisheating Creek at Palmdale	FW	313.0	3641	1018.5	1.8	81.8	12.4	12.43
Manatee River UT	HL	0.3	5	5.4	1.7	0.9	2.2	2.21
Lowry Lake UT	HL	0.3	6	1.9	1.7	1.2	3.0	3.04
Tuscawilla Lake UT	HL	0.3	3	1.0	1.3	1.2	4.8	4.50
Shiloh Run near Alachua	HL	0.4	10	20.9	1.6	1.6	2.3	2.26
Cypress Slash UT	HL	0.4	11	2.7	1.5	1.8	3.0	2.99
Lake June-In-Winter UT	HL	0.6	7	2.4	1.1	1.1	1.5	1.53
Tiger Creek UT	HL	0.9	16	7.3	1.5	1.3	1.6	1.55
Snell Creek	HL	1.7	32	5.4	1.8	1.7	1.5	1.50
Bell Creek	HL	1.9	8	6.6	1.0	1.0	1.6	1.64
Alexander UT 2	HL	2.3	28	15.7	1.3	4.1	3.0	2.96
Jack Creek	HL	2.7	78	18.0	2.7	9.7	3.6	4.78
Gold Head Branch	HL	2.8	7	6.9	1.4	1.0	1.6	1.56
Hammock Branch	HL	3.0	34	16.0	1.3	3.0	2.0	1.98
Jumping Gully	HL	4.2	4	3.0	1.0	0.9	1.3	1.29
Ninemile Creek	HL	6.8	12	5.6	1.2	1.3	1.5	1.55
South Fork Black Creek	HL	26.5	216	89.0	1.4	10.3	1.7	1.70
Carter Creek near Sebring	HL	36.0	55	94.8	2.4	2.9	3.0	4.73
Tiger Creek near Babson Park	HL	53.2	178	189.7	1.6	3.8	3.1	3.41
Catfish Creek near Lake Wales	HL	57.5	504	162.8	2.3	8.5	3.6	3.61
Blackwater Creek near Cassia	HL	118.4	410	885.1	1.7	8.6	6.9	7.23
Livingston Creek near Frostproof	HL	119.8	229	335.1	2.6	6.9	5.7	7.47
Morman Branch UT Spring Run	K	0.5	7	1.2	1.6	1.0	3.1	3.09
Silver Glen UT Spring Run	K	1.0	18	1.8	1.4	0.7	2.1	2.00
Forest Spring Run	K	1.7	67	2.7	1.6	12.6	3.9	3.77
Little Levy Blue Spring Run	K	2.1	113	9.9	2.0	5.4	5.1	5.40
Kittridge Spring Run	K	3.1	15	3.9	1.4	1.4	2.1	2.10
Cedar Head Spring Run	K	5.2	30	20.4	1.2	1.3	2.7	2.72
Alligator Spring Run	K	8.7	88	18.1	1.3	2.0	1.6	1.62
Gum Slough Spring Run	K	27.0	145	56.0	1.4	2.7	1.5	1.55
Juniper Spring Run	K	33.7	52	37.5	1.2	1.6	1.4	1.39
Weeki Wachee River	K	85.9	127	183.5	1.1	2.8	1.1	1.12
Rock Spring Run	K	100.0	54	68.3	1.1	1.0	1.4	1.42
Alexander Spring Run	K	110.0	272	247.3	1.3	1.1	2.0	2.03

Phys. = basin physiography: FW = flatwoods, HL = highlands, K = karst.

Table 4-4. Valley descriptions

Site name	Phys.	DA (sq.mi.)	MBW community	Upstream community	Downstream community	Valley confinement	Wetl. MBW ratio	AFF
Bell Creek UT	FW	0.2	Mesic hammock	Depressional marsh	Stream junction	Confined	0.3	0
Lower Myakka River UT 3	FW	0.4	Hydric hammock	Depressional marsh	Depressional marsh	Well-adjusted	1.1	0
East Fork Manatee UT 2	FW	0.4	Hydric hammock	Depressional swamp	Depressional swamp	Unconfined	4.0	0
Wekiva Forest UT	FW	0.5	Bottomland hardwoods	Seepage swamp	Stream junction	Unconfined	4.4	1
Coons Bay Branch	FW	0.5	Hydric hammock	Depressional marsh	Stream junction	Well-adjusted	1.5	0
Grassy Creek UT	FW	0.8	Cutthroat seep	Depressional marsh	Seepage swamp	Unconfined	3.8	0
East Fork Manatee UT 1	FW	0.9	Hydric hammock	Depressional marsh	Stream junction	Unconfined	2.9	0
Hillsborough River UT	FW	1.0	Mixed swamp	Depressional swamp	Slough	Unconfined	5.2	0
Lower Myakka River UT 2	FW	2.7	Hydric hammock	Depressional marsh	Depressional marsh	Well-adjusted	0.8	0
Blues Creek near Gainesville	FW	3.2	Mesic hammock	Depressional swamp	Depressional swamp	Confined	0.1	0
Cow Creek	FW	5.6	Bottomland cypress	Stream junction	Stream junction	Well-adjusted	2.0	2
Moses Creek near Moultrie	FW	7.8	Bottomland cypress	Stream junction	Stream junction	Well-adjusted	1.2	2
Grasshopper Slough Run	FW	8.7	Mesic hammock	Slough	Slough	Unconfined	0.4	0
Morgan Hole Creek	FW	11.0	Herbaceous wetland	Depressional marsh	Stream junction	Well-adjusted	1.2	2
Tenmile Creek	FW	16.8	Bottomland cypress	Stream junction	Stream junction	Unconfined	1.7	3
Tyson Creek	FW	20.7	Bottomland cypress	Slough	Stream junction	Unconfined	3.8	1
Rice Creek near Springside	FW	45.8	Bottomland cypress	Slough	Stream junction	Unconfined	3.3	2
Bowlegs Creek near Ft Meade	FW	50.9	Herbaceous wetland	Stream junction	Stream junction	Unconfined	3.7	2
Manatee River near Myakka Head	FW	65.7	Bottomland hardwoods	Stream junction	Stream junction	Well-adjusted	0.9	3
Santa Fe River near Graham	FW	94.1	Bottomland cypress	Stream junction	Stream junction	Well-adjusted	0.6	3
Little Haw Creek near Seville	FW	106.2	Bottomland cypress	Lake	Depressional swamp	Well-adjusted	1.3	3
Horse Creek near Arcadia	FW	219.0	Bottomland cypress	Stream junction	Stream junction	Well-adjusted	0.6	4
Fisheating Creek at Palmdale	FW	313.0	Bottomland cypress	Slough	Slough	Unconfined	9.5	5
Manatee River UT	HL	0.3	Seepage swamp	Seepage swamp	Stream junction	Seepage ravine	0.4	0
Lowry Lake UT	HL	0.3	Seepage swamp	Seepage swamp	Stream junction	Seepage ravine	1.8	0
Tuscawilla Lake UT	HL	0.3	Seepage swamp	Seepage swamp	Stream junction	Seepage ravine	0.2	0
Shiloh Run near Alachua	HL	0.4	Hydric hammock	Depressional swamp	Stream junction	Well-adjusted	0.7	0
Cypress Slash UT	HL	0.4	Pine flatwoods	Lake	Seepage swamp	Confined	0.3	0
Lake June-In-Winter UT	HL	0.6	Seepage swamp	Seepage swamp	Lake	Seepage ravine	1.9	0
Tiger Creek UT	HL	0.9	Seepage swamp	Seepage swamp	Slough	Unconfined	2.6	0
Snell Creek	HL	1.7	Hydric hammock	Seepage swamp	Slough	Unconfined	9.8	0
Bell Creek	HL	1.9	Seepage swamp	Stream junction	Stream junction	Unconfined	4.1	0
Alexander UT 2	HL	2.3	Mesic hammock	Depressional swamp	Depressional swamp	Confined	0.2	0
Jack Creek	HL	2.7	Seepage swamp	Depressional swamp	Seepage swamp	Unconfined	1.6	1
Gold Head Branch	HL	2.8	Seepage swamp	Seepage swamp	Lake	Seepage ravine	4.0	0
Hammock Branch	HL	3.0	Bottomland cypress	Depressional swamp	Depressional swamp	Well-adjusted	0.9	1
Jumping Gully	HL	4.2	Xeric upland	Depressional swamp	Depressional swamp	Confined	0.1	0
Ninemile Creek	HL	6.8	Seepage swamp	Seepage swamp	Depressional swamp	Seepage ravine	2.1	0
South Fork Black Creek	HL	26.5	Bottomland hardwoods	Stream junction	Stream junction	Unconfined	2.0	2
Carter Creek near Sebring	HL	36.0	Bottomland hardwoods	Lake	Seepage swamp	Well-adjusted	0.5	1
Tiger Creek near Babson Park	HL	53.2	Bottomland hardwoods	Stream junction	Lake	Well-adjusted	1.1	2
Catfish Creek near Lake Wales	HL	57.5	Bottomland cypress	Lake	Lake	Well-adjusted	0.6	1
Blackwater Creek near Cassia	HL	118.4	Bottomland cypress	Lake	Stream junction	Unconfined	2.4	1
Livingston Creek near Frostproof	HL	119.8	Bottomland hardwoods	Stream junction	Stream junction	Well-adjusted	0.8	1
Morman Branch UT Spring Run	K	0.5	Seepage swamp	Spring	Stream junction	Seepage ravine	6.1	0
Silver Glen UT Spring Run	K	1.0	Seepage swamp	Spring	Slough	Seepage ravine	0.6	0
Forest Spring Run	K	1.7	Seepage swamp	Spring	Lake	Seepage ravine	7.1	0
Little Levy Blue Spring Run	K	2.1	Bottomland hardwoods	Spring	Spring	Unconfined	2.9	0
Kittridge Spring Run	K	3.1	Seepage swamp	Spring	Stream junction	Seepage ravine	11.2	0
Cedar Head Spring Run	K	5.2	Hydric hammock	Spring	Spring	Unconfined	2.4	0
Alligator Spring Run	K	8.7	Mixed swamp	Spring	Stream junction	Unconfined	5.9	0
Gum Slough Spring Run	K	27.0	Mixed swamp	Spring	Spring	Unconfined	31.2	0
Juniper Spring Run	K	33.7	Mixed swamp	Spring	Spring	Unconfined	37.5	0
Weeki Wachee River	K	85.9	Mixed swamp	Spring	Slough	Well-adjusted	0.9	1
Rock Spring Run	K	100.0	Seepage swamp	Spring	Stream junction	Unconfined	3.6	0
Alexander Spring Run	K	110.0	Hydric hammock	Spring	Stream junction	Well-adjusted	0.8	0

Phys. = basin physiography: FW = flatwoods, HL = highlands, K = karst. DA = drainage basin area.
Wetl. MBW ratio = ratio of the riparian wetland width to the meander belt width. AFF = number of alluvial floodplain features.

Table 4-5. Principal components from dimensionless variables

	Component				
	1	2	3	4	5
A+C soils	.880				
Percent A-soil	.869				
Percent D-soil	-.866				
Percent wetlands	-.751				
Percent upland	.669				
Basin grade (ft/ft)	.599				
Bank height ratio	.550				
Hillslope grade (ft/ft)	.512				
Flood/bankfull depth ratio		.805			
Flood/bank height depth ratio		.779			
Ratio of flood to bankfull power		.776			
Ratio of flood to bankfull flow		.722			
Width ratio of floodplain and bankfull channels		.670			
Ratio of flood to bankfull velocity		-.653			
Pools >4 ft deep (%)		.626			
Bifurcation ratio		.534			
MBW to W ratio			.741		
Valley segment slope (%)			.732		
Reach valley slope (%)			.688		
Bankfull slope (ft/ft)			.666		
Ratio of max./min. reach TW depths			.642		.631
W/D ratio			-.637		
Percent C-soil			.605		
Width ratio of bank height to bankfull					
Percent canopy closure US DS				-.844	
Percent canopy closure				-.840	
Percent substrate as SAV				.681	
Mean Rc/W ratio				.657	
Percent substrate as emergent vegetation				.599	
Pools 1-2 ft deep (%)				-.539	
Valley segment sinuosity ratio					
Tightest bend ratio					
Percent substrate as bare sand					
Bankfull area max./min. ratio					.743
Bankfull mean depth max./min. ratio					.722
Bankfull width max./min. ratio					.692
Ratio of mean reach pool and riffle TW depths			.513		.681

Table 4-6. Selected variable comparisons among dimensionless clusters

Cluster	Statistic	%A+C soils	Flood/bankfull depth ratio	Valley segment slope (%)	Bankfull W/D ratio	Canopy closure	%SAV	%Veg	Reach Rc/W ratio	Mn/Mx XSA*
1-A	Mean	72	1.44	1.47	7	67%	0.0	4.3	2.09	3.0
	Std Dev	20	0.21	0.40	3	32%	0.0	10.0	1.48	0.9
1-B	Mean	75	2.02	0.20	26	50%	4.8	3.0	1.14	1.9
	Std Dev	8	0.42	0.13	7	23%	5.5	3.1	0.14	0.6
2-A	Mean	95	1.54	0.44	28	95%	0.5	3.9	0.93	2.4
	Std Dev	6	0.11	0.28	19	3%	1.1	2.9	0.19	0.8
2-B	Mean	89	1.28	0.10	28	63%	7.8	18.6	3.18	1.9
	Std Dev	5	0.08	0.06	12	38%	8.9	15.0	1.55	0.4
2-C	Mean	85	1.16	0.04	66	12%	44.8	12.1	3.10	2.2
	Std Dev	10	0.13	0.02	59	15%	15.8	10.7	2.33	1.6
3-A	Mean	6	1.55	0.39	30	83%	0.0	9.0	1.34	2.8
	Std Dev	7	0.33	0.29	28	17%	0.0	7.2	0.32	0.9
3-B	Mean	38	1.29	0.41	9	74%	0.0	0.8	1.79	2.0
	Std Dev	23	0.21	0.22	3	17%	0.0	1.8	0.69	0.7
3-C	Mean	26	2.18	0.09	18	50%	1.3	13.9	1.61	1.9
	Std Dev	22	0.56	0.06	10	30%	3.5	17.0	0.58	0.4

*Ratio of minimum to maximum channel cross-section area meaured in the reach.

%SAV = submerged aquatic vegetation. %Veg = emergent aquatic herbaceous vegetation.

Table 4-7. Summary of flatwoods and highlands riparian system types

Riparian system type		Basic descriptions			
Name	Acronym	Typical landscape position	Characteristic forms	Characteristic processes	
Root-step channels	HL-RSC	Headwaters draining thick sandy knolls in steep-sloped valleys.	Root-step channels, often in seepage ravines.	Groundwater sapping. Channel grade control & flow resistance by large root weirs.	Colluvial processes dominant
Wide channels of colluvial valleys	FW-CV-WC	Headwaters draining chains-of-wetlands in linearly sloped valleys.	Rosgen C5 channels with high W/D ratios.	In-channel sediment transport continuity (net export). Downcutting resisted by shallow root masses in bed.	Colluvial processes dominant
Narrow channels of colluvial valleys	FW-CV-NC	Headwaters connecting chains-of-wetlands to mid-order streams across convex or concave valley slopes.	Rosgen E5 channels with low W/D ratios.	In-channel sediment transport continuity (net export). Friction resistance due to channel narrowing.	Colluvial processes dominant
Baseflow corridors	HL-BFC	Larger headwaters and middle areas dominated by sandy knolls and large lakes. Can have varying amounts of flatwoods and wetland inclusions.	Wide variety of small to medium capacity channel forms. Small to non-existent alluvial floodplains.	Extended baseflow through most of the year or perennially. Varying degrees of infrequent spates and associated alluviation.	Transition
Compact complex alluvial corridors	FW-AF-CC	Middle basins dominated by flatwoods and wetlands.	Wide variety of small to medium capacity channel forms with sporadic to continuous simple alluvial floodplains.	Highly variable seasonal flow with routine wet-season spates and associated alluviation.	Transition
Wide alluvial valley flats	FW-AF-WF	Wide, flatly sloped valleys in middle and lower basins dominated by flatwoods and wetlands.	Generally wide and shallow channels within very broad and relatively featureless valley fills. Good continuity of alluvial features in the floodplain.	Floodplain deposition of fine textured materials.	Alluvial processes dominant
Sand-ridge alluvial floodscapes	HL-AFS	Lower basins dominated by sandy knolls and large lakes.	Variety of high-capacity channel forms with at least small, continuous alluvial floodplains. Complex alternations of confined and unconfined valleys.	Copious perennial baseflow with sporadic wet season spates.	Alluvial processes dominant
High-gradient alluvial floodscapes	FW-AFS-HG	Moderately sloped valleys in lower basins dominated by flatwoods and wetlands.	Deep powerful channels with well-fit meanders in alluvially complex floodplains. Often Rosgen E5.	Mixed floodscape deposition and scour during routine wet-season floods. Large annual vertical flood fluctuations.	Alluvial processes dominant
Low-gradient alluvial floodscapes	FW-AFS-LG	Low-sloped valleys in basins dominated by flatwoods and wetlands.	Wide powerful channels with well-fit or underfit meanders in wide alluvial floodplains. Often Rosgen C5.	Floodscape deposition during routine wet-season floods. Large annual horizontal flood fluctuations.	Alluvial processes dominant
Colluvial valley clay gullies	CV-CG	Steeply sloped valleys with low-base levels intersecting Hawthorne (clay) or similar outcroppings.	Streams with mixed sand, clay, and rubble beds generally entrenched in V-shaped valleys.	Gullying due to high relief. Floodplain construction restricted by dense cohesive bank materials.	Other

Table 4-8. Summary of karst riparian system types

Riparian system type		Basic descriptions			
Name	Acronym	Typical landscape position	Characteristic forms	Characteristic processes	
Low-magnitude spring runs	K-LM	Seepage coves, seepage ravines, and the valleys of larger streams (yazoos). Often in association with other springheads.	Closed canopy. Small, shallow, sandy beds flanked by sporadic to continuous biological banks.	Low, steady, perennial discharge. Sand ripple bedforms common over shallow root systems in bed. No signs of autochthonous sedimentation. Light limitations prevent SAV establishment.	Light limited
Medium magnitude spring runs	K-MM	Often feeding larger runs downstream via simple valleys.	Closed canopy. Medium, shallow, mixed sand and detrital floc beds flanked by sporadic to continuous biological banks.	Steady perennial discharge. Some autochthonous sedimentation from snails and detritus. Light limitations prevent SAV establishment, but shade-tolerant emergents present.	
High magnitude spring runs	K-HM	Long complex valleys with alternating bottomland swamps, seepage slopes, and/or high sandy bluffs.	Variably open canopy. Complex alternating shallow and deep channel zones. Detrital floc sorted along channel margins in deep zones and across the bed in shallow zones. Sand common. Biological banks common.	Copious perennial discharge. Internal and external sedimentation. Light gaps allow for some SAV establishment. Variability in SAV, deep pools, and bed material sorting probably reflects the fact that no one process dominates.	Transition
Great magnitude, deep spring runs	K-GM-DC	Low-lying complex valleys with alternating bottomland swamps, seepage slopes, and/or high sandy bluffs. Usually discharging to a large river, lake, or coast.	Open canopy. Deep powerful channels, with deep pools and detrital floc sorted to channel margins. Biological banks largely continuous except at anabranches. Sporadic rock outcroppings.	Very copious perennial discharge. Geologic controls may be allowing hydraulic establishment of deep efficient channels. Internal and external sedimentation.	High light availability
Great magnitude, wide spring runs	K-GM-W	Low-lying complex valleys with alternating bottomland swamps, seepage slopes, and/or high sandy bluffs. Usually discharging to a large river, lake, or coast.	Very wide channels with relatively uniform cross-sections and dominance of SAV on mixed sand, detritus, and detrital floc bed. Biological banks dominant.	Very copious perennial discharge. Geologic factors may be allowing biological controls to occupy wide inefficient channels. Internal and external sedimentation.	

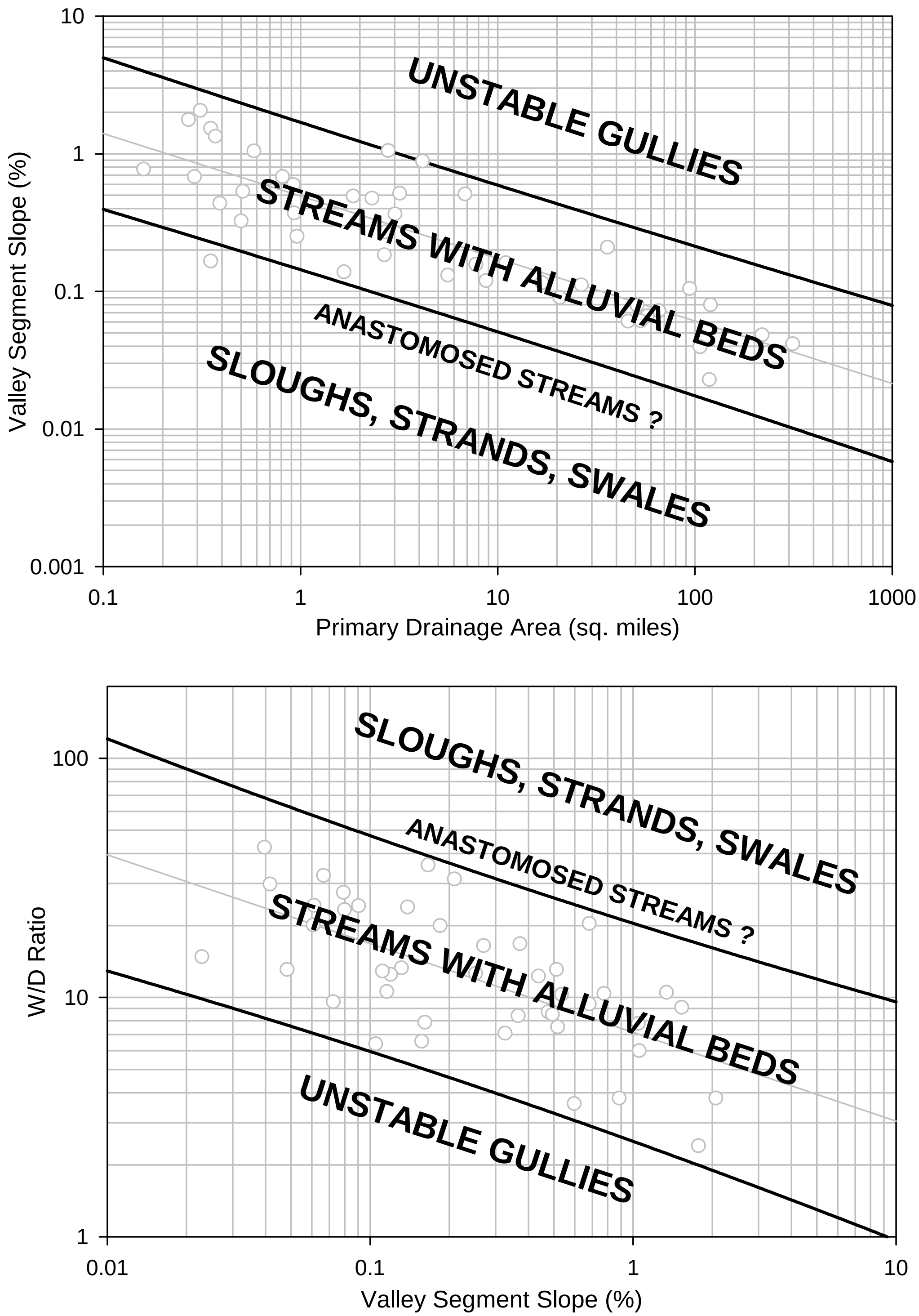


Figure 4-1. Single channel blackwater stream zone of confidence (95% prediction interval).

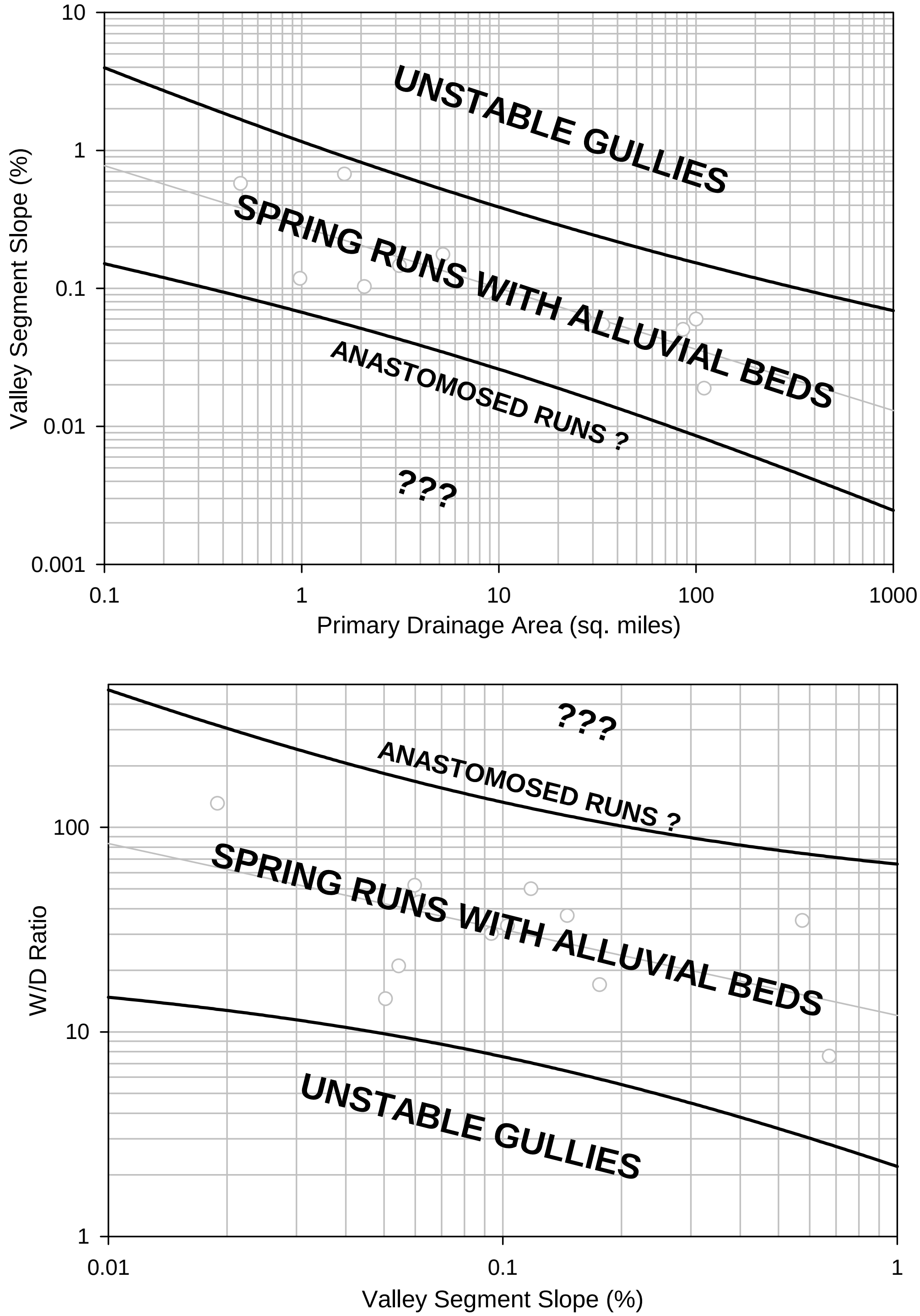


Figure 4-2. Single-channel spring runs zone of confidence (95% prediction interval).

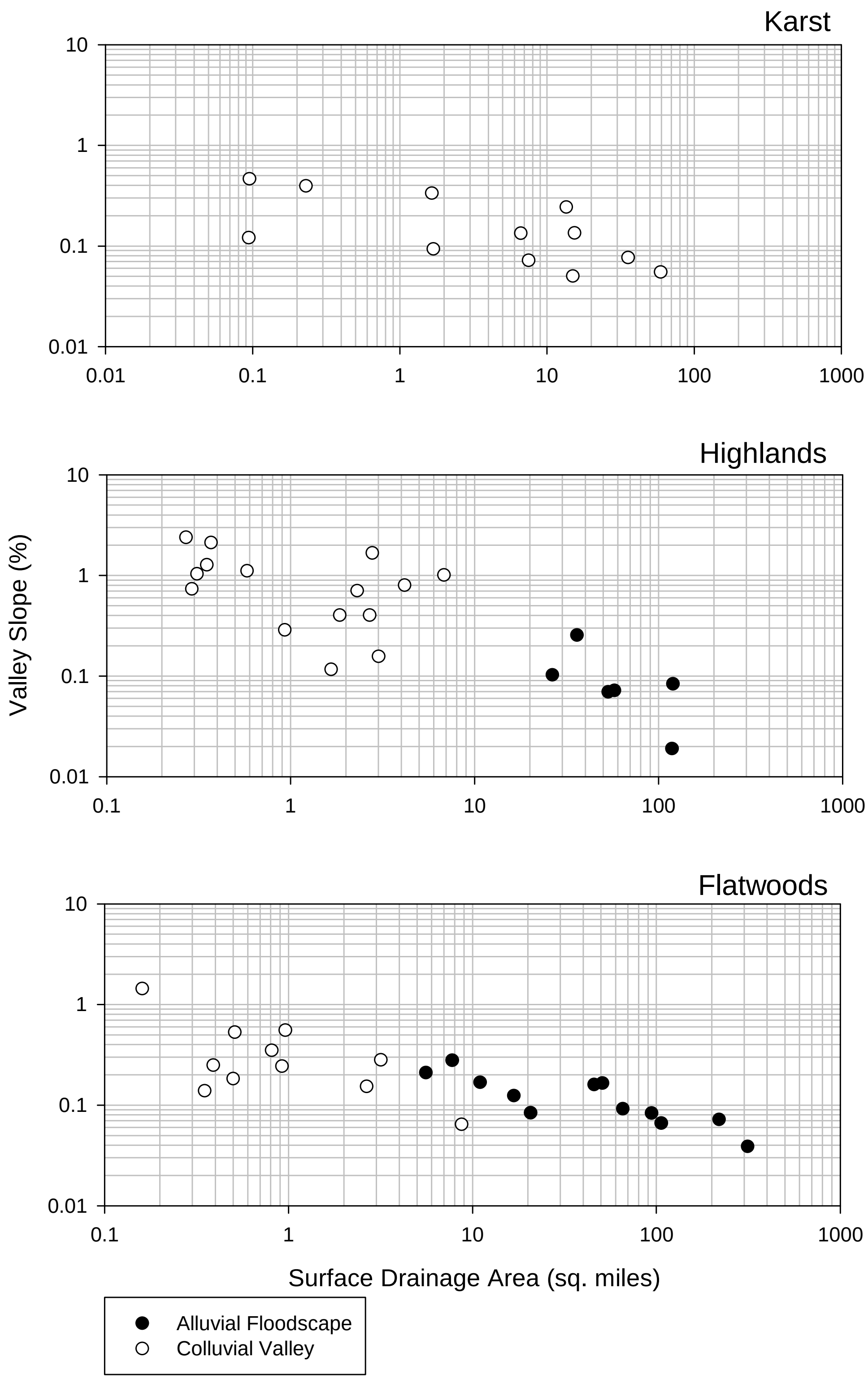


Figure 4-3. Continuous alluvial versus colluvial floodscapes associated with drainage area for three physiographies.

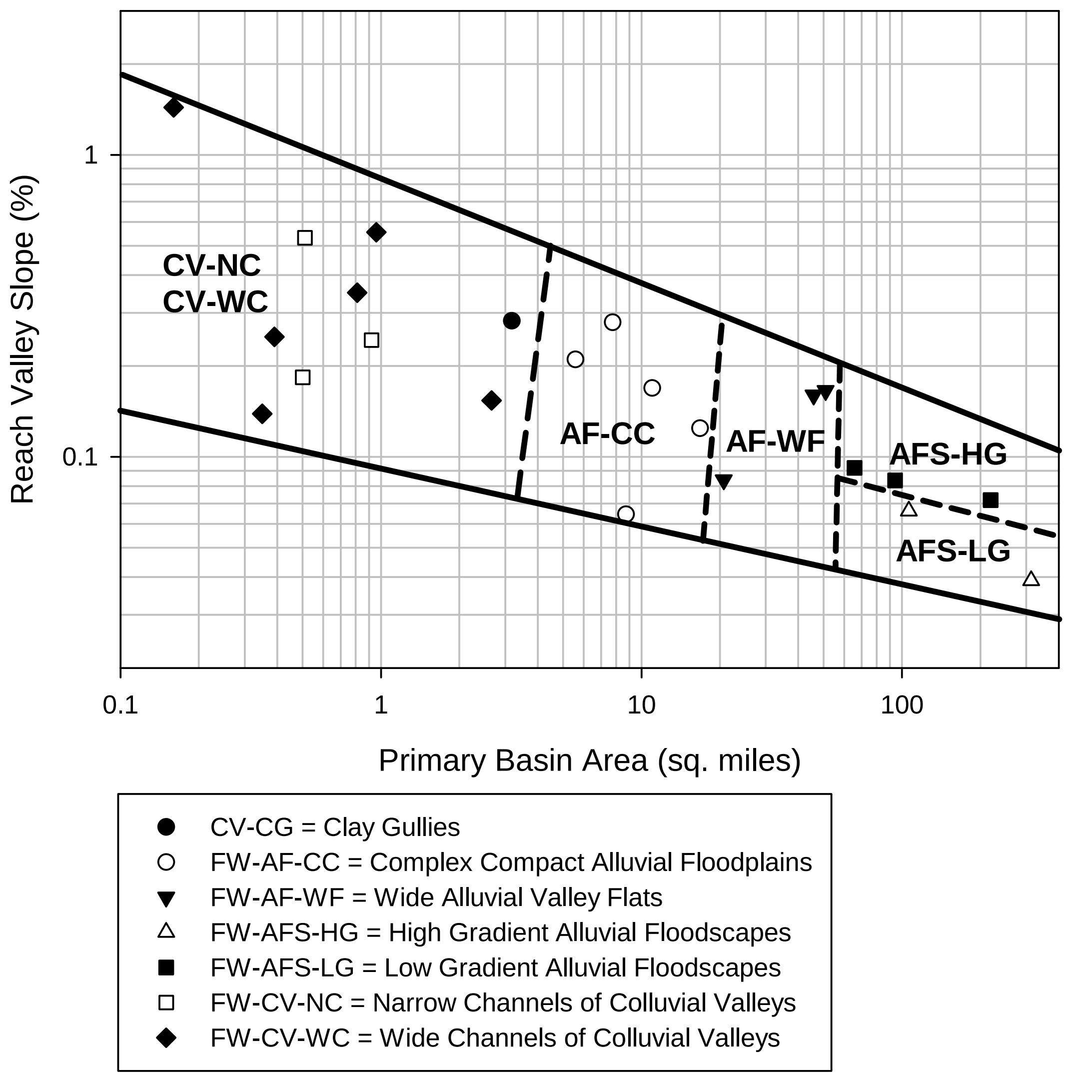


Figure 4-4. Distribution of flatwoods riparian system classes by drainage area and valley slope.

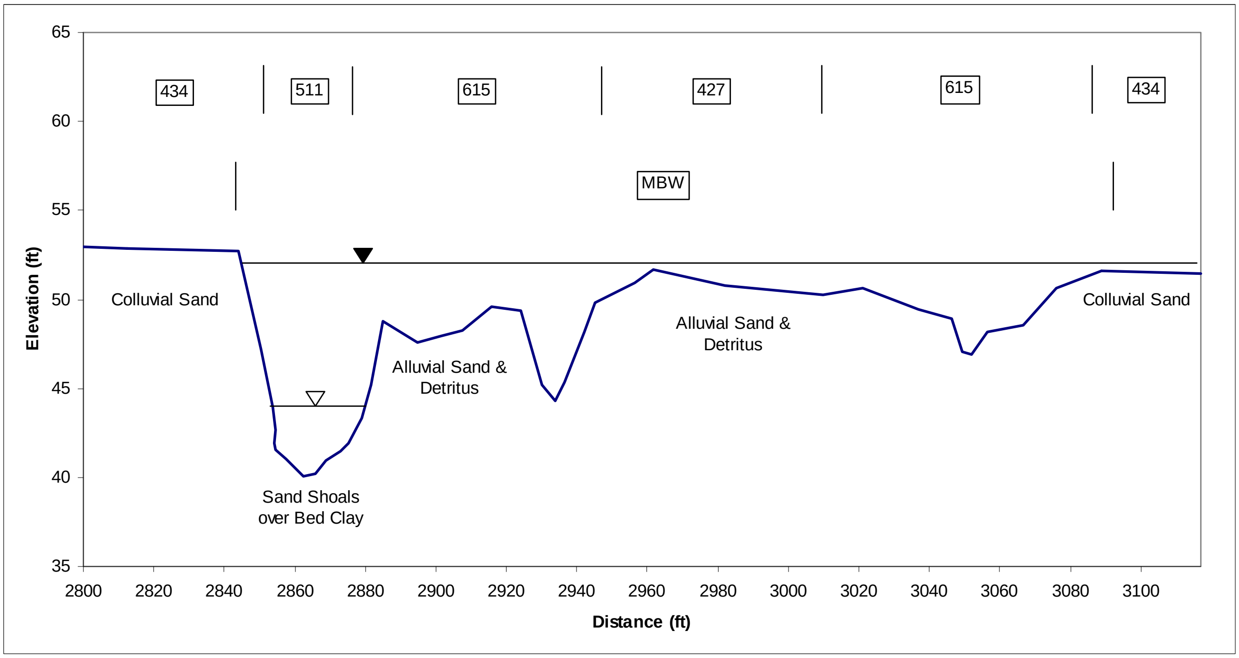


Figure 4-5. Example of riparian system type FW-AFS-HG, Manatee River (see Appendix C for legend).

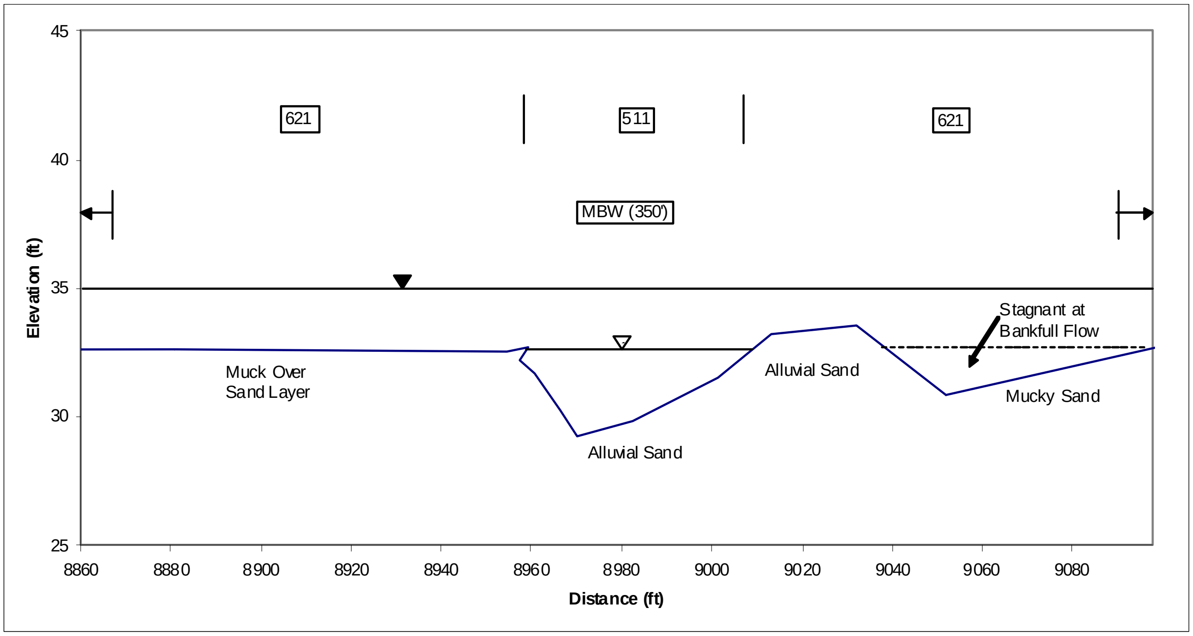


Figure 4-6. Example of riparian system type FW-AFS-LG, Fisheating Creek (see Appendix C for legend).

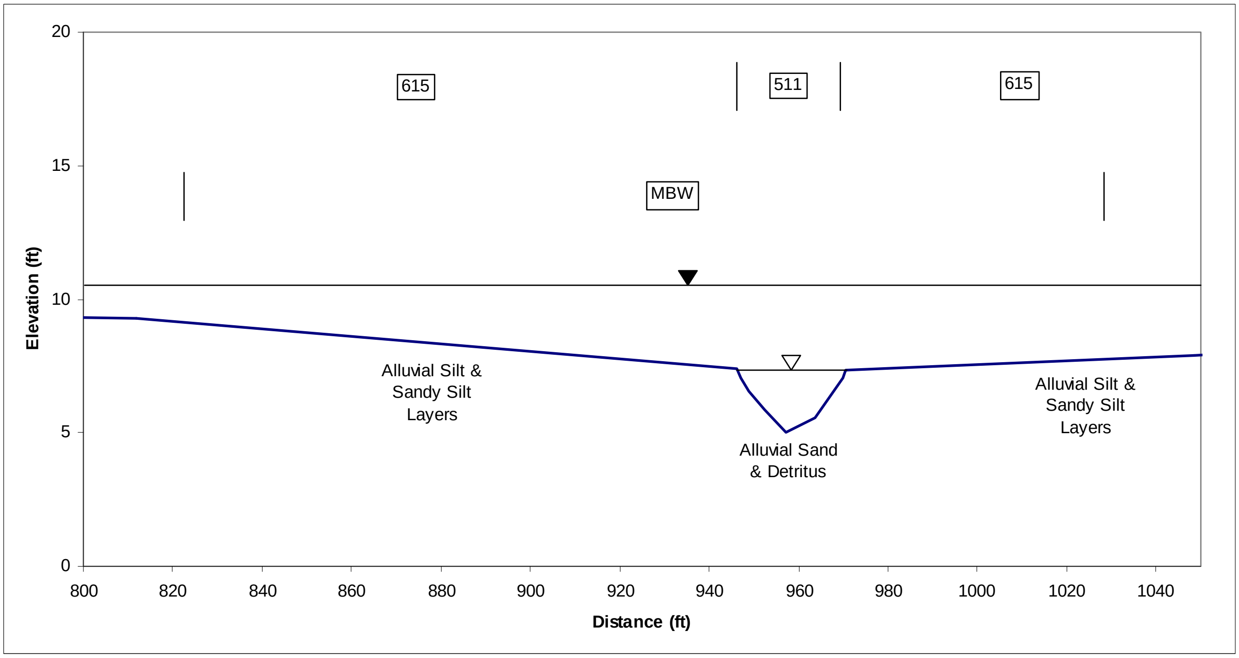


Figure 4-7. Example of riparian system type FW-AF-WF, Rice Creek (see Appendix C for legend).

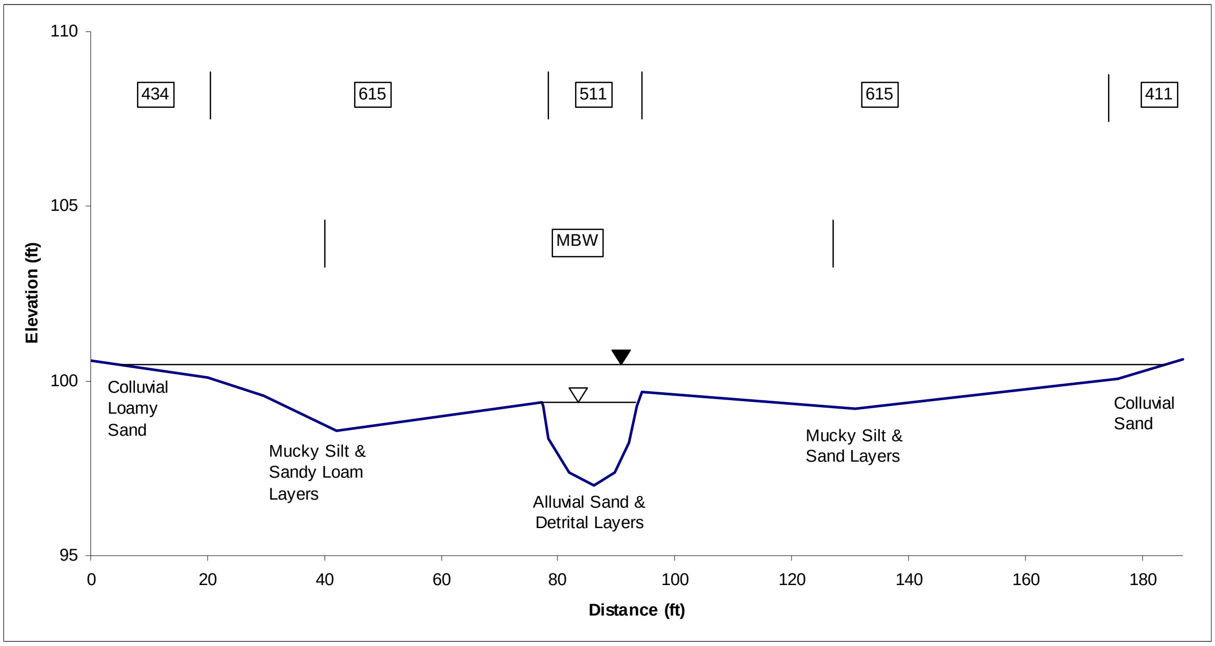


Figure 4-8. Example of riparian system type FW-AF-CC, Tenmile Creek (see Appendix C for legend).

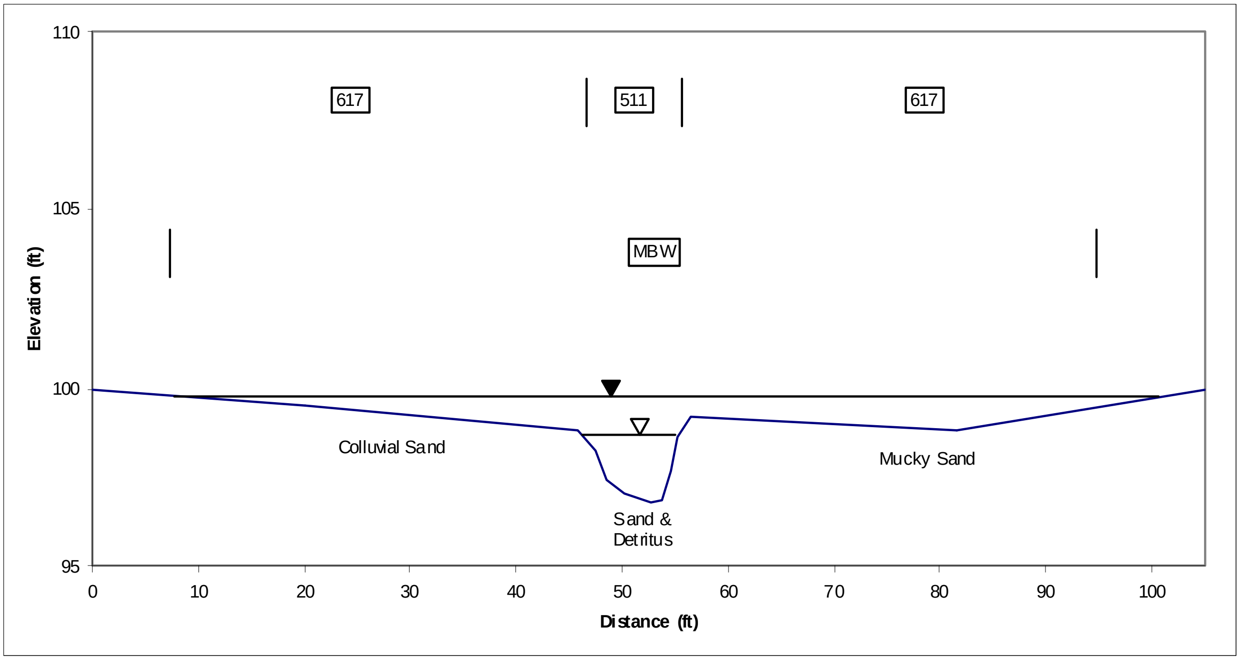


Figure 4-9. Example of riparian system type FW-CV-NC, Wekiva Forest UT (see Appendix C for legend).

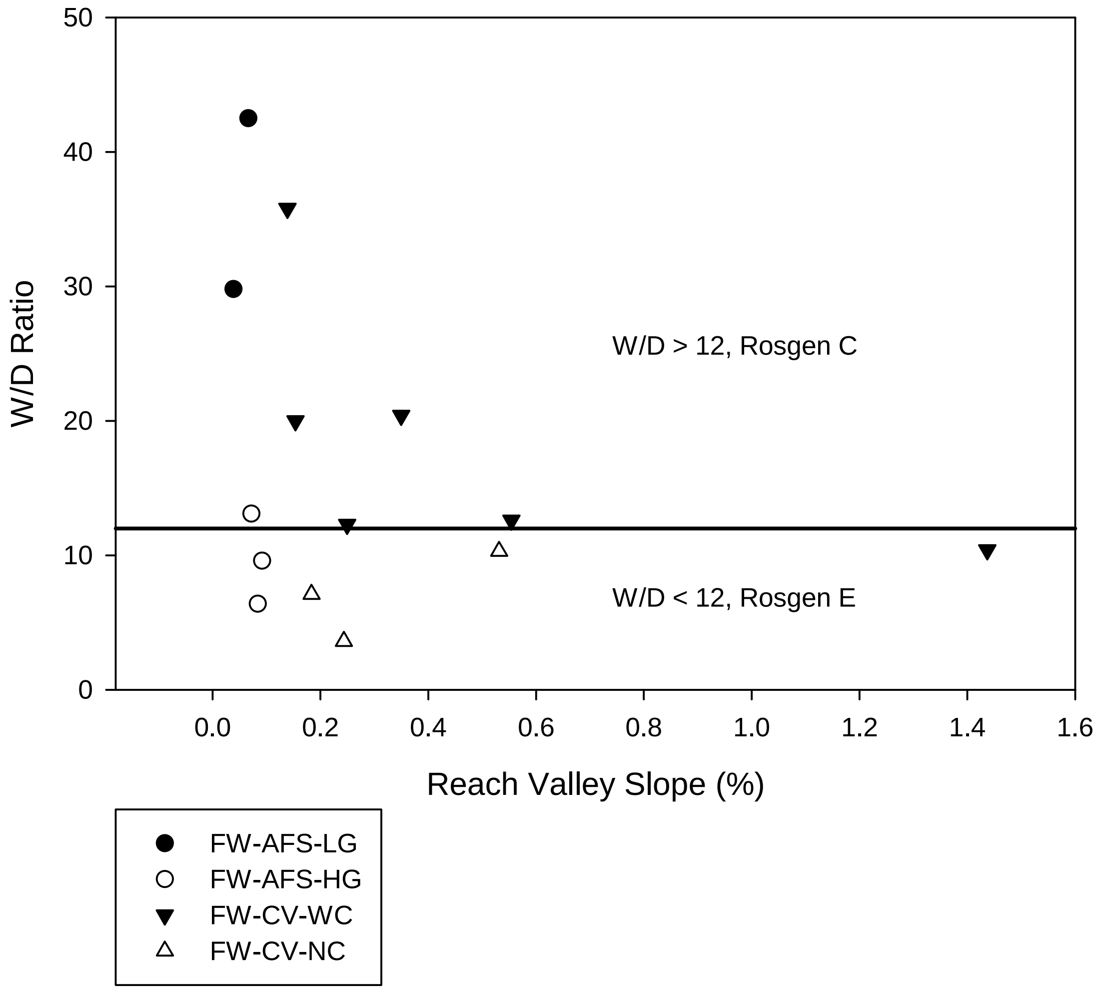


Figure 4-10. Distribution of large and small flatwoods riparian system classes by W/D and valley slope.

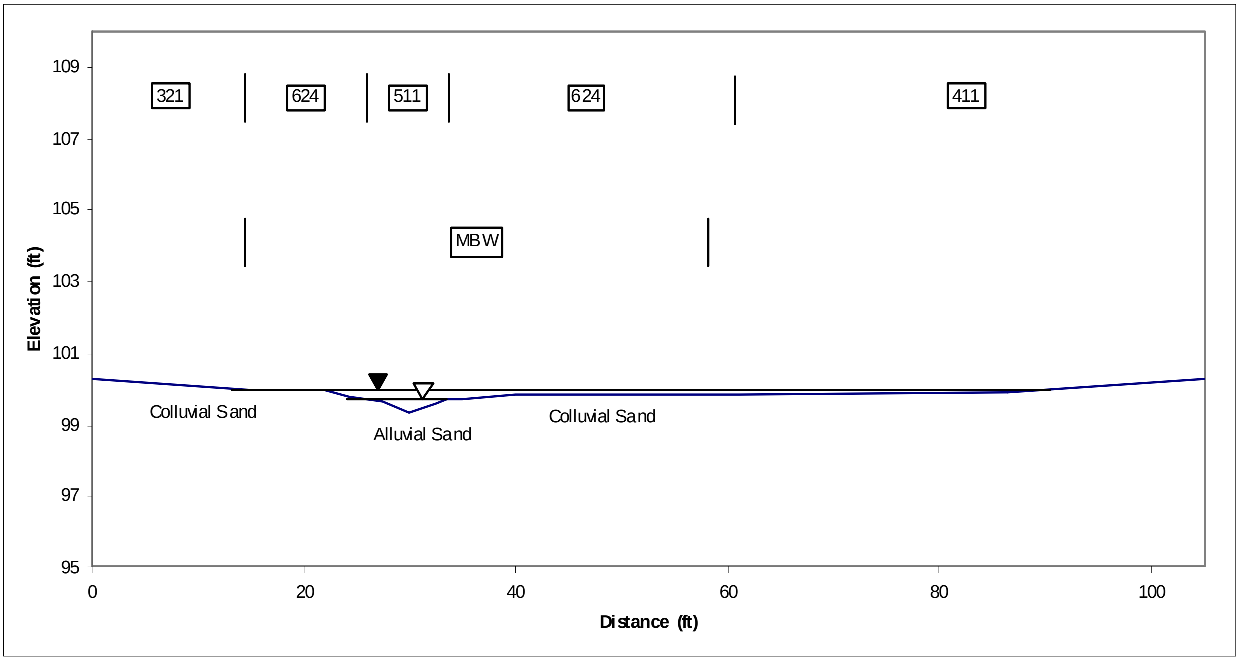


Figure 4-11. Example of riparian system type FW-CV-WC, Lower Myakka UT 3 (see Appendix C for legend).

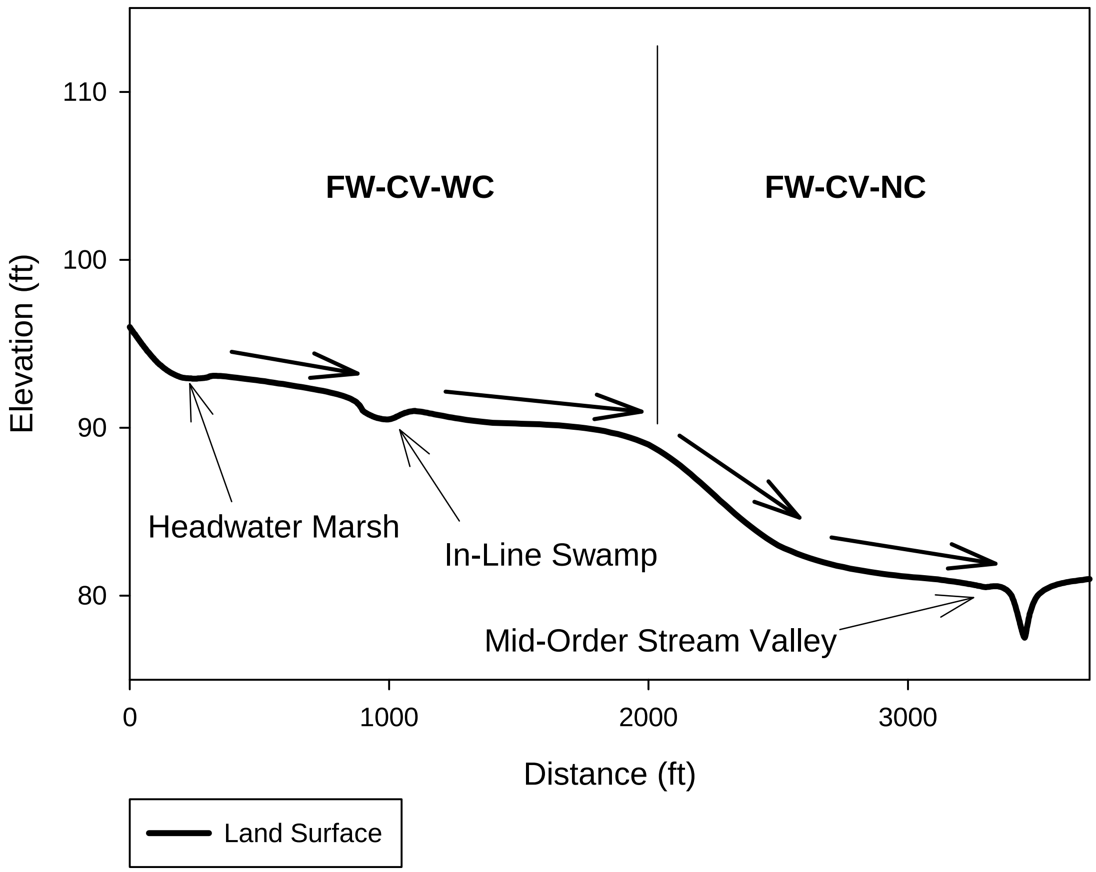


Figure 4-12. Typical landscape positions and valley profile distribution of flatwoods colluvial riparian systems.

Figure 4-13. Partially exposed shallow root discs on a FW-CV-WC channel bed (Lower Myakka UT 2).

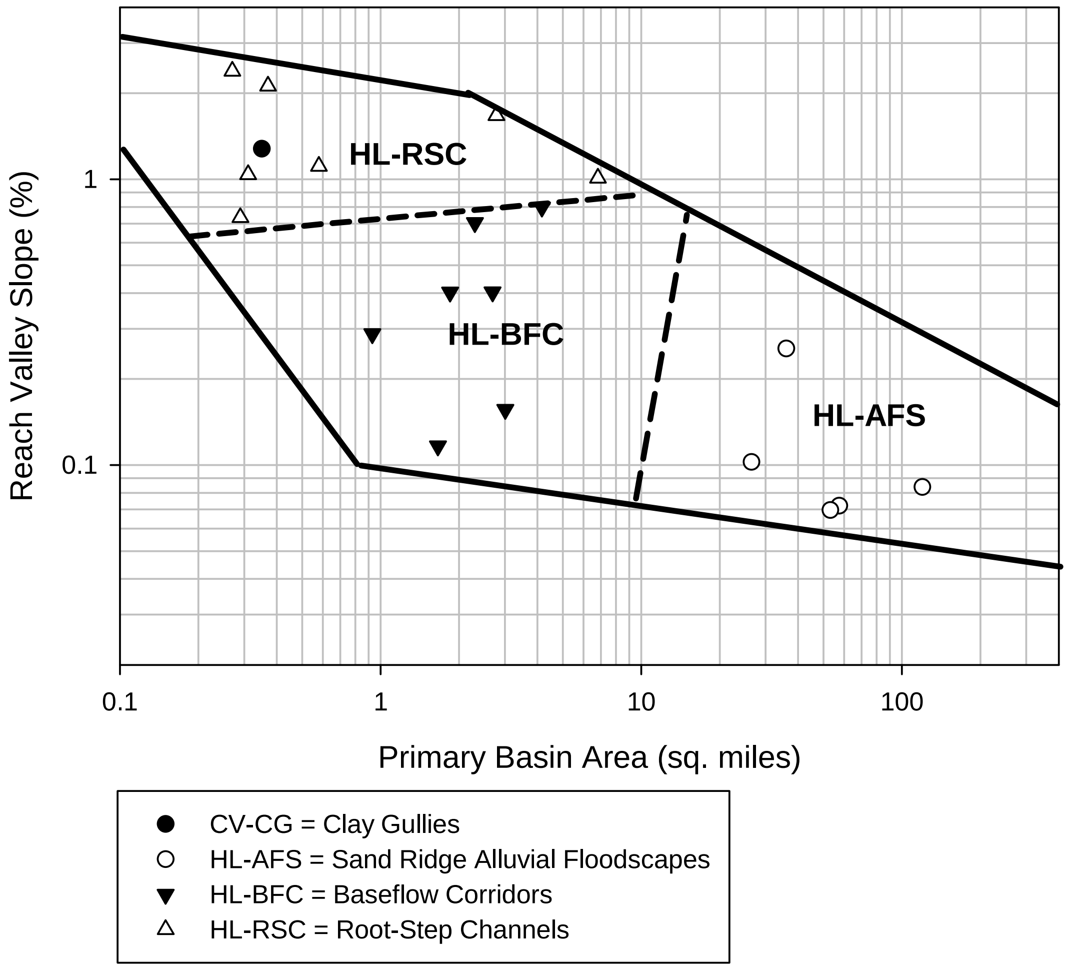


Figure 4-14. Distribution of flatwoods riparian system classes by drainage area and valley slope.

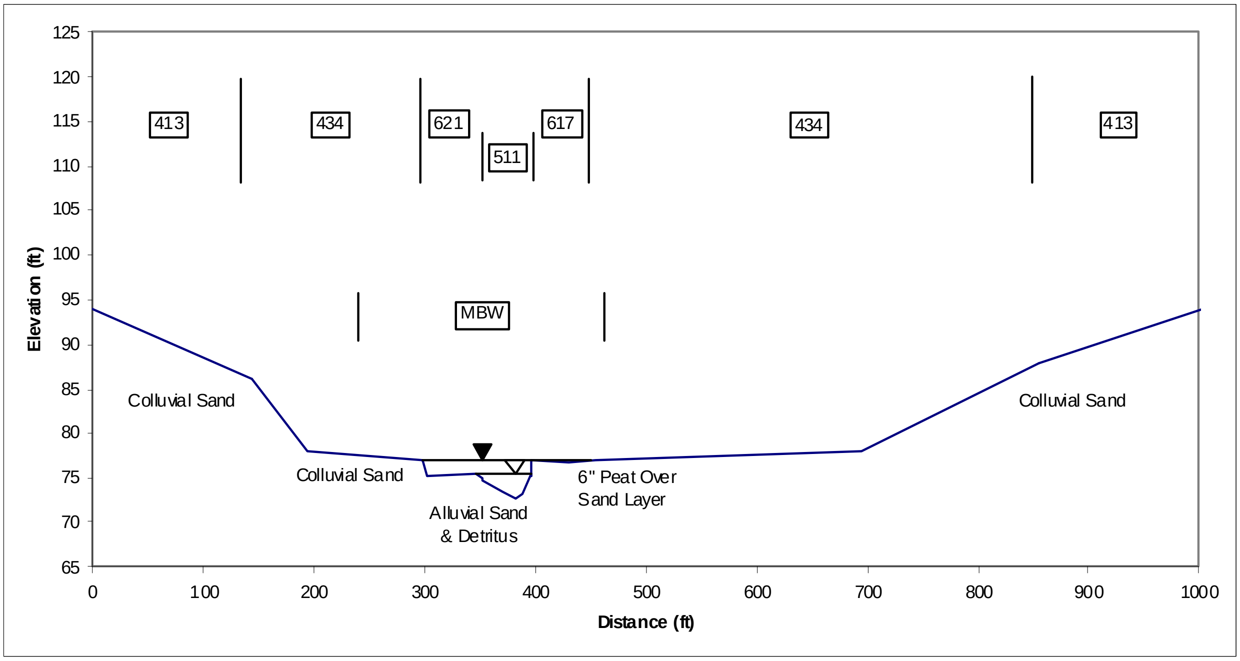


Figure 4-15. Example of riparian system type HL-AFS, Catfish Creek (see Appendix C for legend).

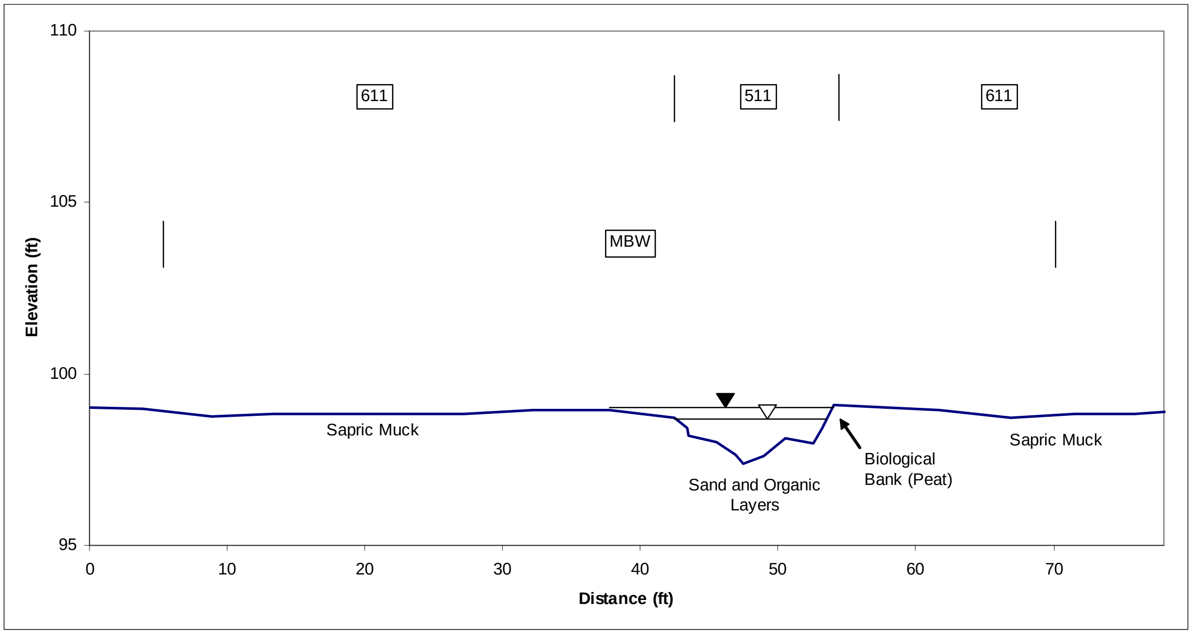


Figure 4-16. Example of riparian system type HL-BFC dominated by seepage, Tiger UT (see Appendix C for legend).

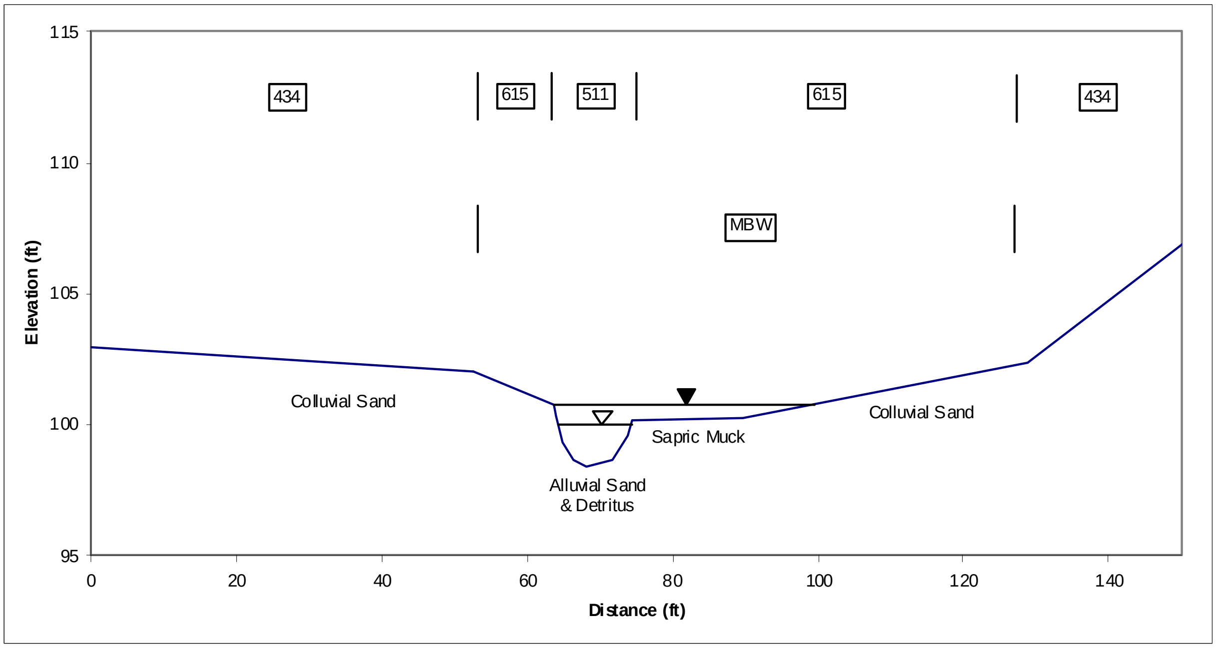


Figure 4-17. Example of riparian system type HL-BFC with blackwater sources, Hammock Branch (see Appendix C for legend).

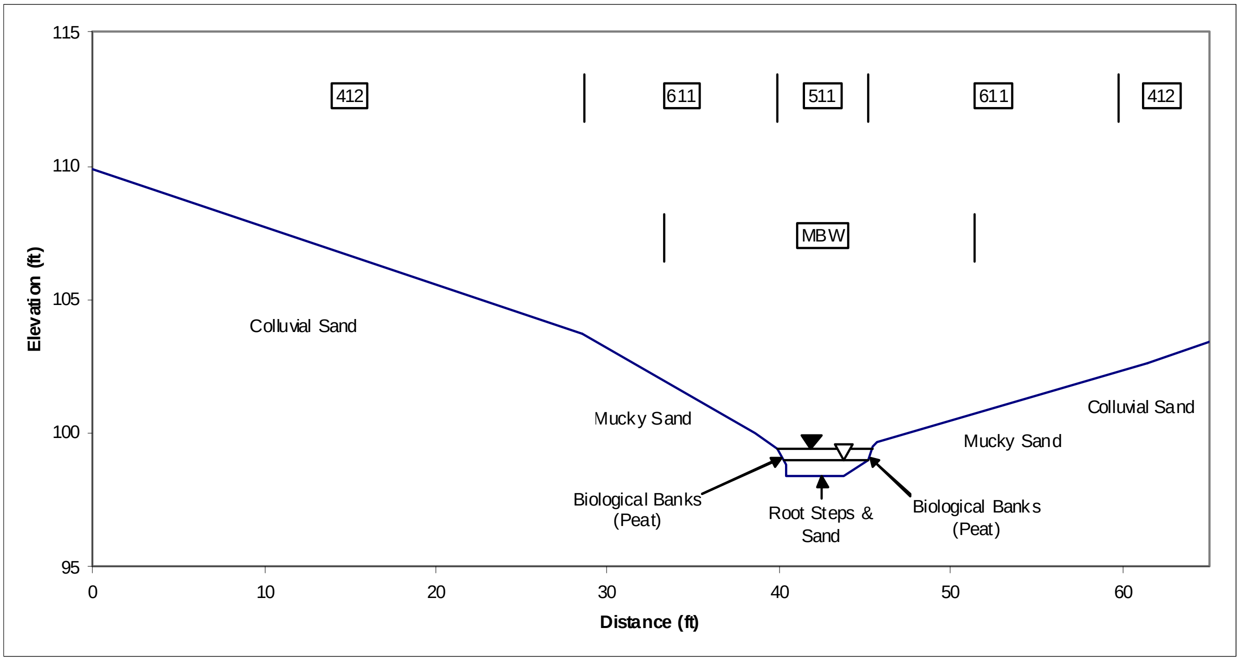


Figure 4-18. Example of riparian system type HL-RSC, Lowry Lake UT (see Appendix C for legend).

Figure 4-19. Root-step and biological bank detail, Tuscawilla Lake UT.

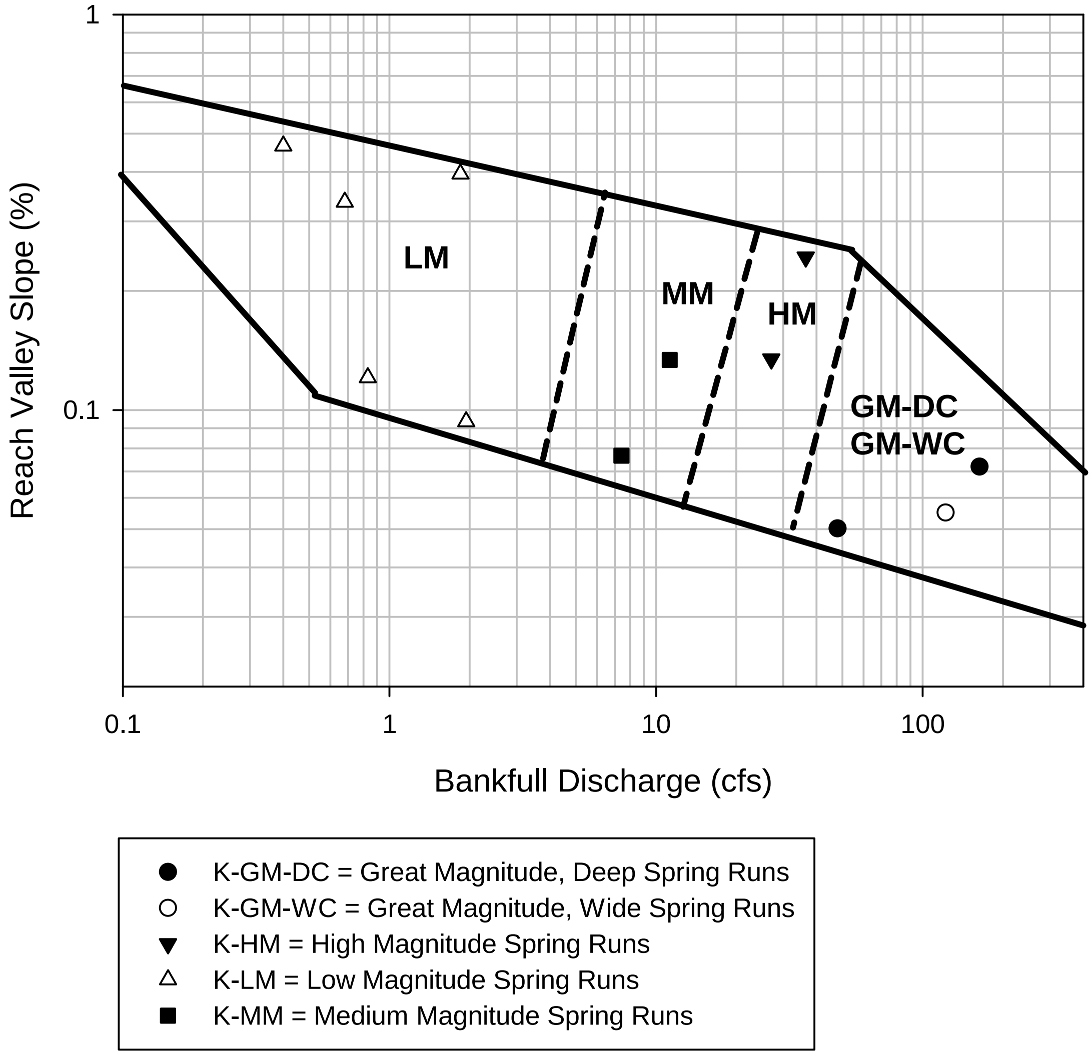


Figure 4-20. Distribution of karst riparian system classes by bankfull discharge and valley slope.

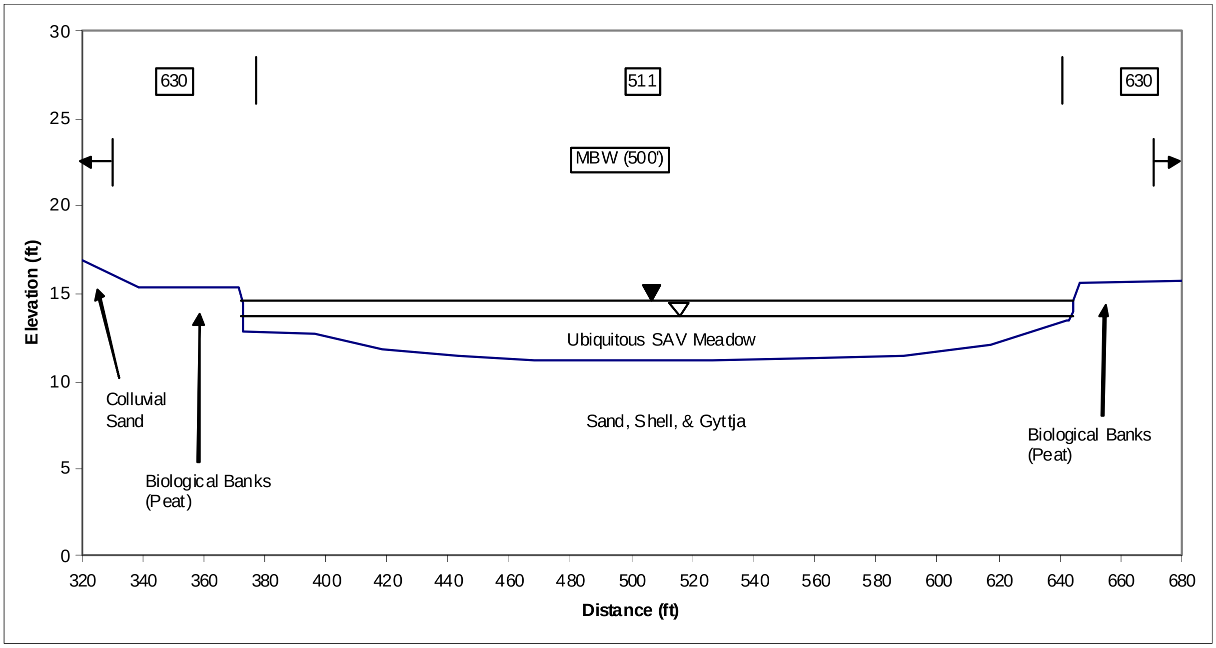


Figure 4-21. Example of riparian system type K-GM-WC, Alexander Spring Run (see Appendix C for legend).

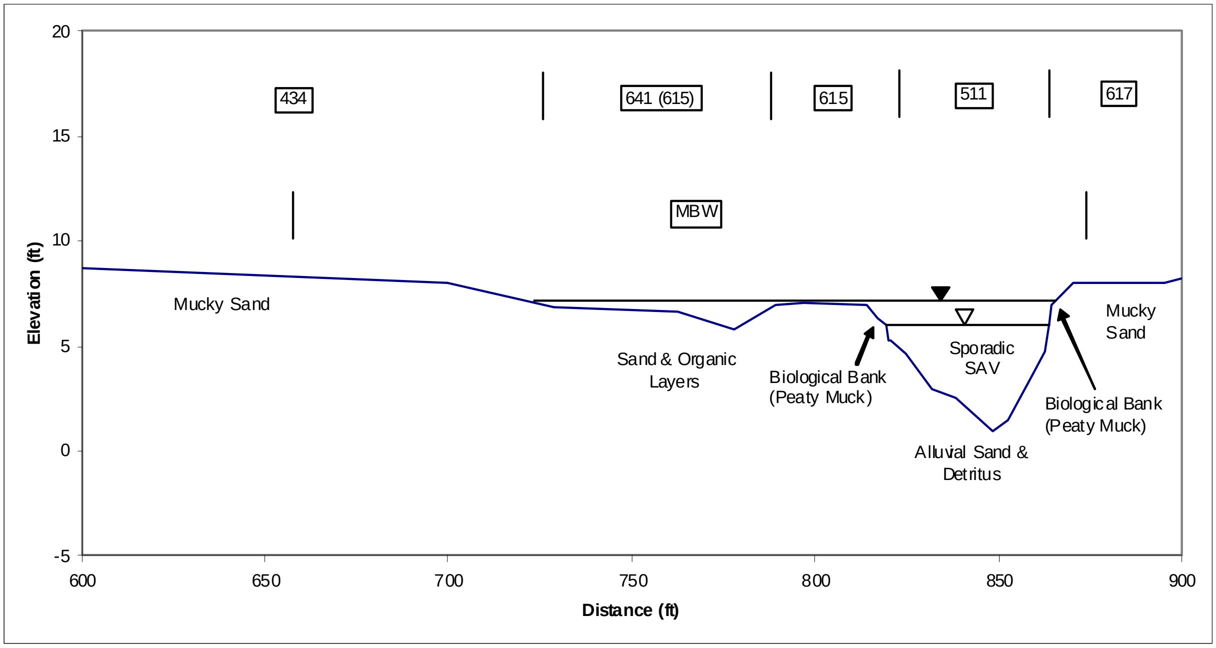


Figure 4-22. Example of riparian system type K-GM-DC, Weeki Wachee River (see Appendix C for legend).

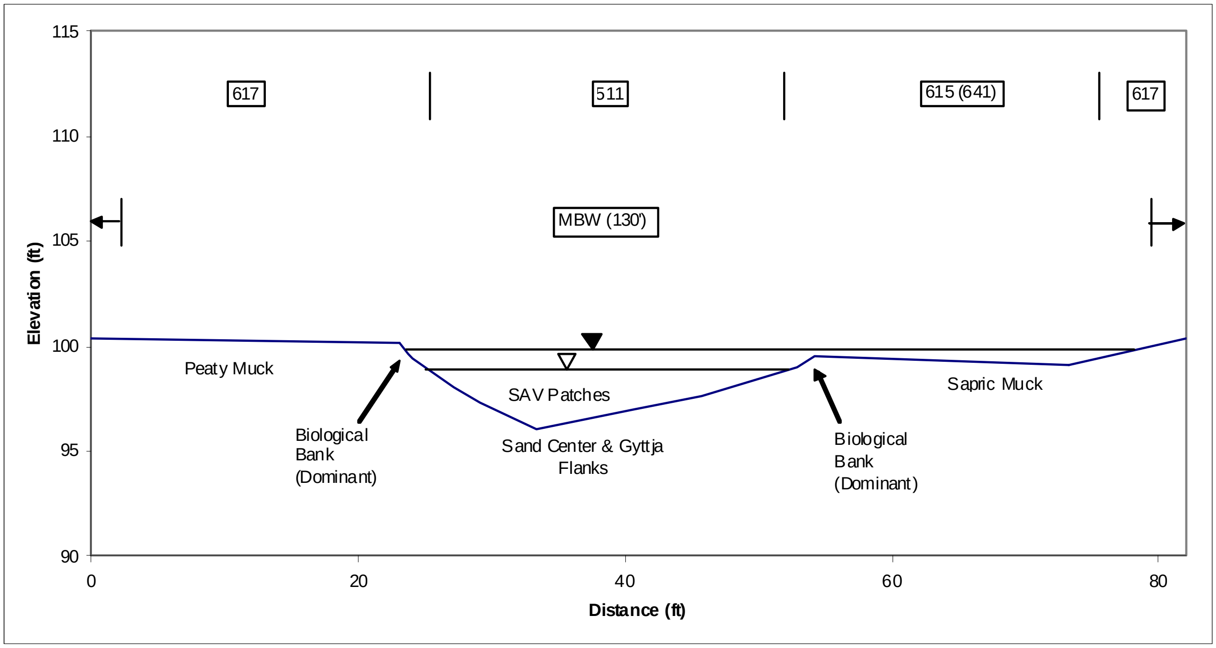


Figure 4-23. Example of riparian system type K-HM, Juniper Creek Spring Run (see Appendix C for legend).

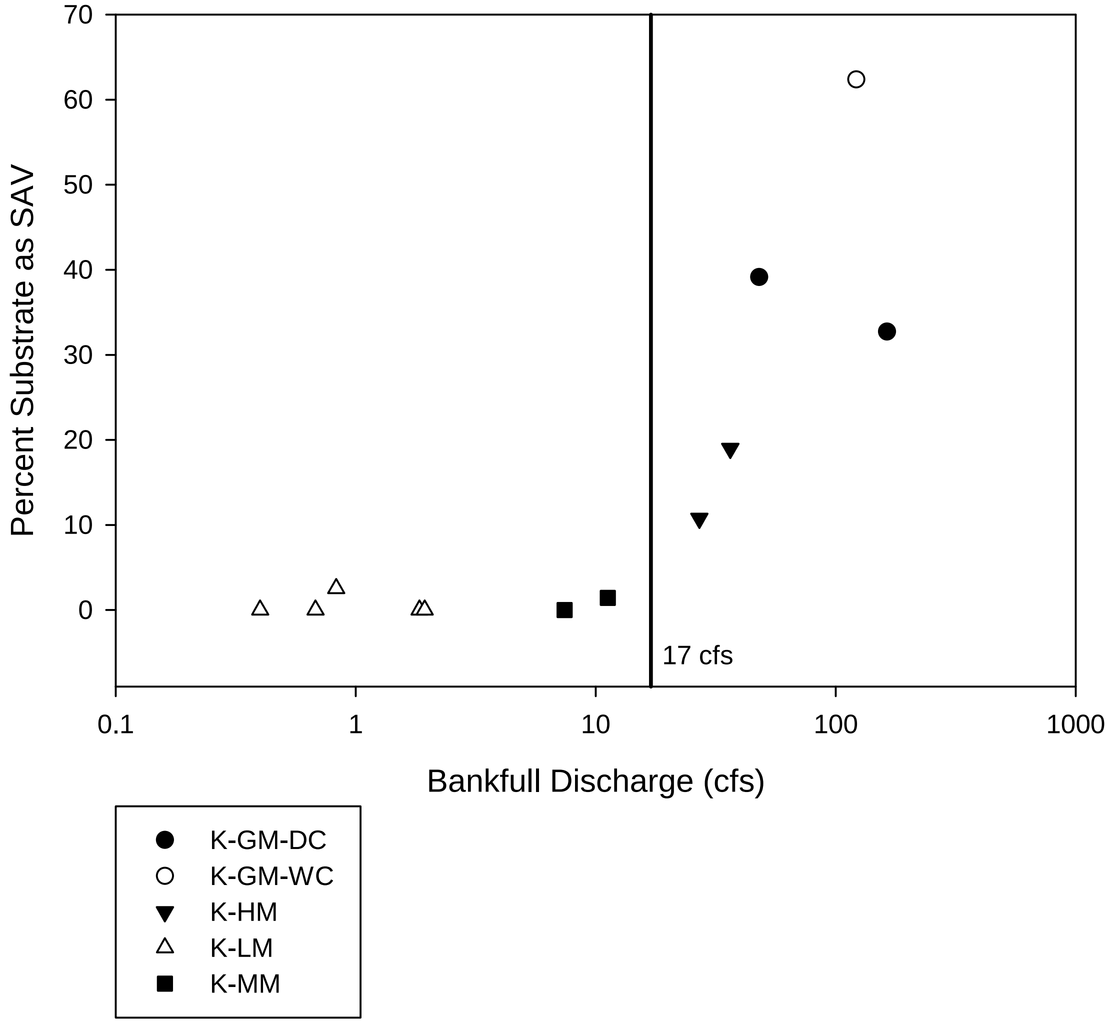


Figure 4-24. Distribution of karst riparian system classes by bankfull discharge and submerged aquatic vegetation.

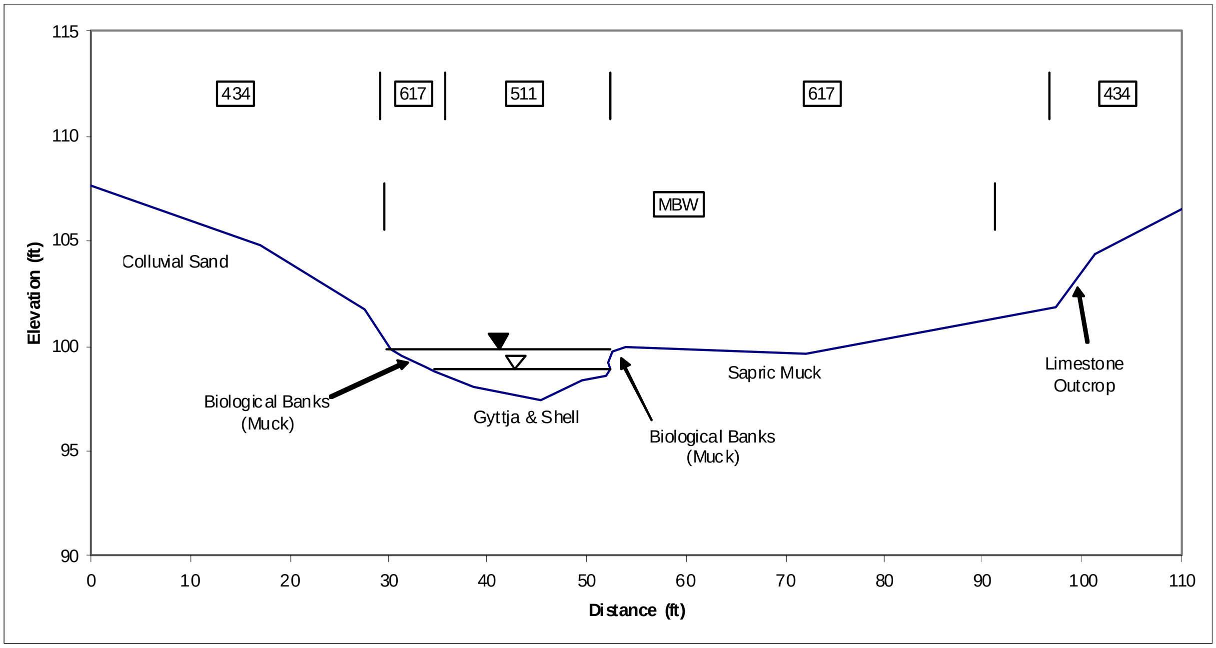


Figure 4-25. Example of riparian system type K-MM, Cedar Head Spring Run (see Appendix C for legend).

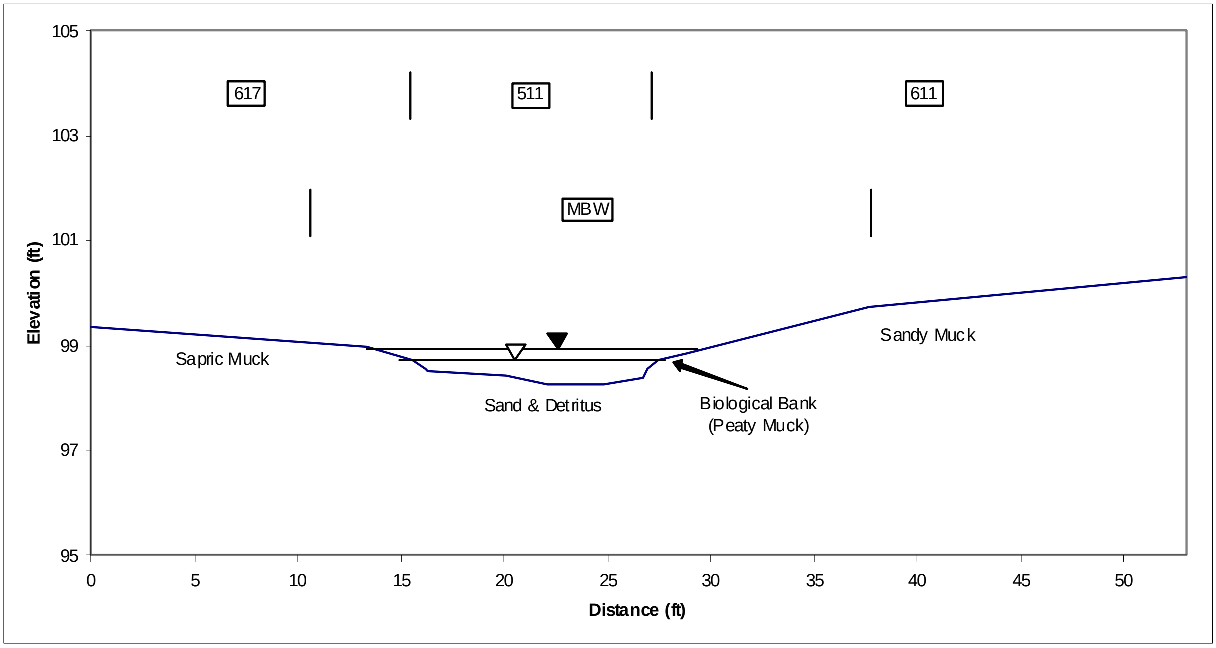


Figure 4-26. Example of riparian system type K-LM, Kittridge Spring Run (see Appendix C for legend).

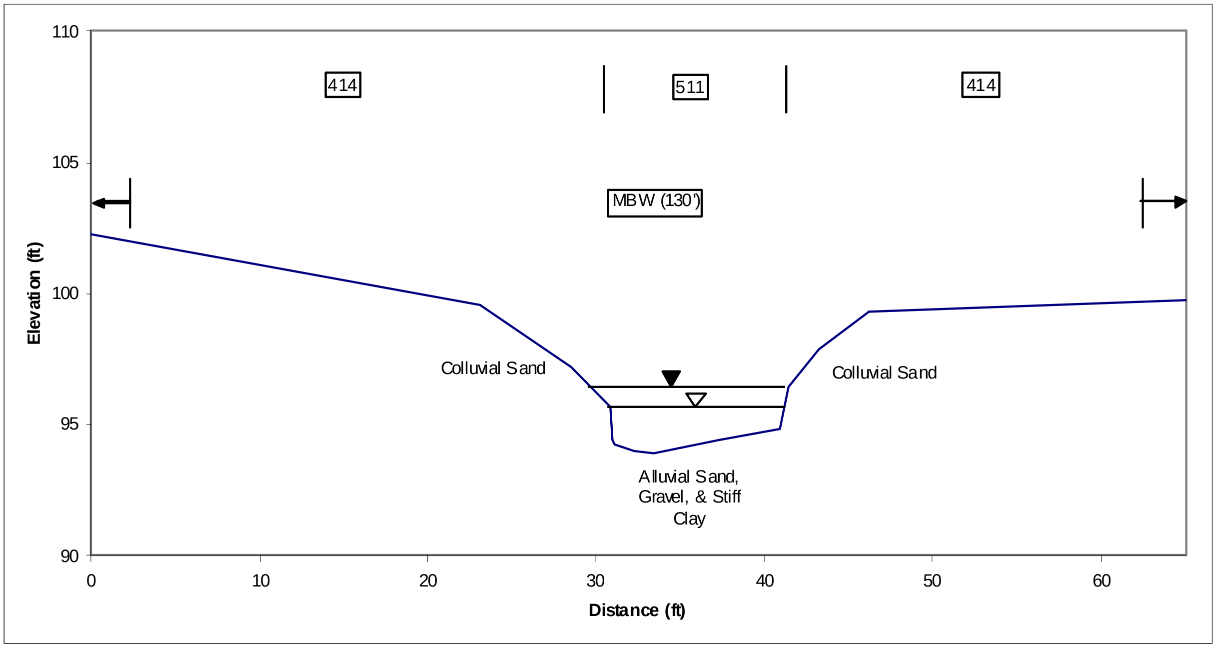


Figure 4-27. Example of riparian system type CV-CG, Blues Creek (see Appendix C for legend).

CHAPTER 5
SUMMARY AND POTENTIAL APPLICATIONS

Summary of Findings

Peninsular Florida streams change gradually along the drainage network in some ways akin to the typical dendritic and alluvial fluvial systems described around much of the world, but they are punctuated and deranged by in-line wetlands and lakes due to local geologic controls and differential weathering of carbonate lithology. The strong wet-dry seasonality of the region also tends to sort hydrobiological and geomorphic processes as a matter of landscape physiography and scale based on the relative infiltration versus runoff capacity of the watershed. Therefore, both large-scale clinal and local-scale zonal concepts are important for understanding Florida stream processes and associated fluvial forms. This fact lends itself well to use of functional process zone concepts for characterizing Florida's streams.

Florida provides a rich environment of 15 types of stream systems under varying degrees of alluvial control and groundwater discharge. The combination of controls on fluvial form depend on the scale and landscape position of the stream, within three different types of physiography; karst, high sandy ridges (highlands), and flatwoods. Consistent associations of channel type were identified and quantified, relating stream type and channel characteristics with watershed size, soils, and valley slope. Floodplain morphology and process are every bit as important for delineating and describing fluvial systems in Florida as are the open channel characteristics. In fact, Florida streams are best conceived as primarily existing along a gradient of differing flood pulse potential and associated fluvial forms in the floodscape, more so than as systems whose processes associate predominantly with bankfull channel form. Channel form is convergent among some classes and can be an important delineator in others. It seems to be most important in the smallest streams and the largest, but not for systems draining intermediate basins. Perhaps the main reason it is important to conceive of Florida streams based largely on the characteristics of their floodscapes is because many of them are routinely flowing in them. Overbank flow is common and sustained, often for more than 25% of the year in many perennial blackwater streams. Portions of the floodplain should actually be viewed as a vegetated wet-season channel with trees. The open channel could be viewed as a special transport-dominated inclusion within the riparian system. In streams draining smaller basins, the flood pulses decrease in importance and associated alluvial floodplain features are diminished or non-existent. Reduction of flood-pulse influence also occurs as a result of increased groundwater mediation of the annual discharge associated with highlands and karst landscapes and a concomitant decrease in runoff spate potential versus that associated with the flatwoods. Some high-relief sandy highlands develop small sapping valleys on the peninsula. These form seepage ravines fed by the unconfined aquifer.

Hydrobiology plays a key role in geomorphology and that role increases with groundwater influence. Groundwater regimes lacking powerful flood pulses or spates allow for certain types of live vegetation communities to provide substantial and dominant bed stabilization and grade control. In the steep-sloped sapping streams this control takes the form of live root-weirs that form a stepped arrangement with pools between the steps. The root weirs are typically formed by tree species that thrive in saturated water regimes. By retarding continued valley grading, these root-step systems prevent excessive dewatering of their seepage valleys, allowing for their continued competitive advantage. Dense meadows of submerged aquatic vegetation can form in streams with copious artesian spring flow. These underwater meadows substantially increase flow resistance and stabilize potentially mobile sediments, keeping the channel wide and shallow and allowing continued light penetration to their bed. The spring runs also produce autochthonous sources of sediment via high productivity of detritus and snail shells forming shelly-organic sediments (detrital floc) that are often laterally sorted by fluvial forces. The channel banks of both seepage streams and artesian streams typically have areas of biologically-mediated levees that mound up over the mineral shoreline. These biological banks consist of thick layers of moss, peat and muck held tightly by dense live root systems of woody vegetation adapted to saturated conditions. This is not simply a matter of classic bank stabilization by roots. The trees and mosses appear to work synergistically to build land and increase direct contact with the steady supply of water at the light-rich channel boundary. The biological banks encroach upon the channel, sometimes forming overhanging ledges ultimately kept in check by water pruning of the roots and cantilever failures.

Self-organization of Florida streams can be rather physically based as it is in streams with alluvial controls around the world, but these controls require certain thresholds in basin size, valley slope, and landscape runoff characteristics. The low elevations and seasonally-wet sub-tropical landscape promote flood-pulse regimes for larger streams associated with significant alluvial floodscape controls. Groundwater sorting also promotes some key biogeomorphic controls. Understanding these self-organizing principles helps to make sense of how Florida streams belong to their watersheds, even when those watersheds are genetically deranged by relictual and modern geological processes. This mix of fluvial, alluvial, biological and geologic controls makes Florida's low- and mid-order streams some of the most fascinating and complex in the world. With that understanding, their protection, management, and restoration must be carefully considered and diligently implemented using the best available science.

Implications for Stream Resource Management

Florida streams are stressed indirectly by agriculture, development and groundwater pumping. Because of intense vegetation controls, the streams are slow to change and are likely to be in a very significant state of decline by the time they display obvious physical responses such as bed degradation, bank erosion and widening, floodplain soil subsidence, or planform avulsions. Furthermore, many of the streams in the state appear to already be damaged or have watersheds with characteristics demonstrated to create long-term problems for streams elsewhere in North America.

The proposed classification identifies stream channels as part of a watershed and valley system. Knowing this system, and particular thresholds that may invoke channel changes, should help Florida's environmental managers make prudent decisions concerning watershed protection and mitigation that are not only related to water quality, but that also are protective of the fundamental associations of fluvial form and hydrologic process.

In addition to indirect effects in the watershed or springshed, many Florida streams have been ditched, filled, cleared, mined, culverted/buried, severely overgrazed or otherwise directly destroyed or largely diminished from their natural level of geomorphic complexity and associated biological functions. This study assists with information necessary to figure out what to put back when someone has an opportunity to do so in such radically disturbed landscapes.

The rest of this chapter summarizes potential strategies or particular viewpoints concerning riparian system conservation and maintenance, restoration, and scientific technology transfer in various land use settings common in Florida. These perspectives are intended to provide guidance on how this information may be useful to private and corporate land owners, conservation organizations, and regulatory programs. This guidance merely reflects the author's opinion and is not intended to thoroughly summarize any particular regulatory program's approach to stream protection, which is beyond the scope of the study. Some of the terms, such as restoration, maintenance, or buffer, may have specific and different meanings among federal, state, and local regulatory programs, so no attempt has been made to standardize the use of these terms on any one program's use. Any such terms, unless specifically noted otherwise, are applied based on their general scientific use, solely in the context of the scientific disciplines employed for this study.

Conservation

Conservation is the deliberate protection of a natural or restorable riparian system corridor. Conservation often requires land purchases or management costs to be derived from among competing priorities or projects. Therefore stream conservation is most likely to be pursued in association with other forms of conservation initiatives. Streams could be viewed as the spines of the ecosystem. They control much of the movement of water across the landscape, certainly providing hydrologic connections among a wide array of waterbody types in Florida.

This research confirmed the presence of some unique fluvial forms in Florida relying on groundwater discharge. Groundwater dependent systems such as root-step channels, baseflow corridors, and all spring runs are unlikely to remain stable or unique if the groundwater recharge of their watersheds is compromised. The conservation of groundwater regime systems starts with protection of the infiltration capacity of their catchments. Groundwater pumping thresholds are also important.

Most headwater streams, particularly those forming chains-of-wetlands, have been destroyed by ditching and clearing. Headwater streams are in the most direct and overall extensive contact with colluvial soils, meaning whatever biogeochemistry functions that contact promotes has probably been altered extensively in Florida. Intact chains-of-wetlands surrounded by extensive native buffers are likely to be worthy of conservation consideration for a wide variety of reasons, including endangered species management, watershed protection, upland and wetland conservation, etc. Intact low-order streams, especially if and when they connect to largely intact mid-order systems downstream, should be high priorities for acquisition and conservation.

Due to the downhill nature of stream systems, the identification and conservation of continuous undamaged riparian corridors is a worthy objective. To best prioritize stream corridor conservation, it is highly beneficial to conduct watershed inventories of the riparian resources and rate their stability, integrity, and diversity of fluvial forms. Seldom will completely whole corridors be found, but much-needed holistic conservation and restoration strategies will emerge from such assessments. To properly conserve Florida’s streams it is likely that portions of damaged riverscapes must also be acquired and subsequently restored.

Water Resource Management

Water resource managers include water suppliers using any combination of surface water or groundwater withdrawals and surface water storage (offline or in-line reservoirs) or aquifer storage systems. Water resource managers also include the designated operators of control structures used to manage water levels and flow releases of interconnected lakes, wetlands, and streams (typically the six Water Management Districts or special-purpose water authorities like the Lake County Water Authority).

Florida law provides Water Management Districts with the authority to determine stream minimum flows and levels (MFL) based on several metrics. Fluvial geomorphology is not explicitly one of them. However, sedimentation is one that is included and it allows some consideration of fluvial geomorphology at least for systems with even modest alluvial control. It is seldom prioritized. In fact, water level and flow regime changes appear to often be considered as if they will have no effect on geomorphology. The underlying assumption that streams and their floodplains are static systems that will not change their shape under a changing flow regime can be misguided and lead to unanticipated problems that are difficult or impossible to remedy once a source of water has become institutionalized. A good example involves the changes that have occurred in the upper Peace River's riparian corridor since the 1950s as a result of groundwater allocations. Our work provides District staff with the means to assess if proposed withdrawals could lead to geomorphic change at the flow thresholds otherwise deemed appropriate based on the metrics that have more commonly been assessed such as in-stream habitat availability and suitability.

Total Maximum Daily Loads (TMDLs) are not a specific land use, but affect virtually all land users. They are required by the U.S. Clean Water Act and Florida Impaired Waterbodies Rule to maintain or improve the ambient water quality of virtually all waterbodies, including freshwater streams. The general concept is that nature provides a certain degree of assimilative capacity for pollutants, which can be expressed as the allowable total maximum load on a daily basis. If a waterbody has been demonstrated to be impaired beyond its TMDL, then watershed solutions must be devised and implemented as a Best Management Action Plan (BMAP). Many states invoke sedimentation TMDLs, viewing excessive sediment transport as an impairment to water quality irrespective of its chemical contamination. Sediment is viewed as a pollutant if it is associated with adverse geomorphic change to the stream channel or floodplain. So far, Florida has rarely, if ever, invoked the TMDL program to protect the geomorphic integrity of its streams. Since many stream types require some sediment yield to maintain their integrity, excessive sedimentation reductions can create problems too. This is often a problem for streams downstream of an in-line reservoir. Sediment problems typically occur in urbanizing watersheds, often taking decades to become noticeable.

Land Development

Most low-impact ordinances in Florida are centered on stormwater quality. However, treatment volumes and techniques suitable for reducing urban pollutants in stormwater may be inappropriate to protect fluvial geomorphic integrity. For example, we are aware of streams in Pinellas County that are well-protected from stormwater pollution, but that are nevertheless massively eroding and threatening homesites because their balance of groundwater versus surface water flow was altered since the

1950s. Most areas with a history of intensive development should consider conducting riparian corridor integrity assessments. It is much easier and less-expensive to fix or restore streams that are in the early stages of channel evolution, before serious bed degradation and channel widening phases commence. Our research should prove helpful for identifying streams that are not in regime or are likely to become out of regime with their watersheds.

Sometimes flood protection ordinances are not sufficient to protect homes from being lost to stream flow due to channel avulsions that will eventually occur within the meander belt of streams with some alluvial floodscape controls. The meander belt of each stream should be identified and development should be restricted from within the meander corridor, even if the meander belt includes hillslopes at elevations higher than the regulatory baseflood level. This situation is most likely to occur in areas with sandhills/scrubs bordering 2nd order or higher streams and near old marine terraces.

Farming and Groves

Tailwater from irrigation practices can greatly increase baseflow to nearby streams. This could ultimately affect geomorphology in streams of the flatwoods areas by changing their hydrology to be more like highlands or karst “physiography.” This could conceivably alter the forested wetlands of the fluvial corridor, perhaps in unpredictable ways.

Florida’s minimum required 25 foot buffers along wetlands, including those of riparian corridors, is probably not adequate for protecting the biological integrity of headwater channels given that streams in such situations often have uplands right up to the banks and their meander belt widths are often well in excess of 50 feet. In other words, a narrow 25 foot buffer would allow farming operations to directly encroach within the meander corridor of the stream, perhaps altering its long-term capacity for self-organization and stability. Buffers in agricultural settings should be set using the outermost limits of either the riparian wetland boundary or the riparian meander corridor, whichever is wider.

Cow-Calf Operations

Clearing stream banks to promote cattle access and overgrazing of riparian corridors can break down the banks and lead to significant erosion that not only impairs the system locally, but can create sediment smothering downstream. Conversely, rural cow-calf properties offer tremendous opportunities to conduct stream conservation and restoration projects not feasible in urban settings. Ranchers may be able to use the riparian corridors on their property as a source of revenue, should the state ever make stream restoration an explicit type of mitigation activity. Existing rules allow for stream impacts to be mitigated by any type of wetland, so incentives are virtually non-existent.

Mining

Phosphate miners are an exception to Florida stream mitigation rules, because the state's mandatory reclamation rule does require explicit mitigation of stream length impacts on a type-for-type and linear foot-for-foot basis. In fact, such requirements were the main reason this study was funded by the Florida Institute of Phosphate Research. The mining companies are actively promoting new technologies to restore Florida streams that will also be useful in other settings.

Some forms of mining that simply leave big pits in the ground have comparatively limited options for on-site stream reclamation, but would benefit from our research if tasked with creating offsite mitigation. Conversely, mineral sands miners working on high sandy ridges create post-reclamation landforms that may be the closest among all

Florida mining operations to putting back a landscape similar to the pre-mining condition topography. This study provides them with tools to be able to carefully restore streams on their extensive landholdings, especially using the data collected from highlands sites. Some titanium mines operate in areas with rare sapping, root-step streams. It is important to protect them from direct and indirect hydrologic impacts.

Restoration

Perhaps the primary use of this research will be as guidance for what to restore on properties where on-site streams have been obliterated or so ubiquitously damaged that few could serve as analogues for restoration design. This study could be viewed as a library of reference reaches, properly placed in their landscape context for inspiring well-conceived stream creation and restoration projects. It can be used for hindcasting historical pre-disturbance conditions and for forecasting restoration outcomes.

Scientific Exchange and Technology Transfer

Florida streams are certainly among the most unique in North America. However, some types of common Florida blackwater streams have clear overlap in form and process with other blackwater streams in the southeastern coastal plain of the United States, particularly those with long-duration overbank flooding. The biggest differences arise with considerations related to the complicating factors related to derangement. Care must be taken when interpreting hydrobiological or geomorphic studies conducted on the riparian systems of the continental landmass versus the peninsula. There is much to be gained by comparative analyses between Florida and other southern states, but transferability should not be blindly pursued. In addition to the geologic differences arising from carbonate geology and associated derangement, peninsular Florida simply has a much more distinct wet and dry season than most of the rest of the southeastern coastal plain.

In fact, peninsular Florida's overall climate, especially the annual rainfall volumes and seasonality are generally more similar to that of some tropical savannas in South/Central America and northern Australia than to that of the neighboring states of Alabama and Georgia. It is not coincidental that Florida's least-altered pine flatwoods communities take on a more savanna-like tree distribution than similar longleaf pine forest communities north of the peninsula. It is probably also not coincidental that Florida has a greater overall abundance of common vertebrate associates of tropical savannas, especially crocodilians and colonial wading birds, than most elsewhere in the southeast. It is probably just as important that Florida stream ecologists and geomorphologists seek to share knowledge with peers working in nearby coastal plain states as it is for us to do the same with those working in large sections of tropical savannas elsewhere in the Americas, Africa, and Australia.

APPENDIX A
FLUVIAL GEOMORPHIC VARIABLE DESCRIPTIONS

Distance dimensions are in linear feet unless otherwise stated. Channel area measures are in square feet unless otherwise stated. Basin area measures are in square miles. Volumetric flow rates are reported in cubic feet per second.

* = dimensionless variable

SiteName

The USGS name of the site or, if not named, our designation. UT means "unnamed tributary." For example, "Lower Myakka UT 2" is an unnamed tributary to Lower Myakka Lake.

Basin Scale Categorical

<u>Physiog</u>: Physiographic regions.

0 = flatwoods (FW) basins have at least 50% D soils

1 = highlands (xeric, HL) have at least 45% A and C soils in combination

2 = Spring runs from karst aquifers (artesian or K).

<u>Geography</u>: North or south peninsula (generally using U.S. Interstate 4 as the divide).

<u>Gaged</u>: If Gaged (1), the site has a long term daily discharge record meeting the study purposes.

Basin Scale Continuous

<u>Drain_Area</u>: Topographic surface drainage area in square miles. For the non-karst streams, this is close to the total surface water and groundwater catchment. For karst runs, this area is the local surface water basin only and it usually does not correspond to the major recharge catchment for the run.

DA_Infilt: Drainage area in square miles. This is identical to Drain_Area for non-karst streams. For karst runs, this is based on the recharge area of the run's main spring(s). This basin therefore represents the dominant catchment for all streams in the study.

A_Soil*: NRCS hydrologic soil group (HSG). Percent of DA.

C_Soil*: HSG. Percent of DA.

D_Soil*: HSG. Percent of DA.

Wetlands*: Percent of DA.

Lakes*: Percent of DA.

Upland*: Percent of DA.

Strah_Order: Strahler network position.

Magn_Order: Cumulative number of segments upgradient of the reference reach (RR).

Drainage Density: Watershed longitudinal length in a straight line (L) divided by basin area (ft/sq. mile).

Bifurcation Ratio*. This is average of the ratios of the number of streams of a given order to the number of streams of the next higher order, using Strahler's ordering system.

DA_L_Rel: Relief from the reach drainage area's longitudinal apex to its mouth along the DA_L line.

HS_Rel: Highest relief along the reach DA's transversal apex to the valley flat's elevation near the reference reach.

DA_L: Longitudinal length of the drainage area from its upper divide to its mouth. Straight line.

DA_W: Widest part of the drainage area transverse to the longitudinal axis. This often occurs above the head of the drainage network.

DA_Shape: Ratio of drainage area in square miles to basin length (DA_L) in miles (sq. miles/mile).

Hillslope*: Overall valley hillslope grade, in percent, on either the left or right hillslope with the highest relief near the RR.

Long_Slope*: Watershed gradient, in percent, from the drainage apex to the valley mouth along the DA_L line.

Valley Scale Continuous

Val_Seg_Rel: Valley bottom along the stream segment from the USGS quads or SWFWMD LiDAR.

Val_Seg_L: Length of the valley segment with an uninterrupted open channel, between the channel's US and DS waterbody junctions.

Seg_Val_Slope*: Longitudinal slope of the valley segment.

W_Wetland: Width of the wetland at the reference cross-section (ft).

W_Wtld_W*: Width of wetland /bankfull width.

MBW_W*: Ratio of meander belt width to bankfull width.

WtldW_MBW*: Ratio of the wetland width to the meander belt width.

Valley_SR*: Valley segment sinuosity ratio. This is the sinuosity of the valley segment as the valley centerline meanders across the landscape. Some valleys appear to be very straight when compared to others, which essentially leads to a hierarchical meander of the channel/valley complex. The channel thalweg sinuosity is relative to the valley centerline length as calculated in this study.

Valley_L: Total length of the valley that is occupied by the reference reach, from the first transition boundary downstream of XS1 up to the valley's ultimate headwaters. This is at least as large, and frequently much larger than the RR's valley segment.

Valley_Trans: Number of transitions along the valley. A transition is defined if a zone in the valley switches from lotic (511) to paralentic (in line depressions) or paralotic (in line sloughs or island segments) and every time the valley switches from confined to unconfined forms.

Valley_T_L: Number of valley transitions divided by the total valley length, expressed as number per linear valley mile.

Zone_L: Average length of valley zones between their delineated boundaries. Equals Valley_L/Valley_Trans.

Zone_L_mn: Minimum zone length in the valley (ft).

Zone_L_mx: Maximum zone length in the valley.

Zone_L_R*: Min/Max ratio of zone lengths in the valley.

Zone_W: Average flat wetland width of each zone at its typical midpoint among the valley's zones.

Zone_W_mn: Minimum zone width in the valley

Zone_W_mx: Maximum zone width in the valley

Zone_W_R*: Min/Max ratio of zone widths in the valley

Valley Scale Categorical

Valley_Con: Categorical data classifying the shape of the valley profile, measured from the reference reach upstream to the headwaters, as

1 = concave,

2 = flat

3 = mixed concave/convex

4 = convex

Reach Scale Continuous

RR_Val_Slope*: Longitudinal slope of the reference reach. RR_HGL_Slope multiplied by Sinuousity.

WClass: Reference section's bankfull width.

W_Max: Maximum measured cross-section bankfull width in the RR.

W_Min: Minimum measured cross-section bankfull width in the RR.

Wx_Wn*: Ratio of maximum to minimum width in the RR.

Wstd: Standard deviation of the RR channel widths.

W_RR_Mean: Average among section widths within the RR.

DClass: Reference section's mean depth at bankfull stage (ft).

MD_Max: Maximum mean cross-section bankfull depth in the RR.

MD_Min: Minimum mean cross-section bankfull depth in the RR.

MDx_MDn*: Ratio of maximum to minimum mean depth in the RR.

MDstd: Standard deviation of the RR channel mean depths.

MD_RR_Mean: Average among section mean depths within the RR.

XSAClass: Reference section's bankfull cross-sectional area in square feet.

XSA_Max: Maximum cross-section area in the RR.

XSA_Min: Minimum mean cross-section area in the RR.

XSAx_XSAn*: Ratio of maximum to minimum area in the RR.

XSAstd: Standard deviation of the RR channel cross section areas in the RR.

XSA_M: Mean area of all RR cross-sections.

TWD: Bankfull thalweg depth of the reference section.

POOLD: Maximum thalweg depth in the RR.

TOB_W: Width of channel at bank height (top-of-bank) at the classification section.

RIFD: Minimum thalweg depth in the RR.

POOL_RIF*: Ratio of max pool to minimum riffle thalweg depths.

TWDstd: Standard deviation of the RR channel thalweg depths.

TWD_Mean: Average RR thalweg depth.

POOL_TWD_Mean: Average pool thalweg depths within the RR.

RIF_TWD_Mean: Average riffle thalweg depths within the RR.

POOL_RIF_Mean*: Ratio of mean pool TW depth to mean riffle TW depth in the RR.

BkHt: Obvious top-of-bank inflection at or above the alluvial transport bankfull stage, reported as a depth above thalweg elevation.

EntrRatio*: Rosgen entrenchment ratio for the classification section.

BHW_BKFW*: Ratio of bank height width to bankfull width.

WDRatio*: Ratio of bankfull width divided by mean bankfull depth at the reference section.

Sinuosity: RR sinuosity ratio (thalweg length divided by valley length).

MBW: Meander beltwidth for the RR (ft).

Bends_L: Average distance between bends.

Bend_No: No. of bends per 100’ length stream.

Bend_12W: Average number of bends/12*bankfull widths.

RC_Min: Radius of curvature of the tightest bend.

RC_Mean: Mean radius of curvature of the RR.

Pool_L: Average distance between pools (a pool must be >1.0 feet deep at TW & at least 1.5x mean classification section's average depth).

Pool_12W: Average number of poolss/12*bankfull widths.

WP: Wetted perimeter at bankfull.

HR: Hydraulic radius at bankfull.

HGL_S*: Water surface slope within the reference reach, using the best available data (1st a measured slope within 75% of bankfull stage, 2nd a slope derived from fitting a line to reliable bankfull indicators, 3rd a slope derived from fitting a line tangential to the riffle crests).

Man_n: Manning's friction factor. Back-calculated from measured discharges within 75% of bankfull stage. If such data are unavailable, mean values derived from similar stream conditions were used.

Vel_BKF: Mean channel velocity at bankfull. 1st from measured values. 2nd from calculated.

Q_BKF: Best calculation of bankfull discharge (1st from direct velocity-area measurement, 2nd from slope-velocity equation).

Shear_BKF: Max bankfull shear stress calculated at bankfull discharge.

Pow_BKF: Stream power as calculated at bankfull discharge.

Pow_BKF_W: Unit power per bankfull bed width.

FLOOD_D: Thalweg depth at the lichen line or best available flood field indicator (e.g. living bank inflection in seepage systems).

FLOOD_W: Width of floodplain at the flood depth indicated by a lichen line or moss collar if no lichen line. Taken at the classification section.

n_FLOOD: Manning's n for the flood section.

Vel_FLOOD: Mean conveyance velocity at flood discharge (fps).

Q_FLOOD: Calculated discharge at the FLOOD stage, using the valley segment slope.

Pow_FLOOD: Stream power calculated for flood depth discharge.

Pow_FLOOD_W: Power per unit width of the floodplain.

FLOOD_TWD*: Ratio of FLOOD depth to bankfull depth at the thalweg.

FLOOD_BkHt*: Ratio of the FLOOD depth to the top of bank height at the thalweg.

FLOODW_BKFW*: Ratio of floodplain (e.g. lichen) width to bankfull width.

Q_FLOOD_BKF*: Ratio of flood to bankfull discharge.

Pow_FLOOD_BKF*: Ratio of flood to bankfull stream power.

Vel_FLOOD_BKF*: Ratio of mean flood to bankfull cross-section velocity.

RcW*: Mean RR radius of curvature divided by mean RR bankfull width.

RcWTight*: Tightest bend in RR. Minimum Rc/average RR W.

BHRatio*: Ratio of thalweg bank height to thalweg bankfull depths.

Reach Scale Categorical

CLASS_ROS: Rosgen Level II channel classification.

Valley_Conf: Categorical (ordinal, so it can be used classification clusters if desired):

0 = seepage ravine (lateral seepage slope flanks the top of bank)

1 = confined valley (upland FLUCCS within most of the MBW)

2 = well-adjusted valley (MBW is dominated by wetland FLUCCS, but is confined on both sides by an upland hillslope. Most outer bends are within 2 bankfull widths of an upland)

3 = unconfined valley (stream meanders through a broad valley flat with outer bends fully contained by wetlands at least 2 bankfull widths beyond the outer bends)

Reach Scale Riparian Ecology and Soils Categorical

MBW_FLUCCS: Dominant FDOT (1999) FLUCCS within the meander belt.

HS_FLUCCS: Dominant FDOT (1999) FLUCCS on the hillslope or other adjacent geomorphic feature adjacent to the meander belt (could simply be an extension of the valley flat in an unconfined system).

Seg_US_BND: Waterbody FLUCCS upstream of the stream segment (511, 6xx).

Seg_DS_BND: Waterbody FLUCCS downstream of the stream segment (511, 6xx).

BKF_IND: Dominant, most reliable bankfull field indicator.

Bed_upper_sed: Dominant sediment texture on the channel bed.

Bank_sed_LB: Dominant sediment texture on the LB.

Bank_sed_RB: Dominant sediment texture on the RB.

MBW_sed: Dominant sediment texture in the meander belt.

HS_sed: Dominant sediment texture in the corridor just outside the meander beltwidth.

Bio_Banks (ordinal, can be used in some numerical tests): Categorical:

4 = Ubiquitous (>90%)

3 = Dominant (>50%)

2 = Present (<50%)

1 = Rare (<10%)

Reach Scale Riparian Ecology and Soils Continuous

No_Bed_Alluv: Number of alluvial channel features in the RR.

No_FP_Alluv: Number of alluvial floodplain features in the RR.

No_Tot_Alluv: Total number of alluvial features in the RR channel and floodplain

Canopy_CL*: Canopy closure at the channel center facing US and DS.

Canopy_Ttl*: Canopy closure at the reference section facing US, DS, LB, RB at the channel center.

In-Stream Habitat Patch Scale Continuous

LWD_Count: Logs per 100 feet of stream length.

Sand*: % of total frequency encountered on the RR substrate. Not percent area.

Mud*: % of total frequency encountered on the RR substrate. Not percent area.

Leaf*: % of total frequency encountered on the RR substrate. Not percent area.

FWD*: % of total frequency encountered on the RR substrate. Not percent area.

Aveg*: % of total frequency encountered on the RR substrate. Not percent area.

Rock*: % of total frequency encountered on the RR substrate. Not percent area.

SAV*: % of total frequency encountered on the RR substrate. Not percent area.

Root*: % of total frequency encountered on the RR substrate. Not percent area.

Root_Steps: No. per 100' channel length.

Pool_No: No. of pools per 100' length stream.

Shallow_Pools*: %No. of pools 1 to 2 feet deep at TW.

Medium_Pools*: %No. 2 to 4 feet deep at TW.

Deep_Pools*: %No. >4 feet deep at TW.

WP: Wetted perimeter at bankfull.

APPENDIX B
HYDROLOGIC VARIABLE DESCRIPTIONS

Distance dimensions are in linear feet unless otherwise stated. Area measures are in square feet unless otherwise stated. Volumetric flow rates are reported in cubic feet per second.

XerSoil. %A+C soils in the watershed.

DA_Main. Primary drainage area. Surface area watershed for blackwater streams and springshed for karst systems.

DA_Surf. Surface area watershed for spring runs.

QBKF. Bankfull discharge.

QFLOOD. Flood channel discharge (as defined in Appendix A).

QBKF_PDS. Average annual bankfull flow frequency calculated by partial duration series.

QFLOOD_PDS. Average annual flood channel flow frequency calculated by partial duration series.

QBKF_Exc. Percent of time bankfull discharge is equaled or exceeded.

QFLOOD_Exc. Percent of time flood channel discharge is equaled or exceeded.

SFSlope. Seasonal flow slope of the dimensionless flow exceedance curve between the 15^{th} and 85^{th} percentiles.

RO. % rainfall that becomes stream discharge.

Jan_Ma12. Mean January flow.

CV_Jan_Ma24. Standard deviation of January flow divided by the mean January flow.

Feb_Ma13. Mean February flow.

CV_Feb_Ma25. Standard deviation of January flow divided by the mean February flow.

Mar_Ma14. Mean March flow.

CV_Mar_Ma26. Standard deviation of January flow divided by the mean March flow.

Apr_Ma15. Mean April flow

CV_Apr_Ma27. Standard deviation of January flow divided by the mean April flow.

May_Ma16. Mean May flow.

CV_May_Ma28. Standard deviation of January flow divided by the mean May flow.

Jun_Ma17. Mean June flow.

CV_Jun_Ma29. Standard deviation of January flow divided by the mean June flow.

Jul_Ma18. Mean July flow.

CV_Jul_Ma30. Standard deviation of January flow divided by the mean July flow.

Aug_Ma19. Mean August flow.

CV_Aug_Ma31. Standard deviation of January flow divided by the mean August flow.

Sep_Ma20. Mean September flow.

CV_Sep_Ma32. Standard deviation of January flow divided by the mean September flow.

Oct_Ma21. Mean October flow.

CV_Oct_Ma33. Standard deviation of January flow divided by the mean October flow.

Nov_Ma22. Mean November flow.

CV_Nov_Ma34. Standard deviation of January flow divided by the mean November flow.

Dec_Ma23. Mean December flow.

CV_Dec_Ma35. Standard deviation of January flow divided by the mean December flow.

d1Min_DL1. Mean of the series of minimum 1-day moving average flow for each year divided by the drainage area.

CV_1dMin_DL6. Coefficient of variation of the series of minimum 1-day moving average flow for each year divided by the drainage area.

d3Min_DL2. Mean of the series of minimum 3-day moving average flow for each year divided by the drainage area.

CV_3dMin_DL7. Coefficient of variation of the series of minimum 3-day moving average flow for each year divided by the drainage area.

d7Min_DL3. Mean of the series of minimum 7-day moving average flow for each year divided by the drainage area.

CV_7dMin_DL8. Coefficient of variation of the series of minimum 7-day moving average flow for each year divided by the drainage area.

d30Min_DL4. Mean of the series of minimum 30-day moving average flow for each year divided by the drainage area.

CV_30dMin_DL9. Coefficient of variation of the series of minimum 30-day moving average flow for each year divided by the drainage area.

d90Min_DL5. Mean of the series of minimum 90-day moving average flow for each year divided by the drainage area.

CV_90dMin_DL10. Coefficient of variation of the series of minimum 90-day moving average flow for each year divided by the drainage area.

d1Max_DH1. Mean of the series of maximum 1-day moving average flow for each year divided by the drainage area.

CV_1dMax_DH6. Coefficient of variation of the series of maximum 1-day moving average flow for each year divided by the drainage area.

d3Max_DH2. Mean of the series of maximum 3-day moving average flow for each year divided by the drainage area.

CV_3dMax_DH7. Coefficient of variation of the series of maximum 3-day moving average flow for each year divided by the drainage area.

d7Max_DH3. Mean of the series of maximum 7-day moving average flow for each year divided by the drainage area.

CV_7dMax_DH8. Coefficient of variation of the series of maximum 7-day moving average flow for each year divided by the drainage area.

d30Max_DH4. Mean of the series of maximum 30-day moving average flow for each year divided by the drainage area.

CV_30dMax_DH9. Coefficient of variation of the series of maximum 30-day moving average flow for each year divided by the drainage area.

d90Max_DH5. Mean of the series of maximum 90-day moving average flow for each year divided by the drainage area.

CV_90dMax_DH10. Coefficient of variation of the series of maximum 90-day moving average flow for each year divided by the drainage area.

ZeroDays_DL18. Mean number of days with zero flow per year.

CV_ZeroDays_DL19. Coefficient of variation of number of days per year with zero flow.times 100.

Baseflow_ML17. Baseflow calculated as mean of the series of minimum 7-day moving average flows for each year divided by the mean annual flow for that year.

CV_BaseFlow_ML18. Coefficient of variability for Baseflow_ML17.

DateMin_TL1. Mean of the series of Julian dates on which the minimum flow occurred for each year.

CV_DateMin_TL2. Coefficient of variation for DateMin_TL1. In Julian date units, but not to be interpreted as an actual day.

DateMax_TH1. Mean of the series of Julian dates on which the maximum flow occurred for each year.

CV_DateMax_TH2. Coefficient of variation for DateMax_TH1. In Julian date units, but not to be interpreted as an actual day.

NumLoPulse__FL1. Mean of the number of flow events per year below the 25th percentile.

CV_NumLoPulse__FL2. Coefficient of variation for NumLoPulse_FL1 times 100.

DurLoPulse_DL16. Median of the series of average pulse durations for flow events below the 25th percentile (calculated for entire record) of each year.

CV_DurLoPulse_DL17. Coefficient of variation of the yearly average low pulse durations multiplied by 100.

NumHiPulse__FH1. Mean of the number of flow events per year above the 75th percentile.

CV_NumHiPulse__FH2. Coefficient of variation for NumHiPulse_FH1 times 100.

DurHiPulse_DH15. Median of the series of average pulse durations for flow events above the 75th percentile (calculated for entire record) of each year.

CV_DurHiPulse_DH16. Coefficient of variation of the yearly average high pulse durations multiplied by 100.

RiseRate_RA1. Mean of the series of change in flow values for days in which the change is positive for the entire record.

CV_RiseRate_RA2. Coefficient of variation for RiseRate_RA1 times 100.

FallRate_RA3. Mean of the series of change in flow values for days in which the change is negative for the entire record.

CVFallRate_RA4. Coefficient of variation for FallRate_RA3 times 100.

Reversals_RA8. Mean of the series of the number of days each year when the change in flow from one day to the next changes direction.

CV_Reversals_RA9. Coefficient of variation of Reversals_RA8 tiimes 100.

Oct_PMAR. The monthly average flow for October multiplied by the number of days in the month, all divided by the total runoff volume for the year.

Nov_PMAR. The monthly average flow for November multiplied by the number of days in the month, all divided by the total runoff volume for the year.

Dec_PMAR. The monthly average flow for December multiplied by the number of days in the month, all divided by the total runoff volume for the year.

Jan_PMAR. The monthly average flow for January multiplied by the number of days in the month, all divided by the total runoff volume for the year.

Feb_PMAR. The monthly average flow for February multiplied by the number of days in the month, all divided by the total runoff volume for the year.

Mar_PMAR. The monthly average flow for March multiplied by the number of days in the month, all divided by the total runoff volume for the year.

Apr_PMAR. The monthly average flow for April multiplied by the number of days in the month, all divided by the total runoff volume for the year.

May_PMAR. The monthly average flow for May multiplied by the number of days in the month, all divided by the total runoff volume for the year.

Jun_PMAR. The monthly average flow for June multiplied by the number of days in the month, all divided by the total runoff volume for the year.

Jul_PMAR. The monthly average flow for July multiplied by the number of days in the month, all divided by the total runoff volume for the year.

Aug_PMAR. The monthly average flow for August multiplied by the number of days in the month, all divided by the total runoff volume for the year.

Sep_PMAR. The monthly average flow for September multiplied by the number of days in the month, all divided by the total runoff volume for the year.

Drainage_Area. Square miles.

MAR. Mean annual runoff (average daily flow times 365.24).

Flash_# RA10. Mean of the series of maximum flows for each year divided by the mean discharge value for the entire record.

Skew MA59. Total skewness. The mean of the total record minus the median of the total record all divided by the mean of the total record.

CV_of_Daily_Flows_Ma3. Mean of the coefficients of variation for each year.

Monthly_Skew_Ma40. The mean of the monthly flows minus the median of the monthly flows, all divided by median of the monthly flows.

Ann_Runoff_Ma41. The mean of the mean annual flows for each year divided by drainage area.

Variability of Annual Flows Ma44. The 90th percentile flow minus the 10th all divided by the median of the annual mean flows.

CV_Monthly_Min_ML13. Standard deviation for the minimum monthly flows of the entire flow record divided by the mean, times 100.

Mn_Ann_Qmin_ML14. The mean of the series of minimum flow ratios divided by the median flow for each year.

Mn_Ann_Qmin_ML22. The mean of the series of minimum flows for each year divided by drainage area.

Oct_Mn_Qmax_Mh1. Mean of the series of maximum flows in October for each year.

CV_Oct_Mh1. Coefficient of variation for Oct_Mn_Qmax_Mh1 for each year.

May_Mn_Qmax_Mh8. Mean of the series of maximum flows in May for each year.

CV_May_Mh8. Coefficient of variation for May_Mn_Qmax_Mh8 for each year.

Mn_25_XCD_MH17. The 25% exceedance value for the entire record divided by the median flow for the entire record.

Mn_Ann_Qmax_MH20. Mean of the series of maximum flows for each year divided by drainage area.

LoPulse_Freq_Fl3.

Num_Floods_FH11. Flood frequency of the average number of flow events above the 1.67 year annual return interval per year. The index is the mean of this series.

Mn_Ann_30d_min_DL13. Annual minimum 30 day flow divided by the median flow for period of record.

Mn_Ann_7d_max_DH12. Annual maximum 7-day flow divided by the median flow for the entire record.

Mn_Ann_30d_Max_DH13. Annual maximum 30-day flow divided by the median flow for the entire record.

Nonflood_Predict_TH3. Maximum number of days in a row during which no flood ($Q_{1.67}$) has ever occurred throughout the record divided by the number of days pr year.

BS1_Flash_# RA11. Bledsoe/Sanborn flash index. Sum of the absolute differences between the flow of each day and the next day divided by the total number of days in the record minus one, all divided by mean flow of the entire record.

Colwell_Pred_TA2. Colwell's predictability index.

Tqmean. Total number of days in the flow record that are above the mean of the record divided by the total number of days in the record.

P100_Q1.67 DH26. Total number of days in the record that are at least at the $Q_{1.67}$ value.

P75_Q1.67 DH27. Total number of days in the record that are at least 75% of the $Q_{1.67}$ value.

P50_Q1.67 DH28. Total number of days in the record that are at least 50% of the $Q_{1.67}$ value.

Q_Mean. Daily mean flow for the record.

Q_Median. Median daily flow for the record.

APPENDIX C
STREAM CROSS SECTIONS

LEGEND

"MBW" is meander belt width.

All elevations and distances are on an arbitrary vertical and horizontal datum.

The 3-digit numerical codes are Level III Florida Land Use and Cover Codes (FLUCCS)

from FDOT (1999) as follows:

321- Palmetto Prairies
411- Pine Flatwoods
412- Longleaf Pine-Xeric Oak
413- Sand Pine
414- Pine-Mesic Oak
415- Mixed Pine (combined xeric and mesic pines and hardwoods)
421- Xeric Oak
425- Temperate Hardwood
427- Live Oak
432- Sand Live Oak
434-Hardwood-Conifer Mixed
511- Stream Channels (with alluvial beds)
611- Bay Swamps
615- Stream and Lake Swamps (Bottomland)
616- Inland Ponds and Sloughs
617- Mixed Wetland Hardwoods
621-Cypress
624-Cypress-Pine-Cabbage Palm (may lack cypress)
625- Hydric Pine Flatwoods
626- Hydric Pine Savanna (this was used for Cutthroat Grass Seeps)
630- Wetland Forest Mixed (even mix of cypress and hardwoods)
641- Freshwater Marsh
643- Wet Prairie

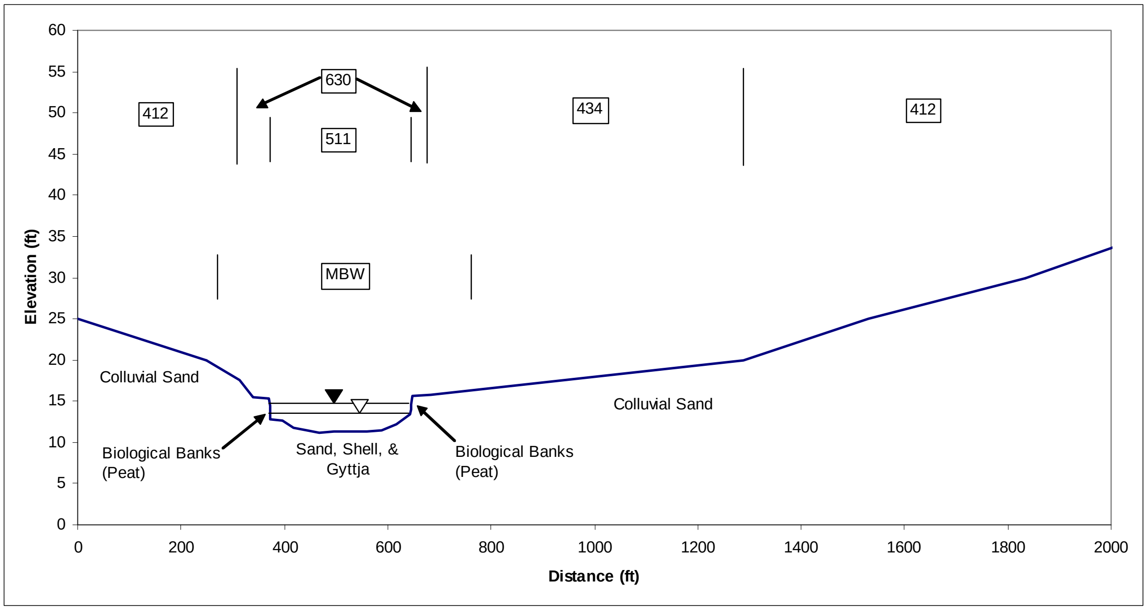


Figure C-1. Alexander Spring Run valley.

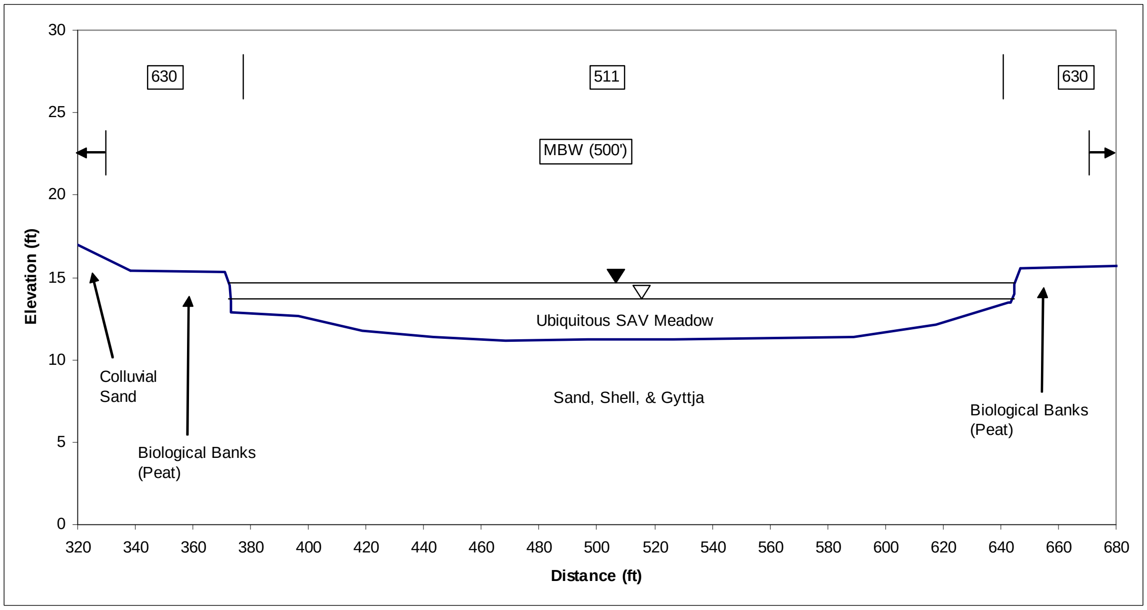


Figure C-2. Alexander Spring Run channel.

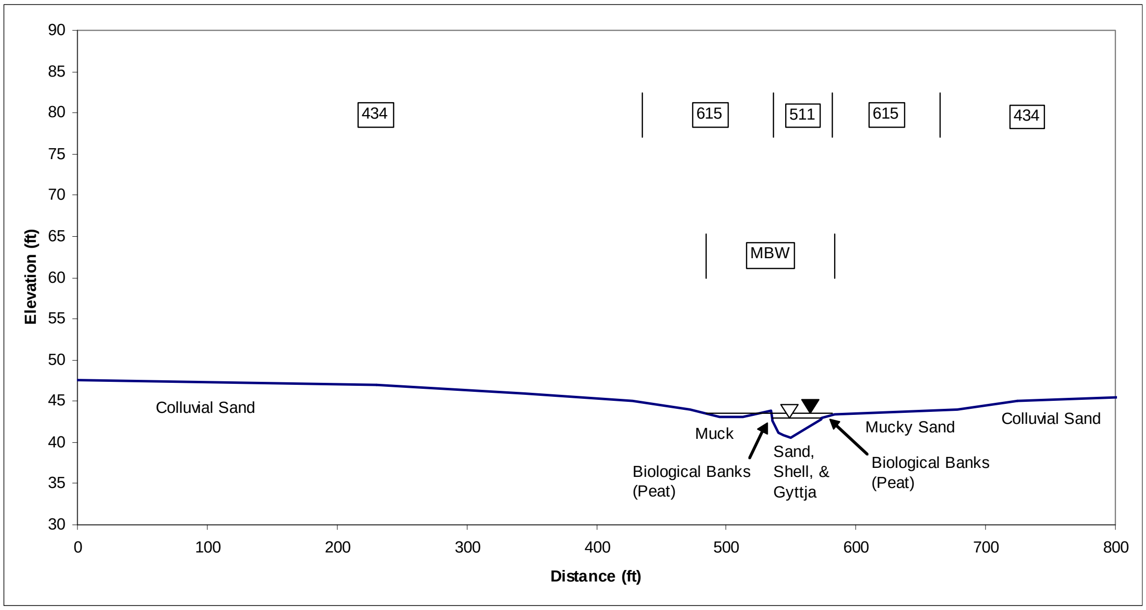


Figure C-3. Alligator Spring Run valley.

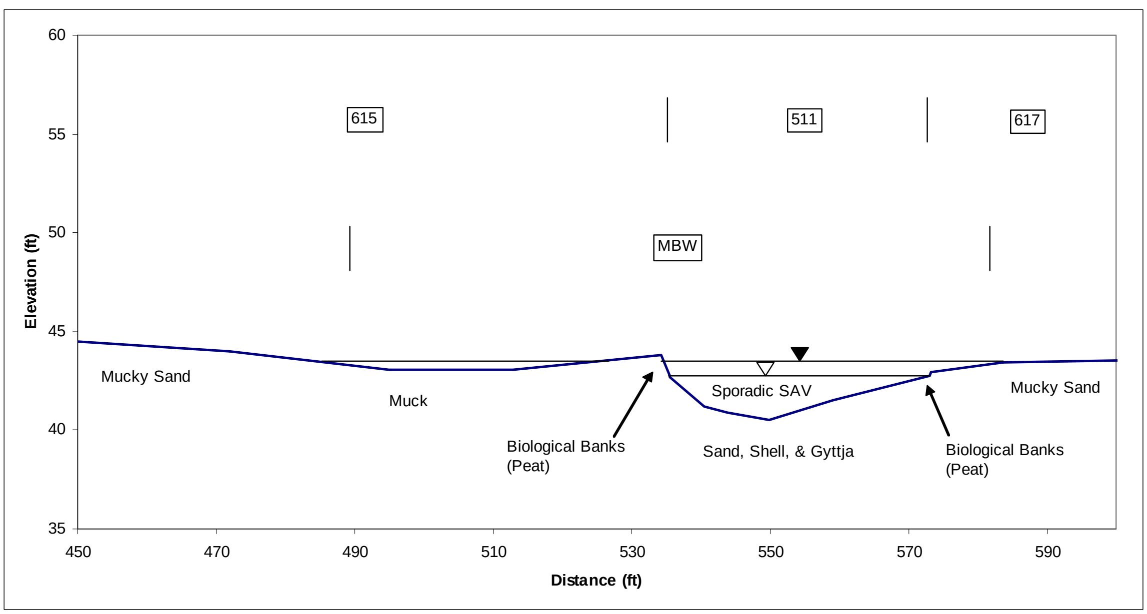


Figure C-4. Alligator Spring Run channel.

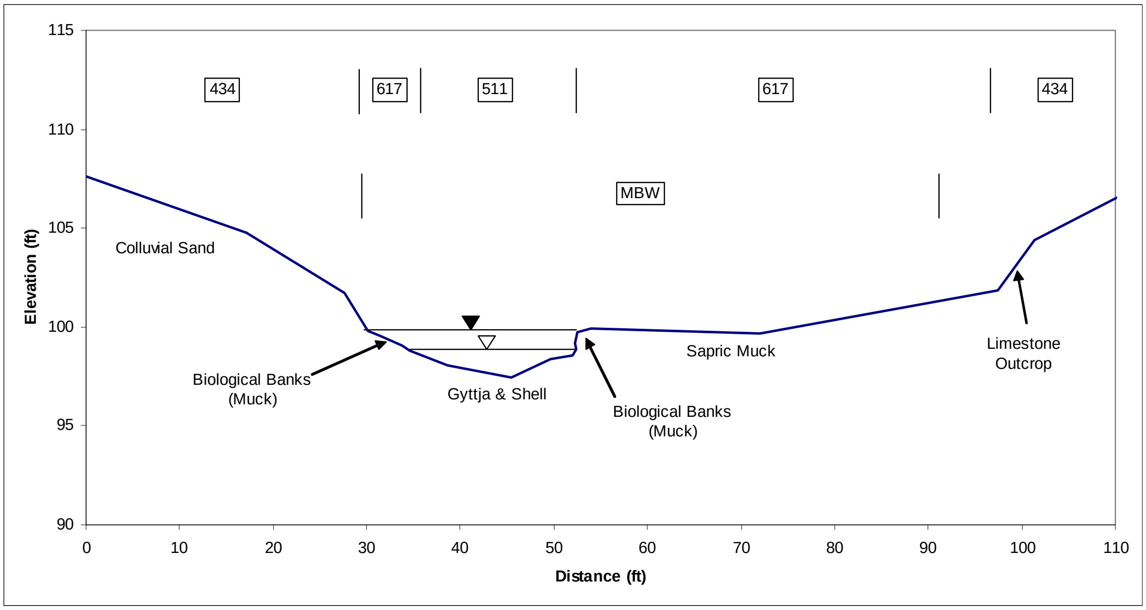


Figure C-5. Cedar Head Run channel and valley.

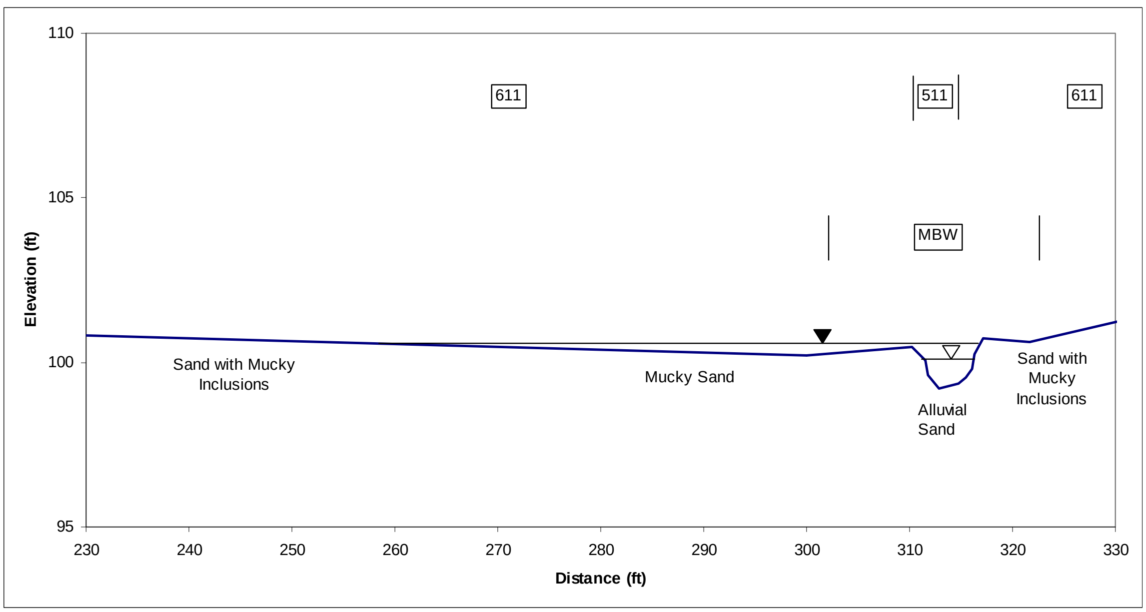


Figure C-6. Forest Run channel and valley.

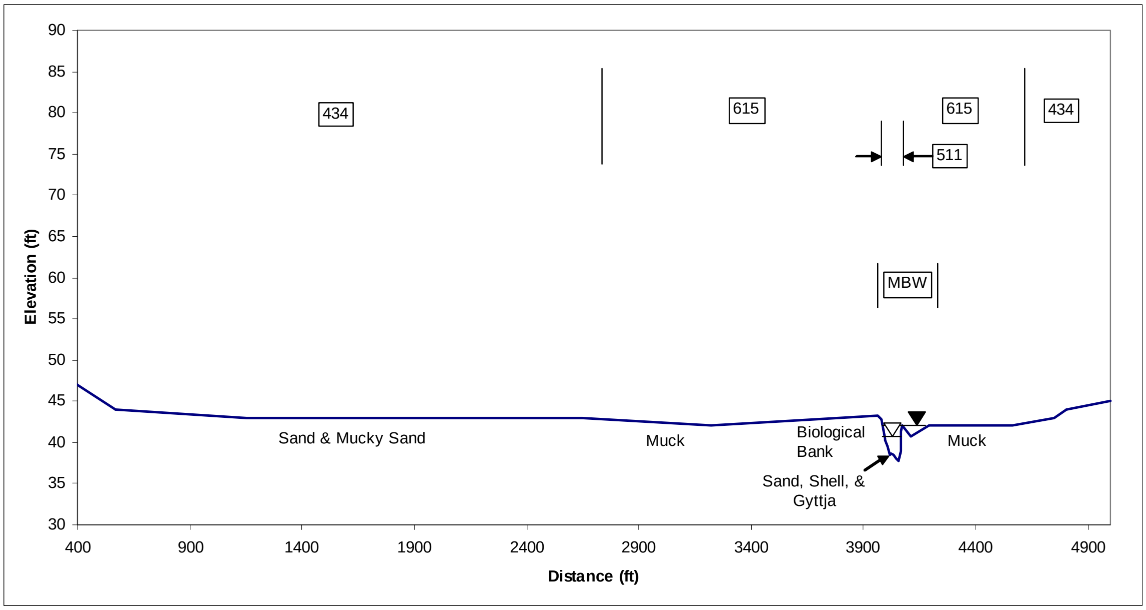


Figure C-7. Gum Slough Run valley.

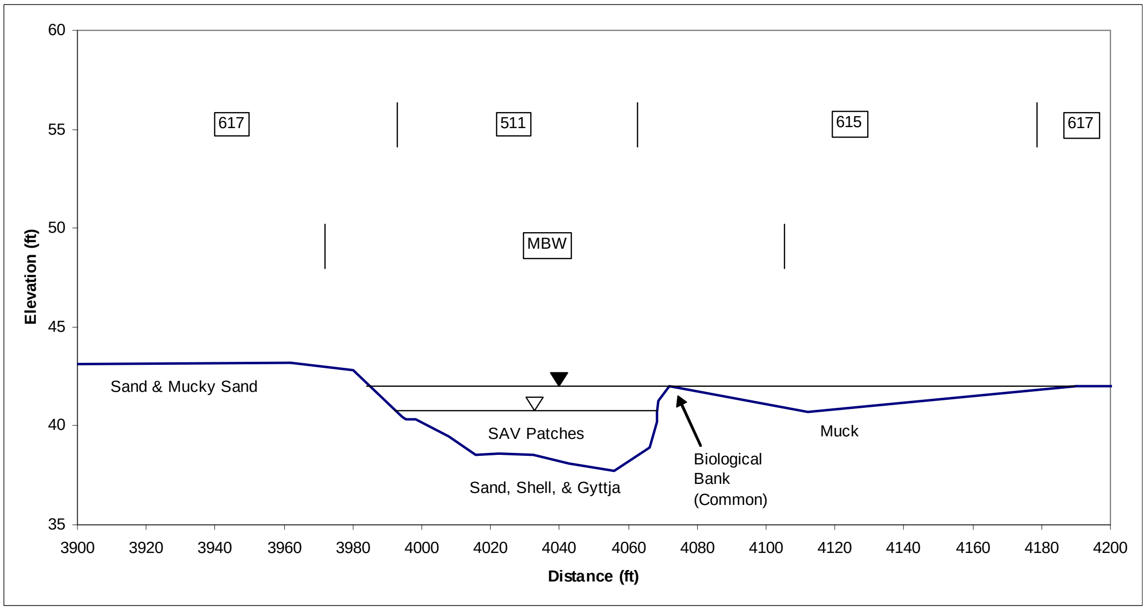


Figure C-8. Gum Slough Run channel.

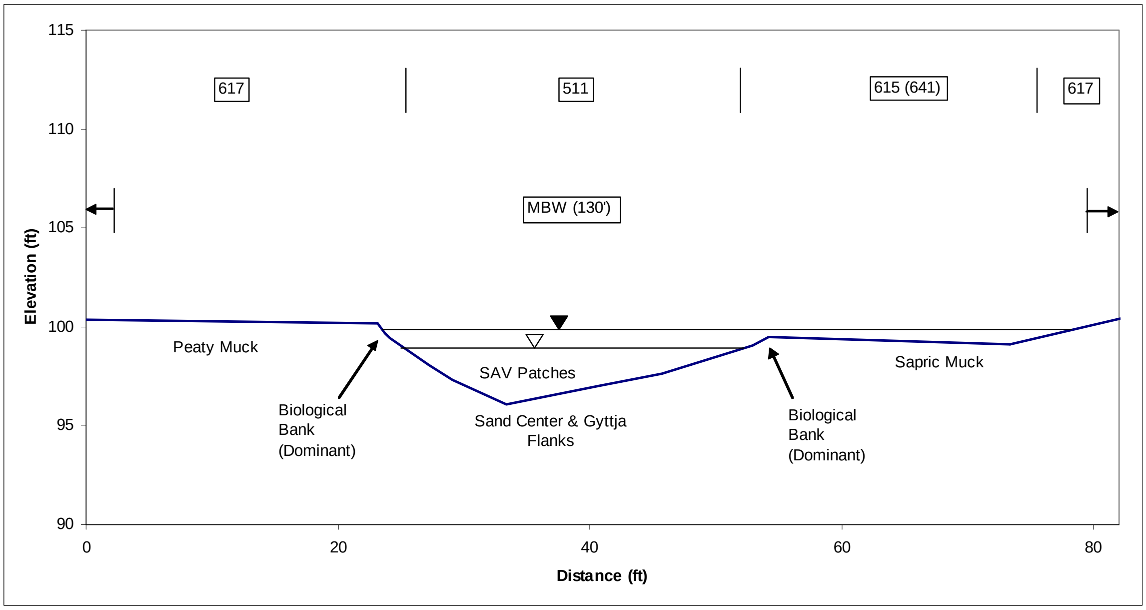


Figure C-9. Juniper Run channel.

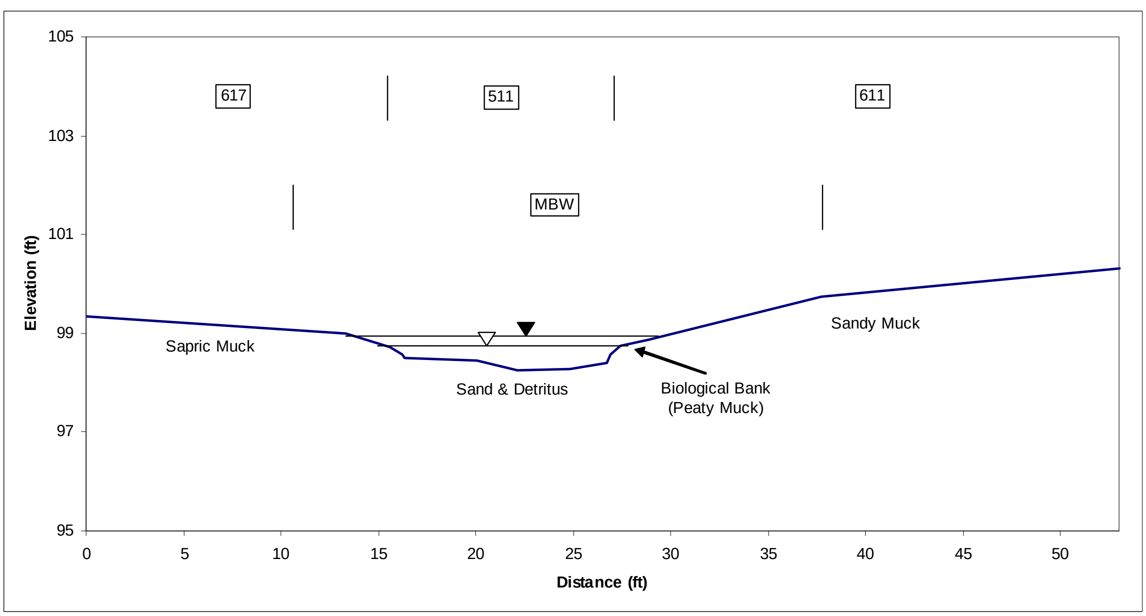


Figure C-10. Kittridge Run channel.

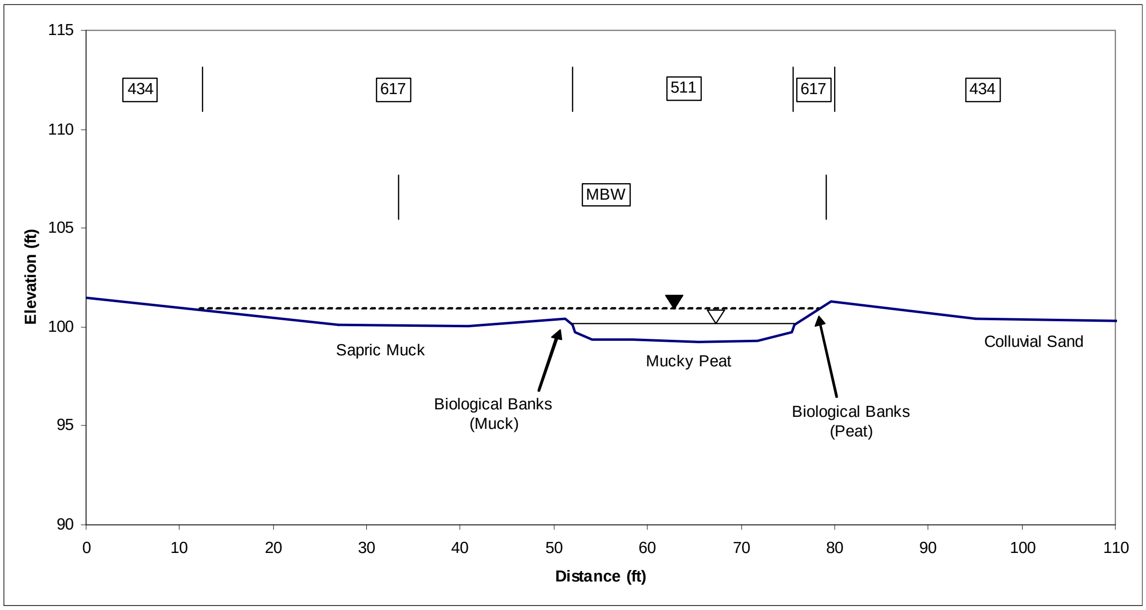


Figure C-11. Little Levy Blue Run channel.

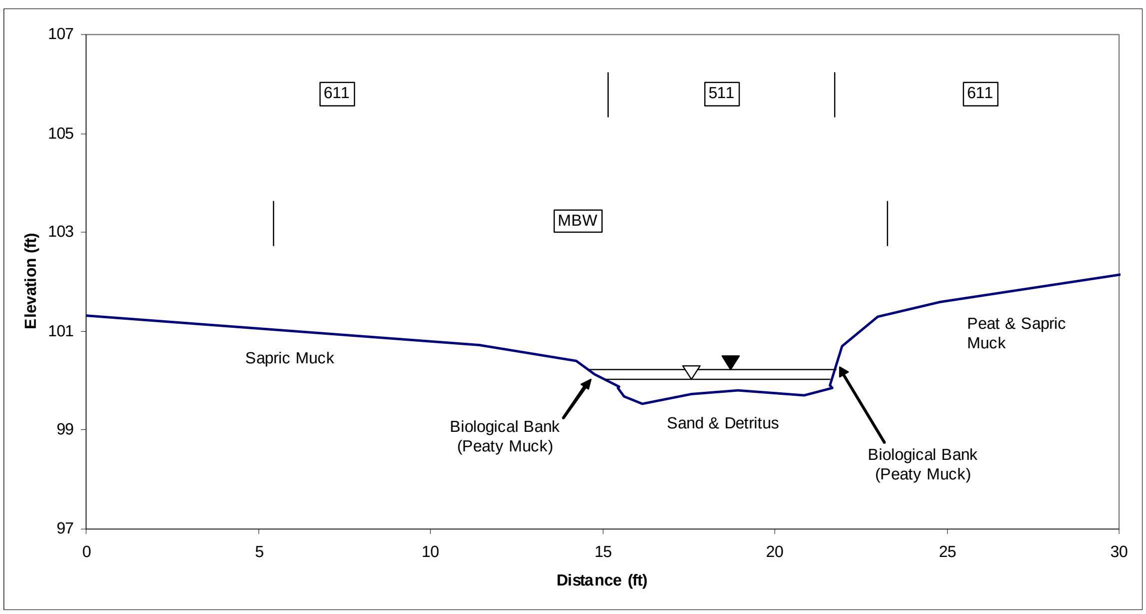


Figure C-12. Morman Branch UT channel.

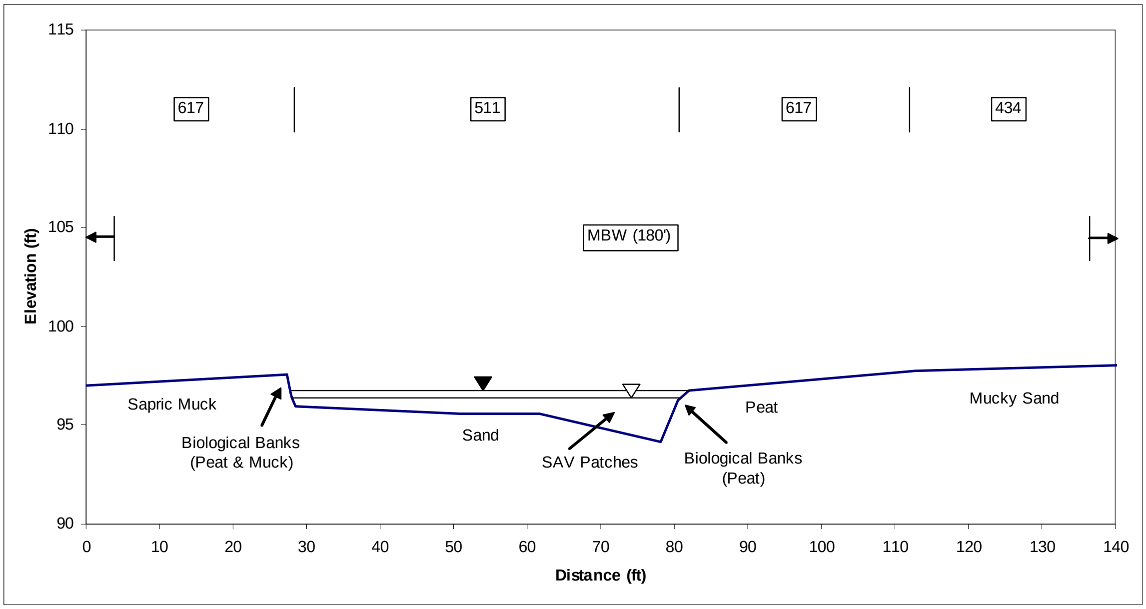


Figure C-13. Rock Spring Run channel.

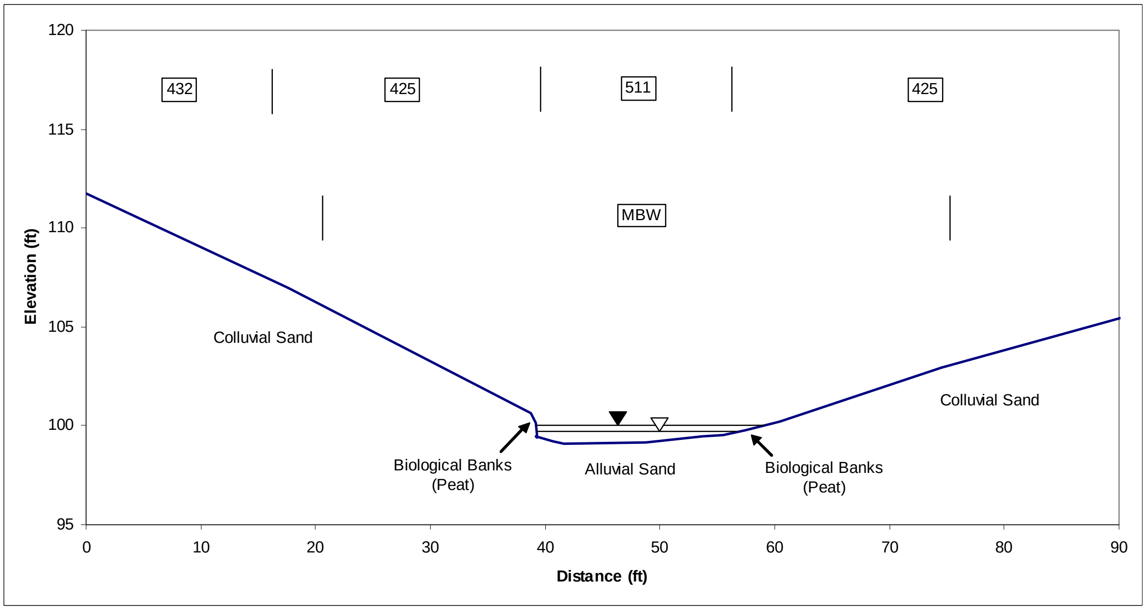


Figure C-14. Silver Glen UT valley.

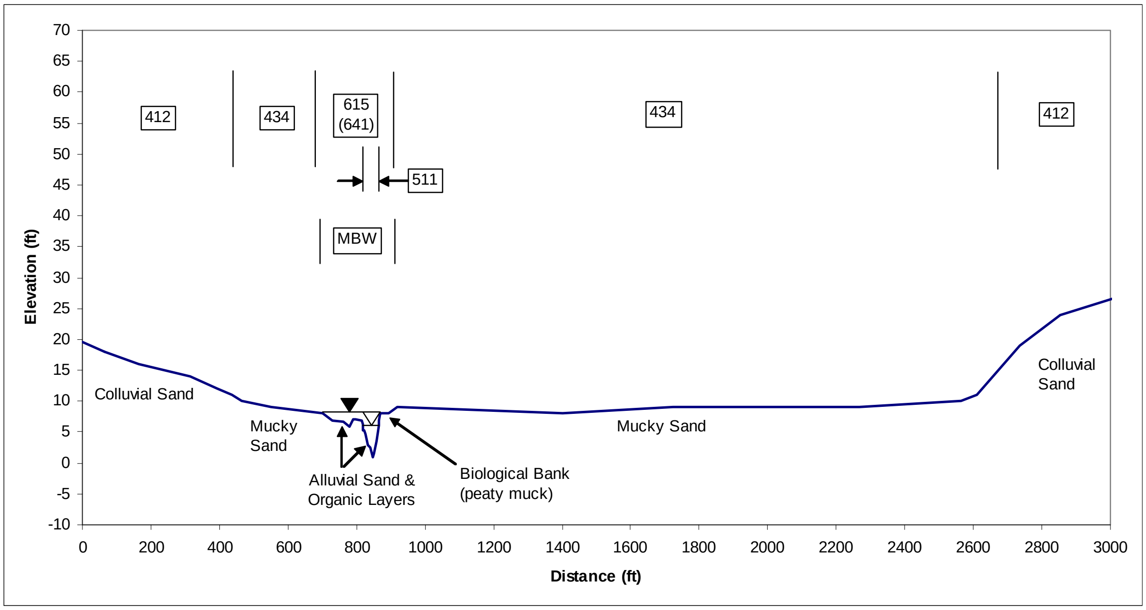


Figure C-15. Weeki Wachee River valley.

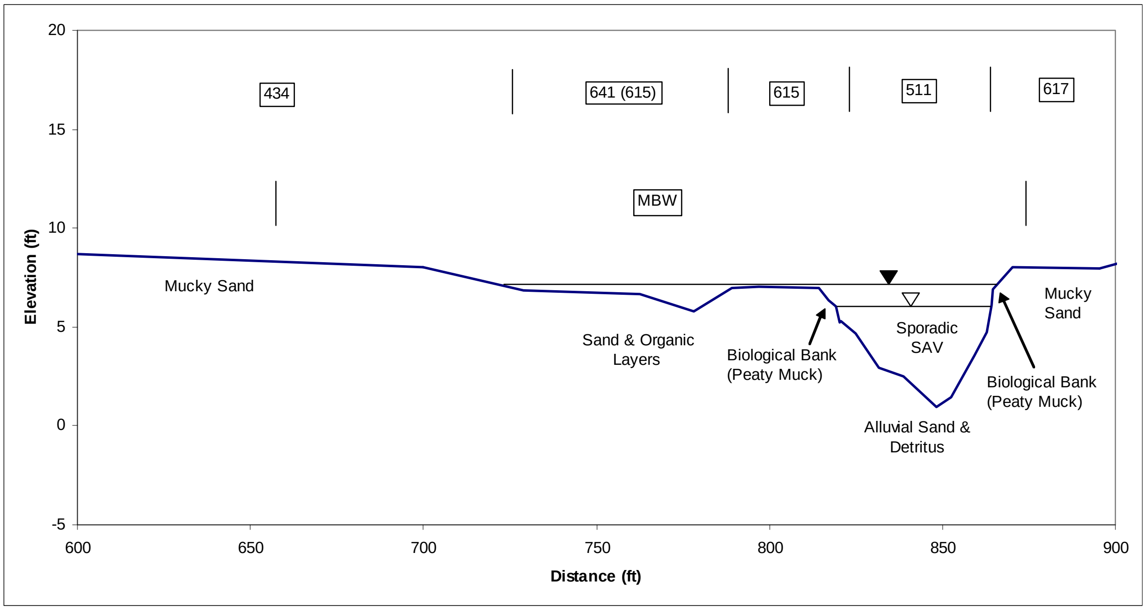


Figure C-16. Weeki Wachee River channel.

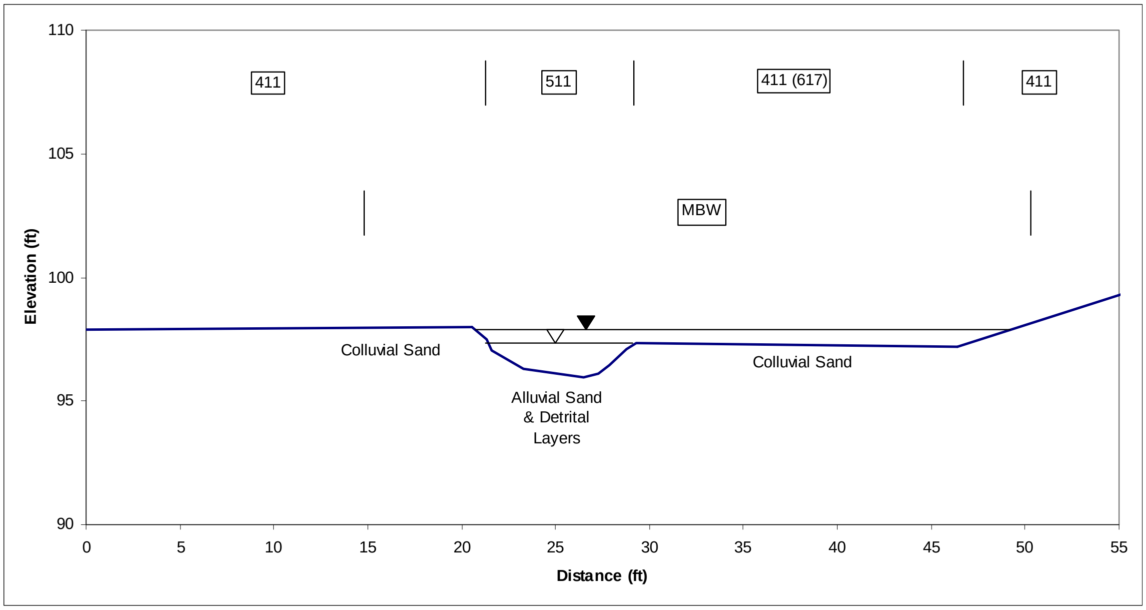


Figure C-17. Alexander UT2 channel and valley.

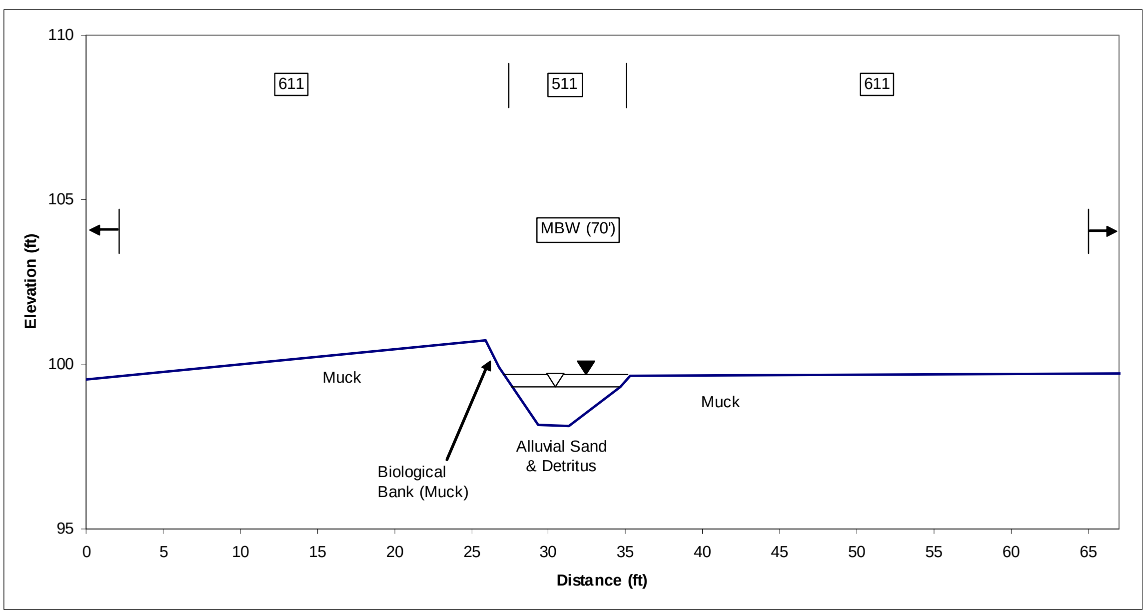


Figure C-18. Bell Creek channel.

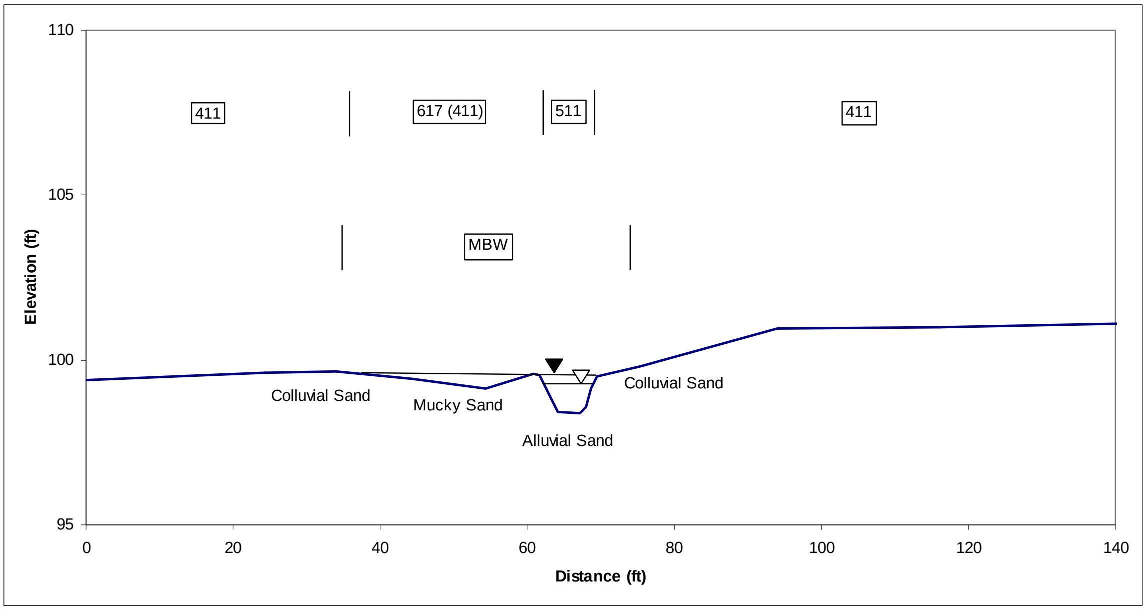


Figure C-19. Bell Creek UT channel and valley.

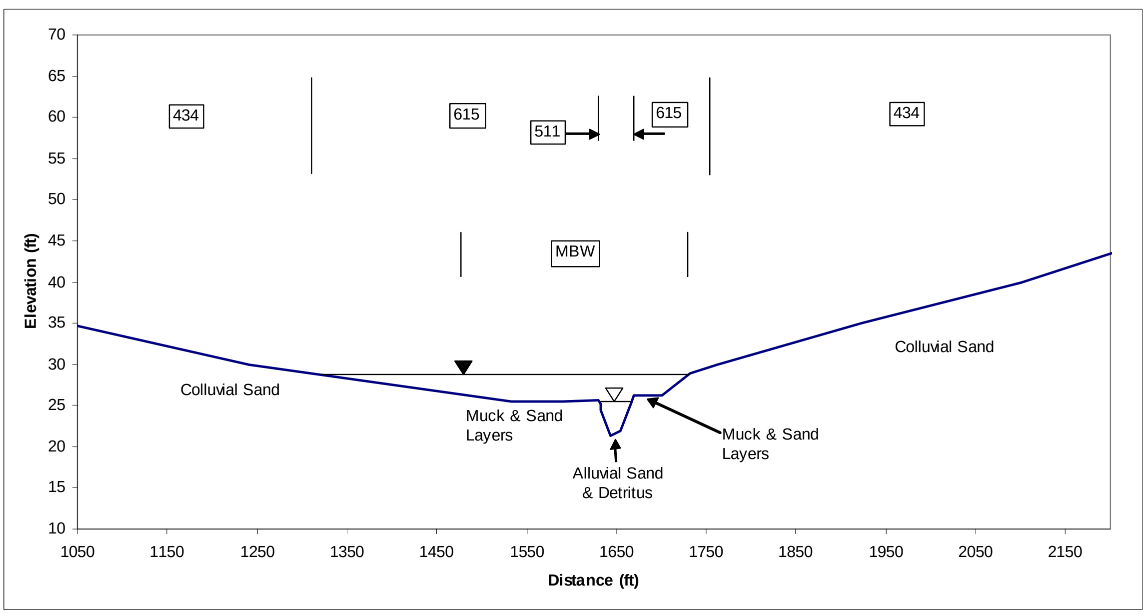


Figure C-20. Blackwater Creek valley.

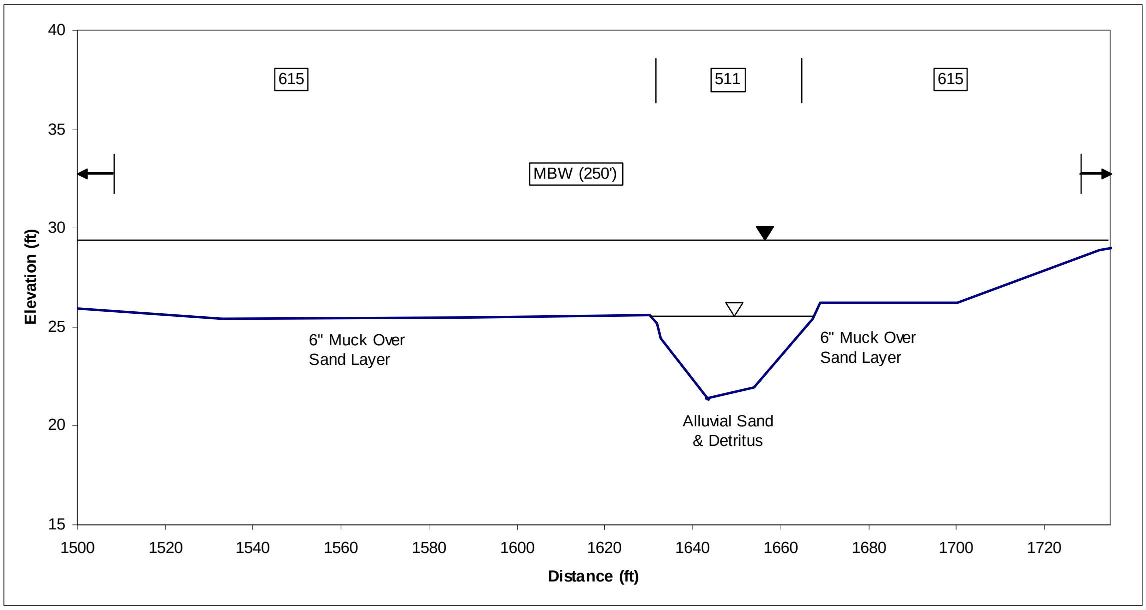


Figure C-21. Blackwater Creek channel.

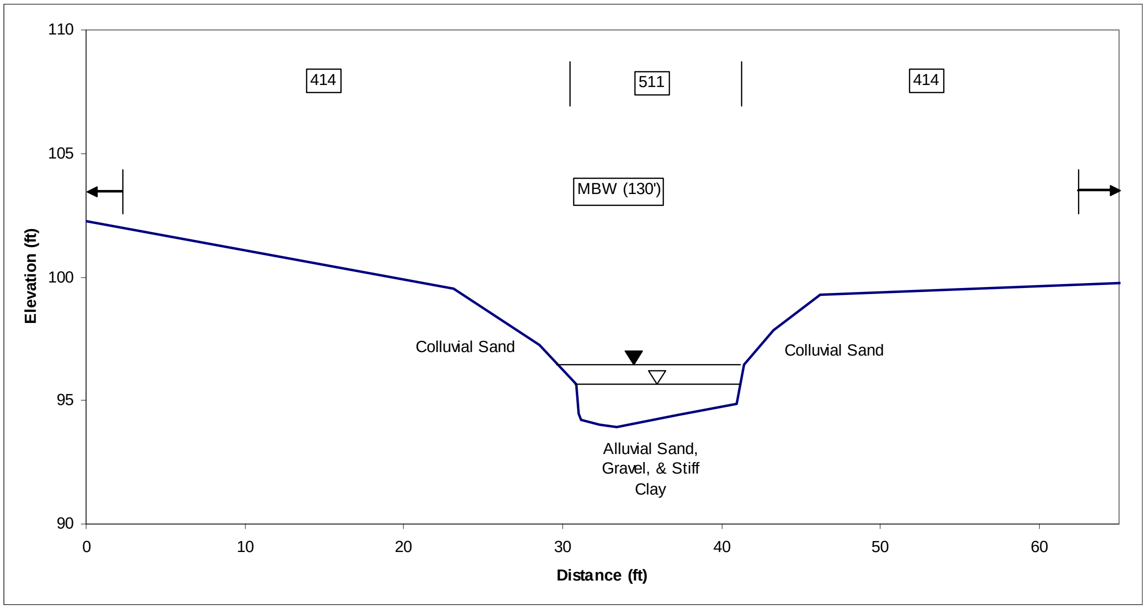


Figure C-22. Blues Creek channel and valley.

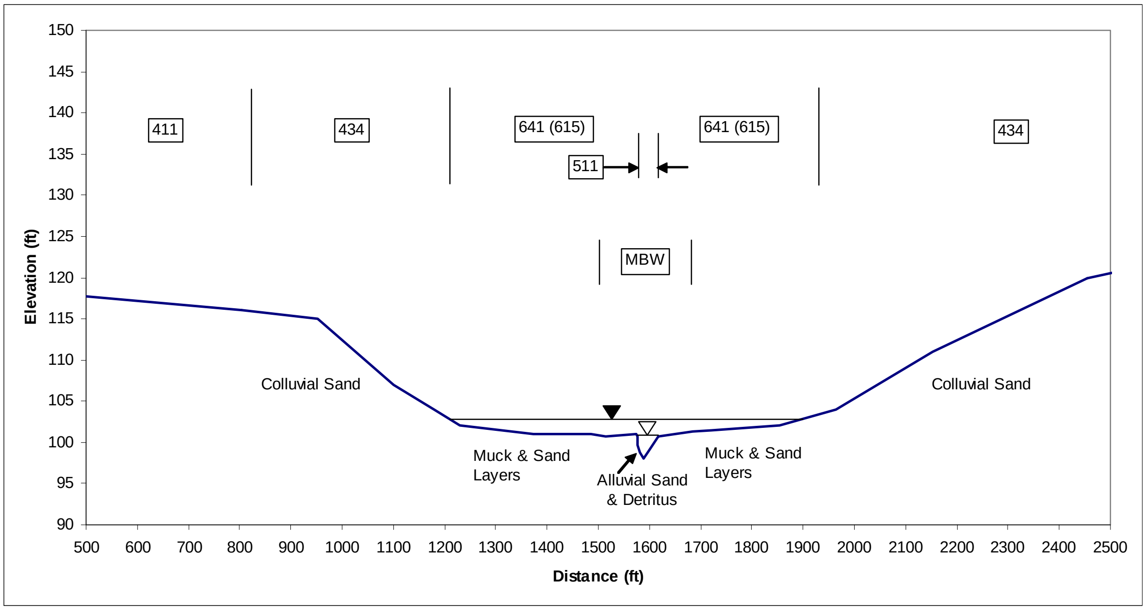


Figure C-23. Bowlegs Creek valley.

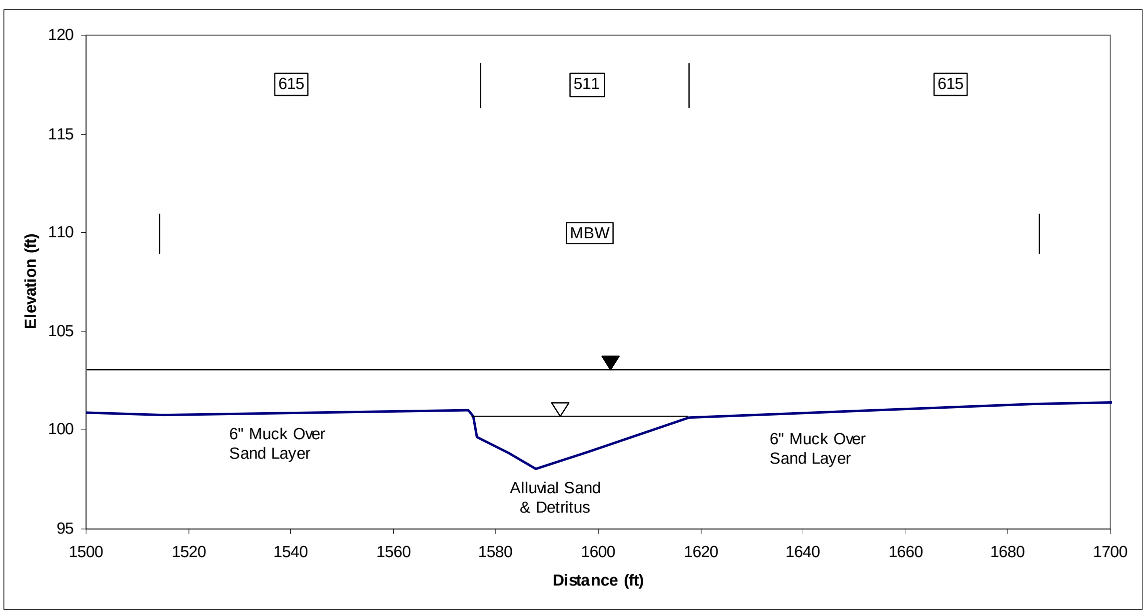


Figure C-24. Bowlegs Creek channel.

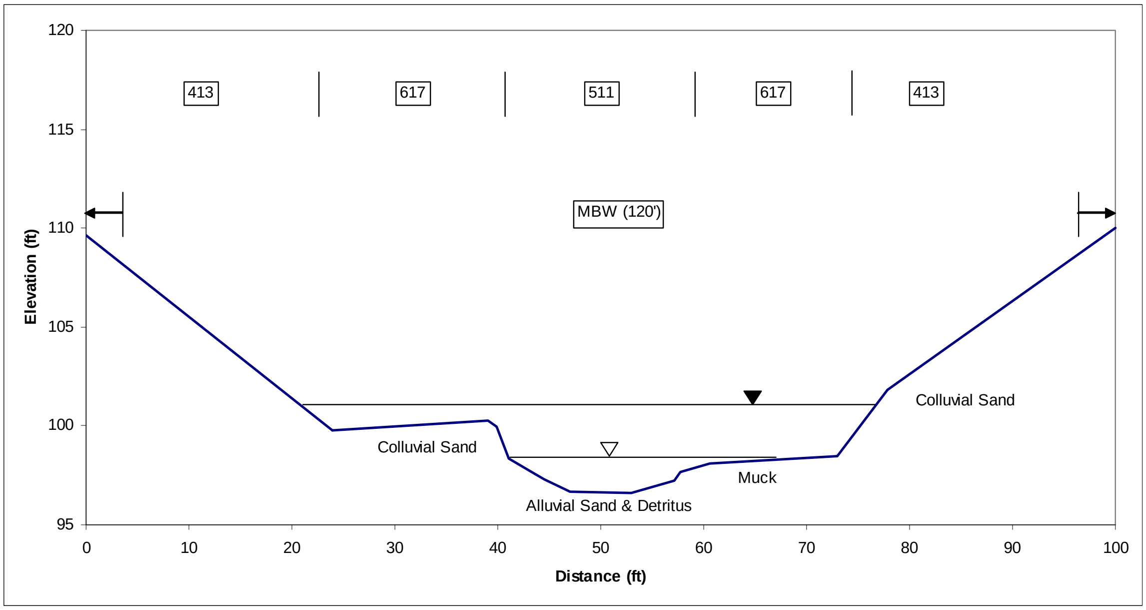


Figure C-25. Carter Creek channel and valley.

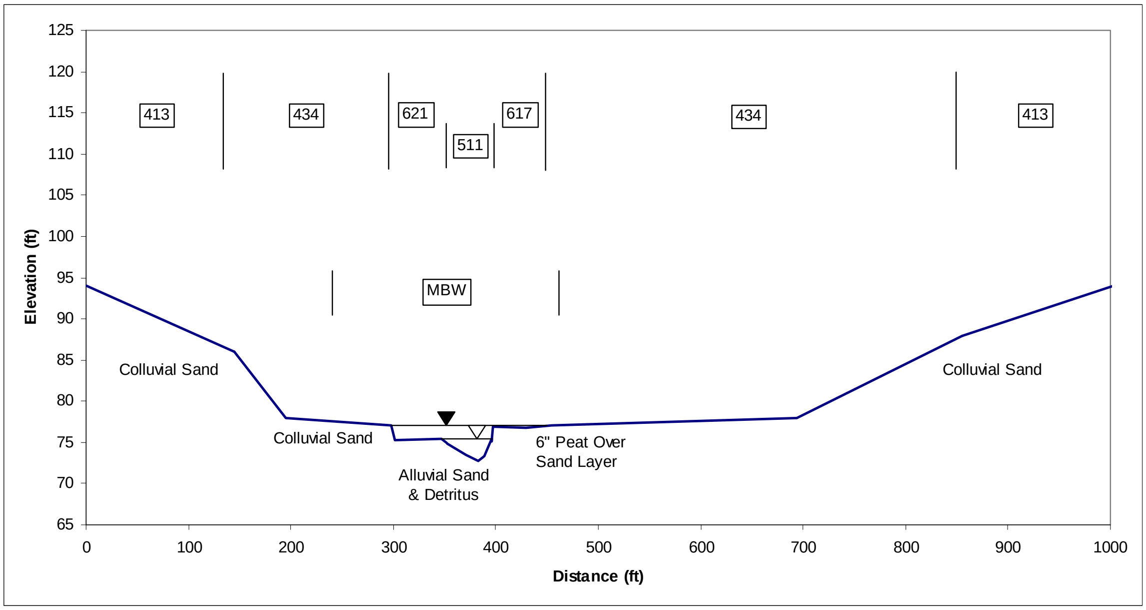


Figure C-26. Catfish Creek valley.

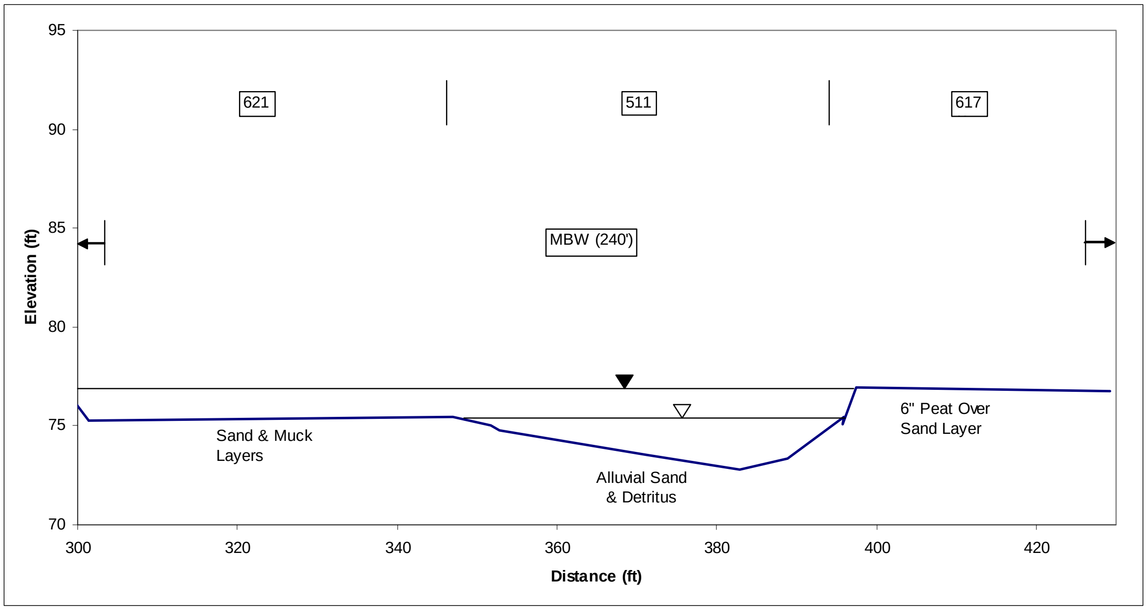


Figure C-27. Catfish Creek channel.

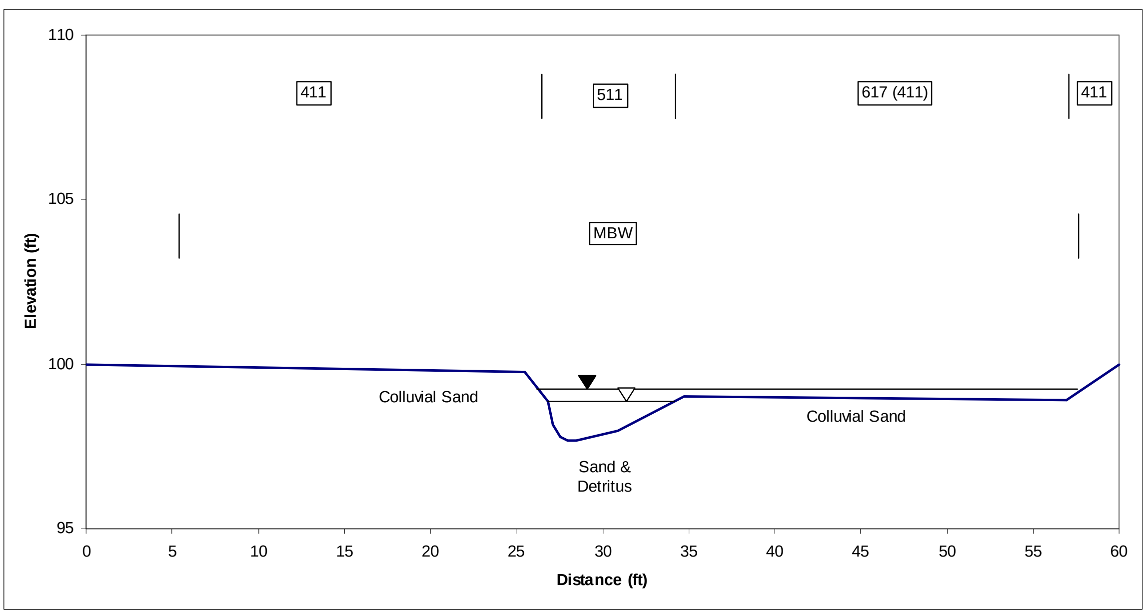


Figure C-28. Coons Bay channel.

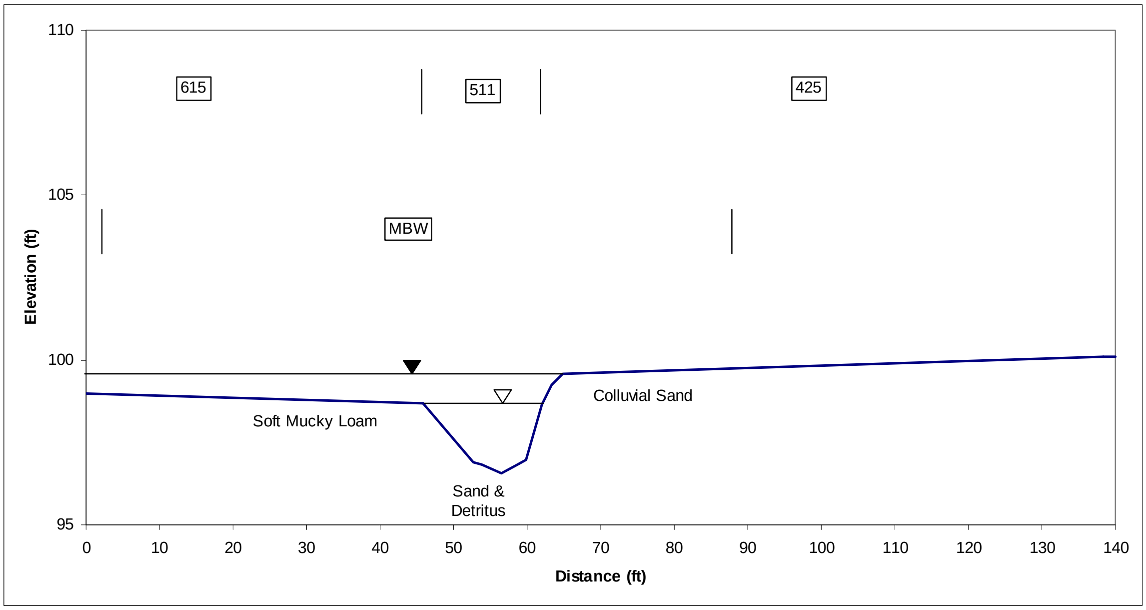


Figure C-29. Cow Creek channel.

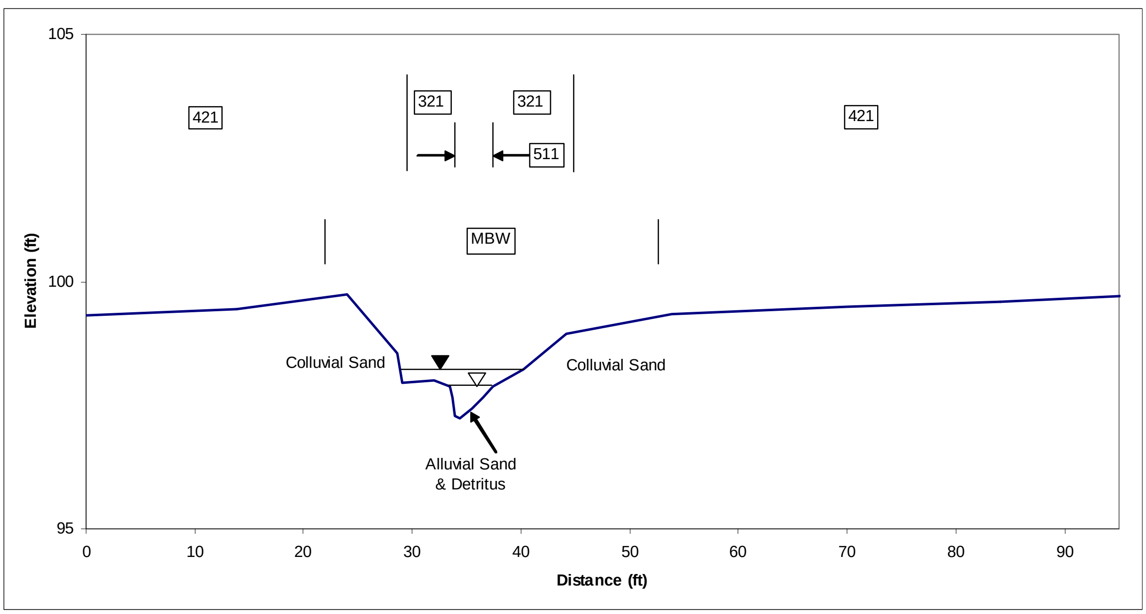


Figure C-30. Cypress Slash UT valley.

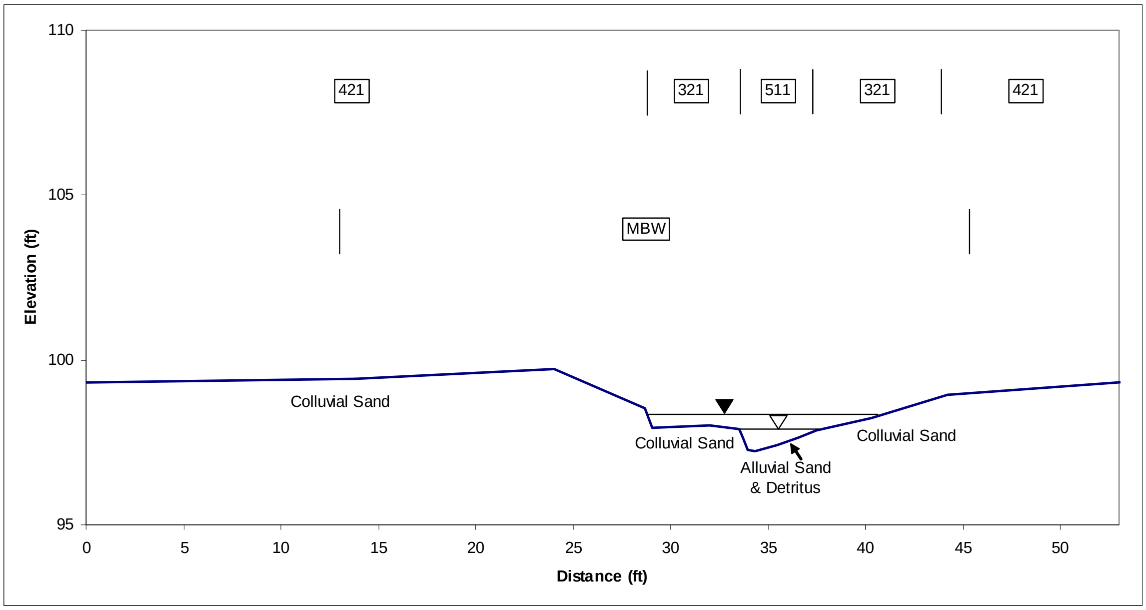


Figure C-31. Cypress Slash UT channel.

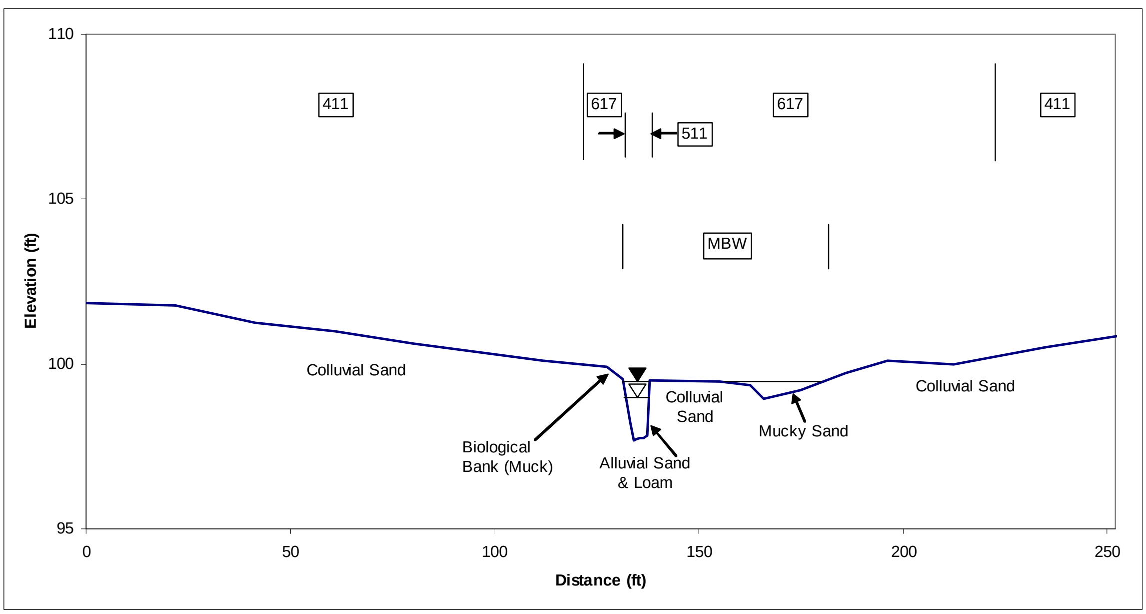


Figure C-32. East Fork Manatee UT1 valley and channel.

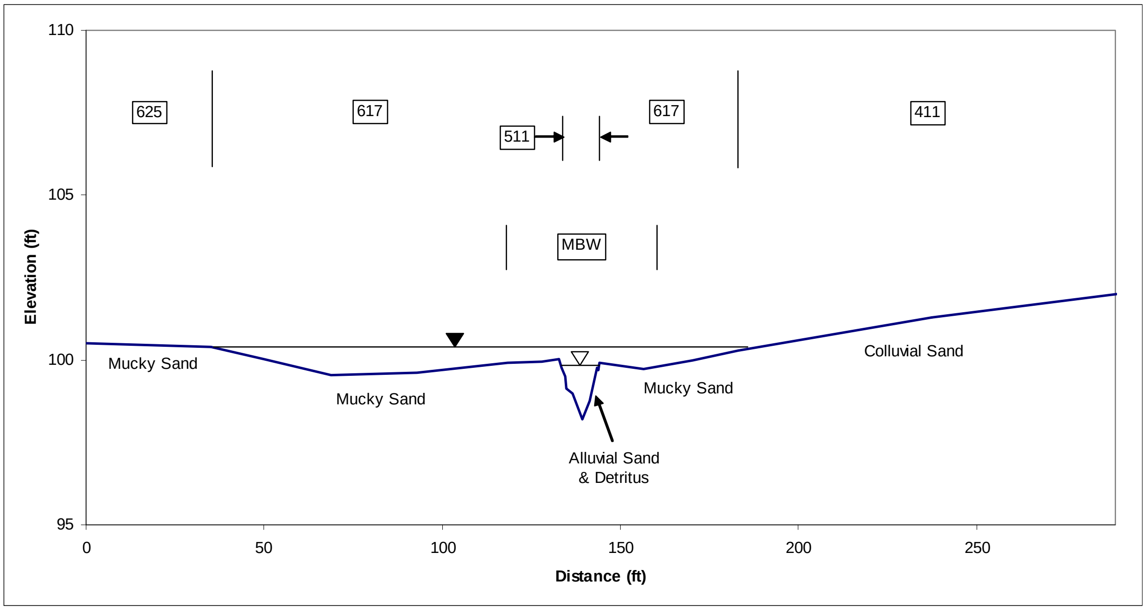


Figure C-33. East Fork Manatee UT2 channel and valley.

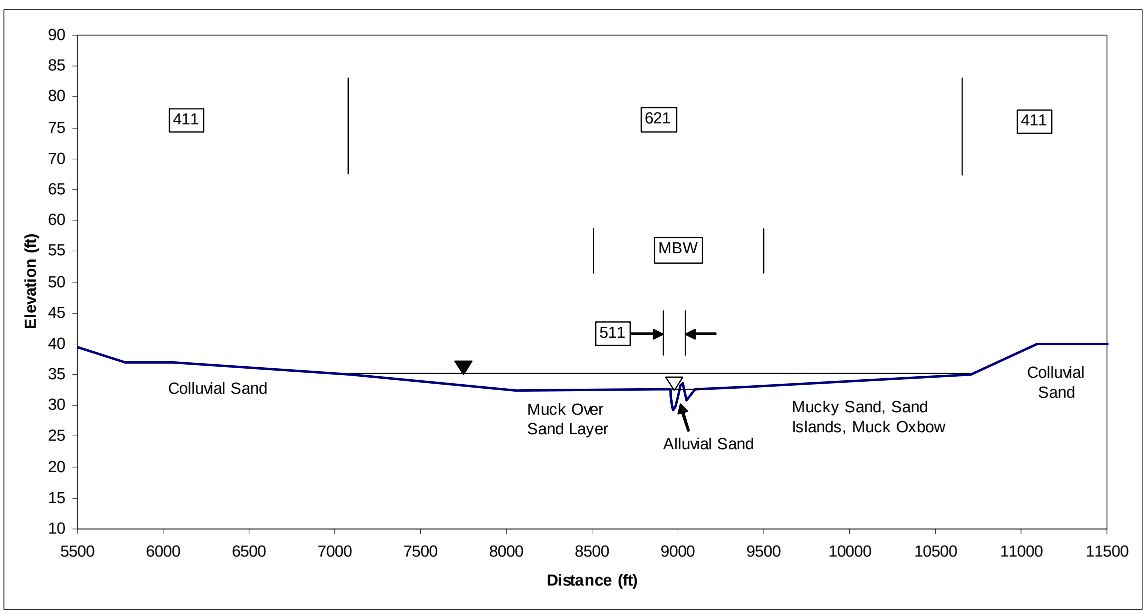


Figure C-34. Fisheating Creek valley.

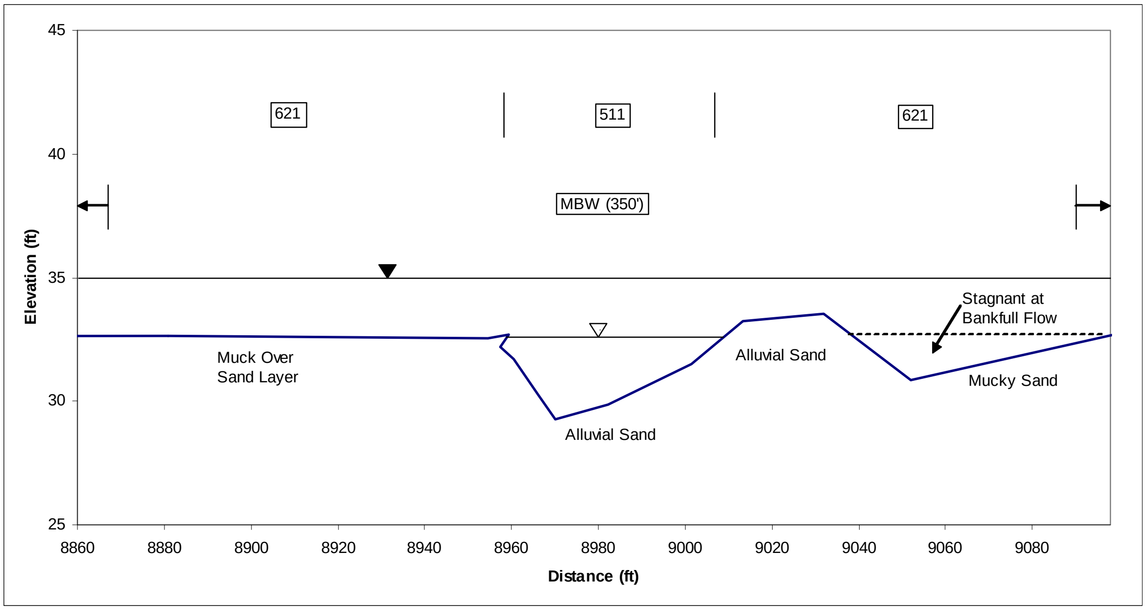


Figure C-35. Fisheating Creek channel.

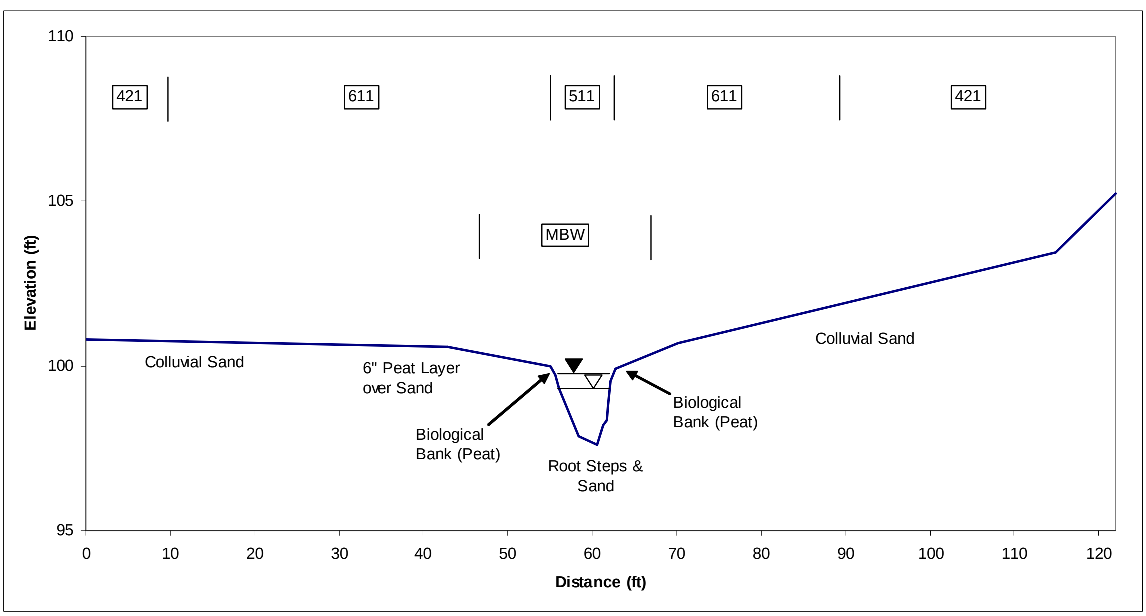


Figure C-36. Goldhead Branch channel and valley.

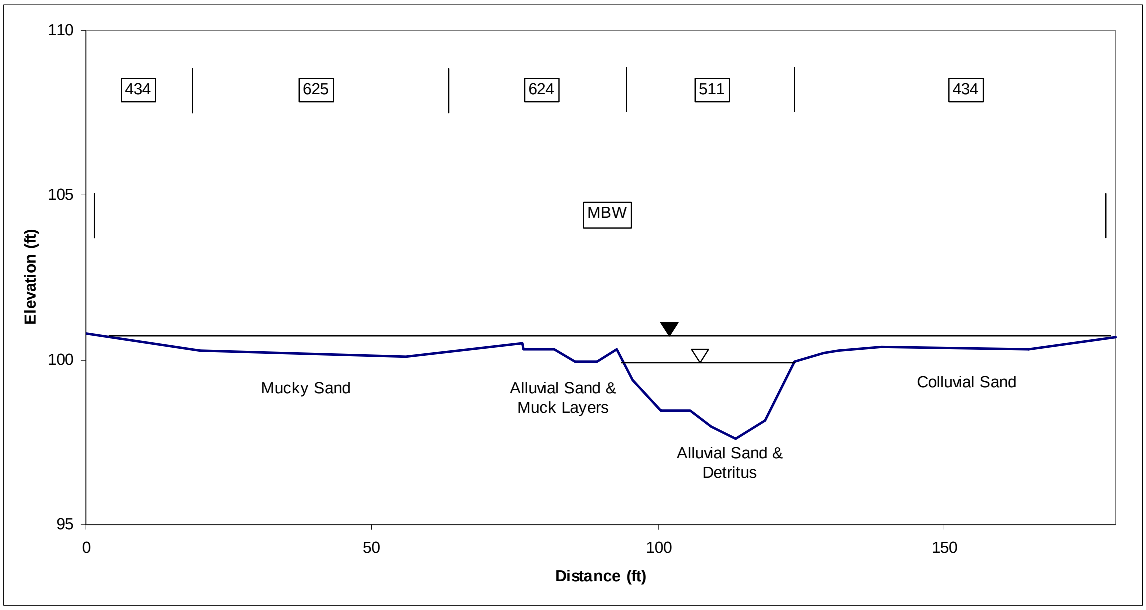


Figure C-37. Grasshopper Slough channel.

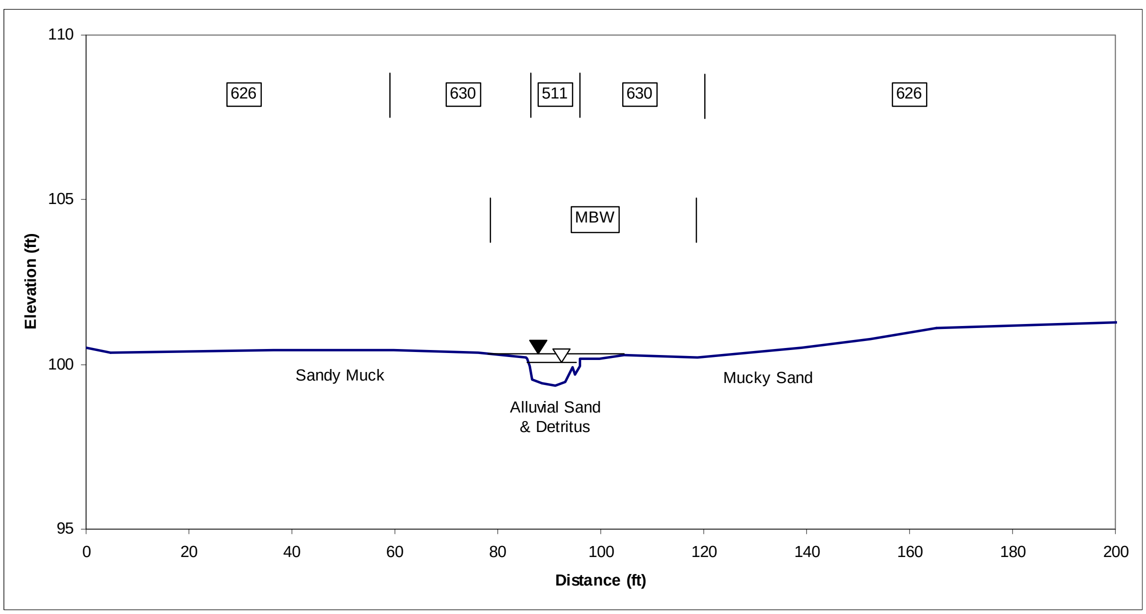


Figure C-38. Grassy Creek UT valley.

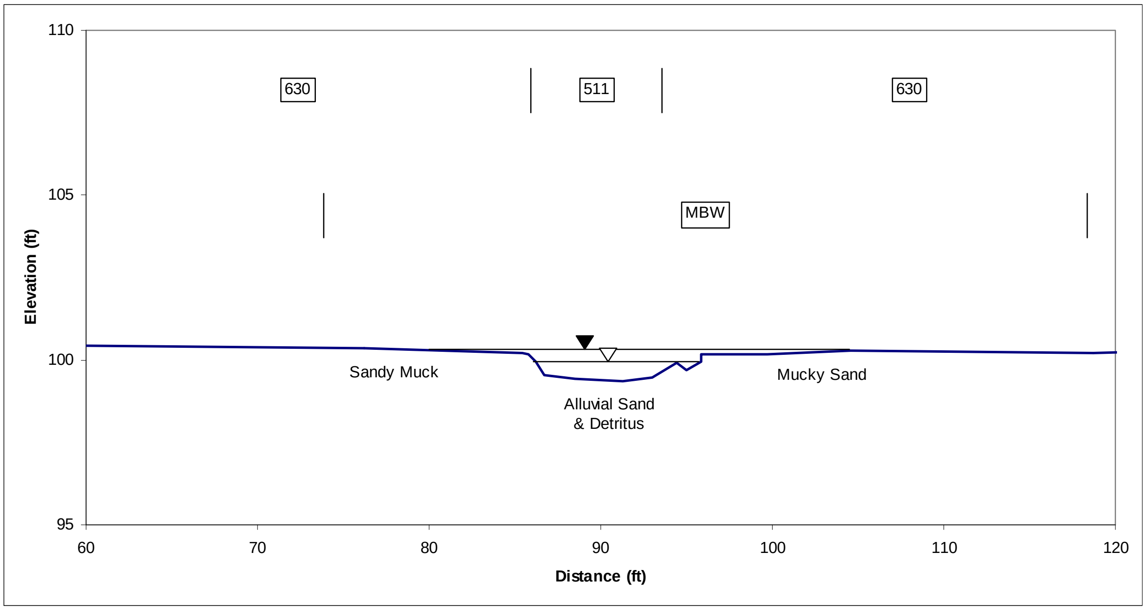


Figure C-39. Grassy Creek UT channel.

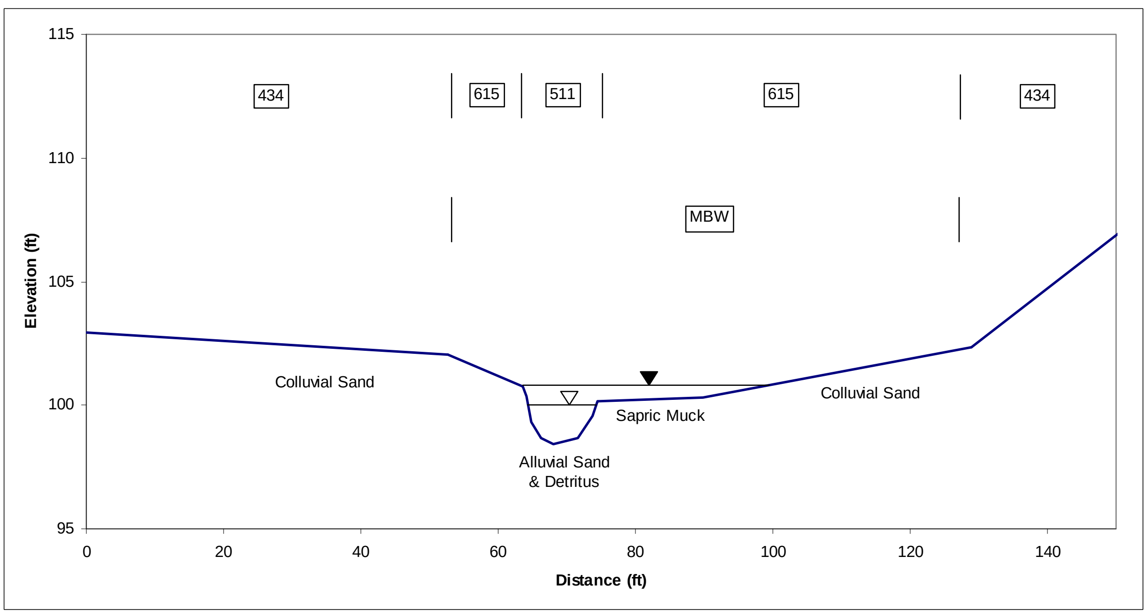


Figure C-40. Hammock Branch channel and valley.

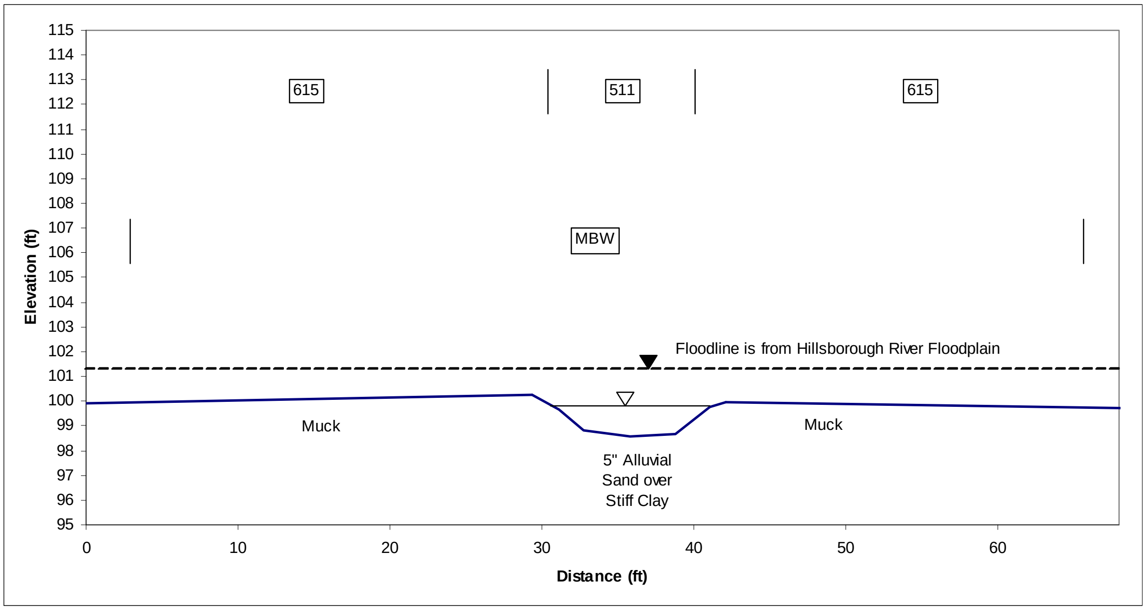


Figure C-41. Hillsborough UT channel.

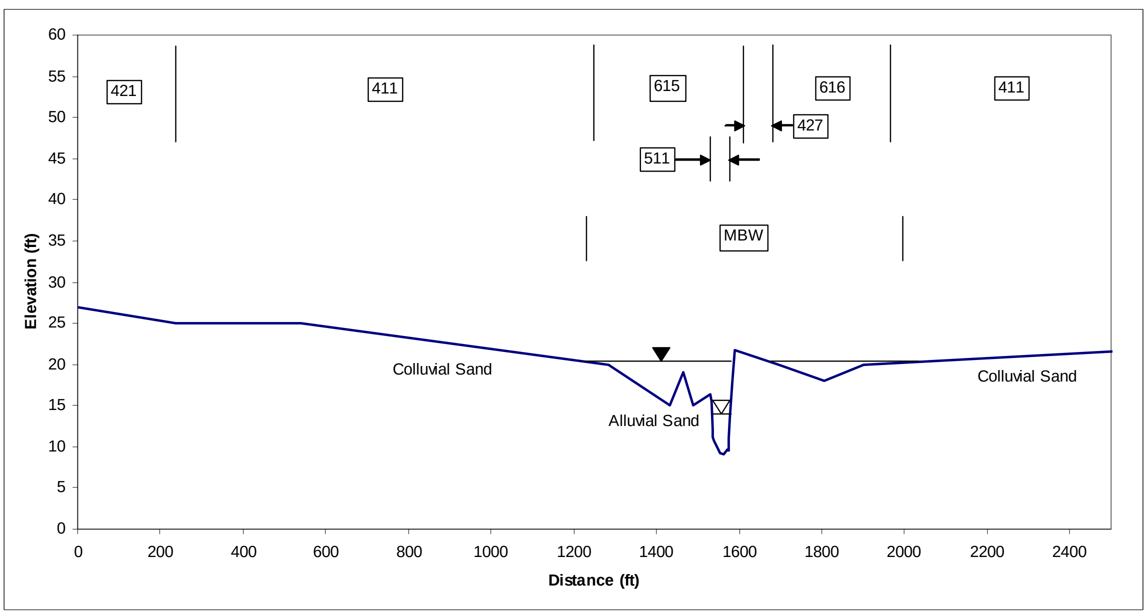


Figure C-42. Horse Creek valley.

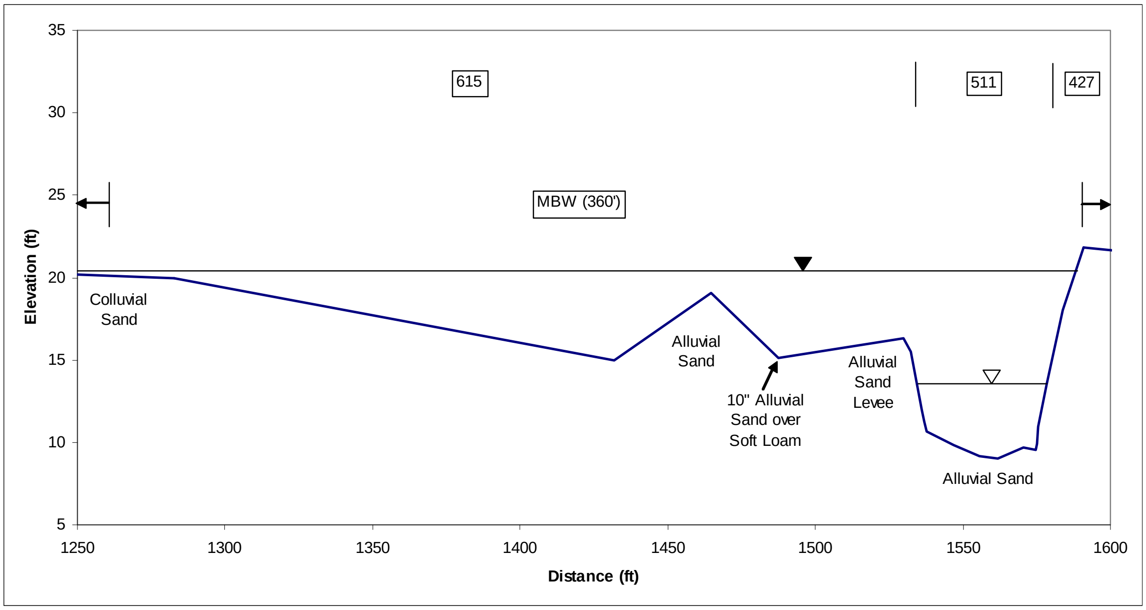


Figure C-43. Horse Creek channel.

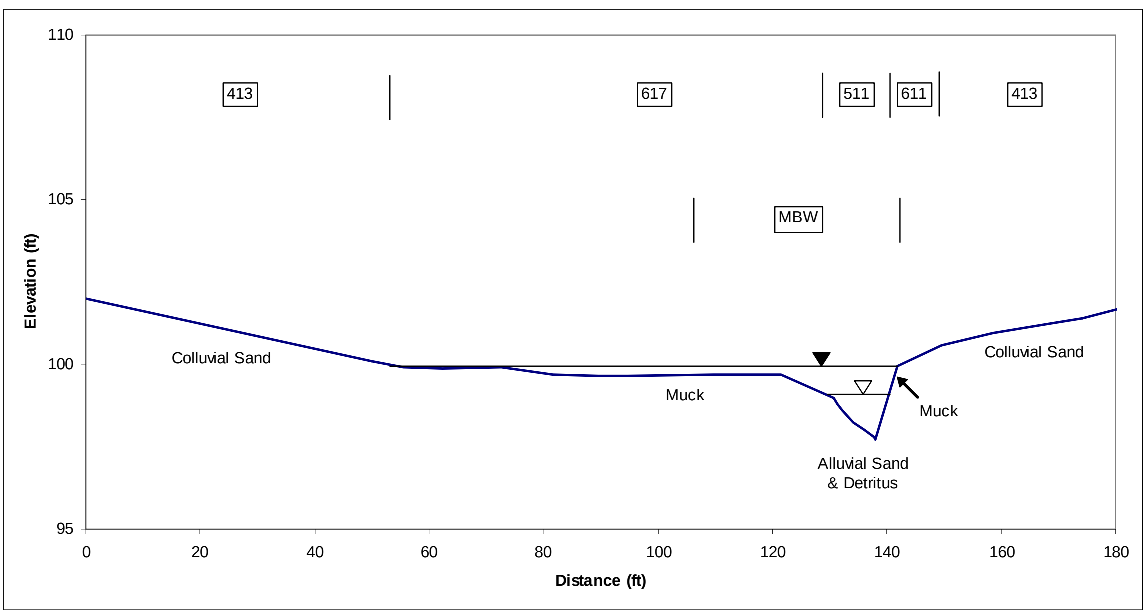


Figure C-44. Jack Creek channel and valley.

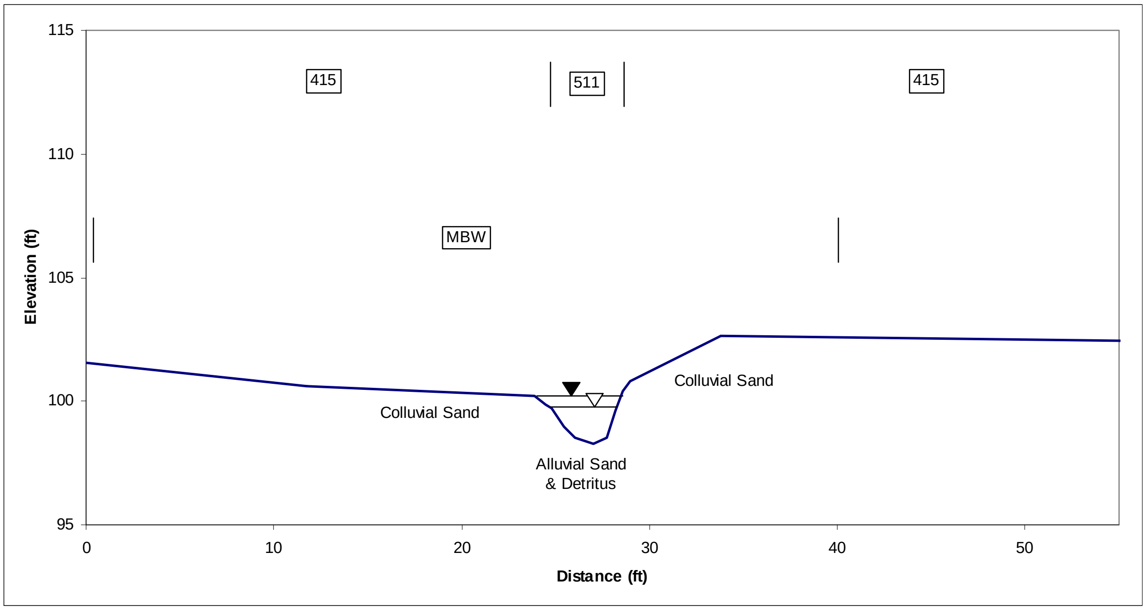


Figure C-45. Jumping Gully channel and valley.

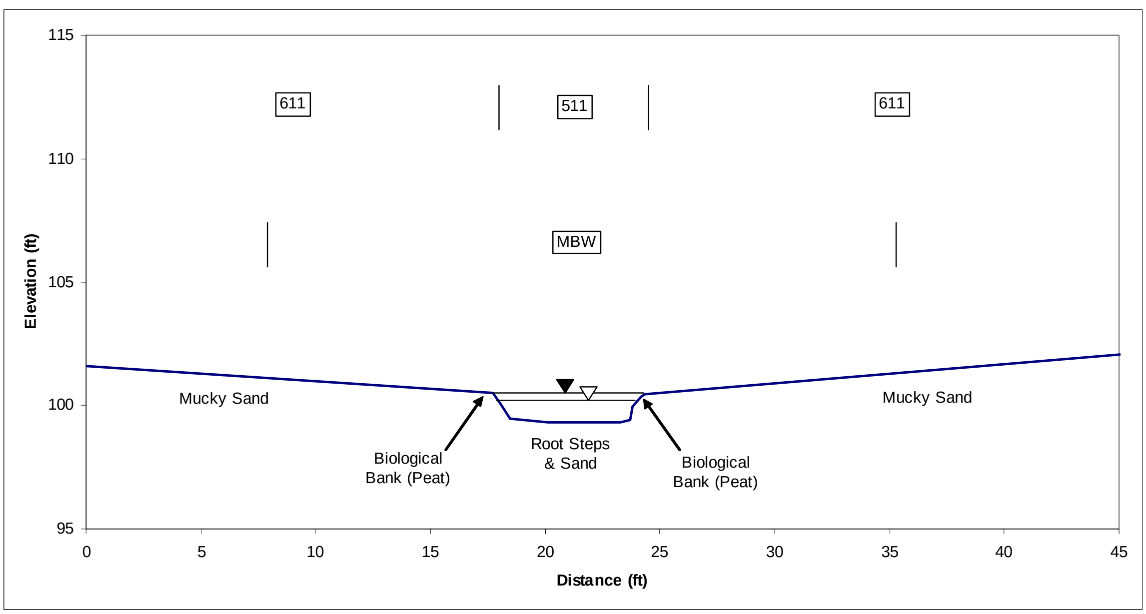


Figure C-46. Lake June-In-Winter UT channel and valley.

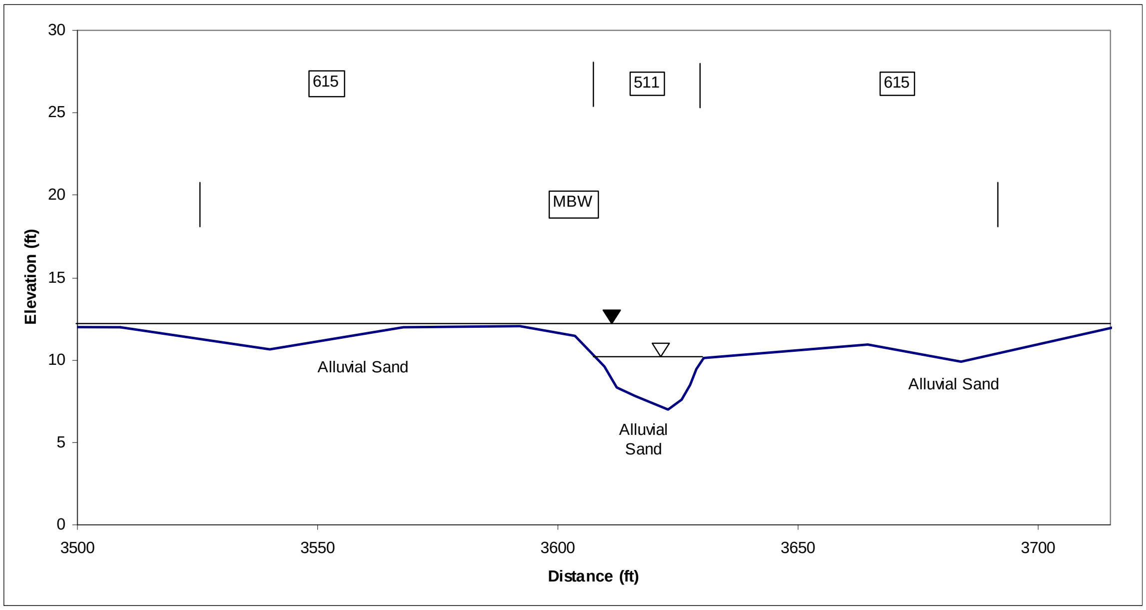


Figure C-47. Little Haw Creek channel.

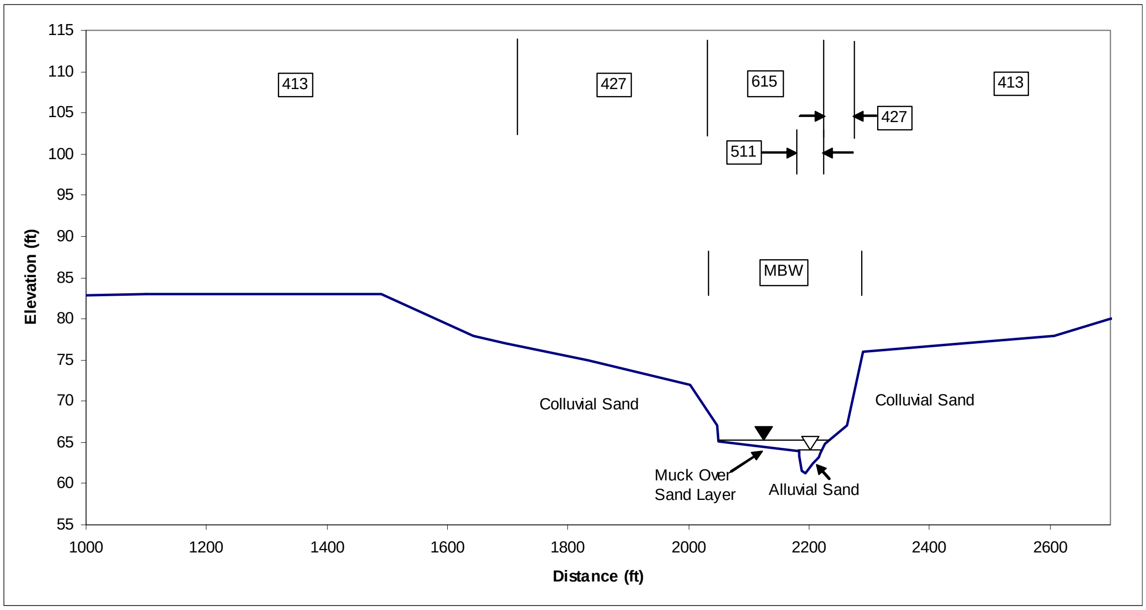


Figure C-48. Livingston Creek valley.

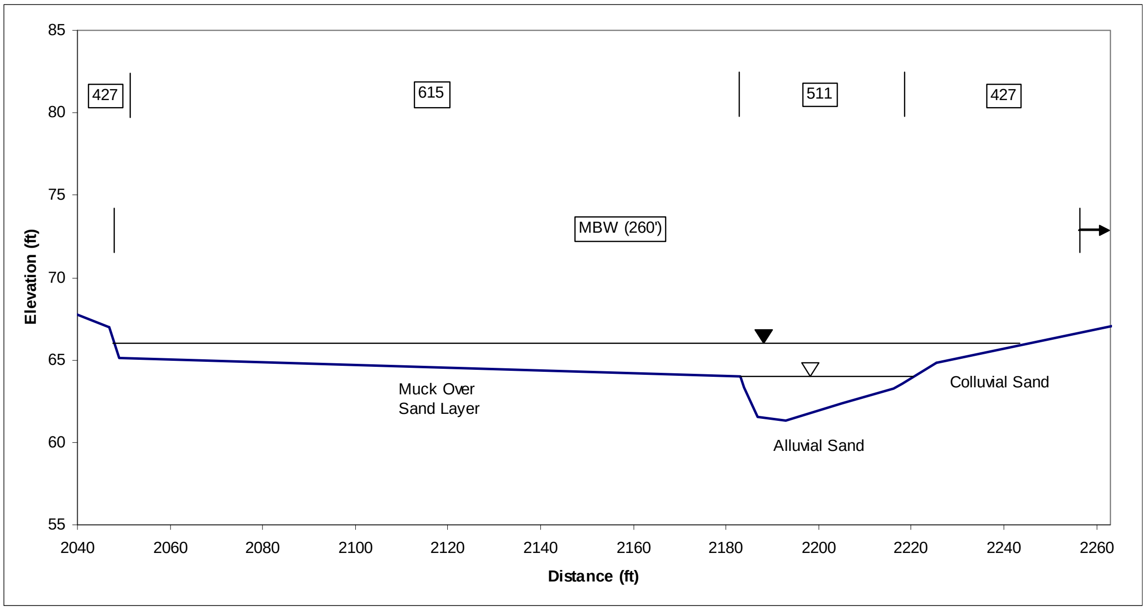


Figure C-49. Livingston Creek channel.

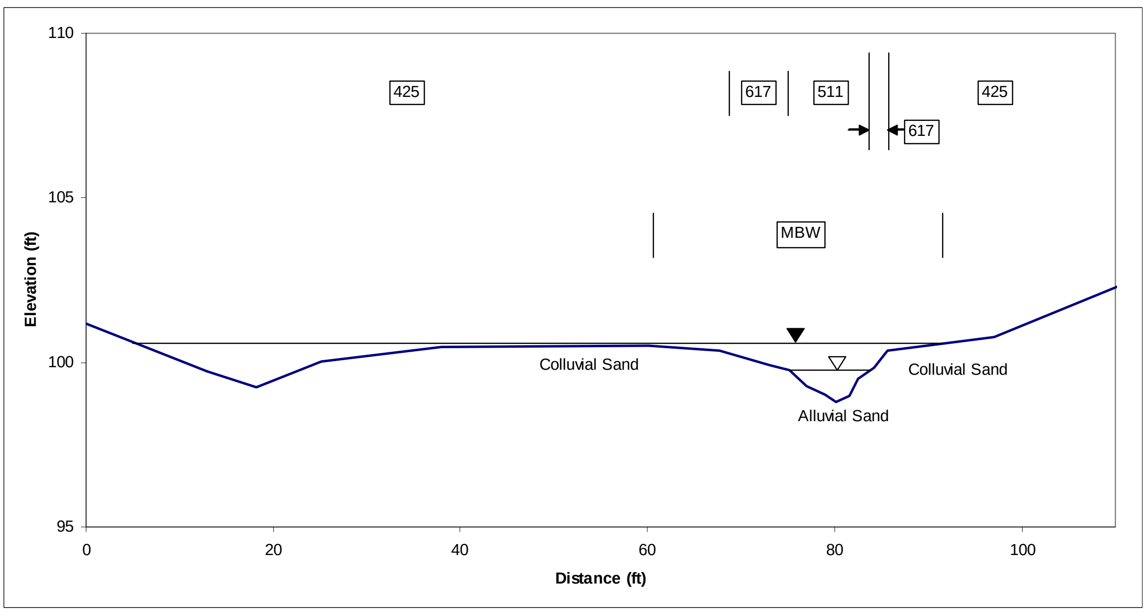


Figure C-50. Lower Myakka UT2 channel and valley.

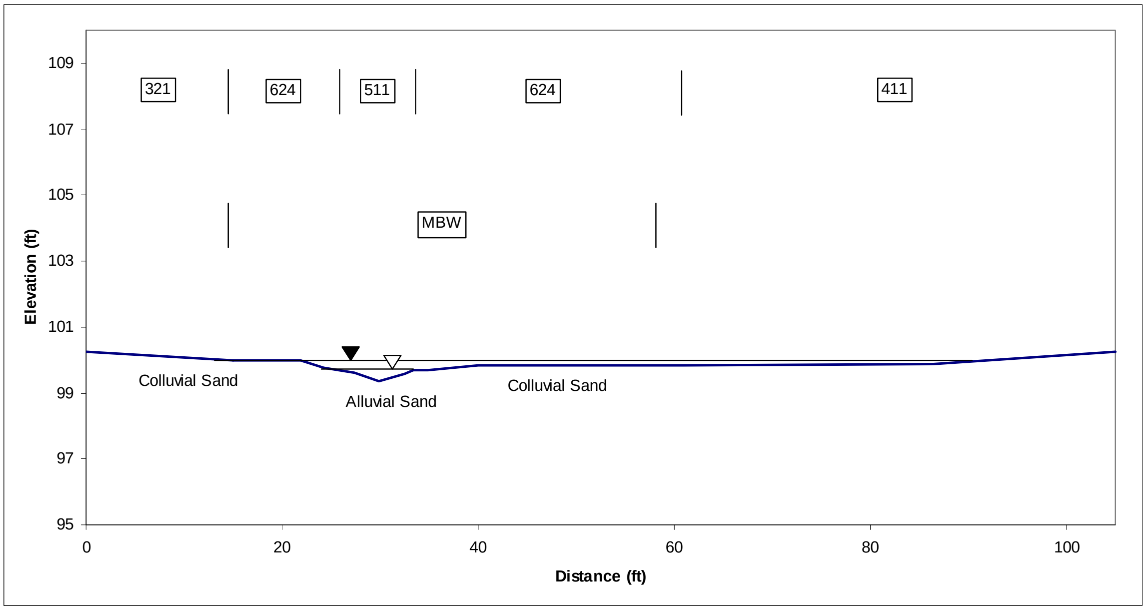


Figure C-51. Lower Myakka UT3 channel and valley.

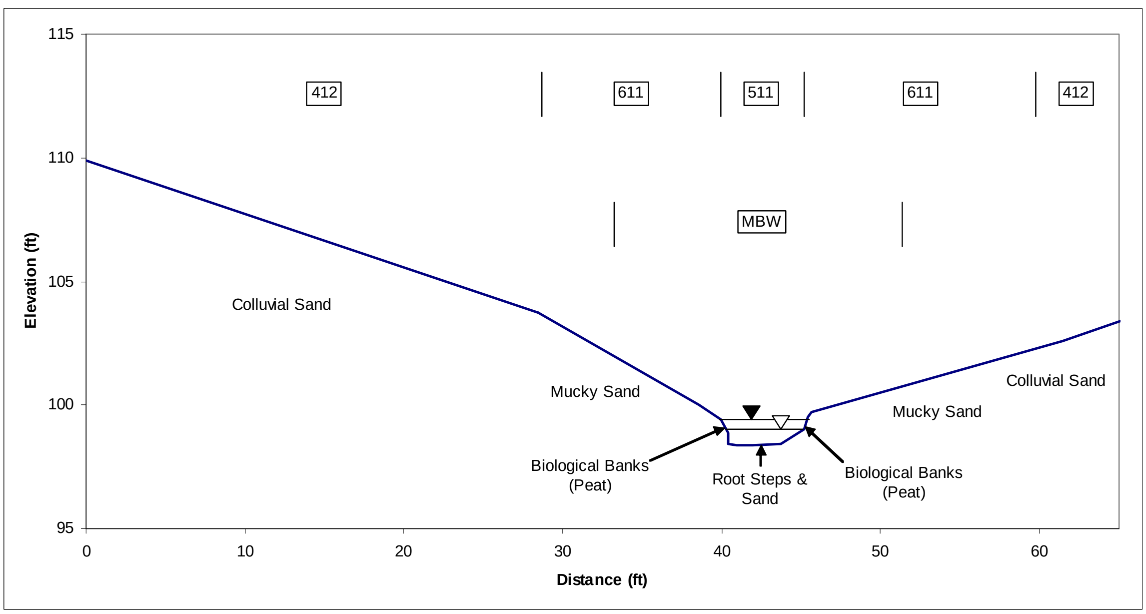


Figure C-52. Lowry Lake UT channel and valley.

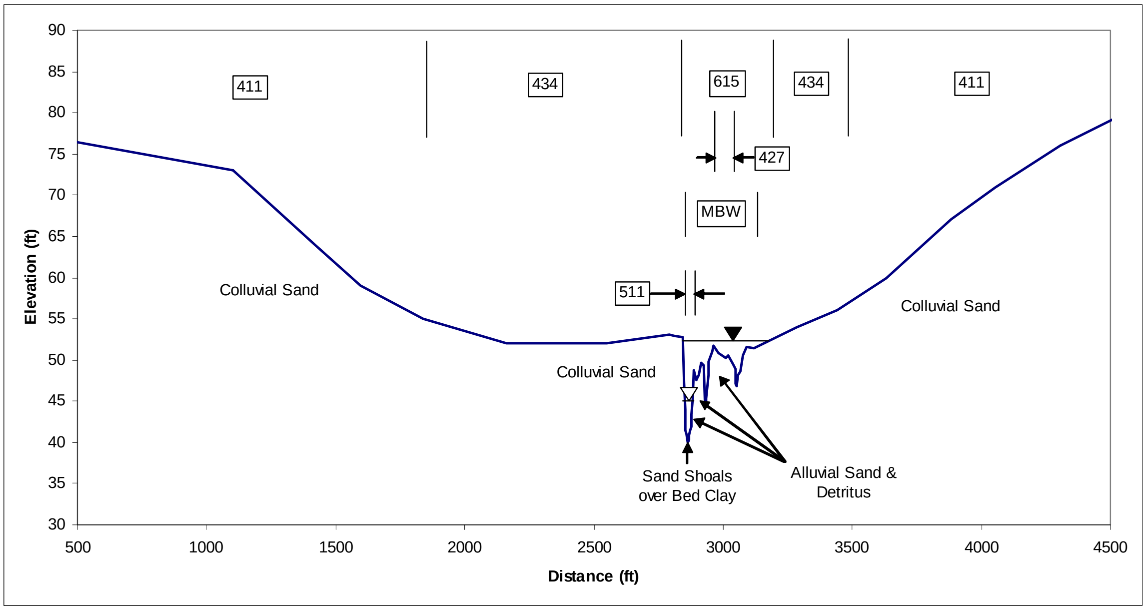


Figure C-53. Manatee River valley.

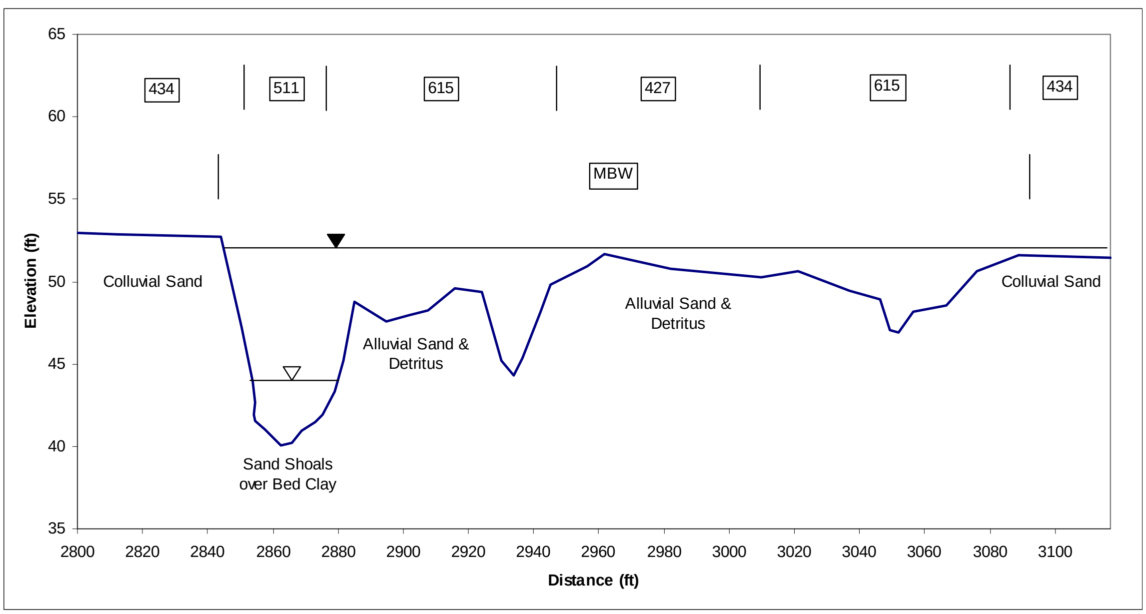


Figure C-54. Manatee River channel.

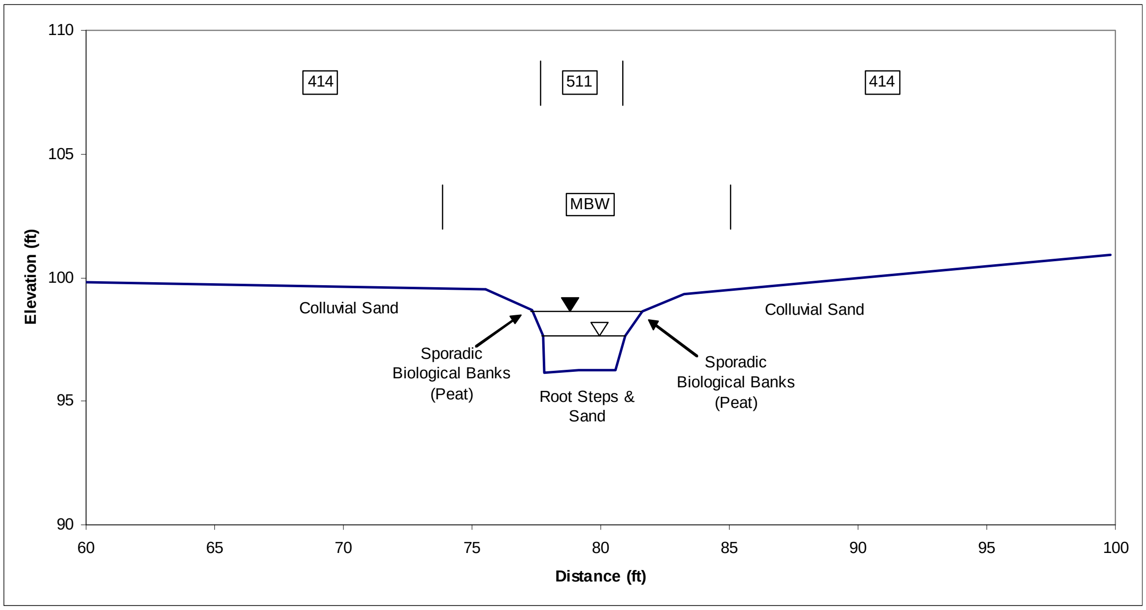


Figure C-55. Manatee UT channel and valley.

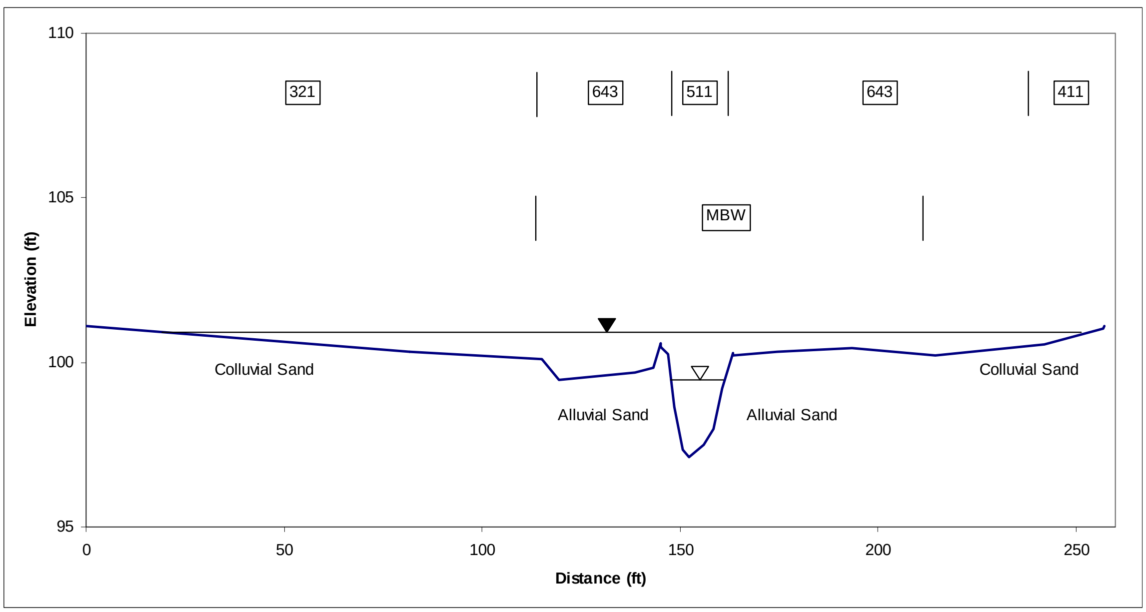


Figure C-56. Morgan Hole Creek channel.

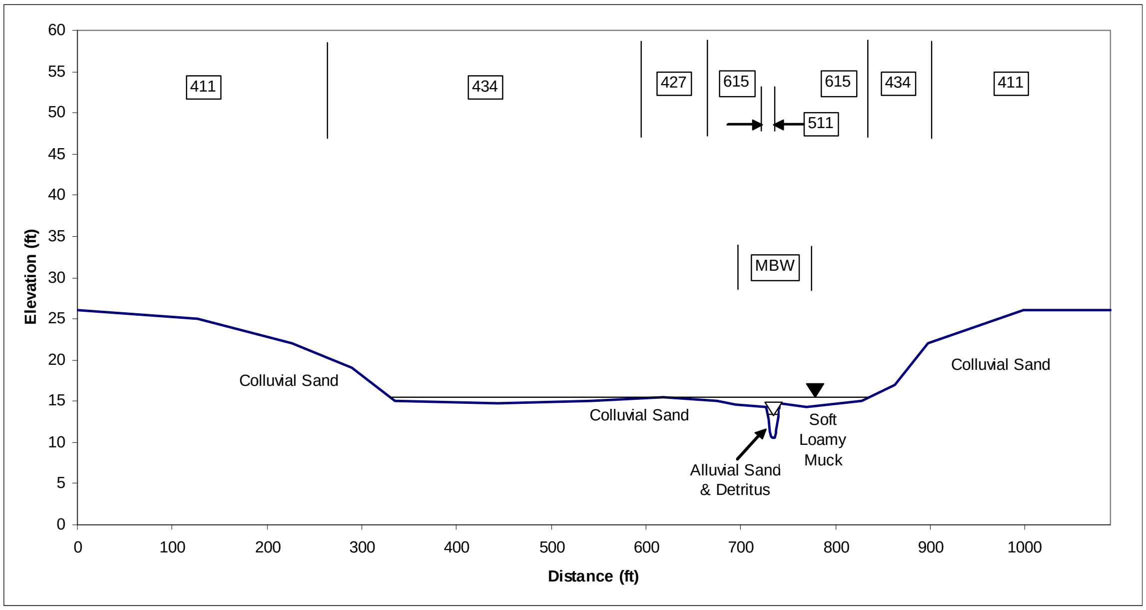


Figure C-57. Moses Creek valley.

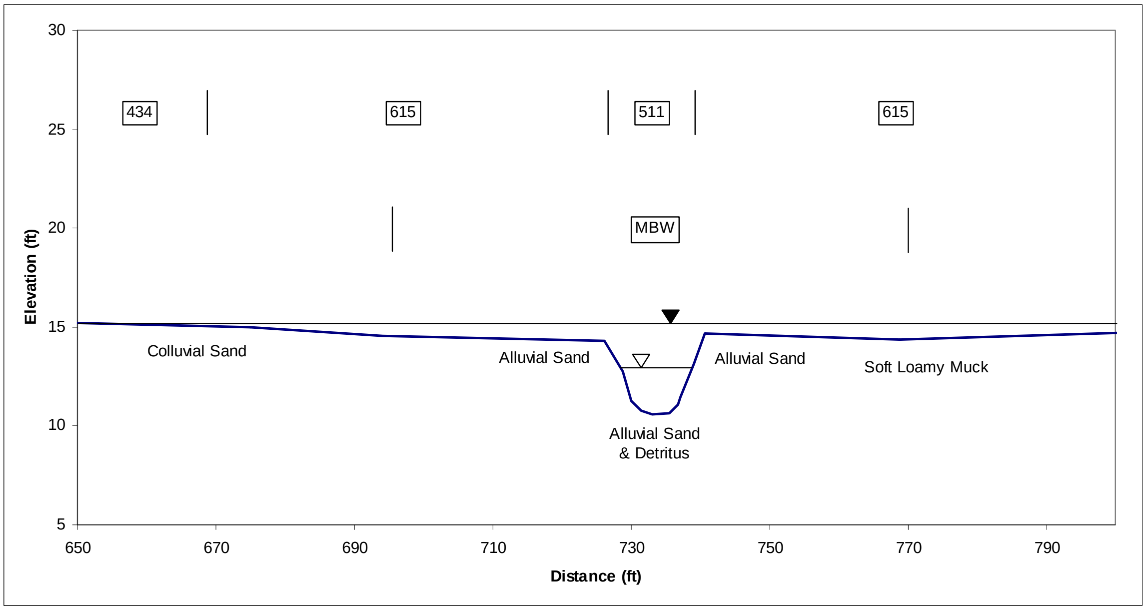


Figure C-58. Moses Creek channel.

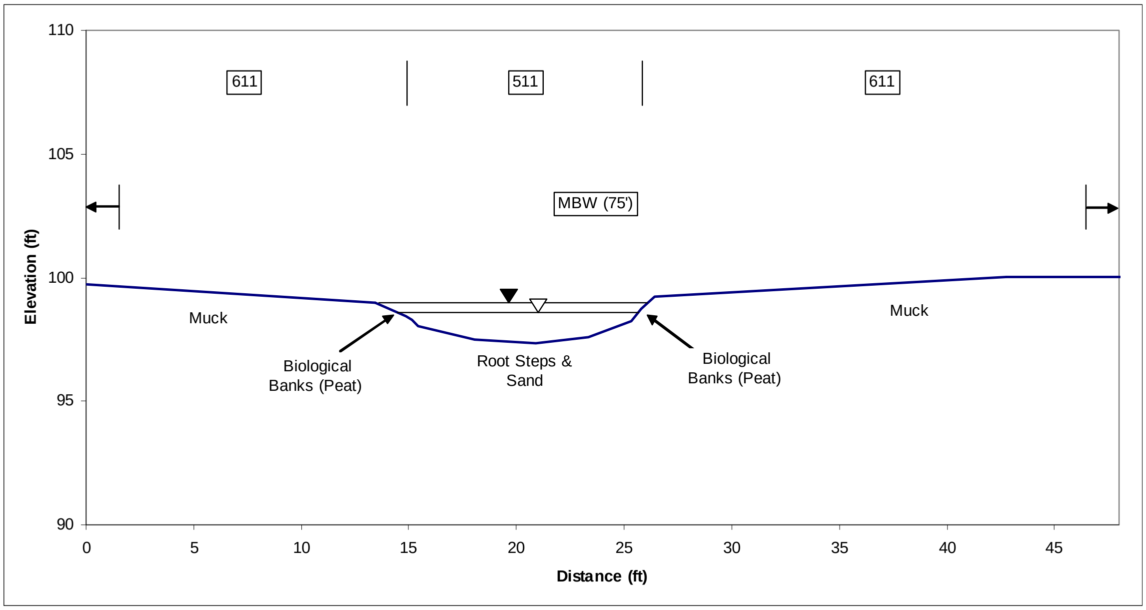


Figure C-59. Ninemile Creek channel and valley.

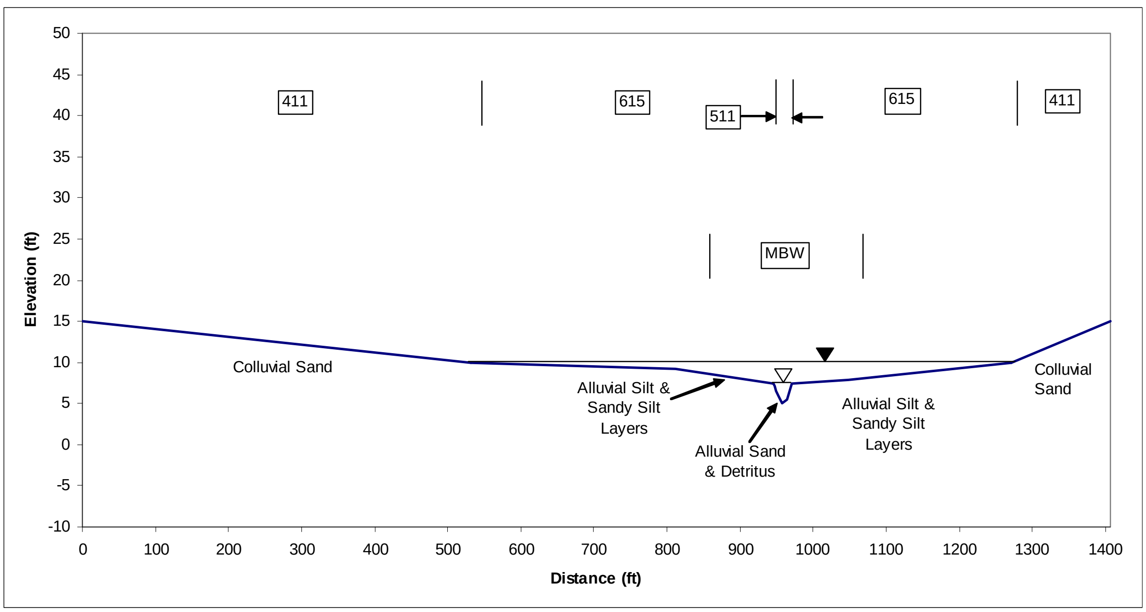


Figure C-60. Rice Creek valley.

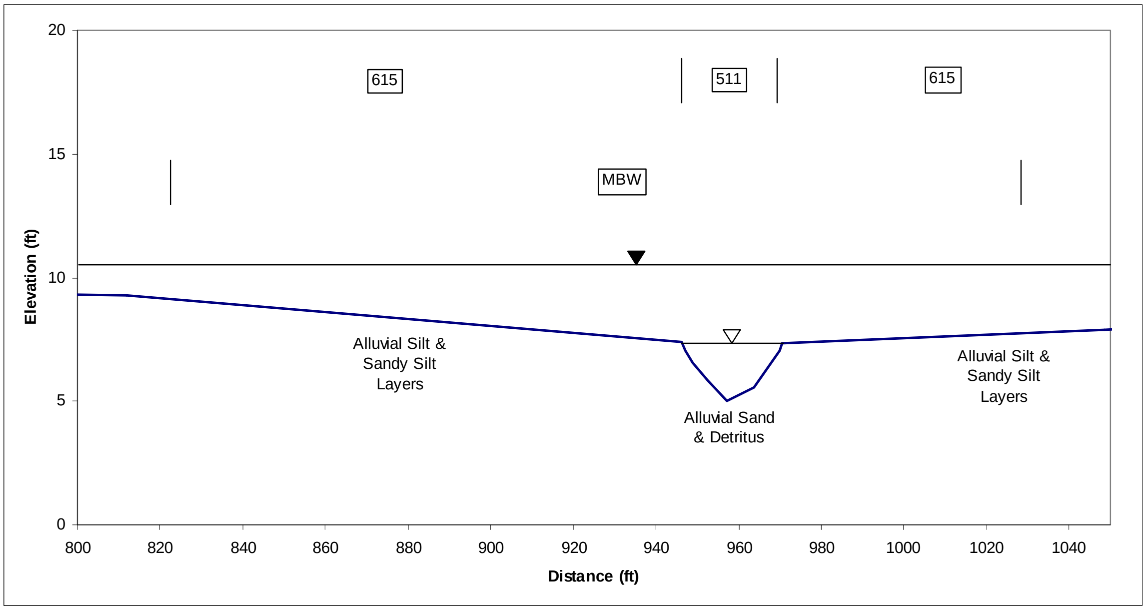


Figure C-61. Rice Creek channel.

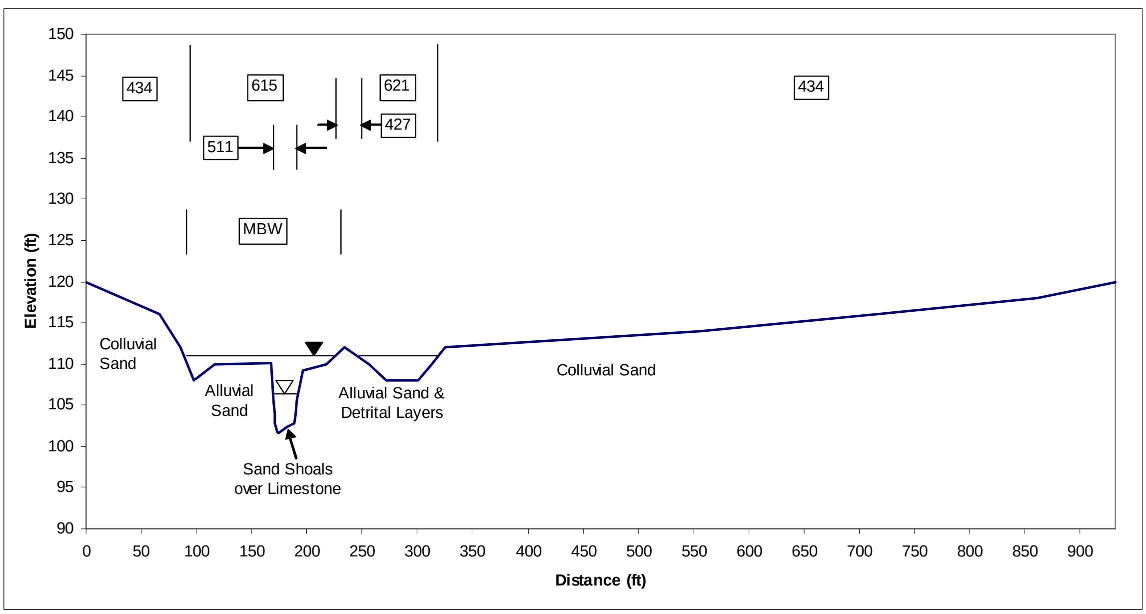


Figure C-62. Santa Fe River valley.

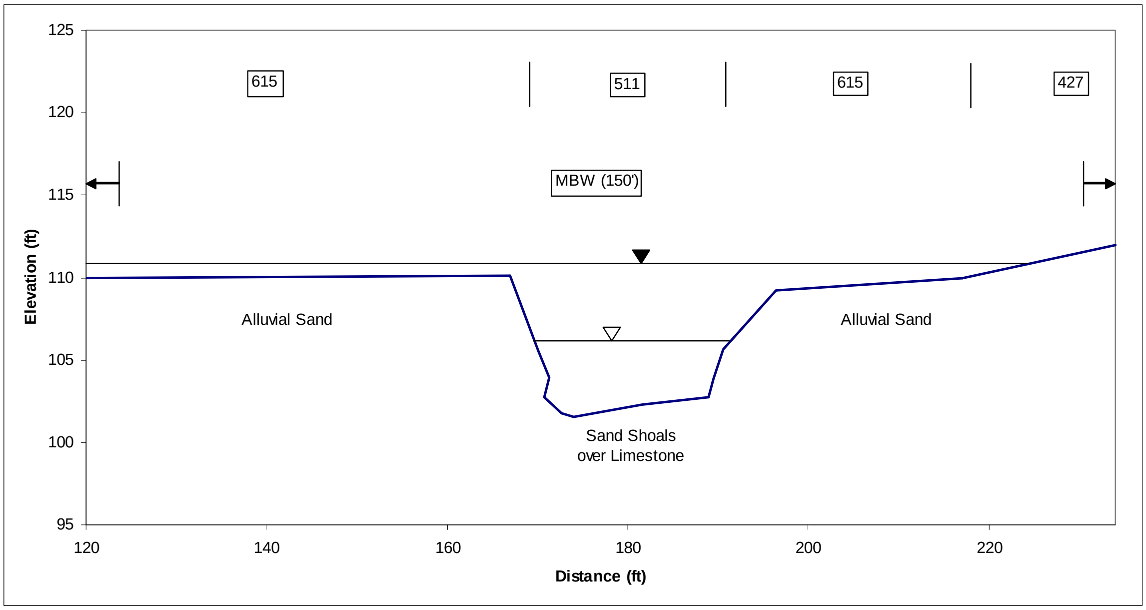


Figure C-63. Santa Fe River channel.

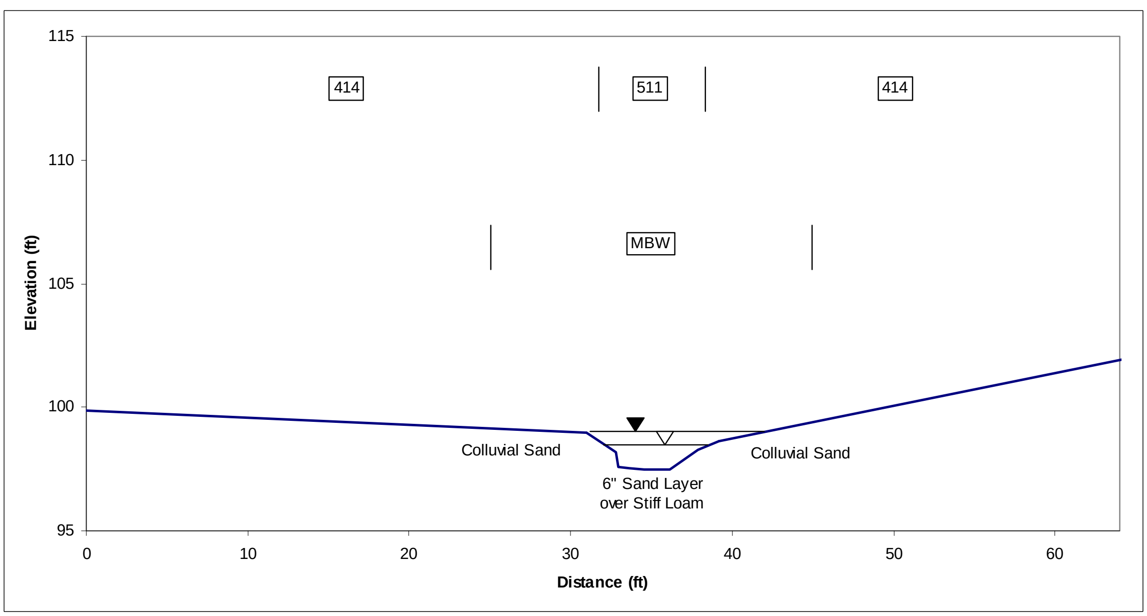


Figure C-64. Shiloh Creek channel and valley.

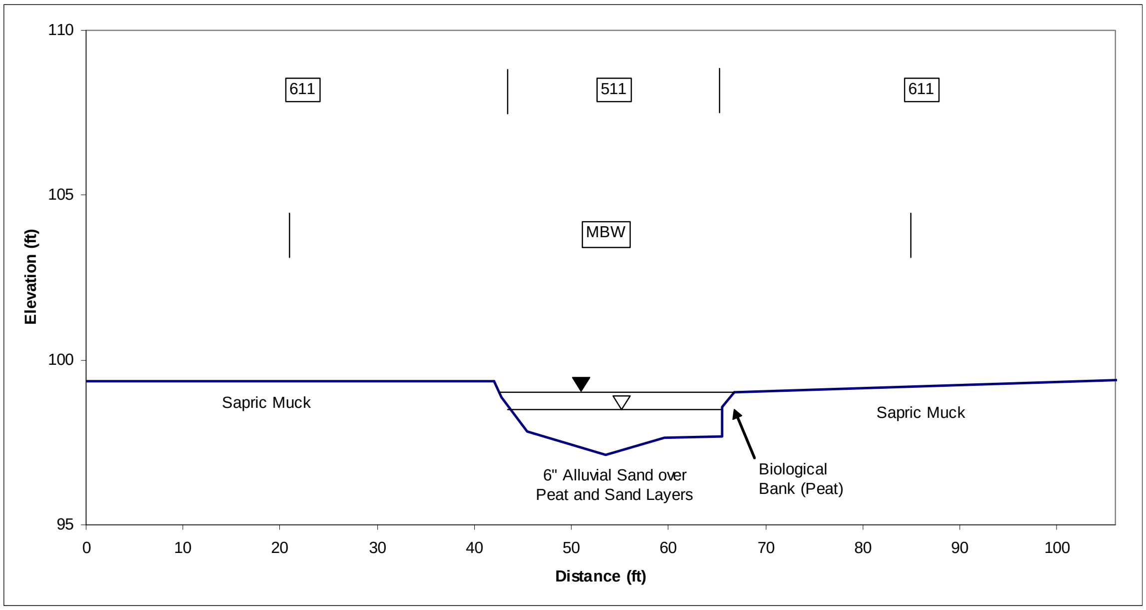


Figure C-65. Snell Creek channel and valley.

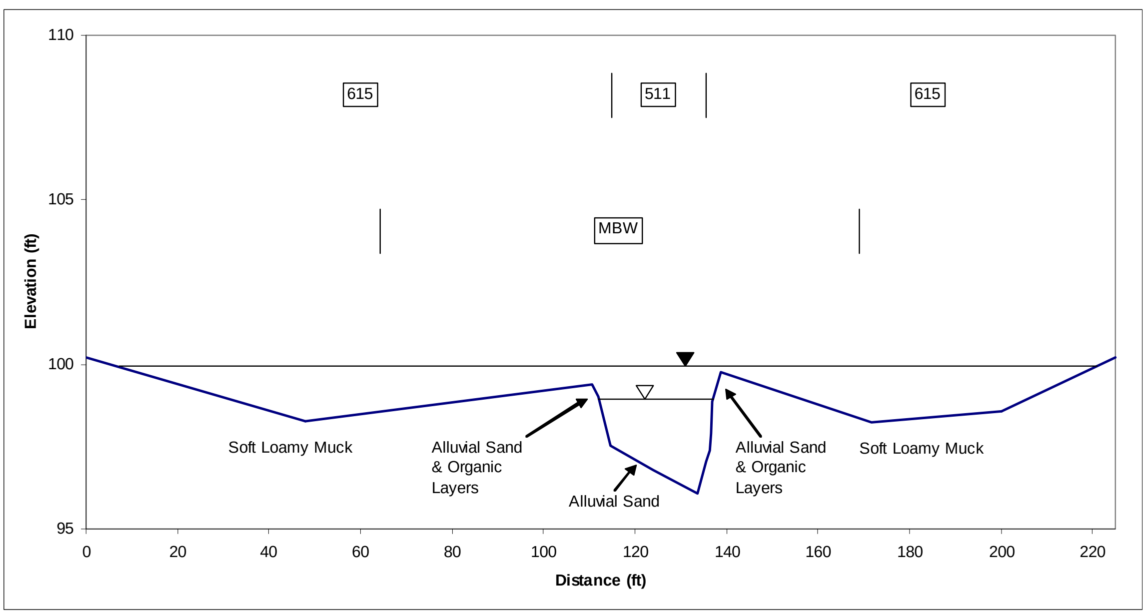


Figure C-66. South Fork Black Creek channel.

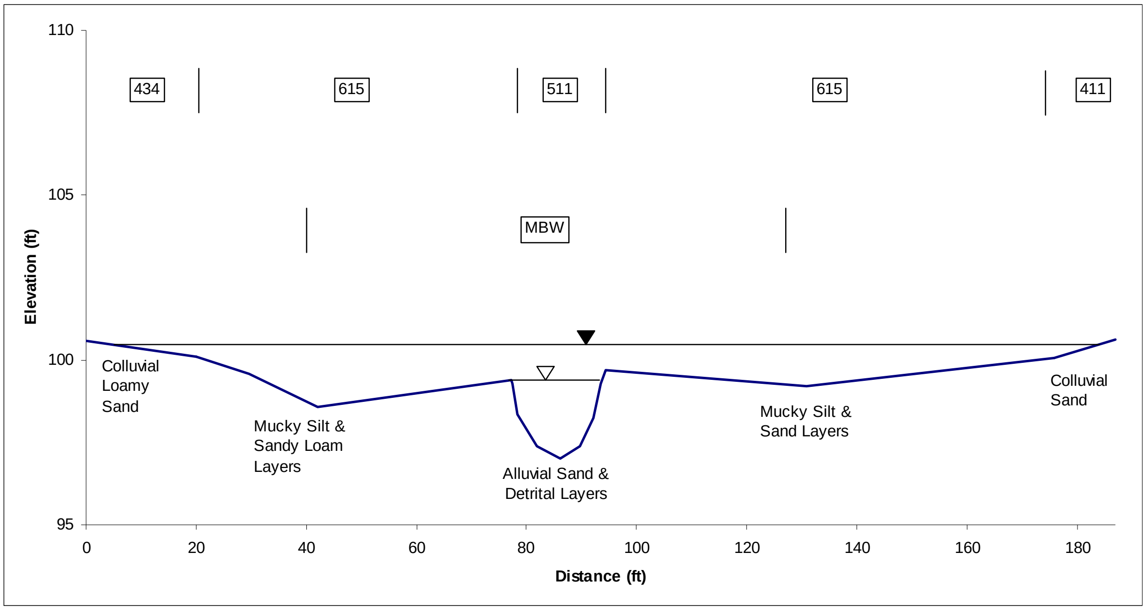


Figure C-67. Ten Mile channel and valley.

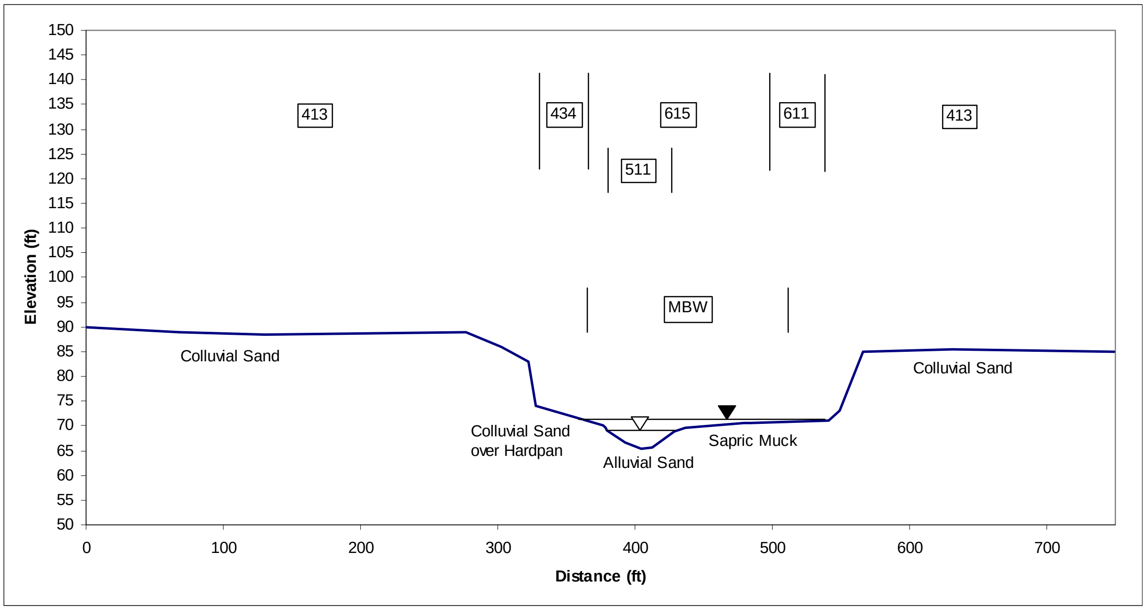


Figure C-68. Tiger Creek valley.

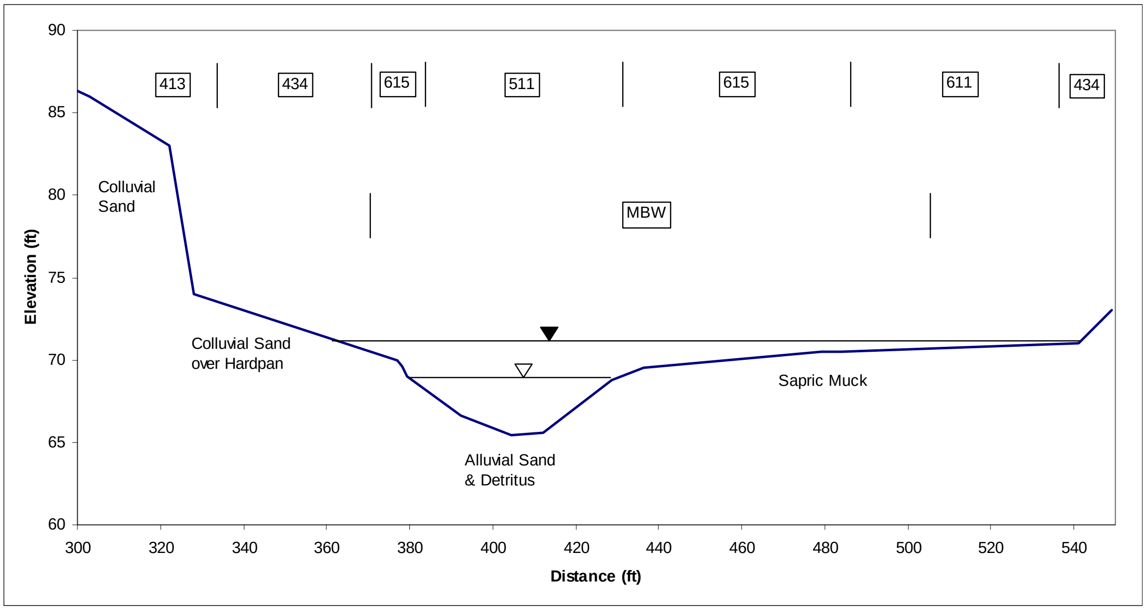


Figure C-69. Tiger Creek channel.

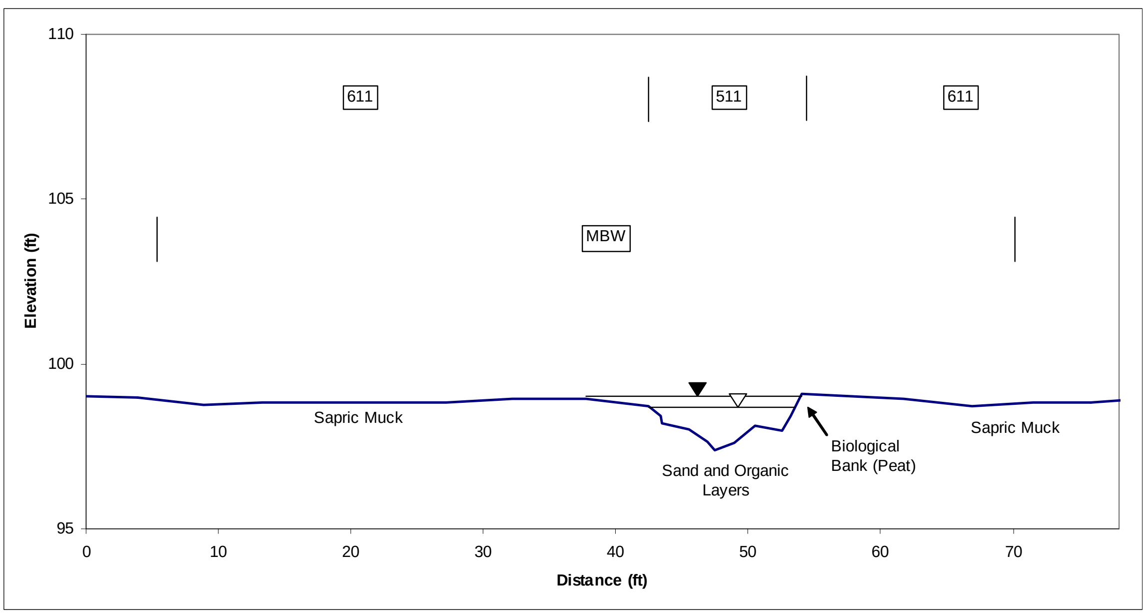


Figure C-70. Tiger UT channel.

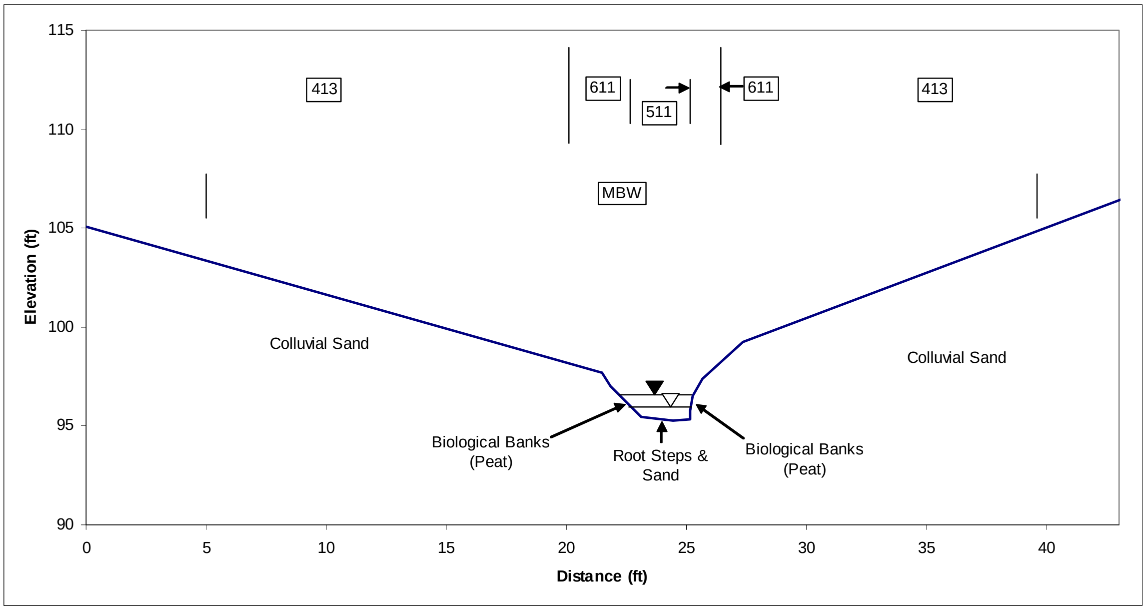


Figure C-71. Tuscawilla UT channel and valley.

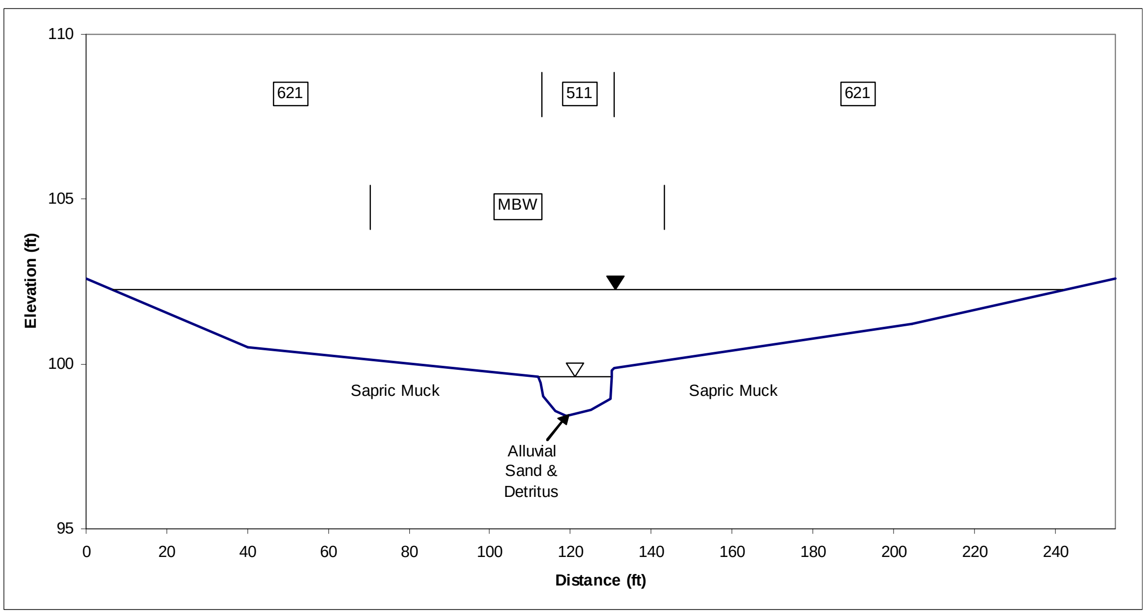


Figure C-72. Tyson Creek channel and valley.

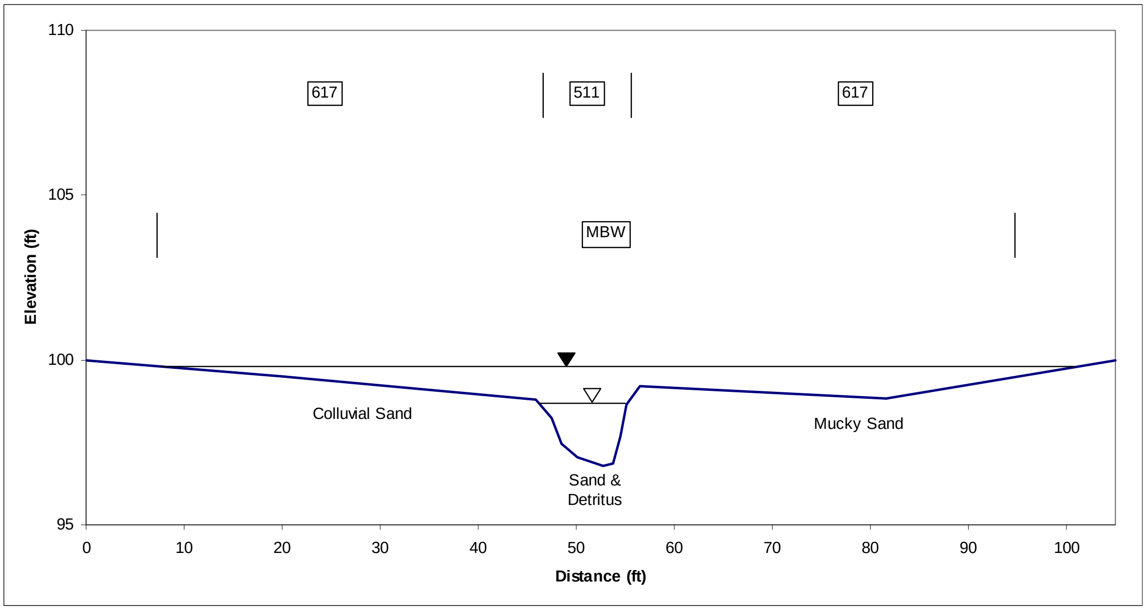


Figure C-73. Wekiva Forest UT channel and valley.

APPENDIX D
CLUSTER ANALYSES DENDOGRAMS

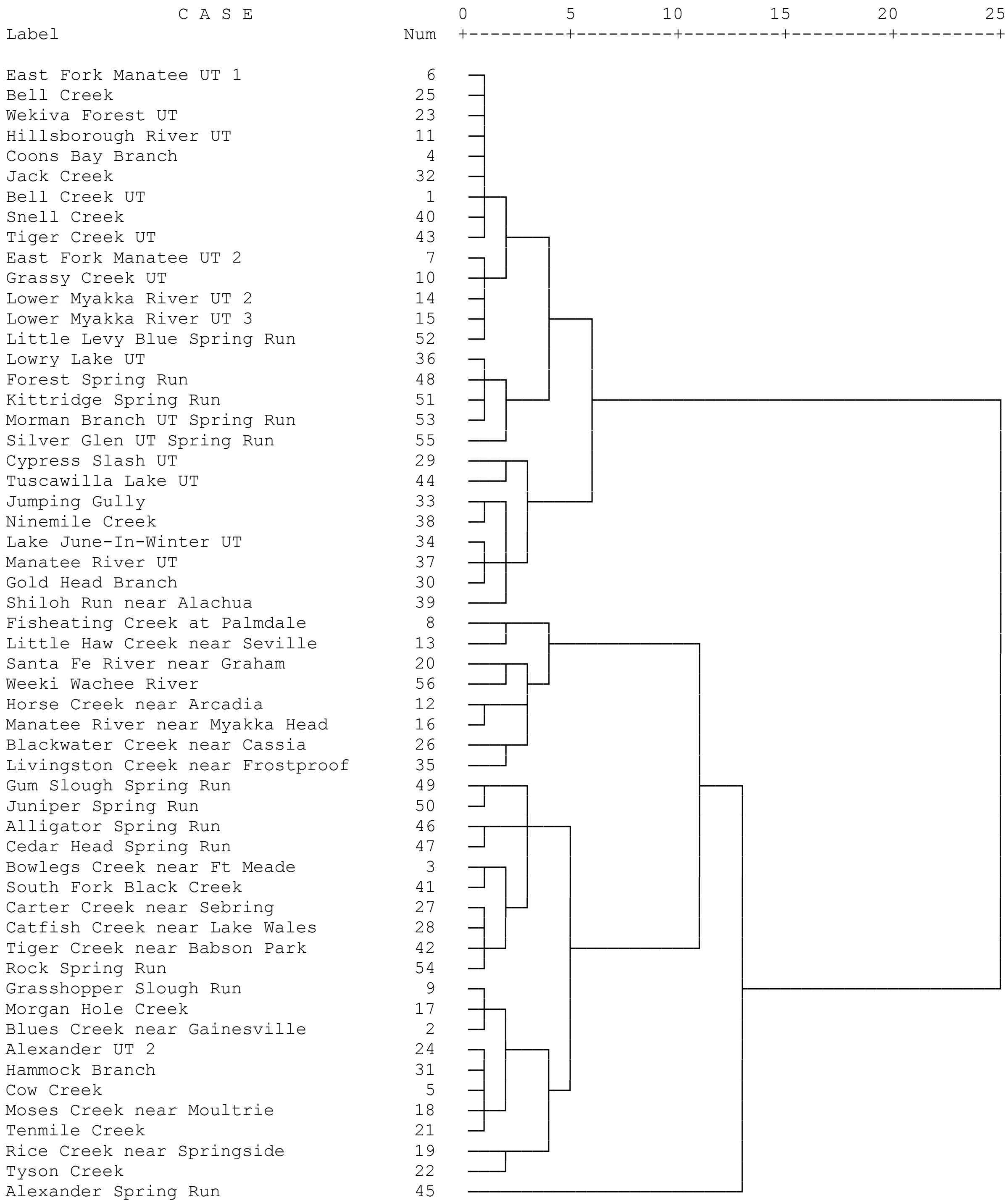


Figure D-1. Dendogram for all sites on all variables.

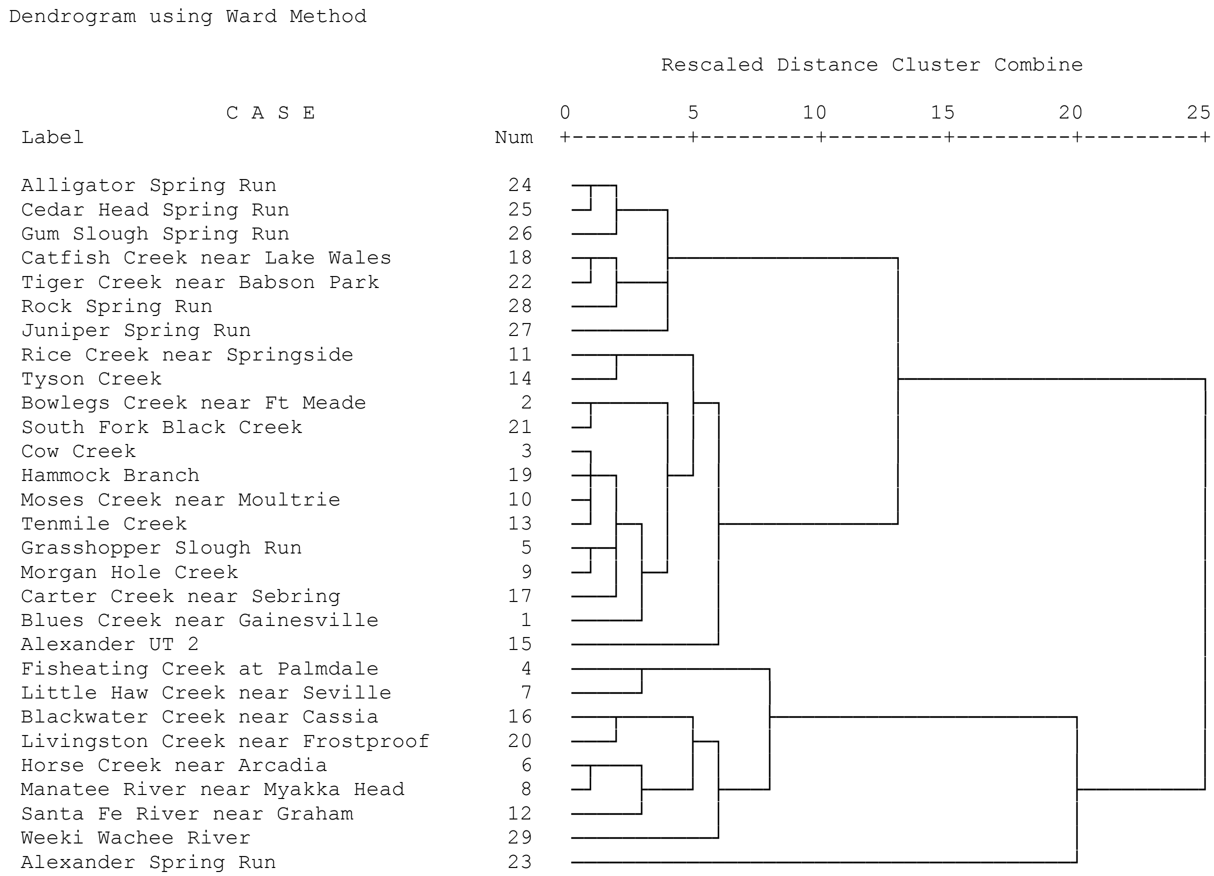


Figure D-2. Dendogram for large sites on all variables.

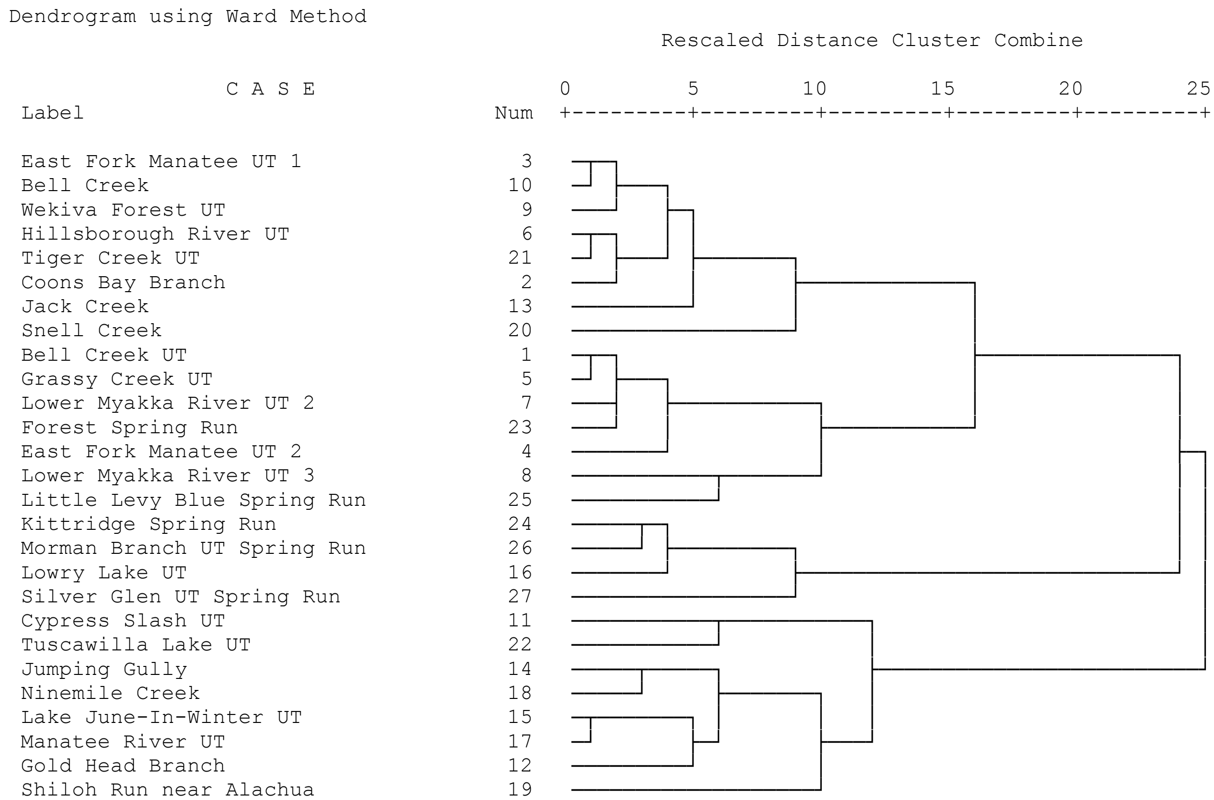


Figure D-3. Dendogram for small sites on all variables.

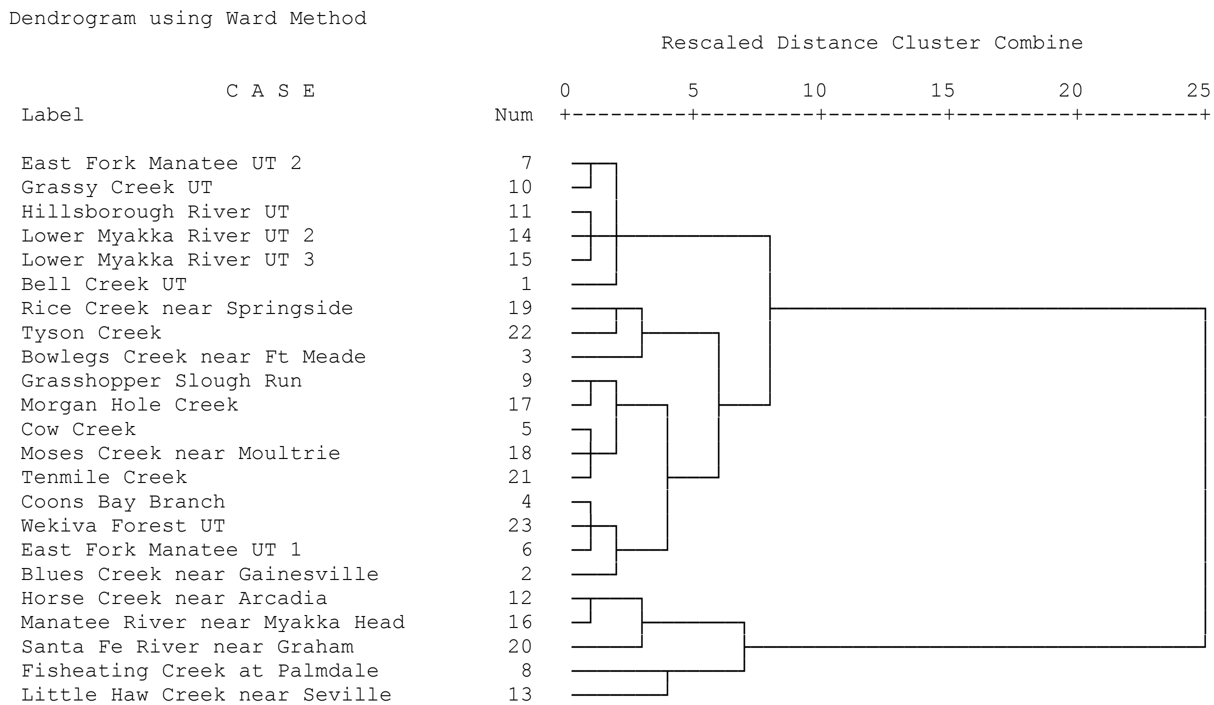


Figure D-4. Dendogram for flatwoods sites on all variables.

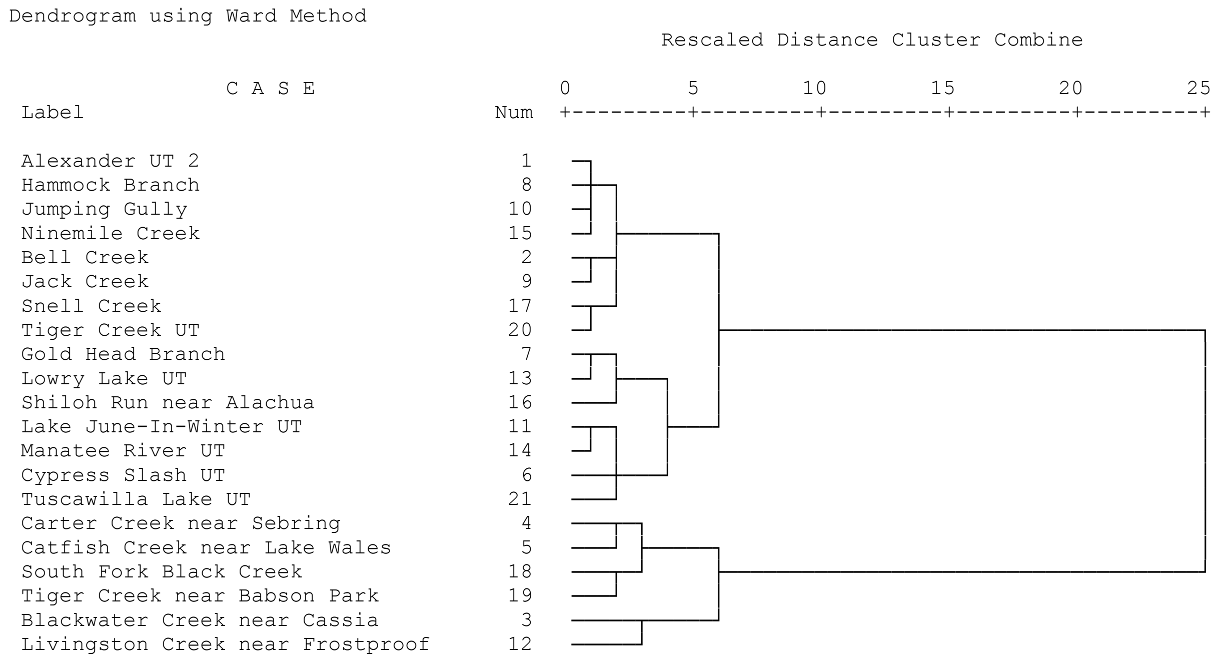


Figure D-5. Dendogram for highlands sites on all variables.

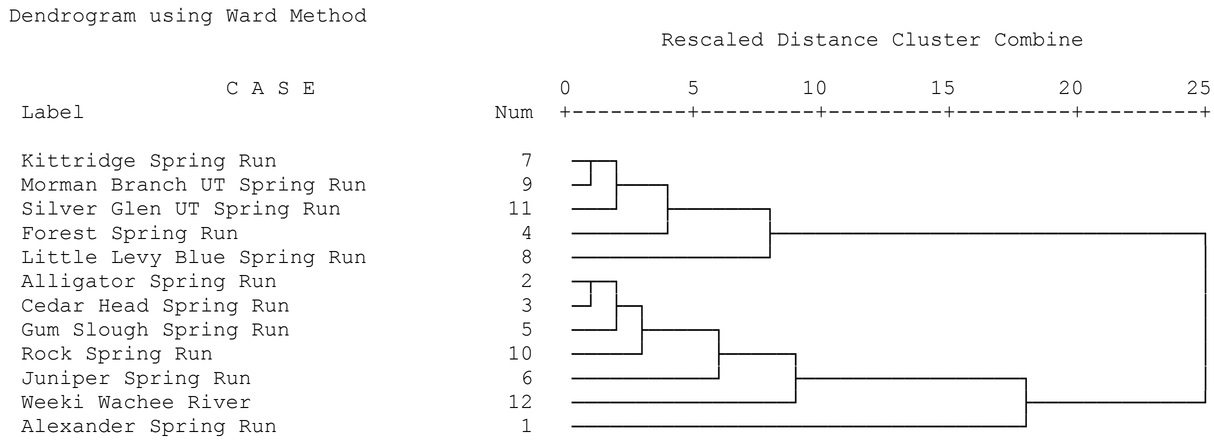


Figure D-6. Dendogram for karst sites on all variables.

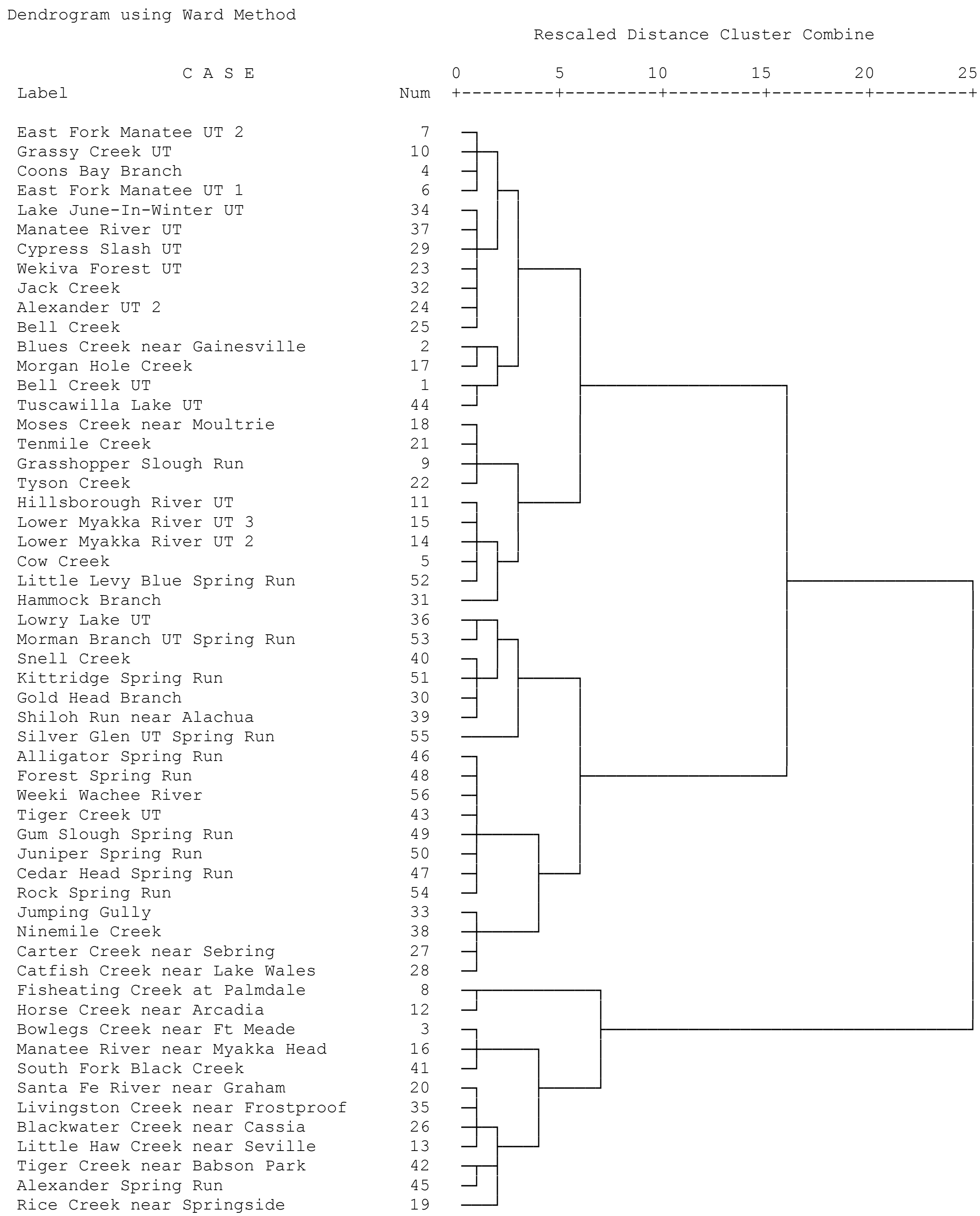


Figure D-7. Dendogram for all sites on watershed variables.

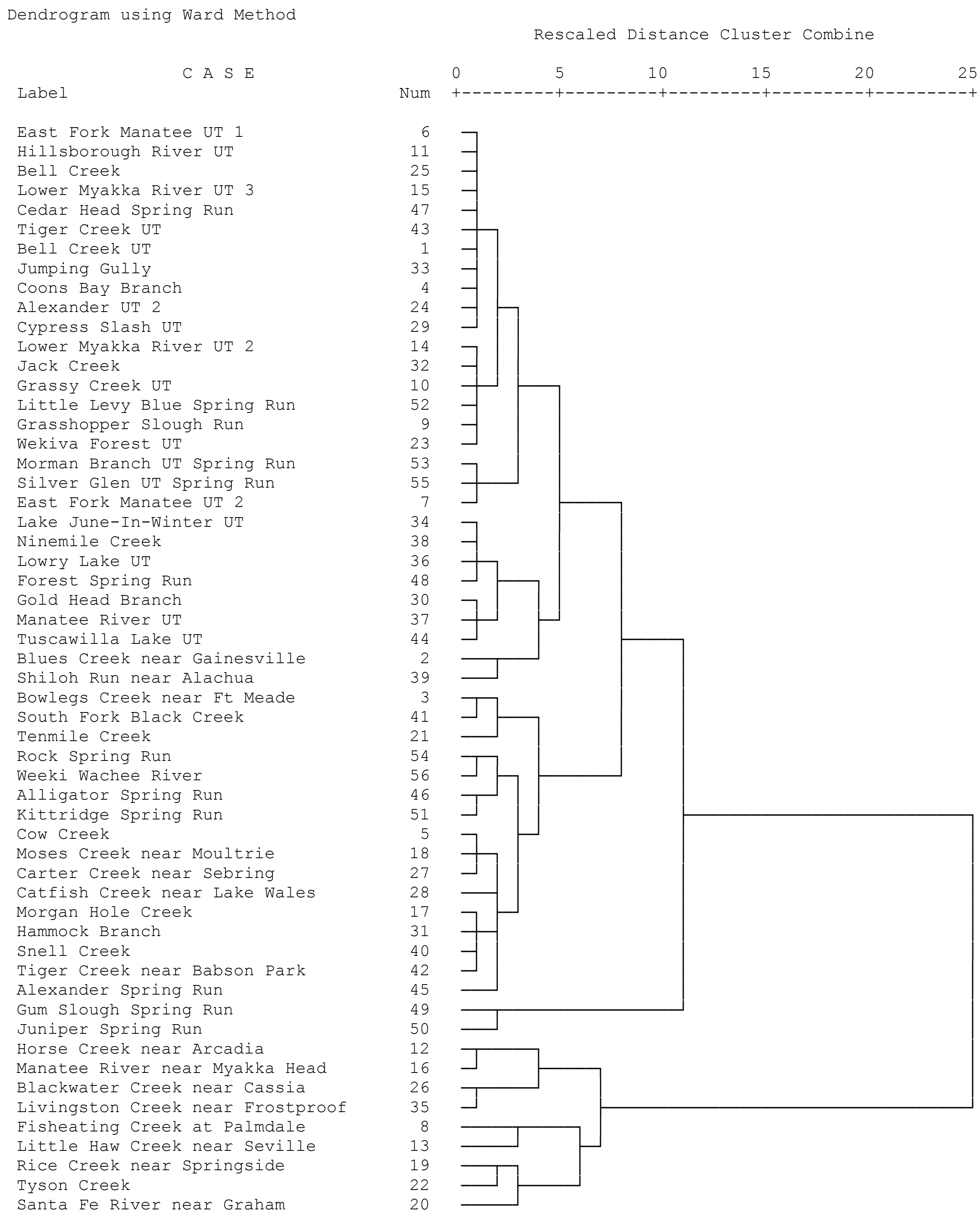


Figure D-8. Dendogram for all sites on valley variables.

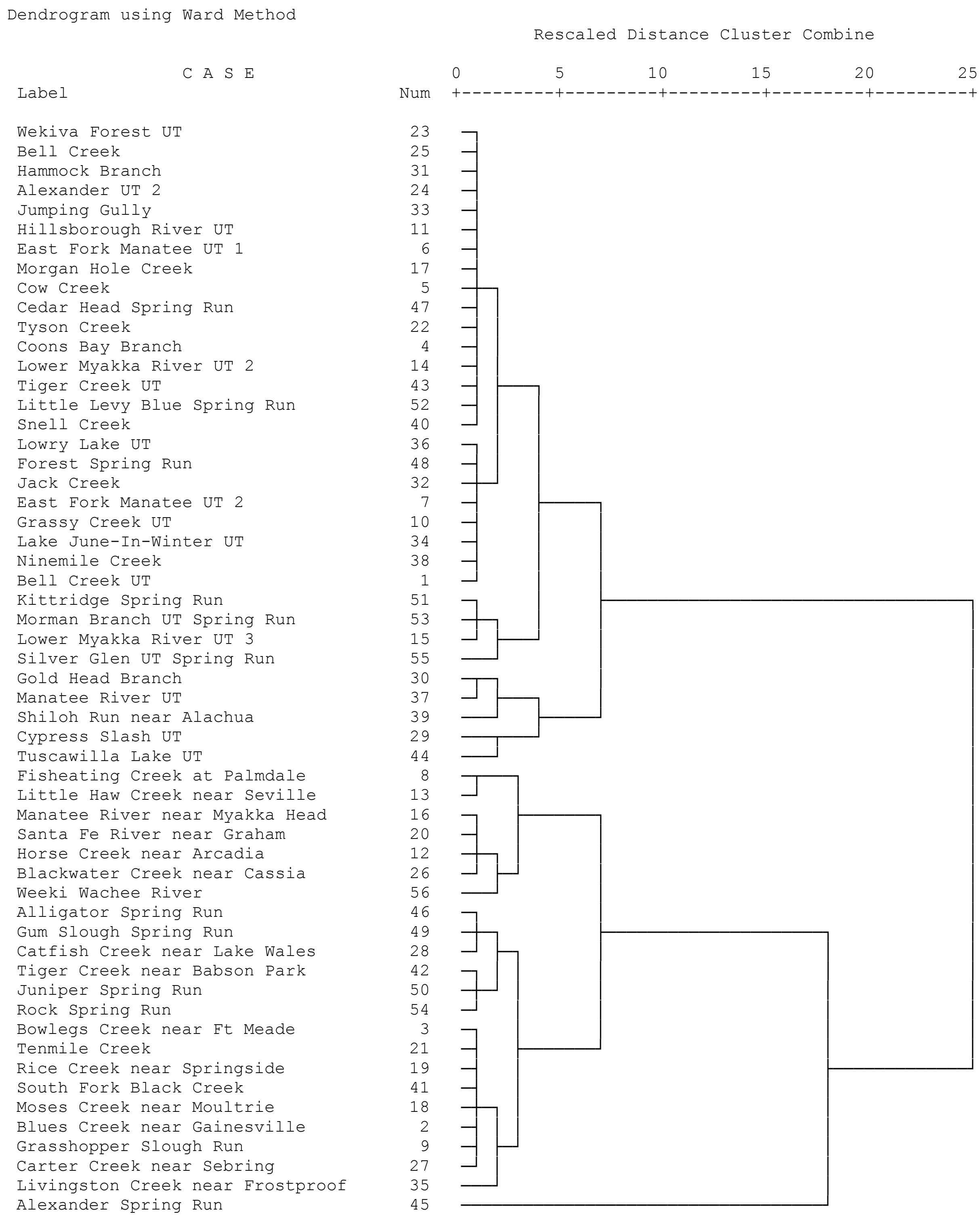


Figure D-9. Dendogram for all sites on reach variables.

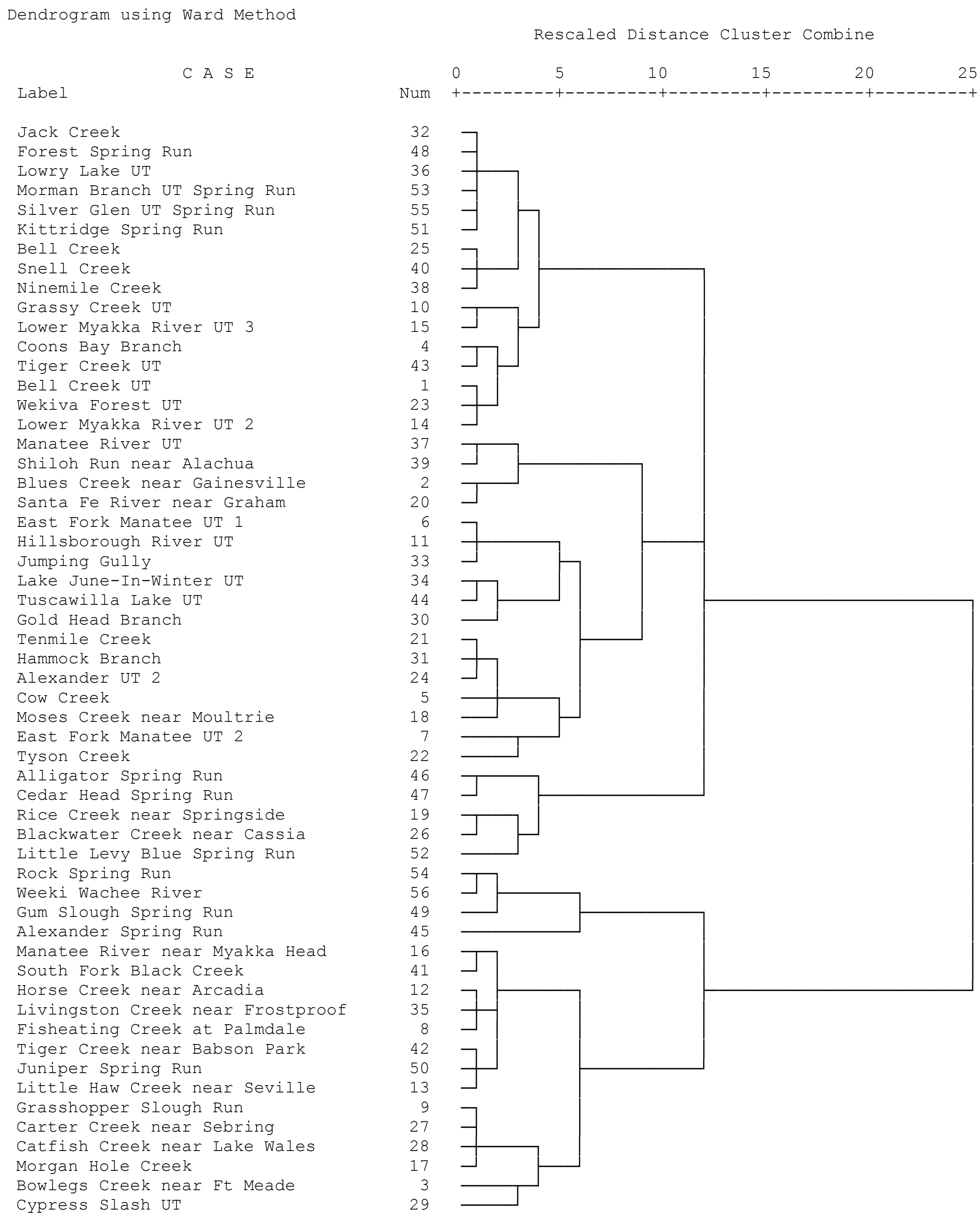


Figure D-10. Dendogram for all sites on habitat patch variables.

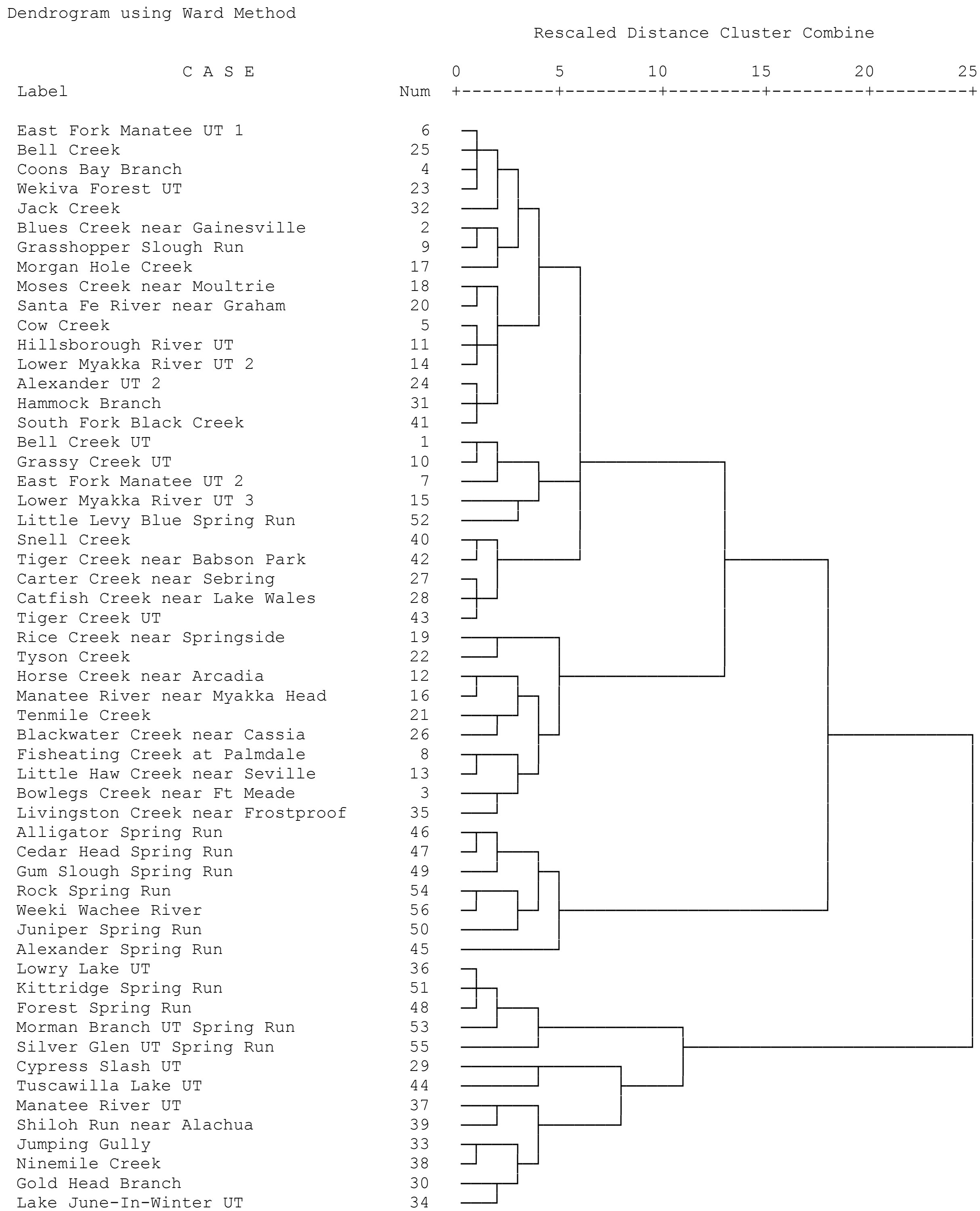


Figure D-11. Dendogram for all sites on dimensionless and unit variables.

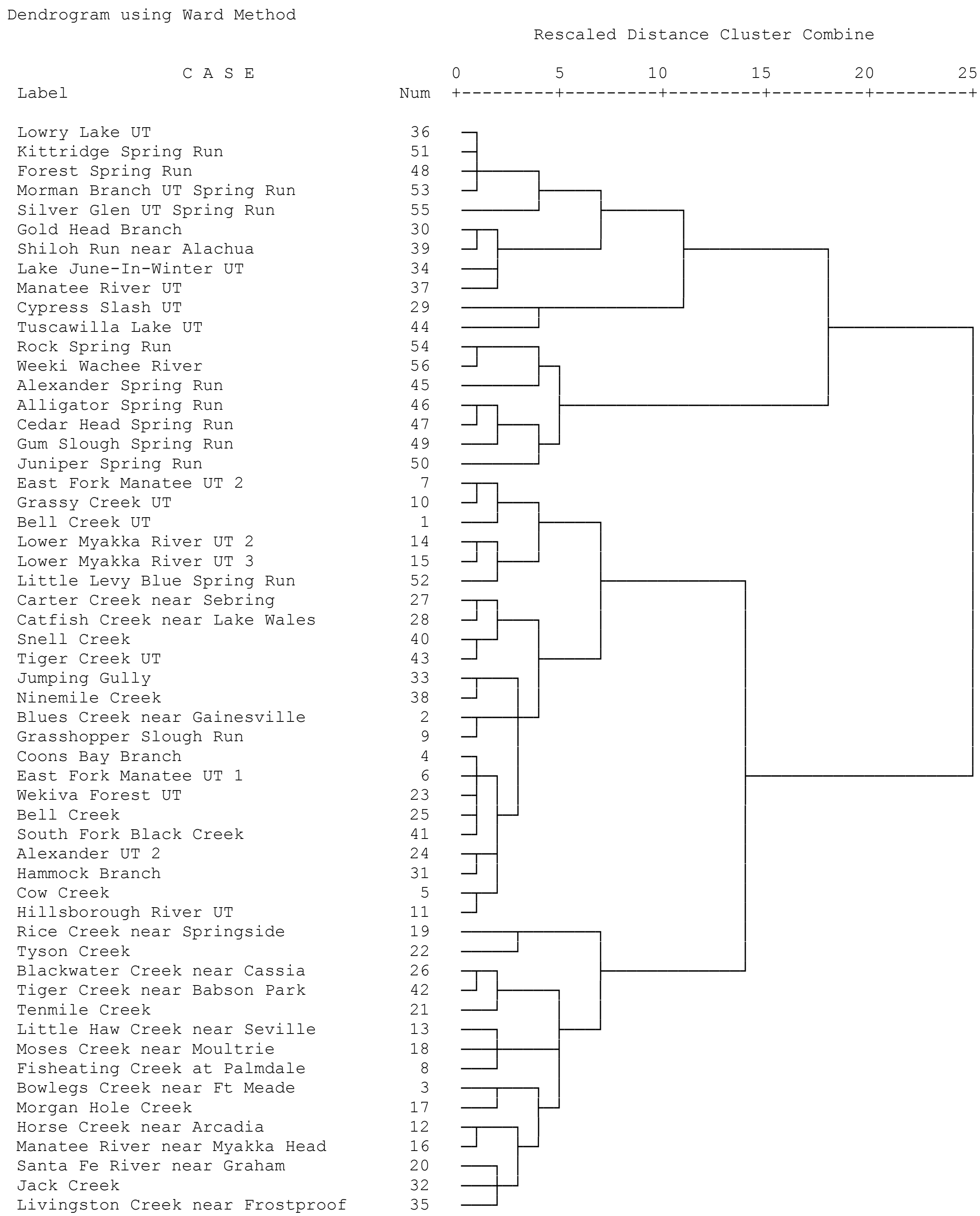


Figure D-12. Dendogram for all sites on dimensionless variables.

APPENDIX E
PRINCIPAL COMPONENTS ANALYSIS TABLES

Table E-1. All cases with all variables, rotated component matrix

	1	2	3	4	5
Mean Reach Riffle TW Depth (ft)	.924				
Mean Reach TW D (ft)	.921				
Riffle TW Depth (ft)	.919				
Mean Reach Pool TW Depth (ft)	.907				
Max Reach Mean Depth (ft)	.901				
Mean Reach Average Depth (ft)	.900				
Min Reach TW Depth (ft)	.899				
Thalweg Flood Depth	.896				
Max Reach Pool TW Depth (ft)	.896				
Classification Bankfull Depth (ft)	.892				
Bankfull Hydraulic Radius	.873				
Min Reach Mean Depth (ft)	.869				
Low Bank Height (ft)	.859				
Pools >4 ft Deep (%)	.835				
Bankfull Discharge (cfs)	.829				
Flood Discharge (cfs)	.762				
Total Alluvial Features	.757				
Watershed Length (ft)	.746				
No. of Alluvial Valley Features	.744				
Stream Power (lb/s)	.739				
Bankfull Mean Velocity (ft/s)	.722				
Flood Stream Power (lb/s)	.718				
Total Valley Length (ft)	.712				
Pools 1-2 ft Deep (%)	-.699				
Primary Basin Area (sq. miles)	.696				
Watershed Width (ft)	.689				
Network Magnitude	.687				
Reach Standard Deviation of XS Area	.679				
Drainage Area (sq. mile)	.657				
No. of Alluvial Bed Features	.643				
Watershed Area to Length Ratio (sq. mi/mile)	.642				
Reach Standard Deviation of TW D	.620				
Bifurcation Ratio	.614				

Table E-1. Continued

	1	2	3	4	5
Reach Standard Deviation of Mean D	.581				
Mean Valley Zone Length (ft)	.535				
No. Valley Transitions	.531				
Ratio of Flood to Bankfull Velocity					
Max-Min Ratio of Zone Lengths					
Watershed Relief on Longitudinal Axis (ft)					
Bends per 100 LF					
Maximum Valley Zone Width (ft)					
Minimum Reach Width (ft)		.967			
Mean Reach Width (ft)		.963			
Min Reach Radius of Curvature (ft)		.962			
Mean Reach RC (ft)		.959			
Classification Bankfull Width (ft)		.959			
Minimum Reach XS Area (ft)		.938			
Maximum Reach Width (ft)		.934			
Mean Reach XS Area		.930			
Classification Cross-Section Area (sq. ft)		.926			
Maximum Reach XS Area (ft)		.904			
Bankfull Wetted Perimeter		.904			
Width at Bank Height		.885			
Mean Distance Between Pools (ft)		.820			
W/D Ratio		.812			
Percent Substrate as SAV		.810			
Mean Distance Between Bends (ft)		.741			
Meander Beltwidth (ft)	.629	.674			
Reach Standard Deviation of Width		.618			
Mean Rc/W Ratio		.573			
Percent Canopy Closure					
Percent Canopy Closure US DS					
A+C Soils			-.725		
Percent A-Soil			-.721		
Percent D-Soil			.710		
Ratio of Flood to Bankfull Power			.652		
Ratio of Flood to Bankfull Flow			.641		
Width Ratio of Floodplain and Bankfull Channels			.627		
Flood/Bank Height Depth Ratio			.571		

Table E-1. Continued

	1	2	3	4	5
Percent Wetlands			.563		
Valley Width at Flood Line			.562		
Valley Segment Sinuousity Ratio			-.540		
Bends per 12 Bankfull Widths					
Bankfull Slope (ft/ft)				.879	
Reach Valley Slope (%)				.871	
Valley Segment Slope (%)				.832	
Root Steps per Stream Length (no./100ft)				.822	
Bankfull Shear Stress (psi)				.779	
Ratio of Max Min Reach TW Depths				.779	
Unit floodplain power				.642	
Ratio of Mean Reach Pool and Riffle TW Depths				.627	
Unit Stream Power				.589	
Manning's n					
Bankfull Mean Depth Max/Min Ratio					
Valley Relief in the Segment (ft)					
MBW to W Ratio					
Width of Riparian Wetland (ft)					.808
Ratio of Wetland Width to Beltwidth					.771
Wetland to Bankfull Width Ratio					.770
Minimum Valley Zone Width (ft)					.685
Mean Valley Zone Width (ft)					.535
Flood Mean Velocity (fps)					
Bankfull Width Max/Min Ratio					

Table E-2. Large sites with all variables, rotated component matrix

	1	2	3	4	5
Riffle TW Depth (ft)	.944				
Mean Reach Riffle TW Depth (ft)	.929				
Mean Reach Average Depth (ft)	.925				
Min Reach TW Depth (ft)	.919				
Mean Reach TW D (ft)	.908				
Max Reach Mean Depth (ft)	.901				
Classification Bankfull Depth (ft)	.888				
Low Bank Height (ft)	.871				
Min Reach Mean Depth (ft)	.865				
Bankfull Discharge (cfs)	.858				
Mean Reach Pool TW Depth (ft)	.841				
Stream Power (lb/s)	.831				
Max Reach Pool TW Depth (ft)	.805				
Pools >4 ft Deep (%)	.803				
Pools 2-4 ft Deep (%)	-.802				
Bankfull Hydraulic Radius	.797				
Thalweg Flood Depth	.768				
Bankfull Mean Velocity (ft/s)	.641				
Flood Stream Power (lb/s)	.578		.518		
Primary Basin Area (sq. miles)	.540				
Watershed Length (ft)	.537				
Reach Standard Deviation of XS Area	.508				
Classification Bankfull Width (ft)		.979			
Minimum Reach Width (ft)		.979			
Mean Reach Width (ft)		.973			
Min Reach Radius of Curvature (ft)		.968			
Mean Reach RC (ft)		.964			
Mean Distance Between Pools (ft)		.961			
Mean Reach XS Area		.954			
Minimum Reach XS Area (ft)		.953			
Bankfull Wetted Perimeter		.950			
Classification Cross-Section Area (sq. ft)		.948			
Maximum Reach Width (ft)		.945			
Maximum Reach XS Area (ft)		.938			
W/D Ratio		.928			
Width at Bank Height		.892			
Percent Substrate as SAV		.763			

Table E-2. Continued

	1	2	3	4	5
Mean Distance Between Bends (ft)		.734			
Meander Beltwidth (ft)		.718			
Mean Rc/W Ratio		.603			
Reach Standard Deviation of Width		.581			
Manning's n		.519			
No. of Alluvial Bed Features					
Percent A-Soil			-.836		
A+C Soils			-.814		
Percent D-Soil			.780		
No. of Alluvial Valley Features			.721		
Ratio of Flood to Bankfull Power			.704		
Flood/Bank Height Depth Ratio			.684		
Total Valley Length (ft)			.683		
Valley Segment Sinuosity Ratio			-.678		
Ratio of Flood to Bankfull Flow			.668		
Bifurcation Ratio			.654		
Total Alluvial Features			.643		
Flood/Bankfull Depth Ratio			.643		
Watershed Area to Length Ratio (sq. mi/mile)			.631		
Width Ratio of Floodplain and Bankfull Channels			.629		.593
Flood Discharge (cfs)	.615		.625		
Maximum Valley Zone Length (ft)			.625		
Network Magnitude			.602		
Watershed Width (ft)			.600		
Drainage Area (sq. mile)			.584		
Percent Wetlands			.572		
Bends per 12 Bankfull Widths		.526	-.538		
Ratio of Flood to Bankfull Velocity			-.530		
Basin Drainage Density (LF/SM)			.509		
No. Valley Transitions					
MBW to W Ratio					
Width Ratio of Bank Height to Bankfull					
Bankfull Slope (ft/ft)				.866	
Reach Valley Slope (%)				.807	
Bends per 100 LF				.798	
Bankfull Shear Stress (psi)				.752	
Pools 1-2 ft Deep (%)				.731	

Table E-2. Continued

	1	2	3	4	5
Root Steps per Stream Length (no./100ft)				.731	
Valley Segment Slope (%)				.675	
Unit Stream Power	.586			.622	
Unit floodplain power				.525	
Percent Substrate as Root Mass					
Ratio of Max Min Reach TW Depths					.774
Reach Standard Deviation of TW D					.767
Reach Standard Deviation of Mean D					.722
Ratio of Mean Reach Pool and Riffle TW Depths					.680
Wetland to Bankfull Width Ratio					.674
Bankfull Mean Depth Max/Min Ratio					.673
Width of Riparian Wetland (ft)					.655
Valley Width at Flood Line			.561		.621
Minimum Valley Zone Width (ft)					.603
Ratio of Wetland Width to Beltwidth					.557
Bankfull Width Max/Min Ratio					.525
Flood Mean Velocity (fps)					
Tightest Bend Ratio					

Table E-3. Small sites with all variables, rotated component matrix

	1	2	3	4	5
Mean Reach Pool TW Depth (ft)	.947				
Mean Reach Average Depth (ft)	.939				
Mean Reach TW D (ft)	.934				
Max Reach Mean Depth (ft)	.927				
Classification Bankfull Depth (ft)	.882				
Min Reach Mean Depth (ft)	.873				
Riffle TW Depth (ft)	.848				
Mean Reach Riffle TW Depth (ft)	.843				
Max Reach Pool TW Depth (ft)	.828				
Pools 1-2 ft Deep (%)	-.825				
Pools 2-4 ft Deep (%)	.825				
Bankfull Hydraulic Radius	.823				
Reach Standard Deviation of TW D	.703			-.603	
Thalweg Flood Depth	.703				
Low Bank Height (ft)	.703				
Min Reach TW Depth (ft)	.677				
Reach Standard Deviation of Mean D	.674				
Network Magnitude	.600				
W/D Ratio	-.574	.514			
Mean Distance Between Pools (ft)	-.556				
Bifurcation Ratio	.545				
Ratio of Flood to Bankfull Flow	-.519				
Ratio of Flood to Bankfull Power					
Percent Substrate as Emergent Veg					
Meander Beltwidth (ft)					
Max-Min Ratio of Zone Lengths					
Total Valley Length (ft)					
Pools per 12 Bankfull Width					
Max-Min Ratio of Zone Widths					
Sinuosity Ratio					
Mean Reach Width (ft)		.926			
Maximum Reach Width (ft)		.864			
Classification Bankfull Width (ft)		.849			
Reach Standard Deviation of Width		.828			
Maximum Reach XS Area (ft)		.822			
Minimum Reach Width (ft)		.807			
Reach Standard Deviation of XS Area		.777			

Table E-3. Continued

	1	2	3	4	5
Mean Reach RC (ft)		.759			
Mean Reach XS Area	.523	.732			
Width at Bank Height		.690			
Minimum Reach XS Area (ft)	.550	.649			
Classification Cross-Section Area (sq. ft)	.523	.646			
Min Reach Radius of Curvature (ft)		.627			
Percent Substrate as Bare Muck/Silt		.614			
Bends per 100 LF		-.586			
Percent Substrate as SAV		.556			
Mean Distance Between Bends (ft)		.548			
Bankfull Width Max/Min Ratio		.544		-.522	
Logs per Stream Length (no./100 ft)		.530			
No. of Alluvial Bed Features		-.508			
Total Alluvial Features					
A+C Soils			.860		
Percent A-Soil			.853		
Percent D-Soil			-.851		
Watershed Relief on Longitudinal Axis (ft)			.804		
Basin Grade (ft/ft)			.751		
Total Valley Relief on Wide Section (ft)			.742		
Flood/Bank Height Depth Ratio			-.706		
Valley Width at Flood Line			-.684		
Width Ratio of Floodplain and Bankfull Channels			-.647		
Percent Wetlands			-.620		
Hillslope Grade (ft/ft)		.517	.610		
Bank Height Ratio			.600		
Ratio of Flood to Bankfull Velocity			.566		
Entrenchment Ratio			-.548		
Percent Upland			.532		
Mean Valley Zone Length (ft)			.507		
Minimum Valley Zone Length (ft)			.504		
Maximum Valley Zone Length (ft)					
Ratio of Max Min Reach TW Depths				-.851	
Ratio of Mean Reach Pool and Riffle TW Depths				-.754	
Valley Segment Slope (%)				-.713	
Reach Valley Slope (%)				-.660	
Root Steps per Stream Length (no./100ft)				-.654	

Table E-3. Continued

	1	2	3	4	5
Maximum Valley Zone Width (ft)				.652	
Ratio of Wetland Width to Beltwidth				.646	
Mean Valley Zone Width (ft)				.626	
Bankfull Slope (ft/ft)				-.618	
Tightest Bend Ratio				-.605	
Width of Riparian Wetland (ft)				.605	
Wetland to Bankfull Width Ratio				.578	
Bankfull Area Max/Min Ratio				-.572	
Bankfull Mean Depth Max/Min Ratio				-.551	
Manning's n				-.543	
MBW to W Ratio				-.523	
No. Valley Transitions					
Flood Stream Power (lb/s)					.951
Stream Power (lb/s)					.926
Unit Stream Power					.922
Unit floodplain power					.896
Bankfull Mean Velocity (ft/s)					.828
Flood Mean Velocity (fps)					.825
Percent Substrate as Bare Rock					.713
Valley Relief in the Segment (ft)					.709
Bankfull Discharge (cfs)					.696
Flood Discharge (cfs)					.625
Bankfull Shear Stress (psi)					.587

Table E-4. Flatwoods sites with all variables, rotated component matrix

	1	2	3	4	5
Classification Cross-Section Area (sq. ft)	.962				
Mean Reach XS Area	.961				
Maximum Reach XS Area (ft)	.959				
Watershed Length (ft)	.943				
Flood Discharge (cfs)	.918				
Reach Standard Deviation of XS Area	.915				
Minimum Reach Width (ft)	.914				
Minimum Reach XS Area (ft)	.912				
Mean Reach Pool TW Depth (ft)	.910				
Meander Beltwidth (ft)	.903				
Mean Reach Width (ft)	.903				
Max Reach Pool TW Depth (ft)	.902				
Bankfull Discharge (cfs)	.900				
Mean Reach TW D (ft)	.891				
Pools >4 ft Deep (%)	.890				
Riffle TW Depth (ft)	.885				
No. of Alluvial Valley Features	.882				
Mean Reach Riffle TW Depth (ft)	.878				
Primary Basin Area (sq. miles)	.876				
Drainage Area (sq. mile)	.876				
Maximum Reach Width (ft)	.869				
Total Alluvial Features	.865				
Min Reach TW Depth (ft)	.862				
Thalweg Flood Depth	.856				
Classification Bankfull Width (ft)	.848				
Total Valley Length (ft)	.839				
Max Reach Mean Depth (ft)	.831				
Network Magnitude	.818				
Mean Reach Average Depth (ft)	.813				
Mean Distance Between Bends (ft)	.809				
Watershed Width (ft)	.806				
Mean Reach RC (ft)	.801				
Stream Power (lb/s)	.797				
Min Reach Radius of Curvature (ft)	.777				
Classification Bankfull Depth (ft)	.766	.501			
Flood Stream Power (lb/s)	.755				
Width at Bank Height	.750				

Table E-4. Continued

	1	2	3	4	5
Watershed Area to Length Ratio (sq. mi/mile)	.740		.529		
Low Bank Height (ft)	.737				
Bankfull Hydraulic Radius	.734	.515			
Valley Width at Flood Line	.731	-.507			
Reach Standard Deviation of TW D	.724				
Min Reach Mean Depth (ft)	.715				
Width Ratio of Floodplain and Bankfull Channels	.709				
Reach Standard Deviation of Width	.709				
Mean Distance Between Pools (ft)	.706				
Mean Valley Zone Width (ft)	.704				
Bankfull Wetted Perimeter	.703	-.503			
Reach Standard Deviation of Mean D	.688				
Maximum Valley Zone Width (ft)	.662				
No. of Alluvial Bed Features	.643				
No. Valley Transitions	.632			-.581	
Bifurcation Ratio	.632				
Maximum Valley Zone Length (ft)	.626				
Bankfull Mean Velocity (ft/s)	.616	.603			
Watershed Relief on Longitudinal Axis (ft)	.593				
Pools 1-2 ft Deep (%)	-.578				
Ratio of Flood to Bankfull Velocity	-.543				
Percent Canopy Closure US DS	-.524				
Percent Canopy Closure					
Max-Min Ratio of Zone Lengths					
Unit Stream Power		.819			
Flood Mean Velocity (fps)		.797			
Bank Height Ratio		.637			
Bankfull Shear Stress (psi)		.612			
Ratio of Wetland Width to Beltwidth		-.608			
Floodplain n		-.600			
Unit floodplain power		.596			
Width of Riparian Wetland (ft)	.502	-.563			
Minimum Valley Zone Length (ft)			.706		
Percent Wetlands			.691		
Percent Upland			-.683		
Valley Segment Slope (%)	-.557		-.658		
Bankfull Slope (ft/ft)			-.656		

Table E-4. Continued

	1	2	3	4	5
Reach Valley Slope (%)			-.650		
Mean Valley Zone Length (ft)			.649		
Ratio of Flood to Bankfull Flow			.623		
Flood/Bank Height Depth Ratio			.621		
Ratio of Flood to Bankfull Power			.615		
Ratio of Max Min Reach TW Depths			-.589		
Bends per 100 LF	-.557		-.569		
Manning's n			-.534		
Flood/Bankfull Depth Ratio			.526		
Ratio of Mean Reach Pool and Riffle TW Depths			-.502		
Transitions per Valley Length (no./mile)					
Tightest Bend Ratio				-.770	
Mean Rc/W Ratio				-.720	
Bankfull Mean Depth Max/Min Ratio				.661	
Pools per 12 Bankfull Width				.632	
Basin Drainage Density (LF/SM)				-.612	
Percent Substrate as SAV				.583	
Width Ratio of Bank Height to Bankfull				.540	
Max-Min Ratio of Zone Widths				-.535	
Logs per Stream Length (no./100 ft)				.520	
Percent Lakes				.503	
Bends per 12 Bankfull Widths					
Bankfull Width Max/Min Ratio					
MBW to W Ratio					
Pools 2-4 ft Deep (%)					
Percent A-Soil					.713
Percent Substrate as Bare Rock					.663
Percent D-Soil					-.634
Valley Relief in the Segment (ft)					.610
A+C Soils					.568
Bankfull Area Max/Min Ratio					-.554
Length of the Valley Segment (ft)					.512
Hillslope Grade (ft/ft)					
Percent Substrate as Leaf Packs					
Total Valley Relief on Wide Section (ft)					

Table E-5. Highlands sites with all variables, rotated component matrix

	1	2	3	4	5
Maximum Valley Zone Length (ft)	.924				
Classification Bankfull Depth (ft)	.912				
Max Reach Pool TW Depth (ft)	.896				
Riffle TW Depth (ft)	.893				
Mean Reach Pool TW Depth (ft)	.892				
Min Reach Mean Depth (ft)	.891				
Mean Reach TW D (ft)	.886				
Mean Reach Riffle TW Depth (ft)	.876				
Bankfull Discharge (cfs)	.873				
Total Valley Length (ft)	.855				
Mean Reach Average Depth (ft)	.848				
Min Reach TW Depth (ft)	.848				
Max-Min Ratio of Zone Lengths	.846				
Minimum Reach XS Area (ft)	.842				
Pools >4 ft Deep (%)	.836				
Flood Discharge (cfs)	.824				
Bankfull Hydraulic Radius	.822				
Low Bank Height (ft)	.819				
Mean Reach XS Area	.816	.508			
Classification Cross-Section Area (sq. ft)	.808				
Max Reach Mean Depth (ft)	.804				
Watershed Relief on Longitudinal Axis (ft)	.789				
Maximum Reach XS Area (ft)	.783	.542			
Percent Substrate as Bare Muck/Silt	.768				
Network Magnitude	.765				
Mean Distance Between Bends (ft)	.749				
Watershed Length (ft)	.747	.539			
Thalweg Flood Depth	.739	.602			
Primary Basin Area (sq. miles)	.712	.618			
Drainage Area (sq. mile)	.712	.618			
No. Valley Transitions	.675				
Mean Valley Zone Length (ft)	.655				
Mean Valley Zone Width (ft)	.645				
Reach Standard Deviation of XS Area	.642	.628			
Watershed Width (ft)	.641	.574			
Percent Substrate as Leaf Packs	.610				
Maximum Valley Zone Width (ft)	.599				

Table E-5. Continued

	1	2	3	4	5
Reach Standard Deviation of TW D	.580				
Pools 1-2 ft Deep (%)	-.563				
No. of Alluvial Valley Features	.555				
Bifurcation Ratio	.553				
Ratio of Flood to Bankfull Flow	.552				
Width of Riparian Wetland (ft)	.546				
Max-Min Ratio of Zone Widths	.525				
Transitions per Valley Length (no./mile)					
Width Ratio of Floodplain and Bankfull Channels					
Percent Substrate as SAV		.838			
Percent Canopy Closure US DS		-.803			
Mean Reach RC (ft)		.790			
Flood/Bank Height Depth Ratio		.783			
Mean Distance Between Pools (ft)		.751			
W/D Ratio		.748			
Bankfull Wetted Perimeter		.745			
Width at Bank Height		.738			
Min Reach Radius of Curvature (ft)		.732			
Reach Standard Deviation of Width		.725			
Percent Canopy Closure		-.724			
Percent Substrate as Emergent Veg		.718			
Flood/Bankfull Depth Ratio		.716			
Maximum Reach Width (ft)	.507	.703			
Meander Beltwidth (ft)	.609	.692			
Mean Reach Width (ft)	.600	.672			
Classification Bankfull Width (ft)	.615	.640			
Watershed Area to Length Ratio (sq. mi/mile)	.631	.635			
Minimum Reach Width (ft)	.603	.633			
Length of the Valley Segment (ft)	.570	.623			
Valley Width at Flood Line	.590	.606			
Bends per 100 LF		-.590			
Ratio of Flood to Bankfull Power		.579			
Basin Drainage Density (LF/SM)		-.572			
Bankfull Width Max/Min Ratio			-.720		
Ratio of Max Min Reach TW Depths			-.699	.560	
Root Steps per Stream Length (no./100ft)			-.673		
Ratio of Flood to Bankfull Velocity			-.663		

Table E-5. Continued

	1	2	3	4	5
Entrenchment Ratio			.655		
Bankfull Slope (ft/ft)			-.617		
Manning's n			-.600		
Valley Segment Slope (%)			-.595		
Minimum Valley Zone Width (ft)			.576		
Ratio of Mean Reach Pool and Riffle TW Depths			-.574	.572	
Reach Valley Slope (%)			-.567		
No. of Alluvial Bed Features			.565		
Sinuosity Ratio			.551		
Hillslope Grade (ft/ft)			-.536		
Total Alluvial Features	.511		.518		
Bankfull Area Max/Min Ratio			-.500		
Bankfull Mean Depth Max/Min Ratio					
Basin Grade (ft/ft)					
Bends per 12 Bankfull Widths				-.773	
MBW to W Ratio				.762	
Pools per 12 Bankfull Width				-.687	
Percent A-Soil				-.668	
Mean Rc/W Ratio				.643	
Tightest Bend Ratio				.611	
A+C Soils				-.585	
Percent D-Soil				.572	
Width Ratio of Bank Height to Bankfull				.551	
Total Valley Relief on Wide Section (ft)				-.535	
Ratio of Wetland Width to Beltwidth					
Stream Power (lb/s)					.898
Unit Stream Power					.869
Unit floodplain power					.868
Flood Mean Velocity (fps)					.775
Valley Relief in the Segment (ft)					.731
Bankfull Mean Velocity (ft/s)					.696
Flood Stream Power (lb/s)		.534			.651
Bankfull Shear Stress (psi)					.565
Percent Wetlands					
Percent Upland					

Table E-6. Karst sites with all variables, rotated component matrix

	1	2	3	4	5
Max-Min Ratio of Zone Widths	.995				
Min Reach Radius of Curvature (ft)	.994				
Mean Reach RC (ft)	.991				
Network Magnitude	.990				
Minimum Reach Width (ft)	.986				
Width at Bank Height	.985				
Classification Bankfull Width (ft)	.984				
No. Valley Transitions	.981				
Mean Reach Width (ft)	.979				
Bankfull Wetted Perimeter	.975				
Minimum Reach XS Area (ft)	.974				
Classification Cross-Section Area (sq. ft)	.967				
Mean Reach XS Area	.966				
Maximum Reach Width (ft)	.963				
Max-Min Ratio of Zone Lengths	.960				
Maximum Reach XS Area (ft)	.943				
Bifurcation Ratio	.926				
Percent Lakes	.923				
Mean Distance Between Bends (ft)	.922				
Meander Beltwidth (ft)	.904				
W/D Ratio	.903				
Valley Width at Flood Line	.847				
Drainage Area (sq. mile)	.818				
Mean Distance Between Pools (ft)	.799				
Total Valley Length (ft)	.789				
Flood Discharge (cfs)	.785	.578			
Percent Substrate as SAV	.782				
Maximum Valley Zone Width (ft)	.768				
Mean Rc/W Ratio	.739				
Watershed Area to Length Ratio (sq. mi/mile)	.708				
Percent Canopy Closure	-.706	-.557			
Watershed Width (ft)	.640				
Primary Basin Area (sq. miles)	.614	.610			
Watershed Length (ft)	.600				
Reach Standard Deviation of Width	.567				-.526
Bends per 12 Bankfull Widths	.528				
Pools 2-4 ft Deep (%)	.507				

Table E-6. Continued

	1	2	3	4	5
Mean Reach Riffle TW Depth (ft)		.945			
Mean Reach TW D (ft)		.938			
Riffle TW Depth (ft)		.937			
Min Reach TW Depth (ft)		.935			
Mean Reach Pool TW Depth (ft)		.929			
Max Reach Pool TW Depth (ft)		.919			
Thalweg Flood Depth		.892			
Stream Power (lb/s)		.888			
Max Reach Mean Depth (ft)		.886			
Unit Stream Power		.886			
Classification Bankfull Depth (ft)		.883			
Mean Reach Average Depth (ft)		.874			
Min Reach Mean Depth (ft)		.868			
No. of Alluvial Valley Features		.857			
Flood Stream Power (lb/s)		.836			
Low Bank Height (ft)		.826			
Bankfull Hydraulic Radius		.822			
Bankfull Mean Velocity (ft/s)		.820			
Bankfull Shear Stress (psi)		.796			
Total Alluvial Features		.791			
Bankfull Discharge (cfs)	.542	.786			
Pools >4 ft Deep (%)		.782			
Valley Segment Sinuosity Ratio		.779			
Pools per 12 Bankfull Width		.749			
Reach Standard Deviation of TW D		.743		.615	
Unit floodplain power		.714			
No. of Alluvial Bed Features		.696			
Reach Standard Deviation of XS Area		.678			
Percent Canopy Closure US DS	-.603	-.639			
Bank Height Ratio		-.636			
Pools 1-2 ft Deep (%)		-.635			
Flood/Bankfull Depth Ratio		-.619	-.526		
Percent Substrate as Leaf Packs		-.619			.533
Ratio of Flood to Bankfull Velocity		-.591			
Flood Mean Velocity (fps)		.567			
Transitions per Valley Length (no./mile)		-.523			
Logs per Stream Length (no./100 ft)		-.516			

Table E-6. Continued

	1	2	3	4	5
Width Ratio of Bank Height to Bankfull		-.516			
Ratio of Mean Reach Pool and Riffle TW Depths		-.506			
MBW to W Ratio					
Percent A-Soil			.883		
A+C Soils			.855		
Percent D-Soil			-.850		
Percent C-Soil			-.812		
Percent Substrate as Bare Muck/Silt			-.808		
Percent Wetlands			-.779		
Percent Upland			.774		
Flood/Bank Height Depth Ratio			-.769		
Percent Substrate as Bare Sand			.746		
Basin Drainage Density (LF/SM)			.619		
Watershed Relief on Longitudinal Axis (ft)			.615		
Basin Grade (ft/ft)		-.566	.576		
Ratio of Flood to Bankfull Power			-.569		
Floodplain n			-.548		.510
Ratio of Flood to Bankfull Flow			-.530		
Percent Substrate as Fine Wood					
Sinuosity Ratio					
Hillslope Grade (ft/ft)					
Tightest Bend Ratio					
Wetland to Bankfull Width Ratio				.950	
Minimum Valley Zone Length (ft)				.890	
Minimum Valley Zone Width (ft)				.852	
Ratio of Wetland Width to Beltwidth				.848	
Width of Riparian Wetland (ft)				.834	
Mean Valley Zone Length (ft)				.825	
Valley Relief in the Segment (ft)				.815	
Mean Valley Zone Width (ft)				.749	
Reach Standard Deviation of Mean D		.570		.710	
Maximum Valley Zone Length (ft)		.511		.666	
Ratio of Max Min Reach TW Depths				.655	
Length of the Valley Segment (ft)	.538			.652	
Pools per 100 LF				.637	
Bankfull Width Max/Min Ratio					
Root Steps per Stream Length (no./100ft)					.825

Table E-6. Continued

	1	2	3	4	5
Bends per 100 LF					.819
Width Ratio of Floodplain and Bankfull Channels					.818
Valley Segment Slope (%)					.701
Entrenchment Ratio					.553
Bankfull Slope (ft/ft)					.537
Manning's n					.515
Total Valley Relief on Wide Section (ft)					
Percent Substrate as Root Mass					
Reach Valley Slope (%)					
Bankfull Area Max/Min Ratio					

Table E-7. All sites with watershed variables, rotated component matrix

	1	2	3	4	5
Watershed Length (ft)	.908				
Drainage Area (sq. mile)	.907				
Primary Basin Area (sq. miles)	.894				
Watershed Width (ft)	.887				
Watershed Area to Length Ratio (sq. mi/mile)	.864				
Network Magnitude	.817				
Bifurcation Ratio	.711				
Percent D-Soil		-.959			
A+C Soils		.918			
Percent A-Soil		.904			
Watershed Relief on Longitudinal Axis (ft)	.548	.556			
Basin Drainage Density (LF/SM)			.786		
Hillslope Grade (ft/ft)			.727		
Basin Grade (ft/ft)			.642		
Total Valley Relief on Wide Section (ft)					
Percent Upland				-.917	
Percent Wetlands		-.515		.782	
Percent Lakes					
Percent C-Soil					.850

Table E-8. All sites with valley variables, rotated component matrix

	1	2	3	4	5
Ratio of Flood to Bankfull Power	.844				
Mean Valley Zone Length (ft)	.842				
Ratio of Flood to Bankfull Flow	.826				
Minimum Valley Zone Length (ft)	.760				
Flood/Bankfull Depth Ratio	.735				
Flood/Bank Height Depth Ratio	.732				
Maximum Valley Zone Length (ft)	.686				
No. of Alluvial Valley Features	.650				
Flood Stream Power (lb/s)	.575	.502			
No. Valley Transitions		.908			
Maximum Valley Zone Width (ft)		.758			
Max-Min Ratio of Zone Lengths		.731			
Max-Min Ratio of Zone Widths		.718			
Meander Beltwidth (ft)		.713			
Total Valley Length (ft)	.527	.682			
Thalweg Flood Depth	.588	.673			
Flood Discharge (cfs)	.552	.664			
Total Alluvial Features	.547	.549			
Length of the Valley Segment (ft)					
Ratio of Flood to Bankfull Velocity					
Width of Riparian Wetland (ft)			.906		
Ratio of Wetland Width to Beltwidth			.894		
Minimum Valley Zone Width (ft)			.890		
Wetland to Bankfull Width Ratio			.878		
Mean Valley Zone Width (ft)		.602	.655		
Valley Segment Sinuosity Ratio					
Valley Relief in the Segment (ft)				.786	
Unit floodplain power				.779	
Flood Mean Velocity (fps)				.754	
Valley Segment Slope (%)				.578	
MBW to W Ratio					
Transitions per Valley Length (no./mile)					
Width Ratio of Floodplain and Bankfull Channels	.500				.713
Valley Width at Flood Line					.701
Floodplain n					.536

Table E-9. All sites with reach variables, rotated component matrix

	1	2	3	4	5
Max Reach Pool TW Depth (ft)	.961				
Mean Reach Pool TW Depth (ft)	.956				
Mean Reach TW D (ft)	.955				
Max Reach Mean Depth (ft)	.943				
Riffle TW Depth (ft)	.934				
Mean Reach Riffle TW Depth (ft)	.928				
Mean Reach Average Depth (ft)	.924				
Min Reach TW Depth (ft)	.899				
Classification Bankfull Depth (ft)	.871				
Low Bank Height (ft)	.863				
Min Reach Mean Depth (ft)	.845				
Bankfull Hydraulic Radius	.820				
Bankfull Discharge (cfs)	.808				
Reach Standard Deviation of TW D	.735				
Reach Standard Deviation of Mean D	.723				
Reach Standard Deviation of XS Area	.717				
Stream Power (lb/s)	.683				
Bankfull Mean Velocity (ft/s)	.604				
Minimum Reach Width (ft)		.970			
Mean Reach Width (ft)		.969			
Min Reach Radius of Curvature (ft)		.968			
Mean Reach RC (ft)		.966			
Classification Bankfull Width (ft)		.961			
Maximum Reach Width (ft)		.947			
Minimum Reach XS Area (ft)		.940			
Mean Reach XS Area		.929			
Classification Cross-Section Area (sq. ft)		.926			
Maximum Reach XS Area (ft)		.903			
Width at Bank Height		.869			
Mean Distance Between Pools (ft)		.823			
W/D Ratio		.819			
Mean Distance Between Bends (ft)		.691			
Reach Standard Deviation of Width		.647			
Bankfull Shear Stress (psi)			.916		
Bankfull Slope (ft/ft)			.844		
Reach Valley Slope (%)			.834		
Unit Stream Power			.829		

Table E-9. Continued

	1	2	3	4	5
Bends per 100 LF	-.515		.560		
Manning's n					
Bankfull Mean Depth Max/Min Ratio				.776	
Ratio of Mean Reach Pool and Riffle TW Depths				.755	
Ratio of Max Min Reach TW Depths				.720	
Bankfull Width Max/Min Ratio				.689	
Bankfull Area Max/Min Ratio				.631	
Tightest Bend Ratio					.823
Mean Rc/W Ratio		.537			.679
Bends per 12 Bankfull Widths					-.621
Pools per 12 Bankfull Width					-.603

Table E-10. All sites with habitat patch variables, rotated component matrix

	1	2	3	4	5
Percent Substrate as SAV	-.868				
Bankfull Wetted Perimeter	-.850				
Percent Canopy Closure US DS	.715				
Percent Canopy Closure	.704				
Percent Substrate as Bare Muck/Silt		.768			
Logs per Stream Length (no./100 ft)		.752			
Percent Substrate as Bare Sand		-.713			
Percent Substrate as Fine Wood		.651			
No. of Alluvial Bed Features			.877		
Pools >4 ft Deep (%)			.736		
Pools 1-2 ft Deep (%)			-.665		.537
Percent Substrate as Root Mass				.801	
Percent Substrate as Emergent Veg				-.636	
Pools per 100 LF				.561	
Pools 2-4 ft Deep (%)					-.969

Table E-11. All sites with dimensionless variables, rotated component matrix

	1	2	3	4	5
A+C Soils	.880				
Percent A-Soil	.869				
Percent D-Soil	-.866				
Percent Wetlands	-.751				
Percent Upland	.669				
Basin Grade (ft/ft)	.599				
Bank Height Ratio	.550				
Hillslope Grade (ft/ft)	.512				
Flood/Bankfull Depth Ratio		.805			
Flood/Bank Height Depth Ratio		.779			
Ratio of Flood to Bankfull Power		.776			
Ratio of Flood to Bankfull Flow		.722			
Width Ratio of Floodplain and Bankfull Channels		.670			
Ratio of Flood to Bankfull Velocity		-.653			
Pools >4 ft Deep (%)		.626			
Bifurcation Ratio		.534			
MBW to W Ratio			.741		
Valley Segment Slope (%)			.732		
Reach Valley Slope (%)			.688		
Bankfull Slope (ft/ft)			.666		
Ratio of Max Min Reach TW Depths			.642		.631
W/D Ratio			-.637		
Percent C-Soil			.605		
Width Ratio of Bank Height to Bankfull					
Percent Canopy Closure US DS				-.844	
Percent Canopy Closure				-.840	
Percent Substrate as SAV				.681	
Mean Rc/W Ratio				.657	
Percent Substrate as Emergent Veg				.599	
Pools 1-2 ft Deep (%)				-.539	
Tightest Bend Ratio					
Percent Substrate as Bare Sand					
Bankfull Area Max/Min Ratio					.743
Bankfull Mean Depth Max/Min Ratio					.722
Bankfull Width Max/Min Ratio					.692
Ratio of Mean Reach Pool and Riffle TW Depths			.513		.681

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BIOGRAPHICAL SKETCH

John Kiefer II was born in Allentown, Pennsylvania and was raised in south Jersey and north Florida. The oldest of three children, John was named for his paternal grandfather, whose appreciation for nature helped inspire his grandson's career path. John II was in the first-ever graduating class of Middleburg High School, Florida. He graduated from the University of Florida in 1989 with a B.S. in Environmental Engineering Sciences and in 1991 with an M.E. His thesis research focused on the biogeochemistry of nutrients and metals in mitigation wetlands at Florida phosphate mines, under the supervision of Tom Crisman, Joe Delfino, and Ronnie Best.

John started his career with a phosphate mining company in 1991 and quickly helped Agrico set precedent for the means to restore large headwater swamps and marshes destroyed by mining. Two years later he joined another mining company, CF Industries, and as Chief Environmental Engineer there led teams that planned and implemented an award-winning reclamation program over a nine year period. During 2002, he joined a consulting firm, BCI Engineers and Scientists in Lakeland, Florida where he serves as Principal Water Resources Engineer helping a variety of governmental and mining clients with planning, design, and permitting for the restoration of radically disturbed watersheds. John is a Professional Engineer registered in Florida and is a Certified Professional Wetland Scientist (Society of Wetland Scientists). Stream restoration is a major emphasis in his practice and this Dissertation topic was selected because he wanted better tools for restoring Florida streams.

John was blessed to marry his soul-mate, Sarah, in Seward, Alaska about 10 years ago. They enjoy nature travel and are continually amazed by earth's bounty. Their young son Nolan aspires to be a "paleo-geneticist" to revive dinosaurs.