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PENINSULAR FLORIDA STREAM SYSTEMS: GUIDANCE FOR THEIR CLASSIFICATION AND RESTORATION

FINAL REPORT

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FINAL REPORT

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PERSPECTIVE

There has been a great deal of public concern about the potential impacts of phosphate mining and whether or not the phosphate industry can reclaim streams to sufficiently restore their essential hydrological and ecological functions. The ability of phosphate companies to obtain permits and mine even ephemeral headwater streams in the future may well depend on their ability to restore low order (headwater) streams following mining.

One approach to stream restoration on mined lands has been to construct a flood plain whose dimensions are based on a 25-year, 24-hour storm event, followed by allowing the stream to gradually cut its own meandering low-flow channel. One example of a stream established by this approach, and now deemed by FDEP and others to be successfully restored, required nearly two decades and additional effort (such as strategic placement of woody debris) to achieve satisfactory sinuosity, vegetative cover, bank stability, and biological richness. Self-organization of channel dimensions can take longer than is acceptable to reach stability or dynamic equilibrium. This suggests that many aspects of the desired stream morphology should be directly constructed rather than allowed to form passively. And, in fact, FDEP now requires greater specificity in stream channel design and construction.

The aim of this project was to provide much-needed information to enable designers to rapidly and accurately fit equilibrium channels to reclaimed basins and to thus provide a basis for improving the ability to restore headwater stream morphology and functions. The initial project emphasis was on restoring headwater streams on reclaimed mined lands, but the information and guidance provided also apply to stream restoration on non-mined lands.

The project goals were to:

- Determine and quantify the functional and morphological attributes of relatively undisturbed low-order (headwater) streams in the phosphate region(s).
- Determine relationships between environmental variables and stream form and functions.
- Incorporate functional relationships into design guidance for new streams on reclaimed phosphate lands.

Work on the first goal was expanded to develop a classification scheme for streams in peninsular Florida. Detailed study of 56 selected stream sites (which included a wide range of gradients in watershed size, soil drainage and valley slopes) provided the hydrological, biological, and geomorphological data needed for achieving the second and third goals. The report also includes brief descriptions of (1) mechanical construction of a valley and channel and (2) an example of enhanced hydraulic carving of a stream channel.

Steven G. Richardson
Reclamation Research Director

ABSTRACT

This project was performed to improve understanding of key physical and ecological attributes of natural streams in peninsular Florida in order to derive a practical process-based classification system; and also to provide design aids to assist with stream restoration in rural settings. Fifty-six of the best remaining stream systems in the peninsula were selected for monitoring of more than 120 quantitative variables known to associate with key stream system processes. The sites covered a wide range of physical gradients including soil drainage condition, drainage area, and valley slope, and were observed at watershed, valley, channel and patch scales. Hierarchical cluster analyses were conducted on the full dataset and various subsets to derive the classification groups. Variables were winnowed to a small group explaining the vast majority of stream variability using principal components analysis. The classification system defines streams based on their hydrobiogeomorphology (HBG) and is hierarchical in scale; first categorizing an area within three watershed soil drainage conditions, then based on valley slope, and finally on channel and floodplain surfaces and their dimensions. Regional curve regressions were developed for use in natural channel design. Practical applications of the system for restoration design and construction are presented.

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Dedicated to the living memory of Jessica Taft, a stream team original and beautiful person who loved Florida and its waterways.

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EXECUTIVE SUMMARY

PROJECT PURPOSE

Peninsular Florida, covering roughly an area ranging from the Santa Fe River to Lake Okeechobee, presents a unique combination of physical and climatic conditions versus those of the northern temperate regions from which most existing stream classification and restoration approaches have been developed. Those differences include low-relief and proximity to sea level, karst bedrock variably mantled by clay and sand, huge pulses of wind and water from cyclonic storms, distinct annual wet and dry seasons, fire as a major ecological process, and mild to hot temperatures with a nearly perennial growing season. In many respects, the peninsula has more in common with tropical savannas than with the neighboring continental land masses of Georgia and Alabama.

Despite a lack of mountainous or piedmont terrain, these factors have culminated in a surprisingly rich array of fluvial forms, some of which are unique to North America and may be globally unique. While most of the major rivers in the state have been well-studied, the lack of knowledge concerning Florida's smaller stream systems is a critical gap to fill. These are the most-common streams, in the most direct contact with the landscape. Further, they are heavily altered and stressed by human activities across the peninsula. We found that about 75% have been ditched, diverted, or otherwise damaged by land use changes altering runoff and water quality characteristics. The need for their protection and restoration is tangible and pressing.

This study set out to describe the natural kinds of small stream systems on the peninsula; gain understanding of their key processes and functional thresholds; and provide conceptual and quantitative restoration design guidance aimed at improving outcomes for Florida streams. In essence, this project provides an original, process-based classification system for peninsular Florida streams and a much-needed basis for how to restore and protect them.

These recommendations are the product of more than six years of research and development. Various key concepts derived during the early to mid-stages of research were assessed and refined in some real-world pilot projects including;

- Designing and constructing stream creation projects at phosphate mines.
- Establishing aspects of minimum flows and levels to prevent significant harm to natural streams and rivers.
- Developing and interpreting aquatic fauna and water quality studies.
- Protection of rare streams from adverse impacts.

CONCEPTUAL MODEL AND METHOD

The first of the guiding concepts is that stream channels, and their biological communities, are very much products of their drainage area and valley condition. The drainage area is the source of water, sediment, and solutes to the valley; the valley modifies the force of the water and also affects the other materials delivered to the channel; and the stream channel routinely carries and further regulates the flow of water and materials in a manner sustaining land surfaces and habitats unique to fluvial systems.

This means that processes operating at the drainage basin, valley, and stream channel (reach) scales need to be understood. Ideally, a stream classification system should not merely measure key variables in the stream channel itself, but should include measurements of watershed and valley characteristics. In other words, the categorization is not just a "stream channel" classification, but is a "stream system" typology. Stream systems are thus defined based on process-form associations occurring at multiple scales.

The second guiding concept is that streams are physically and biologically complex ecosystems that cannot be assessed effectively from the perspectives of a single discipline. Therefore, the classification relies on variables in hydrology, biology, and geomorphology and is thus referred to as hydrobiogeomorphic (HBG) in its approach.

A suite of 56 sites covering wide gradients in watershed size, soil drainage, and valley slopes were selected. Only sites unlikely to be significantly harmed by human activity were included. Perhaps not surprisingly, the vast majority of the sites occurred in state parks, national forests, and conservation easements. Almost nothing in Florida is truly pristine, but the selected streams represent a sampling of the best remaining systems.

We measured or derived data for more than 120 quantitative variables known to associate with important stream functions in hydrology, water quality and biology and that affect the spatial distribution and dimension of the physical habitat of riparian corridors. These variables occurred at the multiple scales and from among the multiple disciplines discussed. We then sought to identify the variables that explained most of the variability in Florida stream characteristics to winnow them down to a more manageable set. This was accomplished using a battery of standard exploratory statistical procedures including principal components analysis, hierarchical cluster analysis, analysis of variance, and linear regression. The result was a classification system that, although complex in its derivation, is comparatively simple in its application. It mainly relies on knowledge of two watershed variables (size and percent cover of well-drained soils), one valley variable (longitudinal slope), and a handful of variables observed or measured at the channel and its adjacent floodplain.

STREAM SYSTEM TYPES

Fifteen basic riparian system types were identified, ranging from heavily shaded streams just a few feet wide that flow for less than half the year, to open systems more than 100 feet wide flowing perennially with copious amounts of crystal clear water. The 15 types were distributed among three landscape settings recognized by previous stream classification systems in Florida: (1) flatwoods, (2) highlands, and (3) karst. Flatwoods landscapes have poorly drained watersheds with high water tables during the wet season. Most of the water is delivered to the stream via shallow wetlands and thin organic and sandy soils near the land surface. This lack of natural reservoir capacity results in stream flow fluctuations largely mirroring the highly variable rainfall patterns. Water quality is typically affected by organic acids in the soils, resulting in highly colored discharge often referred to as “blackwater.”

Highlands landscapes have comparatively well-drained soils, allowing more of the rainfall to infiltrate into a thick, sandy surficial aquifer. Much of the flow reaches the stream via this groundwater pathway. The larger natural reservoir capacity of the sandy aquifer delays much of the water delivery to the stream channel, dampens the runoff response, and facilitates longer stream flow durations versus those of the flatwoods. During the wet season more of the water courses through lakes and wetlands before reaching the stream, setting up the possibility for seasonal differences in water color (highly colored discharge in the wet season, with clearer discharge during the dry season). The greater aquifer and lake storage of these landscapes tends to reduce the magnitude of routine overbank flood events, leading to comparatively smaller floodplains versus flatwoods streams. The watershed serves to dissipate energy in a way that results in gentler, longer, and steadier flow regimes.

Karst landscapes have the greatest natural reservoir capacity, existing in the form of vast subterranean limestone aquifers that discharge water under pressure to the stream channel. This results in the steadiest discharge regimes among the landscape settings, with greatly limited flood pulses. In fact, these karst streams, also referred to as spring runs, exhibit some of the most constant flow regimes in nature. Water tends to be colorless and hard, picking up dissolved calcium from the limestone but very little organic acids.

Thus the streams are first classified based on their watershed characteristics that affect water source, flow regimes, and water quality. These conditions effectively exist along a gradient of groundwater influence. Biological processes affecting stream channel dimension and habitat structure increase in importance with groundwater influence, while systems dominated by surfacewater runoff are more greatly controlled by physics. An important quantitative threshold was identified between flatwoods and highlands streams when more than 40% of the watershed is comprised of well-drained soils. Karst streams are identifiable based on water clarity and hardness, and most are inventoried with their springs mapped by state agencies.

The second major classifier occurs along a gradient of watershed size. This gradient differs among the three landscape settings. Once within a particular landscape setting though, the stream channel and floodplain dimensions increase in a predictable fashion with drainage area size. Larger streams are not merely scaled-up versions of their smaller kin, but tend to add or replace certain habitat types and geomorphic surfaces in the channel and floodplain. The classification system identifies where these transitions tend to occur along the watershed size gradient.

Valley slopes are negatively correlated with drainage area size. However, in some cases valley slope was separately associated with distinctly different stream types draining similar basin sizes, thus making it a third gradient along which important classifying thresholds were identified.

The 15 stream types certainly have some overlap in habitat characteristics, but overall present distinct assemblages of channel dimension, geomorphic surfaces, in-stream habitat, floodplain habitat, flow regime, water quality, fish taxa and/or other ecological factors that are greatly affected by thresholds along the gradients of groundwater influence, basin magnitude, and valley slope. Those three factors are most important because they control how the landscape alters the effects of seasonal rainfall on the stream flow regime, and in turn, its effects on the capacity of the system to conduct geomorphic work affecting the kinds of habitats present and their scale.

GUIDANCE FOR STREAM MANAGEMENT AND CREATION

This classification can be applied with knowledge of a few watershed and valley conditions to predict channel and floodplain conditions in systems where the stream segment has been largely obliterated or altered (e.g., ditched) and the floodplain cleared of its native cover. This is a powerful tool for establishing restoration goals in such highly disturbed settings where an on-site or nearby model or reference stream may be unavailable. The stream systems are also defined in such a way that they can be characterized based on a suite of field observations made directly at the channel reach. This enables meaningful design and outcome measures to be established.

The classification system is the beginning point of design because it helps to establish reasonable expectations for the riparian habitat types and dimension at any point along the drainage network. Once the riparian system type is known, then the project area can be discretized into an assemblage of particular physical (or geomorphic) surfaces associated with that kind of stream system, each of which can be properly patterned and dimensioned to fit the landscape conditions. These surfaces include a main open channel (the riverscape) with distinct banks and bed materials consisting largely of inorganic sediments moved by fluvial forces (alluvium). The alluvial bed materials and banks are organized by flowing water into vertically and horizontally meandering facets forming shoals, pools, bars, and bends. The floodplain (or floodscape) surfaces may or may not be of alluvial genesis. Examples of alluvial floodplain surfaces include natural levees (alluvial ridges) along the channel banks, shallow linear backswamps paralleling the riverscape with alluvial and organic layers, small looping side channels (chutes), partially filled abandoned channels (oxbows), among others. Collectively, the riverscape and floodscape surfaces form a riverine landscape, or riparian corridor, that functions as a whole system to process the water and other materials received.

Many of the surface dimensions are established, in part, using regressions specific to regional conditions, commonly referred to as “regional curves.” Developing regional curves for peninsular Florida was a major endeavor of this study. Because much of the wet-season discharge is far more routinely out of the main channel when compared to streams draining northern, temperate regions, we took the unique step of providing flood-channel regional curves in addition to the traditional bankfull-channel curves. This approach fits concepts for many streams of the seasonal tropics rather well.

The various biological communities and soil substrates occupying the geomorphic surfaces are described as part of the classification, and can thus be properly attributed in the design. The relative influence of biological versus alluvial controls on stream bank and bed material genesis varies among stream types, especially along rather significant gradients related to groundwater influence. Flatwoods landscapes create stream channels via comparatively powerful physical forces that are only resisted by bank vegetation once the channel margins are large enough to allow efficient passage of the normal range of discharges delivered during the wet season. Conversely, many mid-sized and larger spring runs have banks that are built via biological processes as living, moss-covered root mats that mantle the underlying sands and extend out into the channel. Such biological banks are made possible by the steady flow conditions in karst settings. In addition to that example, other forms of biogenesis occur in highlands and karst streams affecting their bed material composition and pool structure. One rather unique stream type, referred to as a highlands root-step channel, has living root-weirs crossing the stream which are only possible under gentle groundwater flow regimes with a comparative lack of powerful runoff pulses. These channels occur in some of Florida’s steepest valleys, and consist of a stepped series of level pools alternating between small cascades a few inches to a couple of feet high.

The design guidance is organized into watershed, valley, riverscape and floodscape components. Also, yet another distinguishing characteristic of peninsular Florida stream networks is that they are often punctuated by in-line wetland and lake depressions lacking a well-defined channel, a condition referred to as a deranged network. Eleven natural connections between in-line waterbodies and stream channels were subject to detailed survey and description to provide designers a library of reaches to draw from when conceiving such transitions. This is especially important at locations where the waterbody overflows into the stream because the geomorphology of the transition offers significant control on the waterbody’s wet season water levels. Further, zones of confidence were determined where drainage area and valley-slope associations create sufficient stream power to carve and maintain an open channel. These zones, plus the transition surveys, offer important information helpful in determining where the stream ends and the in-line wetland begins along a valley, which is a matter of some regulatory and design importance.

Certain valley conditions are not generated by modern fluvial forces but can greatly affect stream system function. Examples include the amount of lateral confinement (how close the channel bends get to the valley hillslopes) or the depth and width of in-line depressions. These valley characteristics can be conceived as embodying different functional process zones (FPZ), each with their own physical and biological characteristics. For example, small flatwoods channels often connect non-alluvial in-line marshes along the valley, therefore forming wetland and stream complexes referred to as a chain-of-wetlands FPZ.

Further variations largely unrelated to fluvial forces (such as the depth to the groundwater table, the fire-frequency of the surrounding uplands, or even the timing of the last hurricane) can greatly affect riparian vegetation composition. When non-alluvial factors like valley confinement, water table depths, and fire frequency are considered, a classification matrix perhaps approaching a hundred stream types would be warranted. It was therefore deemed more beneficial to introduce the FPZ concept as a way to add non-alluvial factors as modifiers to a more basic classification oriented around a core of stream types characterized by their fluvial attributes. A variety of valley-oriented FPZs are described, as are the many variations of vegetation communities encountered for each stream type surveyed. This information should enhance thinking concerning project purpose and ways to achieve it.

The recommended design approach is generally limited to situations where bankfull and flood flows, sediment delivery, and valley form are within the range of nature. It is highly applicable in most rural areas and at phosphate mines because sufficient thresholds of watershed restoration are logistically and economically feasible at such settings. However, it is largely inapplicable to long-standing urban basins where appropriate thresholds of watershed restoration are not typically achievable in a cost-effective manner, critical surfaces are often covered by pavement or important infrastructure, and most of the stream channel elevations have been permanently lowered due to excessive erosion and reduced sediment yields. The approach does provide some useful clues regarding what kinds of stormwater management systems would be necessary for planned future develop to protect intact stream systems, though. For example, low-impact development (LID) approaches emphasizing groundwater infiltration would be rather essential to maintain the future integrity of streams in highlands settings.

IMPLEMENTATION, TESTING, MONITORING

Three new streams were constructed at phosphate mines pilot-testing the recommended design approach and regional curves. Each was constructed in a different way, deploying mechanical and hydraulic construction techniques. Mechanical construction entails the use of earthmoving equipment and hand-labor to build the stream channel, while hydraulic construction recirculates flowing water and sediment slurries through the valley to carve and pattern the stream channel. In the “floodplain-first” style of mechanical construction, the valley is contoured to the floodplain elevation and the channel is then excavated and stabilized within it. In “channel-first” construction, the valley is graded below the floodplain elevation (subgraded), the channel banks are raised and stabilized to design grade first, and then the adjacent floodplain soil layers are backfilled along the channel to the desired elevations. All three methods have resulted in complex, stable channels systems. Each method has its comparative advantages and limitations. For example, the hydraulic carving projects also helped verify the utility of the zone-of-confidence diagrams developed for determining the presence or absence of a stream channel based on valley slope and drainage area associations. Streams carved where the valley slope was predicted to be steep enough and the erosion did not extend into parts of the valley where conditions indicated in-line wetlands would occur.

Soil bioengineering techniques using biodegradable textiles and native plants to stabilize newly created stream banks were successfully adapted to Florida conditions, specifically in a manner to create palmetto-lined banks. Standard natural channel design treatments often deployed in perennial streams using rocks and logs to induce in-stream habitat enhancements (with a wonderful array of names including cross-vanes, root wads, wing-deflectors, and j-hooks) were tested in all-wood applications at perennial and non-perennial Florida streams. Some of the deployments occurred as retrofits to enhance meander and pool structure at streams reclaimed using the previous generation of techniques, as well as at the three new streams described above. The oldest of these structures were placed almost 10 years ago, demonstrating good longevity to date. The vast majority of them have functioned as intended, creating and sustaining the desired local habitat amendments.

Several additional studies were conducted to pilot the application of aspects of the proposed system and to refine it. The most comprehensive was a statewide study commissioned by the Florida Department of Environmental Protection (FDEP) to explore how different stream types might affect sensitivity to nutrient enrichment. AMEC staff applied the classification system to a wide array of streams at or near the classification boundaries within the drainage area/valley slope gradients for the peninsula. This enabled the classification boundary thresholds to be honed more tightly and provided a better sense of the variations that can occur in areas transitional between pairs of closely aligned HBG stream types. That same study also explored a basic extrapolation of the peninsular classification approach to other Florida regions. This helped to affirm what aspects of peninsular Florida streams are unique, placing them in a bigger inter-regional context, and it also helped to better define the northern limits of the peninsular region.

Furthermore, the FDEP study included an assessment of numerous long-term hydrology records. Notable differences in flow duration and the frequency of 90-, 180-, and 360-day continuous flow spells occurred among the peninsular flatwoods HBG stream types. This provided additional reinforcement concerning the merits of the classification breaks, which were originally developed independently of such data.

Aspects of the regional curves and knowledge of floodplain surfaces garnered from this study have been applied to several minimum flow and levels assessments commissioned by water management districts. These were mostly systems at or above the upper range of stream sizes originally studied for this classification system and their study, plus the assessment of several large rivers for the aforementioned FDEP study, allowed us to determine that the upper limit of application for the classification system is about 500 square miles.

The Mosaic Company commissioned a fish study comparing the taxa among several streams distributed between two major HBG categories, finding significant differences. The size and life history requirements of the taxa differed in ways consistent with the differences in hydrology and channel dimensions underlying the HBG stream types. The previously discussed FDEP study also included a pilot project assessing differences in macroinvertebrates between four highlands and flatwoods streams, with the results also seeming to confirm faunal differences between HBG stream types. These findings are particularly instructive because faunal collections were not part of the original data used to derive the classification.

Thus, the original classification and design approach developed from the FIPR Institute funding was tested in a variety of ways, placed in regional context, and its basis and outcomes were slightly refined and expanded prior to issuance of this report. This report incorporates those improvements.

In keeping with the multi-disciplinary design approach, outcome measures are recommended for hydrology, water quality, riparian vegetation, aquatic macroinvertebrates, geomorphology, and fish. Not all of these should be measured every year, but could be assessed when the channel has stabilized after a number of years and again as the planted riparian trees produce a closed canopy some time later. Aspects of project stability and hydrology, however, should be checked annually until the project fully matures. This forms part of a recommended adaptive management approach where potential problems are detected early and can be remediated. Typically, repeated observations of channel width and depth are made at fixed cross-section locations, and bends are inventoried along the entire restoration segment, as are the large woody debris structures. Because channel boundaries are not fixed in nature (bends migrate, shoals move, wood decays), tolerances are recommended before contemplating remedial action.

FUTURE RESEARCH

HBG classification approaches should be applied to the non-peninsular (continental) land masses of the state. The nutrient-sensitivity typology investigations conducted for FDEP in those areas indicated a need for separate HBG categories to be fully developed for northwest and northeast Florida streams because those areas have regionally unique stream types. Each region generally supported streams differing in their combinations of surfaces and dimensions in association with drainage area and soil type. The FDEP study did not elicit the entirety of stream types present in those regions. Fully developing HBG classifications in the northeast and northwest stream regions using the techniques applied to the peninsula would provide the state with a comprehensive and regionally consistent typology.

Preliminary faunal studies suggest value in testing the utility of the HBG classes as categorical variables for better understanding of aquatic taxa assemblages and their controls in Florida streams. Such information could form the basis for assessing biological integrity conditions not currently available for fish, and unavailable for the macroinvertebrates of non-perennial streams. Similar applications could be made regarding water quality issues, including nutrient regimes.

Low-order streams (small headwater streams and their downstream segments) are poorly represented in long-term hydrology gaging studies. These are the most common streams in the state, generally are the most susceptible to alteration, and are in the most extensive shoreline contact with the landscape. Most stream restoration projects will likely occur with these kinds of systems. This, coupled with the fact these systems can be used as sentinels most sensitive to climate change and land use alterations, indicates a compelling need to establish a basic suite of long-term records for these stream types. This study has gaged eight such systems for five years. Those records should be continued for at least another five years, preferably another 15, to develop very statistically robust daily discharge records. Similar records would ideally be developed in about two dozen more reference streams scattered across the peninsula to provide at least three sites for each of the stream types that are not well-represented in existing gage records.

ADVISORY NOTE

The following advisory note, quoted from the National Resource Conservation Services Stream Restoration Design chapter of the National Engineering Handbook (NRCS 2007b), applies to this document as well.

> Techniques and approaches contained in this manual are not all-inclusive, nor universally applicable. Designing stream restoration requires appropriate training and experience, especially to identify conditions where various approaches, tools, and techniques are most applicable, as well as their limitations for design.

The aim of this manual is simply to promote thought regarding the protection and restoration of Florida streams. Every project is unique, with its own potential risks and benefits, and even the authors would not use the information in this manual like some kind of rigorous prescription. There are quite a lot of resources to draw from here, but keep in mind that project success depends on explicit definition of project purpose, developing a sound conceptual model, engaging that concept with sufficient detail in design, constructing the plan with care, monitoring the right things, and constantly thinking about ways to improve the outcomes during the entire process.

CHAPTER 1
INTRODUCTION

PROJECT PURPOSE

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.

Designers of a prospective stream restoration plan in a highly disturbed landscape are often faced with the following concerns:

- What kind of stream should be proposed?
- What are the proper channel and floodplain dimensions and patterns?
- How should transitions between streams and other waterbodies be properly designed?
- What is the right amount and kinds of in-stream habitats to facilitate?
- Where should the riparian corridors be placed most beneficially in the landscape?

The availability of basic design information concerning the technology of stream construction to address such questions has greatly improved. Stream construction in rural watersheds has become an increasingly mature engineering discipline, based on a tremendous amount of stream restoration projects that have occurred during the last decade. For example, the science of natural channel construction technology has matured to the point where the Natural Resources Conservation Service (NRCS) issued *Part 654 of the National Engineering Handbook, "Stream Restoration Design,"* in 2007. However, these kinds of guidance documents are generic and are often based on physical and climatic conditions more applicable to areas outside of Florida than those within the peninsula. Our study builds on the general approaches to natural channel characterization and design, adapting them where appropriate and providing essential new information specific to rural Florida.

This is important because Florida's unique combination of humid subtropical climate, carbonate geology, sandy soils, and low relief have led to a surprisingly wide array of fluvial forms and associated stream types, some of which may be globally unique. Existing stream classification systems and design approaches related to the relief of valleys crossing mountains and piedmont to the coastal plain, and the size of their rocks on the stream bed are limited in their utility in peninsular Florida. For example, the vast majority of streams on the Florida peninsula classify as just two of the 48 Rosgen (1996) stream types. Any reasonably complete characterization of Florida streams would suggest that more than two kinds occur. Therefore this study set out to systematically determine the merits of classifying peninsular Florida streams based on metrics collected at multiple scales, including the reach, valley and watershed. The project developed a series of descriptive stream types based on their hydrology, habitats, dimension, and landscape associations.

Our approach to classification, dubbed "hydrobiogeomorphic," includes variables related to hydrologic processes, fluvial geomorphic process, and riparian and aquatic habitats. It is inherently process-based, relating watershed and valley characteristics to the expression of channel and floodplain habitats at the riparian reach. The hydrobiogeomorphic (HBG) approach is more complete, and inherently more process-based, than other schemes available which typically focus on only one of three categories of variables (hydrology, geomorphology, or ecology).

This research product, because it is focused on providing design guidance, also needed to be quantitative. Existing stream classification schemes in Florida focus either generically on stream channel shape using dimensionless ratios, or on qualitative associations of water quality with aquatic biota, rendering them less useful as design aids. Both schemes simply neglect scale. We contend scale is a major variable that should be directly incorporated in the derivation of categorical stream definitions. As discussed more extensively in Chapter 4, dimension was an essential component to stream classification and neglecting it lumps streams with very different energy regimes and geomorphic processes together.

For example, consider two streams with sandy beds, palmettos (*Serenoa repens*) along their banks, soft water with organic acids, and identical dimensionless channel shape ratios. They both classify as blackwater streams. Based on dimensionless ratios, they both are Rosgen E5 stream types. One is in the headwaters and the other is 50 miles downstream. The first is a mere 6 feet wide and 0.6 foot deep at bankfull stage. Its bankfull discharge is about 2 cubic feet per second. It flows intermittently. The other is 60 feet wide and 8 feet deep with bankfull discharge of 400 cubic feet per second. It flows perennially. The large stream could pass a pod of manatees and the other just a school of minnows. Despite being classified as the same kind of stream based on their water quality and on the shape of their channels, it should be clear that a variety of functional thresholds related to scale, including stream power and habitat structure, are likely to have been crossed. If you are still unconvinced, keep in mind that while one stream barely tops your hiking boots, the other would be impossible to stand in without getting swept away. The one that would carry you away also has many more and much larger alligators. Woe to the unwary stream scientist who neglects scale.

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 of scale and presence of particular combinations of geomorphic habitats. These habitats and their scale are driven by threshold associations in the fluvial forces and water sources that vary with the characteristics of the watersheds and valleys to which the streams belong. Thus HBG 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.

This approach lends itself directly to the main purpose of the study, which 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. The following questions drove the focus of our study, in terms of understanding the form and processes of peninsular Florida's stream systems and how best to design natural channels at phosphate mines and other disturbed rural landscapes:

- How should channels be dimensioned and patterned, in a manner fitting their watershed and valley characteristics?
- What types of streams occur and how are they distributed in the landscape as associates of watershed characteristics and valley form?
- What sediment and soil characteristics are associated with the riparian zone that should be emulated?
- What vegetation associations occur within the riparian corridor as associates of channel type, as well as valley and watershed characteristics?
- What types of in-stream habitats are associated with watershed, valley and channel characteristics and how are they distributed in the channel as a function of stream type?

Knowing these five things will enable designers to build streams that properly fit their landscape, will be more inherently self-sustaining and stable, and will provide good water quality and in-stream aquatic habitat. This research provides guidance assisting designers on how big to make channels, what to plant next to them, what kind of soil amendments are desirable on the bed and banks, and how to attribute aquatic habitat features in the channel and floodplain, among other factors.

This is important because land-use changes that commenced from prior to the 1940s through the 1970s have damaged or destroyed about 75 percent of the low-order streams in the rural areas of peninsular Florida. Often, this means that not very many examples worth mimicking occur on-site even at large land holdings such as a phosphate mine.

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, typically draining watersheds less than 500 square miles. Systems draining larger watersheds generally drain complex networks with multiple water sources that defy simple classification schemes and warrant detailed and independent treatment as unique cases.

This is a guidance document, not a prescription. Every system is unique and the practice of stream restoration requires diligent thought, proper interdisciplinary expertise, and usually benefits from an adaptive management approach. The authors are not responsible for your design. It is our intent to stimulate the thought of qualified design experts, not to shut it down.

GENERAL APPROACH

Conceptual Model

The conceptual model starts with a view of the stream as a system that belongs to its watershed and valley. The stream system is thus defined as a hierarchical association of habitat patches where conditions and processes in the large-scale patches structure those in the next lower scale. This general ecological concept is referred to as "habitat patch dynamics" and it applies well to stream systems (Ward 1989, Poole 2002, Ward and others 2002, Thorp and others 2008). For streams, the patches include the hydro-physiographic region (with similarity of climate and physiography), the watershed, the valley, different geomorphic reaches along the valley, and the individual habitats of the stream channel and floodplain within the reach. In other words, the watershed and valley variably deliver the water, solids, and solutes available from their hydro-physiographic region to the riparian corridor or reach. These materials are sorted within the reach into common fluvial geomorphic surfaces such as pools, riffles, alluvial ridges, chutes, oxbows, lakes, and depositional backswamps in very particular ways along and across the riparian corridor (stream channel and floodplain). Physical and biological interactions within the reach on such surfaces in turn structure the presence and distribution of habitat surfaces and biological communities such as large woody debris, leaf packs, deep pools, root masses, submerged aquatic vegetation, and various floodplain forest types, which in turn structure the wildlife communities of the corridor.

The dynamics between the patches varies with their scale. For example, the channel dimensions at the reach scale can change much faster than the geomorphology of the valley (e.g., years to decades in the former versus centuries to millennia in the latter). Without human intervention, watershed boundaries typically remain static for millennia or longer, while many habitat patches within a channel reach can change anywhere from daily to seasonally. Because the time lags are much greater in the large-scale delivery systems (regions, watersheds, valleys) versus those in the smaller-scale recipient areas (reach, habitat patches) a top-down construct emerges whereby the watershed and valley supply the independent variables and the reach and habitats can be treated as dependent variables. In other words, the geomorphic surfaces at the reach scale, and the repetitive habitat patches distributed on those surfaces within the reach, are viewed as dependent variables structured by processes. For these reasons, this study was structured to seek a logical classification system that explicitly incorporated a hierarchy of scale.

Also, most changes in fluvial systems typically occur in a non-linear fashion over time (Schumm 1977). Few changes in fluvial systems occur in an incremental fashion in response to incremental changes in force or material inputs. This is partly an effect of the different time lags among the hierarchy of patches, but it is also because resistance to change is common in fluvial systems, and change typically occurs only when certain thresholds in the forces or material balance are crossed. The classic generic example of the interaction of lags and thresholds is an avalanche. Snow incrementally accumulates on the mountain slope. It does not incrementally slide down the hill as it slightly builds. Instead, it sticks and must reach a critical mass before it overcomes its external frictional and internal cohesive forces holding it in place. Once it is crosses the release threshold, it abruptly plows over trees, carries soil, and thereby conducts a pulse of dramatic geomorphic work and associated restructuring of habitat patches. The avalanche analogy also provides another important concept regarding extrinsic forces and catalysts. The scenario painted above presumed that an intrinsic force (the mass of the snow) drove the system beyond a threshold. Sometimes the critical mass can be moved only with an additional extrinsic force, like the shock of a loud noise vibrating the snow mass. The effects of lags and thresholds are common in geomorphology, affecting the physical and biological characteristics of mountains, sea floors, and rivers. Because of these effects, a major line of investigation of this study was to identify any thresholds in watershed and valley variables associated with functionally significant differences in reach surfaces and communities.

We also noted that stream segments in peninsular Florida exhibit abrupt and repetitive changes along the valley, forming easily described functional process zones (FPZ) as styled by Thorp and others (2008). Understanding the natural distribution of the FPZs is important for restoration strategy because many of the ditching alterations along the valleys occurring in Florida have homogenized the functions of such zones, while land-use changes in the watershed have shifted the inputs to the FPZs altogether. As mentioned, another key component of the conceptual model recognizes that streams change in dimension and pattern along a gradient of fluvial forces. Larger force regimes are delivered by larger watersheds and can be focused even more by laterally confined and/or longitudinally steep valleys. Site selection was therefore structured to cover a wide array of watershed sizes and valley slopes. This enabled exploration of watershed and valley characteristics associated with potential thresholds in the expression of distinguishing habitats along the fluvial force gradient. The underlying hypothesis was that small streams are not simple scaled-down versions of their larger cousins, but that fundamental habitat differences could be identified along a gradient of watershed size and valley slope as surrogates for stream power. This combination of factors, coupled with the project objectives, led to the development of a quantitative stream classification approach incorporating a hierarchy of scale and based on a suite of interdisciplinary variables associated with stream function.

Thus the HBG classification system was envisioned, which embodies a synthesis of physical and biological factors known to greatly affect the structure and ecological function of natural streams. The key variables in this system are strongly associated with sources of water (and associated biogeochemistry), hydrologic regime, fluvial geomorphology and channel dimension, in-stream habitat substrates, and riparian corridor soils and vegetation. HBG classification combines aspects of physics-based and hydrobiological stream classification approaches. The system seeks to identify quantifiable threshold associations among watershed and valley characteristics with riparian corridor and in-stream habitat patches. These associations enable most streams to be classified from publicly available GIS data, and the streams can also be classified based on field observations.

The system is hierarchical, requiring streams to first be segregated based on broad differences in regional climate and geology (Level A), then by the dominant pathways water reaches the stream and the magnitude of the watershed (Level B), followed by aspects of the valley configuration (Level C), and finally by the dimension and habitats of the channel and floodplain corridor (Level D) (Figure 1.1).

Level A – Region

Following this geographic hierarchy, Florida was divided into three hydro-physiographic regions for stream classification purposes: the Northwest Florida Coastal Plain (NWFCP), the Northeast Florida Coastal Plain (NEFCP), and the Peninsular Florida Coastal Plain (PFCP) (Figure 1.2). A fourth region, the South Florida Coastal Plain (SFCP), consisting of the Everglades and areas fundamentally altered by canals south of Lake Okeechobee, was ignored because it does not contain a sufficient quantity of near-to-natural streams for study. The NWFCP generally comprises the Florida panhandle west of Tallahassee and extends into southern Alabama. The NEFCP generally lies north of the Suwannee River and east of Tallahassee, extending into southern Georgia, and the PFCP generally lies south of the Suwannee River to Lake Okeechobee. Regional boundaries were delineated based largely on studies describing regional differences in geology, climate, streamflow patterns, and fluvial geomorphology, and on numerous site visits conducted to streams across the state and extending into southern Georgia and Alabama. It should be noted that the hydro-physiographic boundaries act as guides, do not necessarily conform to watershed boundaries, and transitions are not nearly as abrupt as a line may suggest.

Each hydro-physiographic region represents a broadly classified population of streams belonging to watersheds with some consistency in their seasonal rainfall volumes, seasonal river flow, and sediment yields. Each region differs in how much soil drainage plays a role in stream channel and floodplain geomorphology, gradient of channel dimension (size) versus drainage area, flow duration versus drainage area, gradient of alluvial habitats versus drainage area, and natural kinds of streams (though there is some overlap in stream types). Regional distinctions in climate and physiography must be taken into account when assigning stream type, and determining which hydro-physiographic region a stream lies within is the first step in classifying Florida streams.

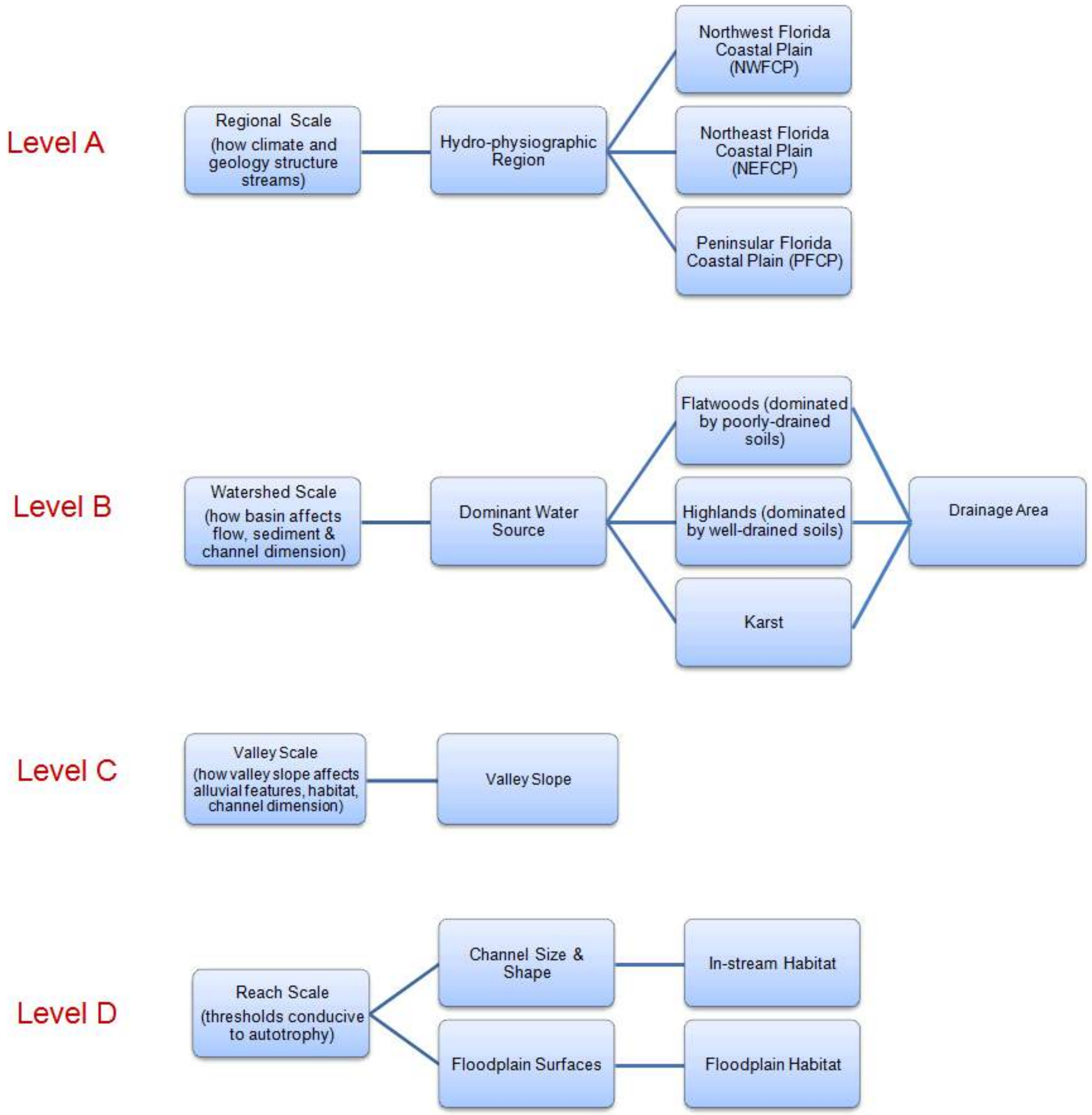


Figure 1.1. Basic Components of a Hierarchical Classification System.

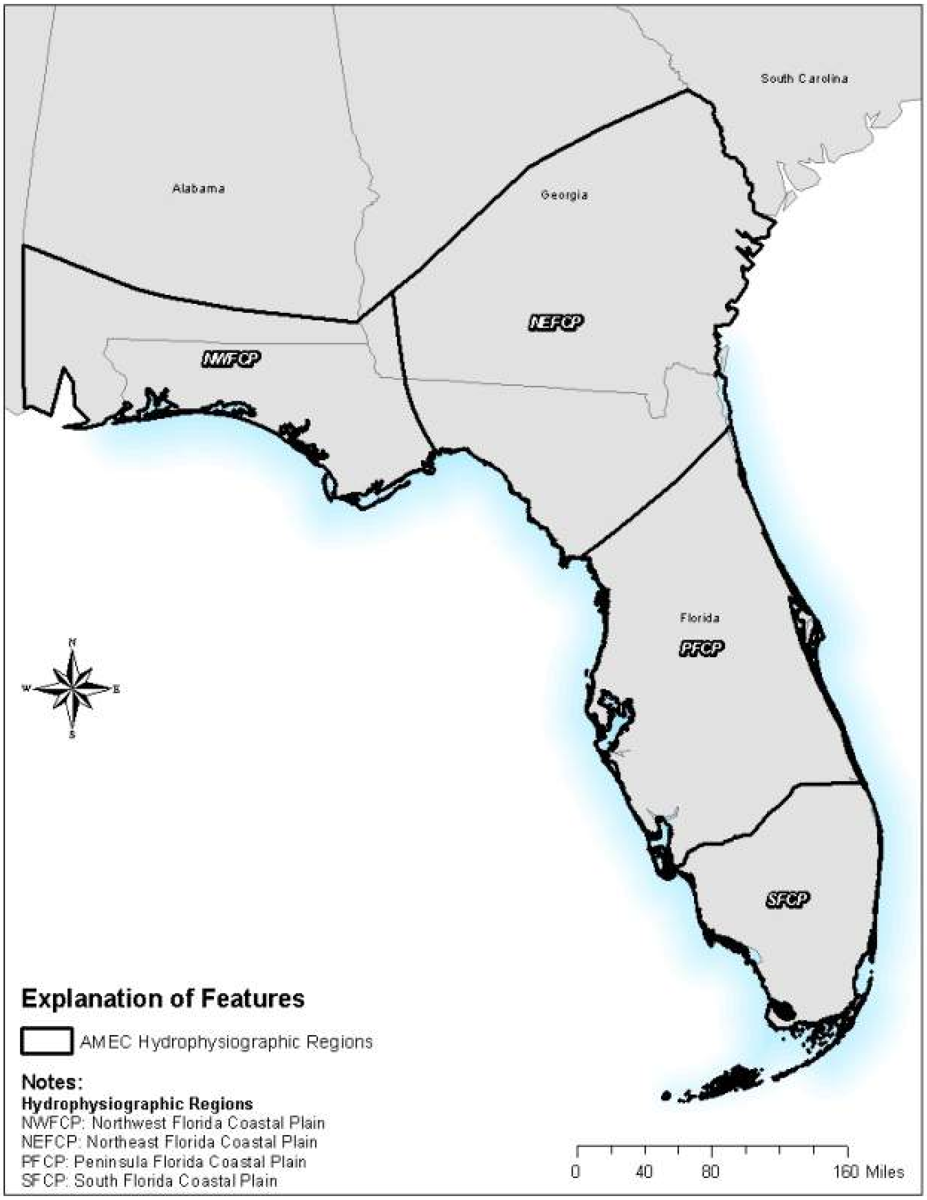


Figure 1.2. Florida Hydro-Physiographic Regions.

Level B – Watershed

Watersheds are the source of water to the stream valley. Their size, soils, and geology affect the volume, timing, and pathways of water reaching the valley floor, as well as the solute and sediment constituents and masses transported. Every stream type defined must fit its watershed conditions. Within a hydro-physiographic region, further definition of stream types with consideration of the size and drainage characteristics of the delivery system is required.

Level C – Valley

While streams belong to their watersheds, they are further defined by their valleys. Some valleys are extensively reworked by ongoing fluvial forces, but all valleys impose some control on riverine function based on characteristics that pre-date the modern climate and were developed under far different conditions. Each valley has such memory and some resist modern changes more than others. This variable resistance has led to the deranged drainage networks common on the peninsula.

Some valley hillslopes closely border and confine stream meanders, serving as comparatively effective lateral inputs of solutes and solids while simultaneously concentrating flow forces. Other valleys are so broad compared to the stream channel meander pattern that they intrinsically dissipate energy during high flow and buffer the stream channel from lateral solids and solutes inputs from the distant upland hillslopes during low flow.

Valleys change longitudinal slope along their profile, with portions of the valley floor being depressional, thus leading to a variety of inline wetlands and lakes which are joined together by sloped valleys supporting alluvial rivers. If such obvious changes in waterbody type can occur in association with valley form, it stands to reason that valley slope and confinement may be important variables contributing to different stream types and functions as well.

In fact, some stream classification systems are based predominantly on variables associated with valley form (Brierley and Fryirs 2005). Further, authors promoting a riverine ecosystem synthesis (Thorp and others 2008) offer a concept of functional process zones (FPZ) that vary along the valley and can repeatedly do so with abrupt physical and biological transitions between each zone. FPZs are typically defined by variables related in large part to valley shape, substrates, and position in the drainage network. It is clear that there is significant value added to incorporate valley variables in any stream classification attempting to relate process and form.

Level D – Reach

The reach is the smallest channel length that can be practically used to study repeating sequences of in-stream and floodplain habitat patches common to a larger valley segment. The major geomorphic surfaces are likely to be well represented in a valley length that is 20 to 30 bankfull channel widths long. So, if the open stream channel is 10 feet wide, the reach is 200 feet long. The reach is defined by its collection of alluvial and adjacent non-alluvial surfaces and includes their associated habitats and biological communities. In concept, the physiography, watershed, and valley provide top-down processes and materials that are expressed as habitat-measurable at the reach scale. Although there are some bottom-up feedback loops of great importance, the simplest conceptualization is that the condition of the reach is dependent on conditions dictated by variation of the larger-scale conditions. Taken to its extreme, some classification systems, such as that of Rosgen (1996), rely predominantly on geomorphic variables at the reach scale to classify stream systems with an assumption that reach-scale form predicts system function. Notwithstanding the massive shortcomings of such an approach, which neglects the importance of scale and the fact that form can converge in association with radically different erosion and biological processes, it is clear that streams cannot be reasonably defined as ecosystems without ample knowledge of the geomorphology and biology at the reach scale.

For these reasons, the conceptual model provides a hierarchical and multi-disciplinary approach that lends itself to the identification of a limited number of variables serving as effective surrogates for complex process-form associations structuring key stream functions and habitat characteristics. The collection and interpretation of data using this model was anticipated to facilitate:

- hindcasting of channel dimension and habitats where the system has been altered or obliterated by ditching with the knowledge of just a few watershed conditions,
- forecasting sustainable stream designs under certain changes to watershed conditions, or
- management of watersheds to protect intact or restored streams.

General Methodology

Stream systems are complex. Stream classification serves as a tool to simplify this complexity for pragmatic reasons, and most variable reductions are disciplinarily biased. For example, some systems are based mainly on channel shape (geomorphology), while some offer hydrology metrics as a master variable that controls all others. The problem with focusing only on channel shape is that different processes frequently lead to convergence of form, and the main problem with hydrology-based classifications is that most streams lack adequate gage records. Instead, this research sought to achieve data reduction, not by ignoring entire key scientific disciplines, but by retaining the disciplines and reducing the number of variables used to describe streams within each discipline to those that were most essential and practical to measure and to those that serve as good surrogates for processes and dynamics occurring among the various disciplines and hierarchy of scale.

The methodology basically was to garner as much information as feasible to describe stream systems across the disciplines of hydrology, geomorphology, and biology ranging across multiple scales, and recognized in the scientific literature as associates of stream function and processes. From an initial complexity of hundreds of variables, exploratory statistics designed for data reduction such as principal components analysis (PCA) and hierarchical cluster analysis (CA) were engaged to identify simpler associations that could be measured in a day but that represented the key aspects of form and function of Florida stream systems. The aim was to develop a quantitative classification system related to process that was practical to use as a restoration conceptualization and design aid. To that end, a classification system emerged that could be engaged using just a handful of variables.

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 subtropical 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: (1) copious and steady groundwater emitted through limestone springs under pressure, (2) unconfined lateral groundwater seepage through thick columns of sand through relict dunes, and (3) surface water runoff seasonally coursing through and over combinations of flat shallow organic and sandy soils. These watershed types correspond respectively to landscapes dominated by low-lying karst terrain, rolling xeric highlands, and the aptly named flatwoods. In essence, these landscapes fundamentally differ in how they capture rainfall and deliver some of it to the stream channel via groundwater discharge.

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 and others 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 kinds of water source landscapes differ in their ability to detain water in natural reservoirs (aquifers) that substantially impact the temporal variability of flow delivered to the stream. Therefore, despite the seasonality of rainfall, even some small streams can be perennial in the groundwater-dominated 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, subtropical streams.

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 excessive cattle grazing, ditching, evidence of recent 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 for these reasons. Fifty-six sites were included in the study (Figure 1.3), 18 of which were gaged with reliable long-term records (Figure 1.4). Almost all of the existing suitable gaged sites were from larger streams. To increase data in headwater streams, our team instrumented an additional eight sites with pressure transducers and developed stage-discharge rating curves for them.

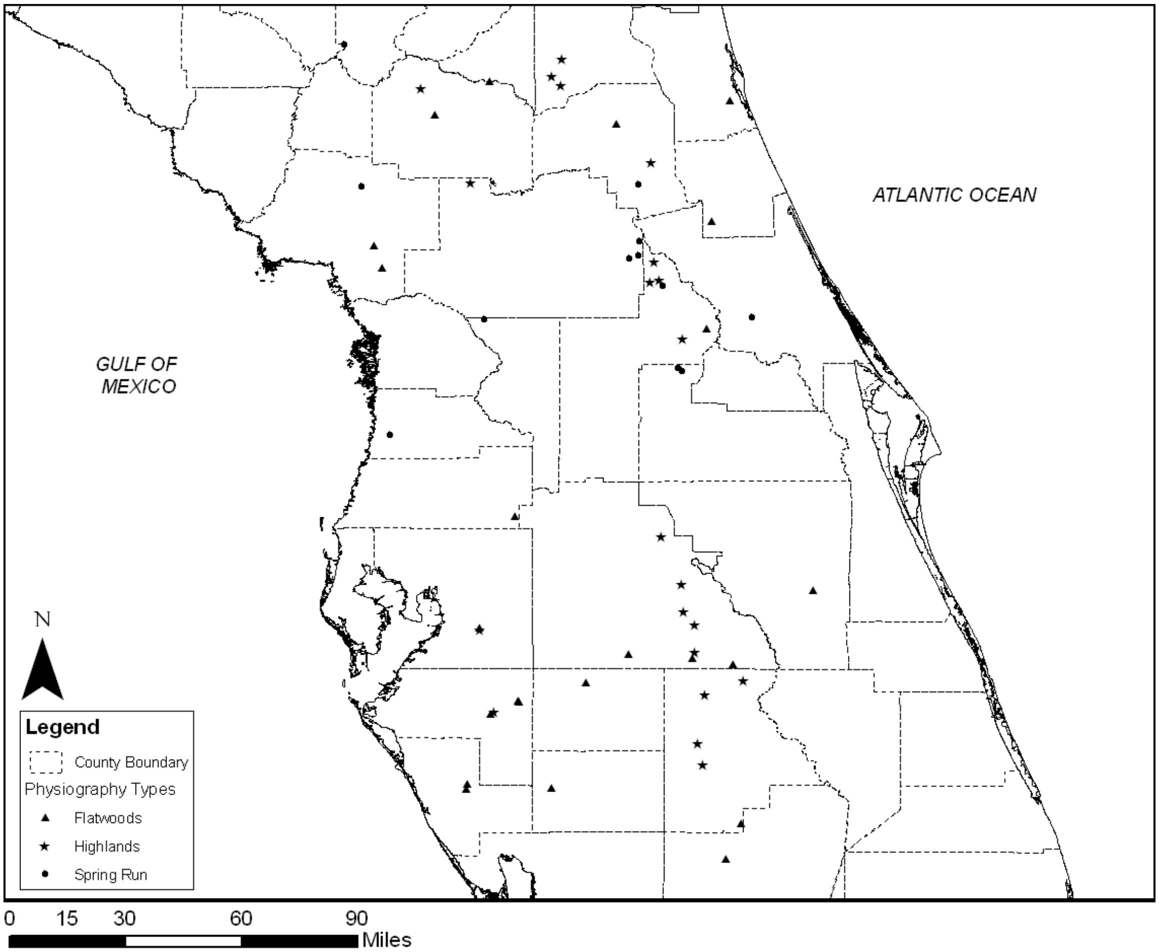


Figure 1.3. Study Sites.

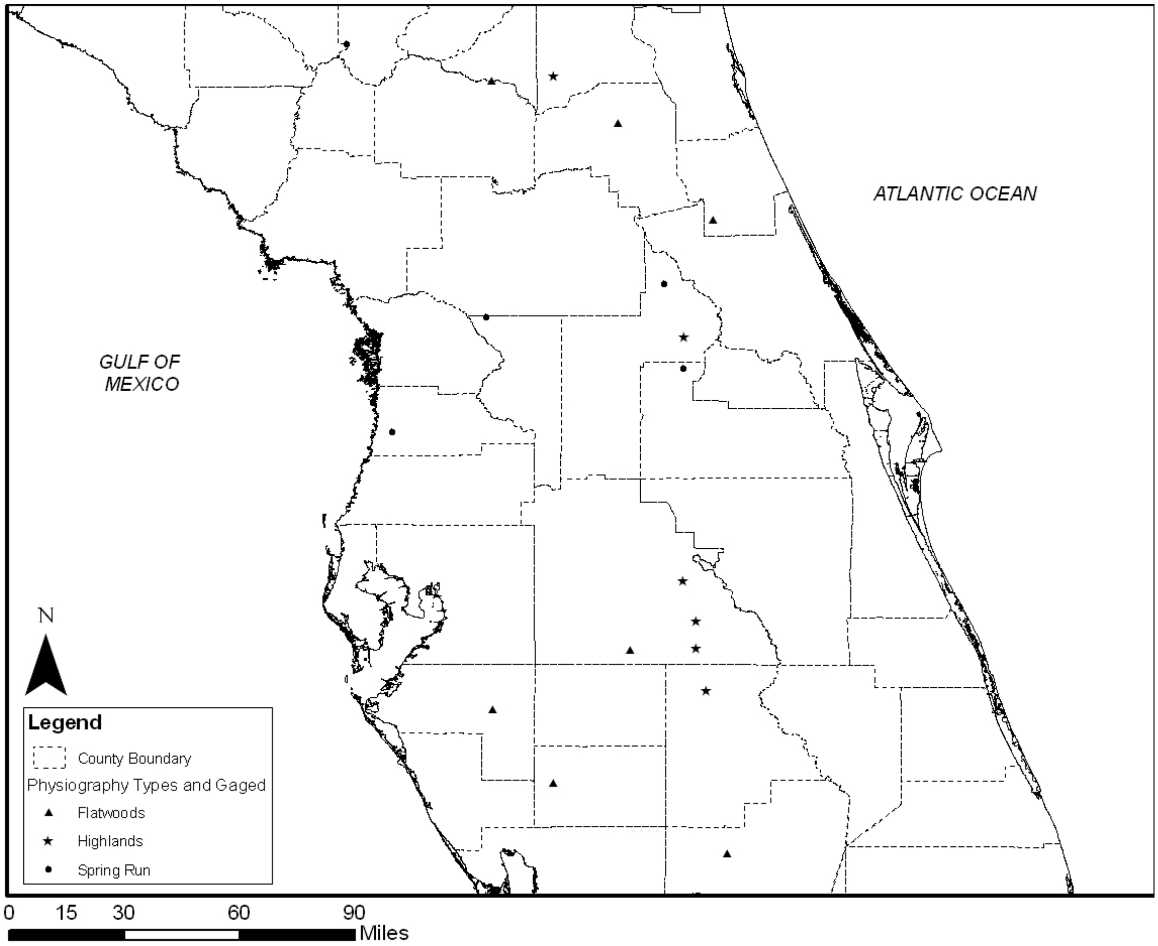


Figure 1.4. Gaged Study Sites.

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.
- 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 and others (1994). Cross-sectional, longitudinal, and in-stream habitat 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. Plan, longitudinal, and cross-section profiles were derived from the survey data.

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 homoscedasticity than others. Data screening started with looking for missing or misentered 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

The document takes the reader through a geographic progression of the results, following the hierarchy of scale in the conceptual model, with discussion and conclusions provided for each progression. Each chapter describes a distinctly different component of the landscape, and in doing so, lays a hierarchical foundation closer to the stream reach. Chapter 2 (Hydrology and Watershed Characteristics) focuses on the watershed scale, with particular emphasis on comparing the hydrologic differences between streams fed by two different aquifer types versus streams fed mostly by rainfall runoff.

Chapter 3 (Valleys and Their Riparian Corridors) focuses on the valley scale, with emphasis on describing the clinal and patchy patterns of Florida’s riparian corridor morphology and floodplain habitats within the drainage networks of different watershed types across the peninsula. It provides an overview of peninsular 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 and others 2008).

Chapter 4 (Natural Kinds of Stream Systems) describes the types of natural stream systems found on the peninsula. It also 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 provides an underlying process-orientation within the classification.

Chapter 5 [Natural Channels (Regional Curves)] presents the findings of a rather standard regression analysis in fluvial geomorphology that relates channel discharge and dimension to watershed size. These regressions are restricted in their application to a single hydro-physiographic region, and are therefore called regional curves. The standard curves of the peninsula developed for this study are compared to those previously developed for the adjacent continental hydro-physiographic regions. The unique aspects of the peninsula's climate and physiography require the presentation of curves that go beyond the "standard" construct and these useful additions and revisions are provided and discussed as well. Regional curves are often used directly as quantitative design aids to restore and fit channels to their watersheds. Chapter 5 thus represents a segue to the remainder of the report, which provides restoration design guidance.

The remaining chapters provide information on how to use the regional curves, the classification system, and some other information as restoration design tools. Stream restoration is still an evolving science, but the bulk of this guidance has been used in our own practice as stream conservation planners and restoration designers during the last several years. This work includes stream evaluation or design assignments for mining companies, water management districts, Florida environmental and wildlife agencies, county governments, and non-profit research and conservation organizations. Several stream creation and enhancement projects constructed under our supervision in recent years were conceived and designed using the methods embodied in this manual. Although the projects are only a few years old or younger, they have resulted in the desired dimension and habitat structure and are being rapidly colonized by appropriate aquatic fauna. Although we feel that the techniques are inherently well conceived based on our own experience, we cannot accept any responsibility at all for the outcome of designs we did not conduct. Your design will be yours, and you follow this guidance entirely at your own risk. By no means are the approaches described in this document offered as the only way to design, nor do we consider this manual to necessarily be everything a designer should know. Most necessary things come from academic preparation and applied experience. We wish to inspire thought in design, not dictate it. We hope this adds to your experience and that you find it helpful.

Chapter 6 (In-Line Waterbody Transitions) provides a basis for delineating the boundaries between alluvial stream channels and in-line wetlands. It presents a simple empirical mechanism for determining the likelihood of a valley segment to support an alluvial stream channel based on watershed size and longitudinal valley slope. It also presents a series of case studies and general conclusions regarding the geomorphology and vegetation of several fluvial to non-fluvial waterbody transitions in deranged networks.

Chapter 7 (Design Concept) provides the overall context and design philosophy underlying the recommendations. It lets the reader know where we are coming from, and establishes a basis for under what circumstances the design guidance is most applicable.

Chapter 8 (Landscape Level Design) summarizes how to use remote sensing data and other readily available digital information to determine if a valley and watershed either historically or currently supports an alluvial stream, and if so, what HBG type. It also touches on how watersheds should be assessed and managed to protect intact or restored stream corridors, including the use of continuous time-series hydrology modeling as a tool to help guide watershed management.

Chapter 9 (Reach Scale Design) focuses on geomorphic and habitat design at the reach scale. It shows how to pattern and dimension stream channels and floodplains consistent with the characteristics of their downhill influencers, the watershed and valley. The chapter presents the essential design variables in their plan view, longitudinal, and cross-section viewpoints within the corridor. It describes natural aggregations of alluvial surfaces appropriate for the development of sustainable FPZs by stream type. This chapter touches on some analytical design checks related to hydraulics and sediment transport as well.

The chapter discusses various habitat zones in the riparian corridor and how to select appropriate amendments and treatments to benefit wildlife for each stream type. It focuses on habitat distribution within the reach scale. Some Florida adaptations of national approaches to in-stream habitat and stabilization treatments using large woody debris and for soil bioengineering of the stream banks are presented.

Chapter 10 (Two Stream Creation Construction Techniques) highlights two construction methods used in stream creation pilot projects at phosphate mines. One technique follows standard mechanical construction of the channel and floodplain using heavy equipment and the other describes an innovative use of recirculating water through a contoured valley to hydraulically construct the stream channel. Although tested at mining properties, both techniques are suitable in some non-mining settings as well.

Chapter 11 (Monitoring and Adaptive Management) offers some preliminary advice on outcome measures aimed at guiding the management of a restored stream system as it matures and for determining when it has reached various stages of physical equilibrium and biological integrity. Rarely is a stream restoration project a “one and done” scenario whereby one can build it and walk away to let it mature on its own. Stewardship will typically include at least several years of monitoring and maintenance before the system will become inherently self-organizing. Powerful forces can be involved and even a well conceived project can become a multi-year exercise in guiding erosion and repairing what refused to be led.

CHAPTER 2
HYDROLOGY AND WATERSHED CHARACTERISTICS

INTRODUCTION

This chapter describes how Florida streams belong to their watersheds. The approach views watersheds as the water supply systems to the drainage network within the stream valleys. The basic watershed types include two kinds 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.

STUDY AREA

The hydro-physiographic region is the broadest level of HBG stream classification and takes into account how large-scale influences such as climate and geology structure streams. Compared to most of North America, Florida has a unique combination of seasonally wet and dry subtropical climate and a geologic history that involved Neogene marine processes on what is now the terrestrial landscape of the peninsula. But Florida is not geologically or climatically homogenous, and various research studies have found and described regional differences throughout Florida in geology, rainfall, streamflow patterns, fluvial geomorphology, and zoogeography. Based on these studies and on field verification visits to streams throughout the state, we divided Florida into three hydro-physiographic regions for stream classification purposes:

the Northwest Florida Coastal Plain (NWFCP), the Northeast Florida Coastal Plain (NEFCP), and the Peninsular Florida Coastal Plain (PFCP). Determining which hydro-physiographic region a stream lies within is the first step in classifying Florida streams, as regionalization affects stream flow in ways that alter associations between watershed size and channel dimension and their habitats. This section characterizes how the three hydro-physiographic boundaries differ based on information from existing studies. Such comparisons place conditions in this study's area, the PFCP, in context to the nearest continental landmasses.

Physiography

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. Most landforms characterizing Florida's modern topography, as well as the streams, lakes, springs, and wetlands dotting the state today, formed during the most recent period of geologic time, the Quaternary (1.8 million years ago to present) (Lane 1994). The Quaternary Period, which is made up of two geologic epochs (the Pleistocene or "Ice Age" and the Holocene), has been a time of worldwide glaciations and widely fluctuating sea levels, with seas alternately flooding and retreating from Florida's land area. At peak interglacial stages, sea level rose to approximately 150 feet above the present level, and peninsular Florida likely consisted only of islands (Lane 1994). As seas retreated, waves and currents eroded a series of relict, coast-parallel scarps and constructed sand ridges spanning the state. Many of these features are found today stranded many miles inland, including the Cody Scarp, Trail Ridge, Brooksville Ridge, and Lake Wales Ridge (Lane 1994). The development of Pleistocene landforms has also been influenced by the karst nature of Florida's foundation, as naturally acidic rain and groundwater have flowed through the limestone for millions of years dissolving conduits and caverns. Sometimes caverns collapse to create sinkholes, the largest of which can be seen today as lakes (Lane 1994).

The peninsula consists of a relatively thin veneer of reworked sand and clay of varying thicknesses over a thick mantle of porous limestone bedrock. Elevations of the dominant terraces range 25 to170 feet above sea level, with extremes ranging from sea level to 300 feet (Schmidt 1997). Sea-level changes have led to the formation of several relict 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.

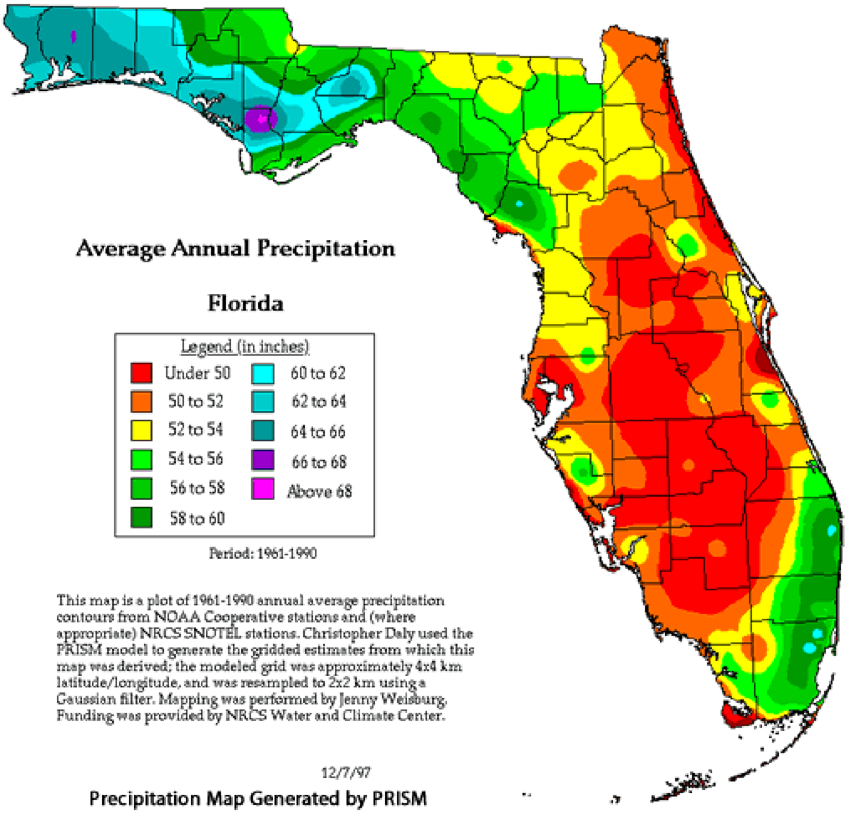
The dominant terraces of the NEFCP have elevations generally ranging from 70 to 170 feet mean sea level (MSL) and water tables are generally high (Schmidt 1997). Extremes vary from sea level to over 250 feet. Coarse sandy soils are dominant, but organic soils are also common around low-lying areas. Within this region, there is a lot of internal drainage in the form of lakes and sinks associated with karst terrain. As a result, the stream drainage network is not as extensive as in other regions.

The NWFCP has greater topographic relief than other areas of the state, with elevations of the largest terraces ranging from 70 to 320 feet above mean sea level (MSL) (Schmidt 1997). Soils here are coarser and drainage density is higher than in other parts of Florida. Major rivers draining the continental landmass dissect the panhandle on their journey to the Gulf of Mexico. The western portion of the panhandle contains the Sand and Gravel Aquifer. As a result, large washload continental rivers and gravel aquifer streams are unique to the NWFCP.

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, sediments, and solutes 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. Large river networks drain multiple geomorphic divisions, often crossing relict marine escarpments exposing geologic layers and valley slopes differing from those of the main surfaces of the watershed. Thus the drainage networks have strong potential to support different kinds of streams varying in their hydrology, hydraulics, and associated biota within a watershed and along the drainage network.

Climate

Although Florida is located at the same latitude as some of the world’s major deserts, it is one of the wettest states in the nation, with an average annual rainfall of 53 inches (Henry 1998). Rainfall throughout Florida varies considerably from place to place, season to season, and year to year (Figure 2.1). Across the state, rainfall varies in terms of the timing and annual volume of precipitation and in the magnitude of monthly potential evapotranspiration. Rainfall in the peninsular portion of the state averages 50 inches per year, with proportionately more summer precipitation as Florida’s peninsular shape, converging sea breezes of the Atlantic Ocean and the Gulf of Mexico, position relative to the Atlantic high pressure system, and tropical and subtropical location make it an ideal spawning ground for thunderstorms (Henry 1998). As a result, most of the peninsula exhibits a fairly pronounced wet and dry season pattern. 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 and others 1994). In the panhandle, precipitation averages 60 inches per year, with proportionately more winter precipitation from large-scale frontal systems than any other part of the state. Northeast Florida rainfall averages between 52 and 56 inches per year, which is more than the peninsula but less than the panhandle. Rainfall throughout the state also varies from year to year with cycles of drought, the occurrence of hurricanes that can yield 5 to 12 inches of rain, and the phenomena of El Niño and La Niña (Henry 1998).



This map is a plot of 1961-1990 annual average precipitation contours from NOAA Cooperative stations and (where appropriate) NRCS SNOTEL stations. Christopher Daly used the PRISM model to generate the gridded estimates from which this map was derived; the modeled grid was approximately 4x4 km latitude/longitude, and was resampled to 2x2 km using a Gaussian filter. Mapping was performed by Jenny Weisburg. Funding was provided by NRCS Water and Climate Center.

12/7/97

Precipitation Map Generated by PRISM

Figure 2.1. Florida's Annual Rainfall.

Nearly 70 percent of Florida's rain is returned to the atmosphere through evaporation and evapotranspiration. The remainder flows to its rivers and streams or seeps into the ground and recharges aquifers. Nearly all of Florida's groundwater originates from precipitation (Berndt and others 1998). Rainfall contributes to streamflow in Florida through several pathways, including overland flow, interflow, and baseflow (Mossa 1998). Rainfall-runoff values vary throughout the state, with the highest rainfall-runoff values in the panhandles (18 to 40 inches per year) and the lowest in the peninsula (less than 18 inches per year) (Gebert and others 1987). In other words, the additional 10 inches of rainfall in the panhandle results in a near doubling of the average annual stream flow versus the peninsula.

Further, as one moves down from the continent to the peninsula, the state becomes more tropical. In the southern portions of the peninsula, all months average over 64 degrees Fahrenheit, and there are distinct wet (June through September) and dry (winter) seasons. In the northern part of the state, some months have an average temperature less than 64 degrees Fahrenheit, and the dry season is not as pronounced (Henry 1998).

Watersheds of the PFCP receive about 50+ inches of rain per year, most of which is delivered during the summer and early fall. The PFCP has the highest potential evapotranspiration (ET) (41 to 49 inches per year) among the three regions. The distinct wet and dry seasons of the peninsula lead to the state's largest seasonal water deficits, which are most severe in April and May. That pattern is more akin to that of tropical savannas in Central and South America versus that of the more temperate parts of northern Florida (Nix 1983). The seasonal water stresses create the potential for a highly variable flow regime that is only ameliorated in areas where the dominant soil characteristics of the watershed consist of thick columns of unsaturated sands allowing for much infiltration, or in porous karst terrain. In comparison, streams of the NEFCP receive between 50 to 60 inches of rain per year, distributed more equitably throughout the year on a monthly basis. Potential evapotranspiration is less severe, and averages about 40 inches a year. Streams of the NWFCP receive much more rainfall (60+ inches of rain per year), most of which is distributed during the winter and spring. NWFCP potential evapotranspiration is also lower than that of the PFCP, at 39 to 41 inches per year (Henry and others 1994).

Streamflow Patterns

Seasonal river flow patterns have been found to differ throughout Florida as well. Kelly (2004) categorized rivers in Florida within two distinct geographic flow patterns based on median monthly flows and monthly rainfall totals at 122 USGS gage sites in Florida: the Southern River Pattern (SRP) and the Northern River Pattern (NRP). The SRP has an evident seasonal flow pattern "of higher flows that generally extend from July to October" (Kelly 2004). This pattern is predominated by a summer rainy season. The SRP is characteristic of all systems within the Southwest Florida Water Management District (SWFWMD), with the exception of systems dominated by spring influences. The South Florida and St. Johns River Water Management Districts (SFWMD and SJRWMD, respectively) also have a number of sites that exhibit this pattern, such as the Withlacoochee River and the St. Johns River (near Deland).

The NRP is characteristic of systems located in the northern and northwestern portions of the state. Peak flows for these systems "consistently occur in the spring, while lowest flows occur in the summer and fall" (Kelly 2004). Rivers that exhibit this type of flow pattern include the Apalachicola and Escambia Rivers. When comparing these two patterns graphically, it is apparent that they are "roughly 180 degrees out of phase" (Kelly 2004). When NRP rivers experience low flows, SRP rivers experience high flows.

A transitional flow pattern described by Kelly is the bimodal river pattern (BRP). These systems typically have a melding of the other two patterns, rather than an intermediate flow pattern between the two. The Santa Fe and St. Marys Rivers are examples of systems that exhibit this flow pattern. Most sites exhibiting this flow pattern exist in a "band that extends from the northeast corner of the state to the Big Bend area" (Kelly 2004) (Figure 2.2). These flow patterns correspond well to the rainfall differences among the three hydro-physiographic regions.

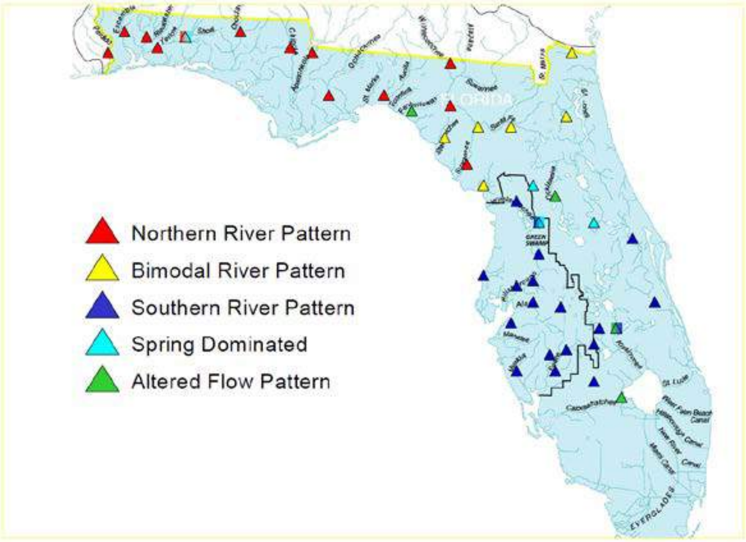


Figure 2.2. River Flow Pattern Regions (from Kelly 2004).

Ecology

The ecoregions of the state are more complex in their distribution versus climate and basic physiographic regions. For example, Griffith and others (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. 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 may 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.

FDEP has regionalized Florida based on benthic macroinvertebrates into five Stream Condition Index (SCI) bioregions: Panhandle, Big Bend, Northeast, Peninsula, and Everglades (Figure 2.3). The purpose of FDEP's regionalization efforts is "to serve as a spatial framework for the assessment and monitoring of ecosystems, ecoregions denote areas within which ecosystems (and the type, quality, and quantity of environmental resources) are generally similar (Omernik 1987).

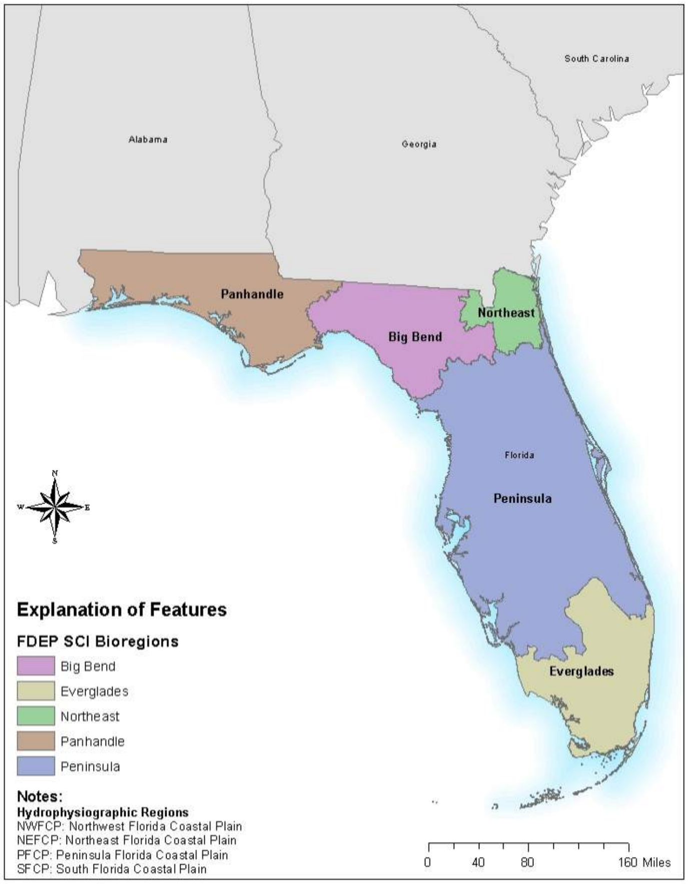


Figure 2.3. FDEP Stream Bioregions (from FDEP 2001a).

Initially, the state was separated into three bioregions (Panhandle, Peninsula, Northeast) based on macroinvertebrate data collected from 80 reference sites across the state in 1992 through 1994. Barbour and others (1996) stated that "regional biological differences in Florida are partly related to acid-base chemistry. Peninsular Florida is dominated by limestone bedrock with streams typically well buffered, whereas streams in the Panhandle are poorly buffered or acidic." Differences presented in macroinvertebrate assemblages between regions included higher values of crustaceans and mollusca in Peninsular Florida, which are not common in the Northeast region. Stoneflies and caddisflies were found to be less common in middle Peninsular Florida than other regions. Since the original regionalization, GIS capabilities have increased, thousands of new Stream Condition Index (SCI) samples have been collected, and the methodology improved. As of 2012, further data analysis was used to make boundary adjustments.

The most prominent change made was the separation of the original Panhandle ecoregion into the Panhandle West and Panhandle East (Big Bend) ecoregions (FDEP 2011a).

Three Hydro-Physiographic Regions for Stream Classification

A synthesis of the distribution of Florida's rainfall, ET, seasonal moisture deficits, seasonal river flow patterns, elevation, geology, and zoogeography suggests three main hydro-physiographic regions for stream classification purposes: the Northwest Florida Coastal Plain (NWFCP), the Northeast Florida Coastal Plain (NEFCP), and the Peninsular Florida Coastal Plain (PFCP) (Figure 2.4). The NWFCP generally comprises the Florida panhandle west of Tallahassee and extends into southern Alabama. The NEFCP generally lies north of the Suwannee River and east of Tallahassee, extending into southern Georgia, and the PFCP generally lies south of the Suwannee River to Lake Okeechobee. It should be noted that the hydro-physiographic boundaries act as guides, do not necessarily conform to watershed boundaries, and transitions may not be as abrupt as a line may suggest. Although the streams in each region typically exhibit fundamentally different flow regimes and fluvial geomorphic associations with their watersheds, it is important to recognize that gradients occur and that streams located within roughly 20 miles of the hydro-physiographic boundaries should be examined for characteristics common to, or intermediate between, the regions.

Each hydro-physiographic region represents a broadly classified population of streams belonging to watersheds with some consistency in their seasonal rainfall volumes, seasonal river flow, and sediment yields. Each region differs in how much soil drainage plays a role in stream channel and floodplain geomorphology, gradient of channel dimension (size) versus drainage area, flow duration versus drainage area, gradient of alluvial habitats versus drainage area, and natural kinds of streams (though there is some overlap in stream types) (AMEC 2013). These regional distinctions must be taken into account when assigning stream type, and determining which hydro-physiographic region a stream lies within is the first step in classifying Florida streams.

Based on these major differences in climate and physiography and stream flow, differences in fluvial geomorphology are expected. For example, Metcalf and others (2009) described differences in the bankfull channel dimension and hydraulics of northeastern and northwestern Florida watersheds. Subsequent to developing our HBG classification for the peninsula, AMEC (2013) conducted extensive groundtruthing of most of the Metcalf and others (2009) streams and numerous streams in the peninsula, and confirmed basic fluvial geomorphic differences between the streams among the three regions (Figure 2.5). This post-hoc investigation also served to confirm the HBG categories and refine their threshold associations with watershed variables. A statistical comparison of the bankfull channel characteristics of the three hydro-physiographic regions using the data of this study and that of Metcalf and others (2009) provided additional and robust confirmation of the concept and general location of the three regions for the purposes of stream classification and restoration design.

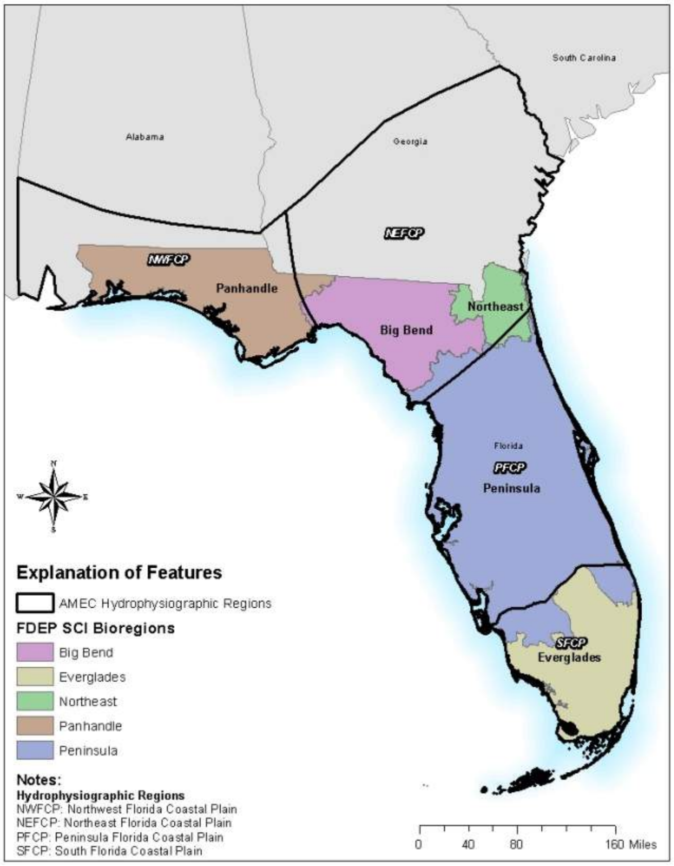


Figure 2.4. Florida Hydro-Physiographic and Stream Bioregions.

METHODS

The approach was to first examine the 18 perennial peninsular Florida streams included by comparing the hydropatterns and basin characteristics among streams draining three different kinds of water supply systems commonly found in the state. Subsequent to that analysis, a larger compilation of perennial and non-perennial stream discharge sites was made to assess associations between drainage area and flow regime for the two non-karst supply systems on the peninsula.

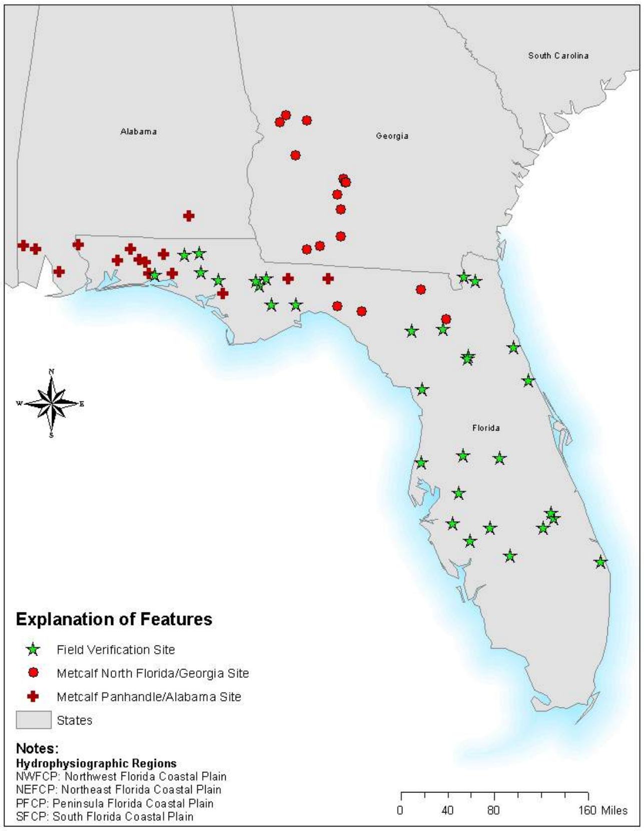


Figure 2.5. Field Verification Sites.

Data Availability and Site Selection

In addition to online 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 field 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.

To conduct a watershed size and flow regime assessment, the non-karst gage records from the perennial streams mentioned above were assessed along with additional peninsular gage records to include 52 streams from the USGS records, 20 sites from the Mosaic Company's consultant ECT, Inc., and eight small streams gaged specifically for this study since 2008 (Figure 2.6). This dataset was compiled to determine if watershed size provided some indication of cumulative multi-year flow duration and on the frequency of 90-, 180- and 360-day continuous flow spells. For this query, sites that were ditched or had greater than 25% of their basin impacted by urbanization, agricultural diversions, or mining were rejected.

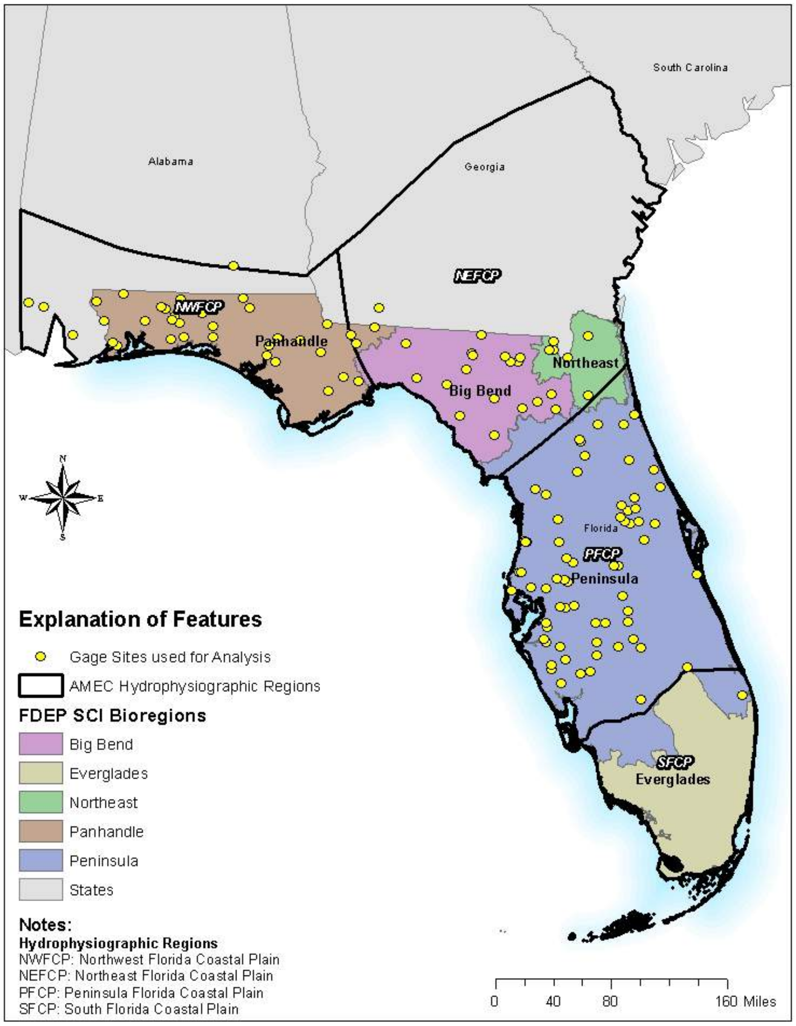


Figure 2.6. Gaged Sites Analyzed for Watershed Scale Effects on Flow Regime.

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 and others (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 and others (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 and others (2004) data for the northern part of the St. Johns 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 and others (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 and others (2002) study of the recharge areas of Lake County and the Ocala National Forest was used to estimate the springshed size for Mormon 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. Each of the 56 selected 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 topographic survey data alone could provide.

Bankfull discharges were calculated by relating field indicators at the surveyed reference reaches to the gage height data. 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.

Eight low-order streams were instrumented for this study (Lower Myakka UT 3, East Fork Manatee UT 1, Lower Myakka UT 2, Grasshopper Slough, Morgan Hole Creek, Cypress Slash UT, Tiger Creek UT, and Jack Creek). Each site was equipped with standard USGS gage plates and a Solinst Levelogger. The Solinst devices are closed-vent pressure transducers that record total pressure (atmospheric plus hydrostatic). Solinst Baraloggers were deployed within 20 miles of each stream gage to correct (subtract) the atmospheric pressure. All devices recorded pressure data on 15 minute intervals.

Discharge rating curves, relating water level (stage) to flow, were developed following the standard USGS velocity-area method using a Sontek acoustic-Doppler velocimeter to record the velocities and calculate the subsection areas and overall discharge for a range of water level and flow conditions at each site. The Sontek device provides automatic quality assurance checks during sampling. Stage-discharge curves were developed from the range of flows measured at each site, with a best-fit regression fit to each curve. In some cases, the relationship was parsed into ranges with different equations applied to each range where necessary to provide an accurate overall fit. These equations were then used to convert the 15-minute stage data from the atmospherically corrected pressure transducer records to flow data. The 15-minute flow data was averaged on 24-hour increments to provide a daily average flow record for each of these eight sites. The period of record ran from mid-2008 through late-2013 (nominally five years).

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 and others 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 and others 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 and others 2009, Warne and others 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 2007-2013 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 within 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.

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 dependent 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.

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.

Once that series of statistical analysis was completed, then the data from the larger body of gage records used to assess flow regime versus watershed size in non-karst streams was graphed into daily discharge hydrographs and flow duration curves for each site. Flow durations[1] were then plotted versus drainage area by hydro-physiographic region and by watershed type (flatwoods versus highlands). These graphs provide a visual basis by which to determine how flow regime relates to drainage area and soil characteristics in each region.

Flow regimes are probabilistic and flow duration is a cumulative summary statistic that can obscure potentially valuable information. For example, a 49% flow duration could represent 180 consecutive days of flow in a year, or 10 separate flow events averaging roughly 18 days each. Therefore, AMEC conducted spells analyses[2] on gaged streams to examine the probability that each site would support a 90-day, 180-day, and 360-day flow period per year. In other words, AMEC determined the number of years each site discharged either 90, 180, or 360 consecutive days for its period of record.

Spells analyses were conducted using the River Analysis Package (RAP) software. This program analyzes data based on calendar year; therefore, if a site is flowing between December and January, the flow event/spell is cut off on January 1. For some sites, this may lead to an underestimation of the actual number of flow events a site has. The percentage of years a site had at least one 90-, 180-, and 360-day flow event was then plotted versus drainage area by hydro-physiographic region and by watershed type. These graphs provide a visual basis by which to determine how flow regime relates to drainage area and soil characteristics in each region.

Bankfull and flood flow spells were calculated for the eight low-order sites gaged for this study manually because software packages such as RAP or GeoTools do not allow partial-year analysis, which would have resulted in more than 10% of the data being discarded. The bankfull events were defined as those with peak discharges occurring at least 7 days apart as a means to assure events were reasonably independent (as per the previously discussed "perennial stream" assessments). An additional criterion was added for these headwater streams, requiring an intervening flow recession dipping below bankfull stage between events. That latter characteristic assures that each bankfull event was rather wholly discrete. That approach makes most sense for systems with characteristically short bankfull exceedance spells lasting a matter of days, versus those of larger perennial rivers which can last for many weeks or months at a time.

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[1] Defined here as the percent of time a site's volumetric flow rate was above 0.05 cubic feet per second (cfs).

[2] Defined as a continuous period of flow within a calendar year. A spell was deemed over when 5 consecutive days of less than 0.05 cfs were encountered.

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. Therefore 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)[3]. This sum was calculated as the percentage of the total drainage area covered by those soil classes. 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. 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 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 difference of the unit discharge between the 15th and 85th flow percentiles represents an index of the routine interannual or seasonal flow differences for Florida waters. Additionally, when

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[3] NRCS did not map any B soils in the PFCP study area.

discharge is plotted against percent exceedance on a probability scale, the range between the 15% and 85% exceedances is linear and tends to become nonlinear beyond that.

This unit seasonal flow difference (SFD) was calculated for the 18 gaged sites and was plotted against the A+C soil index in their watersheds (Figure 2.7). 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% A+C soils and an SFD of 4 when raw data were plotted. Streams with SFD less than 4 and at least 40% A+C soils behaved mostly like groundwater-dominated systems with comparatively steady flow, while the inverse streams were increasingly surface-water-dominated and more seasonally flashy.

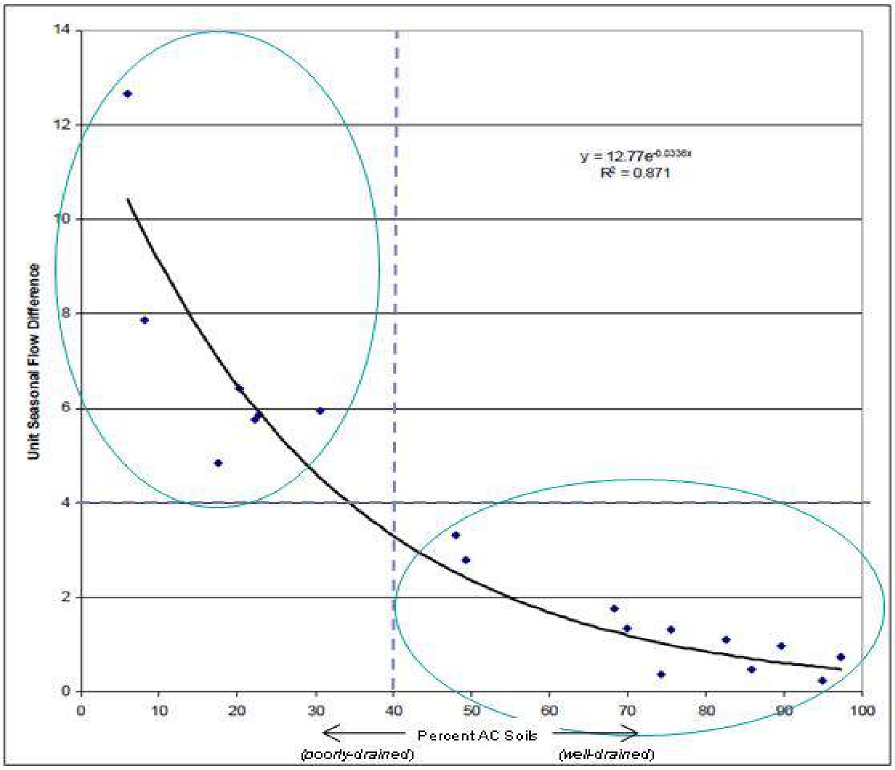


Figure 2.7. Seasonal Flow Variability Versus Soil Drainage (PFCP).

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 (Figure 2.8). Therefore, it appears that flatwoods, highlands, and karst basin types are useful distinctions along a natural gradient of groundwater influence.

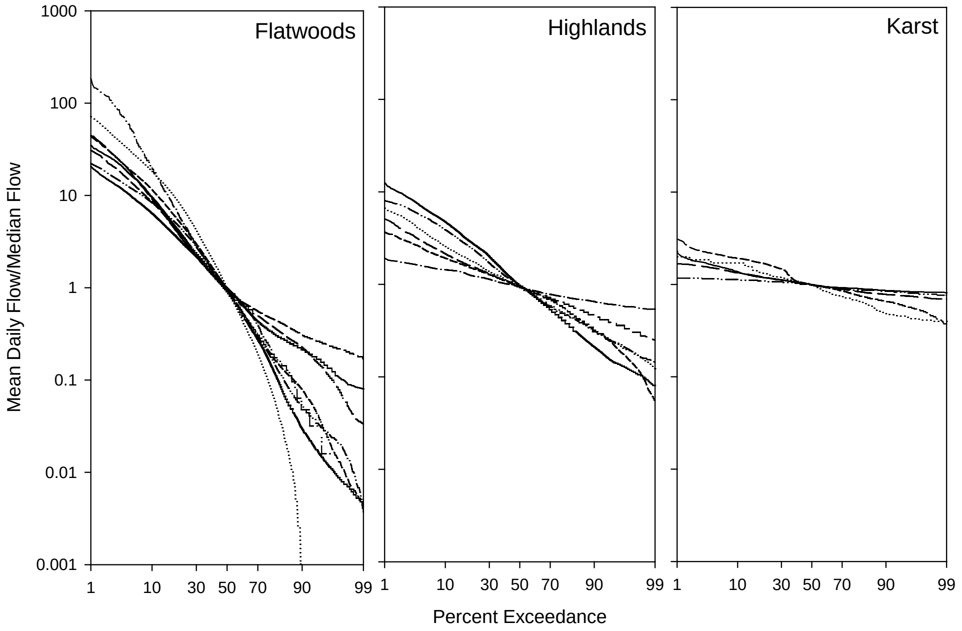


Figure 2.8. Flow Duration for Perennial Streams Draining Three Watershed Types.

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 and others 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 and others 2002, Junk and others 1989, Gupta 1995). Tockner and others (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?”

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 independent flow peaks.

Table 2.3. Discharge 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 and 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.

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 is discussed, followed by event hydraulics data from all 56 sites. As previously mentioned, seasonal flow difference (SFD) was calculated as an index of the overall change in magnitude 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. SFD 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. Rather than analyze the raw differences in unit seasonal discharge magnitude, the SFD can be indexed as a slope of the curve by simply dividing the difference in unit seasonal flows by 70 (the seasonal percentile range). Greater unit "seasonal flow slope" (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 2.9). 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.

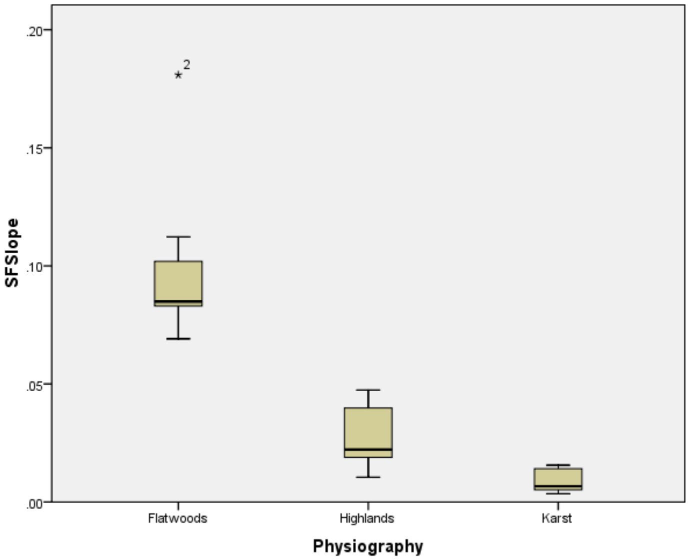


Figure 2.9. Seasonal Flow Variability Box Plots.

To put this into perspective, the total flow fluctuation for perennial flatwoods streams typically ranged across four or five orders of magnitude (Figure 2.8). 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. Spring runs fluctuated a lot less, typically within a single order of magnitude (Figure 2.8). 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 2.10). 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 2.11). 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 2.12). This implies that more alluvial work can typically be done in the wet season floodplain 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 2.13). 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 2.14). 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.

Table 2.4. Watershed and Discharge 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.

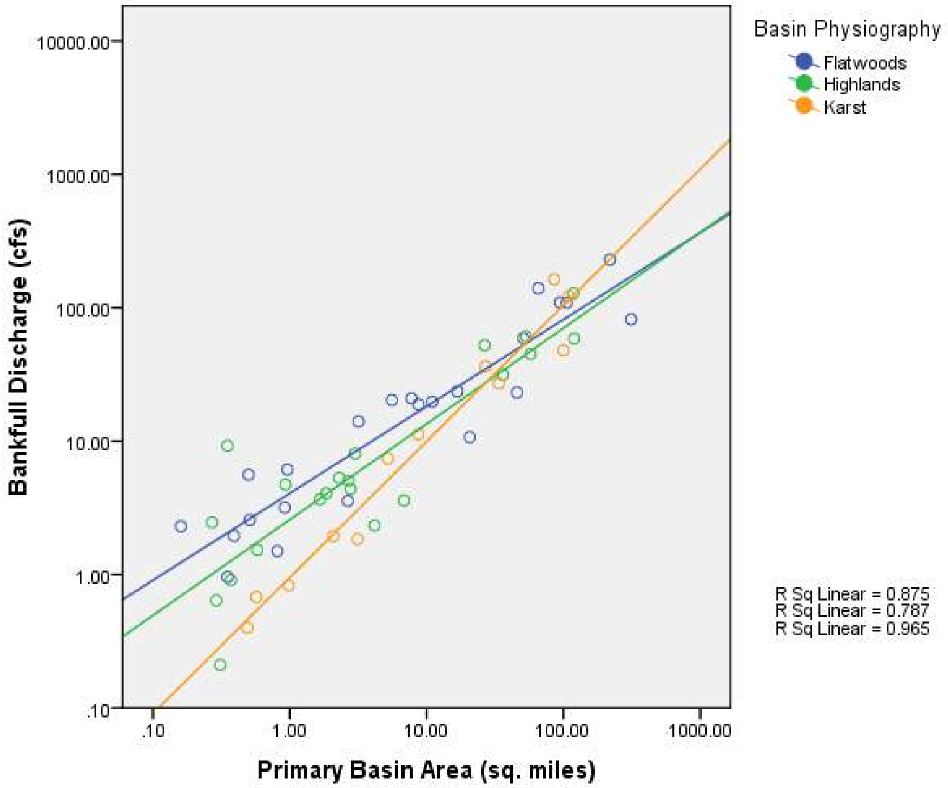


Figure 2.10. Bankfull Discharge Versus Basin Area for Three Watershed Types.

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).

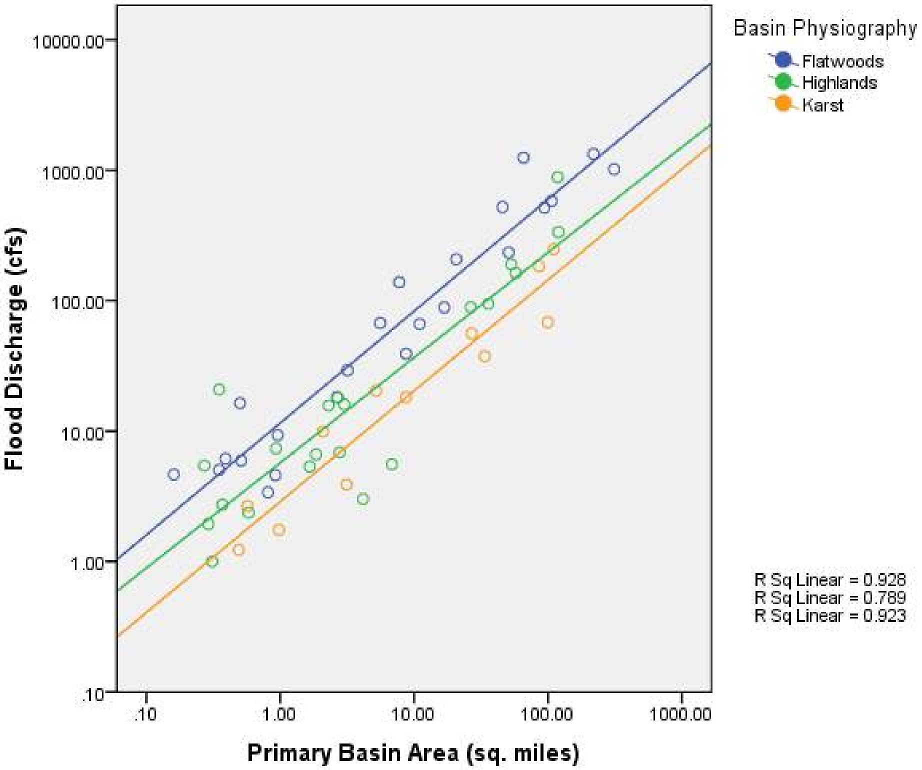


Figure 2.11. Flood Discharge Versus Basin Area for Three Watershed Types.

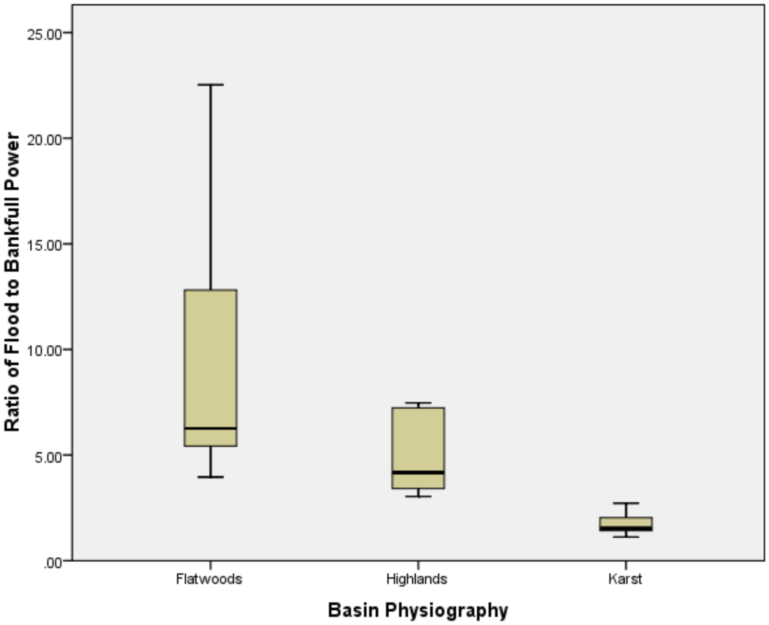


Figure 2.12. Flood/Bankfull Discharge Ratio Boxplots.

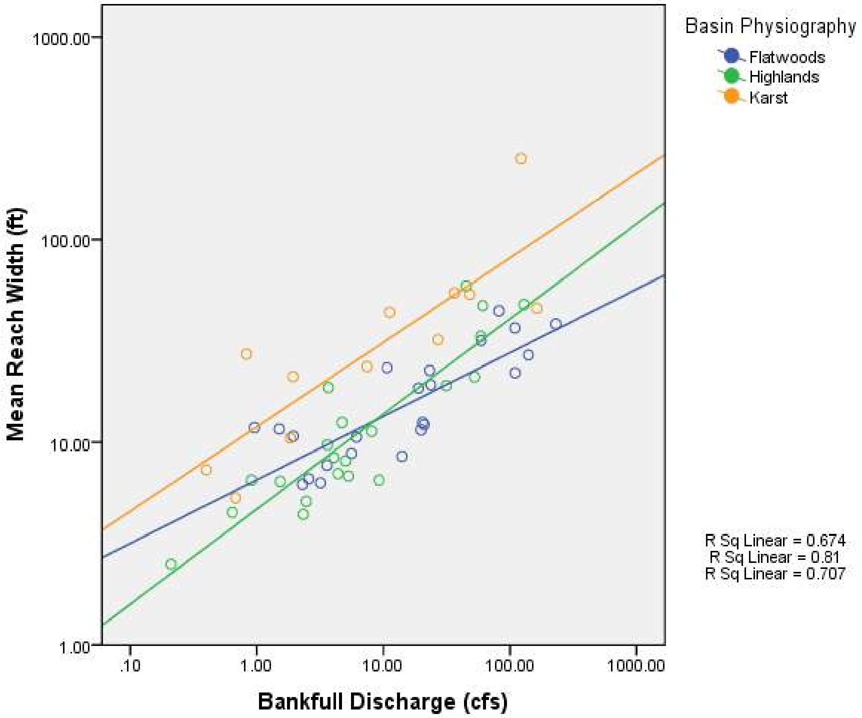


Figure 2.13. Channel Width Versus Bankfull Discharge for Three Watershed Types.

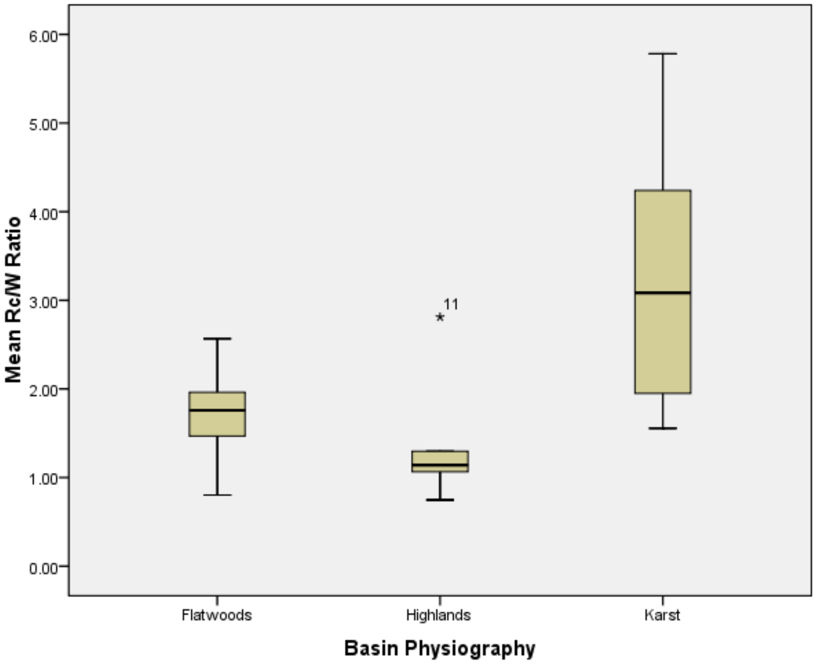


Figure 2.14. Radius of Curvature/Channel Width Ratio for Three Watershed Types.

Overall, statistically indistinguishable fractions of annual rainfall were captured as discharge to perennial 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 in karst systems for providing a specific level of work on the channel.

This 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 or as wide, and 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 and others 2008). The reason cited for this was that the valley flats of the runs were extensively reworked by alluviation during occasional flash-floods and that the smaller constant spring flows subsequently headcut through the newly deposited material as it was quickly revegetated 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 time scales. In Florida's spring runs, the water delivery and sediment production are seemingly in sync (both are rather constant through time) and this results in a comparatively broad channel shape.

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.

Groundwater Regimes and Biologically Mediated Channel Morphology

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 submerged aquatic vegetation (SAV) meadows on their bed (Figure 2.15). 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 2.16). 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 2.17).

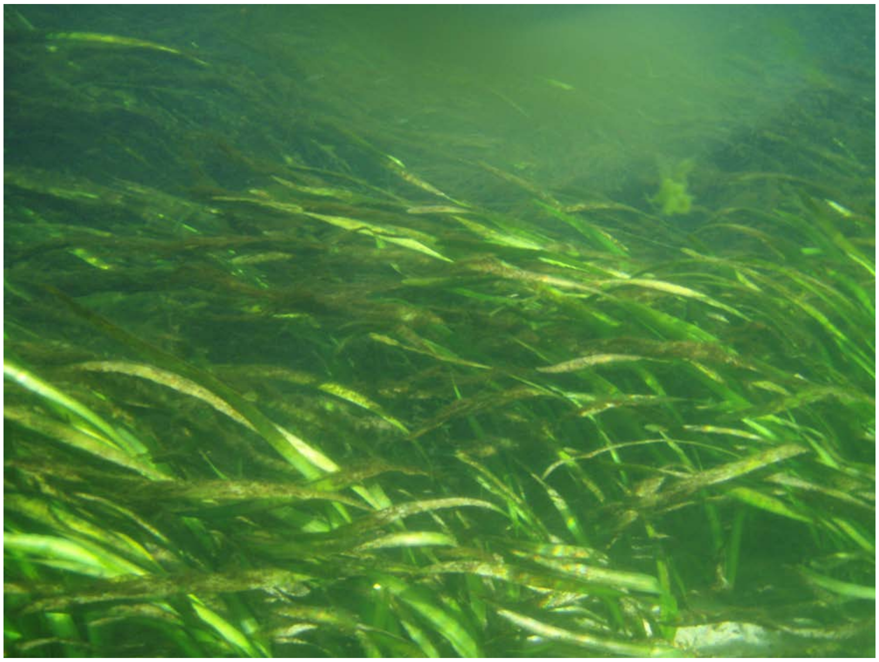


Figure 2.15. Submerged Aquatic Vegetation in Spring Run.

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 2.18). 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.

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 2.19). 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. Once those thresholds of discharge constancy are met, the biological systems establish high frictional resistances not otherwise possible under sandy alluvial control, further decreasing the likelihood of the system shifting to alluvial control by greatly stabilizing the alluvium.

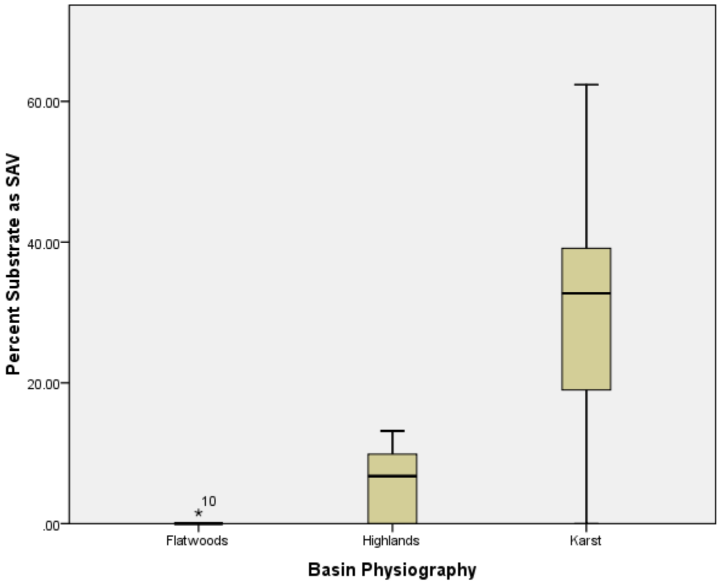


Figure 2.16. Submerged Aquatic Vegetation Cover in Three Watershed Types.

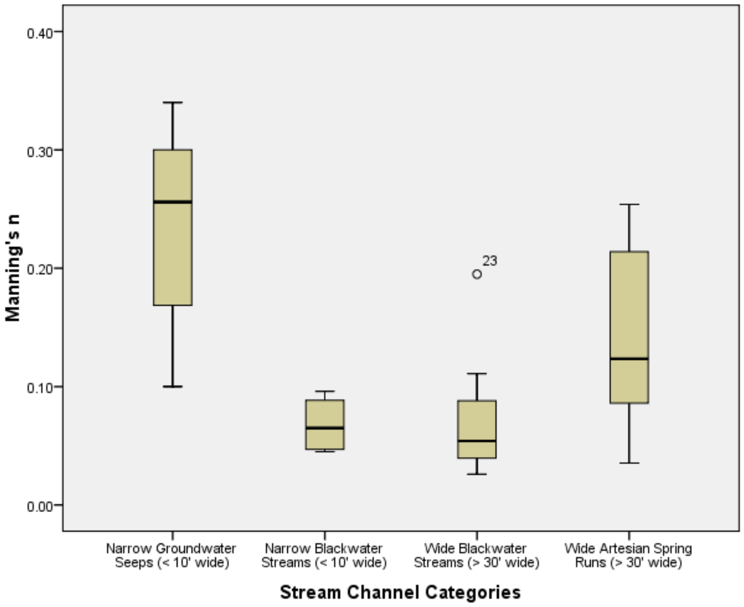


Figure 2.17. Manning's *n* for Streams with Different Width and Water Source.

Figure 2.18. Root-Step Channel with Living Weir.

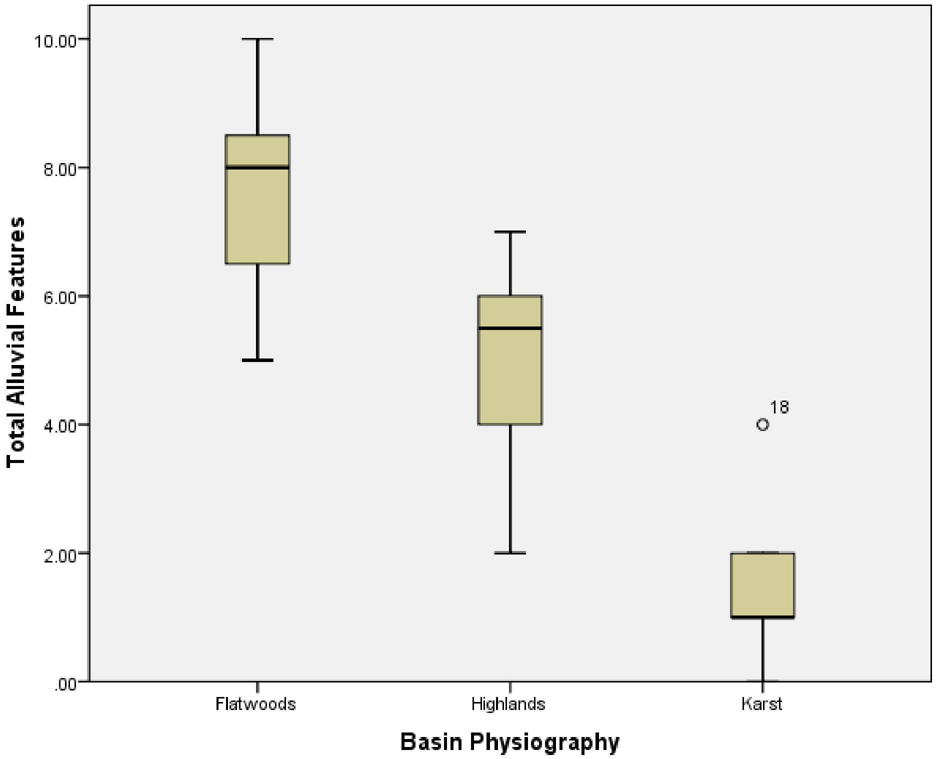


Figure 2.19. Alluvial Features of Perennial Streams for Three Watershed Types.

Fundamentally different biological mechanisms are responsible for increasing friction factors in the groundwater-dominated flow systems, dependent 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 soil 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 maintains and perhaps enhances 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 root 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 2.20). 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 2.21). They appear to be strongly associated with groundwater flow.

Figure 2.20. Biological Banks.

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.

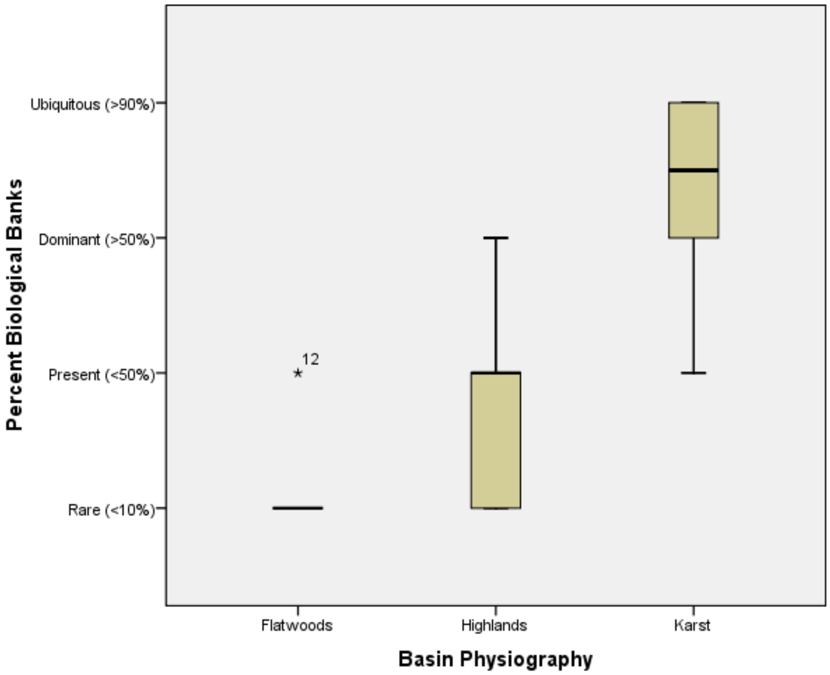


Figure 2.21. Biological Banks' Dominance for Three Watershed Types.

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 bed friction that could counter such encroachment by displacing fluvial stresses to the channel margin, resulting 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 beds 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 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 first-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 and 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 2.22). For comparison, Figure 2.23 shows a typical sandy alluvium from a flatwoods stream channel.

Figure 2.22. Shell and Detrital Floc.

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.

Figure 2.23. Sandy Alluvium with Thin Organic Layers.

Differences in Flow Regime Versus Drainage Area

The distinct wet and dry seasons of the peninsula lead to the state’s largest seasonal water deficits, which are most severe in April and May. The wet season typically starts in June and usually ends in November. The seasonal water stresses create the potential for a highly variable flow regime that is only ameliorated in areas where the dominant soil characteristics of the watershed consist of thick columns of unsaturated sands, allowing for much infiltration.

The FDEP guidance definition of "perennial" is a stream that usually flows continuously and retains water in pools when not flowing (FDEP 2013). The intention was to assure flow regimes conducive to a healthy macroinvertebrate community as defined in the Stream Condition Index (SCI). That definition could encompass systems defined as being intermittent and perennial under some classification schemes based on overall flow duration and groundwater baseflow regimes. Therefore, a new set of terms is likely to be required to avoid confusion with regulatory schemes. Streams with spells in excess of 360 days during most years are likely to be classified as perennial under most schemes. These systems are "annually perennial."

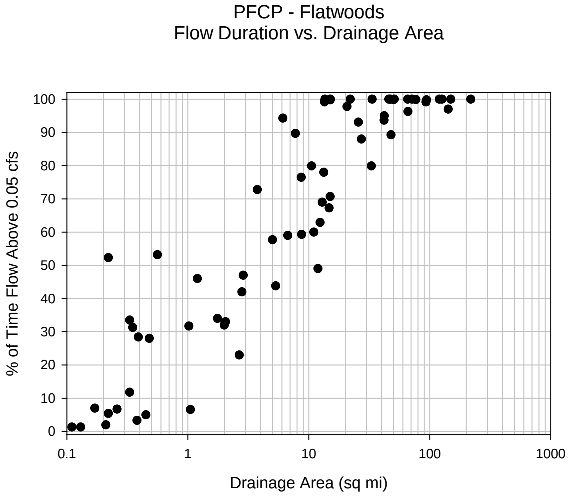
The 180-day spell is a threshold FDEP uses to determine when it is appropriate to conduct an SCI, as flow duration prior to sampling can greatly affect the score for reasons related to hydrologic stress (FDEP 2011b). For example, a perfectly healthy headwater stream that only flows more sporadically may not pass the SCI due to its flow regime, and would falsely be classified as impaired. The peninsular wet season typically lasts five to seven months, potentially adding meaning to a 180 day flow spell as indicative of a system that flows at least the full duration of the wet season. Thus, we suggest referring to systems likely to exceed 180-day flow spells during most years as "seasonally perennial."

A 90-day flow spell represents a duration encompassing about half the wet season and conceptually can be sufficient for short-lived aquatic fauna to complete key aspects of their life-cycle. Such systems are "seasonally intermittent." Systems lacking a 90-day flow spell during most years are deemed to be effectively "ephemeral."

These categories recognize the effects of seasonal rainfall on stream flow regimes that are common in the seasonally wet tropics and sub-tropics. Others working in areas with pronounced differences in seasonal rainfall have found a need to describe more than three (ephemeral, intermittent, and perennial) flow regime categories to usefully categorize stream hydrology. For example, Oueslati and others (2010) described six discharge categories for European streams along the Mediterranean Sea based on seasonality and flashiness of discharge. Low-lying tropical savannas of Australia have much in common with Florida as a stream setting and scientists working there derived four flow categories for that region (Moliere and others 2009). Our proposed system also captures four regimes oriented around wet seasonality: ephemeral, seasonally intermittent, seasonally perennial, and annually perennial.

PFCP Flatwoods

In the PFCP flatwoods, rainfall reaches streams mostly via shallow wetlands when groundwater tables are high and perenniality is largely dependent upon drainage basin size. When flow duration is plotted versus drainage area, clear breaks in the data are found to occur at 1, 4 and 50 square miles (Figures 2.24 and 2.25). Based on an ANOVA Ranks statistical test, significant differences were found between the flow durations of these categories ($p < 0.05$).



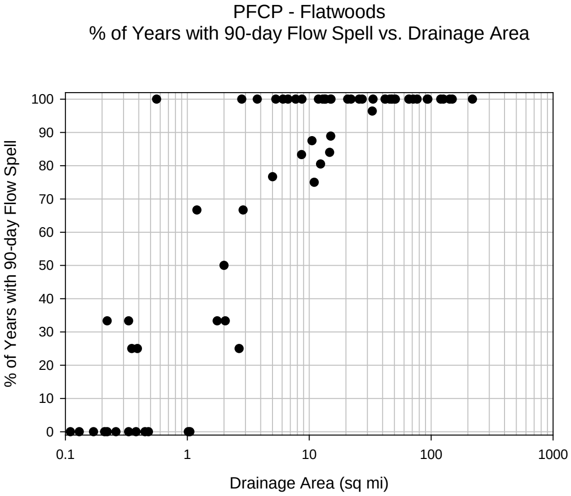
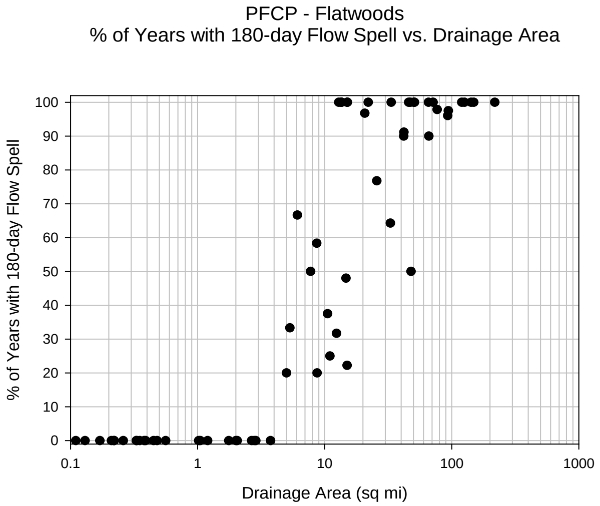


Figure 2.24. Flow Scatterplots Versus Drainage Area for PCFC Flatwoods.



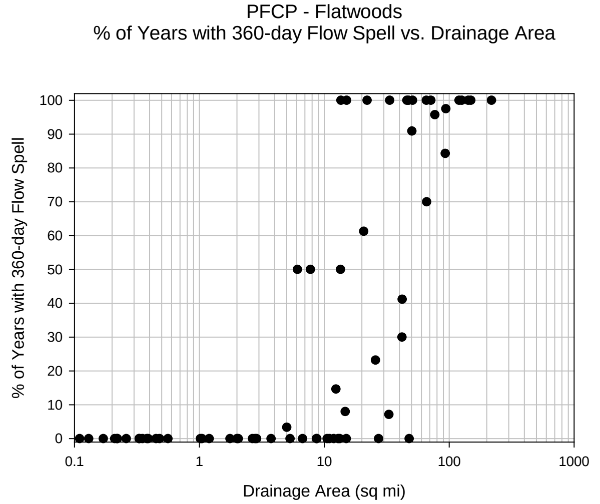
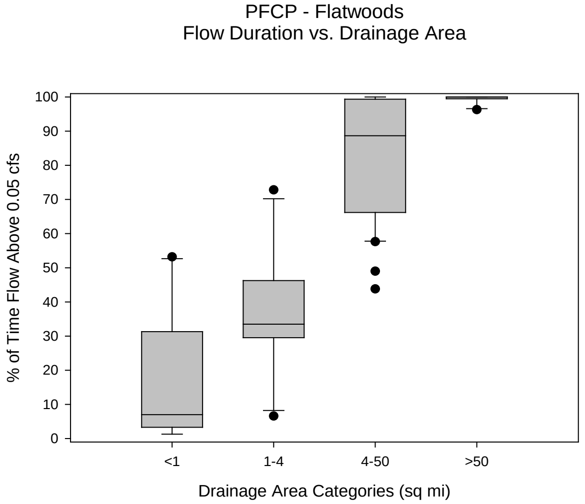


Figure 2.24 (Cont.). Flow Scatterplots Versus Drainage Area for PCFC Flatwoods.

Half the sites under a square mile had less than 20% flow duration and no sites had a 180-day flow spell, though some sites did have a 90-day flow spell. Between one and four square miles, the majority of sites flowed less than 50% of the year and no sites achieved a 180-day flow spell, though some sites did achieve a 90-day flow spell some years. This drainage area threshold happens to be a classification break in peninsular Florida stream types based on differences in their fluvial geomorphology, alluvial surfaces and associated habitats, channel dimension and associated in-stream habitats such as pool and riffle depths, canopy cover, hydrologic fluxes with adjacent wetlands, and other factors represented by 120 variables reported in the scientific literature as having some bearing on stream process and function.

Sites draining less than 4 square miles in the PFCP flatwoods are thus inherently ephemeral although some can be seasonally intermittent. Their basins lack significant groundwater storage and flow responds rather tightly with the antecedent rainfall pattern. These systems typically flow for less than half the total days in a year.



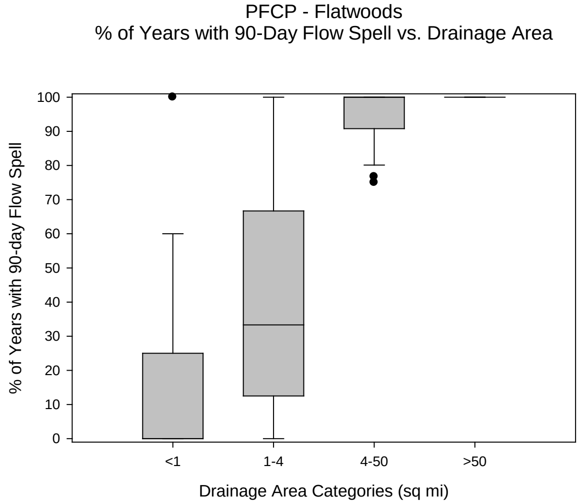
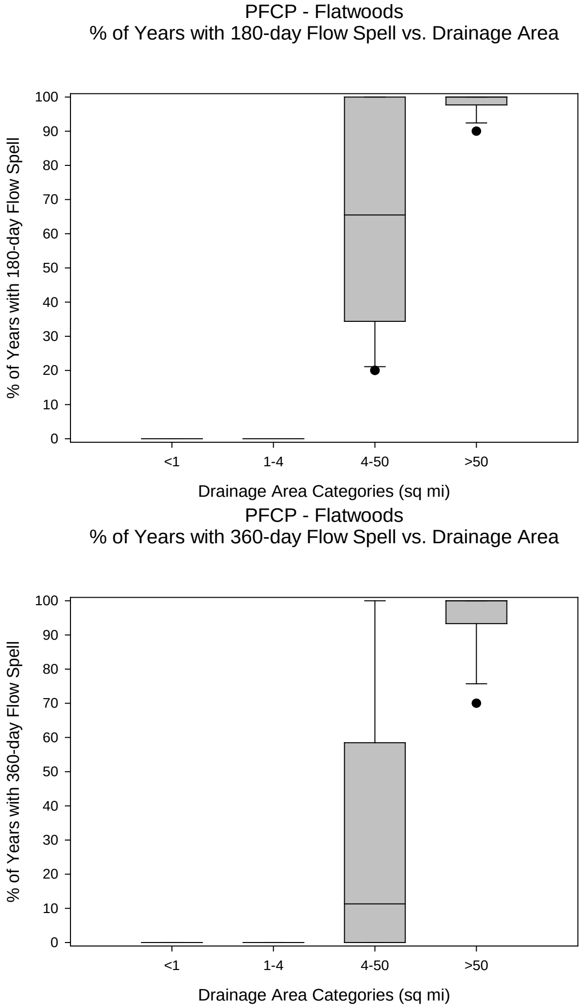


Figure 2.25. Flow Boxplots Versus Drainage Area for PCFC Flatwoods.



PFCP - Flatwoods
% of Years with 180-day Flow Spell vs. Drainage Area

PFCP - Flatwoods
% of Years with 360-day Flow Spell vs. Drainage Area

Figure 2.25 (Cont.). Flow Boxplots Versus Drainage Area for PCFC Flatwoods.

Sites between 4 and 20 square miles achieve a 90-day flow spell in at least 75% of years but more often than not fail to meet the 180-day flow spell. Streams in that drainage area range are therefore characteristically seasonally intermittent although some can be seasonally perennial. These streams typically flow for at least half the total days in a year.

Sites between 20 and 50 square miles frequently flow 90% of the year, achieve a 90-day flow spell in at least 75% of years, and meet a 180-day flow spell from 50% to 100% of years. Some are annually perennial, but most are seasonally perennial. Interestingly, an HBG classification break occurs at 20 square miles between streams with complex compact alluvial floodplains and streams with wide alluvial valley flats. Systems draining at least 50 square miles almost always meet a 90-day flow spell and generally meet a 180-day flow spell for at least 90% of years. These sites are typically annually perennial. Sites draining greater than 60-square-mile watersheds enter into another HBG classification of large-capacity channels in complex alluvial floodplains. It appears that potentially important thresholds in seasonal and perennial flow spells largely correspond to stream classification breaks that were derived from non-flow regime data. The latter observation suggests an association likely to be of some functional relevance, even if it is not related directly to cause and effect.

PFCP Highlands

In the PFCP highlands, annual perenniality is achieved in much smaller basins than in the flatwoods. Streams draining sandhill (highlands) communities on the peninsula are all but assured of being annually perennial at greater than 5 square miles in the highlands basins, a status that requires drainages of at least 50 square miles to assure in the flatwoods. This occurs because the well-drained soils of the highlands contribute groundwater baseflow to streams throughout most of the year. Based on available gage records, streams in the PFCP highlands are seasonally perennial at drainage areas as little as 0.8 square mile (Figures 2.26 and 2.27). Annual perenniality based on 360-day flow spells likely occurs somewhere between 3 and 7 square miles, but there is a data gap in this range. By splitting the difference, annually perennial PFCP highlands streams are likely assured in basins draining at least 5 square miles. This roughly corresponds with a break between the stream classes ultimately delineated between small baseflow channels and larger channels with alluvial floodscapes.

In the available dataset, the two sites below 0.9 square mile were not seasonally perennial, though one was seasonally intermittent. From first-hand knowledge, the streambeds of these two sites do not consistently intersect the water table. There may be sites in this drainage category that do intercept the water table and consequently have more perennial flow, but this cannot be concluded based on the available information.

Case Studies of Low-Order Stream Hydrology

Low-order (first- and second-order) streams, sometimes also referred to as headwater streams, are the most common systems found in the drainage network. As discussed previously, these small streams are seldom gaged and can vary greatly in their hydrology based on soil drainage and other factors. Eight such streams were instrumented for this study with continuous flow records collected and analyzed for a period of record commencing in mid-2008 and ending near the end of 2013, thus providing at least a 5-year daily flow record.

These sites were included in the flow regime analysis discussed above, with cumulative flow days ranging from 22% to 98% of the period of record (Table 2.5). Drainage areas occurred in highlands or flatwoods landscapes, ranging from 0.4 to 11.0 square miles. Despite the variability in conditions, some generalities are suggested. Flatwoods sites draining less than 4-square-mile watersheds flowed for less than one-third of the period, while the larger headwater sites discharged for at least half the days in the record. One of the highlands sites was ephemeral, discharging for less than a third of the record, while the other two highlands sites discharged for at least 89% of the record despite draining less than three-square-mile watersheds.

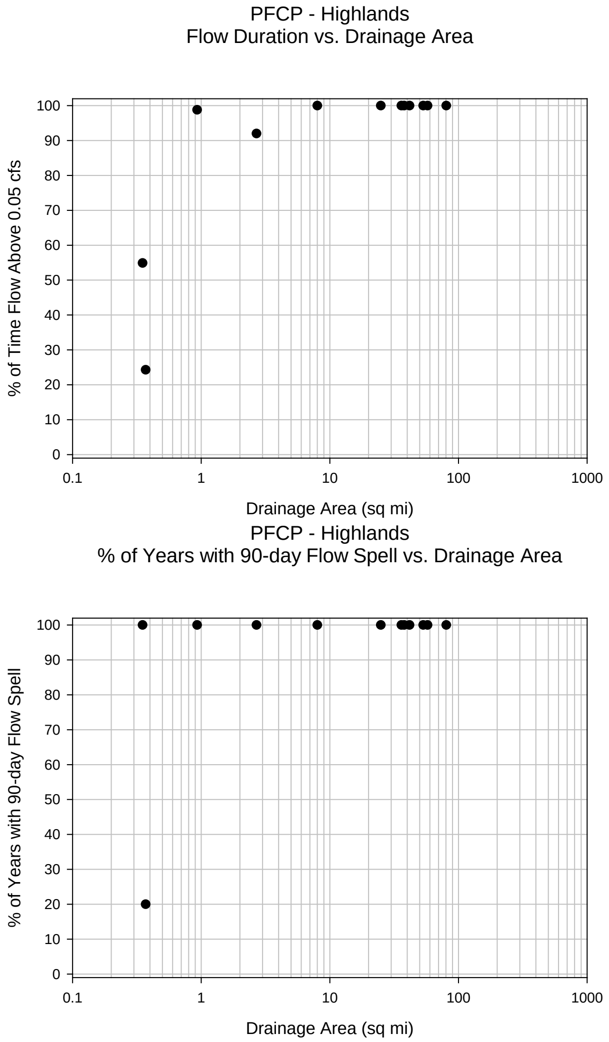
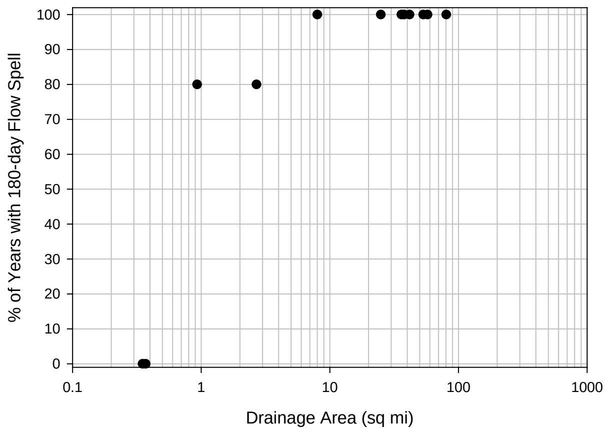


Figure 2.26. Flow Scatterplots Versus Drainage Area for PCFC Highlands.


PFCP - Highlands
% of Years with 180-day Flow Spell vs. Drainage Area

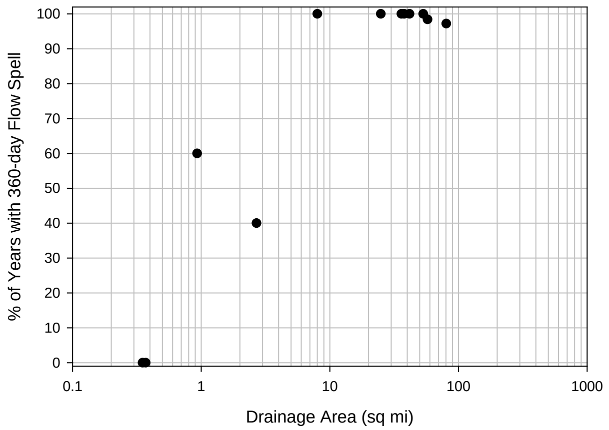
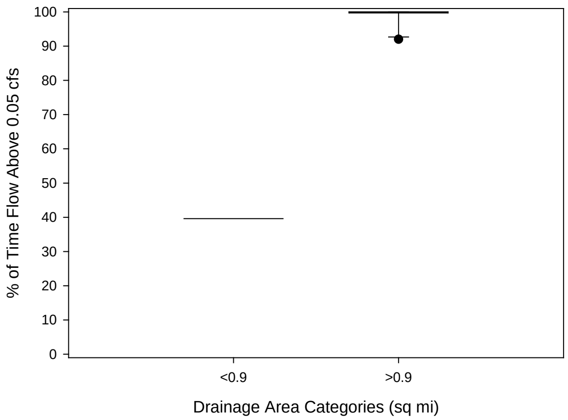
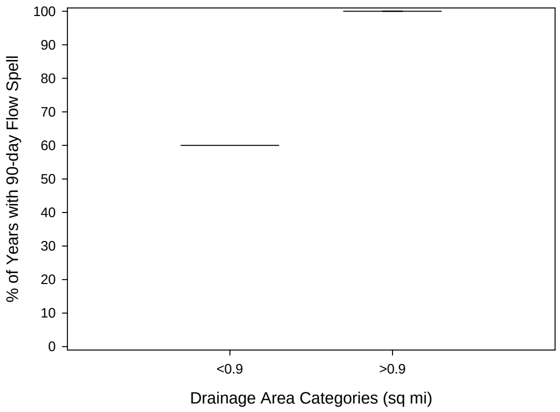

PFCP - Highlands
% of Years with 360-day Flow Spell vs. Drainage Area

Figure 2.26 (Cont.). Flow Scatterplots Versus Drainage Area for PCFC Highlands.

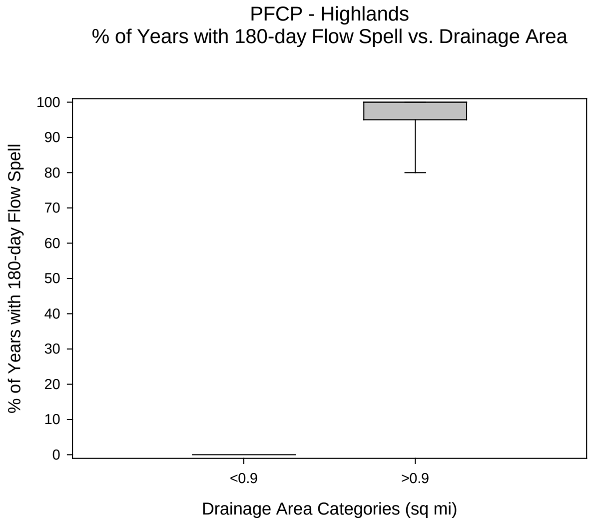


PFCP - Highlands
Flow Duration vs. Drainage Area



PFCP - Highlands
% of Years with 90-day Flow Spell vs. Drainage Area

Figure 2.27. Flow Boxplots Versus Drainage Area for PCFC Highlands.



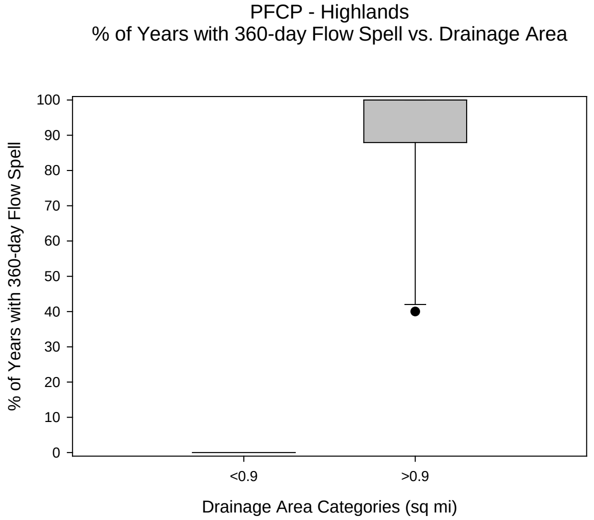


Figure 2.27 (Cont.). Flow Boxplots Versus Drainage Area for PCFC Highlands.

Characteristically, bankfull events occurred several times a year, with each event typically lasting less than a week, and sometimes more than a month (Table 2.5). Bankfull exceedances occurred for 2.3% to 20.9% of the period of record, with most sites below 10%. However, most sites exceeded bankfull discharge for at least 10% of the time they were discharging (average of 20% among sites). These factors indicate that bankfull events are common in the low-order streams and their exceedances comprise a substantial part of the overall flow regime irrespective of whether the site is ephemeral, intermittent, or perennial. No statistically significant differences in bankfull exceedance frequencies occurred between flatwoods and highlands streams (means 4.6 and 3.1, respectively), but the power of the test was weak (t-test p = 0.23, power 0.11).

Although flatwoods streams generally provide greater flood pulses than their highlands counterparts, this pattern does not apply as well to streams draining less than three-square-mile watersheds versus those with larger drainages (Figure 2.11, Table 2.6). In other words, it does not apply as consistently to systems where flood discharges do not occur with sufficient power and frequency to create continuous alluvial floodplain surfaces. Flood flow frequencies were variable among sites, being exceeded from zero to five times per year, with events characteristically lasting a few days. Although it appears that low-order flatwoods sites may have greater overall frequencies of flood flow exceedances versus their highlands counterparts (averages of 2.4 events per year versus 0.6, respectively), the sample is too small to conclude such with statistical significance (t-test at $p = 0.14$ and power at 0.21).

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 can be a very useful restoration design tool and construction mechanism (see Chapter 10), but it is only part of the complete kit, which must necessarily also account for flow variability.

Table 2.5. Bankfull Discharge Characteristics of Eight Low-Order Streams.

Site Name	Phys.	DA (Sq. Mi.)	Period of Record	Percent of Time Flowing* for POR	Bankfull Channel Flow (cfs)	Average Bankfull Flow Exceedances per Year**	Average Bankfull Spell (Days) (Min.-Max.)	Median Bankfull Spell (Days) (25th-75th***)	Percent of Time Bankfull Flow Exceeded for POR	Percent of Time Bankfull Flow Exceeded During Discharge Periods
Lower Myakka UT 3	FW	0.4	Oct 2 '08 - Nov 8 '13	29.0	1.0	4.1	7.4 (1-28)	6 (3.0-11.0)	8.5	29.2
East Fork Manatee UT 1	FW	0.9	Jun 27 '08 - Nov 8 '13	24.7	3.2	3.9	2.1 (1-5)	2 (1.0 - 3.0)	2.3	9.3
Lower Myakka UT 2	FW	2.7	Jun 17 '08 - Nov 8 '13	22.0	3.6	3.1	4.3 (2-13)	3 (2.0 - 5.0)	3.7	16.8
Grasshopper Slough	FW	8.7	Jun 11 '08 - Jul 6 '13	55.9	18.9	4.3	6.9 (2-30)	5 (4.0 - 7.8)	8.2	14.6
Morgan Hole Creek	FW	11.0	Jun 6 '08 - Dec 18 '13	60.3	19.8	7.6	6.2 (1-23)	5 (3.0 - 8.0)	12.9	21.4
Cypress Slash UT	HL	0.4	Aug 7 '08 - Dec 18 '13	27.4	0.9	3.4	8.7 (1-46)	3 (1.3 - 5.0)	8.0	29.2
Tiger UT****	HL	0.9	Jul 14 '08 - Dec 18 '13	98.4	1.0	3.9	6.9 (1-32)	3 (2.0 - 6.0)	10.1	10.3
Tiger UT****	HL	0.9	Jul 14 '08 - Dec 18 '13	98.4	4.7	0.2	2.0 (2-2)	--	0.1	0.1
Jack Creek	HL	2.7	Jun 11 '08 - Oct 22 '13	89.7	5.0	2.0	37 (1-120)	10 (6.5-57.0)	20.9	23.3

DA = drainage area.

POR = period of record.

Phys. = basin physiography.

FW = flatwoods, HL = highlands.

*Discharge greater than 0.05 cfs.

**Based on minimum 7 days between indpendant flow peaks, with recession below bankfull flow between events.

*** percentiles.

****Original bankfull stage used upper inflection, giving 4.7 cfs. System has very steady flow suggesting scour line may be better indicator, giving 1.0 cfs.

Table 2.6. Flood Discharge Characteristics of Eight Low-Order Streams.

Site Name	Phys.	DA (Sq. Mi.)	Period of Record	Percent of Time Flowing* for POR	Flood Channel Flow (cfs)	Average Flood Flow Exceedances per Year**	Average Flood Spell (Days) (Min.-Max.)	Median Flood Spell (Days) (25th-75th***)	Percent of Time Flood Flow Exceeded for POR
Lower Myakka UT 3	FW	0.4	Oct 2 '08 - Nov 8 '13	29.0	5.0	1.8	3.0 (1 - 9)	2 (1.0 - 4.0)	1.4
East Fork Manatee UT 1	FW	0.9	Jun 27 '08 - Nov 8 '13	24.7	4.6	3.2	1.8 (1 - 5)	1 (1.0 - 2.0)	1.5
Lower Myakka UT 2	FW	2.7	Jun 17 '08 - Nov 8 '13	22.0	18.2	0.0	--	--	0.0
Grasshopper Slough	FW	8.7	Jun 11 '08 - Jul 6 '13	55.9	39.1	2.4	4.6 (1 -12)	4 (3.0 - 5.3)	3.0
Morgan Hole Creek	FW	11.0	Jun 6 '08 - Dec 18 '13	60.3	66.3	4.9	3.7 (1 -11)	3 (2.0 - 5.0)	5.0
Cypress Slash UT	HL	0.4	Aug 7 '08 - Dec 18 '13	27.4	2.7	0.6	2.3 (1 - 4)	2 (1.5 - 3.0)	0.4
Tiger UT	HL	0.9	Jul 14 '08 - Dec 18 '13	98.4	7.3	0.0	--	--	0.0
Jack Creek	HL	2.7	Jun 11 '08 - Oct 22 '13	89.7	18.0	1.1	14.0 (2 -43)	7.5 (4.5-17.3)	4.3

DA = drainage area.

POR = period of record.

Phys. = basin physiography.

FW = flatwoods, HL = highlands.

*Discharge greater than 0.05 cfs.

**Based on minimum 7 days between indpendant flow peaks, with recession below flood flow between events.

*** percentiles.

Biota as a Groundwater-Dependent Geomorphic Agent

Florida's subtropical 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. In streams 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. The nearly constant saturation in valleys fed by steady groundwater discharge promoted formation of rich organic soil layers as well as enabling plants to exert geomorphic control on channel shape and dimension. 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. Comparatively powerful seasonal flood pulses precluded plants from establishing the same controls as in the groundwater systems. In the battle between biology and physics, steady groundwater flow in the absence of routine powerful floods can tip the scale toward biology. It is very clear that routine in-channel flow and flood pulses are necessary to structure the geomorphology of the riparian corridor and that fundamentally different stream systems can result based on seasonal flow variability that is heavily mediated by watershed soil drainage conditions and geologic reservoirs in different kinds of Florida watersheds.

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 2.28). 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. The flow regime clusters associated poorly with Rosgen stream type and with FNAI stream type, suggesting that flow regime should be explicitly considered in Florida stream typology in addition to existing characterizations based solely on channel form and on qualitative limnology.

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 watershed type 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 throughout Chapter 3 and an approach that integrates geomorphic features existing at the watershed, valley, reach, and in-stream patch scales is the over-arching subject of Chapter 4.

```
Dendrogram using Ward Method

                                   Rescaled Distance Cluster Combine

                   C A S E
  Label                                   Group

  Carter Creek near Sebring               1 B5 BW
  Tiger Creek near Babson Park            1 C5 BW
  Catfish Creek near Lake Wales           1 C5 BW
  Blackwater Creek near Cassia            1 C5 BW
  Livingston Creek near Frostproof        1 C5 BW
  Little Haw Creek near Seville           1 C5 BW
  Bowlegs Creek near Ft Meade             2 C5 BW
  Rice Creek near Springside              2 C5 BW
  Manatee River near Myakka Head          2 E5 BW
  Santa Fe River near Graham              2 B5 BW
  Fisheating Creek at Palmdale            3 C5 BW
  Horse Creek near Arcadia                3 C5 BW
  Cedar Head Spring Run                   4 C5 SR
  Lowry Lake UT                           4 G5 SS
  Gum Slough Spring Run                   4 C5 SR
  Alexander Spring Run                    4 B5 SR
  Rock Spring Run                         4 C5 SR
  Weeki Wachee River                      4 C5 SR
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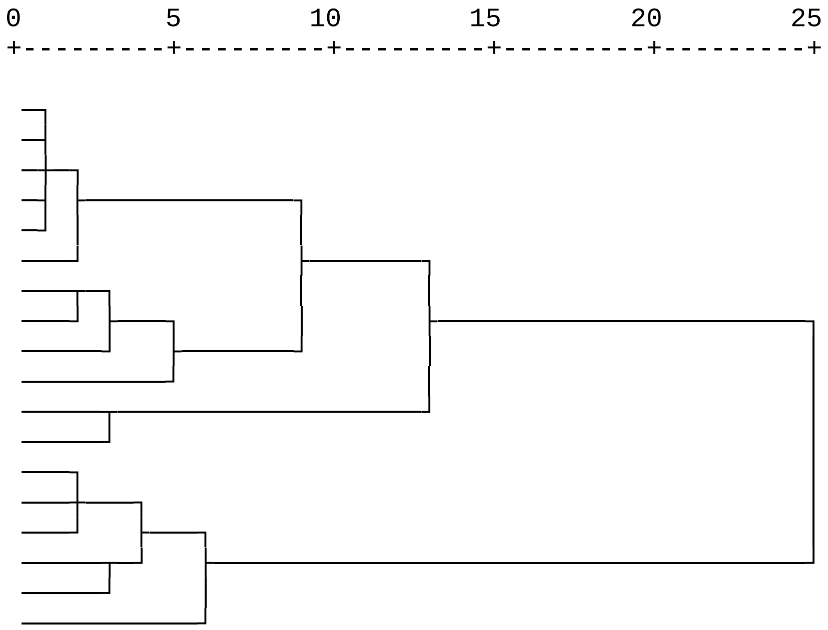


Cluster groups include; Group 1 = high baseflow with runoff spates, Group 2 = flashy intermediate discharge, Group 3 = flashy high discharge, Group 4 = steady groundwater flow. B5, C5, and E5 are Rosgen Level II channel classifications (Rosgen 1996). FNAI (1990) stream classes include; BW = blackwater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

Figure 2.28. Dendrogram of Hydrologic Clusters of Streams.

Research Needed

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.

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, versus those in the perennial streams in Florida. Subtropical 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 mid-reach 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.

CHAPTER 3
VALLEYS AND THEIR RIPARIAN CORRIDORS

INTRODUCTION

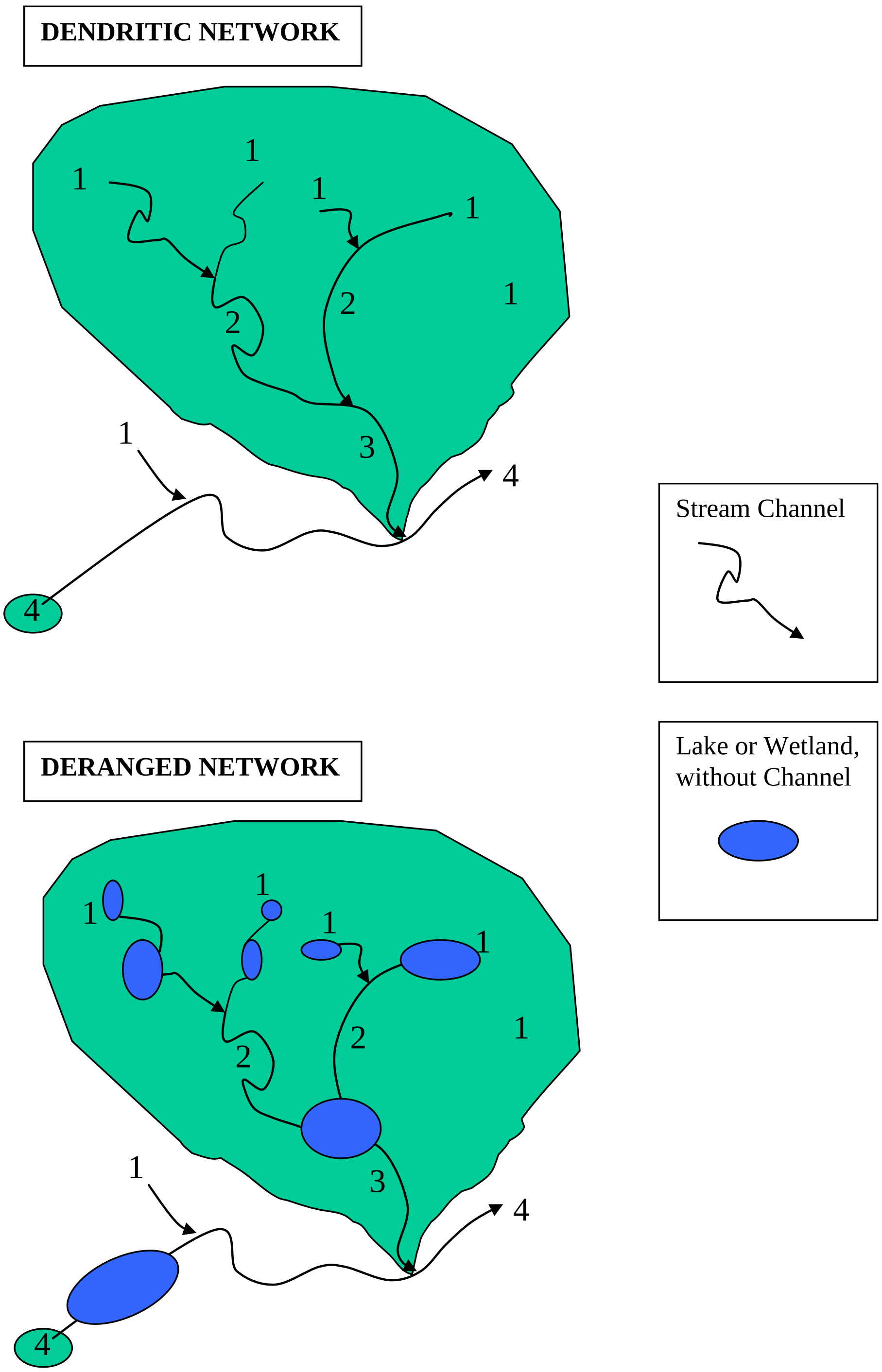
Peninsular Florida's drainage networks consist of complex valleys that offer highly varying degrees of lateral confinement, routinely have discontinuous open channels punctuated by in-line lakes and wetlands, and occur within three different landscapes that vary significantly in their surface water and groundwater discharge capacities. This all occurs within in a lowland, seasonally wet subtropical region 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, and Ocklawaha (Warne and others 2000, Inter-Fluve 1997, Belleville 2001). 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 watershed 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 and in-line waterbodies.

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 network patterns are widely described in textbooks with emphasis on not merely describing the form of the networks but on assessment of how they formed (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 books (Knighton 1998, Schumm 1977, Leopold and others 1964, Gregory and Walling 1973).


DENDRITIC NETWORK

DERANGED NETWORK

Figure 3.1. Dendritic and Deranged Drainage Networks with Strahler Order.

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 unchannelized 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, occur in semi-arid climates with rainfall between six to 30 inches per year (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 at about five to eight miles/mi^2. Most of the world's tropical and subtropical savannas fall in that range of precipitation (Bourliere 1983).

Gregory (1976) also showed that maximum drainage density increases to about 10 miles/mi^2 in more humid climates with at least 59 inches per year. 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, which clearly suggests other factors, such as relief, can modify drainage density.

The seasonal timing and volume of peninsular Florida's rainfall and evapotranspiration patterns fall within the ranges of tropical savannas. Florida differs from most of the globe's savannas, however, because its climate is interacting with geology of marine derivation, replete with carbonate rock under active dissolution and high water tables due to elevations typically within 300 feet of sea level. As will be discussed in more detail, the result is a low-lying landscape dissected by highly variable drainage densities that are among the lowest in the world. Nevertheless, Florida presents a wide array of valley conditions and associated fluvial formations.

Valley Form and Quaternary Climate Fluctuations

Florida has a complex biogeographic and 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. This history has contributed much to the geomorphology of the peninsula's valleys and drainage networks.

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 7 to 115 feet above existing mean sea level (MSL) (Webb 1990). Doline features, likely associated with solution weathering of underlying carbonate bedrock, or to wave action on the ancient sea-floor, 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).

Florida's sandy highlands consist of relict aeolian and coastal dunes that formed and were reworked 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). These relict dunes variably encroach along valley margins, sometimes leading to comparatively pronounced sandy bluffs along portions of the stream channel.

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. 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 stage (Wisconsinan, 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 at 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 have occurred as subsequent sea 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 and others 2008, Miller and Gupta 1999, and Schumm 2005). These texts provide key supplemental contrast to valley process classifications that view drainage networks solely as longitudinally self-organizing systems at equilibrium for sediment transport and deposition (Leopold and others 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 and others 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 and others (2008) attempted to improve description, understanding, and management of riverine systems by recommending discretization 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. For these reasons, FPZs could be viewed as areas requiring their own set of design specifications for stream restoration.

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 lotic 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 FPZs. While it is important to tease out the gradients associated with the scale of the watershed or position in the drainage network, it is just as important to recognize the less predictably structured spatial heterogeneity in river systems. While this is true of virtually all river networks, it is especially critical in deranged ones, where alluvial and biological clines are punctuated by the spatially variable effects of geologic foci with greater effect on geomorphology and biology than the modern alluvial processes.

METHODS

All 56 streams selected for field 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 roughly parallel to the centerline of a valley or by tracing the lowest lying axis along the valley (referred to as the channel thalweg). 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 dendritic networks, stream drainage area increases with stream order but the magnitude may differ among various physiographic settings. This relationship was assessed for the variably deranged networks of the peninsula. Because a small number of third- through fifth-order streams occurred in the study compared with first- and second-order systems, the three mid-order categories were lumped into a single category to facilitate a more equitable comparison. Mean drainage basin size increased with Strahler’s (1957) 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). This suggests that the networks have evolved with alluvial controls, despite the obvious imposition of some geologic control causing the derangement.

Headwater systems of highlands landscapes may warrant additional considerations because internal drainage can lead to delineations of very large watershed areas that would be unlikely for flatwoods (which generally lack internal drainage). For example, of the seven first-order flatwoods streams in the study, the largest drainage area measured was 2.7 square miles (for Lower Myakka UT 2). The two largest first-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.

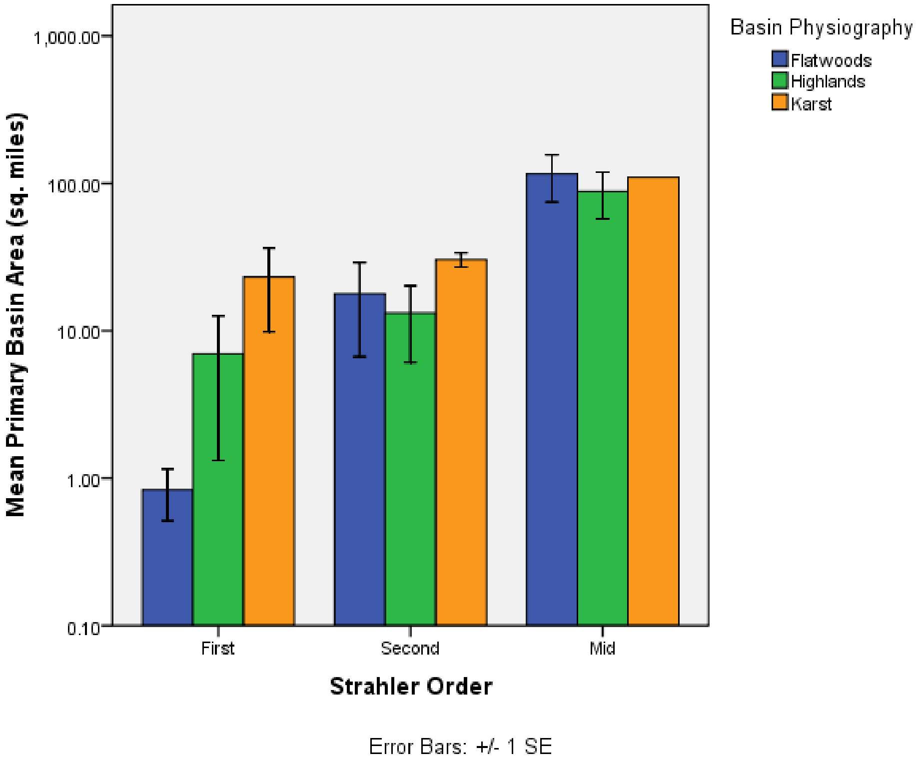


Figure 3.2. Drainage Area Associated Strahler Order in Three Watershed Types.

Table 3.1. Drainage Area ANOVA by Stream Order and Watershed Type.

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 and 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).

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. The lack of a relationship between order and contributing area for the karst systems indicates that the network is essentially under geologic control. The reaches exhibiting alluvial surfaces are foci of alluvial control in an otherwise geologically controlled network (much of which is subterranean).

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.

Peninsular Florida's drainage densities are typically less than a mile per square mile of watershed. This places them 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 well in excess of one mile per square mile (Gregory 1976). This may be due to a combination of factors in addition to low relief and groundwater capture of rainfall, including the simple fact that much of the drainage network is encumbered by in-line lakes and wetlands that directly reduce the total stream length.

In-line waterbody types located immediately downstream of the stream segments studied differed in their distribution by watershed 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 valleys 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 and genesis of highlands and karst valley structure.

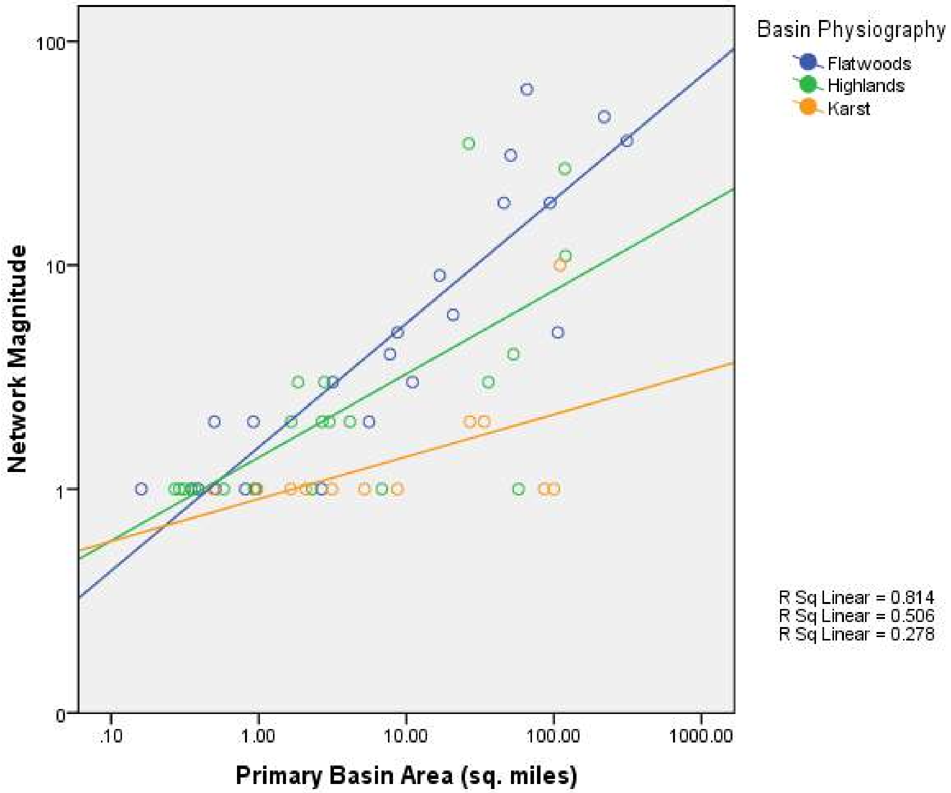


Figure 3.3. Shreve's Network Magnitude Versus Drainage Area.

Table 3.2. Regressions of Valley Variables Versus Drainage Area by Watershed Type.

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%.

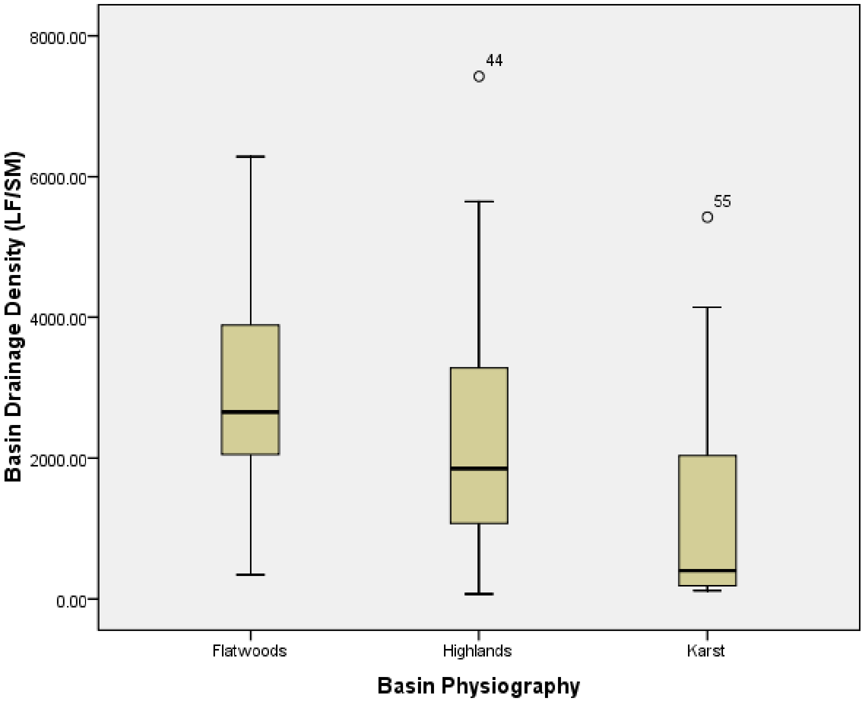


Figure 3.4. Drainage Density for Three Watershed Types.

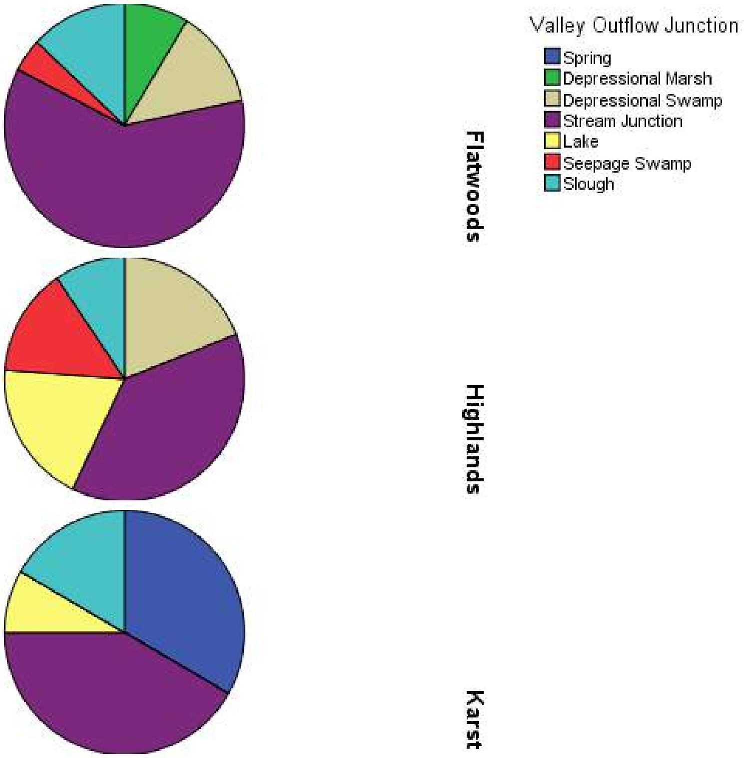


Figure 3.5. Waterbody Type Downstream of the Channel Reach by Watershed Type.

Upstream waterbody types also differed significantly by watershed type (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 in 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 watersheds, 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 differences in waterbody types upstream and downstream of channeled valley segments appear to be an artifact of the older geologic history of the watershed types rather their more modern alluvial controls.

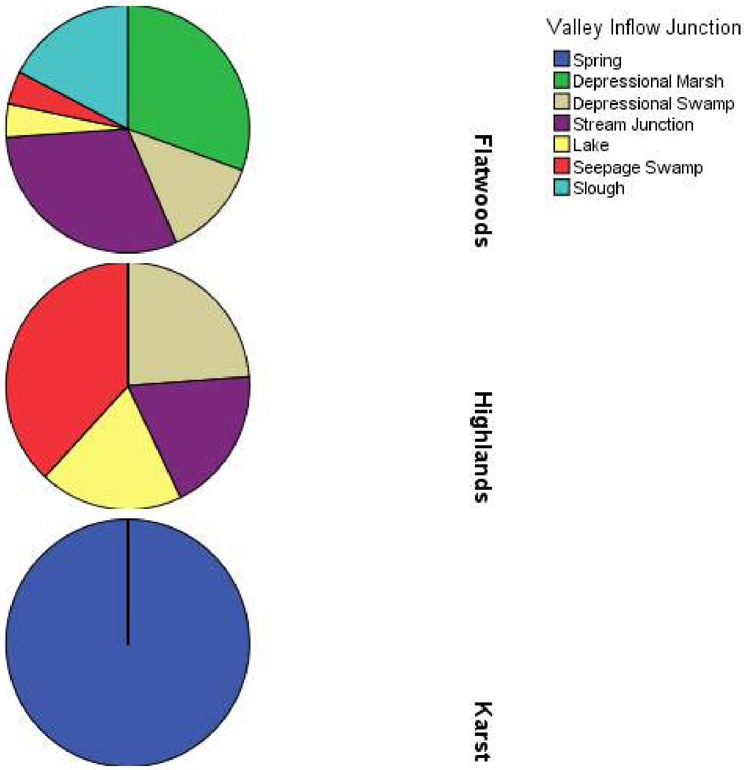


Figure 3.6. Waterbody Type Upstream of the Channel Reach by Watershed Type.

The distribution of dominant riparian community types within stream meander belt also varied by physiography (Pearson Chi-Square, p = 0.003) (Figure 3.7). The meander belt is the generally the lowest, flat part of the valley that the stream meanders across. Streams in the flatwoods coursed mainly through valleys occupied by cypress

(*Taxodium distichum*) 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.

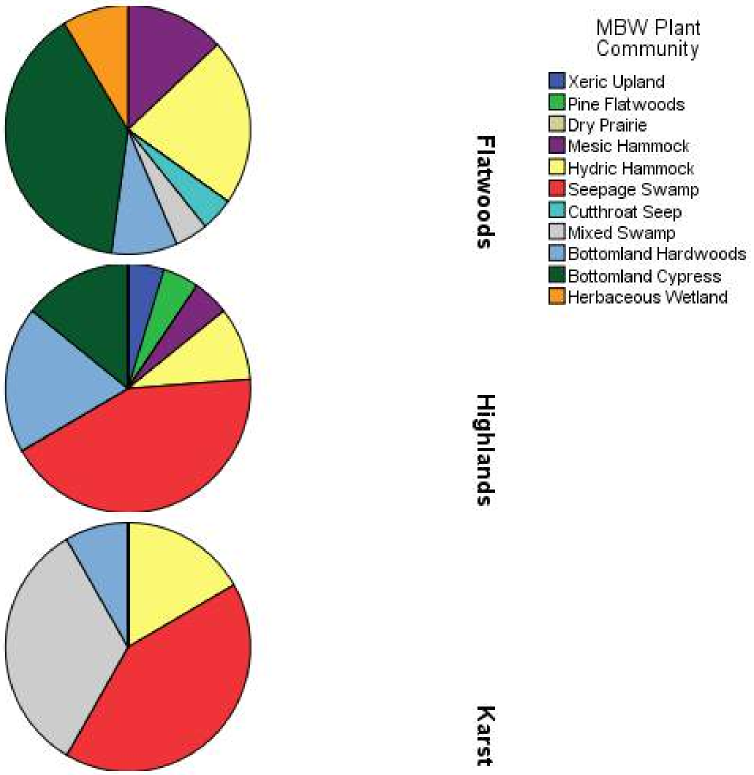


Figure 3.7. Riparian Community Dominant in the Meander Belt by Watershed Type.

The relative distribution of riparian communities also appears to be associated with Strahler's stream order (Pearson Chi-Square, p = 0.039) (Figure 3.8). 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 (third through fifth 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 the lower-lying and larger stream valleys occupying mid-order and high-order positions along the drainage network.

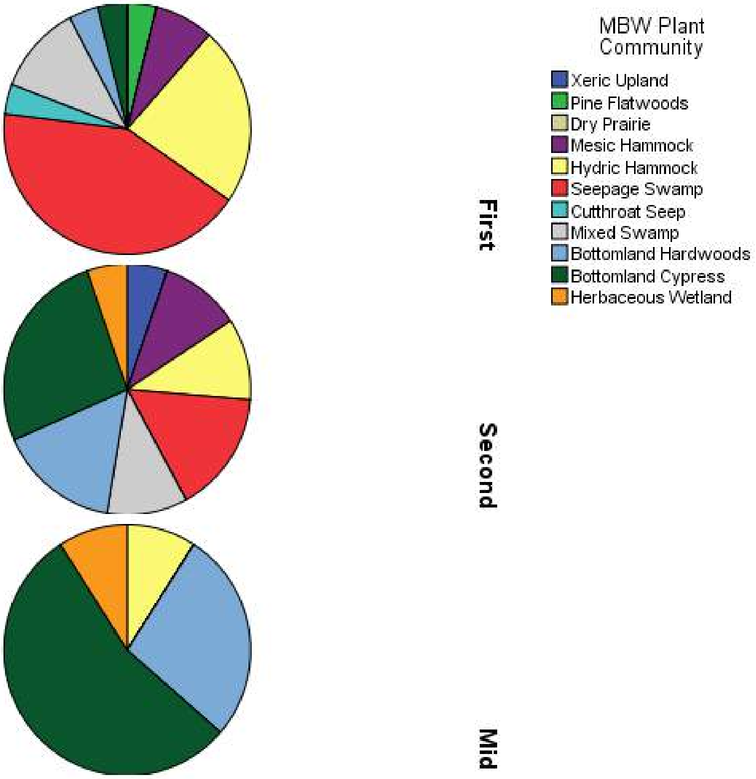


Figure 3.8. Riparian Community Dominant in the Meander Belt by Stream Order.

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 regression constants 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 watershed settings in the headwaters, but 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).

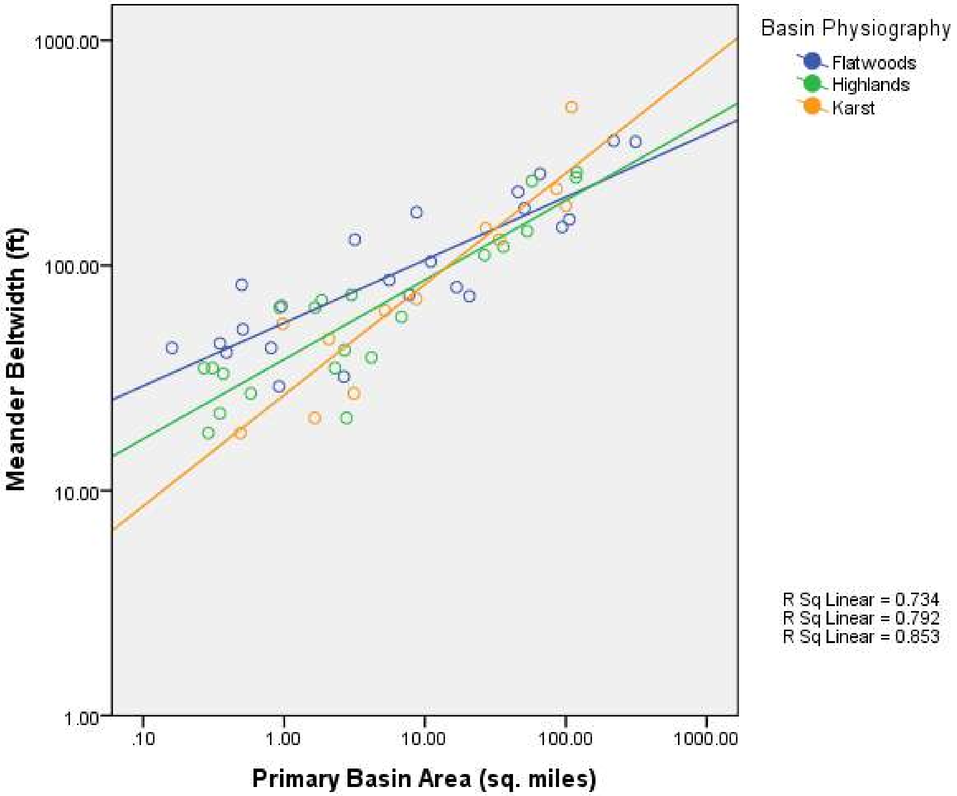
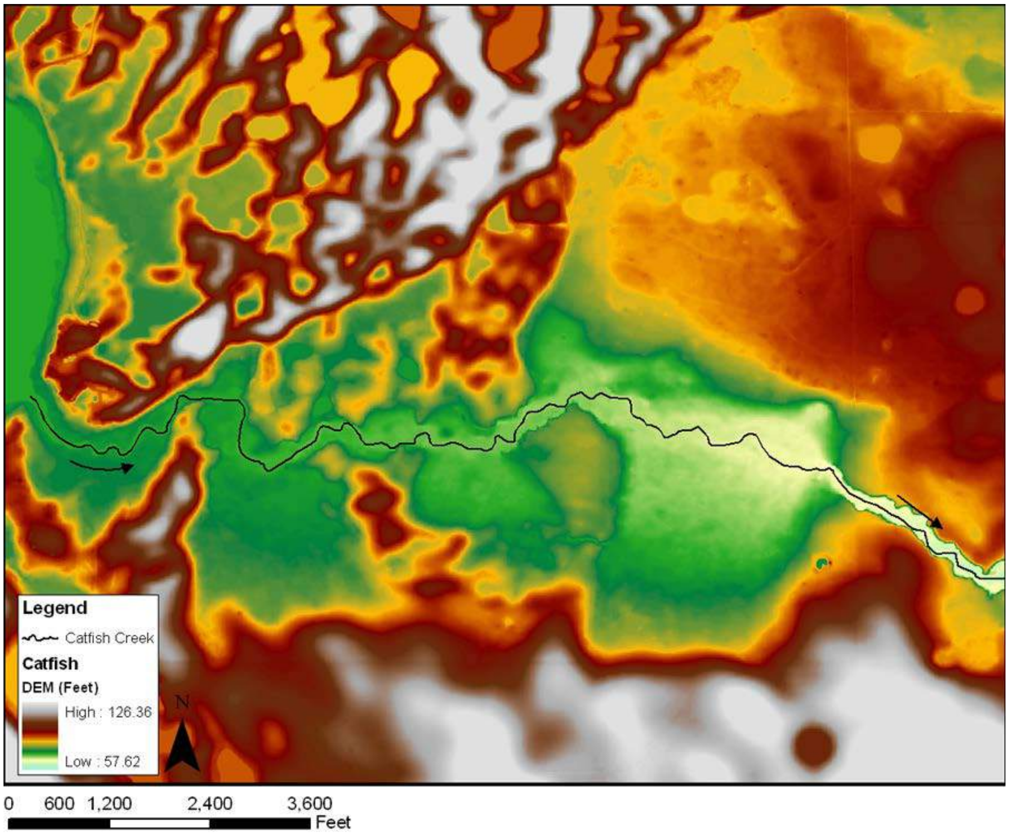


Figure 3.9. Meander Belt Width Versus Drainage Area for Three Watershed Types.

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).



Catfish Creek downstream of Lake Pierce.

Figure 3.10. Alternating Unconfined and Well-Adjusted Meander Belts.

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 watershed types, 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 regression constants 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 "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 watershed type once drainage area reaches about 10 square miles. Regression slopes were statistically similar among all comparisons except for highlands and flatwoods (Table 3.2).

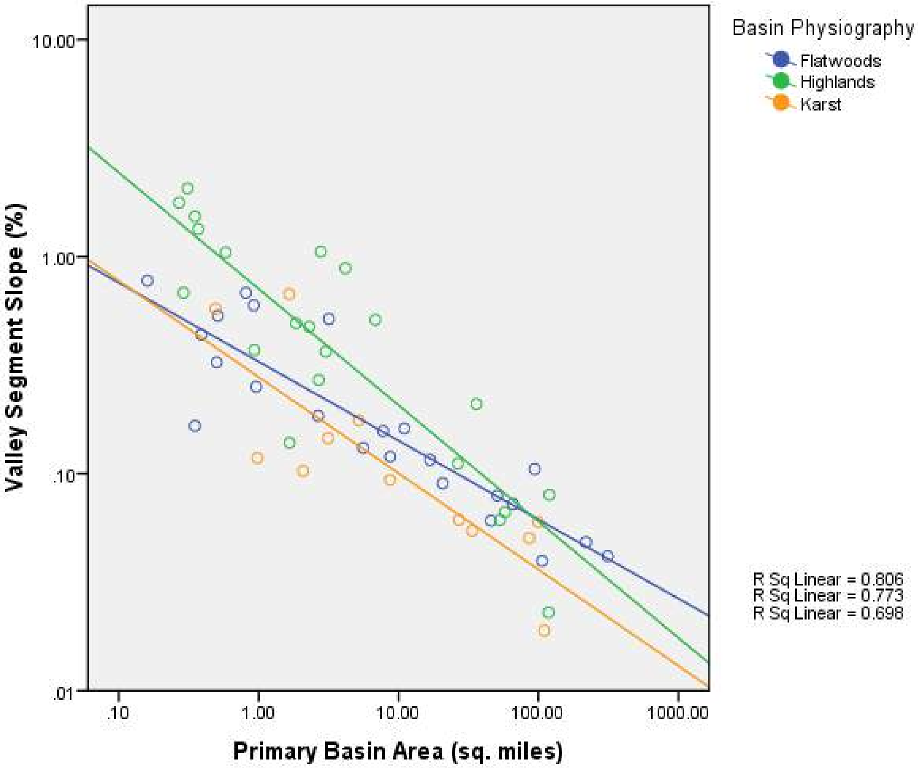


Figure 3.11. Valley Slope Versus Drainage Area for Three Watershed Types.

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 watershed type, without any clear differences in their distribution among the watershed 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) form 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 linear 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 second-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 first-order streams and at their upstream junction with their headwater waterbodies are critical to maintaining their valley grade. Most of these transitions unfold over distances of 50 to 300 feet with poorly defined or anastomosed channels that serve to dissipate hydraulic forces.

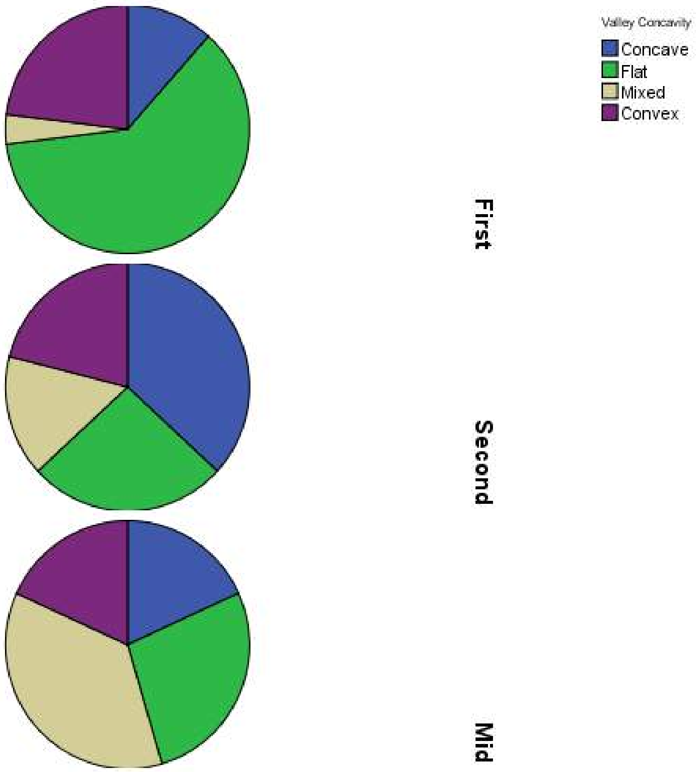


Figure 3.12. Longitudinal Valley Shape Distribution by Stream Order.

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. This suite of repeated foci of non-alluvial controls of valley grade likely affect local hydraulics important to habitat structure.

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 peninsular Florida, the frequency (and length) of punctuation by in-line waterbodies appeared to be inherently scale-dependent 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). This implies a similar balance of the influence of alluvial versus geologic genesis on segment length for these two watershed types. Conversely, karst systems exhibited statistically significant differences in regression slope from flatwoods systems and in regression constant from highlands systems, suggesting that the artesian stream valley lengths may be organized differently.

The number of geomorphic 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 rework 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.

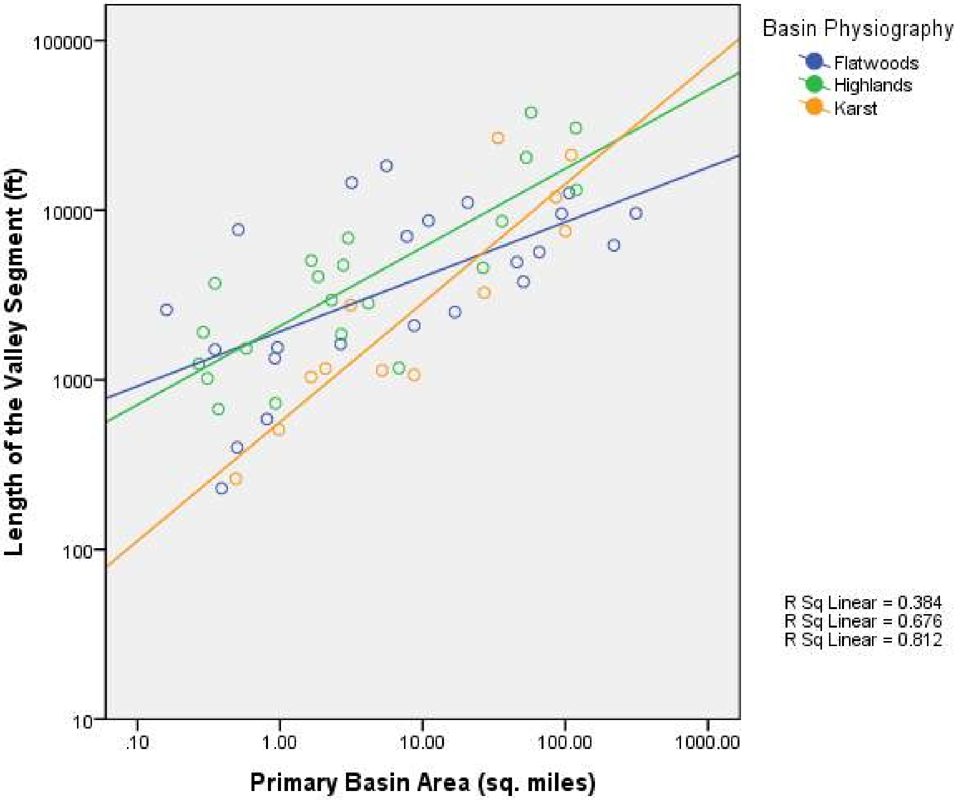


Figure 3.13. Valley Lengths Between Waterbody Junctions Watershed Type.

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 of this is 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 and others 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.

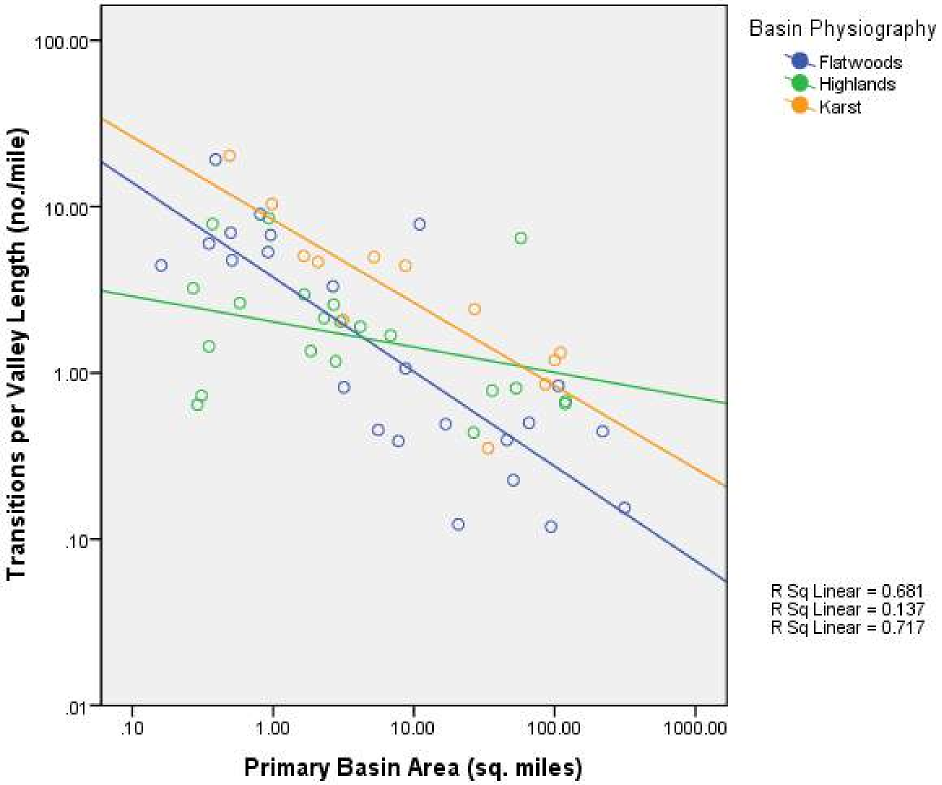


Figure 3.14. Transitions per Valley Mile Versus Drainage Area by Watershed Type.

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 watershed types (Figure 3.15). This is consistent with the fact that deranged networks frequently create wide depressed valleys through which streams can sometimes maintain their continuity, depending on the relative depth of the deranging feature versus the magnitude of sediment and stream power available to rework the depression in a manner suitable to sustain an alluvial stream channel through it. 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).

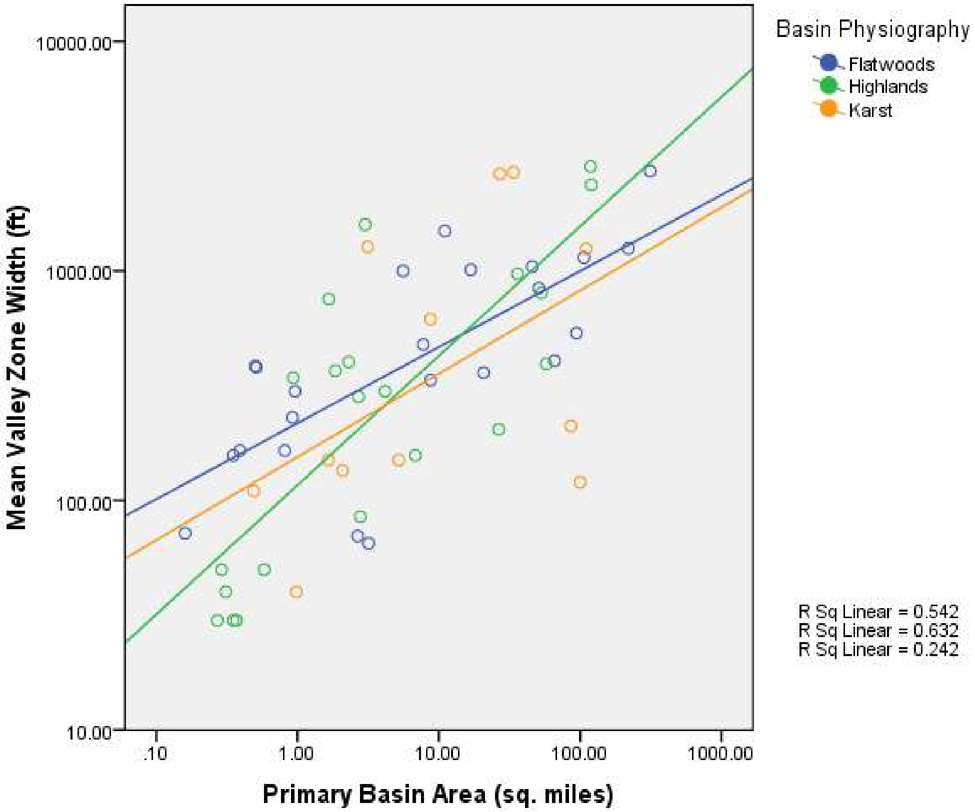
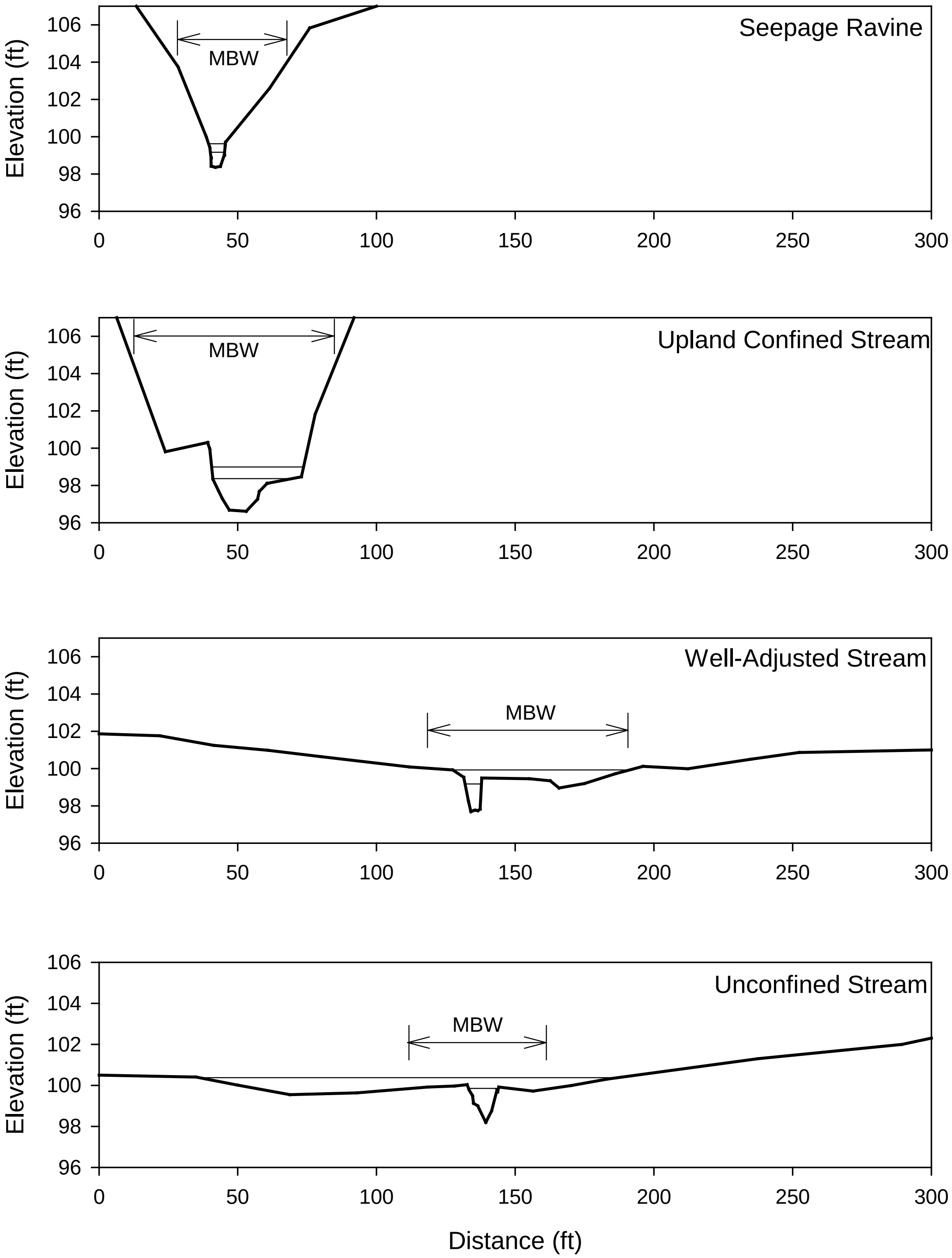


Figure 3.15. Valley Width Versus Catchment Area for Three Watershed Types.

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 or weak to create a floodprone bench or alluvial 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 were 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.



Note: MBW = Meander Belt Width. Upper horizontal line is floodplain width. Lower line is bankfull width.

Figure 3.16. Types of Valley Confinement.

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 surfaces 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 valley included streams encompassed by wetlands with comparatively routine overbank flow and associated surfaces created by floodplain sedimentation from the stream discharge. These forms represent an interaction across the valley flat between paleo-geologic and modern alluvial processes.

Another type of seemingly unconfined stream valley included streams that were largely encompassed by low-lying wetlands that flood, not so much in response to overbank stream flow, but due to seasonally fluctuating local groundwater tables. These wetland surfaces were non-alluvial (colluvial) in genesis. Such stream channels could be deemed “wetland confined” forms from a genesis perspective. In other words, the stream channel carved through a pre-existing wetland surface, as opposed to the wetland surface being built by stream alluvium. Under a geomorphic process characterization, these systems are actually more similar to the upland-confined colluvial valleys than the unconfined alluvial valleys they more closely resemble in terms of habitat types.

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 first- and second-order streams, but only those with wetland flats subject to overbank flooding (well-adjusted and unconfined) were present in third-order and higher systems. Seepage ravines most commonly occurred in first-order systems.

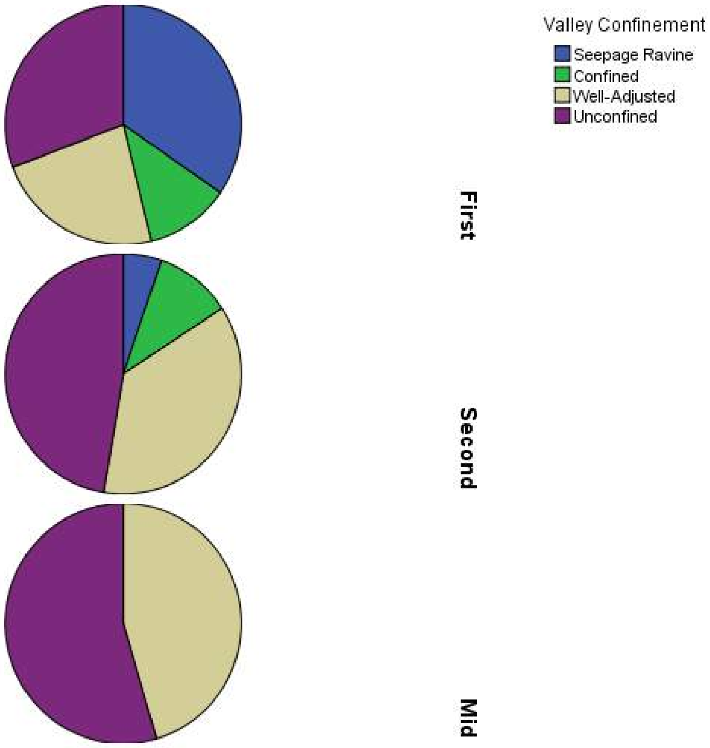


Figure 3.17. Valley Confinement Distribution by Stream Order.

Significant differences in the distribution of valley confinement classes were observed among the different watershed types (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, along with a characteristic presence of peaty or mucky soils, suggests that the karst valleys are more likely to have a history as organically 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, as well as the occurrence of unique sapping processes.

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 valley surfaces of first- and second-order systems have lower overall alluvial sediment origins than higher-order systems.

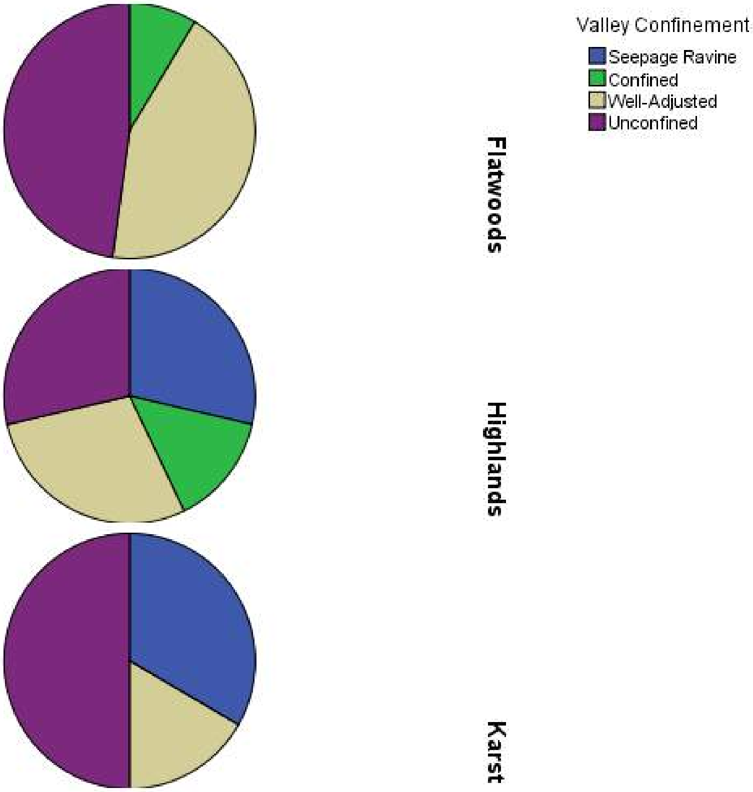


Figure 3.18. Valley Confinement Distribution by Watershed Type.

Significant differences in the distribution of dominant meander belt sediment or soil classes were observed among the different kinds of watershed (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 steady groundwater discharge regimes 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, non-alluvial wetlands in the riparian corridors of Florida.

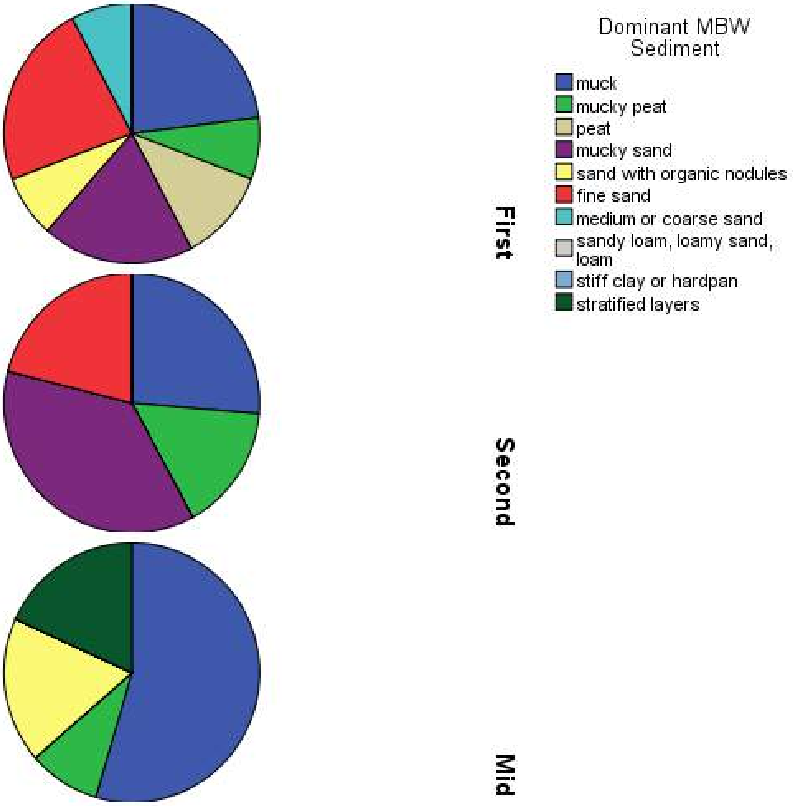


Figure 3.19. Dominant Meander Belt Sediment Distribution by Stream Order.

Channel and Floodplain Hydraulics and Alluvial Features

In Florida's humid subtropical 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 vertical accretions in 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.

Channel features inventoried included sand bed ripples, induced scour pools, bend pools, point bars, and sand shoals or riffles. Floodplain features included natural bank levees (alluvial ridges), linear backswamps with fine textured sediments, floodplain chutes, secondary channels indicative of past avulsions, a ubiquitous valley flat with fine textured soils, sandy bankfull benches between bends, and oxbow lakes or ponds in the floodplain.

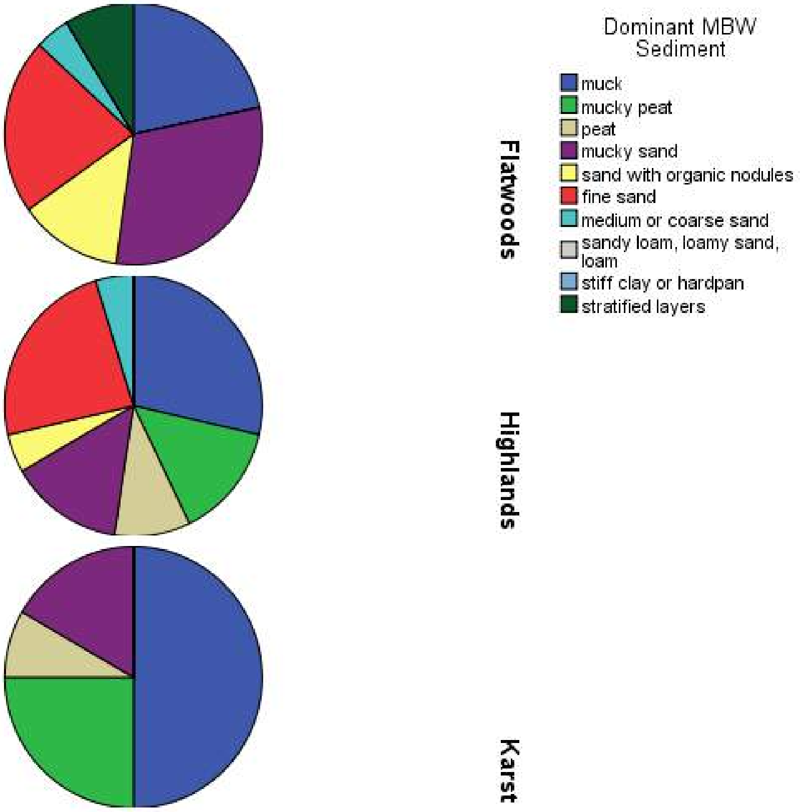


Figure 3.20. Valley Confinement Distribution by Watershed Type.

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.

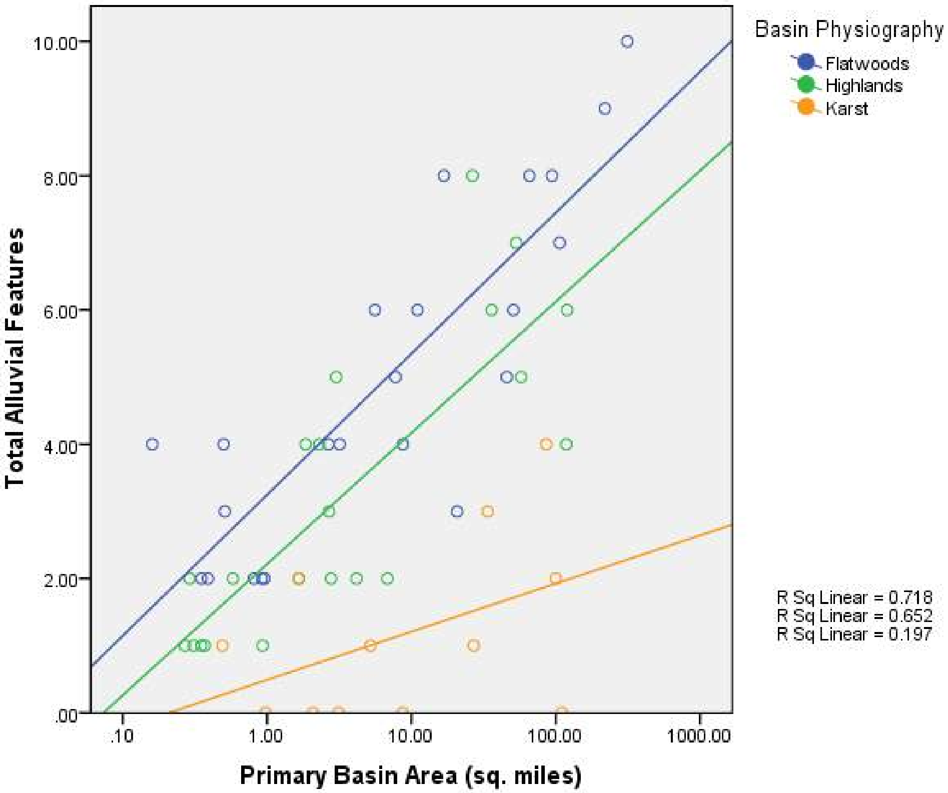


Figure 3.21. Alluvial Features Versus Drainage Area for Three Watershed Types.

Flood and bankfull channels were determined at each reach using the best available and most reliable field indicators (Figure 3.22). These are the flat floodplain when it is present and alluvial, and the inflection in all other non-karst and non-sapping streams. In the latter two groundwater systems, the most reliable bankfull indicators occurred at a scour line where sustained water levels water-pruned the roots of the biological banks. 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 and others 1989). Overbank durations and flood frequencies were generally less for the eight low-order, non-perennial streams gaged for this study (usually less than 10% of the record, occurring about four times per year, with a fair amount of inter-annual variability and differences among sites) (Table 2.5).

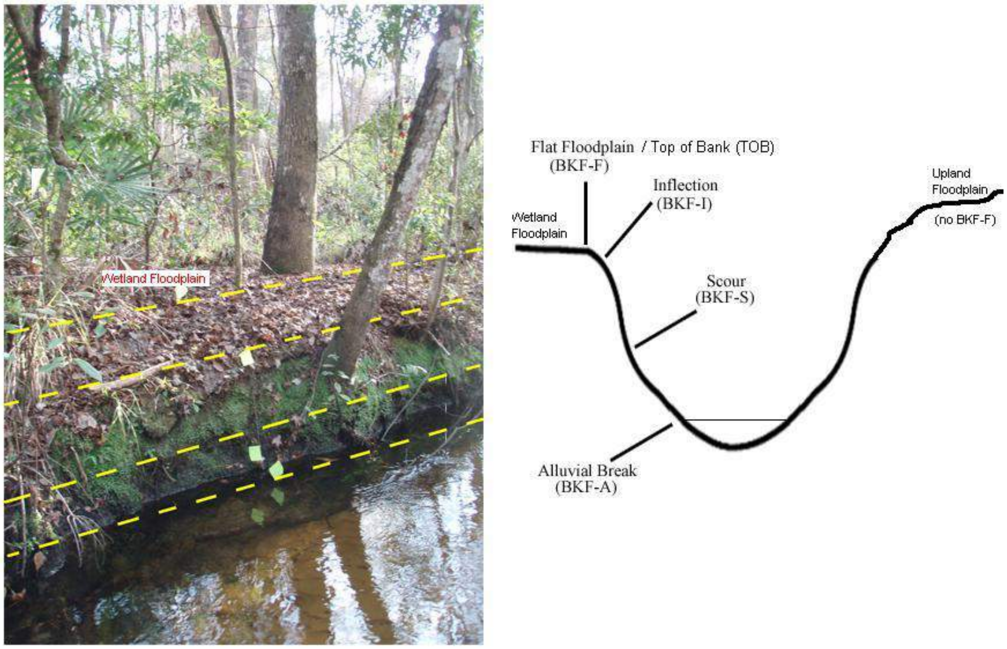


Figure 3.22. Bankfull Indicators.

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). 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 3.23. 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.

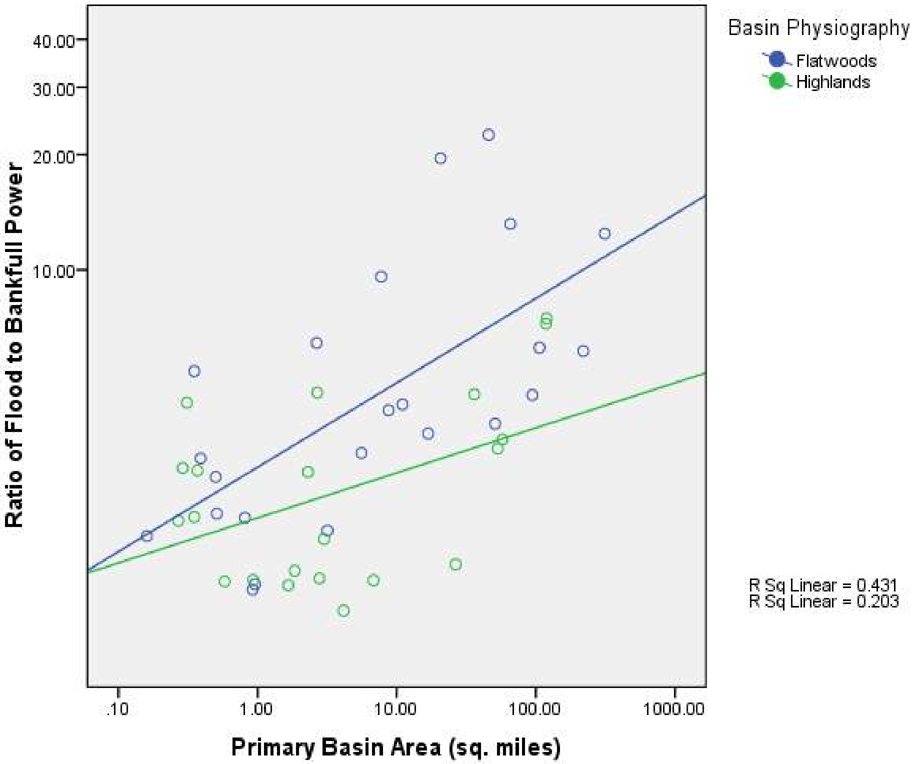


Figure 3.23. Flood/Bankfull Stream Power Versus Drainage Area by Watershed Type.

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 3.24). 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 the larger spates of the flatwoods are necessarily accommodated by larger (wider) flood channels.

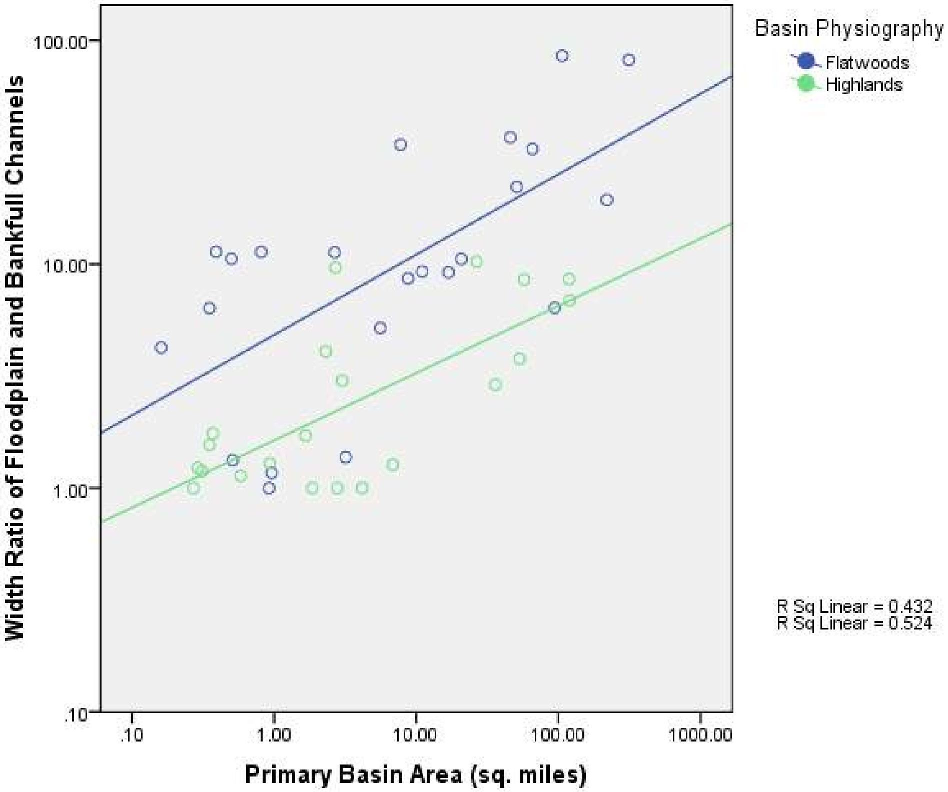


Figure 3.24. Flood/Bankfull Width Versus Drainage Area by Watershed Type.

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, albeit with much scatter. 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 3.25). 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.

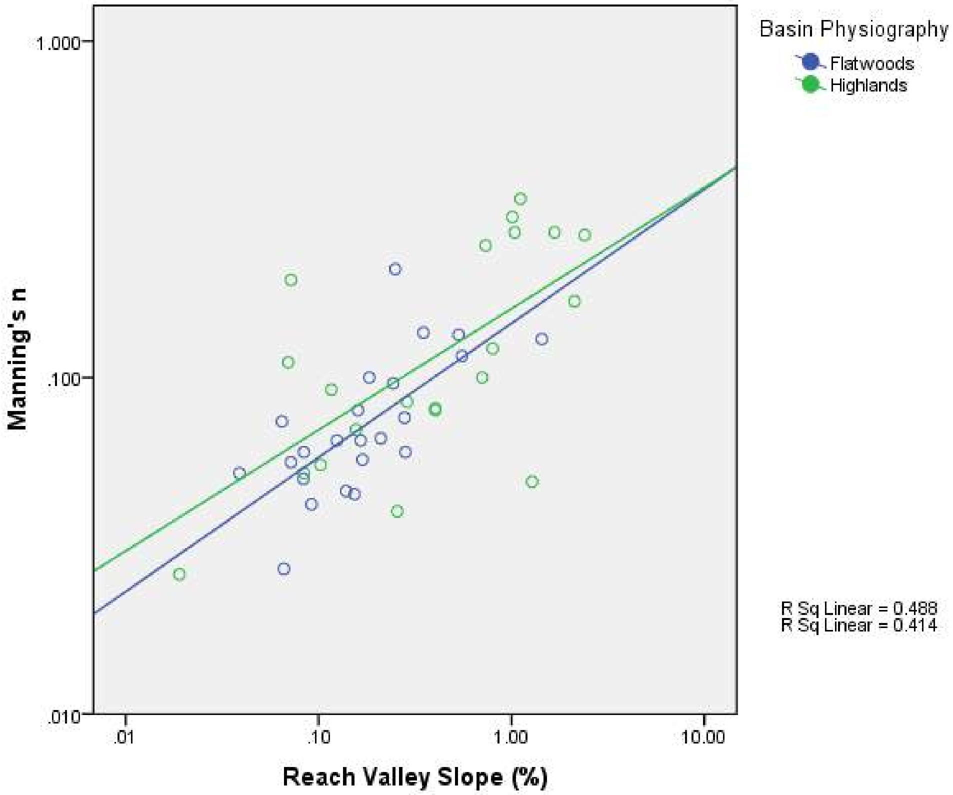


Figure 3.25. Manning's *n* Versus Local Valley Slope by Watershed Type.

However, these general patterns often exhibited many local exceptions and lots of scatter due to peninsular Florida's intense subtropical vegetative controls and how they interact with groundwater flow regimes. Complexities also arose due to a long history of differential solution weathering and previous marine submergence 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 streams in Florida. For that reason, the use of FPZ concepts is 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).

Florida's deranged networks should be viewed as essentially an otherwise dendritic network pocked with foci of geologic control. The varying magnitude of the geologic structures not only creates unchanneled waterbodies with varying depths and area such as in-line lakes and swamps, but also contributes to variable valley confinement along the channeled segments.

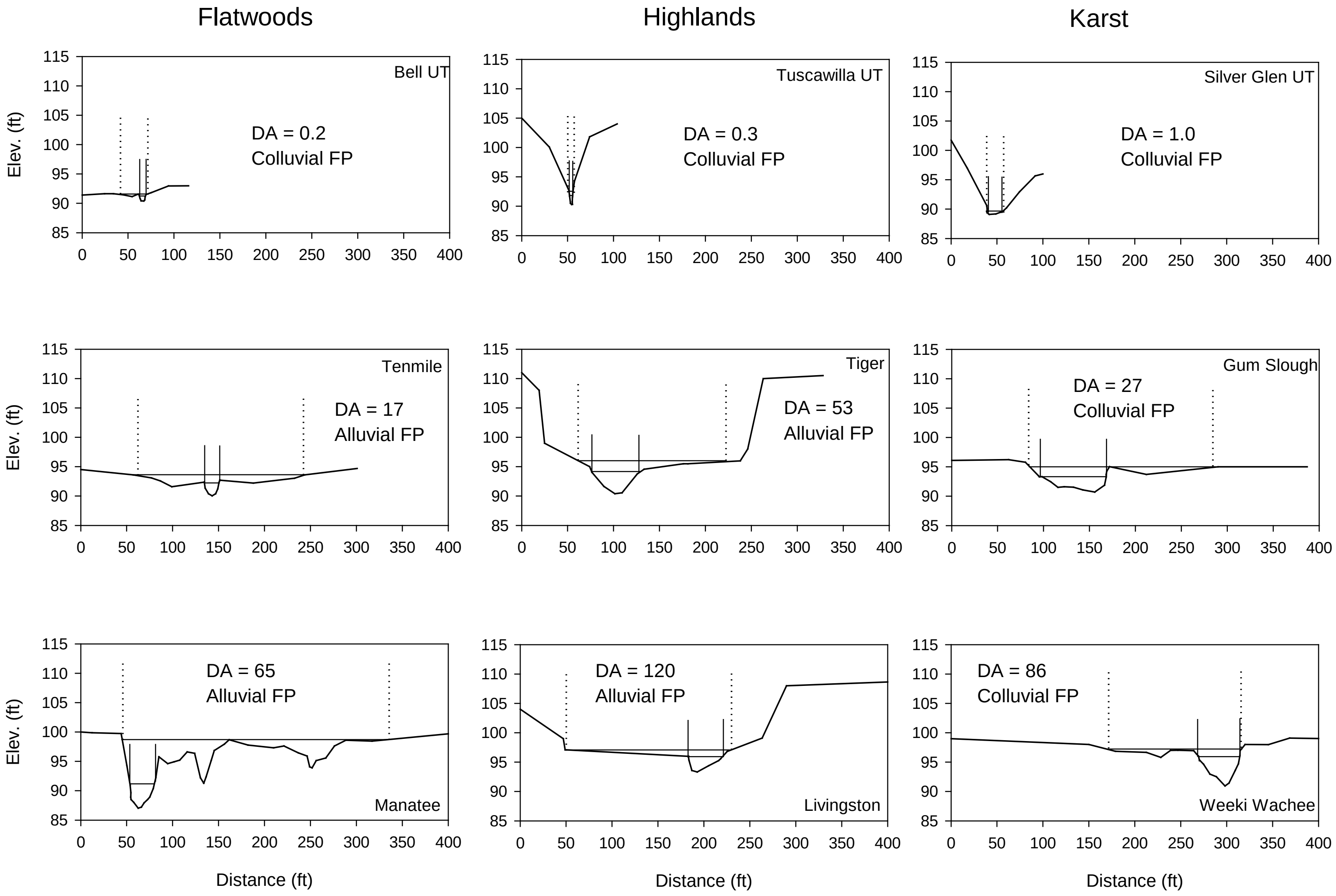
Descriptions of Valley Types and Their Landscape Associations

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 watershed types. Furthermore, the scale dependencies of common processes and associated valley forms differed among these three kinds of watersheds. It is a good idea to view watershed drainage type as the first hierarchy of consideration associated with the valley form and its formative processes.

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-dependent 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 surfaces tends to support niche requirements of different groups of vegetation and, presumably, different meta-populations of aquatic and terrestrial fauna (Thorpe and others 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 (*Quercus virginiana*) were generally only encountered on systems with either confined upland meander belts (colluvial genesis) or on natural sandy levees or islands (alluvial genesis). That example illustrates a key concept that similar plant communities can occupy riparian surfaces of different genesis. Therefore, plant communities alone are not necessarily reliable indicators of the fluvial processes that form and maintain the surfaces they occupy.

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-dependent. The various apparent scale dependencies and their interactions with physiography led to several common types of FPZs that were observed during this study and that became even more apparent after evaluation of these data. In fact, entire riverine classification schemes have been centered on similar aspects of valley controls and associated channel structure in Australia (Erskine and others 2005) and South Africa (Tooth and others 2004, Roux and others 2002). This approach to stream classification is referred to as River Styles (Brierley and Fryirs 2005).

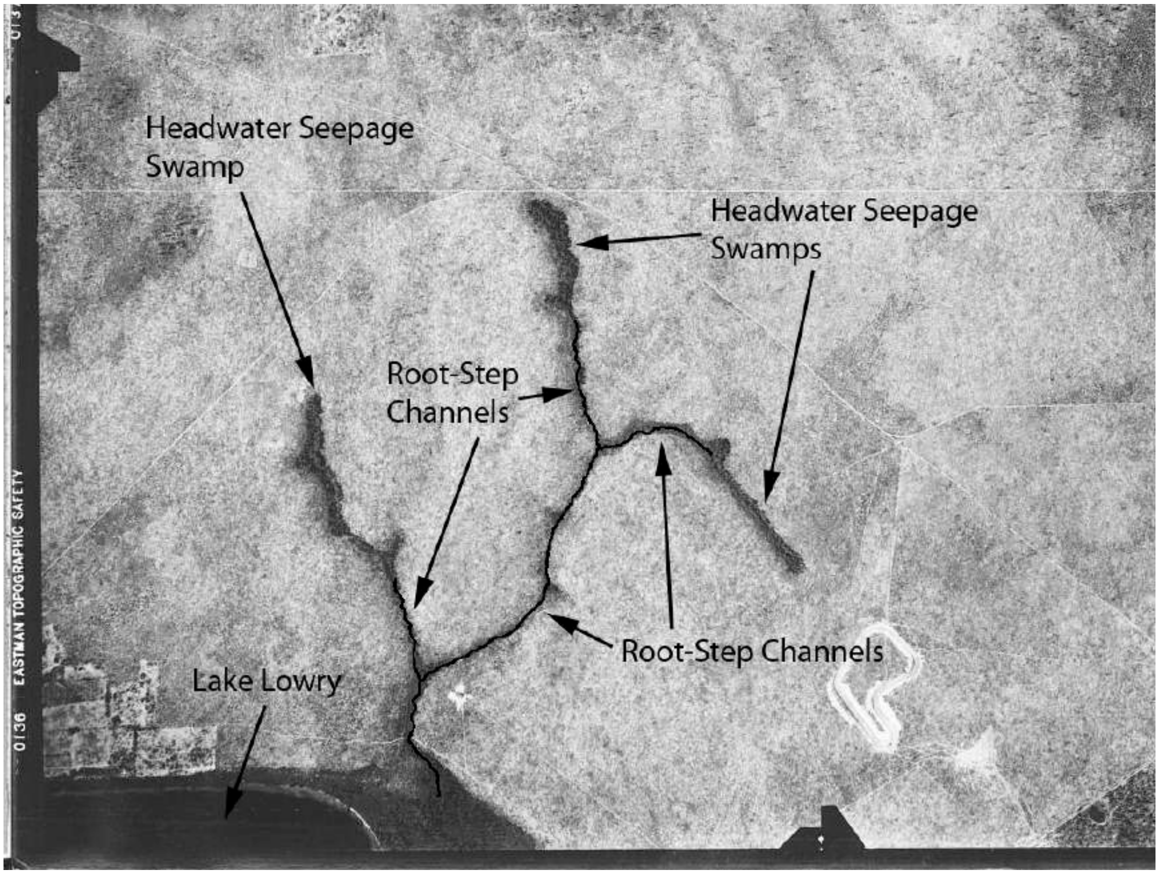
These types of observations revealed several basic types of colluvial versus alluvial valleys occupied by Florida streams. The positions of these systems in the drainage network (in association with drainage area) seemed to differ among the watershed types (Figure 3.26). For example, Tiger Creek drained 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.



Note: Dotted vertical lines delineate floodscape channel and solid vertical lines the bankfull channel. Vertical datums normalized for comparison.

Figure 3.26. Bankfull and Flood Channel by Watershed Type and Drainage Area.

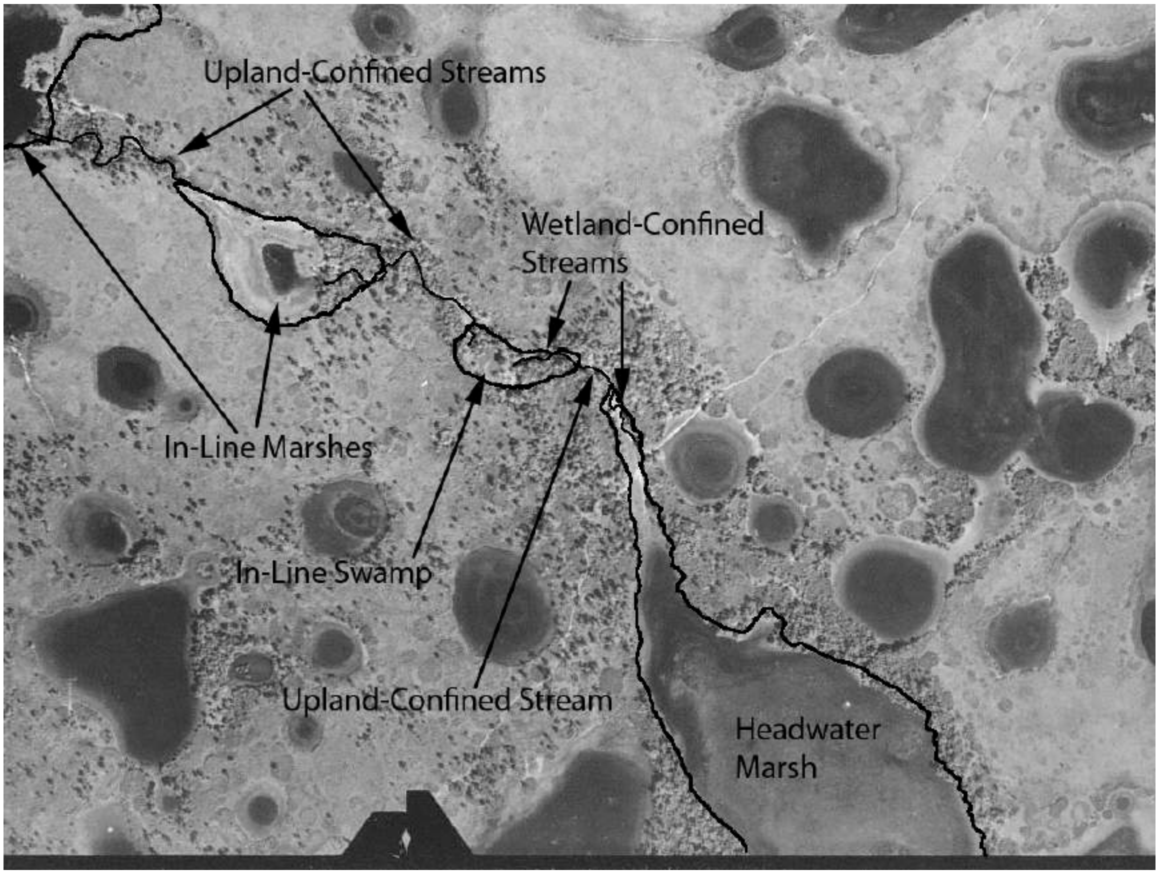
Valleys where alluvial processes and surfaces were almost completely limited to the stream channel bed, and their meander belts were dominated by soils and landscape features not created by modern alluviation were deemed to be colluvial valleys. Colluvial valleys included seepage ravines, upland-confined 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 3.27). 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.



Note: Scale is approximately 1 inch = 2,000 feet. Flow direction is toward the lake. Lake Lowry Unnamed Tributary (USDA 1943a).

Figure 3.27. Sapping Valleys with Seepage Ravines.

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 3.28). 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.

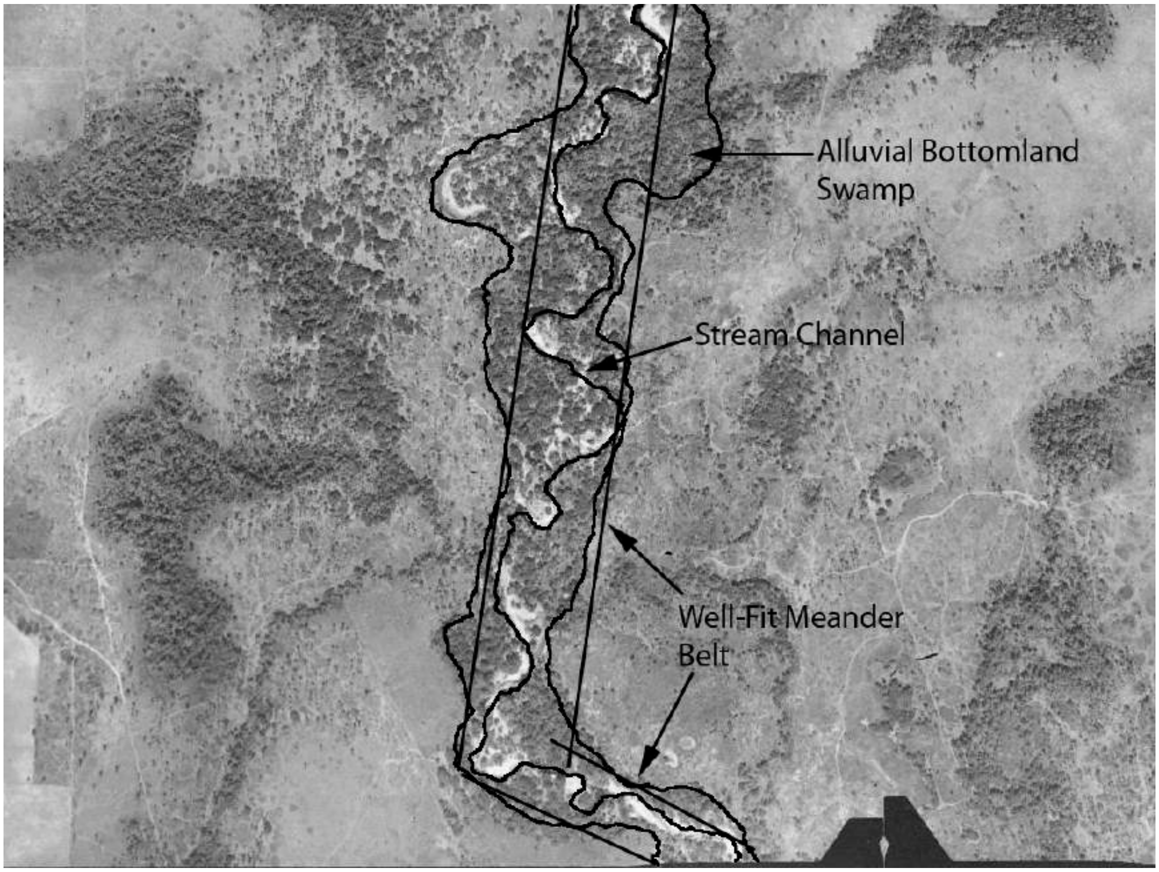


Note: Scale is approximately 1 inch = 1,000 feet. Flow direction is to the northwest. Lower Myakka Unnamed Tributary (USDA 1948).

Figure 3.28. Chain-of-Wetlands with Upland and Wetland Confined Channels.

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 3.28). 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.

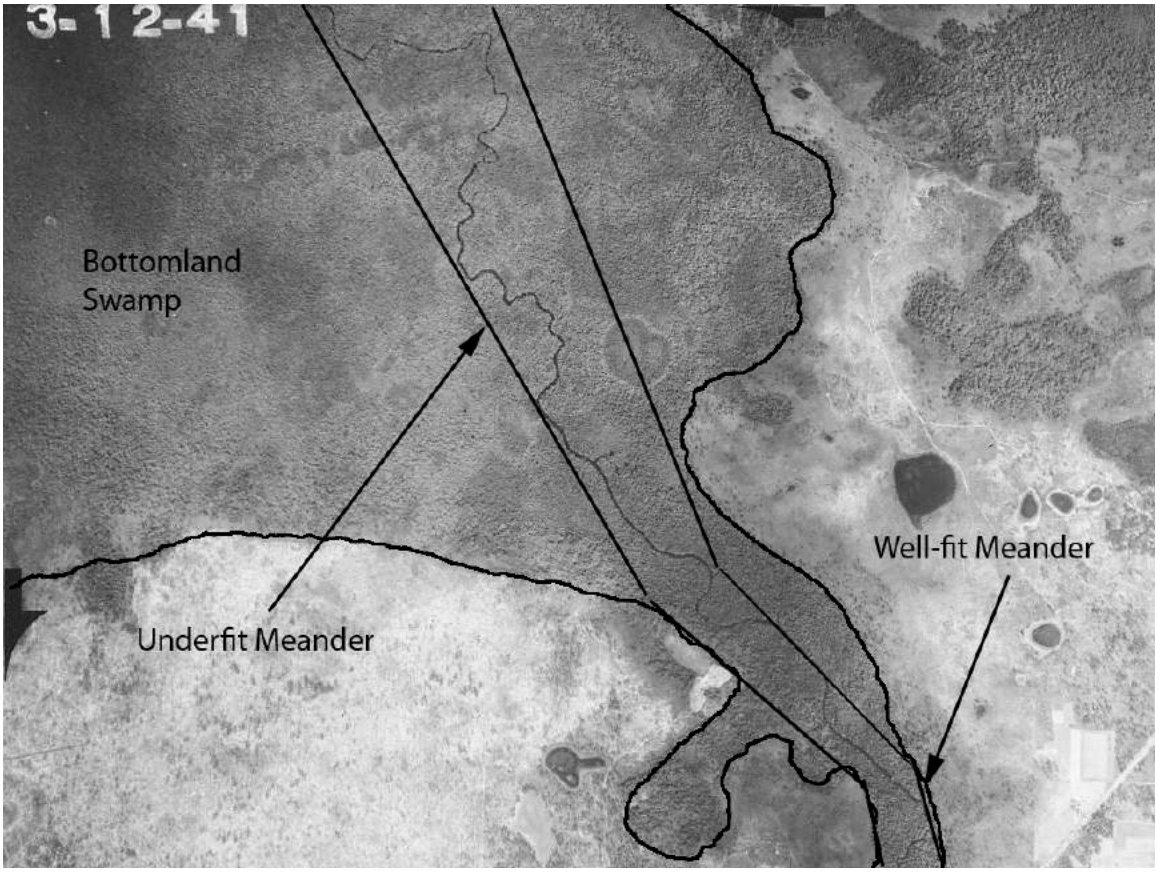
Valleys where alluvial processes and surfaces appeared to directly influence soils and landscape features within the meander belt were deemed to be alluvial. These valleys included well-adjusted floodplains and unconfined floodplains. Well-adjusted floodplain valleys have a channel meander belt that 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 3.29). These streams are said to be well adjusted to their valleys, because they generally meander 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 meandering features roughly parallel to the valley's long axis such as channel levees (alluvial ridges), linear backswamps, and oxbow lakes.



Note: Scale is approximately 1 inch = 1,000 feet. Flow direction is to the south. Horse Creek near Arcadia (USDA 1943b).

Figure 3.29. Well-Adjusted Channel Within a High-Gradient Alluvial Bottomland.

Unconfined channels meander through very wide valley flats compared to their meander belt width (Figure 3.30). 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.



Note: Scale is approximately 1 inch = 2,000 feet. Flow direction is to the southeast. Blackwater Creek near Cassia (USDA 1941).

Figure 3.30. Unconfined Channel Within an Immense Bottomland Forest.

These five genetic 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 formed in interaction with an array of non-alluvial surfaces along the valley. 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 few 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. Further research is needed 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 FPZs. 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.

CHAPTER 4
NATURAL KINDS OF STREAM SYSTEMS

INTRODUCTION

The prioritization of stream restoration projects and the design approaches to fix damaged streams (or arrest further damage) often starts with a regionally applicable 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 previously lacked a systematic, holistic, and quantitative classification for freshwater streams useful for management and restoration. This is necessary 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 a dominance of 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 subtropical climate with a major stochastic presence of powerful tropical storms, most of Florida's streams flow seasonally rather than perennially, and the stream corridors are 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 or in systems dominated by groundwater flow. 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 and others (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.

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 was 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 mid-west, 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. Regional curves developed for this study of peninsular Florida are presented and discussed in Chapter 5.

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 and others 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 dimensionless 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. One key drawback is that use of dimensionless variables leads to stream types that are inherently independent of scale, and many habitat variables are quite dependent on scale. For example, large fish taxa simply cannot swim or reproduce in tiny headwater streams of identical Rosgen type to major rivers 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 Simon and others (2007), Montgomery and Buffington (1997), Juracek and Fitzpatrick (2003), and Harmel and others (1999). Some have found Rosgen's system was readily adaptable to their region of interest (Epstein 2002, Doll and others 2003, Savery and others 2001, Hey 2006).

An earlier regime-theory 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 as neatly (Miller and Gupta 1999, Gupta 1995, McCarthy and others 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 rivers 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, subsequently conveys the routine 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. Hundreds of millions of dollars have been spent to restore flood pulses to the Kissimmee River in south-central Florida to recover lost ecological functions.

Approaches not presuming flawless 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 and others (2005) adopted a similar approach specifically for Australia's tropical rivers, originally identifying nine river types. Saynor and others (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 one 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. The systematic approach taken ended up incorporating a well-established conceptual stream typology for Florida based largely on water sources that serve as top-down controls on water quality and benthic communities (Rogers 1933, Beck 1965, FNAI 1990). The classification approach also attempted to verify the applicability of an existing dimensionless and shape-based stream classification at the reach scale (Rosgen 1996) as part of a process-based approach relating watersheds and valley characteristics to stream type, with mixed results. The recommended classification recognizes that streams are scale-dependent systems that belong to their watersheds and valleys. So, rather than a “stream channel” classification system, this is a more holistic and intrinsically “process-based stream system” classification requiring knowledge of watershed drainage conditions, watershed size, valley slope and position in the drainage network as well as channel shape, dimension, and substrates.

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 FDEP defined three stream regions outside of the Everglades/South Florida region, based on an extensive database of macroinvertebrate species and related metrics (Barbour and others 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 subtropical 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.

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 and others (2009) applied Rosgen's shape-based classification to streams largely confined to northeast 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 northeast Florida and south-central Georgia. This is not surprising given that the panhandle averages about 10 more inches of rain per year than northeast Florida. Examination of hundreds of streams across Florida by our team indicates that Rosgen C5 and E5 classes are the dominant forms on the peninsula.

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 and others 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 and others 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 and others 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, deep sand layers, and lower waterbodies large enough to freely accept the transferred sediment. This process can lead to a relatively straight valley that abruptly terminates at its upstream end at a steep hillslope shaped like an amphitheater. A seep feeding the stream channel typically emanates from close to the base of the amphitheater. 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) can 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 principles 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, subtropical, sandy-soil, low-gradient peninsulas on limestone.

Fundamentally different stream types in the state 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. A regionally specific, process-based, and multi-scale classification is clearly 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 more completely process-based and dimensional classification approach than we previously had is likely to be essential to moving the practice of stream restoration and management forward in Florida.

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.

FNAI "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.

Before discussing the remainder of FNAI stream types, it is important to review three catchment settings (flatwoods, highlands, and karst). 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. 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.

The highlands catenas consist 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. 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 and others 2004). Thirty-three of them have median discharge greater than 100 cfs, reportedly forming the highest concentration of first-magnitude springs in the world (Rosenau and others 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.

FNAI "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 3 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 150 cfs.

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

FNAI "Seepage Streams" originate from shallow groundwaters 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 FNAI's 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 "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 organic sediment derived from biota within the spring run.

The FNAI classification is suitable for conceptual purposes, adequately describing many streams in the state. The delineative criteria are based on water quality (suspended solids, pH, and color), the source of water, and the media it contacts 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 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 4.1 through 4.6 depict photographs comparing perennial spring runs, flatwoods and highlands streams under varying flow conditions.

Alligator Spring Run, September 7, 2008

Figure 4.1. Example of Karst Spring Run at Bankfull Stage.

Little Haw Creek, September 8, 2008

Figure 4.2. Example of Blackwater Stream at Wet-Season Flood Stage.

Rice Creek, July 2, 2008

Figure 4.3. Example of Flatwoods Stream near Bankfull Stage.

Tiger Creek, June 9, 2009

Figure 4.4. Example of Highlands Stream at Bankfull Stage.

South Fork Black Creek, June 19, 2008

Figure 4.5. Example of Highlands Stream at Baseflow Stage.

METHODS

Site Inclusion, Field and Desktop Measures

All 56 sites selected and measured by the methods described in Chapter 1 are included in the classification analysis. 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 based on group categories (flatwoods, highlands, and karst). Separate factors using principal components analysis (PCA) were also derived from all 123 variables for each of these three groups. PCA is a data reduction and exploration technique. Each principal component is derived from a combination of the measured variables, and is often interpretable as a latent variable for processes that cannot be directly measured.

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 run 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 dendrograms 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 rerun on the reduced variable set with varimax rotation. Coefficients were sorted by size, and displays 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.

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.

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.

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.

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 first 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-dependent 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 second 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 third 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 first 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 third 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 fourth 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 fifth 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 Chassahowitzka River, for example. Subgroup 2 consisted of the Weeki Wachee River, the only other first-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 misassigned 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 4.7 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 and others 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 (*Sabal palmetto*) 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 several 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 shortcoming 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 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, amphitheater-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 soil drainage 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) alternates 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 first-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 first-magnitude runs in the study, providing a dominant (bankfull) discharge of 122 cfs and 164 cfs, respectively.

Subgroup 2 included three second-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 third or fourth 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 third-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 (first magnitude greater than 100 cfs, second magnitude between 10 and 100 cfs, third magnitude between 1 and 10 cfs, and fourth 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 6 cfs) which falls well within the second magnitude range. The division between medium and small runs is likely to occur between 1.9 to 7.4 cfs, nominally 5 cfs (plus or minus 2 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 4 root-step systems plus 4 other highlands streams, and 1 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-dependent 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 dependent 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, strongly suggesting limitations related to convergence of form.

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. Subgroup 1 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 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 (9 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 (0 to 3), 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 effects 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. 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 that

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 are 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 subtropical 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 Openness" 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 4.5). 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.

Table 4.5. 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.

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 subgroup represented a catchall of large and small systems draining flatwoods and highlands basins. Percent A+C soils were variable, ranging from 4 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 3 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 of 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 classification 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 that drained a 2.7 square mile basin in the highlands. It was 8 feet wide and 1 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 5 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 that would be a dicey proposition 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 magnitudes and alluvial processes means that other kinds of variables must also be considered.

CONCLUSIONS REGARDING STREAM SYSTEM TYPES

Overview

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 dependent 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 key concepts from the existing limnology-based classification schemes for Florida streams.

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, dependent on landscape-derived hydrology and drainage area. Based on this approach, there appear 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 watershed soil drainage categories 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 cluster 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 kinds of watersheds were combined to create a “blackwater” stream confidence chart applicable to streams in both landscapes (Figure 4.6). Karst systems were statistically different in those associations and so warranted separate consideration (Figure 4.7).

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 watershed types (Table 4.4). Such features seemed to consistently appear in basins larger than four 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 4.8). These thresholds are not absolute and actually have a probabilistic aspect. For example, smaller localized exceptions can occur in both settings. 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 10 and 25 square miles were measured, so the alluvial floodplain threshold for highlands streams could be as low as 10 square miles. Likewise, our continued work in flatwoods basins subsequent to this study has shown the presence or absence of alluvial valley features can vary at sites ranging between approximately 3.5 and 5.5 square miles.

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. 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 are diminished.

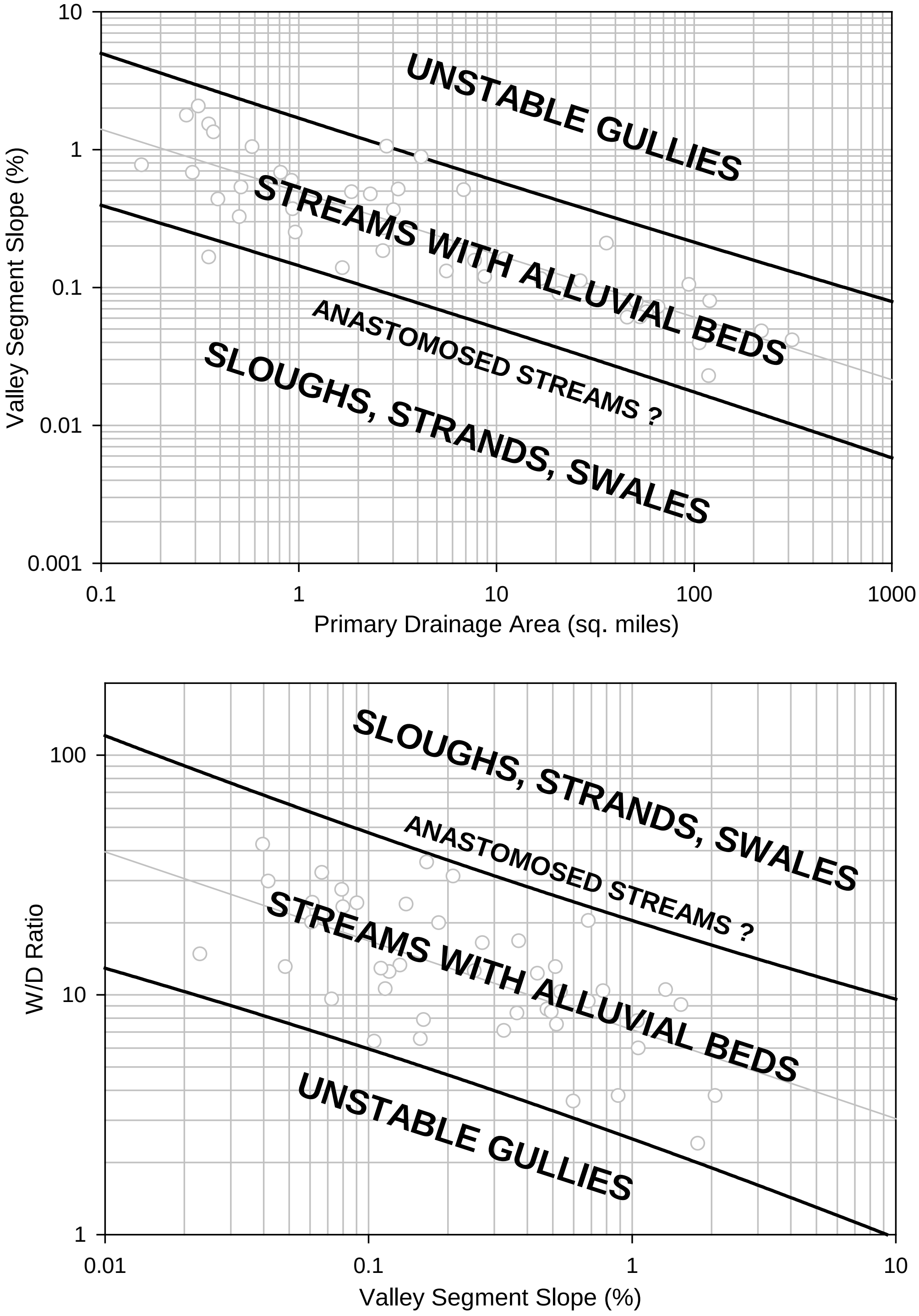


Figure 4.6. Single-Channel Blackwater Stream Zone-of-Confidence.

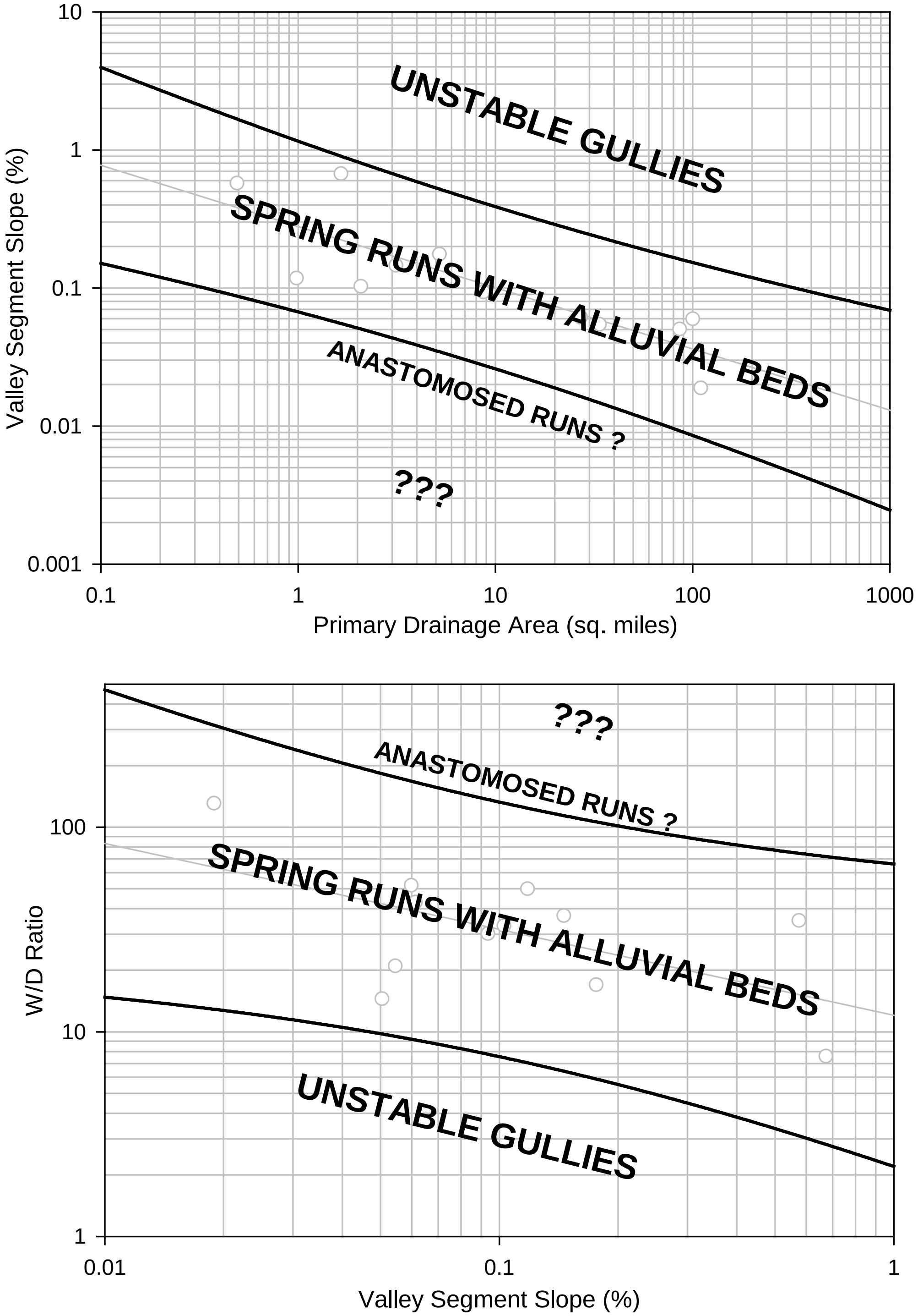


Figure 4.7. Single-Channel Spring Runs Zone-of-Confidence.

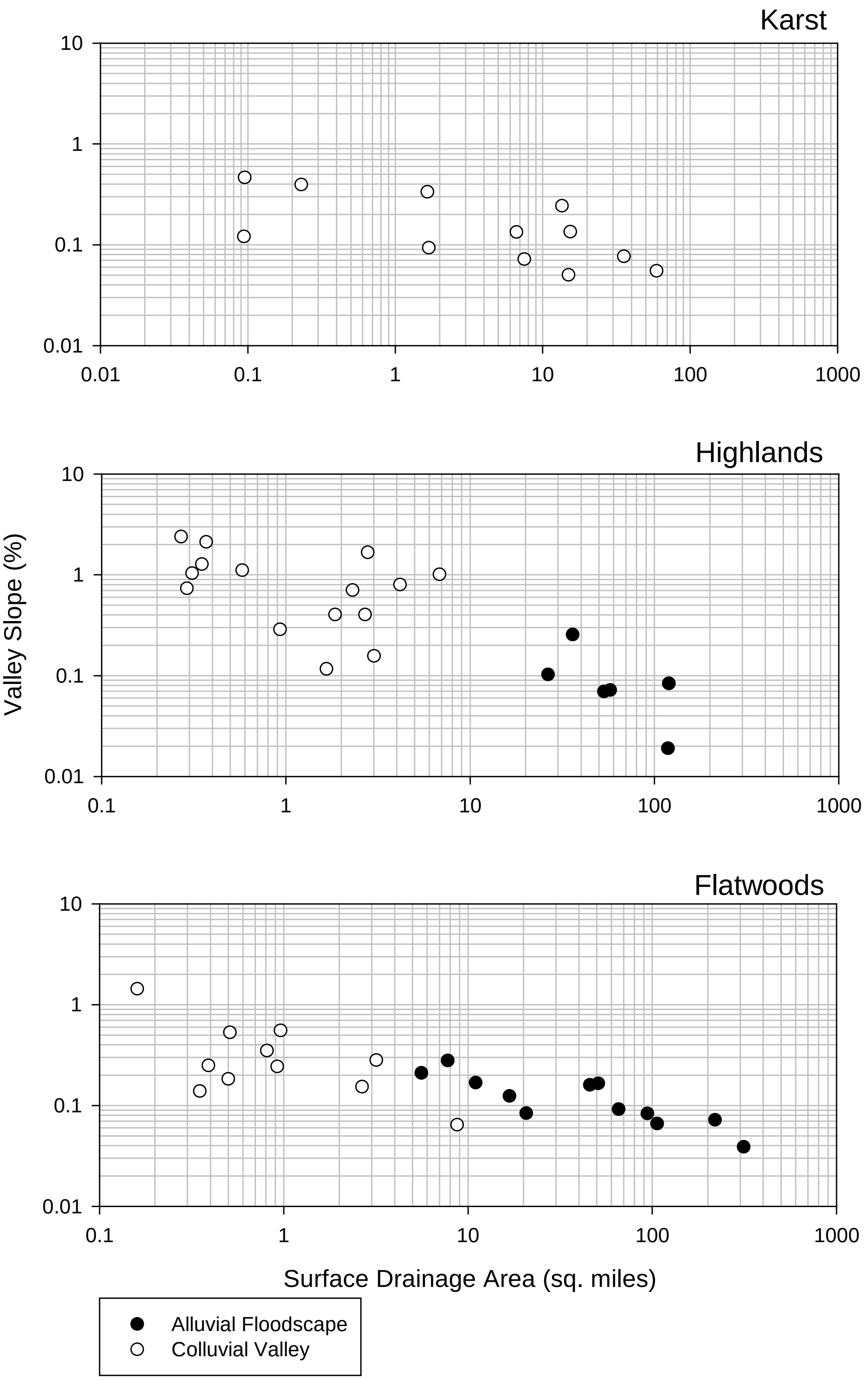


Figure 4.8. Alluvial Valleys Associated with Drainage Area by Watershed Type.

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 (watershed drainage, 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 and others 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 an optional lower-hierarchy modifier instead. We see value in using valley confinement as a way of helping to define some functional process zones within certain stream types.

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. While some in-stream habitats can be used to classify streams, they are largely viewed as dependent variables rather than direct classifiers because they are associated with particular combinations of more universally determinable factors including basin soil drainage, valley slope, bankfull discharge, and seasonal flood discharge. Those latter factors can be estimated 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. In some cases it may be most useful to consider habitat patch variables as monitoring items to determine stream integrity or restoration success. Although habitat types can overlap extensively between certain stream types, the typology helps to narrow down the potential sustainable habitats for a site.

The first step in this delineation is to determine if the basin is draining a flatwoods, highlands, or karst watershed. The vast majority of karst spring runs and their headsprings are inventoried and mapped. Check the applicable FDEP or Water Management District websites 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 watersheds can produce darkly stained water during the wet season, usually soft with low to neutral pH. Flatwoods basins 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[4]. The delineative threshold occurs when HSG soils A+C collectively sum to less than 40% of the total soil cover in the catchment (Figure 2.7). If that is the case, then proceed to the "Streams draining the flatwoods" section. If the HSG A+C cover sums to greater than 40%, 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 40%, the reality is that streams draining HSG A+C soil cover close to that inflection (ranging from 35 to 45%) 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 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 5 to 25 square mile watersheds with 35 to 45% A+C soils because that combination represents the zone of greatest uncertainty concerning the alluvial characteristics of the floodplains between highlands and flatwoods and some of the stream types within each of those two kinds of drainage systems.

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, groundwater pumping, mining, and 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 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). The analysis of basin response to comparatively uncommon storm events [with mean annual (2.33 year), 25-year and 100-year return intervals] cannot substitute for the aforementioned assessment.

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 unsewered lands (Riley 1998). This research is most applicable for rural sites or special conditions where

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[4] Native B soils were not mapped on the peninsula.

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 abbreviations that start with the watershed type (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) or on the discharge class for karst systems (e.g., MM = medium magnitude), 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 Thorp and others (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 report 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 surfaces including anabranches, levees, linear backswamps, etc.

Thorp and others (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 4.9). It should also be recognized that the apparent thresholds among stream classes are actually transitional in nature. The closer the system is to the line, the more likely it is to have shared or intermediate characteristics with the adjacent group. This has been verified by visiting more than 14 systems near the “lines” during 2011 (AMEC 2013). Furthermore, some systems close to the line may occasionally be more properly classified in the adjacent group. These classes should be viewed more as central tendencies than as absolute or rigid thresholds. They were derived to help organize thought concerning common associations of fluvial form and process in Florida landscapes, not to prescribe it.

Streams Draining Flatwoods

The delineative threshold for applying this section occurs when HSG soils A+C collectively sum to less than 40% of the total soil cover in the catchment. Five of the six main classes proposed for flatwoods landscapes sort well along a plot of reach valley slope versus drainage area (Figure 4.9). 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 are associated with these two classes.

Figure 4.9 was developed in two phases. The first phase involved assessment of the 23 flatwoods sites included in the original FIPR study (Kiefer 2010). Some gaps near the original classification boundaries were further explored as part of an AMEC (2013) study conducted for the FDEP. AMEC (2013) involved field reconnaissance of 14 additional peninsular sites selected purposefully to fill in those gaps, as well as desktop analysis of an additional 116 streams to further refine the upper and lower boundaries for single-thread streams and to extend the classification to its useful limits for larger streams. This approach enabled the delineative boundaries between types to be more finely resolved. Even so, it is important to understand that streams exist along a continuum and that sites located close to the classification line may be intermediate in characteristics or may be better described by the adjacent classification at times. Therefore, further guidance on the use of field indicators at such sites is provided.

Wide Channels of Colluvial Valleys (FW-CV-WC)

Two kinds of low-order streams are common in the flatwoods. The most common, FW-CV-WC systems, represent the fluvial forms usually draining headwater wetlands or chaining together two wetland depressions along a low-order valley. In other words, these systems are most often encountered as the interior stream linkages in chains of wetlands. They are characterized by high W/D channels that drain small flatwoods basins through colluvial floodscapes (Figure 4.10). Watersheds range from 0.1 to 4 square miles, with valley slopes ranging from 0.07% to 2%. These floodscapes usually occupy first-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.

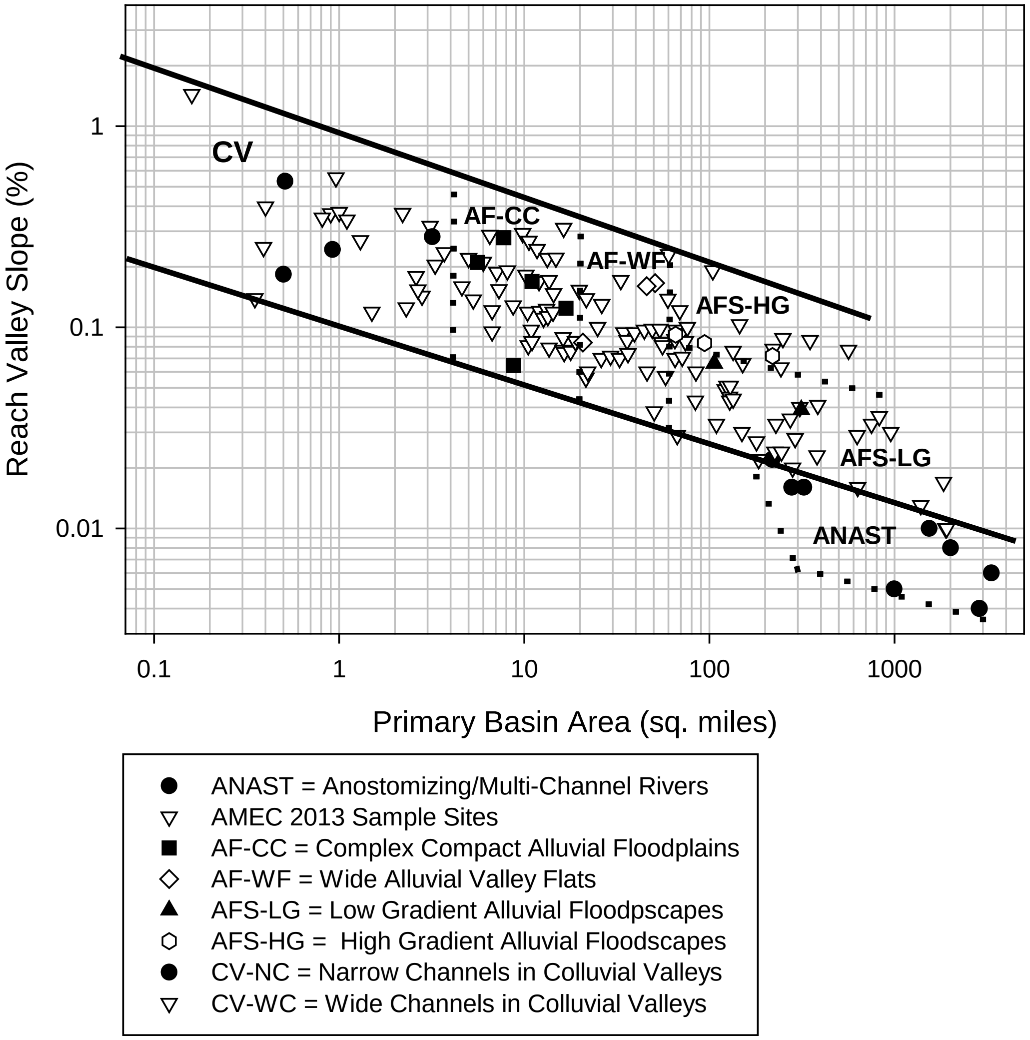


Figure 4.9. Flatwoods Riparian System Types by Drainage Area and Valley Slope.

The second kind of common low-order flatwoods stream type, FW-CV-NC, has comparatively low W/D channels. These are discussed in the following section, but for now it is instructive to preview their differences from the FW-CV-WC type. 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 second-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 4.10). This means that they terminate at the relatively low local 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 first-order chain.

Lower Myakka UT 3

Figure 4.10. Example of FW-CV-WC Riparian System.

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 4.12). 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 first-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).

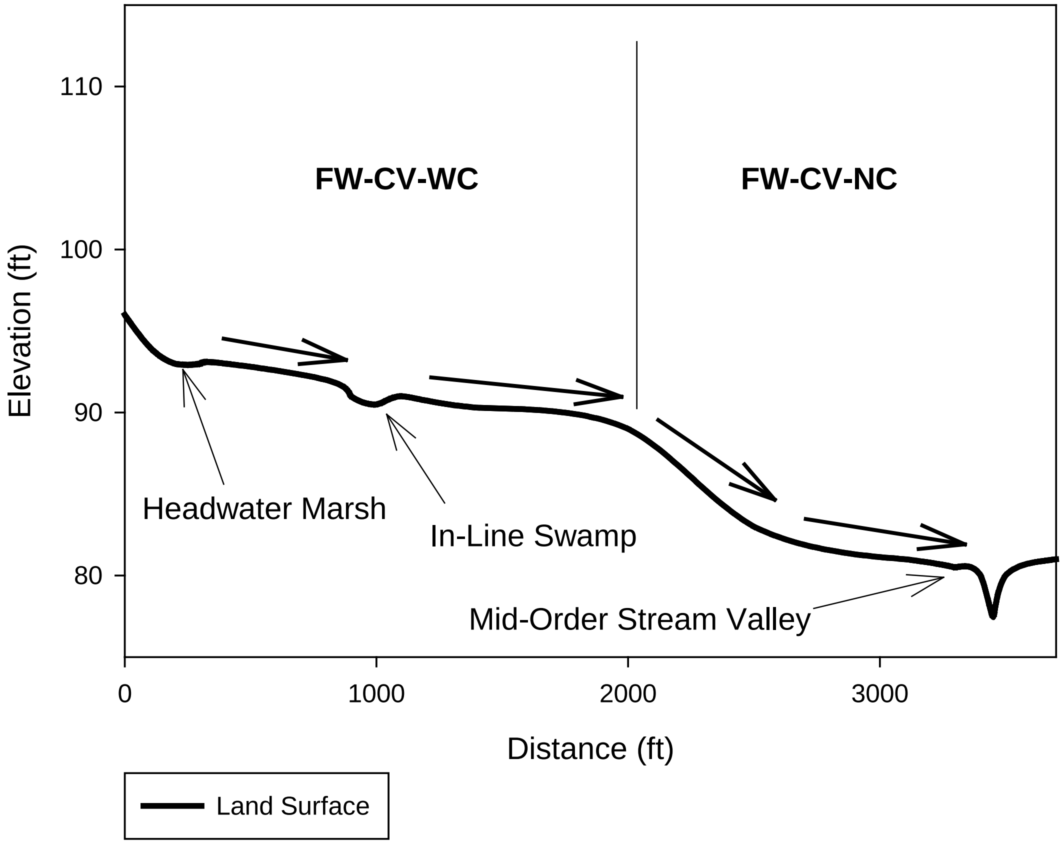


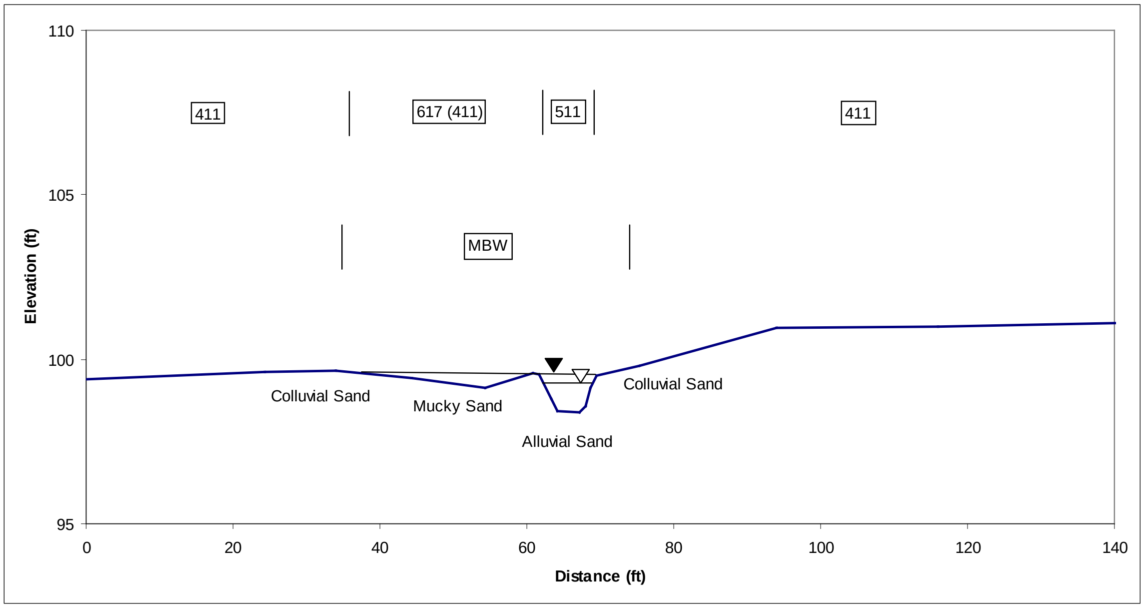
Figure 4.11. Typical Landscape Positions of Flatwoods Colluvial Systems.

The colluvial floodscapes of FW-CV-WC systems typically consist of either sand or mucky sand soils with hillslopes that may or may not confine the meander belt (Figure 4.13). 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 (*Quercus laurifolia*)]. Pines and palmettos often flank most of the narrow meander corridor, which is typically less than 75 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 (*Pinus elliotii*), and often with dense wax myrtle (*Myrica cerifera*) thickets.

Lower Myakka UT 2

Figure 4.12. Partially Exposed Shallow Root Discs on a FW-CV-WC Channel Bed.

Figures 4.13 through 4.17 depict a suite of characteristic valley plant community and soil cross-sections. The communities follow the Florida Land Use and Cover Classification System (FLUCCS), which uses a three-digit code for each community type (FDOT 1999). Collectively, these sections illustrate that FW-CV-WC riparian communities are subject to the soil moisture and fire frequencies of the surrounding landscape and that alluvial processes are unlikely to be a major factor in defining them far from the channel. Figure 4.13 depicts a common configuration where the valley has comparatively lower soil moisture regime with fire frequencies high enough to partially penetrate the meander belt. The meander belt therefore consists of patchy hydric hammock vegetation (617) interspersed within a matrix of pine flatwoods (411). The hydric hammock, where present, hugs the channel, within 10 to 15 feet of the banks where soil moisture is likely to be greatest during the wet season. Characteristic bank and meander belt species include laurel oak, buttonbush (*Cephalanthus occidentalis*), slash pine, and cinnamon fern (*Osmunda cinnamomea*) in the hydric patches, with saw palmetto, slash pine, blueberry (*Vacciunium* sp.), live oak, and bracken fern (*Pteridium aquilinium*) on most of the rest of the surface.

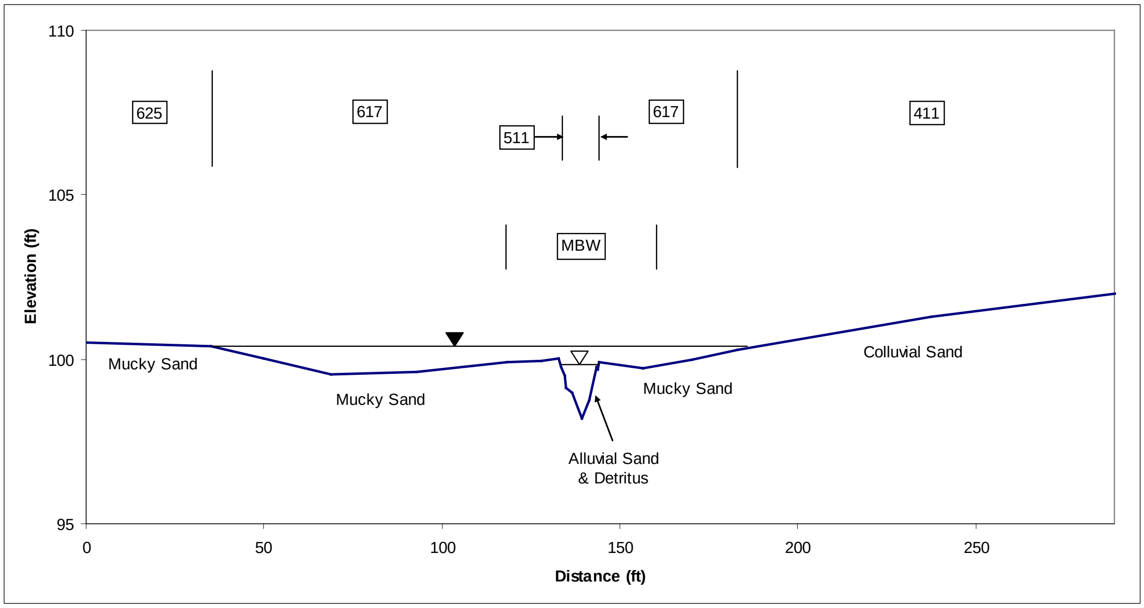


Bell Creek UT

Figure 4.13. Section of a FW-CV-WC System with Flatwoods Confined Valley.

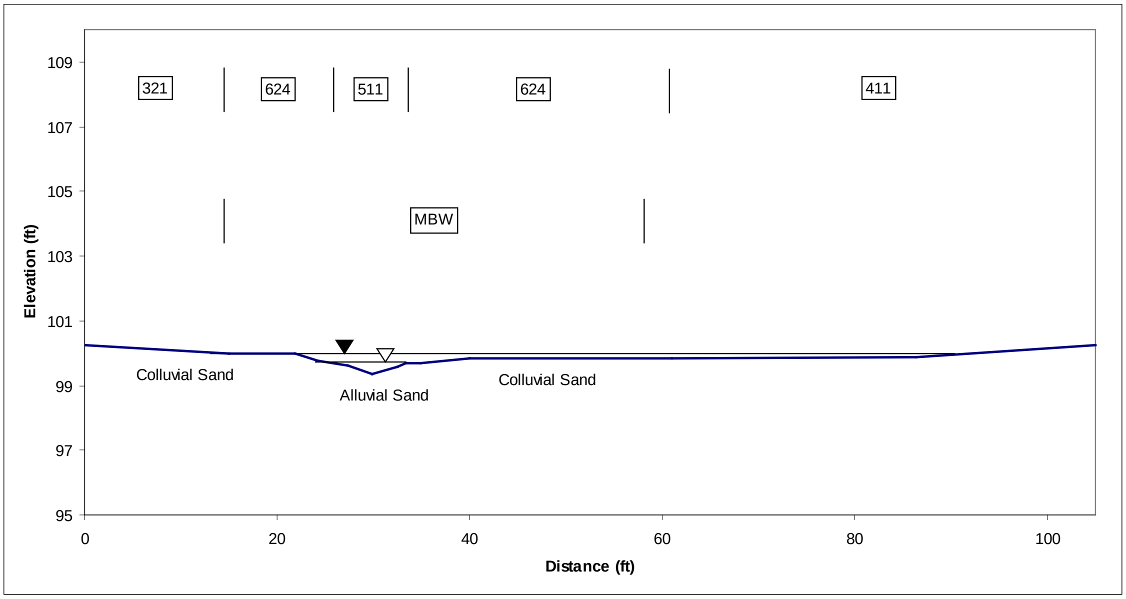
Figure 4.14 also depicts a valley flanked by pine flatwoods (411), but with the meander belt running well-within a wide colluvial shallow hardwood swamp (617) in an area with deeper and wider wet-season inundation than the previous example. The swamp would likely be present, and perhaps deeper, without the stream channel draining it. Its surface is non-alluvial. Fire rarely penetrates the swamp due to its sustained soil wetness. Dominant species in the wetland include laurel oak, red maple (*Acer rubrum*) and water oak, with scattered slash pine and saw palmetto. Bank species include those taxa plus buttonbush, dahoon, gallberry (*Ilex glabra*), blackgum, Walter's viburnum (*Viburnum obovatum*), highbush blueberry (*Vaccinium corymbosum*), cinnamon fern, and wax myrtle.

Figure 4.15 illustrates a case where the landscape is dominated by a dry prairie community type (321) associated with the highest fire frequency of Florida uplands. Fire penetrates the entire valley, leading to a fire-tolerant assemblage in the meander belt (624). The dominant plants are fire-tolerant species such as cabbage palm, slash pine, Fakahatchee grass and saw palmetto, with early colonizers such as wax myrtle (dense) and Carolina willow (*Salix caroliniana*) (scattered). The banks support those species plus some scattered buttonbush and Walter's viburnum.



East Fork Manatee UT 2

Figure 4.14. Section of FW-CV-WC System with Unconfined Swamp Valley.

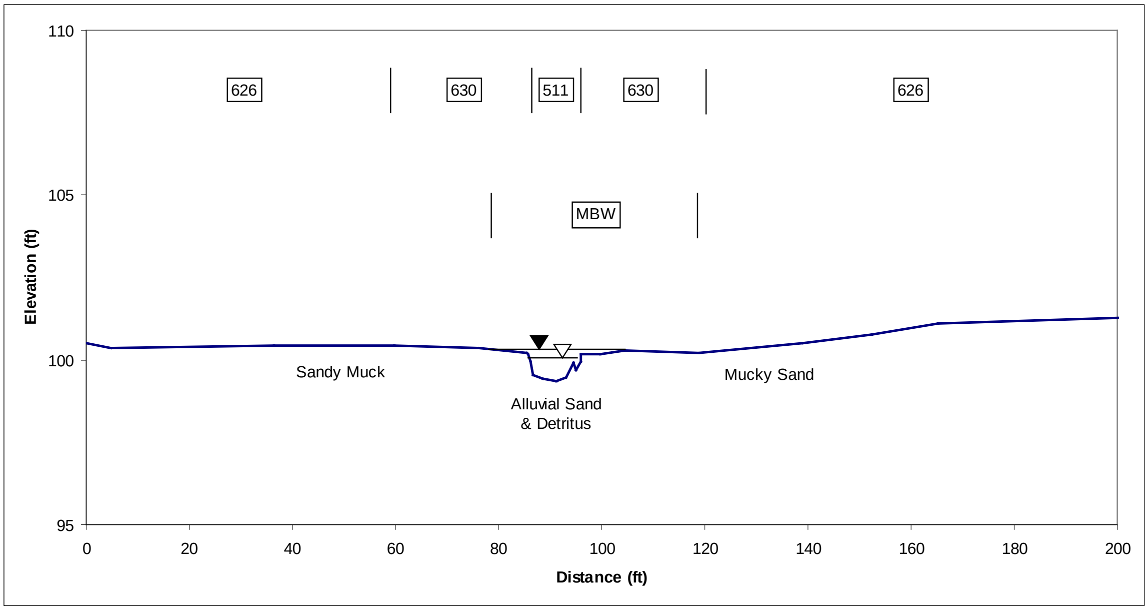


Lower Myakka UT 3

Figure 4.15. Section of a FW-CV-WC System with Dry Prairie Confined Valley.

Figure 4.16 also illustrates a valley dominated by a pyrogenic community, but in this case one with a wet soil moisture regime due to a high groundwater table. The resultant dominant hillslope community is part of a much broader regional cutthroat grass savanna (626) with a scattered open canopy of slash pine and patches of gallberry and saw palmetto. The meander belt is subsumed by a slightly broader mixed hardwood and conifer swamp (630). The stream banks and swamp consists of dense patches of gallberry, with scattered shiny lyonia (*Lyonia lucida*), slash pine, cutthroat grass

(*Panicum abscissum*), and cinnamon fern. It is essentially an extension of the cutthroat community where the hardwood shrubs, especially gallberry thickets, and pines create substantially more canopy cover. Patches of grassy arrowhead (*Sagittaria graminea*) occur on the channel bed.

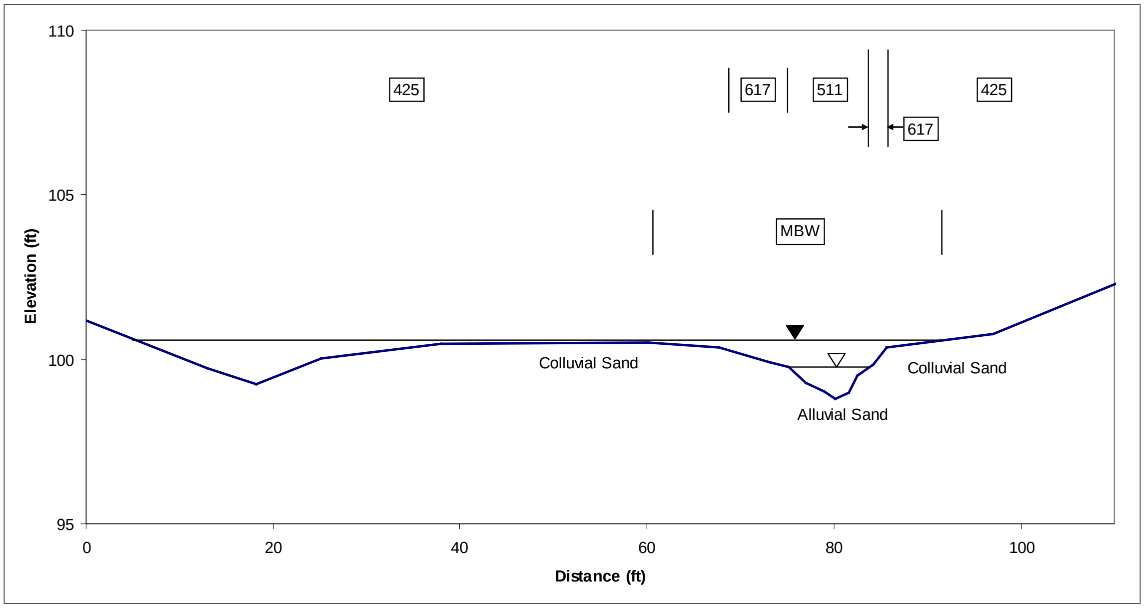


Grassy Creek UT

Figure 4.16. Section of FW-CV-WC System with Seepage Wetland Confined Valley.

Figure 4.17 depicts a situation where the fire frequency is comparatively low in the upland valley hillslopes bordering the meander belt. This leads to a fire-intolerant mesic hammock community (425) dominated by live oak, cabbage palm and saw palmetto. This community closely flanks a narrow wetter zone within 5 to 10 feet of the channel banks (617) within the meander belt supporting wax myrtle, laurel oak, cabbage palm, and Walter's viburnum with some live oak and palmetto. Although not depicted on the cross-section, the terrestrial landscape beyond the valley slopes consists of a large expanse of pine flatwoods savanna. The mesic hammock in the valley is a gallery forest, providing a line of dense cover and additional biodiversity to the matrix of fire-scoured communities in the region.

This series of case studies illustrates that the composition and forest structure of riparian corridors associated with FW-CV-WC stream channels are greatly influenced by fire and soil moisture gradients largely unrelated to the presence of alluvial processes. As a result, the communities can vary greatly among locations in time and space. Notwithstanding such diversity of potential communities, most FW-CV-WC corridors we observed consisted of generally narrow hydric hammocks bordering and shading the channel in an otherwise pyrogenic landscape with a more scattered open tree canopy on the valley hillslope and beyond.



Lower Myakka UT 2

Figure 4.17. Section of FW-CV-WC System with Mesic Hammock Confined Valley.

The bankfull channel in FW-CV-WC systems can be entrenched by up to a few inches, especially when coursing through an upland confined valley, but also often grades smoothly to the valley flat, particularly when flanked by unconfined wetlands. Riverscapes are nominally 1.5 feet 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 usually classify as Rosgen C5 types. In-stream 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 characteristically provide ephemeral connections between shallow depressional waterbodies, forming chains-of-wetlands in the upper parts of the drainage network. Sometimes flow may be seasonally intermittent. 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 little studied. AMEC-BCI (2011) sampled fish from six FW-CV streams in DeSoto County, Florida, finding an assemblage of small bodied, stress-tolerant species similar to those occurring in regional wetland depressions. This collection was consistent with the shallow water depths and non-perennial flow regimes of these systems. Although mammal use of such corridors has not been widely studied, it seems likely 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 4.9. It is also necessary to verify that the valley slope is generally flat or perhaps slightly convex and that it is close to an upstream 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 feet wide, drained by meandering riverscapes with W/D ratios greater than 11 (Figure 4.18). Bankfull field survey is uncomplicated, relying on delineation of the valley flat or easily read bank inflections.

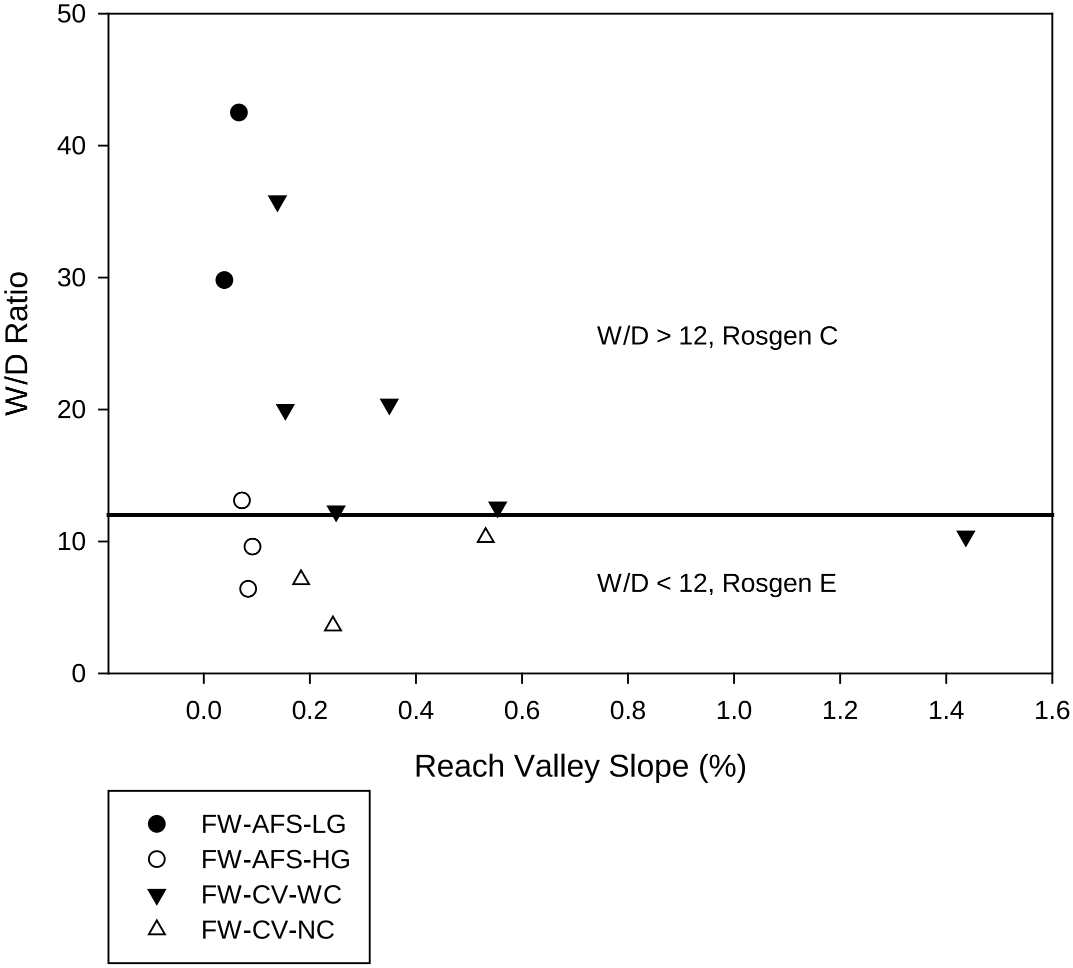


Figure 4.18. Flatwoods Riparian System Types by W/D and Valley Slope.

FW-CV-WC systems are most likely to be heterotrophic (based on carbon sourced from outside the channel, typically leaf litter from plants growing near the banks and in the floodplain). This is due to their heavily shaded channels, ephemeral to seasonal flow patterns, and darkly colored waters precluding the sustained establishment of plants (emergent aquatics, periphyton, or phytoplankton) in the open channel. Even when only partially shaded in valleys with high fire frequency, these systems are likely to remain heterotrophic due to short flow spells and dark water color. Autotrophic patches in the stream channel, when present, are most likely to consist of emergent aquatics of species that can tolerate chaotic flow spells and variable water depths (e.g., grassy arrowhead). These systems are unlikely to routinely support extensive patches of periphyton or sustained populations of phytoplankton.

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 4.19). Watersheds ranging from 0.1 to 4.0 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 second-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, Hillsborough River UT, 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 confined 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.

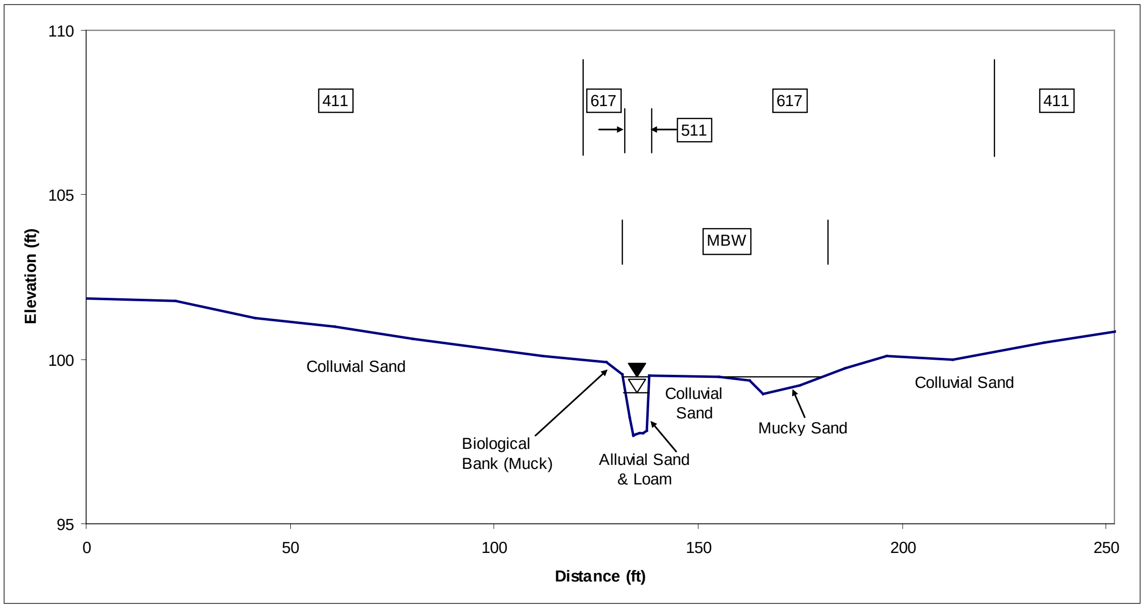
As in FW-CV-WC systems, the riparian communities are distributed across three key surfaces (channel banks, meander belt, valley hillslope). Perhaps the most common arrangement is a narrow hydric hammock (617) or shallow forested hardwood wetland within the meander belt that is bordered by pine flatwoods (411) hillslopes (Figure 4.20). Water oak (*Quercus nigra*), laurel oak, red maple, sweetbay, wax myrtle, dahoon, cabbage palm, American elm (*Ulmus americana*), and scattered slash pine and saw palmetto are common species in the hydric hammock and along the stream banks. There is much similarity in dominant and common meander belt species among FW-CV-WC and NC corridors. One apparent difference is that the NC systems tend to have greater occurrences of sweetbay and loblolly bay, usually on the stream channel banks. This may be due to the greater channel depths of the NC systems, placing the bank bottom closer to the groundwater table for longer duration.

Wekiva Forest UT

Figure 4.19. Example of FW-CV-NC Riparian System.

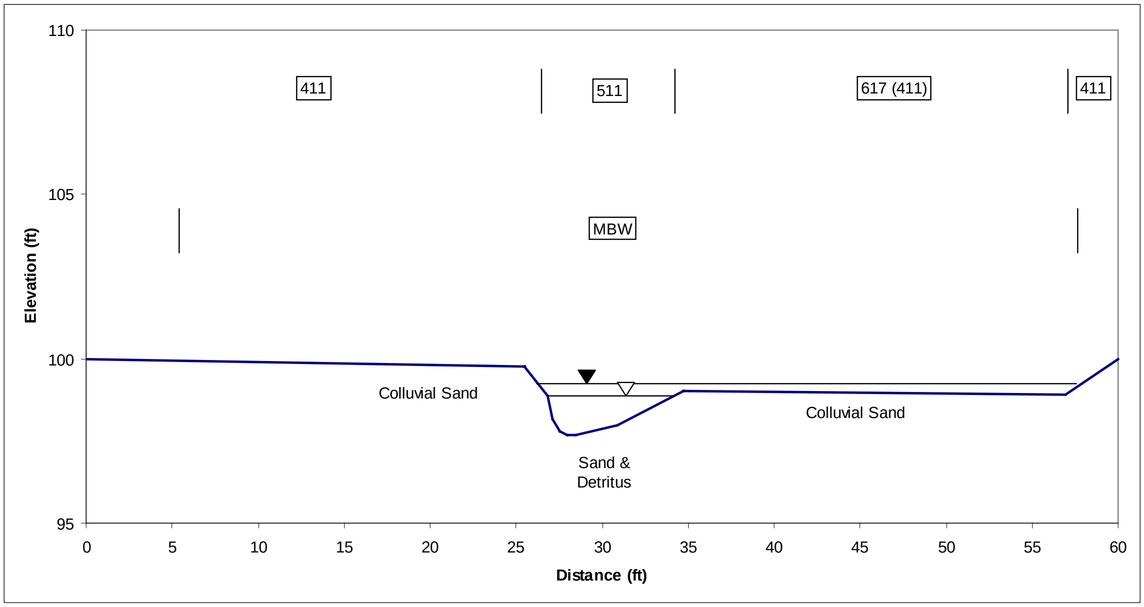
The hydric hammock can be sporadic, occupying very little of the meander belt (Figure 4.21) or can be wider while rather continuously subsuming the meander belt (Figure 4.22). Slash pine and dense saw palmetto are common with scattered live oaks where pine flatwoods occur within the meander belt.

Figure 4.23 depicts a FW-CV-NC stream segment where it is crossing the floodplain of the larger river to which it is a tributary. The vegetation is growing on an alluvial surface derived from the larger system and the species composition reflects the upper portion of the bigger river's floodplain community [615: cypress, cabbage palm, ironwood (*Carpinus caroliniana*), red maple, redtop panicum (*Panicum rigidulum*), and beakrush (*Rhynchospora* sp.)]. The cypress, and perhaps the ironwood, would not be normal for a FW-CV-NC corridor. The dominant riparian vegetation upstream of the receiving river's floodplain was a narrow hydric hammock with saw palmetto, cabbage palm, sweetbay, American elm, and red maple.



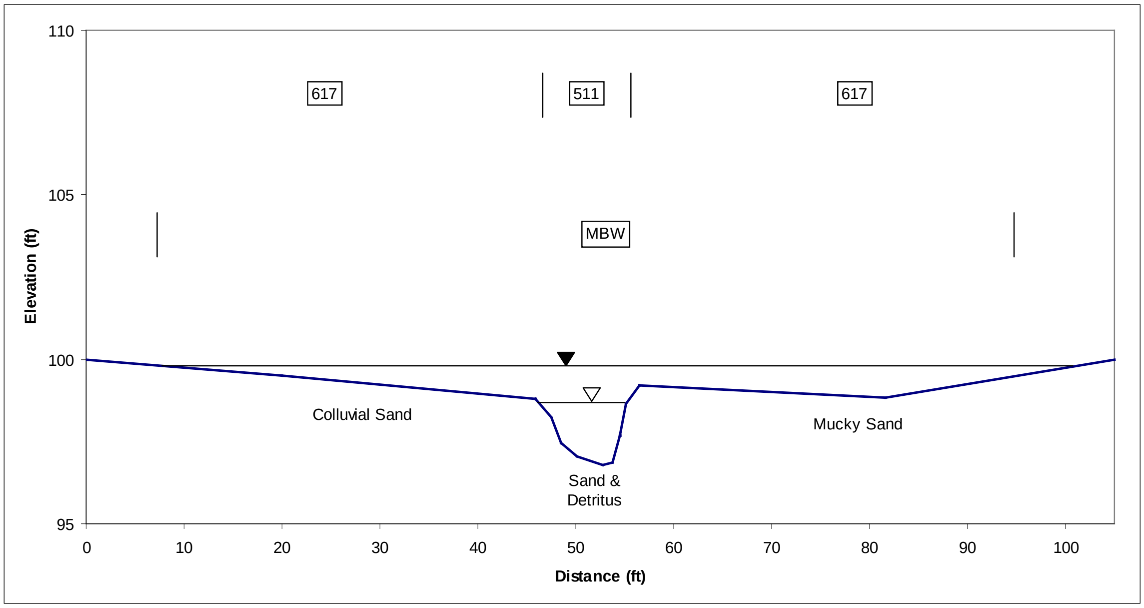
East Fork Manatee UT 1

Figure 4.20. Section of FW-CV-NC System with Unconfined Hydric Hammock.



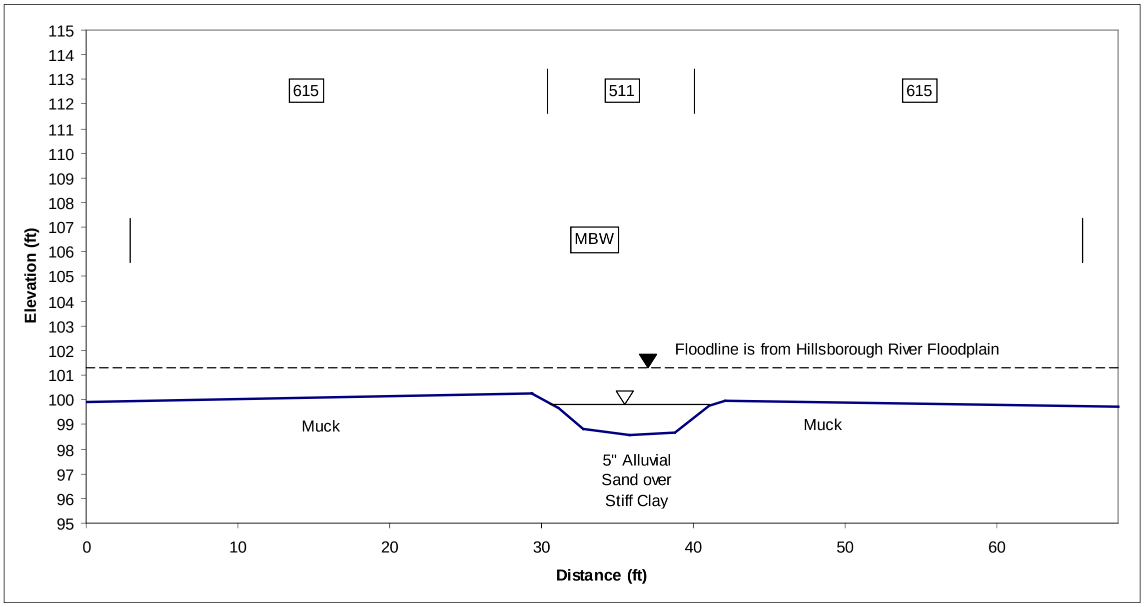
Coons Bay Branch

Figure 4.21. Section of a FW-CV-NC System with Flatwoods Confined Valley.



Wekiva River UT

Figure 4.22. Section of a FW-CV-NC System with Unconfined Hydric Hammock.



Hillsborough River UT

Figure 4.23. Section of a Tributary FW-CV-NC System Flowing Across Floodplain.

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 less than 2 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 usually 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 ephemeral to seasonally intermittent 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 4.9. 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 less than 75 feet wide, and drained by tightly meandering riverscapes with W/D ratios less than 12 (Figure 4.18). Bankfull field survey is uncomplicated, relying on delineation of easily read bank inflections. To more fully understand the FW-CV-NC channels it is helpful to compare them to the somewhat closely aligned FW-CV-WC channels described previously.

FW-CV-NC systems are most likely to be heterotrophic. This is due to their heavily shaded channels, ephemeral to seasonal flow patterns, high shear stress, and darkly colored waters which preclude the sustained establishment of plants in the open channel. Even if only partially shaded in valleys with high fire frequency, these systems are likely to remain heterotrophic due to short flow spells and dark water color. FW-CV-NC systems are unlikely to routinely support extensive patches of emergent aquatics, periphyton, or sustained populations of phytoplankton.

Compact Complex Alluvial Corridors (FW-AF-CC)

FW-AF-CC systems typically drain larger flatwoods basins than the FW-CV systems and those smaller than the FW-AF-WF class (Figure 4.9). They have alluvial floodplain features, but these may be more sporadically formed than those of the FW-AF-WF 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 at least partially alluvial valleys. This is a complex of small, variably alluvial systems. These systems typically drain watersheds ranging from 4 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 4.24).

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.

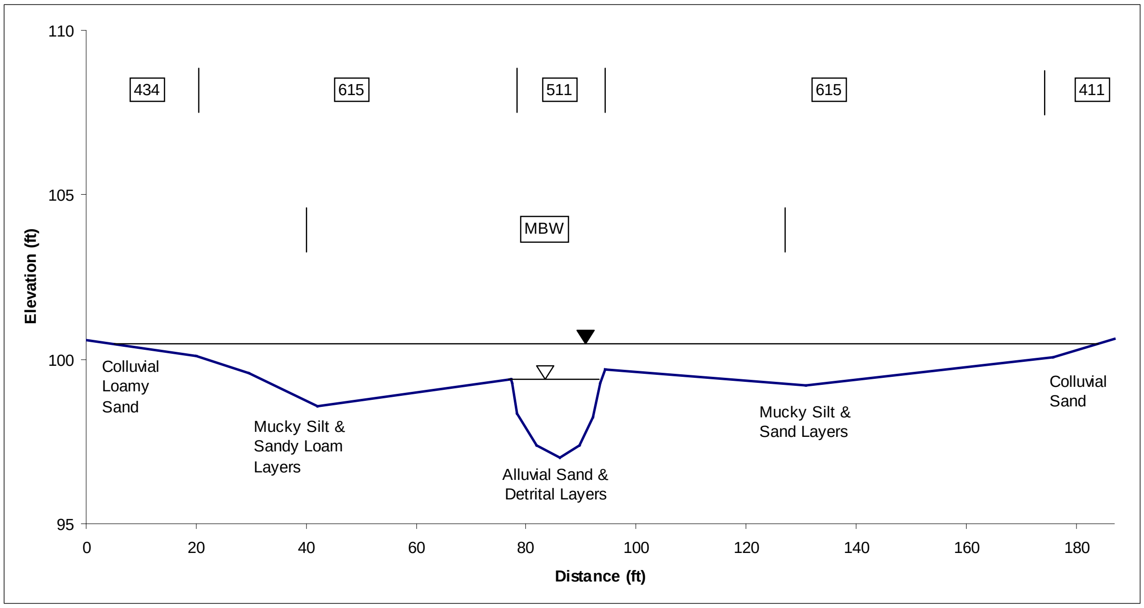
The riparian vegetation can consist of virtually any wetland bottomland species common in Florida. Cypress is common in the backswamps, but not ubiquitous, and hardwoods dominate most of the riparian corridor. Most sites are densely forested, but valleys with high fire frequencies can have areas vegetated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

Figure 4.25 depicts the most characteristic arrangement of surfaces across FW-AF-CC riparian systems. These include a forested wetland (615) established on small alluvial ridges along the channel banks with a lower-lying backswamp between the ridge and colluvial valley hillslope. The backswamp in this case has soil layers formed from sandy and silty alluvium, and organic soil accumulation within the meander belt, and is influenced by hillslope erosion on its outer edges. The swamp is dominated by bald cypress, sweet gum, red maple, cabbage palm, and laurel oak.

Tenmile Creek

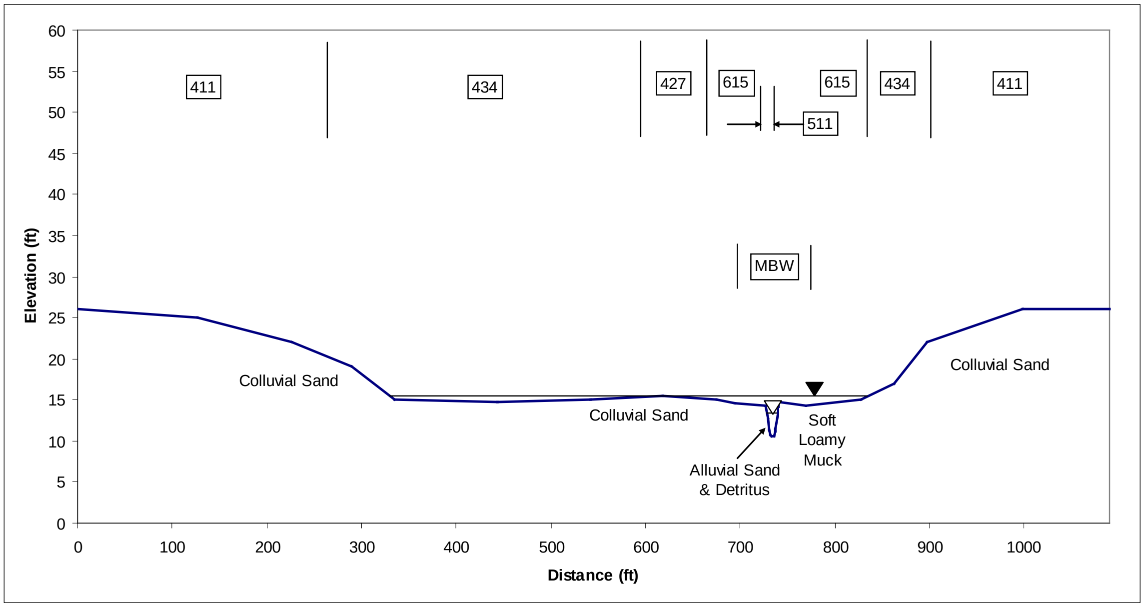
Figure 4.24. Example of FW-AF-CC Riparian System.

Figure 4.26 depicts a valley with a more complex geomorphic history. The bulk of the valley floor consists of an upper terrace with upland sands, occupied by a mixed upland pine and oak forest with dense saw palmetto (434). It is likely a relict of previous fluvial processes that are no longer active. Hardwoods (sweetgum, ironwood, laurel oak and American elm) and cabbage palm dominate as the terrace transitions (427) toward the low-lying and alluvially active backswamp (615) flanking the stream's meander belt. The backswamp is dominated by cypress, buttonbush, American elm, ironwood and red maple (615). These species plus palmetto, cabbage palm, swamp dogwood (*Cornus foemina*), green ash (*Fraxinus pennsylvanica*), laurel oak, water hickory (*Carya aquatica*), and blackgum occur on the channel banks, alluvial ridge, and low-lying areas within the meander belt. The pronounced outer hillslopes are pine flatwoods. The stream meanders through the upper terrace (434, 427) forming a lower, alluvially active floodplain surface akin to that encountered in the previous case, Figure 4.25. Such upper relict terraces are not common in peninsular Florida streams, but this case illustrates the need to examine the sediments for signs of modern alluviation.



Tenmile Creek

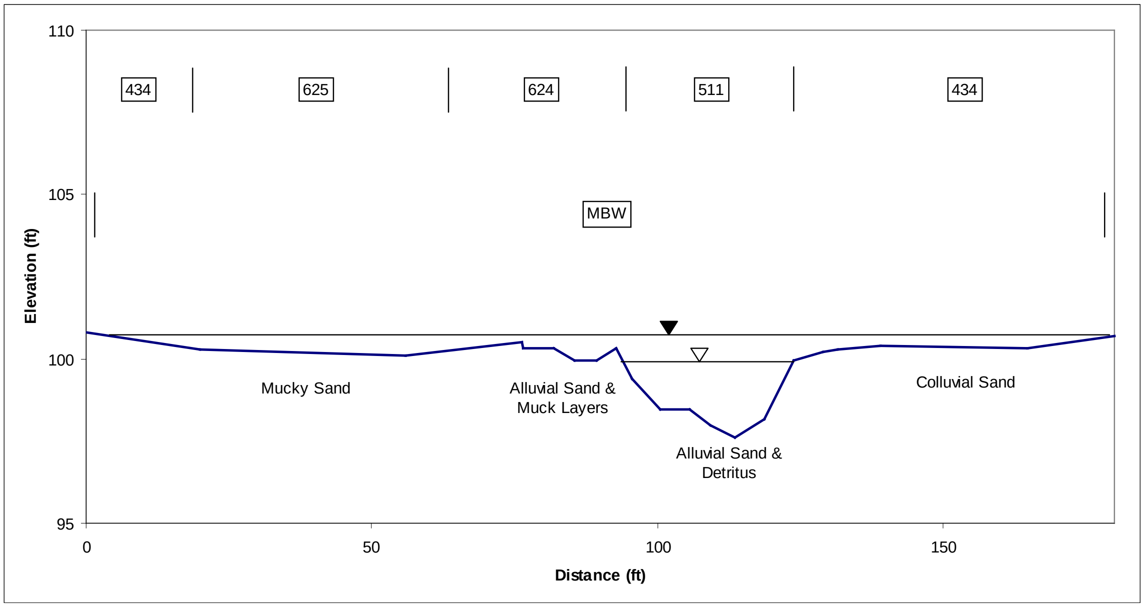
Figure 4.25. Section of a FW-AF-CC System with Unconfined Hydric Hammock.



Moses Creek

Figure 4.26. Section of FW-AF-CC System within a Relict Floodplain Terrace.

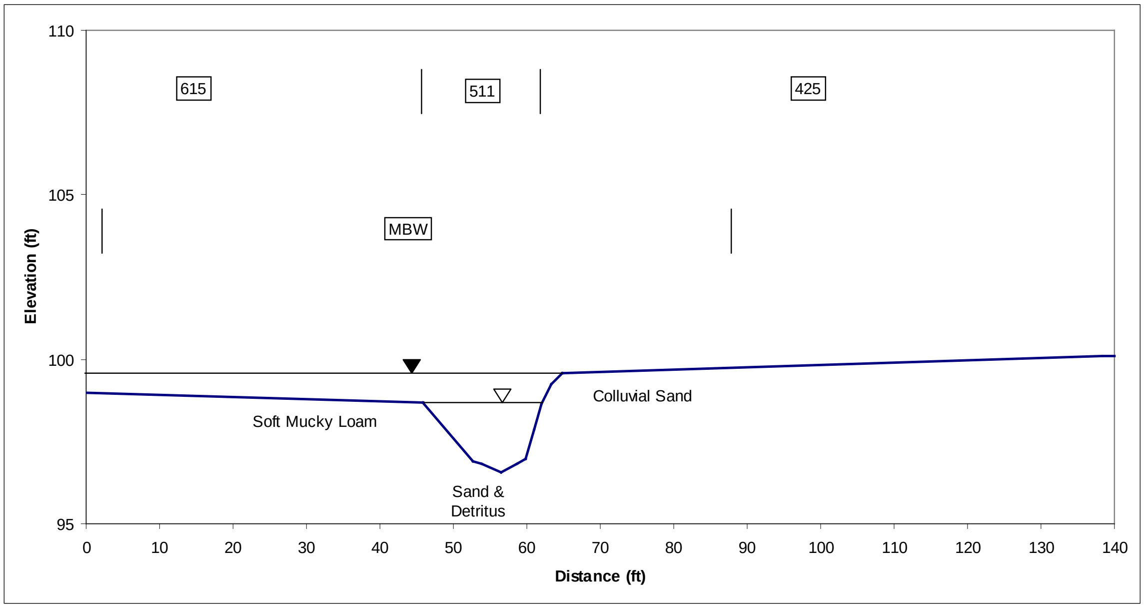
Figure 4.27 illustrates a system with a subtle alluvial ridge and a comparatively narrow alluvial backswamp tightly confined by the adjacent uplands. Note that the meander belt is wider than the alluvial surfaces. This site occupies a low gradient valley with numerous in-line sloughs that appear to be trapping much of the sediment load, leading to less deposition in the floodplain. The valley hillslope is subtle in this very flat south Florida landscape. The dominant hillslope community is a mosaic of pine savanna and hammocks with live oak, south Florida slash pine (*Pinus elliotii* var. *densa*), saw palmetto and cabbage palm (434) that can range from scattered open to fully closed canopies. Patches of hydric pine flatwoods (625) with scattered open canopy of pines, sparse palmetto, and dense wet prairie ground cover occur along the riparian corridor. The channel banks and narrow alluvial backswamp (624) are dominated by maidencane, cabbage palms, south Florida slash pines and scattered live oak and palmettos. This is a low-gradient pyrogenic landscape where fire plays a greater role than fluvial geomorphology in structuring the vegetation distribution within the riparian corridor.



Grasshopper Slough

Figure 4.27. Section of FW-AF-CC System with an Upland Confined Meander Belt.

Figure 4.28 provides another example of a tightly confined FW-AF-CC system where the alluvial surface is rather continuous along the corridor, but it not always present along both channel banks. In this case the valley hillslope has lower fire frequency and is part of an extensive closed-canopy upland temperate forest (425) consisting of live oak, sweetgum (*Liquidambar styraciflua*), and cabbage palm (with planted slash pines). The backswamp (615) is dominated by cypress, cabbage palm, and ironwood with a beakrush ground cover. The channel banks and subtle alluvial ridge include those species plus water locust (*Gleditsia aquatica*), Walter's viburnum, and wax myrtle.

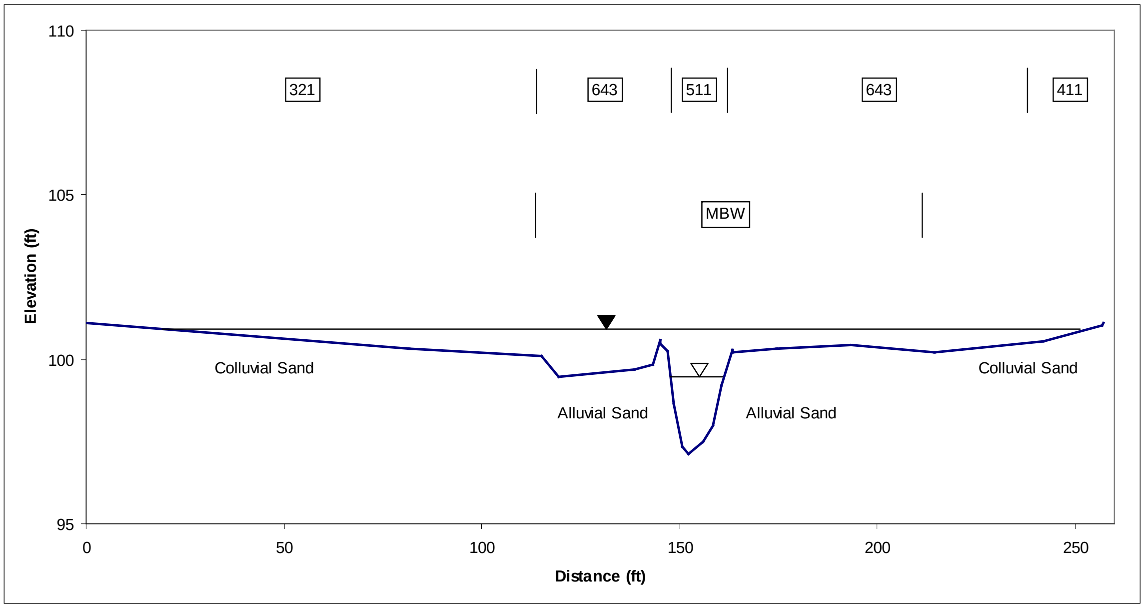


Cow Creek

Figure 4.28. Section of FW-AF-CC System with Upland Confinement.

Figure 4.29 provides a case study in a setting with very high fire frequency. Most of the surrounding landscape and hillslope exists as dry prairie (321) or savanna-like flatwoods (411). The meander belt is well fit to a wet prairie community (643) with sand cordgrass (*Spartina bakeri*), carpetgrass (*Axonopus* sp.), witchgrass (*Dichanthelium* sp.), and wiregrass (*Aristida stricta* var. *beyrichiana*). Channel banks are lined by sand cordgrass, wax myrtle, and scattered laurel oaks and slash pine. These case studies illustrate that although FW-AF-CC systems provide important floodplain alluvial surfaces occupied by wetland communities, community structure is also greatly influenced by local fire and water table interactions independent of fluvial process.

The bankfull channel of FW-AF-CC systems 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 larger FW-AFS systems. Riverscapes are nominally 3 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 hardwood shrubs with some early colonizers like wax myrtle.



Morgan Hole Creek

Figure 4.29. Section of FW-AF-CC System with Wet Prairie Meander Belt.

These valley segments connect 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. Flow regimes are usually seasonally intermittent, but some systems can be seasonally perennial. 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. In fact, AMEC-BCI (2011) made fish collections from five FW-AF-CC systems and found them to include all the species collected in the smaller FW-CV streams made at the same time, plus an assortment of larger-bodied fish species with greater dissolved oxygen requirements and taxa more adapted to open water habits and sand bed spawning. This suggests that FW-AF-CC systems provide lotic niche space not available in smaller streams based on their longer flow duration, larger sandy shoals, and deeper pools.

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 4.9. 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.

FW-AF-CC systems are most likely to be heterotrophic. This is due to their heavily shaded channels, sporadically high shear stress, and darkly colored waters which preclude the sustained establishment of plants in the open channel. Even if only partially shaded in valleys with high fire frequency, these systems are likely to remain heterotrophic due to dark water color and mobile sandy channel beds. These systems are unlikely to routinely support extensive patches of emergent aquatics, periphyton, or sustained populations of phytoplankton.

Wide Alluvial Valley Flats (FW-AF-WF)

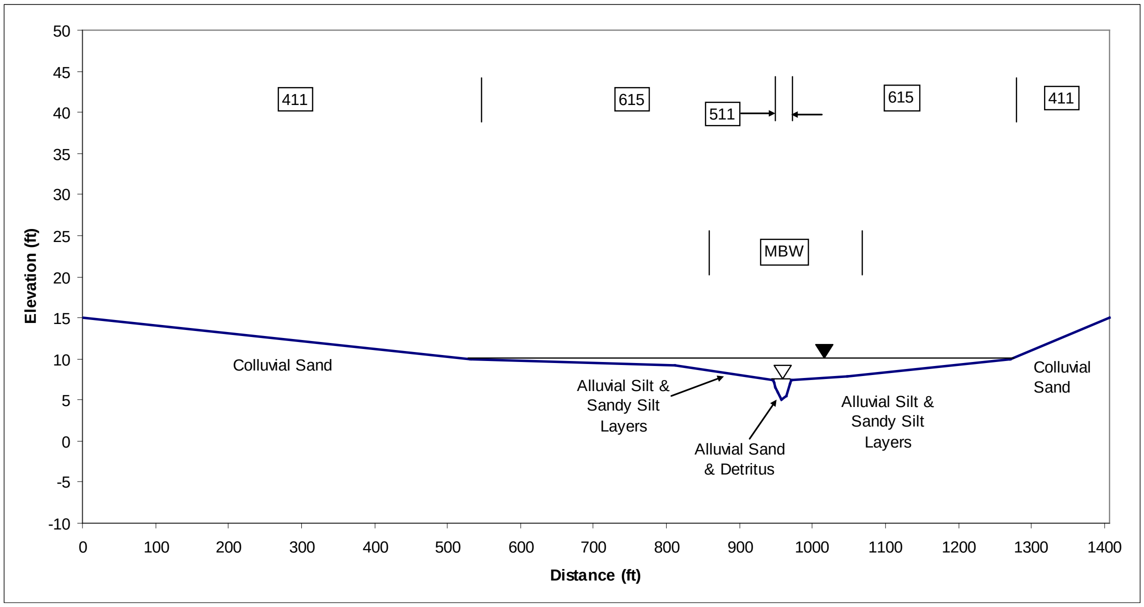
FW-AF-WF systems drain larger flatwoods basins than the FW-AF-CC basins and smaller ones than those of the two FW-AFS classes. Their most notable features include a comparatively simple alluvial floodscape with non-entrenched and wide meandering blackwater riverscapes. These systems typically drain watersheds ranging roughly from 20 to 60 square miles which routinely generate discharge volumes sufficient to transport and deposit fine alluvium in the vegetated floodscape at valley slopes greater than 0.03%. 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 4.30). 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. Figure 4.31 represents the most typical community surfaces, which include a broad valley flat occupied by a bottomland swamp (615) growing in vertical accretions of fine alluvium interspersed with organic soils. This bottomland and channel banks are dominated by bald cypress, blackgum, laurel oak, water hickory, cabbage palm and ironwood. The bottomland floodplain is flanked by pine flatwoods hillslopes (411).

Rice Creek

Figure 4.30. Example of FW-AF-WF Riparian System.



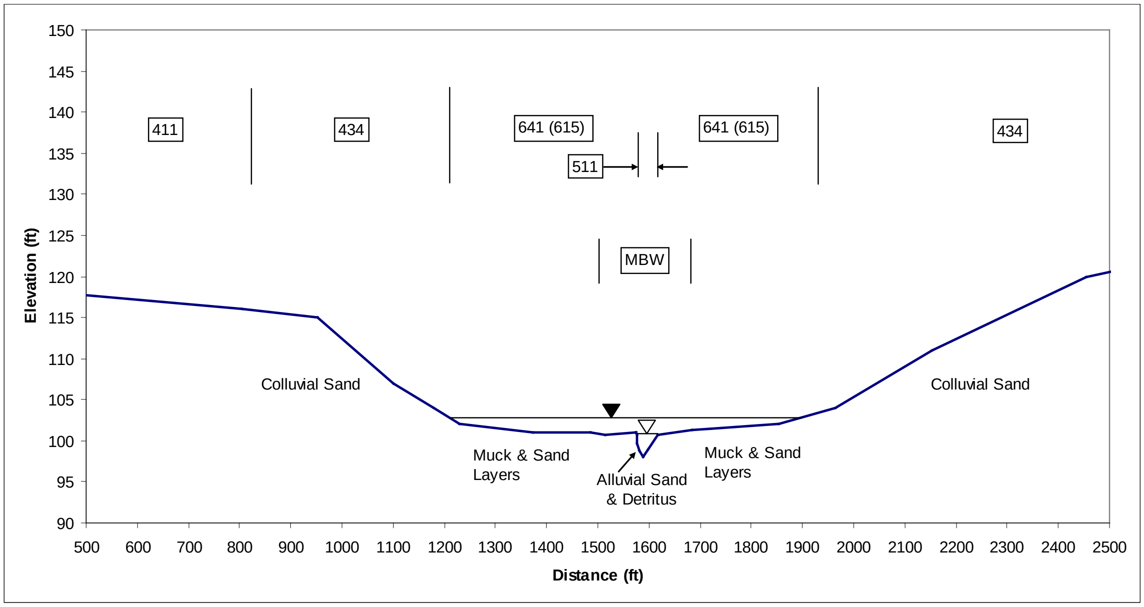
Rice Creek

Figure 4.31. Section of FW-AF-WF System with an Unconfined Bottomland Swamp.

Figure 4.32 depicts a system with similar geomorphology to the previously described site. This site, however, was greatly affected by hurricanes that killed the forest, leaving the site in a stage of early herbaceous succession. The bottomland marsh (641) is dominated by soft rush (*Juncus effusus*) and maidencane (*Panicum hemitomon*), with some saltbush (*Baccharis* sp.). Scattered surviving red maples, laurel oak, blackgum, and sweet gum are present, suggesting a 615 community prior to the storm. Shallow channel margins have duck potato (*Sagittaria latifolia*) and pennywort (*Hydrocotyle umbellata*). Areas upstream less affected by the winds were closed canopy forests dominated by red maple and laurel oak. The valley hillslopes consisted of oaks and pines.

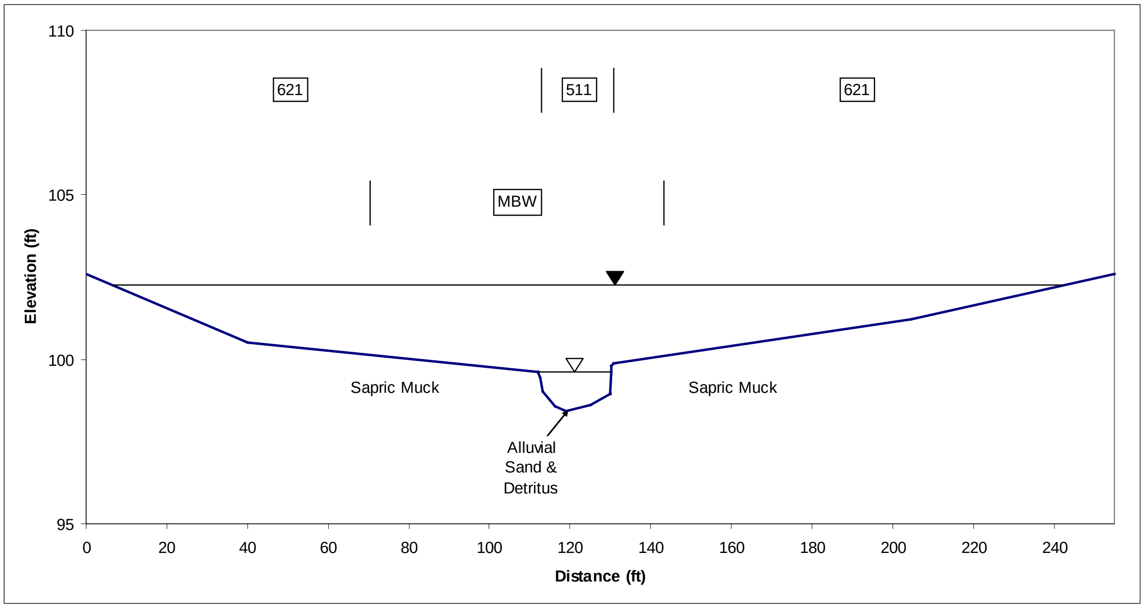
Figure 4.33 represents a case where the floodplain hydroperiod and depths seemed to be greater than those in the previous examples and organic sediment processes were dominant in the valley flat. Distinct alluvial layers were not apparent, probably due to bioturbation. The bottomland swamp was substantially dominated by bald cypress, with scattered red maple, dahoon, blackgum and green ash and occasional wax myrtle and cabbage palm on the banks.

Although FW-AF-WF systems tend to occur as “classic” alluvial floodplains with vertical sediment accretions and varying mixtures of characteristic bottomland hardwoods on the valley flat, variants occur based on chronic hydroecological factors, including seasonal flood durations and depths favoring organic soil building processes, and on stochastic events including severe windstorms that can reset succession.



Bowlegs Creek

Figure 4.32. Section of FW-AF-WF System Affected by Hurricanes.



Tyson Creek

Figure 4.33. Section of FW-AF-WF System with an Unconfined Cypress Swamp.

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 normally 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. Flow regimes tend to be seasonally perennial in most of these sites, with some achieving annual perenniality. 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 the valley slope-drainage area zone of confidence depicted on Figure 4.9. 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.

FW-AF-WF systems are most likely to be predominantly heterotrophic, with the potential for small autotrophic patches. This is due to their heavily shaded channels and darkly colored waters which preclude the sustained establishment of submerged plants in the open channel. Even if flowing through partially shaded bottomlands, the main channel is likely to remain heterotrophic due to dark water color and mobile sand beds. FW-AF-WF systems are unlikely to routinely support periphyton or sustained populations of phytoplankton, but they can support patches of emergent vegetation in light gaps near the channel margins.

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 4.34). These systems typically drain watersheds in excess of 60 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 0.05% (or 2.6 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 4.9). This is true of all of the riparian system classes among all landscape settings.

Manatee River

Figure 4.34. Example of FW-AFS-HG Riparian System.

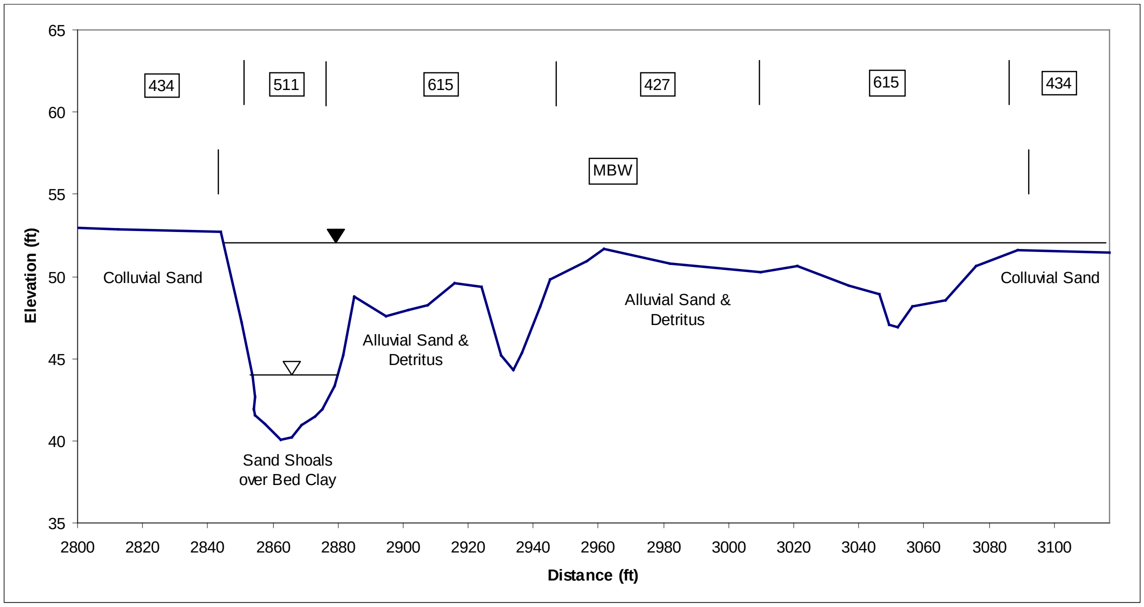
Riparian corridors with this combination of drainage area size and valley slope appear to be associated with mid-order systems crossing old marine terraces or other scarps and their valley flats are typically less than 1,000 feet wide, flanked by steep upland hillslopes. This combination of floodplain confinement and longitudinal slope promotes the deepest routine flood depths among the sites studied, in excess of 9 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 or chutes 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 9 feet.

The riparian vegetation partially sorts in association with these alluvial features, increasing the plant community diversity within the riparian corridor versus less undulating floodplains. Common inclusions are hydric or mesic oak hammocks on islands or sandy bank levees, often with palmetto. Cypress, blackgum or popash (*Fraxinus caroliniana*) variably occupy the linear backswamps. The oxbow lakes sometimes have floating-leaf emergent communities. Chutes can be vegetated by sedges or other emergent wetland plants but are usually unvegetated, depending on depths and shade.

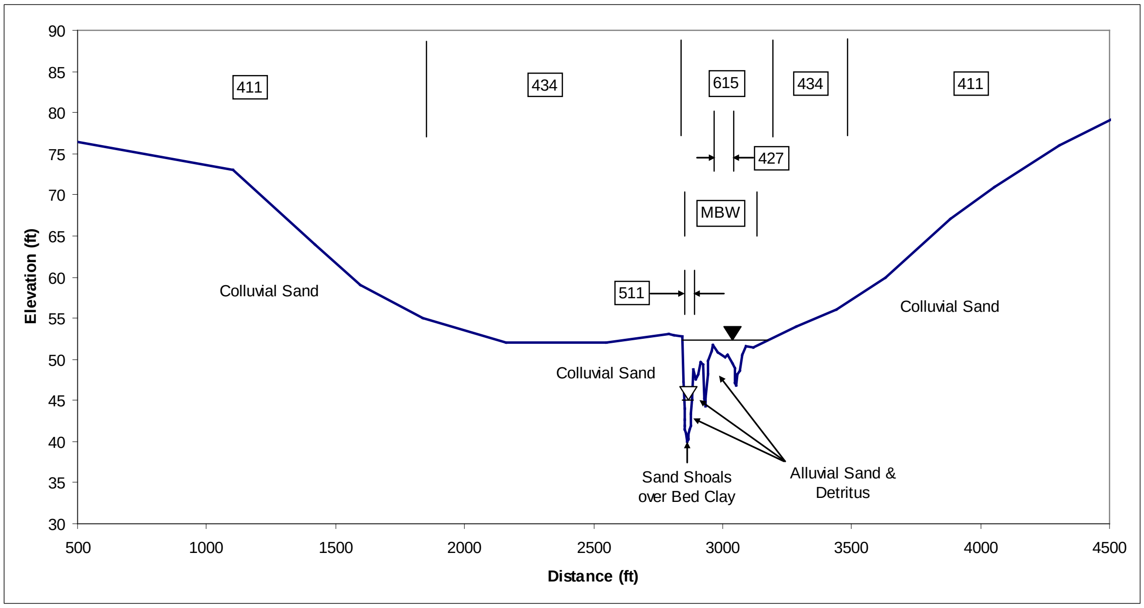
Figure 4.35 shows a typical FW-AFS-HG riparian system cross-section, with a deep main channel, an alluvial ridge, chute, and backswamp confined by upland hillslopes. The 7+ foot high channel banks exhibit zoned vegetation with wetland species such as water hickory, popash, Carolina willow, and laurel oak occupying the lower portion (roughly between baseflow and bankfull stage). The upper portion, typically at or above bankfull stage, has laurel oak, water locust, palmetto, and live oak. Although not obvious on this section, a gradually sloped bench, up to a few feet wide, occurred discontinuously along the lower bank zone supporting wetland trees. The higher sandy floodplain ridges and confining bluffs have live oak, dense saw palmetto and long-leaf pine (*Pinus palustris*) (434) or hammocks dominated by live oak with palmetto (427). The lower floodplain surfaces (615) are hydric hammocks dominated by laurel oak, pop ash, water locust, and live oak.

Figure 4.36 is a wider perspective of the previously described site, showing that the active alluvial meander belt is incised within a much larger relict valley bottom. This condition suggests at least two periods of downcutting and floodplain building over the ancient marine escarpment this valley crosses.



Manatee River

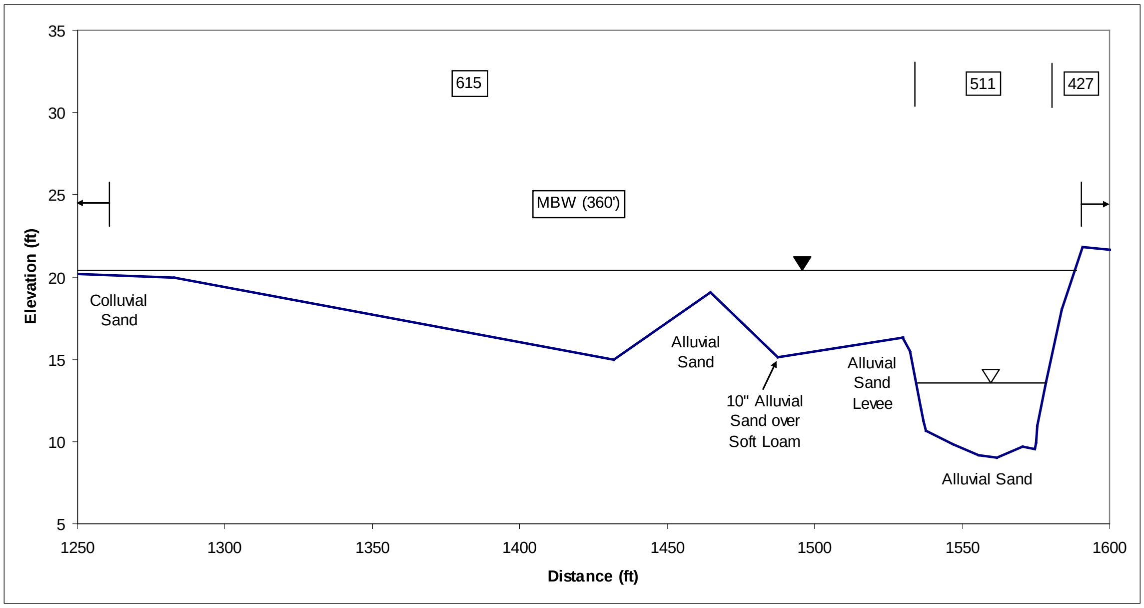
Figure 4.35. Section of FW-AFS-HG System with a Confined Bottomland Swamp.



Manatee River

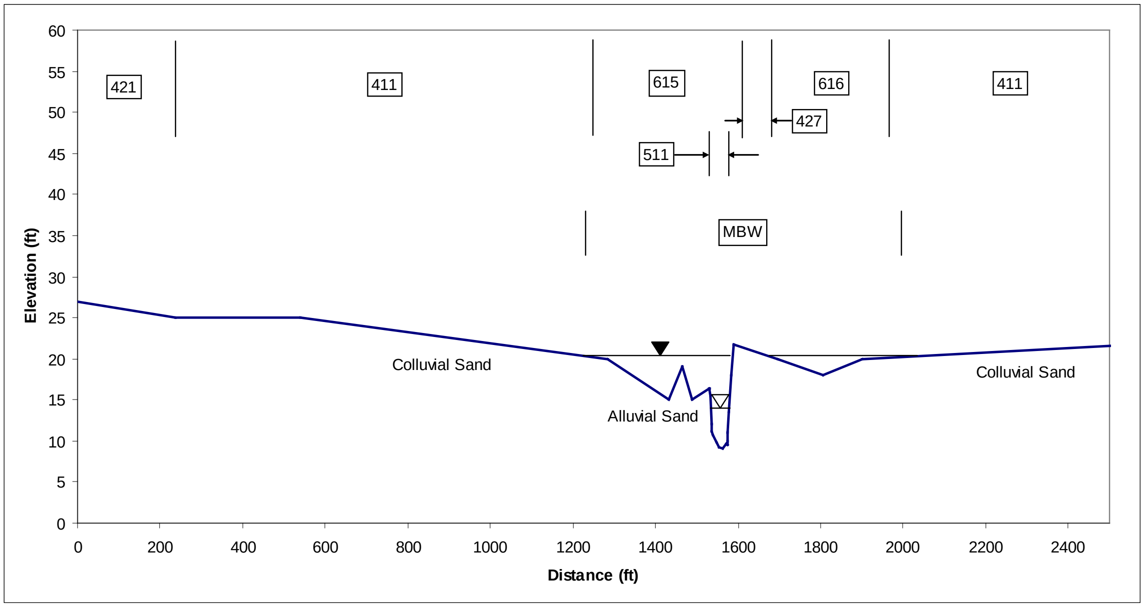
Figure 4.36. Section of FW-AFS-HG System Showing Relict Valley Floor.

Figure 4.37 provides another example of a complex FW-AFS-HG alluvial meander belt confined by uplands. The lower channel banks below bankfull stage are occupied by Carolina willow and cypress, with laurel oak, cabbage palm and cypress above bankfull stage. The bottomland swamp (615) has dense laurel oak, and cabbage palm with scattered cypress and live oak on the ridges and a dominance of popash, cypress, laurel oak, water locust, and cabbage palm with some buttonbush in the lower surfaces. The upland bluffs (427) are dominated by live oak and dense saw palmetto. Figure 4.38 depicts a wider section of the same system, indicating no obvious upper terrace in this case, but including an oxbow pond and slough (616). Oxbows are sporadic features in most FW-AFS-HG systems. Floodplain communities in FW-AFS-HG corridors occupy a combination of broad and narrow alluvial surfaces with pronounced differences in elevation and sediment texture that associate with flood depth and duration characteristics greatly influencing the community composition.



Horse Creek

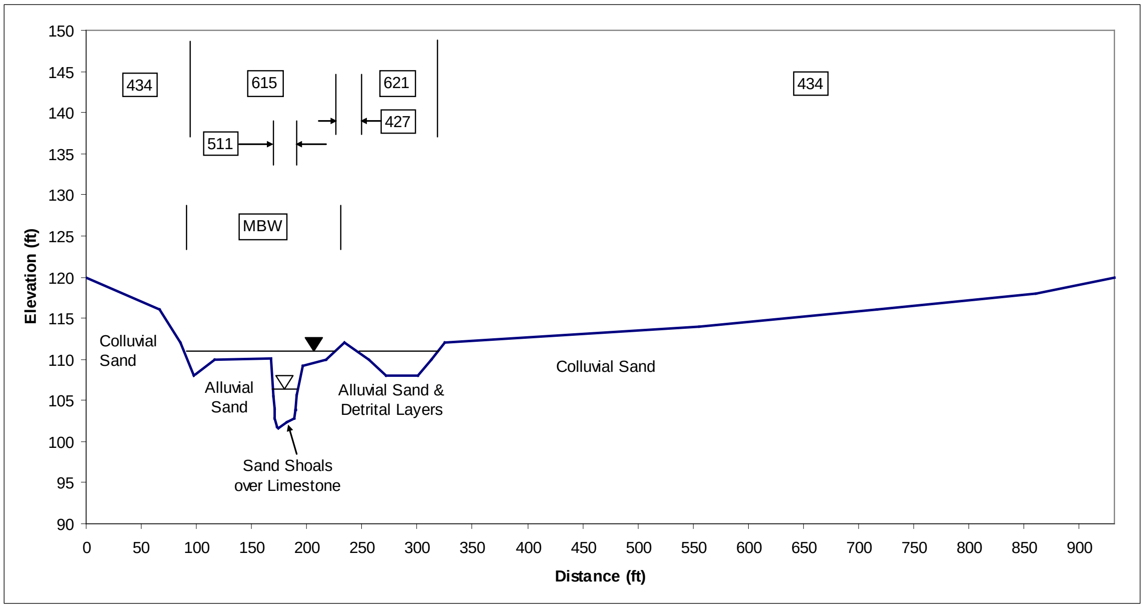
Figure 4.37. Section of FW-AFS-HG System with a Confined Bottomland Swamp.



Horse Creek

Figure 4.38. Section of Confined FW-AFS-HG System without a Relict Terrace.

Figure 4.39 illustrates a site with a small oxbow swamp close to the main channel (621) dominated by cypress with red maple, sweet gum, and laurel oak. The high alluvial ridge (427) is dominated by dense palmetto, live oak, laurel oak and sweet gum. The backswamp (615) has cypress, sweet gum, red maple, and laurel oak. The channel banks are lined by variable mixtures of dense palmetto, laurel oak, ironwood, green ash, water oak, and buttonbush, with live oak, sweet gum, wax myrtle, and Walter's viburnum confined to the upper areas.



Upper Santa Fe River

Figure 4.39. Section of FW-AFS-HG System with a Confined Swamp.

The crest of the bankfull channel in FW-AFS-HG systems 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 characteristically at least 3 feet deep with mobile sandy shoals and a dominance of pools often in excess of 6 feet deep at bankfull stage. 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. Banks tend to be occupied by woody plants or palmettos that are well rooted from the crest of the levee to the baseflow level, usually adding shear strength to the vast majority of the bank despite it being at least several feet high (Figure 4.40).

Upper Santa Fe River

Figure 4.40. Palmetto-Reinforced Bank.

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. Flow regime is characteristically annually perennial, but water levels vary by several feet between the wet and dry seasons. 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 4.9. 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 and others 2010). 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 and closest to the bed elevation of the valley flat, linear backswamp, or secondary channels (in that order of priority) in the floodplain 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.

Most FW-AFS-HG systems are likely to be heterotrophic due to their heavily shaded channels, powerful wet-season flow spates generating high shear stress, and deep darkly colored waters which preclude the sustained establishment of plants in the open channel. The channel canopy begins to open up when FW-AFS-HG systems drain at least 200-square-mile watersheds, leading to a wide enough channel to preclude complete canopy closure over it. Even in such partially shaded-in channels, these systems are likely to remain heterotrophic due to routine scouring discharges and dark water color. FW-CV-NC systems are unlikely to routinely support extensive patches of emergent aquatics, periphyton, or sustained populations of phytoplankton.

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 60 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 0.02% 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 4.41). 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.

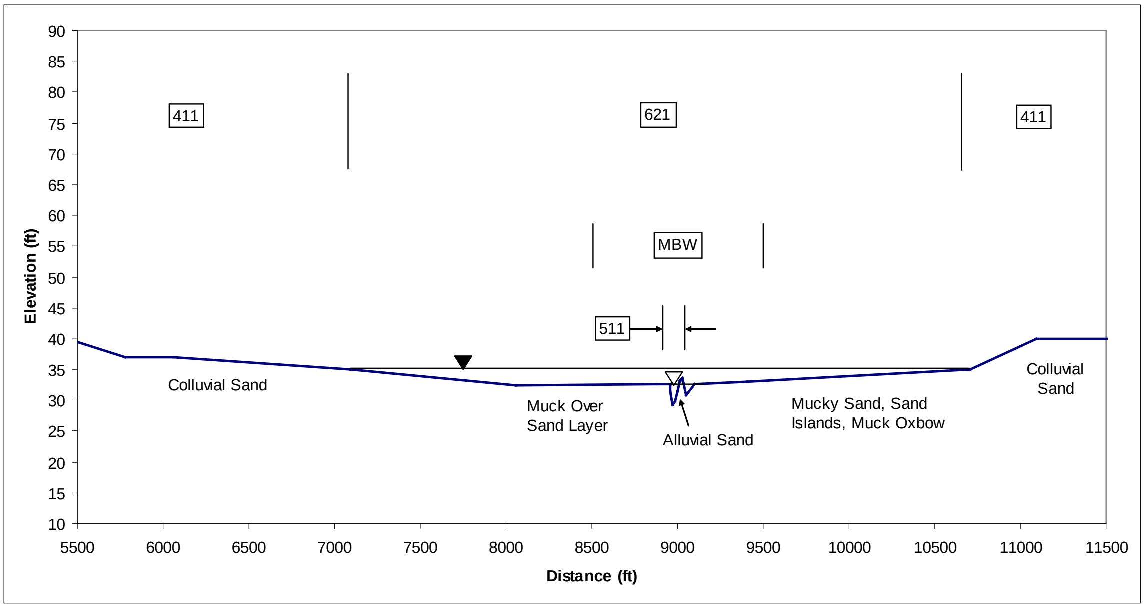
Fisheating Creek

Figure 4.41. Example of FW-AFS-LG Riparian System.

The big floods generated from these mid-order watersheds create floodscapes populated with a diverse 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, valley flats and 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.

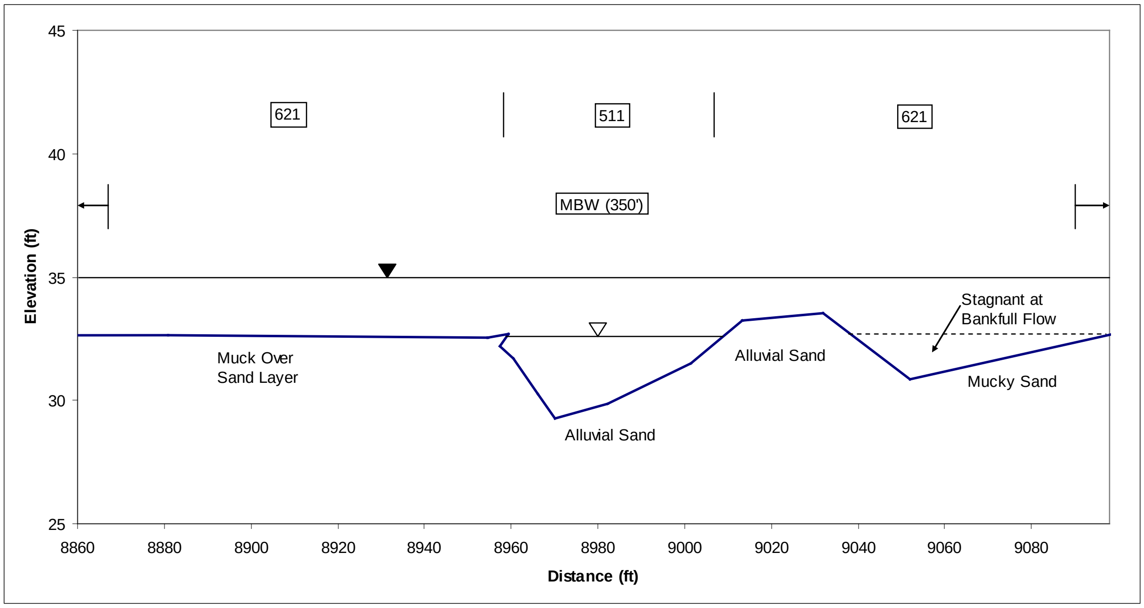
Figure 4.42 shows a complete view of a large, 3,000-foot-wide FW-AFS-LG floodplain. This subsumes the 1,000-foot-wide meander belt. The bottomland swamp (621) is dominated by cypress with scattered cabbage palm, red maple, and laurel oak on the typical surface. Figure 4.43 illustrates the system in more detail near the channel. The alluvial ridges are low and discontinuous, supporting greater dominance of cabbage palm and live oaks at the crests of the higher levees. Most of the embankment is dominated by cypress with scattered wax myrtle and cabbage palm. The secondary channel is comparatively stagnant when the main channel is flowing full, with thick marsh groundcover dominated by knotweed (*Polygonum* sp.).



Fisheating Creek

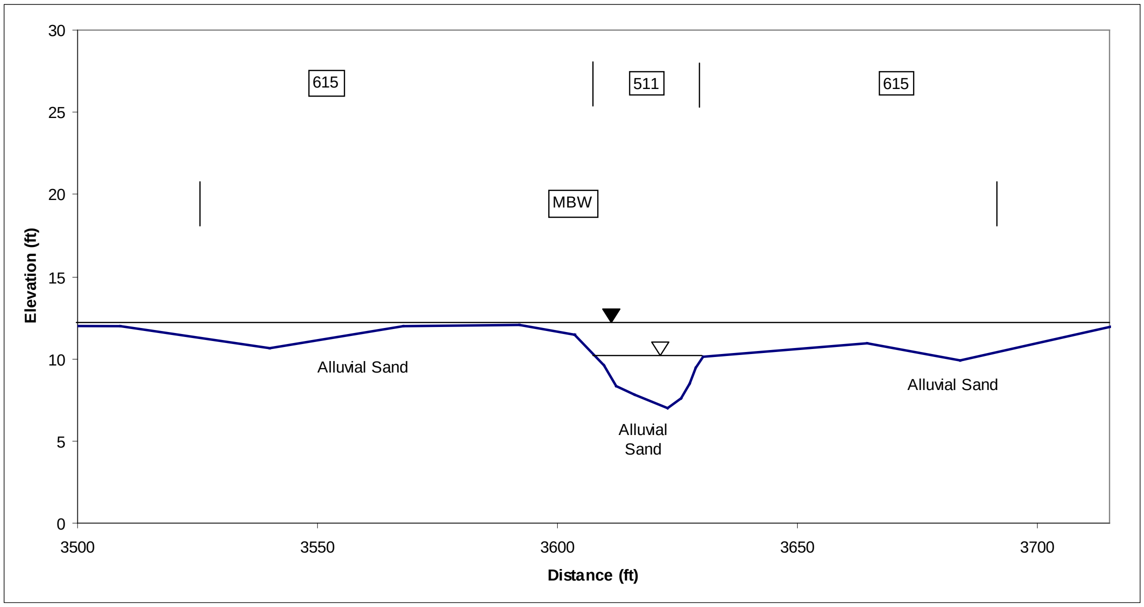
Figure 4.42. Section of FW-AFS-LG Valley with an Unconfined Swamp.

In the previous example, the floodplain occupies a very broad and shallow valley flat with combined alluvial and organic accretions. Figure 4.44 depicts a more compact example of a FW-AFS-LG system with a broad sandy alluvial ridge backed by a sandy alluvial linear backswamp. The lower parts of the channel bank support cypress with some buttonbush. The upper portions of the levees support palmetto, cabbage palm, and laurel oak. The bottomland swamp (615) is dominated by cypress in the lowest-lying areas with cabbage palm, laurel oak, red maple, and Walter's viburnum co-dominant with cypress throughout the rest of the surface. Floodplain communities in FW-AFS-LG corridors occupy massive alluvial surfaces, with their structure and composition largely sorting based upon the elevations of these surfaces relative to the depths of the seasonal flood pulses delivered.



Fisheating Creek

Figure 4.43. Section of FW-AFS-LG near Main Channel.



Little Haw Creek

Figure 4.44. Section of FW-AFS-LG System with a Well-Fit Swamp.

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 3 feet deep with mobile sandy shoals and a dominance of pools at least 5 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 (usually greater than 15). These riverscapes should classify as Rosgen C5s. Submerged aquatic vegetation can occur but will be rare or patchy and may be 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. Flow regime is characteristically annually perennial. 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 seems to be 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 4.9. Valley flats should be 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.

Most FW-AFS-LG systems are likely to be predominantly heterotrophic due to their shaded channels, powerful wet season flood pulses moving sandy shoals on the river bed, and darkly colored waters which retard the sustained establishment of plants in the open channel. The channel canopy is at least partially open in most systems, leading to potential autotrophic patches especially near the shallow channel margins. Emergent plants tolerant of submergence, with attached periphyton, could occur in such patches. For example, these conditions were present on one of the systems studied (Fisheating Creek). However, FW-AFS-LG systems seem unlikely to routinely support perennial patches of periphyton or sustained populations of phytoplankton.

Streams Draining Areas of Sandy Highlands

The delineative threshold for applying this section occurs when HSG soils A+C collectively sum to greater than 40% of the total soil cover in the catchment (Figure 2.7). All three of the main classes proposed for highlands landscapes sorted well along a plot of reach valley slope versus drainage area (Figure 4.45).

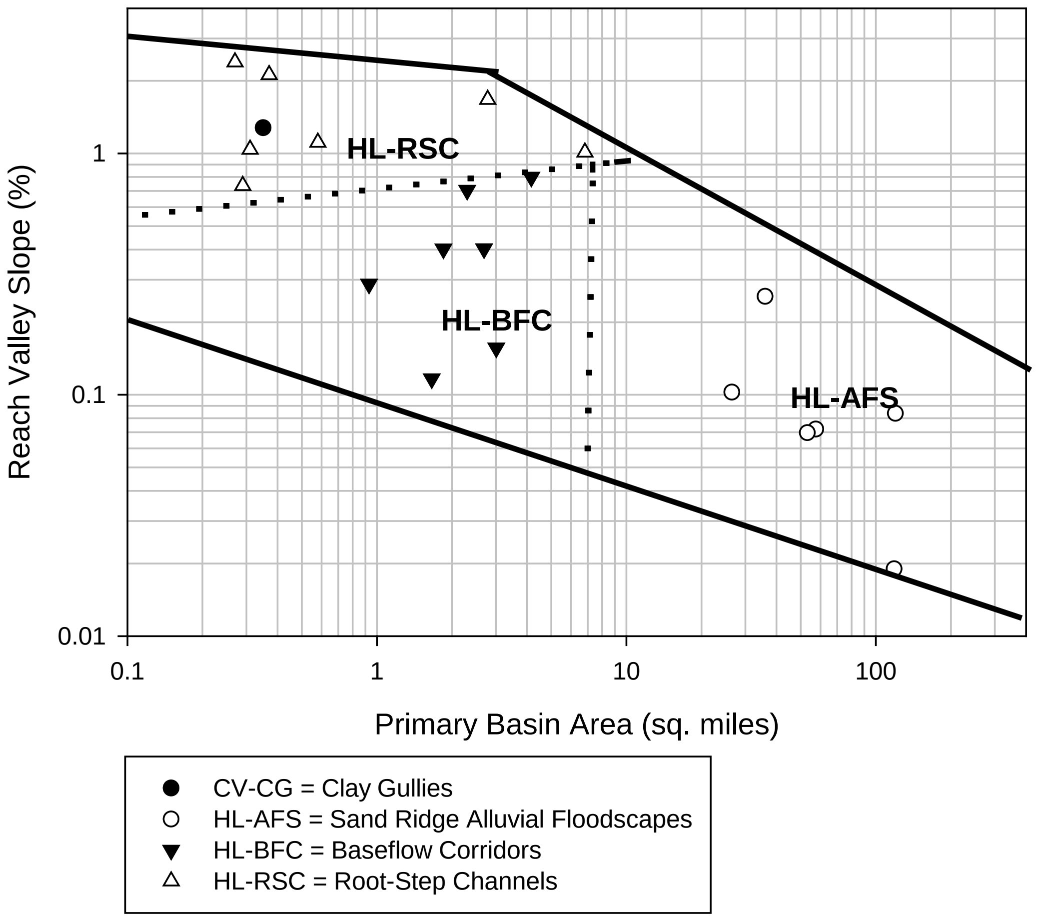


Figure 4.45. Highlands Riparian Systems by Drainage Area and Valley Slope.

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 of less than a square mile, with some draining up to several square miles. Their watersheds rarely generate discharge volumes sufficient to transport and deposit fine alluvium in the vegetated floodscape. Valley slopes range 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 4.46).

Manatee River UT

Figure 4.46. Example of HL-RSC Riparian System.

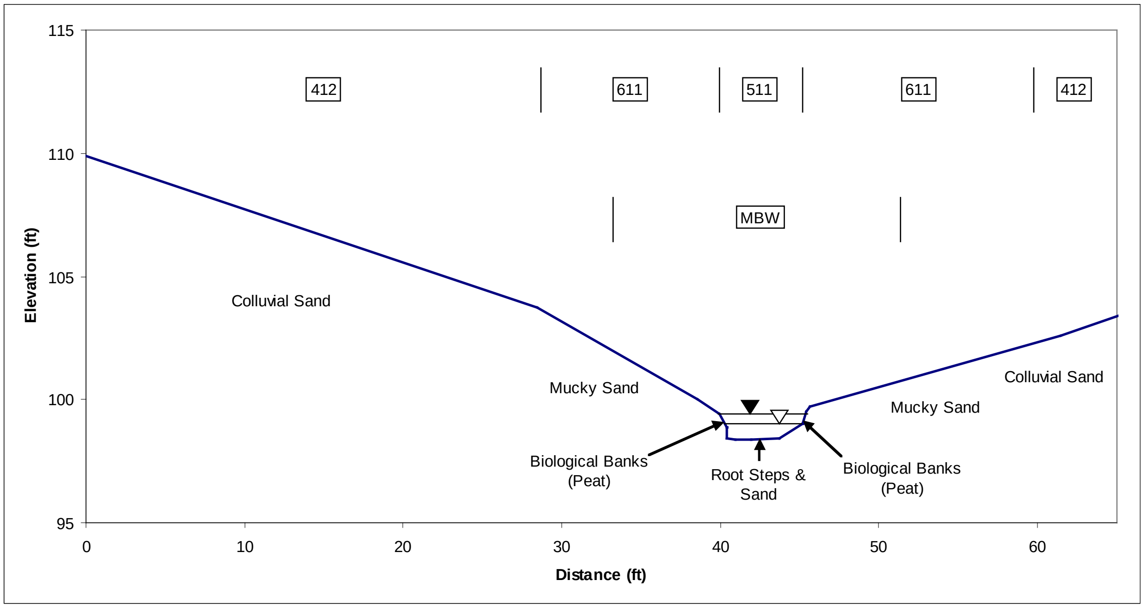
These systems practically never receive alluvial spates and as a result their banks are typically constructed by biologically mediated processes and include moss-covered live root masses growing in peat or peaty muck (Figure 4.46). These biological banks can be continuous or sporadic along the floodscape 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.

Tuscawilla Lake UT

Figure 4.47. Root-Step and Biological Bank Detail.

Figure 4.48 depicts a common valley section for an HL-RSC riparian system. In this case, a seepage slope swamp (611) flanks the entire channel providing gaining amounts of groundwater discharge to the stream. The bank vegetation is consistent with that of the seepage slope, dominated by sweetbay and mosses, with laurel oak, pipestem (*Agarista populifolia*), swamp bay (*Persea palustris*), saw palmetto and wood fern (*Dryopteris ludoviciana*). The upland recharge areas consist of a long-leaf pine and xeric oak sandhill community (412). Figure 4.49 shows a system in a similar valley configuration draining a larger watershed. Bank vegetation is dominated by sweetbay, dahoon, loblolly bay, blackgum, laurel oak, yellow anise (*Illicium parviflorum*), swamp bay, saw palmetto, and buttonbush. Dog hobble (*Leucothoe axillaris*), Virginia willow (*Decodon verticillatus*), Virginia chain fern (*Woodwardia virginica*), cinnamon fern and highbush blueberry are frequent. Figure 4.50 also illustrates a similar hydroecological configuration with banks dominated by dahoon, loblolly bay, wax myrtle, sweetbay, red bay, highbush blueberry, saw palmetto, cinnamon fern and occasional live oak and slash pine. These three cases represent the majority of HL-RSC systems. Variations occur based on the amount and source of baseflow to the stream.

Figure 4.51 represents a variation where most of the water comes from a concentrated headwater source flowing through sand rather than muck. The headwater is an amphitheater-like escarpment in the sandhill providing copious flow of clear (non-tannic) water referred to as a steephead. This is in juxtaposition to the aforementioned examples that receive their groundwater discharge through combinations of headwater and lateral seepage slopes through muck layers providing highly colored water. Bank vegetation along the steephead-fed stream consists of red bay, loblolly bay, sweetbay, Virginia willow, pipestem, and blackgum.



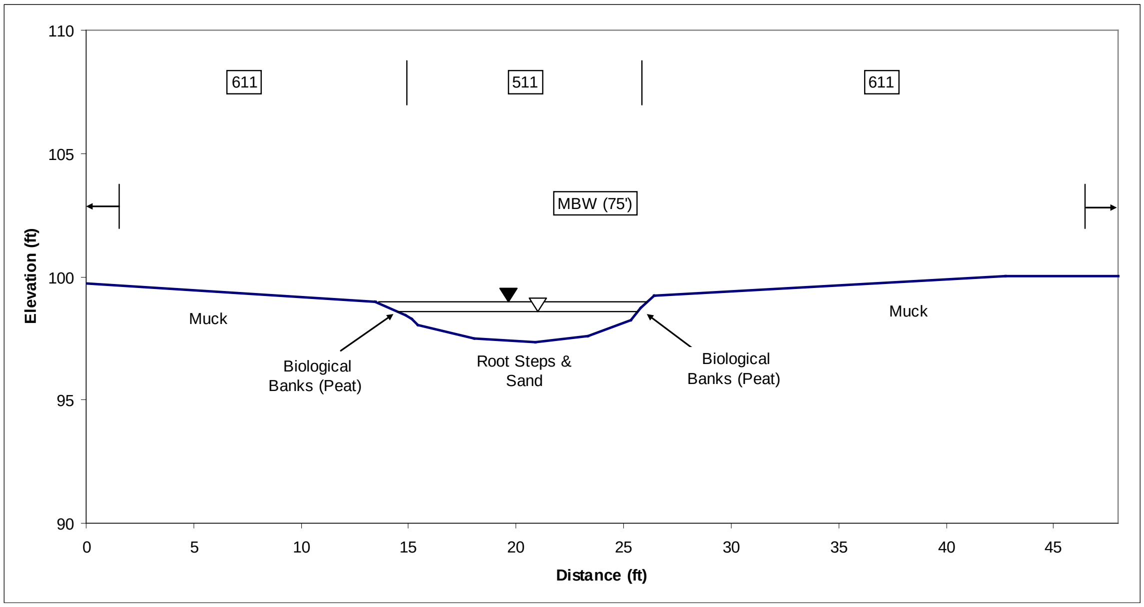
Lowry Lake UT

Figure 4.48. Section of a Small HL-RSC System Confined by Seepage Slopes.

Figure 4.52 depicts a variation where most of the seepage is sourced from a mucky headwater bay swamp with comparatively little lateral seepage. Bank species consist of slash pine, sweetbay, water oak, wax myrtle, buttonbush, and laurel oak.

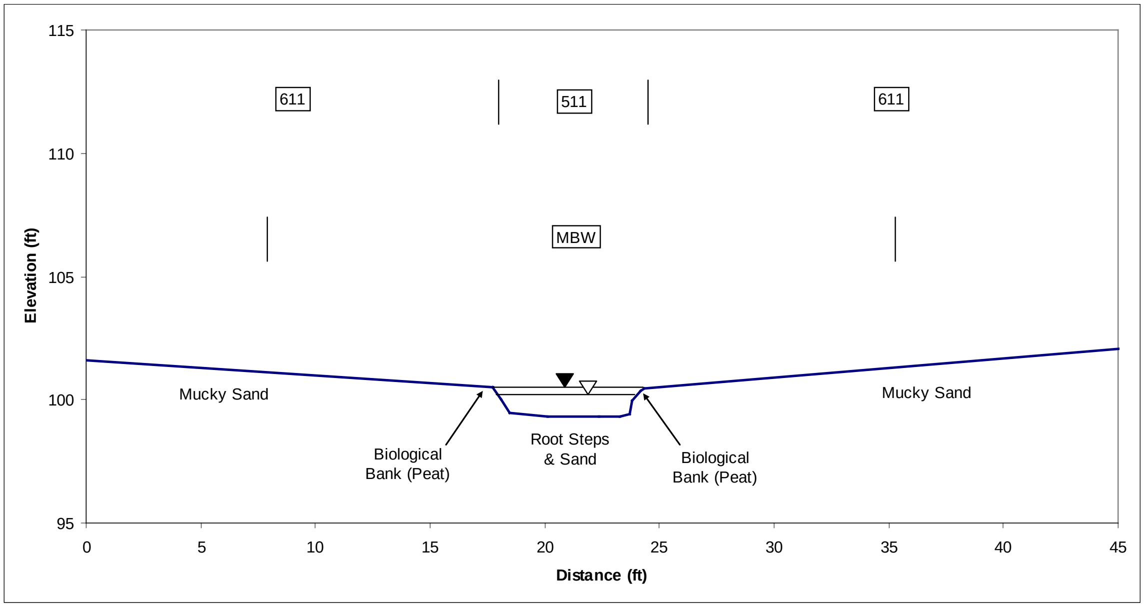
Figure 4.53 crosses an HL-RSC system dissecting a high river bluff near an old marine escarpment. The RSC stream starts abruptly in a wet flatwoods. The aforementioned systems receive copious baseflow most of the time, but this system lacks major lateral or headwater seeps, only receiving comparatively small amounts of seepage through its channel banks. Its bank vegetation is saw palmetto, dahoon, water oak, cinnamon fern, slash pine, wax myrtle, laurel oak, and swamp bay.

Figure 4.54 depicts an even drier variant of HL-RSC riparian systems. In this case the stream dissects an upland ridge between a bayhead-fringed lake upstream and a broad cutthroat seep downstream. The water table is usually well below the stream channel, discharging instead to the cutthroat seep at lower elevation. Therefore, the stream merely flows ephemerally based on when the lake levels rise high enough. The root-steps are from palmettos and pines rather than the bays, dahoon holly, and blackgum swamp trees forming them in most other HL-RSC sites studied. Bank vegetation includes dense saw palmetto, scattered longleaf pine, and patches of winged sumac (*Rhus copallina*), blueberry, and sand cordgrass. In general, the riparian vegetation depends heavily on headwater and lateral seepage discharges that are most characteristically, but not universally, intercepted by the stream channel. The presence or absence of local seepage faces near HL-RSC systems clearly drives the species composition.



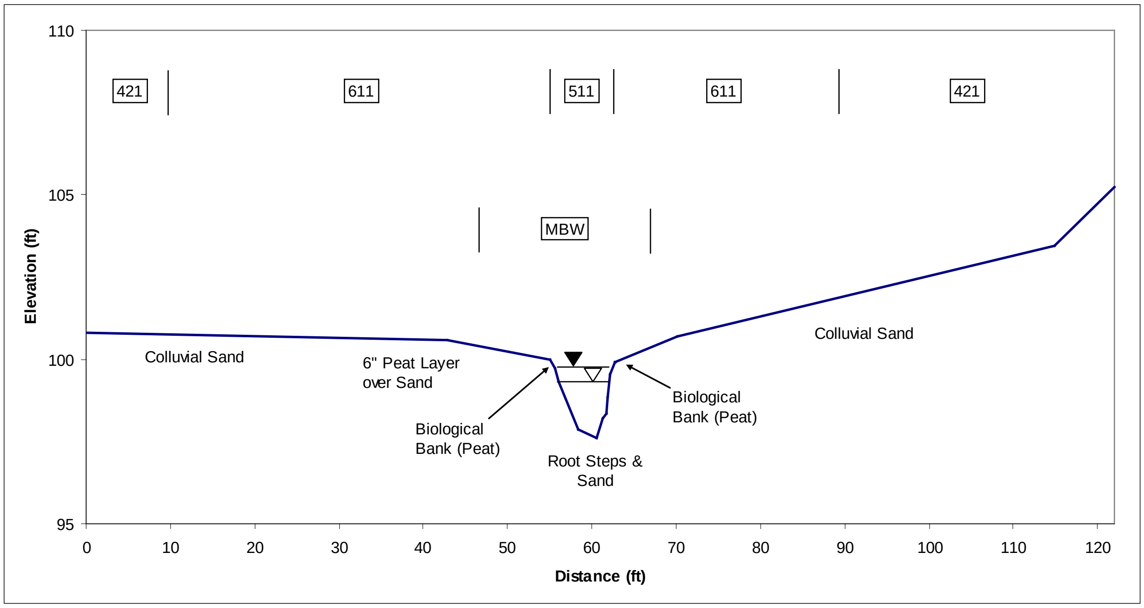
Ninemile Creek UT

Figure 4.49. Section of a Large HL-RSC System Confined by Seepage Slopes.



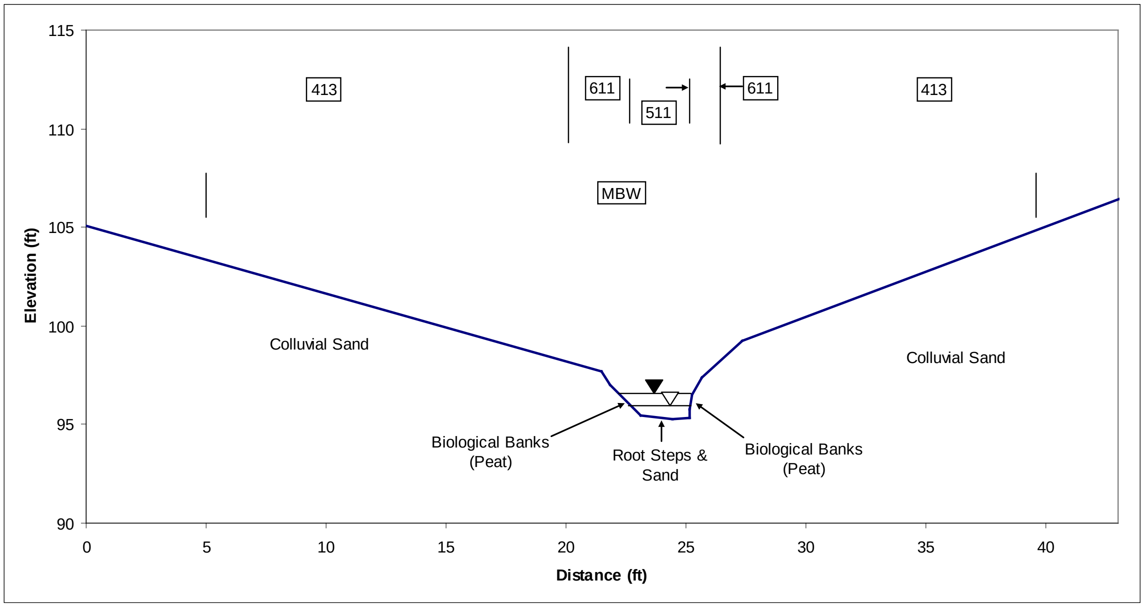
Lake June-In-Winter UT

Figure 4.50. Section of HL-RSC System Draining a Large Bayhead.



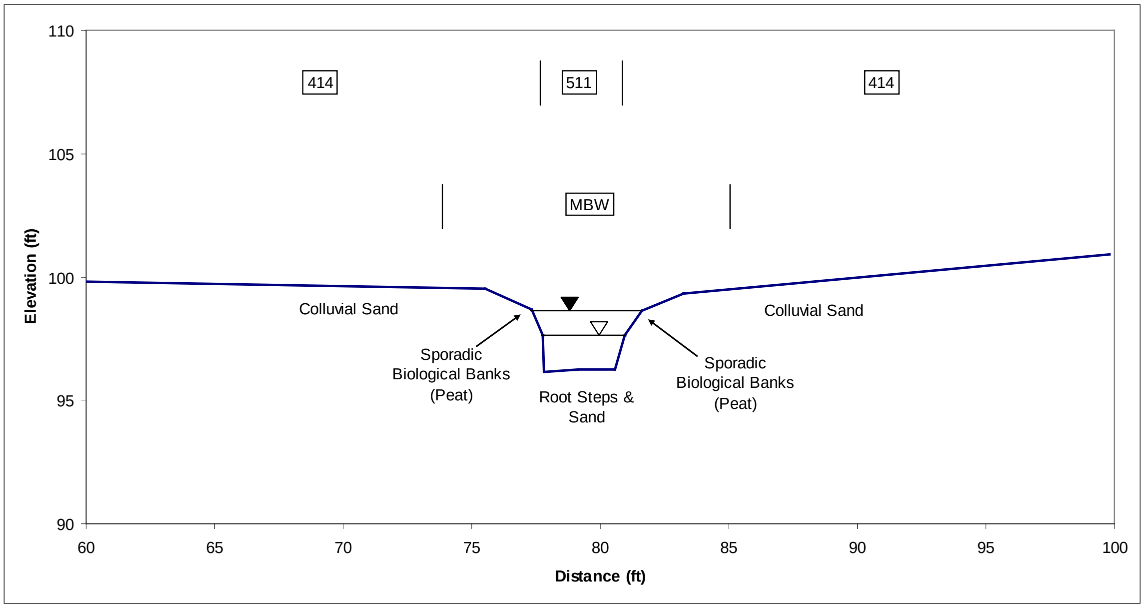
Goldhead Branch

Figure 4.51. Section of HL-RSC System Draining a Steephead.



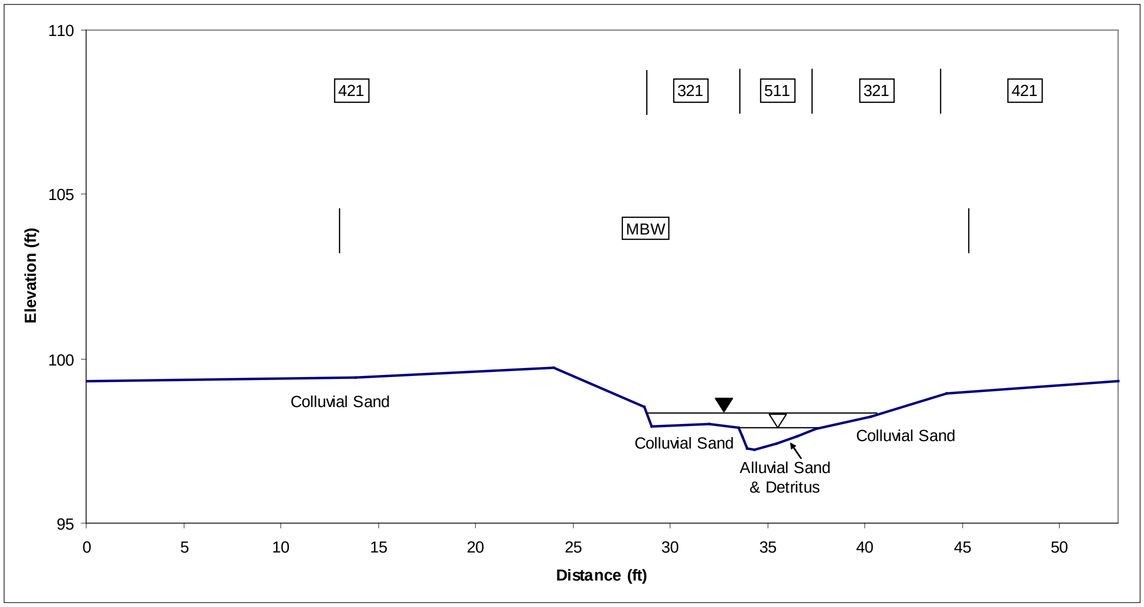
Tuscawilla UT

Figure 4.52. Section of HL-RSC System Draining a Large Bayhead.



Manatee River UT

Figure 4.53. Section of HL-RSC System Crossing a River Bluff.



Cypress Slash UT

Figure 4.54. Section of HL-RSC System Confined by Xeric Hillslope.

The bankfull channel of HL-RSC systems 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 small 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 are usually topped by scrub or sandhill communities. Gage records are virtually non-existent for these systems. Based mostly on vegetation and seasonal observations of the study sites, flow is likely to be seasonally perennial to annually perennial for steephead systems and those with extensive lateral seepage slopes. Systems with narrow seepage fringes and those fed solely by headwater bay swamps may be seasonally intermittent to seasonally perennial. Very limited lateral connections occur from the riverscape to the floodscape. Fauna benefitting from these systems probably take advantage of the common perennial or nearly perennial longitudinal flow connections between waterbodies.

Ephemeral HL-RSC systems with low groundwater tables differ significantly in vegetation and in root-step species composition from the aforementioned more common variants. They probably should be considered a separate stream type, but not enough of them were encountered during this study or otherwise to make that generalization.

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 4.45. It is also important to verify a receiving waterbody with relief and capacity to accept the sediments necessary to have allowed formation of a sapping valley, typically a doline lake, large sinkhole, or river with high bluffs. 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.

HL-RSC systems are most likely to be highly heterotrophic. This is due to their heavily shaded channels and, in most cases, darkly colored waters which preclude the sustained establishment of plants in the open channel. The only unshaded system encountered had ephemeral flow with dark color, precluding autotrophic conditions as well. HL-RSC systems are unlikely to routinely support extensive patches of emergent aquatics, periphyton, or sustained populations of phytoplankton.

Baseflow Corridors (HL-BFC)

HL-BFC systems drain small to 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 are 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 10 square miles which rarely generate discharge volumes sufficient to transport and deposit fine alluvium in the vegetated floodscape at valley slopes ranging from 0.1% 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 5 and 20 square miles. However, subsequent hydrology research suggested annual perenniality is rather consistent in highlands streams draining at least 7-square-mile catchments, therefore the classification boundary is tentatively indicated at that threshold (AMEC 2013).

These systems are intermediate in form between systems that 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 4.55).

Tiger Creek UT

Figure 4.55. Example of HL-BFC Riparian System with Limited Runoff Pulses.

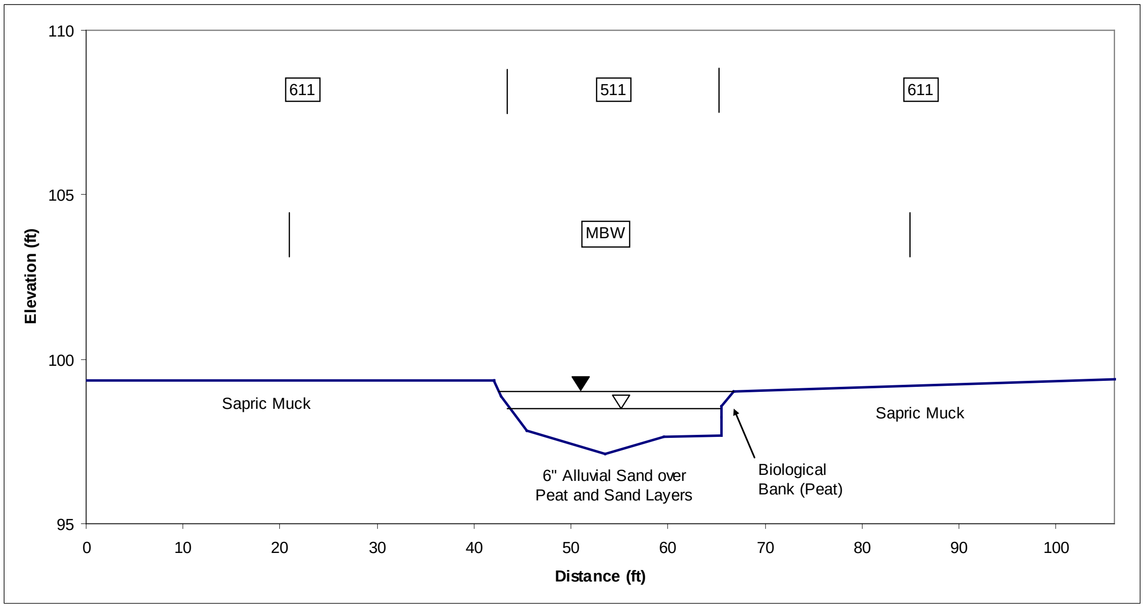
However, as increasing amounts of D soils and wetlands occur in the watershed, these systems can begin to pick up occasional spates that form sporadic alluvial benches at the bankfull stage. Good examples include Jack Creek and Hammock Branch (Figure 4.56). Systems with increasing influence from D soils 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.

Hammock Branch

Figure 4.56. Example of HL-BFC Riparian System with Routine Runoff Pulses.

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 1 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.

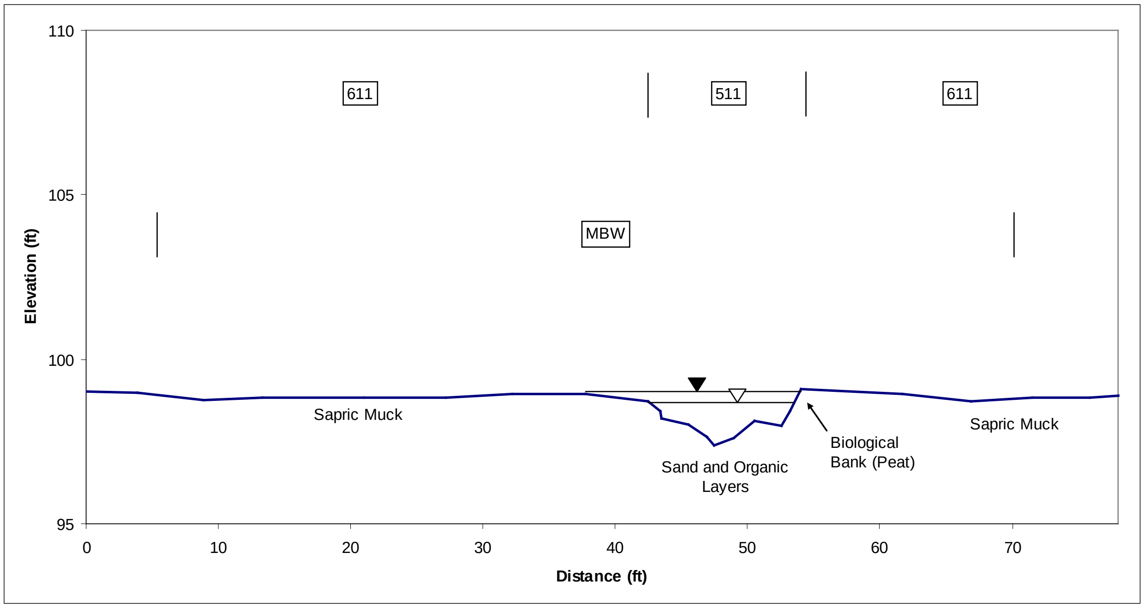
Figure 4.57 illustrates a HL-BFC channel that receives copious amounts of steady groundwater discharge from a series of large lateral and headwater bay swamps. Dominant species in the lateral swamps (611) and stream banks include sweetbay, cabbage palm, red maple, yellow anise, swamp dogwood, and buttonbush. The tree canopy was variably thinned by hurricanes, and scattered patches of golden club (*Orontium aquaticum*), lizard's tail (*Saururus cernuus*), and cow lily (*Nuphar lutuem*) exist on the stream bed and its margins. Figure 4.58 depicts a similar hydrogeomorphic configuration in a smaller system. Dominant seepage swamp (611) and bank vegetation consists of sweetbay, red maple, wax myrtle, saw palmetto, loblolly bay, cinnamon fern, and Virginia willow. Sporadic golden club occurs on the channel margins. The system represented by Figure 4.59 has very similar species.



Snell Creek

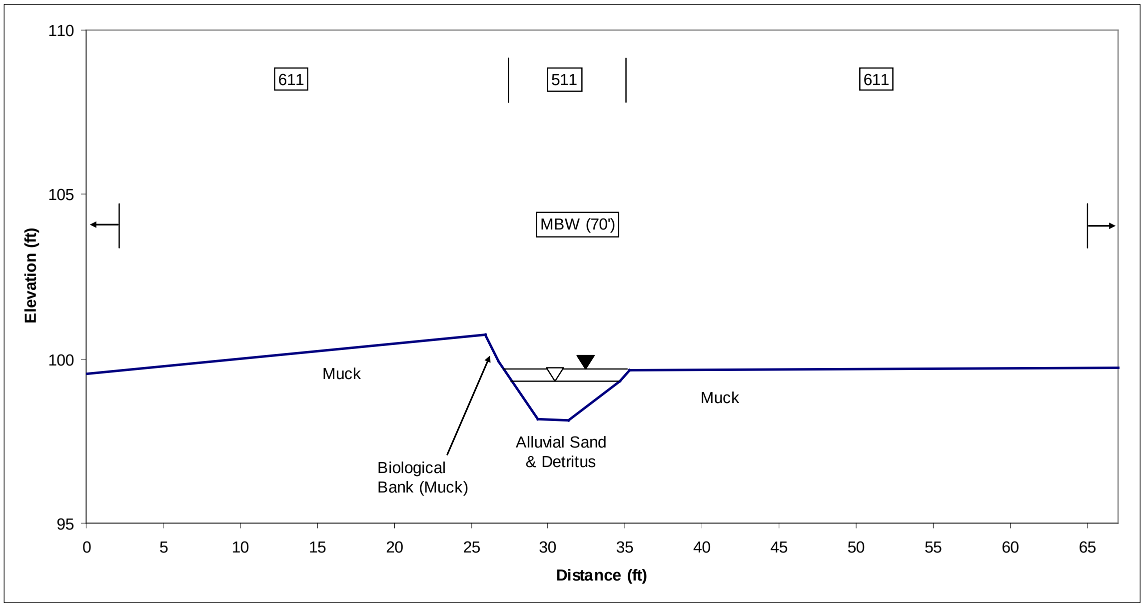
Figure 4.57. Section of HL-BFC System Confined by Large Seepage Swamp.

The previously described sites drain watersheds delivering comparatively greater dominance of groundwater flow with limited runoff events. They function more like spring-fed streams than like flatwoods streams in that respect. In contrast, Figures 4.60 and 4.61 show valley sections from stream segments draining large lake or swamp depressions that can generate more frequent flood pulses from stormwater runoff. As a result, they have wider flood benches mantled by muck. The stream channel in Figure 4.60 is flanked by a hardwood swamp (617) dominated by dahoon with common laurel oak, palmetto, swamp dogwood, wax myrtle, and Walter's viburnum. Bank species are similar and small patches of golden club occupy the bed. A narrow seepage swamp (611) with dahoon, sweetbay, palmetto, and loblolly bay flanks the steeper hillslope. The upland hillslopes (413) abruptly transition to dense saw palmetto, scrub oaks, and sand pines.



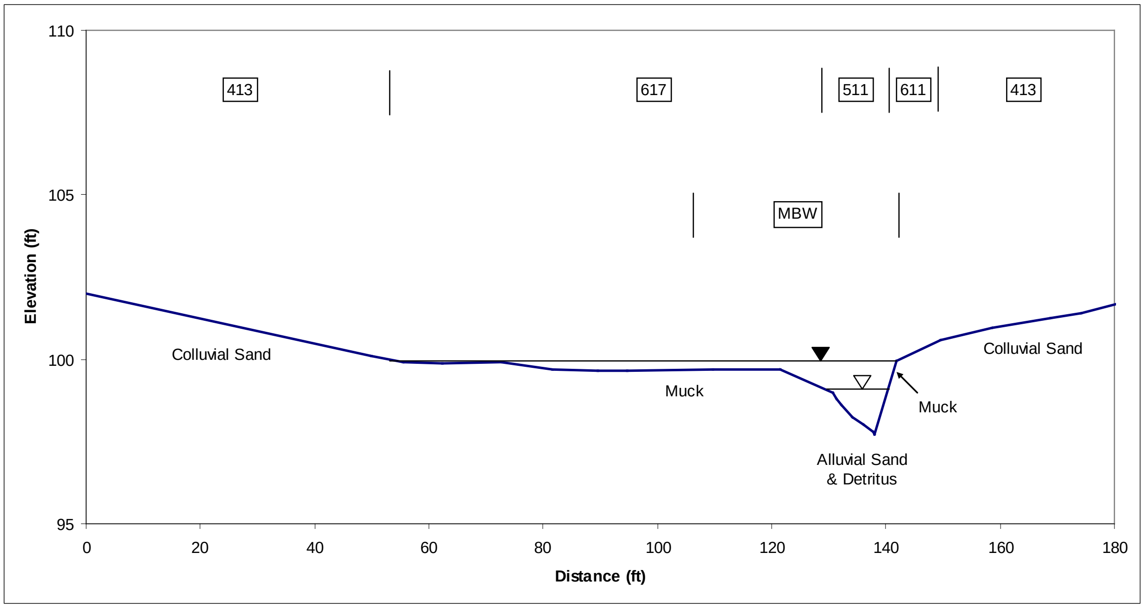
Tiger Creek UT

Figure 4.58. Section of HL-BFC System Confined by Seepage Swamp.



Bell Creek

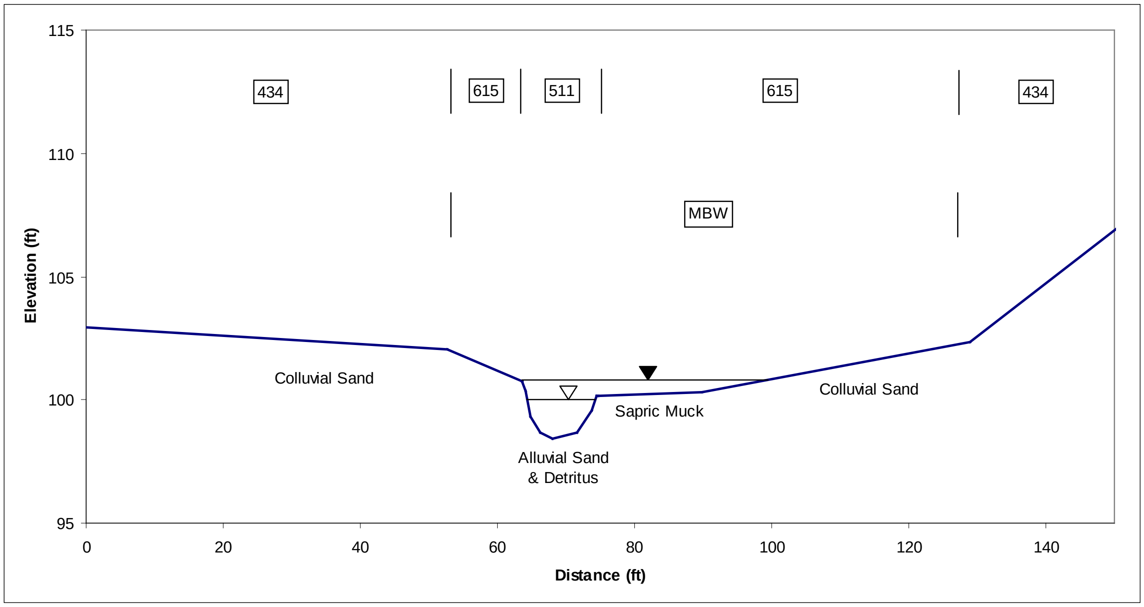
Figure 4.59. Section of HL-BFC System Confined by Seepage Swamp.



Jack Creek

Figure 4.60. Section of HL-BFC System Draining Large Wetland-Lake Headwaters.

Figure 4.61 illustrates a valley with a bottomland swamp (615) occupied by sweet gum, ironwood, wax myrtle, bald cypress, cabbage palm, laurel oak and buttonbush. The valley hillslopes are mesic hammocks with a variety of upland hardwoods and long-leaf pine (434)

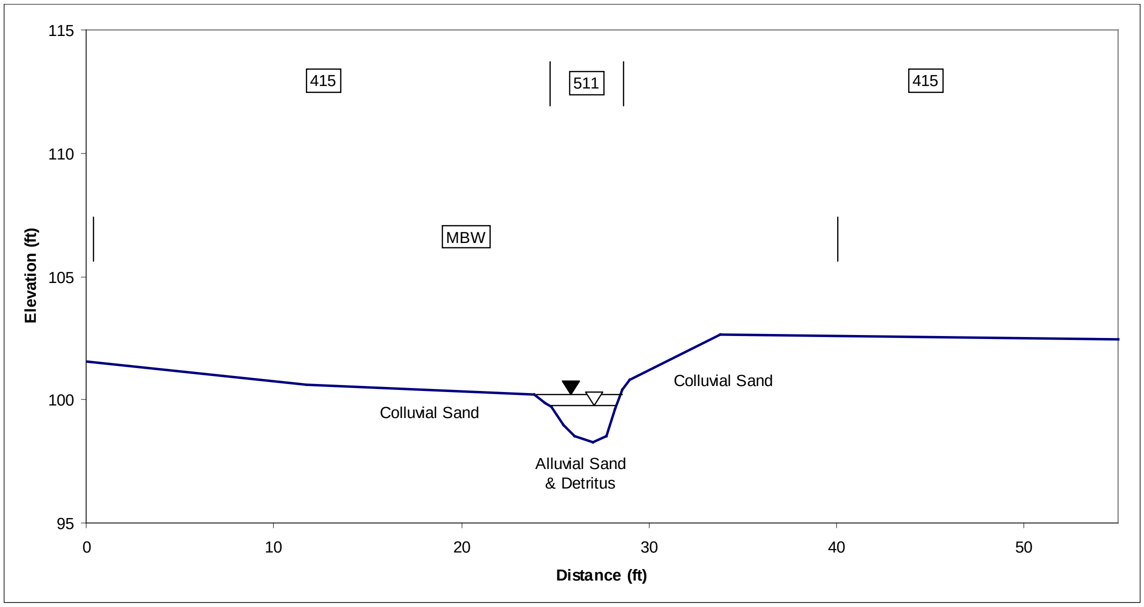


Hammock Branch

Figure 4.61. Section of HL-BFC System Draining Large Wetland Headwaters.

Figure 4.62 pictures a small HL-BFC drainage system on the cusp of valley slope necessary to support HL-RSC riparian systems. A single root-step occurs downstream of the study reach, none within it. As with the previous two examples, this system has depressional surface waters in the headwater parts of its watershed. The stream meanders through a tightly confining upland and receives little lateral groundwater input. The banks and hillslope consist of saw palmetto, dahoon, slash pine, sand pine, and wax myrtle. Riparian vegetation in these systems mainly depends on non-alluvial factors related to local seepage faces and water table elevations.

The bankfull channel of HL-BFC systems 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 is 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.



Jumping Gully

Figure 4.62. Section of Small HL-BFC System Draining a Small Watershed.

These valley segments connected non-riverscape and riverscape waterbodies, providing direct channel connections to various types of flowing waterbodies in the drainage network. Limited gage records suggest flow is characteristically annually perennial, with some smaller systems being seasonally perennial (AMEC 2013). 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 4.45. 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.

HL-BFC systems are most likely to be heterotrophic, with potential for minor autotrophic patches greatly limited in time and space. This is due to heavily shaded channels and, in most cases, darkly colored waters which preclude the sustained establishment of flora in the open channel. In some systems, dry season flow has little color, thus establishing the potential for patches of periphyton growth on a seasonal basis where light gaps occur. Patches of emergent aquatics often occur on the stream bed, but HL-BFC systems are unlikely to routinely support extensive cover of submerged aquatics, periphyton, or sustained populations of phytoplankton.

Sand Ridge Alluvial Floodscapes (HL-AFS)

HL-AFS systems drain large highlands watersheds. They have alluvial floodplain features, but these may be smaller and less diverse 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.

The lower limit of watershed size necessary to support these systems is somewhat indeterminate due to a lack of suitable research sites between 5 and 20 square miles. Discharge records suggest highlands systems may universally become annually perennial when draining watersheds of at least 7 square miles (AMEC 2013). Therefore, the classification break is suggested at seven square miles (Figure 4.45). Discharge regimes sufficient to transport and deposit fine alluvium in the vegetated floodscape occur at minimum valley slopes ranging from 0.01% to 0.05% (Figure 4.45). 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 4.63).

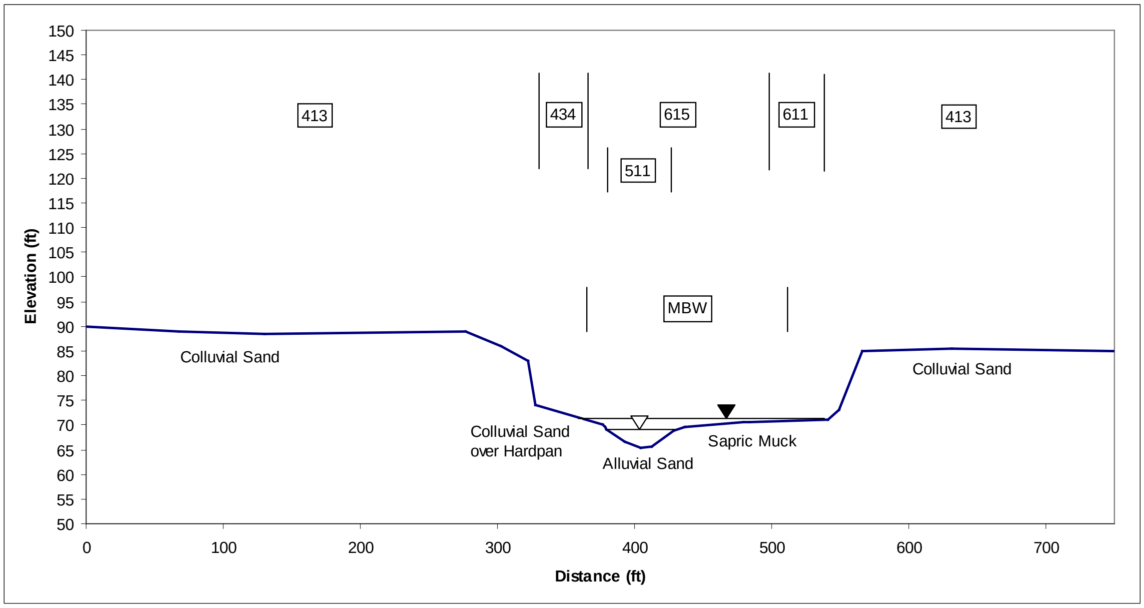
Catfish Creek

Figure 4.63. Example of HL-AFS Riparian System.

The floods generated from these large watersheds create narrow floodplains which can be discontinuous along a given bankline and highly variable in width, ranging from 50 to 500 feet wide. However, an alluvial floodplain occurs rather continuously along the valley, occupying at least one bank or the other. 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 be vegetated by herbaceous emergent wetland plants. Figures 4.64 through 4.69 illustrate cases where the active alluvial floodplain is incised between high sandy bluffs formed among the regional relict dunescapes. The active floodplain has cut through a relict valley flat in some cases as well. In contrast, Figures 4.70 and 4.71 represent cases where the meander belt is unconfined by such bluffs. HL-AFS river reaches often alternate between these two configurations along the valley.

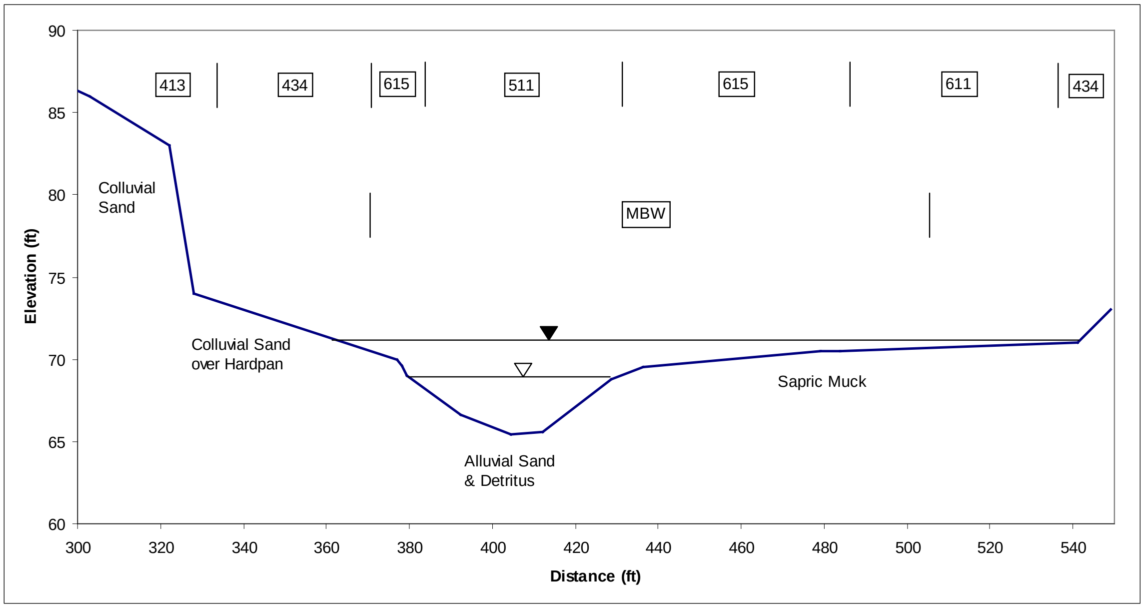
Figure 4.64 provides a wide valley and upland cross section. The uplands are dominated by sand pine and xeric oak scrub (413) with some mesic oak and pine hammocks (434) bordering portions of the floodplain. The channel meanders across an active floodplain consisting mainly of a bottomland swamp (615), variably flanked by seepage swamps (611) (Figure 4.65). The bottomland swamp and banks are dominated by red maple, buttonbush, laurel oak, and cabbage palm with common Carolina willow, blackgum, sweetbay, and saw palmetto. The seepage swamp is dominated by sweetbay and red maple, with dense Virginia chain and cinnamon ferns as groundcover, and some laurel oak, cabbage palm, buttonbush and lizard's tail throughout.



Tiger Creek

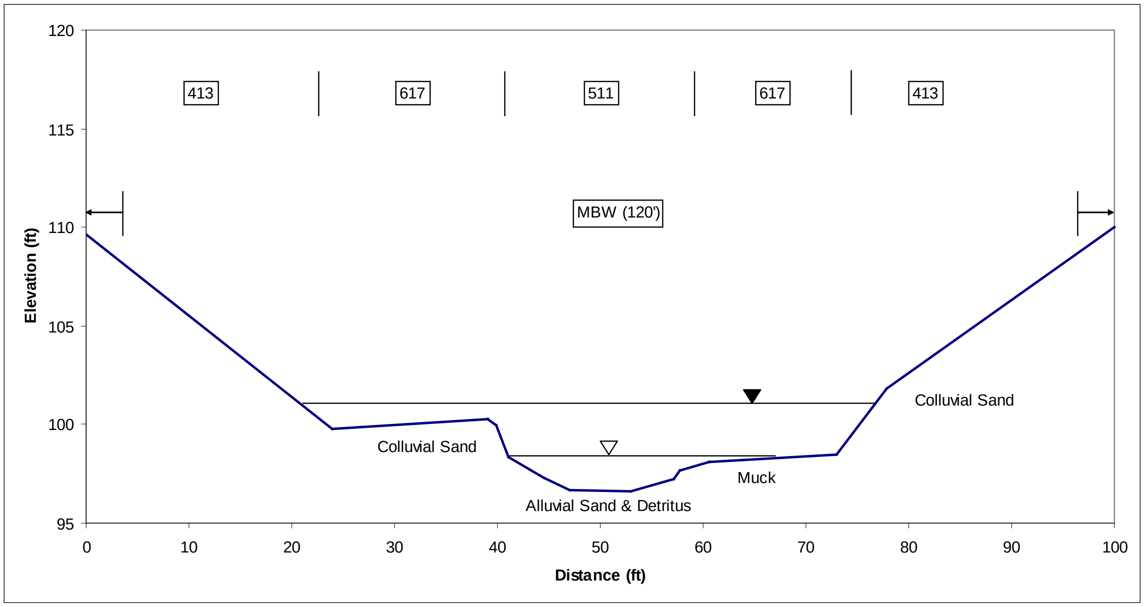
Figure 4.64. Valley Section of HL-AFS System with Xeric Bluffs.

Figure 4.66 illustrates a site with similar xeric upland bluffs, but with two terraces on the valley floor. These alternate from side to side of the channel. The lower terrace is an alluvially active bankfull bench with water oak, laurel oak, Carolina willow, saw palmetto, buttonbush, wax myrtle, and royal fern (*Osmunda regalis*) growing on muck. The higher terrace is dominated by wax myrtle, cabbage palm, water oak, and pignut hickory (*Carya glabra*) growing on colluvial sands. Although both surfaces are mapped as 617 (bottomland swamp), the higher terrace presents more like a hydric hammock in places. Channel banks are similar in species composition to that of the lower terrace. The transition between the 617 and 413 (scrub) communities is abrupt, with a very dense palmetto line. The channel borders the 413 community in places, especially at the outer parts of bends.



Tiger Creek

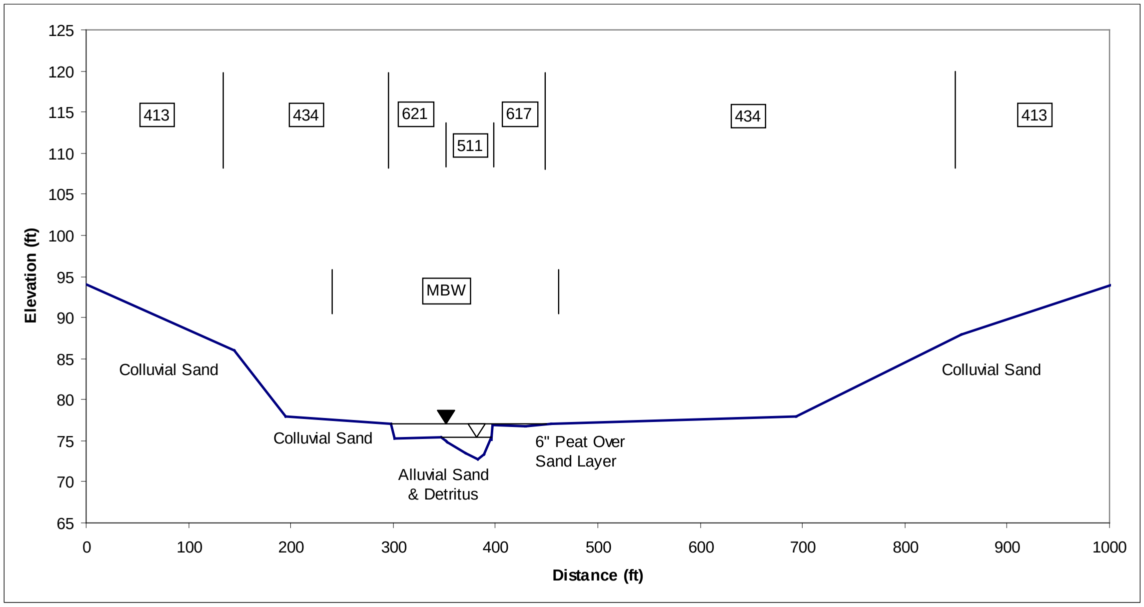
Figure 4.65. Channel Section of a Confined HL-AFS System.



Carter Creek

Figure 4.66. Section of a Confined HL-AFS System with Two Wetland Terraces.

Figure 4.67 shows another active alluvial valley entrenched within a larger relict valley flat flanked by high sandy bluffs in ancient xeric scrublands. The relict valley floor consists of a broad mesic hammock of live oak, cabbage palms, pignut hickory, persimmon (*Diospyros virginiana*), red bay (*Persea borbonia*), beauty berry (*Callicarpa americana*), red maple, and longleaf pines (434). The lower active terrace is dominated by bald cypress (621) or has cypress co-dominant with dahoon, cabbage palm, laurel oak, red maple, wax myrtle, and buttonbush with some Carolina willow, swamp dogwood, blackgum, and sweetbay (617). Bank species are generally similar. This is a wide, gently flowing channel allowing good light penetration to the stream. Thus, point bars are densely covered by cattail (*Typha* sp.), pickerelweed (*Pontedaria cordata*), maidencane, beakrush, and club-rush (*Eleocharis cellulosa*). Some outer bends cut steeply into the adjacent uplands and are bordered by dense palmetto and live oak. Patches of submerged aquatic vegetation occur on the sandy stream bed.



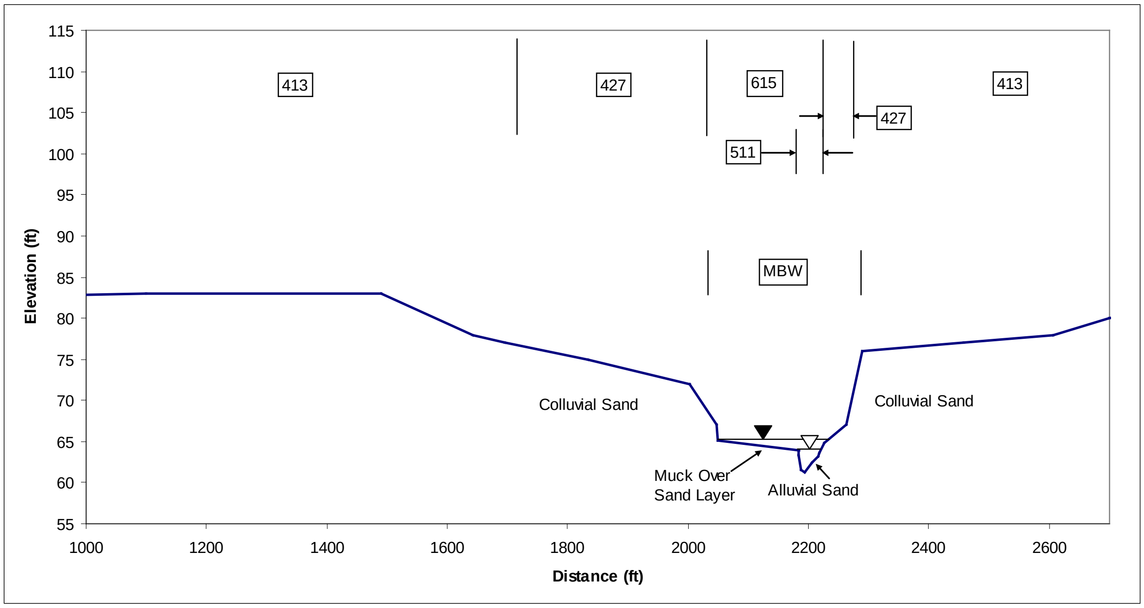
Catfish Creek

Figure 4.67. Valley Section of HL-AFS System with Upland and Wetland Terraces.

Figures 4.68 and 4.69 detail a system deeply dissecting, and tightly confined by, an ancient xeric dunescape. Figure 4.68 shows that the alluvially active valley forms a bottomland swamp (615), which is flanked by mesic live oak hammocks (427). Xeric habitats occur at higher elevations (413).

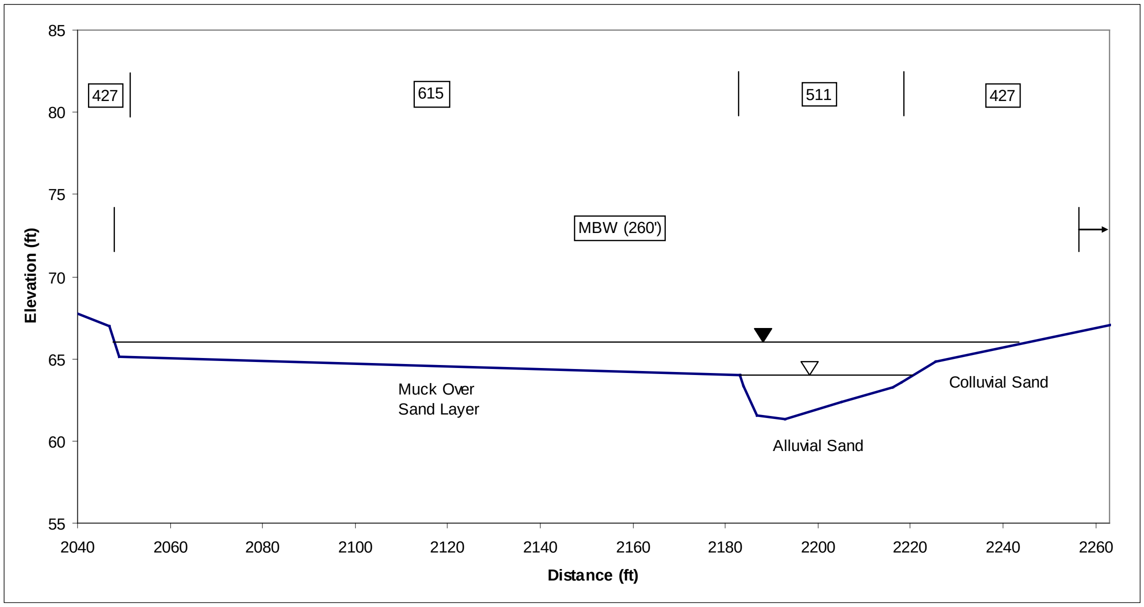
The bottomland swamp (615) and channel banks in Figure 4.69 are dominated by popash, red maple, buttonbush, and cabbage palm. This wide channel has sedges, pickerelweed, cow-lily, cattail, and duck potato growing on shallow channel margins. Outer bends often cut directly into the mesic hammock and banks are densely lined by saw palmetto, live oak and laurel oak. Portions of the stream bed have submerged aquatic vegetation.

Figure 4.70 illustrates a case where the meander belt is unconfined by upland bluffs and is instead subsumed within a large bottomland swamp (615). An alluvial ridge extends from the channel margins across part of the valley floor, thus creating a linear backswamp between the ridge and valley hillslope. The alluvial ridge and banks are dominated by sweet gum, sweetbay, wax myrtle, and red maple, with occasional needle palm (*Rhapidophyllum histrix*). The backswamp is dominated by red maple, buttonbush, sweet gum, and blackgum, with a variably dense groundcover of lizard’s tail and red-topped panicum.



Livingston Creek

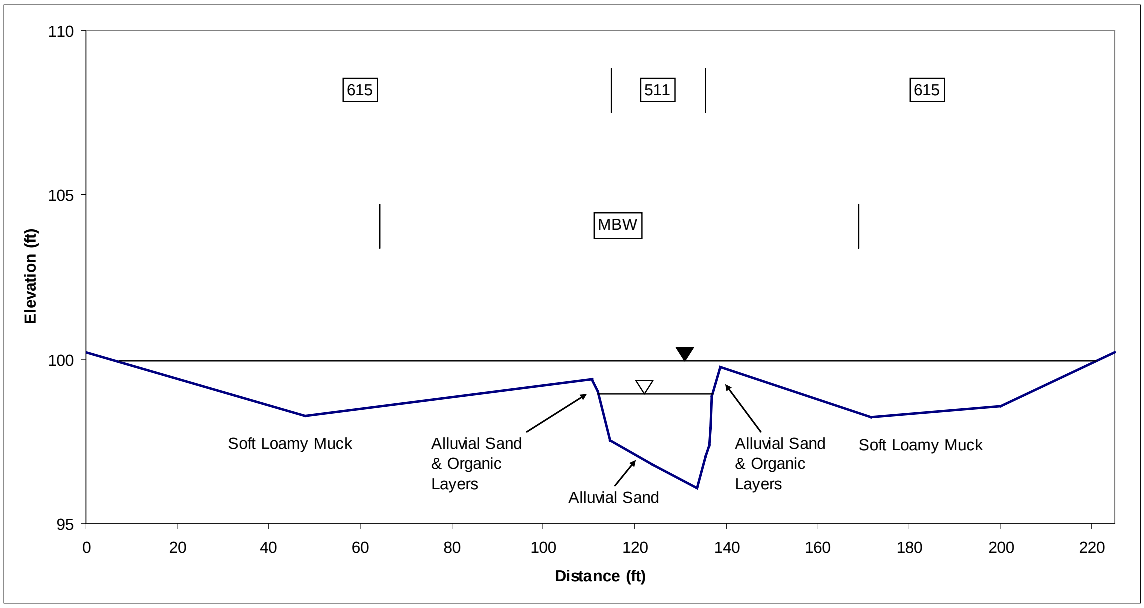
Figure 4.68. Valley Section of HL-AFS System with Xeric Bluffs.



Livingston Creek

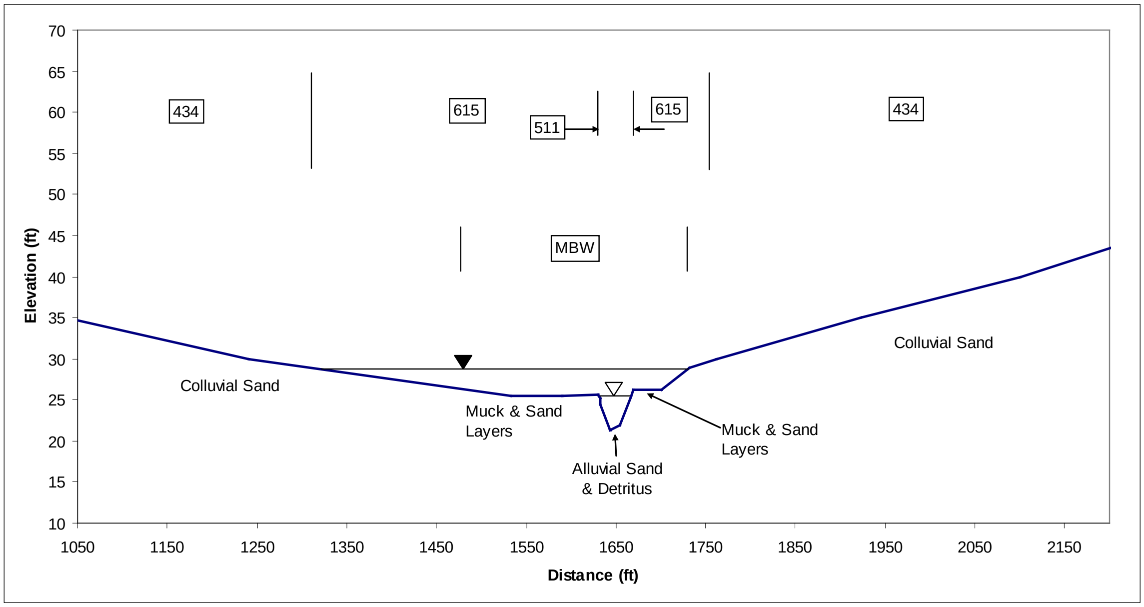
Figure 4.69. Channel Section of a Well-Fit HL-AFS System.

Figure 4.71 depicts a system near where it is transitioning from an unconfined to well-fit valley form, at a moderately unconfined location. The bottomland swamp is dominated by bald cypress, cabbage palm, red maple, laurel oak, and sweet gum, with patches of lizard's tail growing on vertical accretions of sandy alluvium and muck forming a comparatively featureless valley flat.



South Fork Black Creek

Figure 4.70. Section of an Unconfined HL-AFS Riparian System.



Blackwater Creek

Figure 4.71. Valley Section of an Unconfined to Well-Fit HL-AFS System.

These case studies illustrate the wide array of valley surfaces HL-AFS systems can border or form: ancient high, sandy bluffs; relict upland or wetland terraces; seepage swamps; hydric hammocks; and active alluvial surfaces with hardwood, cypress, or mixed bottomland swamps. Some channels flow wide and shallow enough to support emergent and submerged aquatic vegetation. These factors suggest HL-AFS riparian systems support very high amounts of terrestrial and aquatic biodiversity associated with a characteristically complex array of alluvial and colluvial surfaces, a concept that is especially strengthened knowing that these systems typically also link large in-line and headwater lakes and depressional wetlands.

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 4 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 B5s 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. Flow regimes are characteristically annually perennial. 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, aquatic reptiles, and amphibians including various aspects of their life cycles. 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. Based on local-scale and valley-scale physical diversity, these systems should support among the most diverse fisheries and terrestrial fauna of Florida stream corridors.

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 4.45, with some practical caution applied in 5 to 20 square mile catchments. 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.

HL-AFS systems can be naturally heterotrophic or autotrophic. Channels become wide enough to allow some light penetration to the stream for systems draining watersheds in excess of 35 square miles. Smaller HL-AFS systems are likely to be predominantly heterotrophic due to channel shading and colored waters. Water color in some systems can be much more intense during the wet season than dry season, suggesting potential for dry-season autotrophic conditions where canopy openings allow. Systems with greater than 35-square-mile watersheds typically had at least some margins with emergent aquatic vegetation, while some systems with more than 55-square-mile basins supported patches of submerged aquatic vegetation. Some stream segments receive pulses of phytoplankton-laden waters from culturally eutrophic lakes upstream, which may have diminished the submerged aquatic vegetation communities observed in this study. The occurrence of submerged aquatics is not assured based solely on basin size, though. For example, the 118-square-mile aptly named Blackwater Creek lacked any submerged aquatics (probably because it drains immense well-colored headwater wetlands and a highly colored lake). The potential for extensive periphyton or phytoplankton communities seems to depend not only on channel width, but also on the biogeochemistry of the large in-line waterbodies affecting the concentrations of color, nutrients, and lake-derived algal plankton being passed on to the stream channel.

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. 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 4.72). The only exception occurs for certain types of the largest runs.

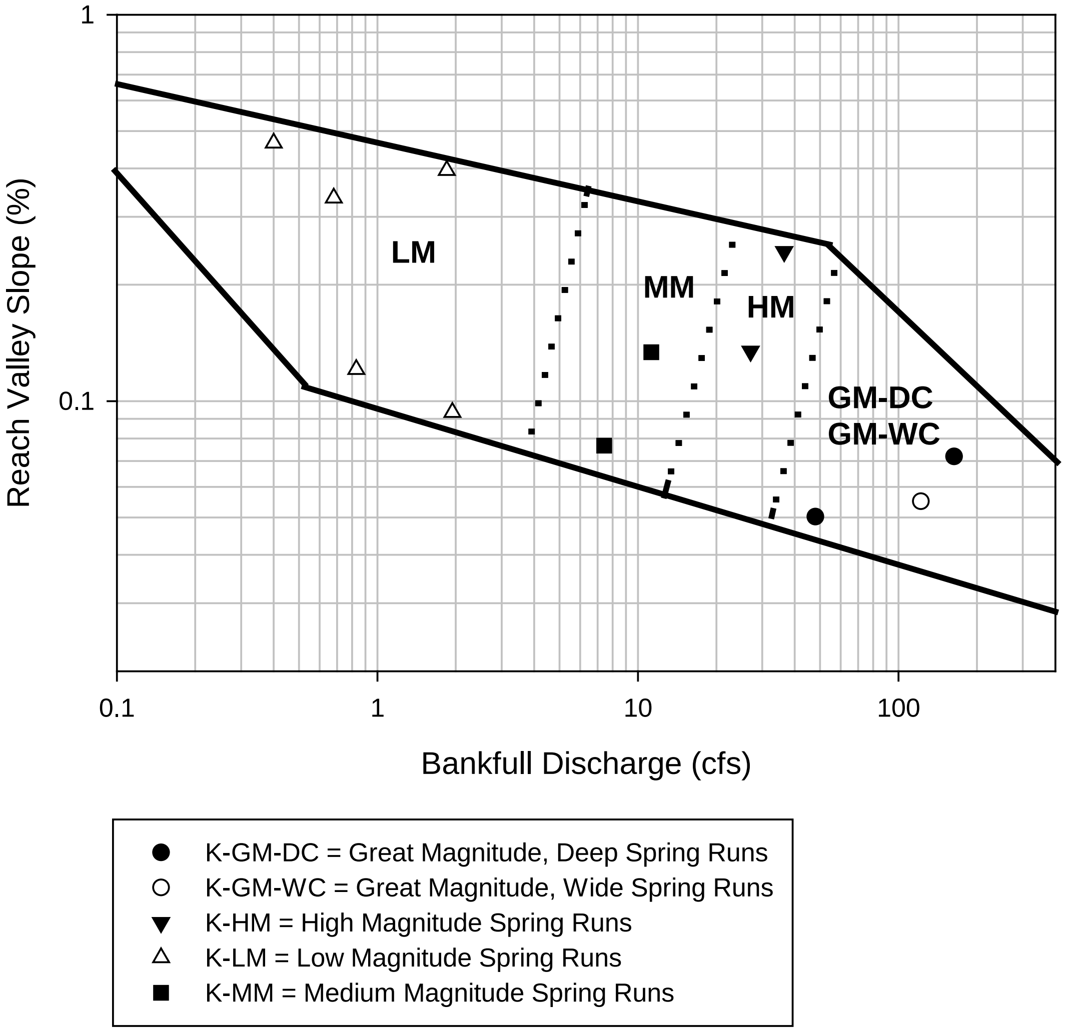


Figure 4.72. Karst Riparian Systems by Bankfull Discharge and Valley Slope.

Low-Magnitude Spring Runs (K-LM)

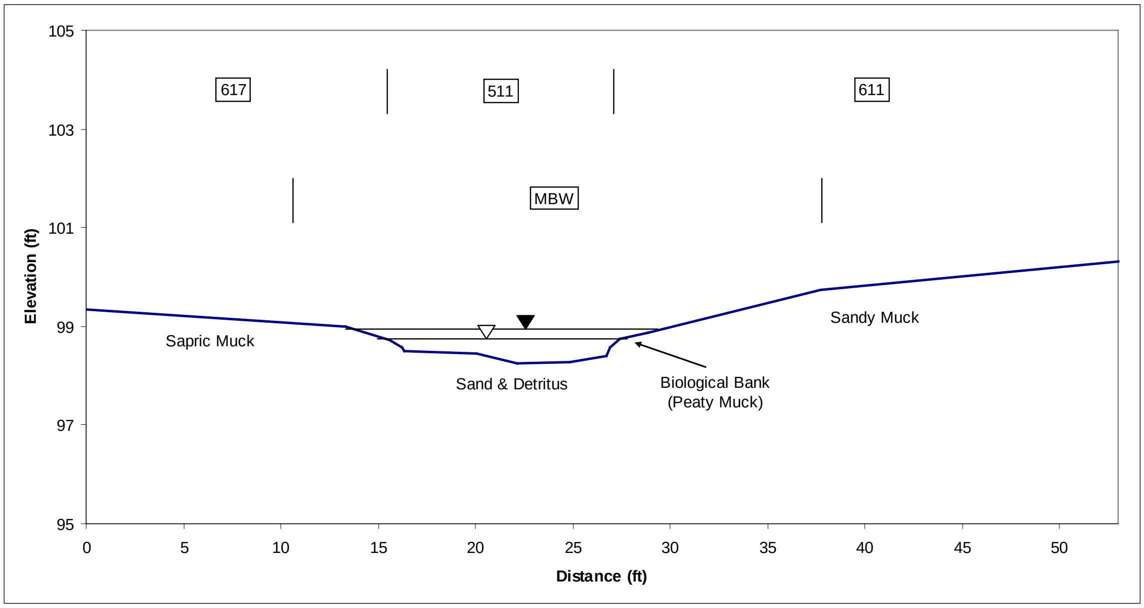
K-LM systems receive comparatively low flow from their springsheds. They lack alluvial floodplain features. These systems include closed canopy riverscapes that steadily trickle through seepage ravines in low-lying hammocks or swamps. Dominant discharge typically ranges from 0.2 to 5 cfs. Examples from this study included portions of Forest Spring Run, Kittridge Spring Run, Mormon Branch UT, and Silver Glen UT (Figure 4.73).

Kittridge Spring Run

Figure 4.73. Example of K-LM Riparian System.

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 larger spring run classes discussed in the following sections, 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.

Figure 4.74 provides an example of the most common configuration of a K-LM riparian system. These systems characteristically, but by no means universally, are found coursing through wetlands with a surficial seepage component, which supplements the artesian flow received by the stream's karst headspring. In this case, the system meanders through a colluvial hydric hammock (617) on one side with cabbage palm, water oak, green ash, ironwood, tulip poplar (*Liriodendron tulipifera*), sweet gum, and laurel oak on one side and a seepage slope (611) dominated by sweetbay, pipestem, and red maple on the other.



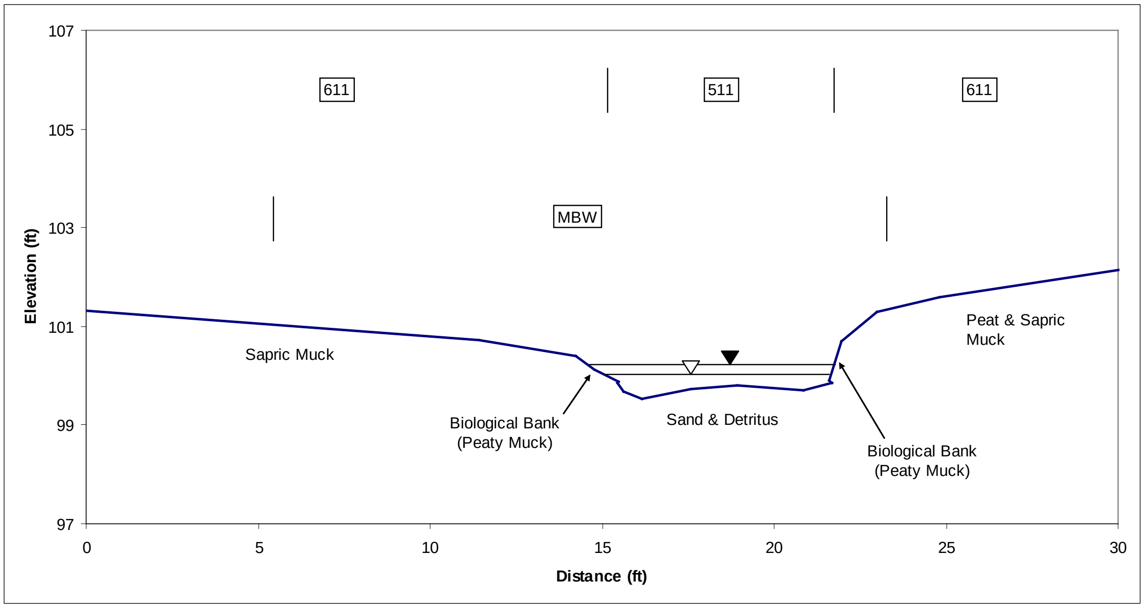
Kittridge Spring Run

Figure 4.74. Section of a Typical K-LM System Bordered by Seepage Swamp.

Figure 4.75 depicts a smaller, but otherwise similar, system flanked by a seepage slope (611) on both sides of the channel with sweetbay, red bay, highbush blueberry, cabbage palm, shiny lyonia, pipestem, and wax myrtle. Anise and slash pine also occurred away from the stream bank. Patches of lizard's tail occurred on the shallowest parts of the stream bed.

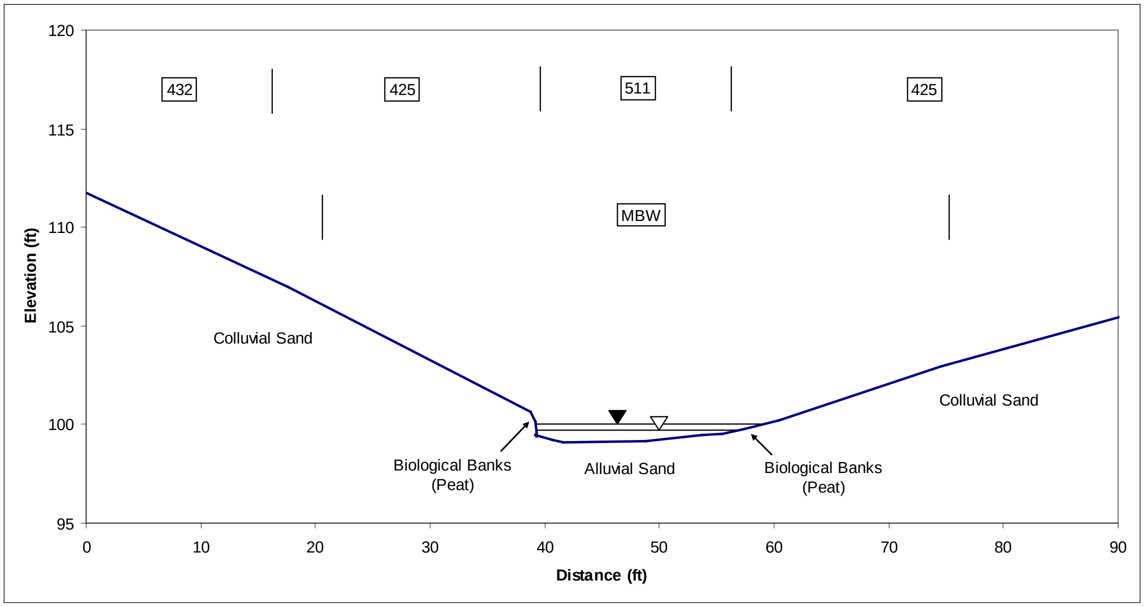
Figure 4.76 shows a common case lacking colluvial swamps, where the run is confined by comparatively steep upland hillslopes instead. Bank vegetation is growing in peaty organic soil masses forming biological banks with cabbage palm, wax myrtle, saw palmetto, dahoon, live oak, red bay, water oak, persimmon, southern red cedar (*Juniper cilicicola*), swamp dogwood, and pipestem. Beyond the stream banks, drier species such as grand magnolia (*Magnolia grandiflora*), rusty lyonia (*Lyonia ferruginea*), and basswood (*Tilia americana*) appear as well (425).

Figure 4.77 exhibits a spring run meandering along a comparatively steep valley segment. Some root-steps and undercut root disks span the channel. The greater valley slope is also associated with a comparatively low W/D channel form and the greater energy allows for a discontinuous floodprone bench on the seepage slope (611). Dominant plants include loblolly bay, red maple, water oak, and cabbage palm with some lizard's tail in local depressions. The riparian communities of K-LM systems depend largely on lateral seepage conditions.



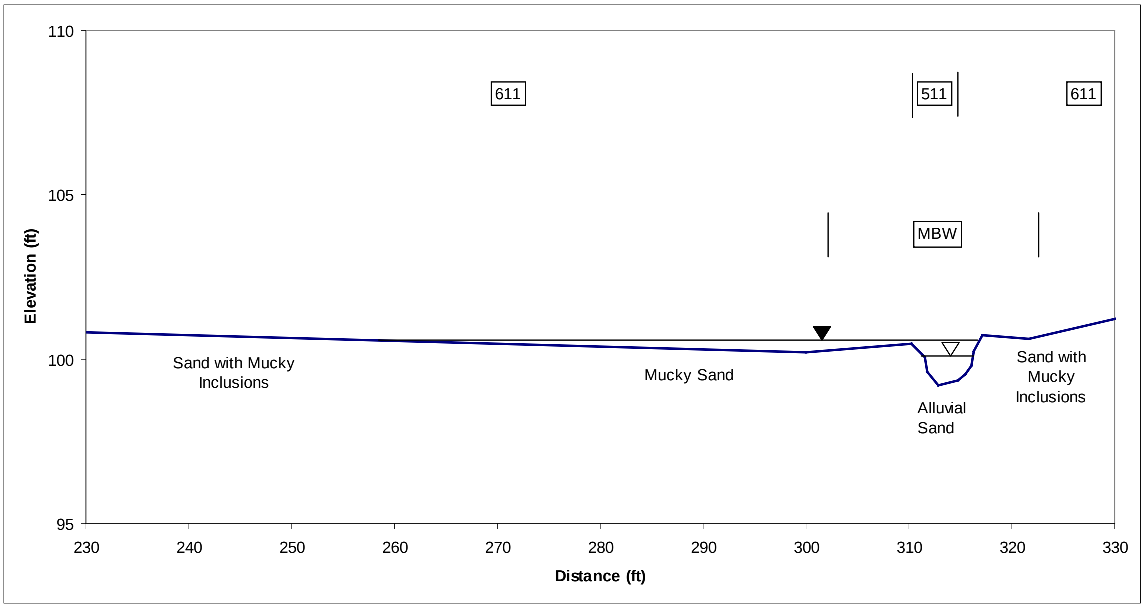
Mormon Branch UT

Figure 4.75. Section of a Small K-LM System Bordered by Seepage Swamps.



Silver Glen Springs UT

Figure 4.76. Section of a Larger K-LM System Bordered by Mesic Uplands.



Forest Spring Run

Figure 4.77. Section of K-LM System within a Longitudinally Steep Valley.

The bankfull channel of a K-LM system 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 5 feet. W/D ratios vary widely (7 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. Gage data is largely absent, but seasonal visits and the limited hydrologic data on the headsprings suggest that most of these systems are annually perennial, or at least seasonally perennial. 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 4.72. 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 1 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.

K-LM systems are most likely to be heterotrophic. This is due to their heavily shaded channels. All the systems studied occupied deep, perennially moist valleys likely to retard fire. Some patches of shade-tolerant emergent aquatics can occur in the shallow gently flowing portions of the stream bed, but they are typically small. K-LM systems are unlikely to routinely support extensive patches of emergent aquatics, periphyton, or sustained populations of phytoplankton.

Medium-Magnitude Spring Runs (K-MM)

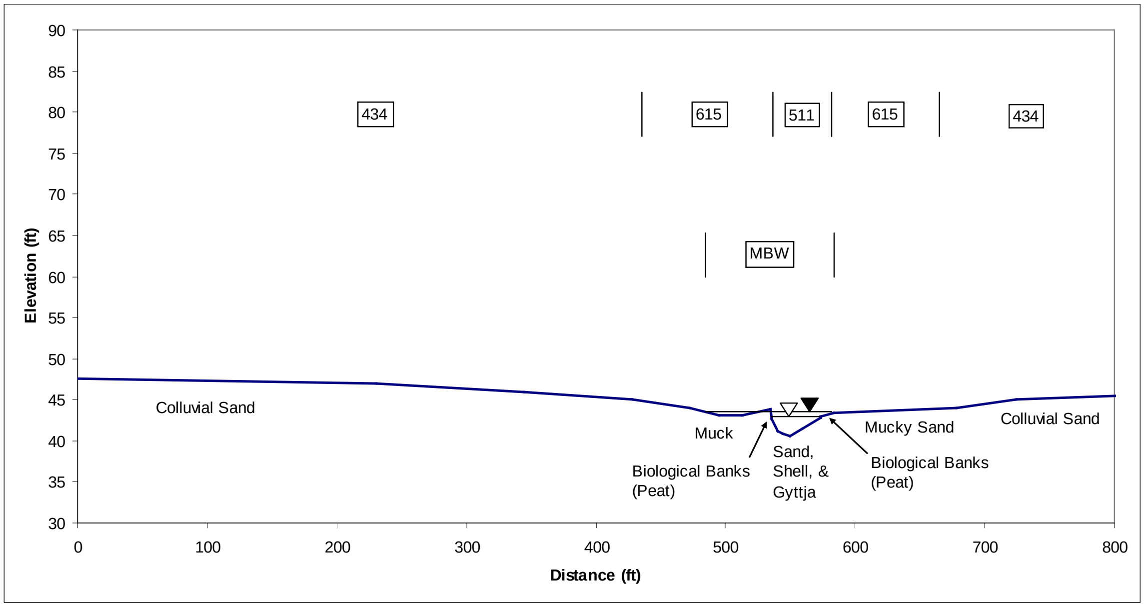
K-MM systems receive moderate flow from their springsheds. They lack alluvial floodplain features. These systems include closed canopy riverscapes that gradually meander through hillslope morphologies that can consist of large unconfined wetland flats, seepage slopes, or well-adjusted to partially confining upland sand or limestone bluffs. Bankfull discharge ranges from 5 to 20 cfs. Examples from this study included portions of Alligator Run and Cedar Head Run (Figure 4.78).

Cedar Head Spring Run

Figure 4.78. Example of K-MM Riparian System.

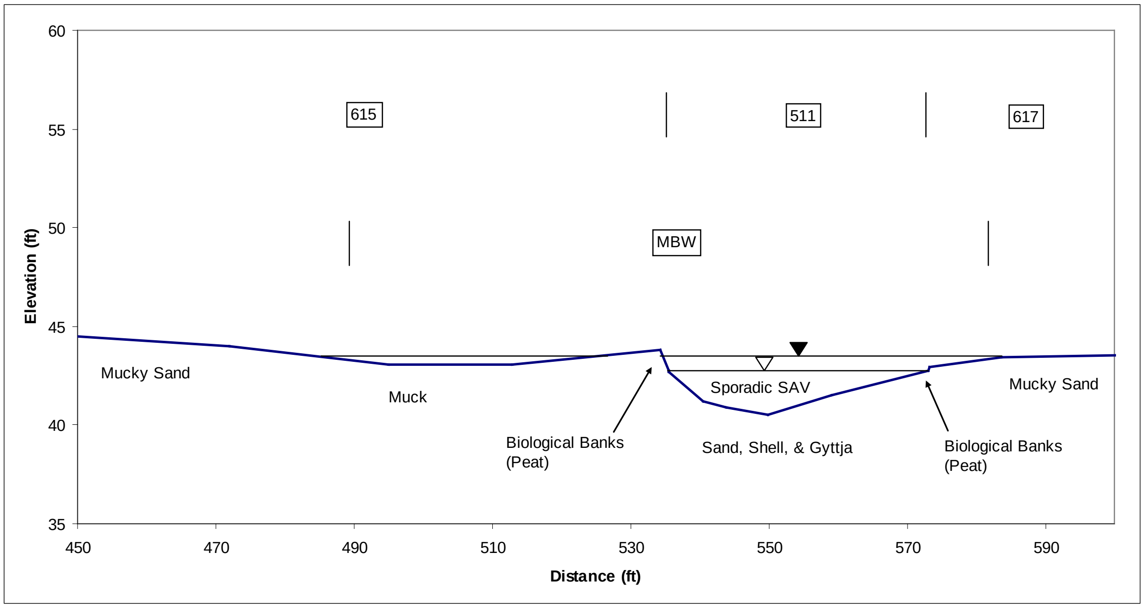
The active floodscape is generally confined to a narrow band of vertical fluctuation below the top-of-bank, rarely resulting in overbank discharge to the valley floor. Flood stage is typically less than one foot above bankfull stage and the riverscape is generally entrenched by greater than a foot into 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 largest 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.

Figures 4.79 and 4.80 cover a site where the channel meanders unconfined through a bottomland swamp (615) flanked by an extensive mesic hammock (434). The dominant swamp and channel bank flora include red maple, cypress, wax myrtle, swamp bay, live oak, Virginia willow, buttonbush, shiny lyonia, and swamp dogwood. Sporadic SAV is growing in scattered light gaps in the channel.



Alligator Spring Run

Figure 4.79. Valley Section of K-MM System.

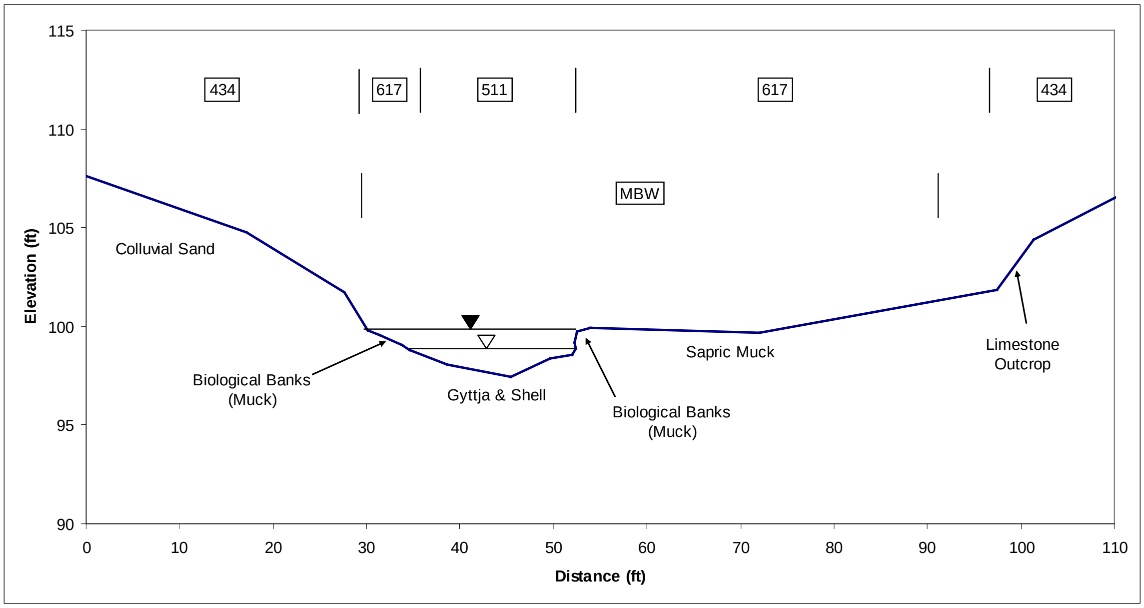


Alligator Spring Run

Figure 4.80. Channel Section of K-MM System.

Figure 4.81 depicts an organic valley flat bottomland (617) confined by limestone and sand bluffs (434). The channel has a well-fit meander across the valley floor. Dominant swamp and bank vegetation includes ironwood, red maple, sweet gum, laurel oak, buttonbush, and wax myrtle. Little to no SAV occurs. The bed material is largely comprised of organic floc (gyttja) and snail-shell hash. KL-MM riparian vegetation generally depends mainly on local water table elevations.

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 less 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 pools, large woody debris, fine woody debris, overhanging roots, and leaf packs. Emergent aquatic vegetation is present, usually along the channel margins, sometimes in thick stands that comprise up to 40% of the riverscape bed. Typical emergent vegetation includes shade tolerant wetland species such as lizard's tail and golden club. 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 4.82).



Cedar Head Spring Run

Figure 4.81. Valley Section of K-MM System with Rock and Sand Bluffs.

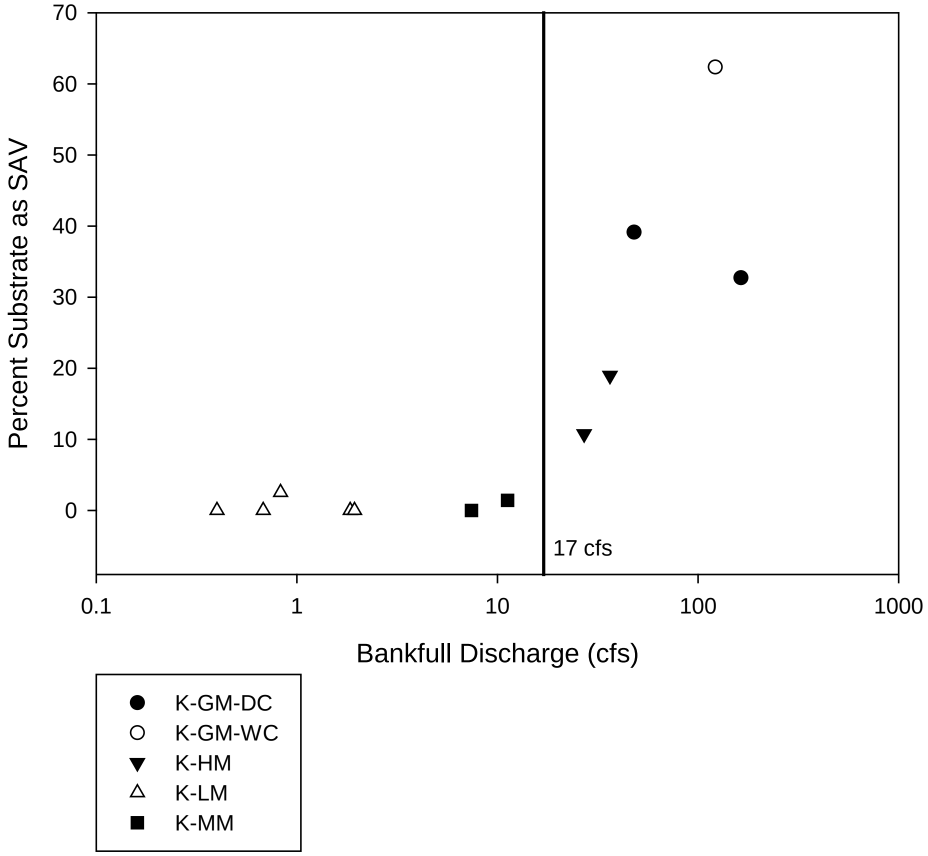


Figure 4.82. Percent SAV Cover Versus Bankfull Discharge and Run Type.

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. Flow regime appears to be characteristically annually perennial. 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 are 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 4.72. 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.

K-MM systems are likely to be primarily heterotrophic with patches of emergent vegetation on some shallow channel surfaces. This is due to their heavily shaded channels. All the systems studied occupied deep, perennially moist valleys likely to retard fire. Some patches of SAV can occur in sporadic light gaps but they are typically small. K-MM systems are unlikely to routinely support extensive areas of periphyton or sustained populations of phytoplankton.

High-Magnitude Spring Runs (K-HM)

K-HM systems receive copious flow from their springsheds, but less than the Great Magnitude sites described in the following sections. 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. Bankfull discharge is typically between 20 and 40 cfs. Examples from this study included portions of Gum Slough Run and Juniper Creek (Figure 4.83).

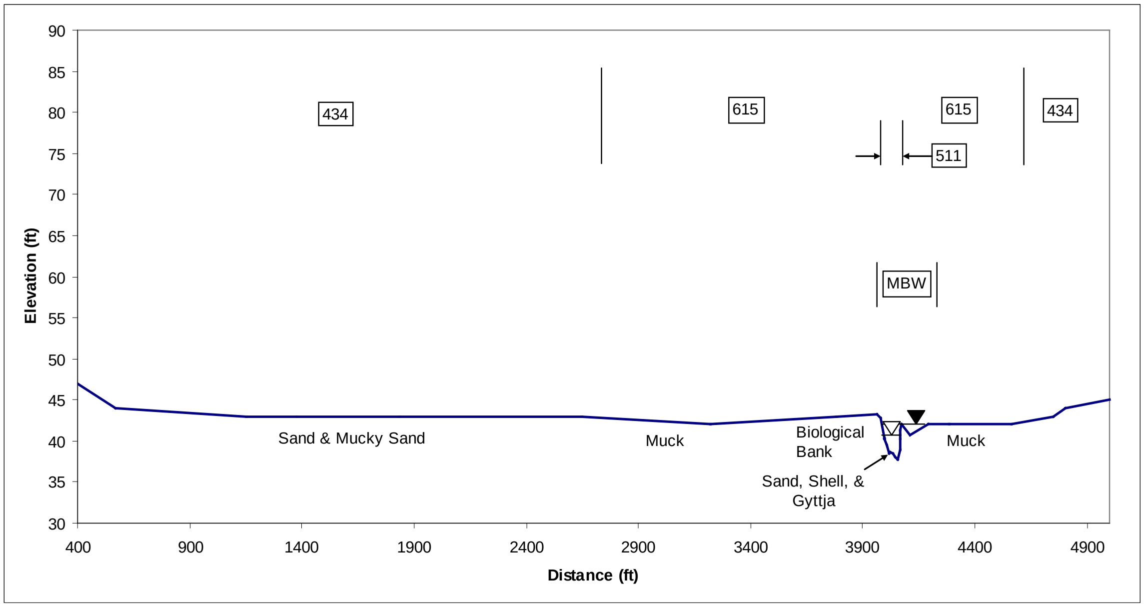
Juniper Creek

Figure 4.83. Example of K-HM Riparian System.

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 on occasional 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 (*Cladium jamiacense*). 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.

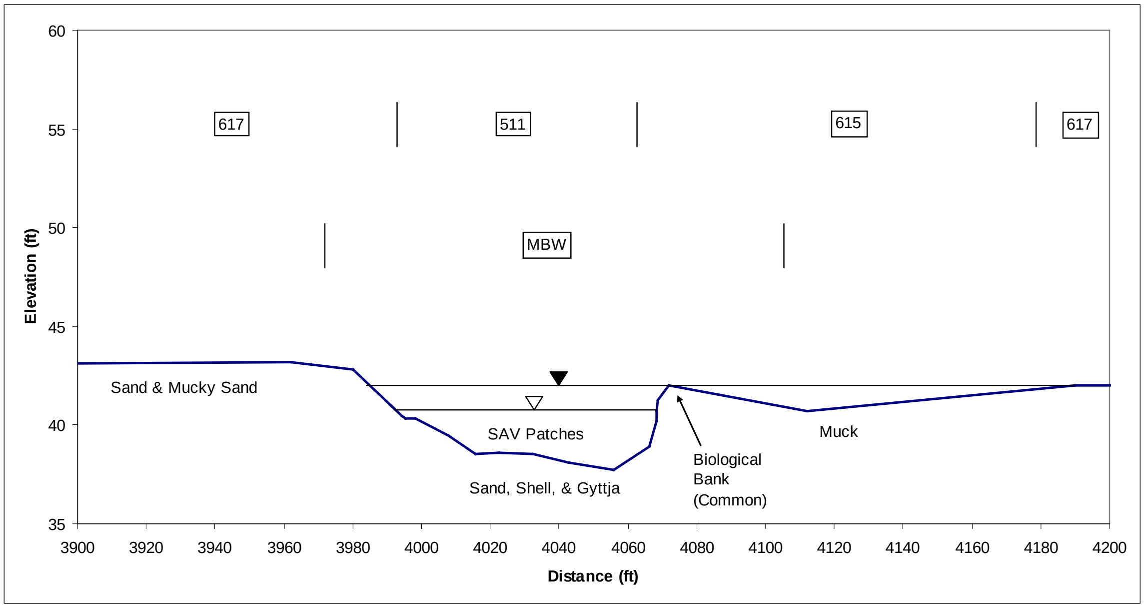
Figure 4.84 depicts a site set within a broad mesic hammock (434) flanking a bottomland swamp (615) through which the stream meanders. Figure 4.85 shows a more detailed view of the stream and swamp corridor section. Most of the swamp and channel banks consist of bald cypress, red maple, buttonbush, wax myrtle, swamp bay, sweetbay and sawgrass (615), with some slightly higher surfaces exhibiting more dominance by laurel oak and cabbage palm (617). SAV occurs in the channel.

As in the previous case, Figure 4.86 depicts a channel section with a distinct riverscape flanked by biological banks and discontinuous shallow anabranches or organic benches (615, 641) at lower elevation than the surrounding hydric hammocks (617). The organic anabranches and channel banks support cabbage palm, swamp bay, wax myrtle, red maple, dahoon, Virginia willow, swamp dogwood, and occasional bald cypress. Some benches consist of thick layers of sapric muck with very high water content unable to support trees, and are dominated by sawgrass or beakrush. Discontinuous SAV meadows occur in the channel. A variety of emergent aquatic patches also occurs on the shallow channel margins. K-HM riparian vegetation associates strongly with local water table elevations.



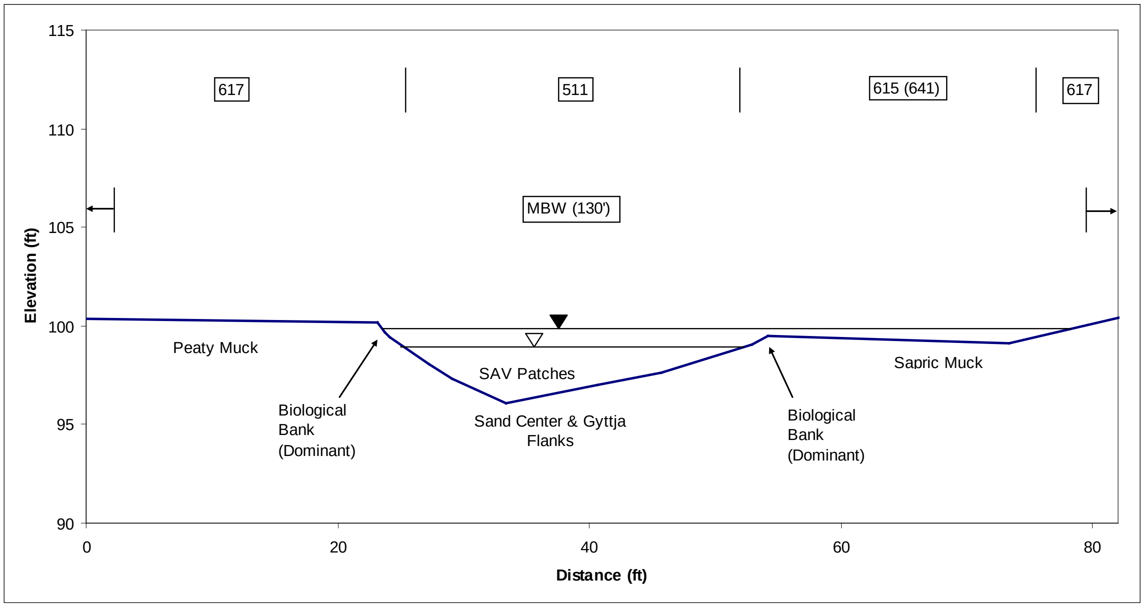
Upper Gum Slough Spring Run

Figure 4.84. Valley Section of K-HM System.



Upper Gum Slough Spring

Figure 4.85. Channel Section of K-HM System.



Juniper Creek

Figure 4.86. Channel Section of K-HM System with Swamp and Marsh Benches.

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 2 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 4.82).

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. Flow is typically annually perennial. 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 4.72. 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.

K-HM systems are likely to be autotrophic with some heterotrophic characteristics. This is due to their partially shaded channels. All the systems studied occupied deep, perennially moist valleys likely to retard fire. Patchy SAV meadows typically are present. K-HM systems are likely to also routinely support extensive patches of emergent aquatics and periphyton. Sustained populations of phytoplankton seem unlikely due to generally strong flow with low residence times; however, algal blooms may be possible under combined effects of cultural eutrophication and drought (or artificial flow reductions).

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. Bankfull discharge is typically greater than 40 cfs. The lone example from this study included part of Alexander Spring

Run (Figure 4.87). Similar sites are known from other locations such as the Rainbow River and Chassahowitzka River.

Alexander Spring Run

Figure 4.87. Example of K-GM-WC Riparian System.

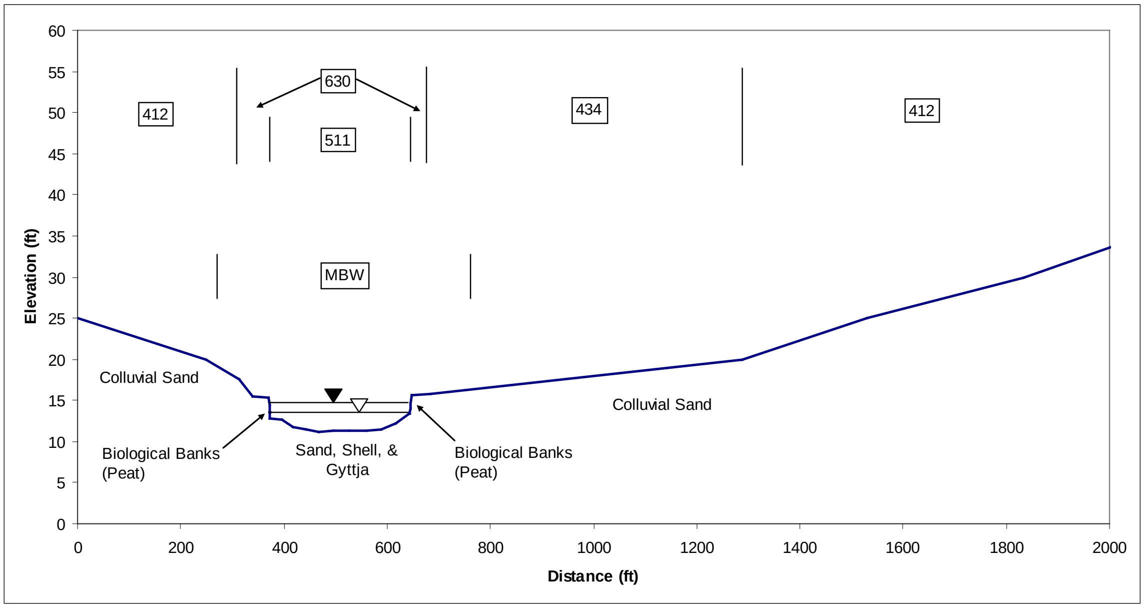
The active floodscape is generally confined to a narrow band of vertical fluctuation below the top-of-bank, rarely resulting in overbank discharge to the valley floor. Flood stage is typically less than a foot above bankfull stage and the riverscape is generally entrenched by greater than a foot into 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 the riparian corridor. Most areas have densely forested hardwood swamps or hydric hammocks.

Figures 4.88 and 4.89 illustrate valley and channel detail cross-sections of a characteristic K-GM-WC riparian system. The very wide channel gently meanders through an almost equally narrow bottomland swamp. The swamp is bordered by extensive mesic hammock (434) and longleaf pine-wiregrass sandhill (412). The dominant bank and swamp (630) species include cabbage palm, wax myrtle, red maple, slash pine, live oak, sweetbay, and red cedar with occasional cypress. Saw palmetto and shiny lyonia become more common several feet away from the banks. Dense ubiquitous SAV meadows cover the stream bed. Communities reflect local water table depths.

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 (or gyttja) 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 B5s in portions of the stream valley with high sandhill or scrub bluffs. 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.

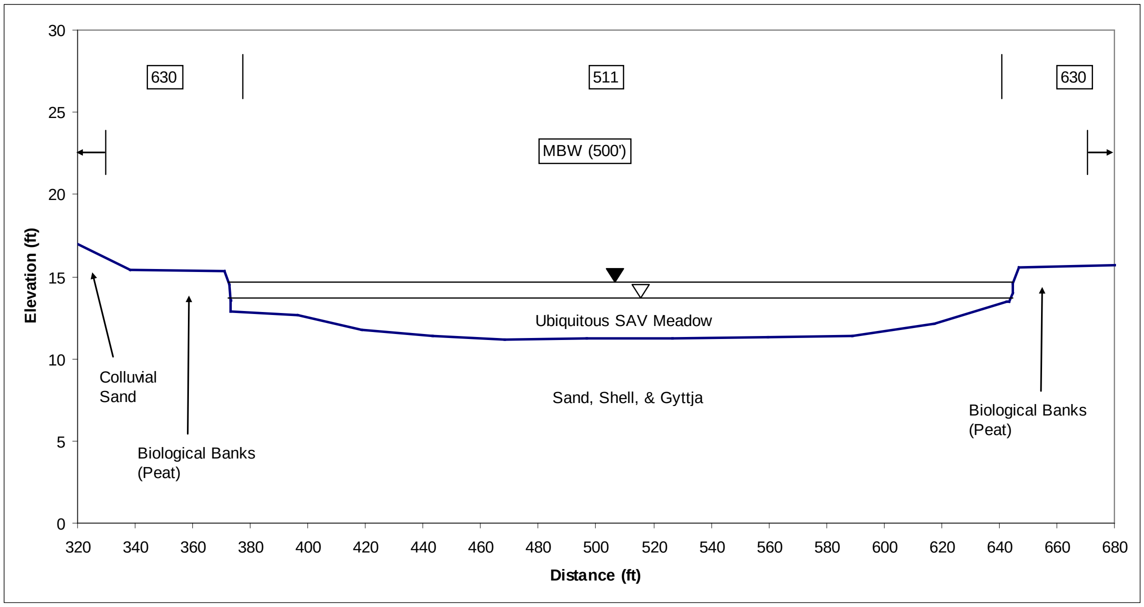
These valley segments connect headwater springs to non-riverscape and riverscape waterbodies, providing direct channel connections to various types of flowing waterbodies in the drainage network. The copious discharge is annually perennial. Lakes (or saltwater bays), stream junctions, or other spring 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 4.72). 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 types of stream systems occur and they are all well known. Bankfull field survey is straightforward and relies on root scour lines at bank inflections.



Alexander Spring Run

Figure 4.88. Valley Section of K-GM-WC System.



Alexander Spring Run

Figure 4.89. Channel Section of K-GM-WC System.

K-GM-WC systems are extensively autotrophic. This is due to their very wide channels that normally carry clear water. Allochthonous carbon enters these systems as well from adjacent and headwater swamps. Dense SAV meadows are characteristically present. K-GM-WC systems also routinely support extensive patches of emergent aquatics and periphyton. Sustained populations of phytoplankton seem unlikely due to generally strong flow with low residence times; however, algal blooms may be possible under combined effects of cultural eutrophication and drought (or artificial flow reductions).

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. Bankfull discharge typically exceeds 40 cfs. Examples from this study included portions of Rock Spring Run and the Weeki Wachee River (Figure 4.90). Similar sites are known from other locations such as the lower Silver River and portions of the Ichetucknee River.

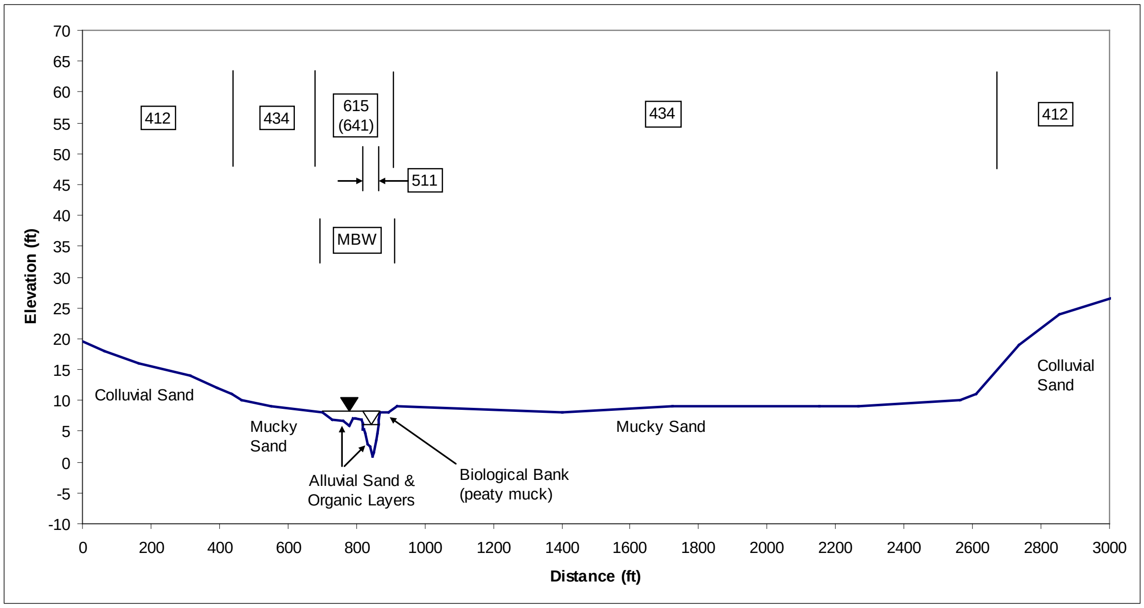
Weeki Wachee River

Figure 4.90. Example of K-GM-DC Riparian System.

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.

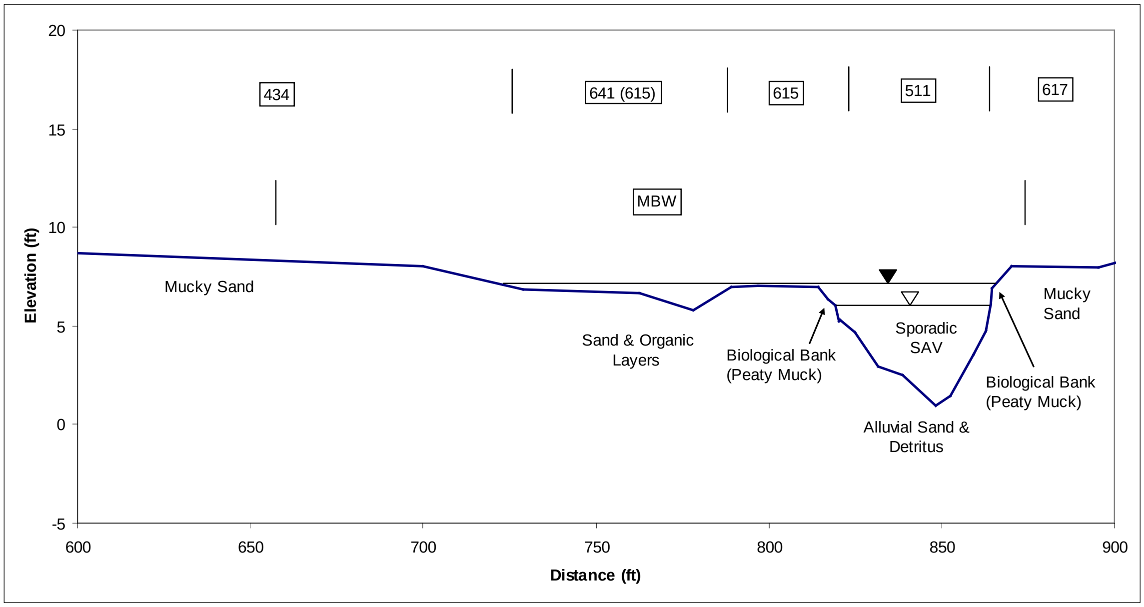
Figures 4.91 depicts an active meander belt entrenched within and confined by a broad relict valley floor currently dominated by mesic hammock (434) with longleaf pine sandhills on the outer valley hillslopes (412). The channel system consists of deep, powerful riverscape with patches of SAV. Boat traffic may be reducing SAV cover. The channel is generally bordered by forested wetland species (615/617). Marsh vegetation (641) sporadically occurs on benches akin to those observed in K-HM systems (Figure 4.92). Dominant bank and swamp (615/617) species include cypress, dahoon, sweetbay, swamp dogwood, Carolina willow, red maple, and wax myrtle. Dominant marsh vegetation (641) includes sawgrass, duck potato, and Carolina willow.

Figure 4.93 provides a cross-section of a similar system with more limited boat traffic. SAV meadows are patchy, but are common and dense. Patches of cow-lily occur on the bed on the shallow channel margins. Bank and swamp (617) species include red maple, cabbage palm, sweet gum, loblolly bay, and wax myrtle, with scattered Carolina willow. Riparian vegetation in K-GM-DC systems generally depends on local water table elevations, although patchy alluvial benches can support emergent marsh or floating leaf emergent communities, either slightly above or below the bankfull stage.



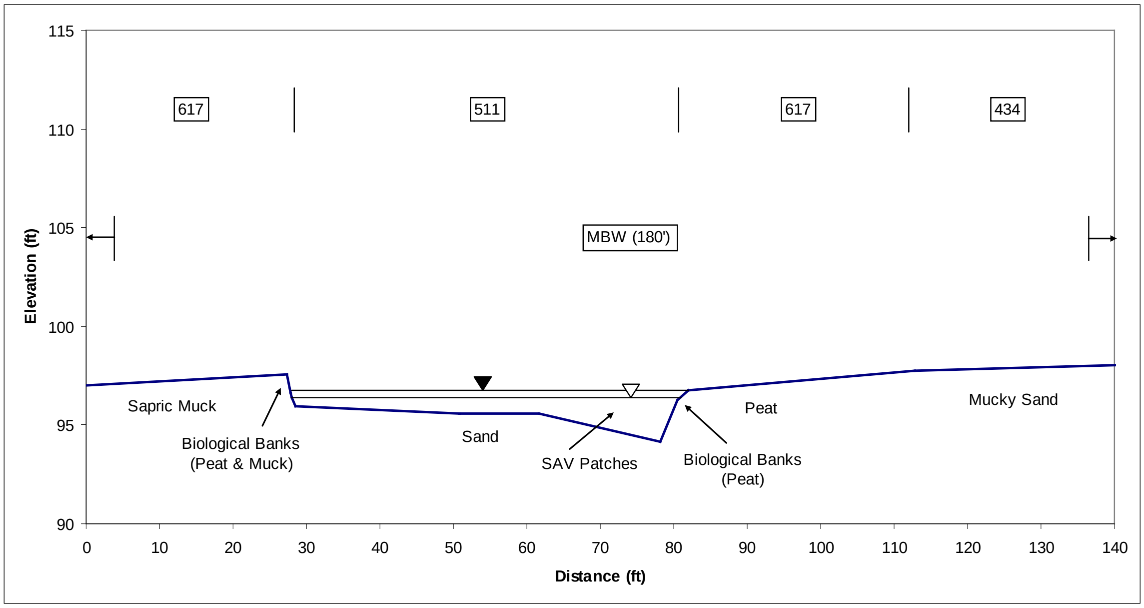
Weeki Wachee River

Figure 4.91. Valley Section of K-GM-DC System.



Weeki Wachee River

Figure 4.92. Channel Section of K-GM-DC System.



Rock Spring Run

Figure 4.93. Section of K-GM-DC System.

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 5 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 E5s or even B5s 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 occasional limestone exposures. Emergent aquatic vegetation is sporadically present, usually along the shallow bankfull benches where they occur. 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. Flow is copious and annually perennial. 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, bottomland 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 4.72 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 streams of this type 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.

K-GM-DC systems are largely autotrophic. This is due to their wide, open to partially shaded channels that normally carry clear water. Allochthonous carbon enters these systems as well from adjacent and headwater swamps. Discontinuous SAV meadows are characteristically present. K-GM-DC systems also routinely support patches of emergent aquatics and periphyton. Sustained populations of phytoplankton seem unlikely due to generally strong flow with low residence times; however, algal blooms may be possible under combined effects of cultural eutrophication and drought (or artificial flow reductions).

Colluvial Clay Gullies (CV-CG)

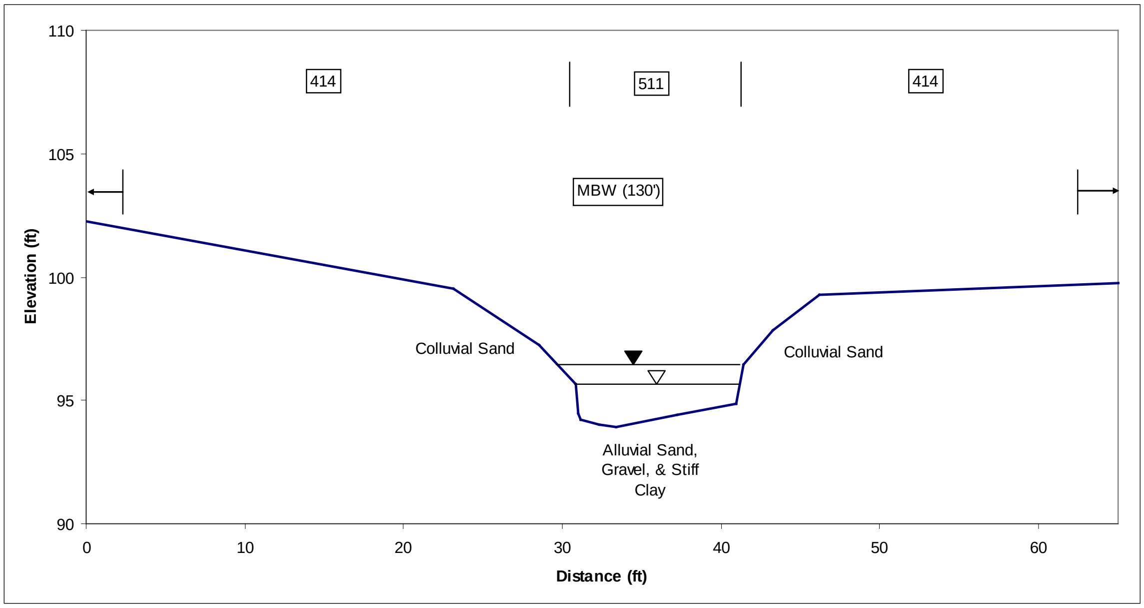
Shiloh Run and Blues Creek are functionally confined and entrenched channels within well-drained rolling landscapes with mixed sand and clay outcroppings (Figure 4.94). These systems could be referred to as "clay gullies of colluvial valleys" (CV-CG). However, the form may be convergent from different 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 the characteristic that they drain two of the highest overall relief valleys in the study.

Blues Creek

Figure 4.94. Example of CV-CG Riparian System.

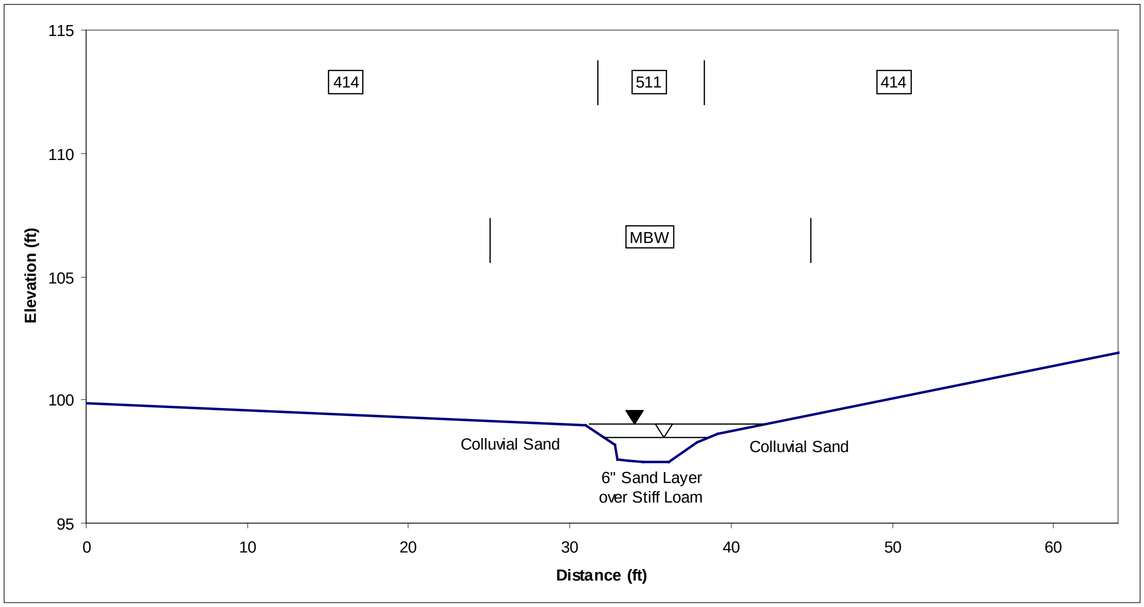
Figure 4.95 depicts a CV-CG system draining a headwater swamp to a sinkhole, intersecting a stiff clay layer and phosphatic gravel on the way. The stream lacks a floodplain and is a gully deeply dissecting the surrounding upland hammock (414). Bank vegetation reflects the species of the hammock, including grand magnolia, live oak, sweet gum, ironwood, loblolly pine (*Pinus taeda*), water oak, American elm, hawthorn (*Crataegus* sp.), southern red oak (*Quercus falcata*), and laurel oak, with patches of dwarf palmetto (*Sabal minor*), which is largely absent from the rest of the hammock.

Figure 4.96 depicts a CV-CG system draining to a larger stream valley. Its grade is largely controlled by an intersection with stiff clay loam, preventing the formation of distinct pools. It also lacks a floodplain, meandering as a shallow gully through the local mesic hammock (414). Dominant bank species are wetter than those of the hammock, including red maple, water oak, and American elm, versus the upland oaks, Hercules club (*Zanthoxylum clava-herculis*), sweet gum, and beauty berry of the hammock. The riparian vegetation in CV-CG systems seems to reflect that of the adjacent hammocks, and is little influenced by fluvial forces.



Blues Creek

Figure 4.95. Section of CV-GC System Draining to Sinkhole.



Shiloh Run

Figure 4.96. Section of CV-GC System Draining to Stream Junction.

Some Additional Special Cases

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-to-form factors associated with the presence or absence of alluvial channels for a given landscape class.

Our study design sought to explore potential differences between surface water- and groundwater-dominated systems and thus systematically excluded streams with rather equal input from runoff versus spring discharge. Such streams occur, sometimes downstream of spring runs we studied in the same valley (e.g., Juniper Run and Mormon Branch UT), as the run picks up additional runoff tributaries downstream. It seems these kinds of systems are sufficiently complex and few enough in number to warrant investigation as special cases. Some such mixed-source systems include the largest and most iconic rivers in the state, discussed next.

Large Rivers of Complex Watersheds

Groupings of rivers draining watersheds in excess of 500 square miles can be problematic for general classification based on complexities regarding their water sources and valley hydrogeology, as well as matters related to zoogeography. Further, such rivers are relatively few in number. Instead of a classification system, each arguably warrants and deserves independent study and individualized management plans. Examples of such systems in the PFCP include the lower Santa Fe, middle St Johns, lower Hillsborough, mid- to lower Peace, mid- to lower Kissimmee River, Ocklawaha, lower Myakka, mid- to lower Withlacoochee, and Caloosahatchee Rivers. The Santa Fe, St. Johns, Hillsborough, Ocklawaha, and Withlacoochee Rivers received mixed water sources from runoff and karst aquifers, as did the Peace River prior to regional over-pumping. These mixed-source systems do not apply well to our classification concept.

Of those nine streams, five have had major hydraulic modifications in the form of dams (Hillsborough, Ocklawaha), canals (Kissimmee, Caloosahatchee), or substantial dredging activities (Peace) over the decades. The Myakka and Santa Fe also have moderately altered hydrology regimes based on land use and water use. The St. Johns has well-documented water quality problems. The drainage alterations and in-line dam (really a weir) on the Withlacoochee are more moderate, but nevertheless renders the system less than perfectly natural. The problem with our approach working to classify larger rivers is that it relies on having examples of reasonably intact or nearly natural watersheds to assure the baseline is not excessively affected by human activity. Arguably, a statistically meaningful sample of such large river systems is unachievable today.

However, some commonalities occur among the case studies of large rivers. First, they all have wide open channels and canopy is unlikely to limit aquatic primary productivity. Second, they either currently have, or prior to alteration had, substantial overbank flooding lasting most of the wet season during most years (Figure 4.97). These long flood durations lead to increased biologically structured surfaces that affect the floodplain plant distribution. Namely, nurse logs and stumps become important colonization sites for tree species that would be stressed by the long hydroperiods and deep waters of the seasonal flood pulses (Figure 4.98). Perhaps more importantly, these flood pulses might shift viewpoints of what constitutes a channel versus a floodplain. If a conveyance carries water for a whole season, should it be called a floodplain? What effects do such prolonged lateral hydraulic connections between the open channel and the vegetated flood channel have on nutrient spiraling and other matters of ecosystem function? Studies of large PFCP rivers should especially conceptualize the "stream" as a dual-channel system consisting of a normal-flow open channel inset within a much larger vegetated flood pulse channel.

Lower Wekiva River

Figure 4.97. Water Stain Lines Several Feet Above Floodplain of a Large River.

Middle St. Johns River

Figure 4.98. Root Exposures and Nurse Log Decay in a Large River Floodplain.

Third, the St. Johns, Myakka, and Kissimmee Rivers have large in-line lakes. These non-riverine discontinuities exert differences in residence time likely to affect trophic conditions and continuity of sediment transport. Portions of the St Johns, Ocklawaha, Withlacoochee, Kissimmee, Hillsborough, and Myakka Rivers and Fisheating Creek rather frequently alternate between single thread alluvial channels, multi-threaded (anastomosing) alluvial channels, and non-alluvial billabongs.[5] These factors mean that the river flow encounters rather tight sequencing (every few thousand feet to every few miles) of alternating short and long residence times and presentation of different instream habitat types (and presumably of biological taxa), that could confound the results of limnology studies, depending on sampling locations within the river. Figure 4.9 depicts a slope boundary between single-thread and multi-thread (anastomosing) channel planforms. Because of the way the systems alternate as described, FPZ concepts should apply well to these large complex rivers.

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[5] "Billabong" is used here in reference to over-dimensioned channel reaches taking the form of relatively narrow flow-through lakes. These features are "over-dimensioned" because they present substantially larger cross-sections than the alluvial river reaches do. The billabongs are typically under non-alluvial geologic controls, perhaps associated with bedrock fractures or outcrops related to carbonate solution geology.

Distinguishing Similar Stream Types in the Field

Dichotomous Key

The following dichotomous key is useful for rapid screening from among the 15 stream types for systems draining less than 500 square mile catchments. It is intended to serve as a simple technique that can be applied with confidence at sites with limited disturbance and those that are not in transitional positions along the classification gradients. It is highly recommended to read the full description of any stream type assigned by this key as part of the full classification assessment before deciding on a type. For sites at transitional areas along the classifying gradients, it is better to invoke a weight-of-evidence approach to assure the most applicable classification. Guidance for doing so on a pairwise basis is presented after this key.

1. The channel lacks an active alluvial floodplain and cuts into a clay layer along most of the reach. If NOT, go to 2. If YES, the stream is a colluvial valley clay-gully (**CV-CG**).
2. At least 50% of the bankfull discharge is estimated to consist of discharge from an artesian limestone aquifer. If NOT, go to 3. If YES, go to 2.a.
    a. Bankfull discharge is less than 5 cfs. If NOT go to 2.b. If YES, the stream is a low-magnitude spring run (**K-LM**).
    b. Bankfull discharge is less than 20 cfs. If NOT go to 2.c. If YES, the stream is a medium magnitude spring run (**K-MM**).
    c. Bankfull discharge is less than 40 cfs. If NOT go to 2.d. If YES, the stream is a high-magnitude spring run (**K-HM**).
    d. The width/depth ratio at the classification riffle is greater than 60. If NOT, the stream is a great-magnitude, deep spring run (**K-GM-DC**). If YES, the stream is a great-magnitude, wide spring run (**K-GM-WC**).
3. At least 40% of the watershed consists of well-drained soils (NRCS hydrologic soil groups A and C). If NOT, go to 4. If YES, go to 3.a.
    a. The system has an active alluvial floodplain. If YES, the system is a highlands alluvial floodscape stream (**HL-AFS**). If NOT, go to 3.b.
    b. Stream bed has at least 0.75 root-steps per 100 linear feet of channel. If NOT, the system is a highlands baseflow channel (**HL-BFC**). If YES, the system is a highlands root-step channel (**HL-RSC**).
4. System has a continuous, active alluvial floodplain. If NOT, go to 4.a. If YES, go to 4.b.
    a. Width/depth ratio at classification section is greater than 11. If NOT, the system is a flatwoods, colluvial valley, wide-channel stream (**FW-CV-NC**). If YES, the system is a flatwoods, colluvial valley, narrow-channel stream (**FW-CV-WC**).
    b. At least seven alluvial features occur in the floodplain and bankfull channel, and bankfull pool depths generally exceed four feet at the thalweg. If NOT, go to 4.c. If YES, go to 4.d.

c. Average bankfull channel width is less than 20 feet. If NOT, the system is a flatwoods, wide-alluvial valley-flat corridor (**FW-AF-WF**). If YES, system is a flatwoods, complex-compact stream corridor (**FW-AF-CC**).
d. Width/depth ratio at the classification section is at least 15. If NOT, the system is a flatwoods, high-gradient alluvial floodscape (**FW-AFS-HG**). If YES, the system is a flatwoods, low-gradient alluvial floodscape (**FW-AFS-LG**).

Sites occurring at or near classification boundaries established in association with drainage area and valley slope, such as those depicted in Figures 4.9, 4.45, and 4.72, often are intermediate in form, thus requiring further investigation to most properly categorize them. The boundary lines, although drawn narrowly on the graphs, are actually fuzzy and systems plotting near the line could actually be one of two types based on factors beside drainage area or valley slope. Comparisons are not only required between adjacent stream classes within a given watershed type (e.g., HL-RSC versus HL-BFC), but also between some streams occupying watersheds near the soil drainage threshold used to distinguish Highlands and Flatwoods types. For example, a stream draining a 30-square-mile watershed with 40% A+C soils could be either an HL-AFS or a FW-AF-WF. This section addresses the key field indicators that can be used in all the possible pair-wise comparisons within and between Flatwoods and Highlands streams that are especially useful for making a call between two classification possibilities where forms are intermediate or mixed because they occur near a transition in soil drainage, watershed size, and/or valley slope between two stream types.

For spring runs, the distinguishing factor is always a karst water source typically taking the form of a spring vent or vents supplying at least 50% of the bankfull discharge to the channel. To verify that a site is indeed in a Karst watershed as defined in this classification system, the vent(s) must be located, the spring discharge must be measured and then compared to a calculation or measurement of overall bankfull discharge. If it is at least 50%, the site is by definition a Karst type. The flow thresholds that separate the various Karst stream types from each other on Figure 4.72 are sufficient for our purposes until such time as a more complex typology for spring runs is derived that also includes mixed flow regime sites with less than 50% discharge from limestone artesian springs.

For Highlands and Flatwoods basins, the following guidance is offered. Where the term “reach” is mentioned, it refers to the surveyed reference reach which is at least 20 bankfull widths long.

FW-CV-WC Versus FW-CV-NC

Bankfull channel shape is the primary distinguishing field variable because it is a strong associate of the key differences in sediment transport capacity and fish passage depths that separate these two kinds of stream systems. If the bankfull W/D is less than or equal to 11, then the site is NC, else it is WC. Secondarily, if the minimum thalweg depth in the reach is less than or equal to 1 foot deep at bankfull stage, then the site is more likely WC, else it is NC. For the NC sites, we are looking for comparatively deeper channels with lower W/Ds, indicating their effective sediment transport capacity.

FW-CV- Versus FW-AF-CC

FW-AF-CC streams are distinguished from both FW-CV- types (WC and NC) by the presence of continuous alluvial surfaces in the floodplain and larger channel dimension. Continuity of alluvial surfaces can sometimes be difficult to confirm in situations where stream corridors have a single floodplain indicator that is extensive but naturally sporadic in occurrence such as a floodplain secondary channel or chute. Sporadic to nearly continuous alluvial deposits typically occur at sites near the classification boundary. In such cases, the CC channels can be distinguished based on the reach meander belt width (MBW), which serves as an index of the minimum width of the active floodplain. Where a nearly continuous bankfull bench or a naturally discontinuous single alluvial floodplain feature type occurs and the MBW is at least 75 feet wide, the system should be classified as FW-AF-CC, and if the alluvial features are absent or the MBW less, then the site is one of the CV types.

Also, CC bankfull channels are simply bigger. If the average bankfull thalweg depth among all pools for the reach is less than 2.3 feet, the site is CV, else CC. If the average riffle thalweg depth in the reach is less than 1.5 feet, then CV, else CC. Further, if the cross-section area of the classification riffle is less than 12 square feet, or the average cross-section area among all riffle sections in the reach is less than 12 square feet, then the site is CV, and if larger then it is CC. The presence of sufficient floodplain alluviation is the better indicator, but if channel dimension variables are relied upon a weight-of-evidence approach should be taken.

FW-AF-CC Versus FW-AF-WF

CC sites are more likely, but not ubiquitously so, to have alluvial ridges and linear backswamps as their alluvial features, while WF sites tend toward comparatively large valley flats without alluvial ridges. However, intermediate forms occur near the classification boundary whereby the floodplains have features that appear to be either large backswamps with small or sporadic ridges or small valley flats with such ridges. These streams can be distinguished based on differences in sedimentation regimes that affect channel shape and width. If the floodplain surfaces are intermediate and the W/D at the classification riffle is less than or equal to 15, the site should be classified as CC, else WF. Another approach is based on channel width. If the average bankfull width for all 21 sections in the reach is less than 20 feet, then the site is CC, else WF.

FW-AF-WF Versus FW-AFS-

These WF streams can look a lot like scaled-down versions of their FW-AFS- counterparts (especially LG systems, sometimes like HG). Near classifying boundaries the distinguishing factors center on differences in channel size, pool depths, and total alluvial features in the riparian corridor. If the total alluvial features are readily and robustly identifiable, the sites can simply be distinguished using them. If the reach has six or less such features, it is WF. If it has at least seven such features, it is AFS.

Otherwise, the following factors should be determined and the site classified based on how the majority of them fit if the total alluvial features of the reach were altered or otherwise difficult to interpret: (1) If the reach classification section or the reach mean riffle cross-section areas are less than 70 square feet, then the system is WF, else AFS; (2) If the smallest bankfull riffle thalweg depth in the reach is less than 2.5 feet, then the site is WF, else AFS; (3) If the mean thalweg depth for all riffle sections in the reach is less than three feet, then the site is WF, else AFS; (4) If the maximum pool bankfull thalweg depth is less than five feet, then the site is WF, else AFS; (5) If the average reach pool thalweg depth is less than 4.7 feet, then the site is WF, else AFS; (6) If the classification riffle’s flood thalweg depth is less than 5.7 feet, then the site is WF, else AFS; (7) If all bend pools have thalweg depths at least four feet deep, then the site is AFS, else WF.

FW-AFS-HG Versus FW-AFS-LG

The HG systems characteristically have well-adjusted and arrestingly rough floodplains, while the general impression of a LG floodplain is that of a broad flat bottomland swamp that serves to dissipate energy. When occurring along valley slopes close to the classification boundary, these types can exhibit intermediate floodplain roughness and can be distinguished based primarily on channel shape, width, and entrenchment in the floodplain associated with slope effects on stream power and sediment transport effectiveness in the bankfull channel. One categorical item of interest is that HG systems provide floodplain transport at energy levels too high to allow for enough fine sediment deposition to support a valley flat, so if such a feature is readily apparent the site is LG. However, some LGs also lack valley flats, so the absence of that feature cannot be used to confirm that HG conditions prevail. Further, if SAV is present, it cannot be an HG system. An absence of SAV, however, does not confirm LG conditions because few of them support SAV patches.

The primary dichotomous distinguishing factor is bankfull channel shape at the classification riffle because it relates to sediment transport differences in these two types of systems. If the W/D is less than 15, the site is HG, else LG. If the W/D ratio is hovering very close to 15 and there is some question as to whether or not it is under alluvial control, then the following secondary characteristics could be used to further inform the distinction. To emphasize, these characteristics are generally inferior to the W/D ratio for distinguishing these systems and should only be invoked if a decent classification riffle cannot be observed. Use a weight-of-evidence approach. A bank height ratio (BHR) greater than 1.1 indicates HG systems, else LG. The BHR equals the thalweg depth measured at the classification riffle at the top-of-bank divided by the bankfull indicator's thalweg depth at the same section. If the bankfull width at the classification section is less than 50 feet wide, then the site is HG, else LG. If the flood thalweg depth at the classification riffle is greater than eight feet, then the site is HG, else LG. These latter two factors can be difficult to measure accurately and only apply for watersheds up to 350 square miles.

HL-RSC Versus HL-BFC

The main segregating factor is vertical roughness of the bankfull channel related to the presence of root-steps. Streams located near the classification boundary can have varying amounts of root-steps. A sporadic occurrence of such features does not necessarily create an overall function or indicate a dominance of processes associated with the formation of HL-RSC systems. Thus all the root steps in the reach should be inventoried and expressed as the number per 100 linear feet of channel. If the number is at least 0.75 per 100 feet, then the system is HL-RS, else BFC (Table 4.9).

A secondary consideration involves potential fish passage depths across the limiting root-step riffle in the reach. If the minimum bankfull riffle depth in the reach is greater than or equal to 0.8 feet, the system is typically a BFC, else RSC.

Table 4.6. Root-Step Densities and Friction Factors.

Site	Stream Type	Root Steps per 100'	Manning's *n*
Gold Head Branch	HL-RSC	2.17	0.27
Cypress Slash UT	HL-RSC	1.68	0.17
Tuscawilla UT	HL-RSC	1.55	0.27
Lake June-In-Winter UT	HL-RSC	1.51	0.34
Manatee River UT	HL-RSC	1.16	0.27
Lowry Lake UT	HL-RSC	0.84	0.25
Ninemile Creek	HL-RSC	0.83	0.30
E. Fork Manatee River UT1	FW-CV-NC	0.63	0.10
Alexander UT2	HL-BFC	0.63	0.10
Jumping Gully	HL-BFC	0.36	0.12
Forest Spring Run	K-LM	0.29	0.26

HL-RSC Versus FW-CV-

Where these systems occur close to the watershed classification boundary near 40% A+C soils and steep valley slopes, sporadic root-steps can occur. Also, in some unstable, evolving streams, migrating knickpoints can be stalled at root masses on the stream bed, presenting a superficial resemblance to natural highlands root-step weirs.

The difference is that the evolving streams will typically expose flat discs of roots generally less than three inches in diameter that are largely undercut, with water flowing under the disk, as opposed to massive roots that are not undercut. The unstable systems will also typically display other signs of excessive erosion such as raw, collapsing banks on some straight reaches and excessive sedimentation and habitat smothering in pools. The flatwoods streams will lack moss collars or biological banks, but not all root-step systems have these.

Where the exposed root masses are in fact natural, the distinguishing factor is the step density of at least 0.75 per 100 linear feet of channel for RSC systems (Table 4.9). One could also measure bankfull slope and discharge to calculate bankfull Manning's *n*. If it is at least 0.25, the system is RSC, else FW-CV (Table 4.9). Also, we have not encountered an RSC system with less than 50% of its watershed occupied by A+C soils, but this is not deemed sufficient for use as a sole dichotomous classifier.

HL-BFC Versus HL-AFS

Where these systems occur near classification boundaries in a drainage area, the characteristic appearance of alluvial floodplain features can be sporadic to continuous, making it difficult to distinguish the systems on that primary delineative factor. In such cases the systems can be more readily classified based on channel dimension, factors related to their sediment supply and transport capacity, and flood regimes. If SAV is present in a forested bottomland system, the site is AFS. However, absence of SAV can also occur in AFS systems. If at least six total alluvial features are present, the system is AFS. However, some AFS systems can have as few as four and some BFC systems as many as five such surfaces.

If the criteria above remain non-delineative, then W/D ratio at the classification riffle can be used to dichotomously classify the systems. If it is equal to or greater than 25, the system is AFS, else BFC. This suggests comparatively higher sediment supply and lower in-channel transport capacity for the downgradient AFS systems. If the MBW is at least 100 feet, the site is AFS, else BFC, indicating differences in minimum lateral alluvial dimension in the floodplain. Flood depths at the classification riffle greater than 3.2 feet indicate AFS systems, else BFC, but these can be tricky to measure.

Channel dimensions of AFS systems are larger than the BFC sites. If the minimum reach riffle thalweg depth is greater than 1.4 feet, then AFS, else BFC. If the mean reach riffle thalweg depth is at least 1.6 feet, the system is AFS, else BFC. If the classification section cross-section area or reach mean cross-section area is at least 24 square feet, then AFS, else BFC. If the classification section bankfull width is greater than 24 feet, then the system is AFS, else BFC. If the mean reach bankfull width is at least 19 feet, the system is AFS, else BFC. When using the channel dimension criteria, a weight-of-evidence approach is to be taken whereby the classification follows the majority of calls.

HL-BFC Versus FW-CV-

These systems can have significant overlap in drainage area and typically present similarities in overall channel dimension and habitat structure when they do. The main functional delineator is the dry-season flow regime. The vast majority of BFC channels are seasonally perennial to annually perennial, while the vast majority of FW-CV- sites are ephemeral to seasonally intermittent. However, deeply incised FW channel valleys and systems draining watersheds near the soil drainage threshold of 40% A+C coverage can be intermediate in hydrology. An even bigger problem is that very few systems in these categories are gaged and at least a 2-year record from representative (close to average) rainfall years is necessary to make a reasonably informed call regarding the hydrology regime and a 10-year general record would be preferable.

Absent the ability to make hydrology observations, in-stream alluviation can be delineative. Although none of these stream types have alluvial floodplain features, they do have in-channel alluvium. If only one kind of alluvial feature is present, the system is BFC. Greater numbers can occur in both types, so two or more is not delineative. BFC systems can also be confirmed by the presence of even a sporadic biological bank covering as little as 10% of the total bank length, as these are virtually absent in the FW-CV- systems. The mere absence of a biological bank is not delineative, however, because some BFC systems lack them as well.

Absent an interpretable discharge record, or if either of the two confirmatory factors for BFC systems listed above fail to occur, the site's type could be considered largely indistinguishable and interchangeable between the HL and FW condition. The geomorphic ramifications of such ambiguity are inconsequential, but in-stream faunal expectations would remain more of an open question.

HL-BFC Versus FW-AF-CC

These systems can have significant overlap in drainage area and typically present similarities in overall channel dimension and shape when they do. The main delineator is the presence of alluvial floodplain features in the CC system. If such features are absent, the system is BFC. However, where potential BFC systems occur in drainage basins close to the 40% A+C soil threshold, they can support sporadic to rather continuous bankfull benches. The CC channels we studied lacked such benches and instead the dominant floodplain surfaces were those that extended further from the channel and at comparatively higher elevation related to the channel thalweg, typically included small alluvial ridges and linear backswamps, and sometimes chutes, valley flats, laminar soil layers, or even small oxbows. Therefore, if rather discontinuous alluvial floodplain features are present and the only alluvial floodplain feature consists of bankfull benches, the system fits the BFC model best, else CC.

If the alluvial floodplain features are altered or otherwise hard to rely upon, then flood depths equal to or greater than three feet occur in CC systems, else BFC. If the mean reach riffle thalweg depth is less than 1.6 feet, the system is BFC, else CC. If the minimum riffle depth is less than 1.4, the system is BFC, else CC. This overall suite of characteristics is consistent with the concept that the greater flood pulses of the FW systems carry alluvium further across the valley and fill at greater depths within the meander belt than HL streams draining similarly sized watersheds. If channel characteristics are used, apply a weight-of-evidence approach.

HL-AFS Versus FW-AF-CC

The smallest HL-AFS systems can overlap basin area sizes with a small subset of larger FW-AF-CC streams. Where these two overlap in that regard, near the drainage boundary of 40% A+C soils, the channels can have very similar overall dimension except for width and W/D. They also can overlap in the number of total and floodplain alluvial features and meander belt width. Because of greater channel width and less-colored dry-season water, some (but not all) HL-AFS systems support SAV communities within forested meander belts, while these communities are absent from CC sites with forested meander belts. If the system is not annually perennial, it is more likely to be a FW-AF-CC type.

The best single dichotomous field indicator is W/D ratio. If the W/D ratio is less than 15, the site is FW-AF-CC, else HL-AFS. To add to the weight of evidence, if the classification section’s bankfull width is less than 20 feet, the site is FW-AF-CC, else HL-AFS. If the mean reach bankfull width is less than 18 feet, it is a CC system, else HL-AFS. Basically, it appears the HL-AFS systems are less competent to transport their sediment supply, leading to wider channels at their major sandy shoals.

HL-AFS Versus FW-AF-WF

The FW-AF-WF streams fall well within the center of the basin area range encompassed by HL-AFS systems. Where these two overlap in watershed size, near the drainage boundary of 40% A+C soils, the channels can have very similar overall shapes and dimensions. They also can have overlap in the number of total and floodplain alluvial features and meander belt width. Because of their comparatively clear dry season water, some (but not all) HL-AFS systems support SAV communities within forested meander belts, while these communities are absent from WF sites with such corridors. HL-AFS systems are characteristically annually perennial, so if less than 90% of the years on a 2- to 10-year record fail to produce a 360-day spell, the system is more properly listed as an FW-AF-WF type.

Absent adequate delineative information, the site’s type could be considered largely indistinguishable and interchangeable between the HL and FW condition. Geomorphic interpretations are unlikely to be greatly affected by such a decision, but hydroecological expectations would remain an open question without further site-specific hydrology monitoring or modeling.

HL-AFS Versus FW-AFS-HG

The uppermost ranges of HL-AFS systems' drainage areas and valley slopes can overlap with the smaller half of the range of FW-AFS-HG systems. Where these systems occur near the 40% well-drained soil delineator, they will present similar ranges in bankfull channel area, meander belt width, and flood widths, generally due to similar amounts of valley confinement. However, the HG systems tend to contain a greater diversity of alluvial features. Total alluvial features are eight or less for HL-AFS systems and at least eight for HG systems. Therefore, that variable can be used as a dichotomous delineator for all values except eight. Likewise, the floodplain alluvial features can be used to distinguish the less alluvial HL-AFS systems from their more alluvial HG systems for all values except three.

If the site cannot be distinguished based on either of those two features, then differences in flood depth at the classification cross-section and W/D ratio can be used. If the flood thalweg depth is at least 8 feet, the site is HG, else HL-AFS. That reflects the difference in peak flood-pulse volumes these systems routinely receive during the wet season. Since the floodplain widths in the HG systems tend to be confined by the valley hillslopes in well-adjusted valleys, the flood volumes reach greater depths as opposed to greater widths in the HG systems.

If W/D ratio is less than 15, the site is HG, else HL-AFS. This difference is associated with the characteristic valley types and locations of the HG systems where they have comparatively more bankfull transport capacity versus sediment supply than the HL-AFS systems experience.

HL-AFS Versus FW-AFS-LG

The larger and lower gradients of the HL-AFS systems overlap in drainage area with the smallest FW-AFS-LG systems. Where these systems occur near the 40% well-drained soil delineator, they will present similar ranges in bankfull channel area, meander belt width, and flood depths. However, the LG systems tend to contain a greater diversity of alluvial features. Total alluvial features are eight or less for HL-AFS systems and at least seven for LG systems. Therefore, that variable can be used as a dichotomous delineator for all values except seven and eight. Likewise, the floodplain alluvial features can be used to distinguish the less alluvial HL-AFS systems from their more alluvial LG systems for all values except three.

If the site cannot be distinguished based on either of those two features, then differences in flood width at the classification cross-section can be used. If the flood width is at least 700 feet, the site is LG, else HL-AFS. That reflects the difference in peak flood-pulse volumes these systems routinely receive during the wet season. The greater flood volumes spread out more in the LG systems, which are typically unconfined.

A secondary dichotomous indicator may be bankfull width at the classification section. If the stream drains less than a 200-square-mile watershed and the bankfull width is less than 50, the site is a HL-AFS, else LG.

Distinguishing Flow Regime in Absence of a Long-Term Gage Record

Some planners may wish to rapidly distinguish between basic flow regimes using watershed and reach variables as a surrogate for a nonexistent gage record. In general, this can be accomplished in accordance with the following key. The suggested approach follows concepts taken in other regions where watershed characteristics, site-specific vegetation or other biological indicators, and/or bed materials are used as the delineative factors for assigning flow regime (Nadeau 2011, NC Division of Water Quality 2010). Much professional judgment can be applied using the hydroperiod ranges of the dominant bank flora. A convenient system is the FDEP's wetland delineation vegetation index, which ranks species based on their distribution in Florida wetlands as being obligate (characteristically only found in wetlands), facultative wetland (usually in wetlands, sometimes uplands), facultative (no wetland or upland bias), or upland (characteristically found in uplands).

Although the key has been tested on systems gaged for this study, and on separate project sites in DeSoto and Hardee counties, it is far from fully vetted and is deemed preliminary. Further, it only applies well to systems without adverse anthropogenic impacts.

For larger streams with high banks, the vegetation in the lower portion of the embankment should be assessed (generally between the bankfull and baseflow stages). In such cases, vegetation growing on the alluvial ridge should be ignored. Vegetation actually growing in the stream bed should also be ignored. However, systems with SAV (excluding grassy arrowhead) are presumably annually perennial.

The FDEP vegetation index is a blunt instrument for assessing flow regime and more direct knowledge of species hydroecology and hydric soils of the banks can provide superior indication of the likely duration of local water levels in the channel. Wetland scientists with relevant Florida plant hydroecology and soils knowledge can use such characteristics to make better informed decisions regarding flow regime.

Key for Highlands Watersheds

IF the drainage area is greater than 7 square miles, THEN the site is ANNUALLY PERENNIAL.

IF the drainage area is 1 to 7 square miles,

> AND the bank vegetation closest to the channel bed is dominated by obligate or facultative wetland species without common occurrence of upland species, THEN the site is ANNUALLY PERENNIAL;

ELSE, AND the bank vegetation closest to the stream bed is dominated by obligate and facultative wetland species with common occurrence of upland taxa, THEN the site is SEASONALLY PERENNIAL.

IF the drainage area is less than 1 square mile,

AND the bank vegetation closest to the channel bed is dominated by obligate or facultative wetland species without common occurrence of upland species, THEN the site is ANNUALLY PERENNIAL;

ELSE, AND the bank vegetation closest to the stream bed is dominated by obligate and facultative wetland species with common occurrence of upland taxa, THEN the site is SEASONALLY PERENNIAL.

ELSE, AND the obligate or facultative wetland species are co-dominant with facultative or upland species, THEN the site is SEASONALLY INTERMITTENT;

ELSE, AND the reach exhibits co-dominance of upland or facultative species with or without common facultative wetland or obligate wetland taxa, THEN the site is EPHEMERAL.

Key for Flatwoods Watersheds

IF the drainage area is greater than 50 square miles, THEN the site is ANNUALLY PERENNIAL.

IF the drainage area is between 20 and 50 square miles,

AND the bank vegetation closest to the stream bed is dominated by obligate and facultative wetland species without common occurrence of upland taxa, THEN the site is ANNUALLY PERENNIAL;

ELSE, AND the bank vegetation closest to the stream bed is dominated by obligate and facultative wetland species with common occurrence of upland or facultative taxa, THEN the site is SEASONALLY PERENNIAL.

IF the drainage area is between 4 and 20 square miles,

AND the bank vegetation closest to the stream bed is dominated by obligate and facultative wetland species without common occurrence of upland taxa, THEN the site is ANNUALLY PERENNIAL;

ELSE, AND the bank vegetation closest to the stream bed is dominated by obligate and facultative wetland species with common occurrence of upland or facultative taxa, THEN the site is SEASONALLY PERENNIAL;

ELSE, AND the obligate or facultative wetland species are co-dominant with facultative or upland species, THEN the site is SEASONALLY INTERMITTENT.

IF the drainage area is between 1 and 4 square miles,

AND the reach lacks all but sporadic alluvial surfaces in its floodplain, THEN the site is EPHEMERAL;

ELSE, AND the reach has continuous alluvial features in the floodplain with co-dominance of upland or facultative species with or without common facultative wetland or obligate wetland taxa, THEN the site is EPHEMERAL;

ELSE, AND the reach has continuous alluvial features in the floodplain with obligate or facultative wetland species co-dominant with facultative or upland species on the banks, THEN the site is SEASONALLY INTERMITTENT.

IF the drainage area is less than 1 square mile, THEN the site is EPHEMERAL.

SYSTEM SUMMARY

Overview

A hydrobiogeomorphic (HBG) classification system for peninsular Florida streams was developed that embodies a broad combination of physical and biological factors known to greatly affect the structure and ecological function of natural streams. The key variables in this system are strongly associated with sources of water (and associated biogeochemistry), hydrologic regime, fluvial geomorphology, channel dimension, in-stream habitat substrates, and riparian corridor soils and vegetation. HBG classification combines aspects of physics-based and hydrobiological stream classification approaches. The system identified quantifiable threshold associations among watershed and valley characteristics with riparian corridor and channel habitats and surfaces. These associations enable most streams to be simply classified from publicly available GIS data. Furthermore, the Florida HBG stream classification system appears to capture and quantify key form and process associations likely to affect trophic status and ecological function, which is a readily testable presumption.

The stream system types ordinate along a gradient related to discharge magnitude and power. This gradient is readily expressed by plotting stream sites on a graph depicting the association between drainage basin area and valley slope (Figure 4.6). Stream power is simply defined as the product of stream discharge times the change in elevation in the water surface between two points. Therefore, a graph of valley slope versus watershed area integrates the effects of the full flow regime in a manner analogous to calculating an index of the overall stream power regime of a site. This concept is important, because although the sites occur along a smooth power gradient, large magnitude streams are not merely bigger copies of their smaller counterparts. In fact, habitat additions and substitutions occur as one moves along the power gradient due to threshold effects in the magnitude, frequency, and duration of the flow regime and the way those affect the development and distribution of alluvial surfaces.

The basis of the hydrobiogeomorphic approach to classification is the identification of distinctly different natural kinds of streams based on their process-form associations. The classification is firmly rooted in the concept that streams belong to their watersheds and that they differ in their habitat composition in association with watershed and valley characteristics. The associations among watershed, valley, and channel-scale variables are strong enough to assist in delineating the natural kinds of streams in a manner with practical and functional utility in guiding management decisions for the protection and restoration of riparian ecosystems. The "stream" is defined as a system formed by the habitats of its open channel and a riparian floodplain, with top-down processes originating from the watershed and valley forming and maintaining those habitats. In other words, this approach provides more than a classification of stream channels. It is characterizing critical interdisciplinary variables across the entire hierarchical and open system upon which the fluvial ecology relies. It is a "stream system" classification.

Fifteen natural kinds of stream systems were identified within the PFCP based on hierarchical cluster analysis of sites using more than 120 variables reported in the literature as having process-form associations with fluvial habitats. Five types were karst spring runs, three drained highlands watersheds, six drain flatwoods watersheds, and one was found in both flatwoods and highlands landscapes. Many more sub-types could be layered upon the basic 15 kinds based on the plant communities occupying the riparian corridor, although those are constrained to certain limited associations with position in the drainage network and stream type. These communities not only exist in association with stream power gradients, they vary with fire frequency and water table gradients as well. The system can be expanded or adapted to particular needs.

The system focuses on wadeable streams, largely to keep watersheds small enough to exhibit relatively homogenous conditions, thus avoiding the greater mix of conditions likely to be encountered by large basins. For example, the over 2000-square-mile watershed of the Ochlocknee River crosses three different major hydro-physiographic regions (two in Florida and a third in Georgia); and many of the peninsula's larger rivers such as the Suwannee, St. Johns, Lower Santa Fe, and Withlacoochee drain complex basins with combined runoff and karst water sources. Although systems draining up to

300-square-mile watersheds were quantified for this study, subsequent observations by the team indicate that the classes derived apply well up to about 500 square miles in the PCFP. Beyond that, streams tend to enter into a widely divergent array of unique river conditions that vary among sites. Aside from a very small number of generalities, streams draining larger than 500-square-mile basins should be treated as unique case studies rather than as part of a population of clearly identifiable classes.

General Benefits of Multi-Scale, Hierarchical Classification

Using the thresholds and associations observed from this study, stream managers can make informed decisions regarding the inherently self-sustaining channel and floodplain dimension and shape in nature 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 thresholds in the data, including:

- Landscape Hydrologic Soil Group conditions where systems shift the balance from an effective dominance of runoff to groundwater sources.
- Threshold ranges where systems begin to form alluvial features in the floodplain associated with drainage basin area in different watershed types.
- Channel width and water source thresholds necessary to support submerged aquatic vegetation communities and the presence of noticeable primary production in the bankfull channel.
- Combined valley slope and landscape characteristics associated with root-step seepage streams in sapping valleys.
- Appropriate drainage area and valley slope combinations for channels of different width-to-depth ratios, commonly used in shape-based classification schemes.
- The lower and upper limits of valley slope and drainage area beyond which the occurrence of natural stable streams with sandy beds becomes 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. Having said that, we have been applying aspects of this system since 2009, finding merit in its use regarding water quality, environmental flow, channel stability, and restoration alternatives studies.

The main benefit of a multi-scale approach is that it helped to delineate the scale-dependent limits and conditions of alluvial versus other kinds of stream channel and floodplain control processes operating in three different catchment types in Florida. It overcame issues related to the convergence of form that sometimes occur using shape-based classification, adding proper context for such schemes 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 from 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 capacities organizing riverscapes and floodscapes 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 runoff-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.

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.	
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.	
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.	
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.	
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.	
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.	
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.	

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. This has been done on an ad-hoc basis for every project our team has engaged in during the last few years where natural streams meeting the inclusionary criteria have been encountered. So far, the vast majority of the nearly three dozen sites examined in this manner clearly fit the expected typology, while sites occupying watershed types and sizes near the classification "threshold" boundaries often tended to be intermediate in their alluvial surfaces and dimension between the types bordering the line.

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, aquatic species distribution data may help to resolve if some of the proposed 15 fluvial forms suggested by geomorphology and hydrology should be expanded or lumped for specific biological management purposes. An applicable study of the stream fishery on a 20,000 acre property in Desoto County confirmed some key population differences between the FW-CV and FW-AF streams (AMEC-BCI 2011).

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 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 fully 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 drainages, 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 large Florida streams were confirmed to be intermediate forms situated between more powerful alluvial single-thread channels and less powerful slough/strand/swale conveyances with fully non-alluvial beds (AMEC 2013).

The transitions between wetlands or lakes and their connecting stream channels are important in deranged networks. Our team has measured such transitions to better define their properties for in-line wetlands in drainages of less than 12 square miles. However, similar measurements for the natural transitions for in-line lakes would be useful if a representative sample of undredged, undammed, or otherwise unaltered sites could be located.

Locations where tributaries cross the valley sideslopes of larger receiving streams present highly variable settings that are sometimes inconsistent with the expected stream type given its drainage area and valley slope. For example, we applied the HBG classification system to 64 sites not included in the development of the classification system. Classification based on reach-scale indicators observed in the field was consistent with that predicted by mapping data at the watershed and valley scales for 89% of these sites. Six of the seven incongruent sites occupied valley sideslopes or were within the bottomland of a larger stream.

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 to obtain a 10- to 20-year discharge record. That would be a good start, but even more, perhaps 24 such sites, should be established to fully determine the flow regimes of low-order Florida streams in association with their landscape attributes.

This research focused on non-tidal streams. Florida currently lacks a hydrobiogeomorphic approach to tidal stream classification that is process-based and quantitative. Such a classification would likely provide similar practical benefits for systems in near-coastal settings.

This research focused on the Peninsular Florida Coastal Plain streams. A preliminary typology was developed for the Northwest and Northeast Florida hydrophysiographic regions (AMEC 2013). That typology was aimed at identifying classification thresholds useful for numeric nutrient assessments, but strongly indicated value in taking a hydrobiogeomorphic approach in these two regions for other reasons as well. Watershed soil drainage and size had strong associations with the hydrology and geomorphology of the streams in those areas, and those regions had some overlap in stream types observed on the peninsula, but generally required a unique suite of classes. A study design similar to that engaged on the peninsula seems warranted to robustly classify streams on the continental land masses of northern Florida.

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 subtropics. 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-zone 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 Louisiana), and environments rich in karst springs wherever they occur.

CHAPTER 5
NATURAL CHANNELS (REGIONAL CURVES)

INTRODUCTION

Regional curves, which relate bankfull discharge and channel geometry (cross-sectional area, width, and depth) to drainage area in regions of similar climate, geology, and vegetation, greatly aid in creating initial targets for natural channel designs. Bankfull discharge, or the flow that fills a stable alluvial channel to the elevation of the active floodplain, is a useful parameter in developing regional curves because its stage is reasonably identifiable in the field, and it is the flow most often used to estimate the channel-forming discharge. Dunne and Leopold (1978) describe bankfull discharge as "the most effective stream-flow for moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphological characteristics of channels." It is related to meander geometry characteristics (Ackers and Charlton 1970), and is the breakpoint between processes of channel formation (erosion) and floodplain formation (deposition) (Copeland and others 2000). While regional curves provide important information for natural channel structure, they also aid in estimating bankfull discharge and channel geometry in ungaged watersheds where drainage area is known, help confirm field identifications of bankfull stage, and allow for comparisons between regions (Leopold 1994). It is important to recognize that stream channel dimension varies substantially in nature, and although regional curves often explain more than 75% of the variability in channel size, the natural variability is so large that regional curve data should be used as a starting point of restoration design. Final design dimensions should be verified using multiple methods, carefully considering how the watershed and valley conditions may differ from "average" characteristics.

Peninsular Florida has abundant karst landforms, as naturally acidic rain and groundwater have flowed through carbonate bedrock for millions of years, dissolving conduits and caverns and leading to the formation of sinkholes and lakes. With approximately 16,000 km of rivers and streams, 7,800 lakes, 33 first-magnitude springs, and millions of acres of wetlands, Florida supports more rivers and streams than other karst areas due to low elevation, abundant precipitation, and high water tables (Kautz and others 1998). Groundwater is abundant, and there are many surface water and groundwater connections through features such as sinkholes, springs, and seepage through the sandy surficial aquifer. These conduits are not uniformly distributed throughout the landscape, and any given watershed can provide a variety of water sources to the stream. Baseflow contributions influence hydrographs, resulting in delayed and prolonged floods (Mossa 1998). Peninsular Florida streams commonly drain three different kinds of landscapes, which influences the way water is delivered to the stream. To recap:

(1) Karst – a groundwater-dominated system providing perennial discharge from a confined aquifer consisting of carbonate rock in karst terrains.

(2) Highlands – a groundwater-influenced system 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). Seepage stream watersheds also provide runoff during intense, high-volume rain events. The seepage basins occur 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).

(3) Flatwoods – a runoff-dominated water supply system consisting 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).

Thus, the data were examined for verification of whether peninsular Florida regional curves should be further split by these watershed types. These different kinds of watersheds, and their derivation, are described in more detail in Chapter 2.

METHODS

Tasks completed to develop regional curves for peninsular Florida included: (1) selecting 56 gaged and ungaged stream sites spanning a variety of drainage area sizes, valley slopes, watershed types (flatwoods, highlands, karst) and geographies (northern and southern peninsula); (2) conducting reference reach surveys to determine bankfull channel geometry and discharge; (3) developing and analyzing regional curves for peninsular Florida based on the entire data set as well as subsets of the data (watershed type, geography); (4) estimating bankfull return intervals for peninsular Florida streams; (5) evaluating bankfull sediment transport association with drainage area; and (6) comparing regional curves developed for peninsular Florida to regional curve studies from other hydro-physiographic regions nearby.

Site Surveys

A reference reach survey was conducted at each of the 56 study sites following Harrelson and others (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 the bankfull width, mean bankfull depth, maximum bankfull depth (or thalweg depth), bankfull cross-sectional area, slope, and sinuosity of the channel (Leopold 1994). Twenty one cross-sections were measured at each site, including six detailed cross-sections with bankfull indicators and a Rosgen (1996) classification riffle which extended at least several bankfull widths into the floodplain. A Leica Total Station and a handheld data collector running Carlson SurvCE were used to record measurements to about 1000th of a foot, as per precision of the equipment. Depth of the water at the thalweg was recorded to the nearest 10th of a foot. Survey data were downloaded and plotted using RIVERMorph 4.0.1 Stream Restoration Software (RIVERMorph). Many additional data parameters were also collected during the survey, including stream habitat types and quantities, canopy cover, and bank and floodplain vegetative species.

Surveyed sites range in drainage area from 0.2 to 311 square miles and in valley slopes from 0.02 to 2.06% (Table 5.1). Sites were further divided into subsets based on their watershed type and geography to check for compelling differences. Twenty-three sites drain flatwoods watersheds, 21 drain highlands watersheds, and 12 are spring runs draining karst terrains. Thirty sites are located in the northern portion of the peninsula (above the 28.5 degrees north latitude line), while 26 are located in the southern portion of the peninsula (below the 28.5 degrees north latitude). This division was used to check for differences in channel geomorphology potentially associated with a subtle north-south climactic gradient that exists within the peninsula as the landscape becomes increasingly tropical.

An important component of the field survey was the proper identification of bankfull stage, or the elevation at which the stream just begins to overflow onto its active floodplain. Field identification of bankfull stage is the method most often used to estimate the channel-forming flow, though its correct identification in the field can be difficult and subjective (Johnson and Teil 1996, Knighton 1998). Therefore, various bankfull indicators were systematically surveyed and analyzed to assess which is the most reliable and appropriate indicator for peninsular Florida streams, including the elevation of the valley flat or position on the bank where slope first becomes level (BKF-F), inflection or break in slope of the bank (BKF-I), top of point bar, top of scour or undercuts in the bank (BKF-S), bottom of moss collars, and the alluvial break (BKF-A) (Figure 3.22).

Generally, the elevation of the alluvial valley flat (when present) was determined to be the most reliable indicator for peninsular Florida streams with unconfined wetland floodplains, the upper inflection point for streams with an upland floodplain, the inflection point closest in elevation to the linear backswamp or chutes in a wetland floodplain with an alluvial ridge, and the scour or moss line for spring runs (Blanton and others 2010, Kiefer 2010).

Table 5.1. Summary of Site Characteristics.

Site Name	Physiography	Drainage Area (Sq.Mi.)	Gage I.D.	Valley Slope (%)	Geography	Rosgen Class	Stream Order
Bell Creek UT	FW	0.2	None	0.77	S	E5	1
Blues Creek near Gainesville	FW	3.2	USGS 02322016	0.52	N	B5	2
Bowlegs Creek near Ft Meade	FW	50.9	USGS 02295013	0.08	S	C5	4
Coons Bay Branch	FW	0.5	None	0.53	S	E5	1
Cow Creek	FW	5.6	None	0.13	N	C5	2
East Fork Manatee UT 1	FW	0.9	None	0.60	S	E5	2
East Fork Manatee UT 2	FW	0.4	None	0.44	S	C5	1
Fisheating Creek at Palmdale	FW	313.0	USGS 02256500	0.04	S	C5	3
Grasshopper Slough Run	FW	8.7	None	0.12	S	C5	2
Grassy Creek UT	FW	0.8	None	0.68	S	C5	1
Hillsborough River UT	FW	1.0	None	0.25	S	C5	1
Horse Creek near Arcadia	FW	219.0	USGS 02297310	0.05	S	C5	5
Little Haw Creek near Seville	FW	106.2	USGS 02244420	0.04	N	C5	2
Lower Myakka River UT 2	FW	2.7	None	0.18	S	C5	1
Lower Myakka River UT 3	FW	0.4	None	0.17	S	C5	1
Manatee River near Myakka Head	FW	65.7	USGS 02299950	0.07	S	E5	4
Morgan Hole Creek	FW	11.0	None	0.16	S	E5	2
Moses Creek near Moultrie	FW	7.8	USGS 02247027	0.16	N	E5	2
Rice Creek near Springside	FW	45.8	USGS 02244473	0.06	N	C5	4
Santa Fe River near Graham	FW	94.1	USGS 02320700	0.11	N	B5	3
Tenmile Creek	FW	16.8	None	0.12	N	E5	2
Tyson Creek	FW	20.7	None	0.09	S	C5	3
Wekiva Forest UT	FW	0.5	None	0.33	N	E5	2
Alexander UT 2	HL	2.3	None	0.48	N	E5	1
Bell Creek	HL	1.9	None	0.49	S	E5	2
Blackwater Creek near Cassia	HL	118.4	USGS 02235200	0.02	N	C5	4
Carter Creek near Sebring	HL	36.0	USGS 02270000	0.21	S	B5	2
Catfish Creek near Lake Wales	HL	57.5	USGS 02267000	0.07	S	C5	1
Cypress Slash UT	HL	0.4	None	1.34	S	E5	1
Gold Head Branch	HL	2.8	None	1.05	N	E5	2
Hammock Branch	HL	3.0	None	0.37	N	E5	2
Jack Creek	HL	2.7	None	0.27	S	C5	2
Jumping Gully	HL	4.2	None	0.88	N	E5	2
Lake June-In-Winter UT	HL	0.6	None	1.05	S	E5	1
Livingston Creek near Frostproof	HL	119.8	USGS 02269520	0.08	S	C5	3
Lowry Lake UT	HL	0.3	SJR 72051622	0.68	N	G5	1
Manatee River UT	HL	0.3	None	1.77	S	B5	1
Ninemile Creek	HL	6.8	None	0.51	N	C5	1
Shiloh Run near Alachua	HL	0.4	USGS 02322050	1.53	N	E5	1
Snell Creek	HL	1.7	None	0.14	S	C5	2
South Fork Black Creek	HL	26.5	None	0.11	N	C5	4
Tiger Creek near Babson Park	HL	53.2	USGS 02268390	0.06	S	C5	2
Tiger Creek UT	HL	0.9	None	0.37	S	C5	1
Tuscawilla Lake UT	HL	0.3	None	2.06	N	G5	1
Alexander Spring Run	K	110.0	SJR 18523784	0.02	N	B5	3
Alligator Spring Run	K	8.7	None	0.09	N	C5	1
Cedar Head Spring Run	K	5.2	None	0.18	N	C5	1
Forest Spring Run	K	1.7	None	0.67	N	E5	1
Gum Slough Spring Run	K	27.0	USGS 02312764	0.06	N	C5	2
Juniper Spring Run	K	33.7	None	0.05	N	C5	2
Kittridge Spring Run	K	3.1	None	0.15	N	B5	1
Little Levy Blue Spring Run	K	2.1	None	0.10	N	C5	1
Morman Branch UT Spring Run	K	0.5	None	0.57	N	F5	1
Rock Spring Run	K	100.0	USGS 02234610	0.06	N	C5	1
Silver Glen UT Spring Run	K	1.0	None	0.12	N	G5	1
Weeki Wachee River	K	85.9	USGS 02310525	0.05	N	C5	1

Regional Curve Development and Analysis

Data obtained from the reference reach surveys were used to determine bankfull discharge, bankfull cross-sectional area, bankfull width, mean bankfull depth (also referred to as the hydraulic depth), and bankfull thalweg depth. Bankfull channel geometry parameters were calculated two ways, depending on the use of the data. For equitable comparison to previously published north Florida regional curves, the values of the classification cross-section during the reference reach survey conducted at each study site were used, while data intended for defining natural condition and for use in design guidance curves were synthesized by averaging the results from the classification section with the smallest remaining riffle section surveyed. The averaging approach eliminated some of the random vagaries of channel dimension caused by biological controls or local wind-storm effects, and improved the regression fit (R^2).

Bankfull discharge was estimated either by direct field measurement using velocity-area techniques sampled with an acoustic Doppler velocimeter or by using reference reach survey data of the field bankfull stage in conjunction with the most current USGS stage-discharge rating table. Regional curves were created in Sigmaplot 11 by plotting the various bankfull parameters (discharge, cross-sectional area, width, and thalweg depth) against drainage area on a log-log scale. A power function regression was fit to the data, and the coefficient of determination (R^2) was determined.

To determine whether peninsular Florida regional curves should be further split by physiography (flatwoods, highlands, karst) or geography (northern, southern peninsula), data were sorted by each of these subsets, and separate regional curves were created. Raw data from both the present work and previous regional curve studies conducted on the continental land mass of northern Florida, southern Georgia and southern Alabama were entered into Sigmaplot 11, and regional curves for each bankfull parameter were $\log_{10}$-transformed and compiled into one graph for visual comparison. Similar analyses were conducted comparing samples taken from the northern versus southern half of this research’s study area and comparisons were also made between streams draining the three kinds of watersheds within the study area.

Regression tests were then performed on the $\log_{10}$-transformed data to determine whether significant differences exist in the regression slopes and/or constants of bankfull discharge and channel geometry regressions between peninsular Florida streams and other Coastal Plain regional curves using SPSS 16.0. The tests consisted of a multiple regression technique that allows for the use of categorical and continuous variables to assess differences in the regression coefficients (Keith 2006). The procedure codes the categorical variables (e.g., region or watershed type) as dummy variables, centers the continuous independent variable data (drainage area) by subtracting the sample mean from each sample value, calculates a series of cross-products of each category and centered independent variable, and regresses the dependent variables versus blocks of the dummy variables and the cross-products. The resultant ANOVA table then enables separate evaluation of the statistical significance of the regression slope and constant.

The method's regression constants are positioned at the average log-drainage area size rather than at the "intercept" with the lowest value.

Hydrology Analysis

The return interval associated with bankfull discharge was also estimated for nominally perennial peninsular Florida streams. Long-term hydrologic data for the 18 USGS gaged sites were used to analyze how frequently and for how long the bankfull discharge occurs. Recurrence intervals were estimated using an annual maximum series from a Log Pearson Type III distribution (skew coefficient of -0.1) in RIVERMorph (USGS 1982). An annual maximum series, which is a data series comprising the maximum peak flow in each year of record, cannot determine a return interval of less than one year. A partial duration series, which is a data series comprising all events during the period of record that exceed some set criterion (i.e., all floods above a selected base), can determine a return interval of less than one year. Continuous discharge data from the USGS were also used to develop flow duration curves for each gaged site and to determine the percentage of time that the bankfull discharge was equaled or exceeded at each gaged site. The methods and results for comparing the hydrology data from 18 perennial streams, by watershed type, are explained in greater detail in Chapter 2.

Eight multi-year gage records were established in comparatively small streams not represented well by the USGS records. The available five-year records were examined for bankfull frequency (partial duration series) and percent exceedance for the available period of record. Independent events were defined for partial duration series, as explained in Chapter 2. The records were not long enough to calculate reliable annual maximum series. This analysis was conducted to determine how often bankfull discharges occur in smaller, generally non-perennial streams in comparison to larger and perennial ones.

Sediment Analysis

Bankfull sediment transport curves were developed using a compilation of suspended sediment concentration (SSC) and bedload sampling conducted on the eight streams gaged for this study during 2008 and 2009. Attempts were made to collect at least four samples from each stream, covering a range of discharge conditions bracketing bankfull stage. This was achieved for five of the sites based on the available flow patterns (Jack Creek, Grasshopper Slough, Lower Myakka UT 2, Morgan Hole Creek, and Tiger UT). Discharge was measured concurrently with sediment sampling using USGS velocity-area methods with a Sontek handheld acoustic-Doppler velocimeter. SSC collections deployed a handheld US DH-81 depth-integrated sampler in accordance with the Equal Discharge Increment Method (EDIM) (Edwards and Glysson 1999). Bedload sampling was conducted using a US BL-84 Helley-Smith sampler following the Single Equal-Width Increment (SEWI) method for streams flowing greater than 10 feet wide and the Multiple Equal-Width Increment (MEWI) method for streams less than 10 feet wide (Edwards and Glysson 1999).

Laboratory methods for determining fine sediments (ASTM 2000), moisture content (ASTM 2005), sediment sieve analysis (ASTM 2006), drying procedures (ASTM 2007a), sediment concentrations in water samples (ASTM 2007b), and percent organic material (ASTM 2007c) followed standard procedures. Laboratory analysis was conducted in BCI's USACE-certified materials lab in Lakeland, FL. Total load was calculated from the concentration and discharge data by summing the suspended and bedload results obtained from each sampling event. The total, bedload, and suspended loads were then plotted for each site versus discharge and the bankfull loads were interpolated from those associations for each stream. Bankfull loads were then regressed against drainage area.

RESULTS AND DISCUSSION

Regional curves relating drainage area to valley slope, bankfull discharge, bankfull cross-sectional area, bankfull width, bankfull mean depth, and bankfull thalweg depth were developed and are presented below. When warranted, regional curves were further split based on watershed type (flatwoods, highlands, karst) and channel W/D ratios. Bankfull discharges equaled or exceeded an average of 25% of the period of record for 19 perennial blackwater streams with long-term USGS gages, indicating that bankfull discharge is a common occurrence and the floodplain could be viewed as a vegetated wet-season channel.

Thus regional curves relating drainage area to seasonal high flood discharge and flood width were also developed. Hydrology assessments also confirmed the utility of considering the karst streams for separate bankfull and floodplain regional curves from the other two watershed types. Annual bankfull flow frequencies, bankfull exceedance durations, and percentage of rainfall delivered as annual streamflow were all similar between flatwoods and highlands streams (Tables 2.3 and 5.2). These two watershed types exhibited statistically significant differences in their seasonal flow variability and ratio of floodplain flow power to bankfull power (Table 2.3). These results suggested that bankfull channels function similarly between highlands and flatwoods streams, but that their floodplains do not. This concept was further tested by comparing the regional curves among the three kinds of watersheds. Lastly, results comparing regional curves developed for peninsular Florida to those developed in other hydro-physiographic regions of Florida, Alabama and Georgia are presented. Measurement data collected during the reference reach surveys used to develop peninsular Florida regional curves are provided in Table 5.2.

Although flatwoods and highlands streams have different water delivery systems, regression tests indicated no significant differences in bankfull discharge, bankfull cross-section area, mean bankfull depth, or channel width as they relate to drainage area between those systems (Table 2.3). Therefore, bankfull regional curves were developed collectively for flatwoods and highlands physiographies and designated as “blackwater” streams. Karst bankfull dimensions were rather consistently statistically significantly different from the other two drainage area types (Table 2.3). In addition to regressing against drainage (recharge) area, karst system data were plotted versus bankfull discharge because it is not always feasible to delineate a proper catchment area for karst streams, while it is comparatively straightforward to measure or calculate their bankfull discharge. Thus separate regional curves relating channel size to bankfull flow were developed for karst systems.

No significant differences were found in the bankfull discharge (p = 0.93 for regression constant, 0.51 for regression slope) or cross-sectional area (p = 0.66 for constant, 0.18 for slope) based on the north-south geography division within the peninsula among blackwater streams. This suggests that the peninsula functions as a reasonably homogenous hydro-physiographic region for those kinds of watersheds.

Some differences in channel shape (widths and depths) did emerge, but this was likely an artifact of a greater frequency of stream types favoring low W/D ratios in the northern part of the study area (e.g., sapping headwater valleys) versus some types favoring high W/D ratios in the south (e.g., interior links in headwater chains of wetlands). Differences were significant for regression constant for width (p = 0.004) and thalweg depth (p = 0.026), but not regression slope (p = 0.20 and 0.42, respectively).

Because some stream types tend toward different shape factors, regressions for separate categories of W/D ratio were developed. Channel W/D ratios greater than 12 formed the population of wide-shallow streams, while those less than 12 were categorized as narrow-deep channels. A case could be made for cutoffs ranging from 10 to 15 based on our data, varying the ratio by stream type, but Rosgen’s (1996) classifying threshold of 12 seems like a good overall number to use.

Table 5.2. Summary of Site Measurement Data.

Site Name	Phys	Drainage Area (Sq.Mi.)	Bankfull Indicator	Bankfull Channel Discharge (cfs)	Bankfull Cross-Sectional Area (Sq. Ft.)	Bankfull Channel Width (Ft.)	Bankfull Thalweg Depth (Ft.)	Flood Channel Discharge (cfs)	Flood Channel Width (Ft.)	% of Time Bankfull Flow Exceeded for POR
Alexander Spring Run	K	110.0	BFS	121.9	567.0	251.3	2.8	247.3	272	38.0
Alexander UT 2	HL	2.3	BFI	5.3	8.6	6.8	2.0	15.7	28	N/A
Alligator Spring Run	K	8.7	BFS	11.3	61.0	43.8	2.5	18.1	88	N/A
Bell Creek	HL	1.9	BFI	4.1	7.4	8.4	1.5	6.6	8	N/A
Bell Creek UT	FW	0.2	BFI	2.3	3.3	6.2	1.0	4.7	26	N/A
Blackwater Creek near Cassia	HL	118.4	VF	128.7	108.8	47.8	4.3	885.1	410	13.0
Blues Creek near Gainesville	FW	3.2	BFI	14.0	14.0	8.5	2.5	29.3	12	N/A
Bowlegs Creek near Ft Meade	FW	50.9	VF	59.1	55.9	31.7	3.3	234.1	703	14.0
Carter Creek near Sebring	HL	36.0	BFS	31.5	26.7	19.0	2.0	94.8	55	23.0
Catfish Creek near Lake Wales	HL	57.5	VF	45.1	66.9	59.0	2.1	162.8	504	35.0
Cedar Head Spring Run	K	5.2	BFS	7.4	25.6	23.6	1.8	20.4	30	43.0
Coons Bay Branch	FW	0.5	BFI	2.6	5.0	6.6	1.2	5.9	9	N/A
Cow Creek	FW	5.6	BFI	20.3	15.5	12.5	1.9	67.5	65	N/A
Cypress Slash UT	HL	0.4	BFI	0.9	1.7	6.5	0.7	2.7	11	8.0
East Fork Manatee UT 1	FW	0.9	BFI	3.2	6.4	6.3	1.5	4.6	6	2.3
East Fork Manatee UT 2	FW	0.4	BFI	2.0	9.2	10.7	1.2	6.2	122	N/A
Fisheating Creek at Palmdale	FW	313.0	VF	81.9	87.2	44.5	4.3	1,018.5	3641	40.0
Forest Spring Run	K	1.7	BFI	0.7	3.1	5.3	1.1	2.7	67	N/A
Gold Head Branch	HL	2.8	BFS	4.4	6.6	7.0	1.6	6.9	7	N/A
Grasshopper Slough Run	FW	8.7	VF	18.9	22.3	18.5	2.2	39.1	160	8.2
Grassy Creek UT	FW	0.8	BFI	1.5	5.8	11.6	0.9	3.4	132	N/A
Gum Slough Spring Run	K	27.0	BFS	36.4	106.8	54.5	2.8	56.0	145	35.0
Hammock Branch	HL	3.0	BFI	8.1	14.3	11.3	2.2	16.0	34	N/A
Hillsborough River UT	FW	1.0	VF	6.1	10.2	10.6	1.6	9.3	12	N/A
Horse Creek near Arcadia	FW	219.0	BFI	230.0	113.8	38.3	4.5	1,330.8	743	21.0
Jack Creek	HL	2.7	BFI	5.0	5.4	8.1	1.0	18.0	78	20.9
Jumping Gully	HL	4.2	BFI	2.3	4.9	4.4	1.7	3.0	4	N/A
Juniper Spring Run	K	33.7	BFS	27.1	52.7	32.1	3.0	37.5	52	N/A
Kittridge Spring Run	K	3.1	BFS	1.8	3.5	10.5	0.6	3.9	15	N/A
Lake June-In-Winter UT	HL	0.6	BFI	1.5	5.7	6.4	1.3	2.4	7	N/A
Little Haw Creek near Seville	FW	106.2	VF	109.2	97.9	36.6	5.6	580.5	3127	25.0
Little Levy Blue Spring Run	K	2.1	BFS	1.9	15.8	21.1	0.8	9.9	113	N/A
Livingston Creek near Frostproof	HL	119.8	VF	58.8	64.1	33.3	3.6	335.1	229	34.0
Lower Myakka River UT 2	FW	2.7	VF	3.6	4.0	7.7	1.0	18.2	87	3.7
Lower Myakka River UT 3	FW	0.4	VF	1.0	3.9	11.8	0.7	5.0	75	8.5
Lowry Lake UT	HL	0.3	BFI	0.6	2.6	4.5	0.7	1.9	6	48.0
Manatee River near Myakka Head	FW	65.7	BFI	139.9	72.9	26.9	4.1	1,246.6	882	12.0
Manatee River UT	HL	0.3	BFS	2.5	6.2	5.1	1.5	5.4	5	N/A
Morgan Hole Creek	FW	11.0	BFI	19.8	17.9	11.5	2.4	66.3	107	12.9
Morman Branch UT Spring Run	K	0.5	BFS	0.4	1.4	7.3	0.3	1.2	7	N/A
Moses Creek near Moultrie	FW	7.8	BFI	20.9	25.9	12.2	3.2	138.4	418	7.0
Ninemile Creek	HL	6.8	BFS	3.6	10.2	9.7	1.1	5.6	12	N/A
Rice Creek near Springside	FW	45.8	VF	23.2	43.5	22.6	3.3	521.9	834	34.0
Rock Spring Run	K	100.0	BFS	48.0	73.2	53.6	3.5	68.3	54	54.0
Santa Fe River near Graham	FW	94.1	BFI	109.6	80.6	22.0	4.9	516.4	141	13.0
Shiloh Run near Alachua	HL	0.4	BFI	9.2	4.2	6.5	1.0	20.9	10	N/A
Silver Glen UT Spring Run	K	1.0	BFS	0.8	10.1	27.2	0.6	1.8	18	N/A
Snell Creek	HL	1.7	BFI	3.7	21.7	18.6	1.8	5.4	32	N/A
South Fork Black Creek	HL	26.5	BFI	52.3	44.4	21.0	3.4	89.0	216	26.0
Tenmile Creek	FW	16.8	VF	23.7	34.8	19.2	2.8	88.6	177	N/A
Tiger Creek near Babson Park	HL	53.2	BFI	60.9	95.4	47.2	3.8	189.7	178	17.0
Tiger Creek UT	HL	0.9	VF	4.7	8.7	12.5	1.2	7.3	16	0.1
Tuscawilla Lake UT	HL	0.3	BFS	0.2	2.0	2.5	1.2	1.0	3	N/A
Tyson Creek	FW	20.7	VF	10.7	28.0	23.3	1.8	207.7	246	N/A
Weeki Wachee River	K	85.9	BFI	163.6	161.2	45.8	5.7	183.5	127	36.0
Wekiva Forest UT	FW	0.5	BFI	5.6	9.2	8.8	1.6	16.4	93	N/A

BFI = alluvial inflection, BFS = scour or moss line, VF = valley flat.

Bankfull Regional Curves

Bankfull Discharge

Relationships for bankfull discharge as a function of drainage area for blackwater and karst systems are shown in Figures 5.1 and 5.2, respectively. Power function regression equations, corresponding coefficients of determination (R^2), and sample sizes are:

$Q_{bkf\text{-}blackwater} = 3.2\ A_d^{0.69}$ $R^2 = 0.83$ n = 44 (1)
$Q_{bkf\ -karst} = 0.78\ A_d^{1.1}$ $R^2 = 0.96$ n = 12 (2)

where Q_{bkf} = bankfull discharge in cubic feet per second (cfs) and A_d = watershed drainage area in square miles. Bankfull discharge is directly related to drainage area with 83% of the variability in discharge for blackwater streams and 96% for karst streams explained by drainage area.

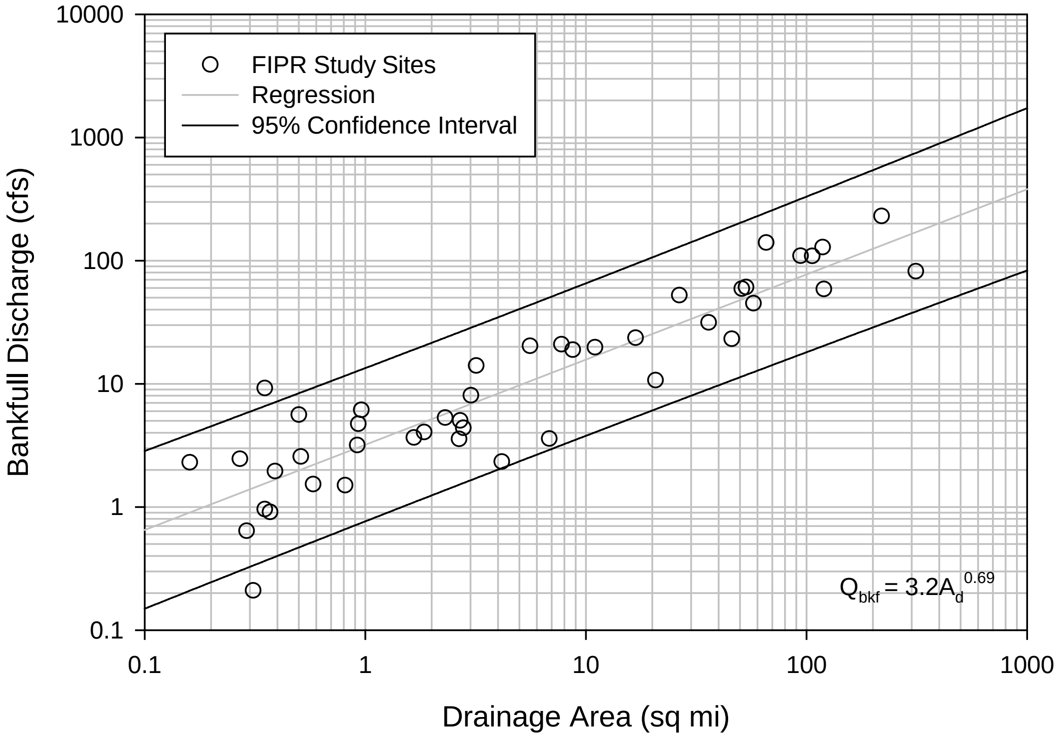


Figure 5.1. Bankfull Discharge Versus Drainage Area for Blackwater Streams.

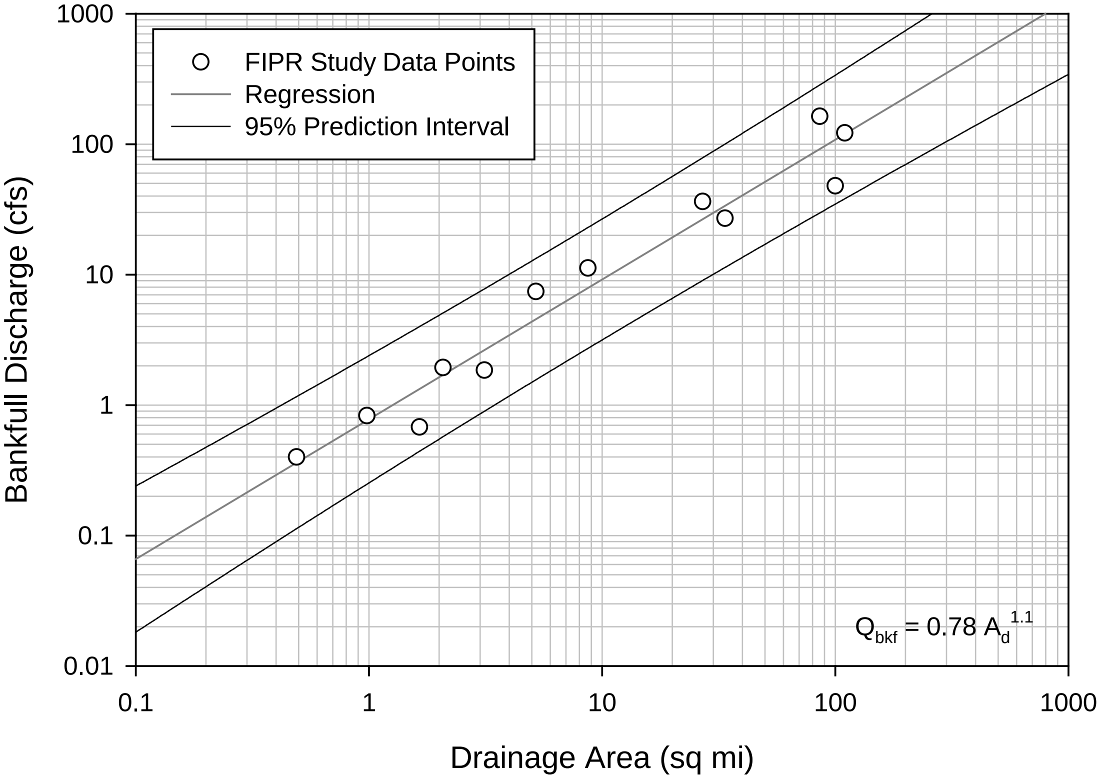


Figure 5.2. Bankfull Discharge Versus Springshed Area for Karst Streams.

Peak flow data for the gaged sites were analyzed to estimate the bankfull discharge return interval using Log Pearson Type III distributions. The bankfull discharge ranged from less than 1 year to 1.44 years, which is more frequent than the average 1.5-year return interval often cited in the literature (Dunne and Leopold 1978, Leopold 1994), but consistent with findings from other southeastern United States Coastal Plain studies (Sweet and Geratz 2003, Metcalf and others 2009). This type of analysis is traditional for regional curve development, but is a bit anachronistic because it cannot determine return intervals of less than one year. A partial duration series analysis provides fundamentally different, and more intuitively realistic, results versus an annual maximum series for return intervals of less than 1.65 years (Maidment 1992). The two series converge at return intervals exceeding 10 years, with the partial duration analysis providing superior estimates below that threshold (Langbein 1949). Since bankfull events occur multiple times a year in Florida, a partial duration series is clearly warranted.

Partial duration series calculations require some exercise in professional judgment to assure statistical independence of each flow event. For large and perennial streams, an event was tallied when the daily flow record exceeded the bankfull discharge and exhibited at least a 7-day period between the daily maxima. These criteria thus recorded all pulses fluctuating above bankfull stage, an important distinction for some systems that sustain continuous flow above bankfull for months at a time. The partial duration series assessments for perennial streams indicated a wide range of bankfull frequencies from 8 to 42 times per year. Flatwoods and highlands streams were statistically indistinguishable, with mean frequencies of 19 and 20.5 events per year, respectively. Karst systems were more frequently crossing bankfull thresholds, at an average of 33 times per year, but that was not due to laterally extensive flood events. The higher frequency of the bankfull events in karst systems was due to the fact that their vertical bankfull limits were typically entrenched and therefore frequently pulsed slightly above and below the bankfull threshold. The statistics described above apply to nearly perennial streams.

Eight non-perennial or low-order streams gaged from mid-2008 to late 2013 for this study averaged bankfull frequencies of 4 times per year, ranging from 0.2 to 7.6 annual events per site (Table 2.5). Unlike larger perennial rivers, individual pulses almost always rose above and receded below bankfull stage between events. Occurrence of three to four such events was rather typical. Bankfull discharge exceedances averaged 9% of the period of record for these systems, with sites ranging from 2.3% to 20.9%. Bankfull events lasted an average of 10 days among sites (range for site averages was 2.1 to 37 days). The average among the site medians was 4.6 days, with most sites exhibiting median events from 3 to 5 days. The longest bankfull spell was 120 days, which was an outlier. The next longest was 46 days.

An analysis of the flow duration at the perennial USGS gaged sites was conducted and bankfull discharge was found to be equaled or exceeded approximately 25% of the time, on average, for the nearly perennial blackwater streams (Table 2.2). The low-order streams studied exhibited bankfull exceedances of 2.3% to 20.9%.

The lengthy cumulative bankfull exceedance of the more perennial streams is typically occupying a floodplain with a variety of alluvial features and bottomland swamps, suggesting that the floodplain could be viewed as a vegetated wet-season channel, following conceptual models that apply well to stream corridors in the seasonal tropics (Junk and others 1989, Gupta 1995, Mossa and others 2002, Warne and others 2000). Thus additional regional curves were developed for the flood channel of flatwoods and highlands streams. As mentioned, flatwoods and highlands streams were found to have significantly different flood discharges and flood widths based on drainage area, thus separate regional curves were developed based on watershed type. Karst stream floodplain characteristics also differed on these variables from the blackwater systems. The differences established a distinct threshold of floodplain activity and dimension associated with the amount of groundwater influence on the hydrology of the stream. Systems with greater capture and delivery of stream discharge through groundwater pathways generally had smaller floodplain corridors than streams with runoff-dominated hydrology.

The bankfull frequencies and exceedances observed suggest that wadeable streams in peninsular Florida achieve bankfull stage relatively frequently compared to the modal values elsewhere, implying that the channels are formed by relatively frequent flows. These findings will be useful to restoration scientists working in Florida, who should be careful not to overbuild bankfull channels to convey the oft-cited standard 1.5-year flood, and instead should pay additional attention to the morphology of the floodplain and valley to handle such discharges.

Cross-Sectional Area

Relationships for bankfull cross-sectional area as a function of drainage area for blackwater systems and as a function of bankfull discharge for karst systems are shown in Figures 5.3 and 5.4. Power function regression equations, corresponding coefficients of determination (R^2), and sample sizes are:

$A_{bkf\text{-}blackwater} = 6.63\ A_d^{0.51}$ $R^2 = 0.86$ n = 44 (3)
$A_{bkf\text{-}karst} = 5.03\ Q_{bkf}^{0.81}$ $R^2 = 0.89$ n = 12 (4)

where A_{bkf} = bankfull cross-sectional area in square feet and A_d = watershed drainage area in square miles. Bankfull cross-sectional area is directly related to drainage area, with 86% of variability in cross-sectional area for blackwater streams explained by drainage area and 89% for karst streams explained by bankfull discharge.

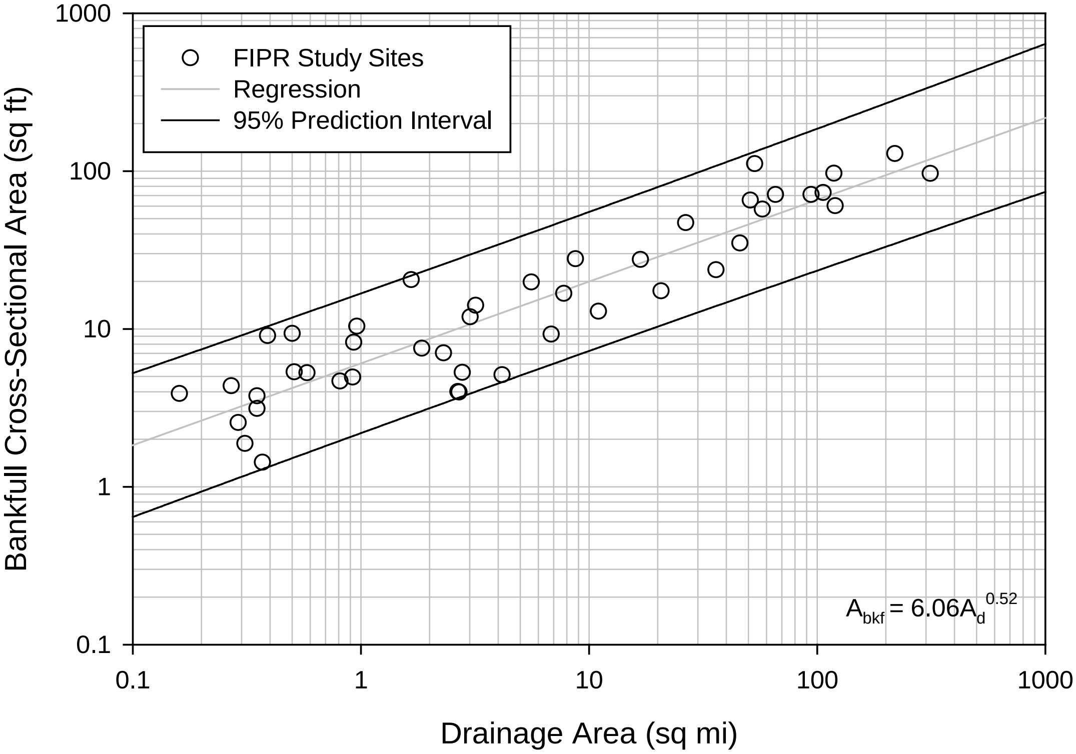


Figure 5.3. Bankfull Cross-Sectional Area Versus Drainage for Blackwater Streams.

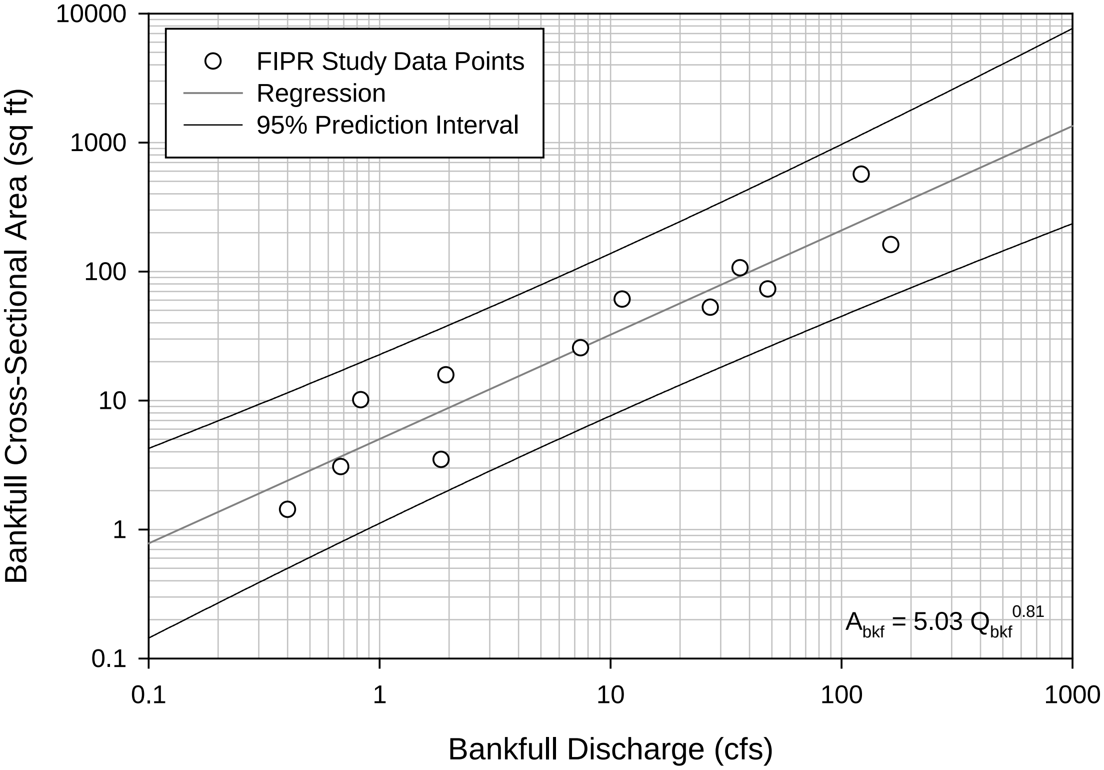


Figure 5.4. Bankfull Cross-Sectional Area Versus Discharge for Karst Streams.

Bankfull Width

Relationships for bankfull width as a function of drainage area for blackwater systems and as a function of bankfull discharge for karst systems are shown in Figures 5.5 and 5.6. Power function regression equations, corresponding coefficients of determination (R^2), and sample size are:

$W_{bkf\text{-}blackwater} = 8.09\ A_d^{0.30}$	$R^2 = 0.75$	n = 44	(5)
$W_{bkf\text{-}karst} = 11.91\ Q_{bkf}^{0.42}$	$R^2 = 0.71$	n = 12	(6)

where W_{bkf} = bankfull width in feet, and A_d = watershed drainage area in square miles. Bankfull width is directly related to drainage area, with 75% of variability in width for blackwater streams explained by drainage area and 71% of variability for karst streams explained by bankfull discharge.

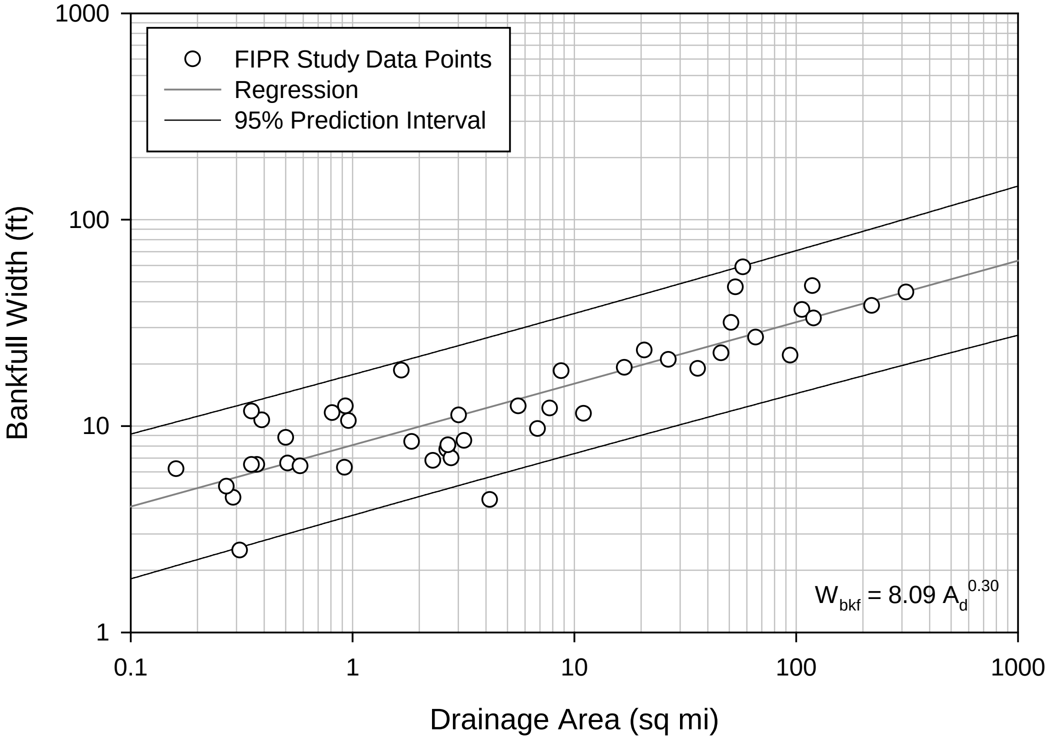


Figure 5.5. Bankfull Width Versus Drainage Area for Blackwater Streams.

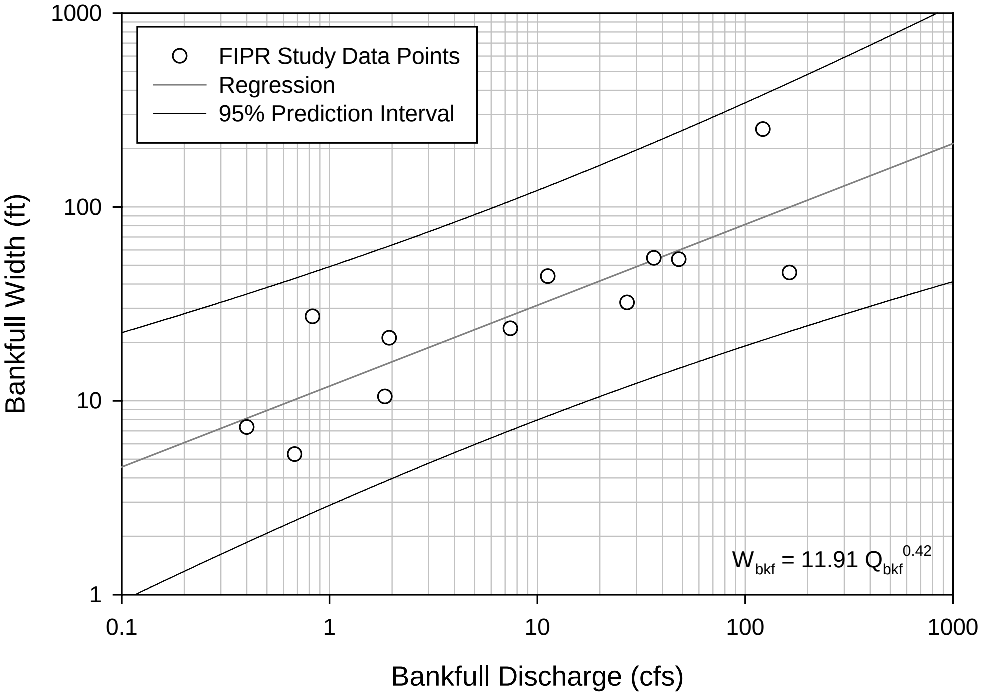


Figure 5.6. Bankfull Width Versus Bankfull Discharge for Karst Streams.

Relationships for bankfull width as a function of drainage area for blackwater systems with W/D ratios greater than 12 (Rosgen C5) and less than 12 (Rosgen E5) are shown in Figures 5.7 and 5.8. Power function regression equations, corresponding coefficients of determination (R^2), and sample size are:

$W_{bkf\text{-}C5} = 10.74\ A_d^{0.25}$ $R^2 = 0.71$ n = 22 (7)
$W_{bkf\text{-}E5} = 6.88\ A_d^{0.27}$ $R^2 = 0.76$ n = 22 (8)

where W_{bkf} = bankfull width in feet, and A_d = watershed drainage area in square miles. Bankfull width is directly related to watershed size, with 71% of variability in C5-stream width and 76% in E5-stream width explained by drainage area.

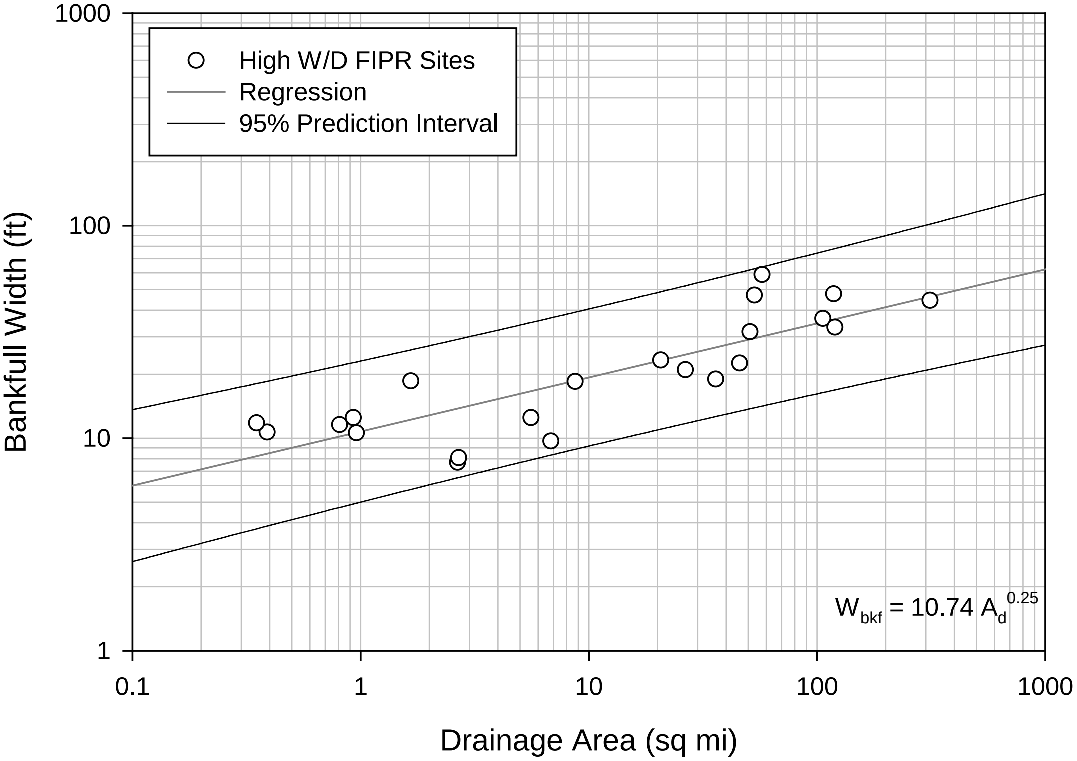


Figure 5.7. Bankfull Width Versus Drainage Area for C5 Blackwater Streams.

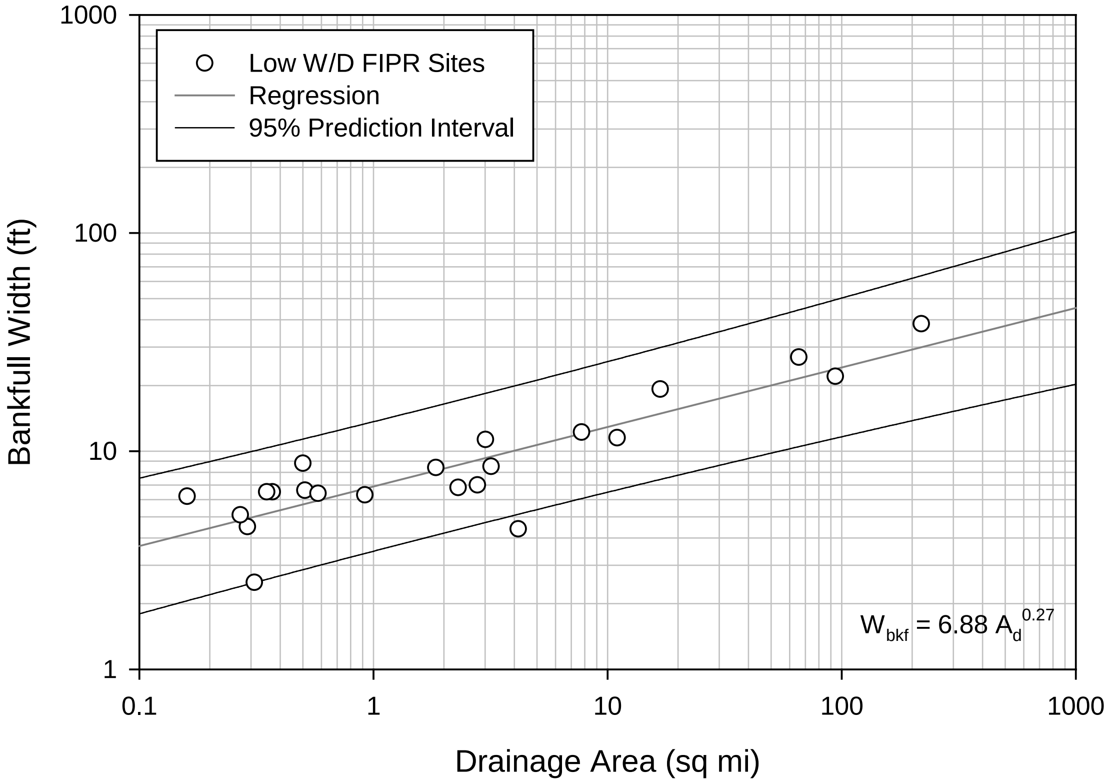


Figure 5.8. Bankfull Width Versus Drainage Area for E5 Blackwater Streams.

Bankfull Thalweg Depth

The relationships for bankfull thalweg depth as a function of drainage area for blackwater systems and as a function of bankfull discharge for karst systems are shown in Figures 5.9 and 5.10. Power function regression equations, corresponding coefficients of determination (R^2), and sample size are:

$Dtw_{bkf\text{-}blackwater} = 1.31\ A_d^{0.23}$ $R^2 = 0.76$ n = 44 (9)
$Dtw_{bkf\text{-}karst} = 0.65\ Q_{bkf}^{0.41}$ $R^2 = 0.86$ n = 12 (10)

where Dtw_{bkf} = bankfull thalweg depth in feet, and A_d = watershed drainage area in square miles. Bankfull thalweg depth is directly related to drainage area, with 76% of variability in depth for blackwater streams explained by drainage area and 86% of variability for karst streams explained by bankfull discharge.

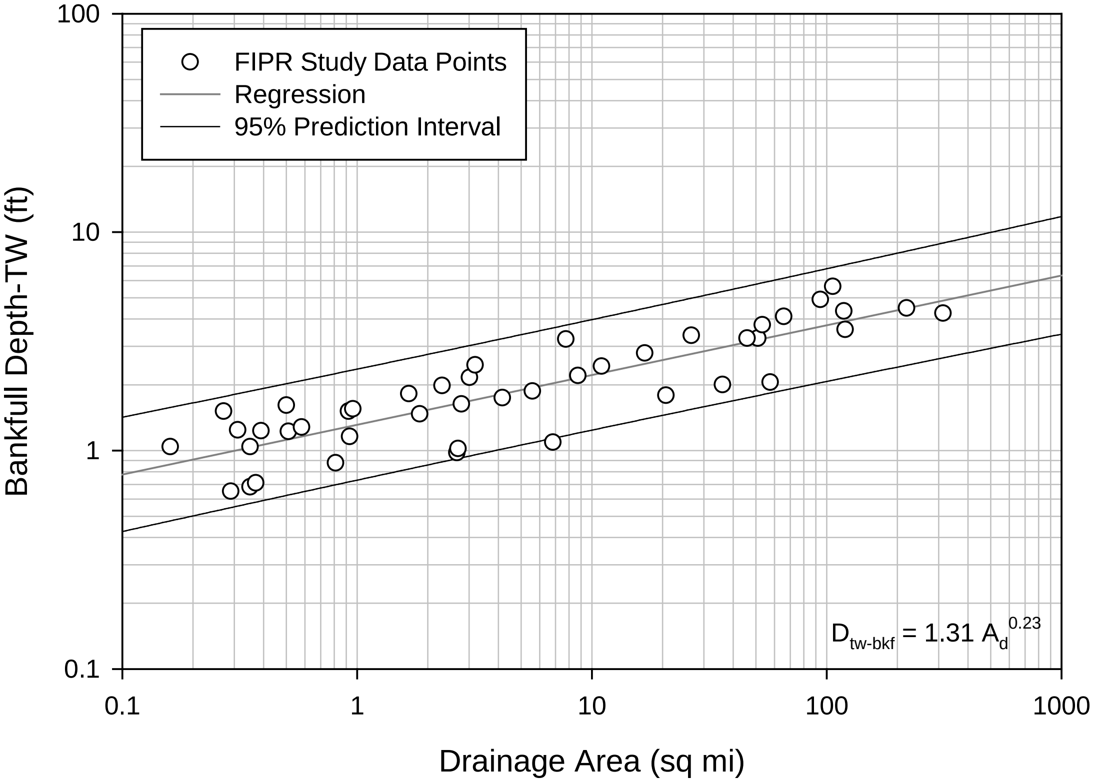


Figure 5.9. Bankfull Thalweg Depth Versus Drainage Area for Blackwater Streams.

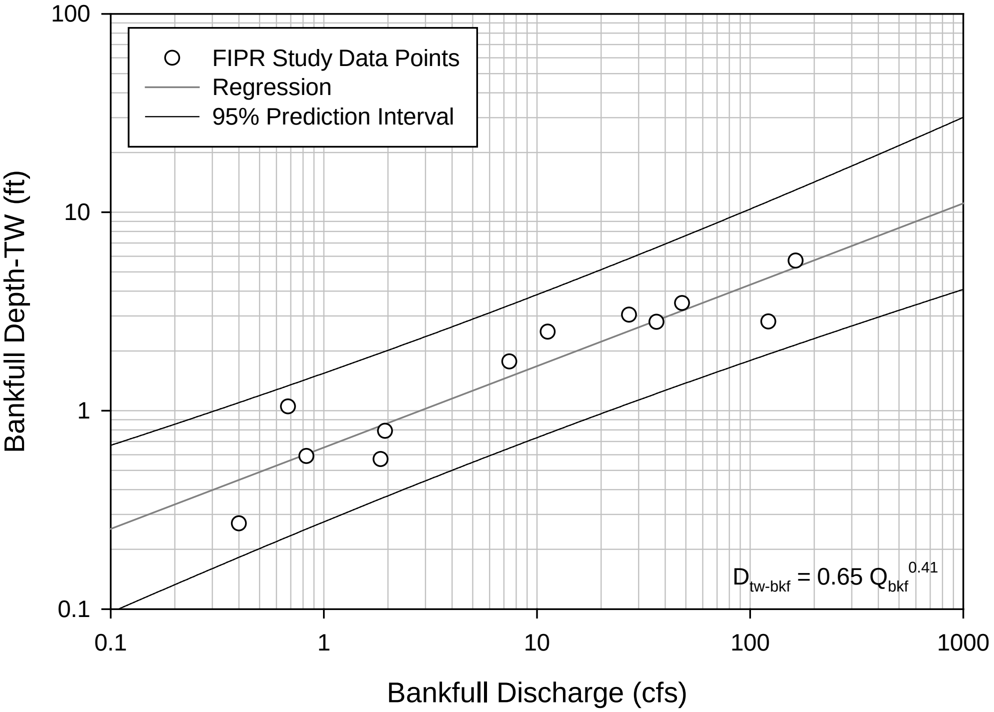


Figure 5.10. Bankfull Thalweg Depth Versus Bankfull Discharge for Karst Streams.

Relationships for bankfull thalweg depth as a function of drainage area for blackwater systems with W/D ratios greater than 12 (Rosgen C5) and less than 12 (Rosgen E5) are shown in Figures 5.11 and 5.12. Power function regression equations, corresponding coefficients of determination (R^2), and sample size are:

$Dtw_{bkf\text{-}C5} = 1.09\ A_d^{0.25}$ $R^2 = 0.77$ $n = 22$ (11)
$Dtw_{bkf\text{-}E5} = 1.45\ A_d^{0.24}$ $R^2 = 0.84$ $n = 22$ (12)

where Dtw_{bkf} = bankfull thalweg depth in feet, and A_d = watershed drainage area in square miles. Bankfull thalweg depth is directly related to watershed size, with 77% of variability in C5 stream width and 84% in E5 stream width explained by drainage area.

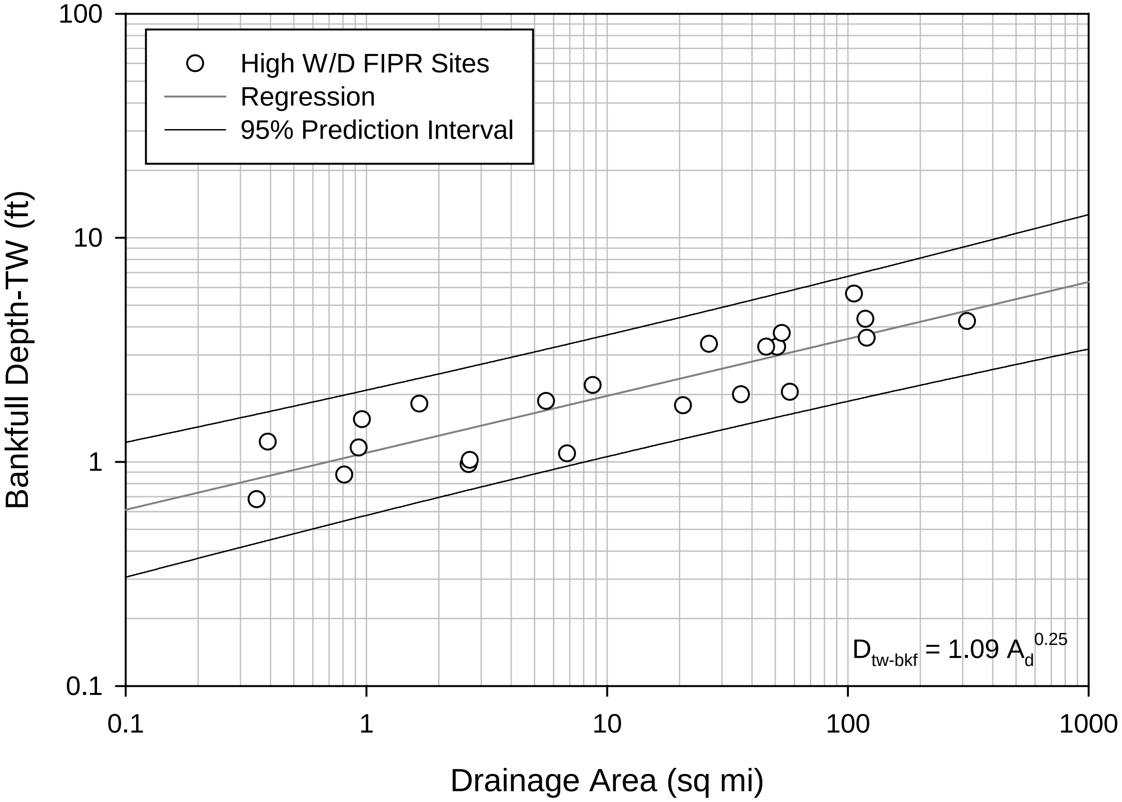


Figure 5.11. Bankfull Thalweg Depth Versus Drainage for C5 Blackwater Streams.

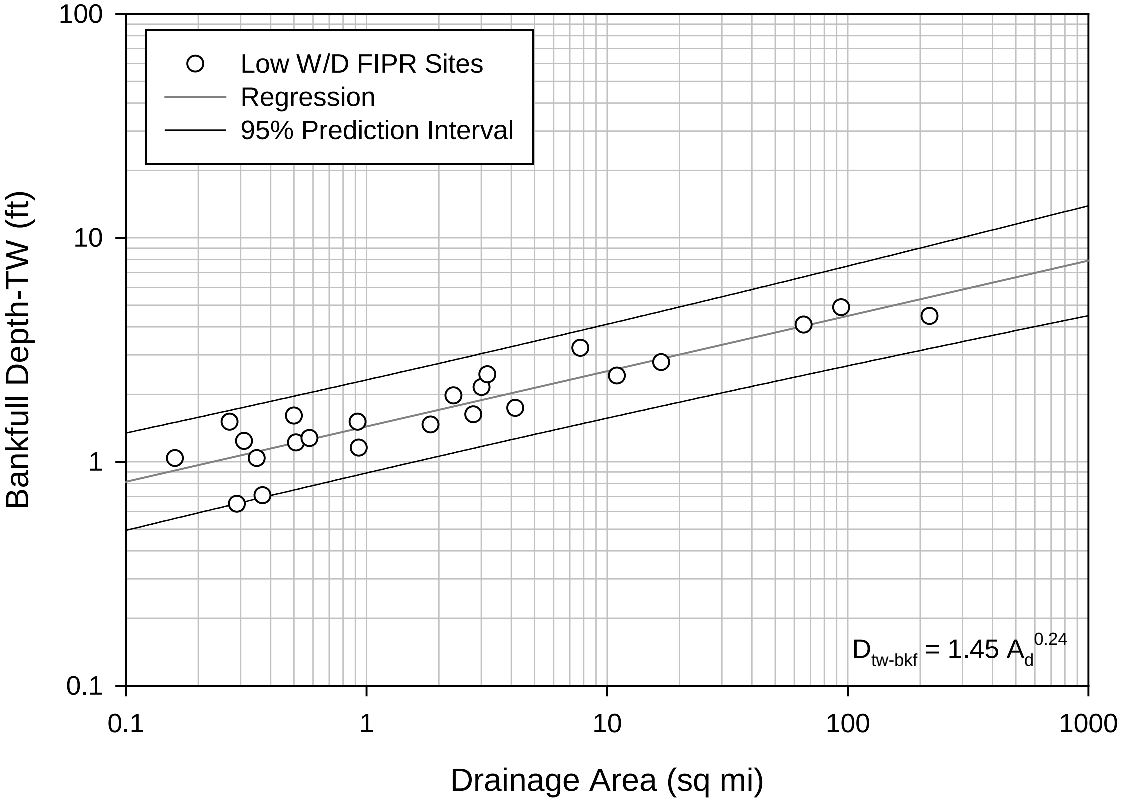


Figure 5.12. Bankfull Thalweg Depth Versus Area for E5 Blackwater Streams.

Many published regional curve sets provide average depth, calculated as the bankfull cross-section area divided by bankfull width. The average depth is therefore just an area/width index or shape factor for the channel also referred to as the "hydraulic depth" by water resource engineers. Instead, the thalweg depth reported in the regressions for this study represents a true vertical dimension at the low point in the channel cross-section and is therefore a more useful design tool. The bankfull thalweg depth reported is that which was measured and averaged at two riffles for each stream evaluated. It provides a superior and representative design metric useful for fish passage assessments. For most low-order, sand-bed streams, the thalweg depth provides a good approximation of the characteristic bed elevation for channels roughly trapezoidal in cross-section, while hydraulic depth obscures this critical information by averaging in the greater elevations of the bank slopes. Bankfull area, W/D ratios, and bank slopes should be checked to assure the overall cross-section is patterned and dimensioned properly. In our direct experience hydraulic depth adds little to nothing to the assessment as it tends to be highly variable in Florida streams (with drainage area explaining less than 60% of the variability).

Floodscape Regional Curves

Floodscape Discharge

The relationships for flood discharge as a function of drainage area for the two kinds of blackwater systems and karst systems are shown in Figures 5.13 and 5.14. Power function regression equations, corresponding coefficients of determination (R^2), and sample size are:

$Q_{flood\text{-}Flatwoods} = 11.55\ A_d^{0.86}$ $R^2 = 0.93$ n = 23 (13)
$Q_{flood\text{-}Highlands} = 5.72\ A_d^{0.81}$ $R^2 = 0.79$ n = 21 (14)
$Q_{flood\text{-}Karst} = 2.41\ A_d^{0.90}$ $R^2 = 0.92$ n = 12 (15)

where Q_{flood} = flood discharge in feet, and A_d = watershed drainage area in square miles. Flood width is directly related to drainage area, with 93% of variability in flood discharge in flatwoods streams, 79% in highlands streams, and 92% in karst streams explained by drainage area. The distinction for blackwater streams draining less than three-square-mile watersheds may be comparatively irrelevant, with greater scatter among the highlands streams in that range, and no alluvial floodplain features in either flatwoods or highlands systems. For larger drainages, the distinction becomes more physically relevant.

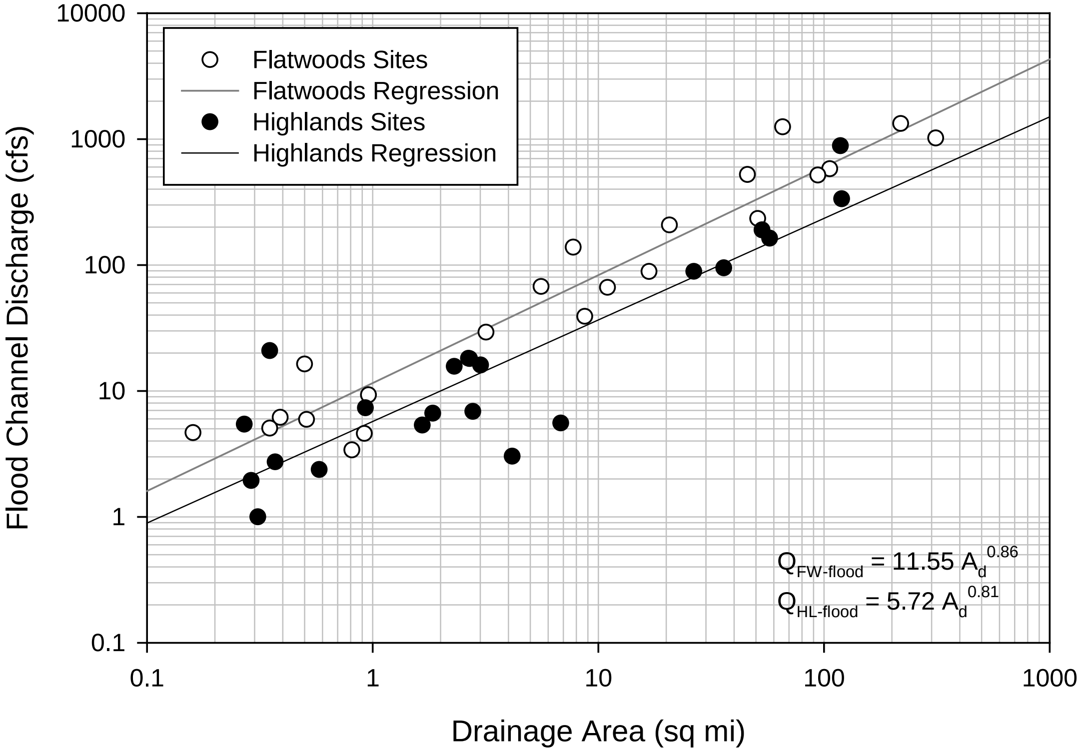


Figure 5.13. Flood Discharge Versus Drainage Area for Blackwater Streams.

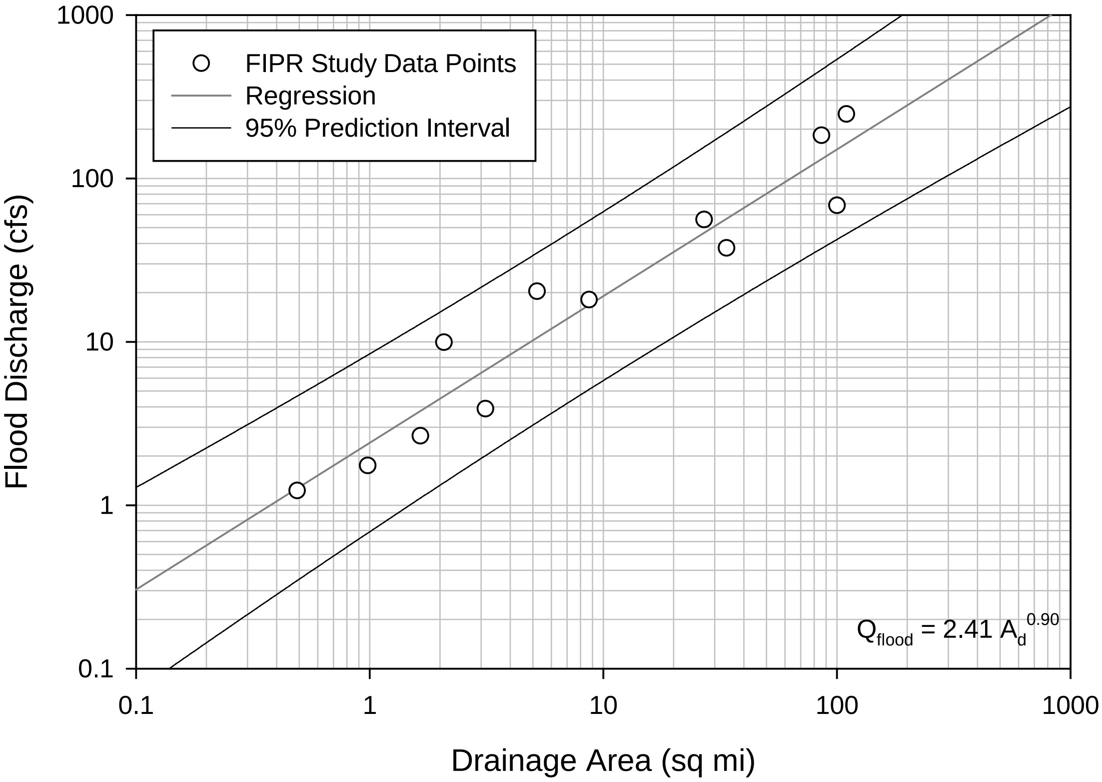


Figure 5.14. Flood Discharge Versus Springshed Area for Karst Streams.

Floodscape Width

The relationships for flood width as a function of drainage area for blackwater and karst systems are shown in Figures 5.15 and 5.16. Power function regression equations, corresponding coefficients of determination (R^2), and sample size are:

$W_{flood\text{-}Flatwoods} = 45.26\ A_d^{0.60}$ $R^2 = 0.61$ n = 23 (16)
$W_{flood\text{-}Highlands} = 11.29\ A_d^{0.67}$ $R^2 = 0.73$ n = 21 (17)
$W_{flood\text{-}Karst} = 22.96\ A_d^{0.39}$ $R^2 = 0.49$ n = 12 (18)

where W_{flood} = flood width in feet, and A_d = watershed drainage area in square miles. Flood width is directly related to drainage area, with 61% of variability in flood width in flatwoods streams, 73% in highlands streams, and 49% in karst streams explained by drainage area. It is notable that the floodplain R^2 values are less than those of the bankfull channel. This is likely due to the fact that the bankfull channel dimensions were more accurately measured, but also is attributable to the facts that bankfull channels are more fully adjustable and inherently self-organizing than the flood channels based on their smaller scale, greater concentration and duration of fluvial forces, and the fact that peninsular Florida floodplain dimensions are often associated with ancient valley formations or other conditions in addition to modern fluvial processes.

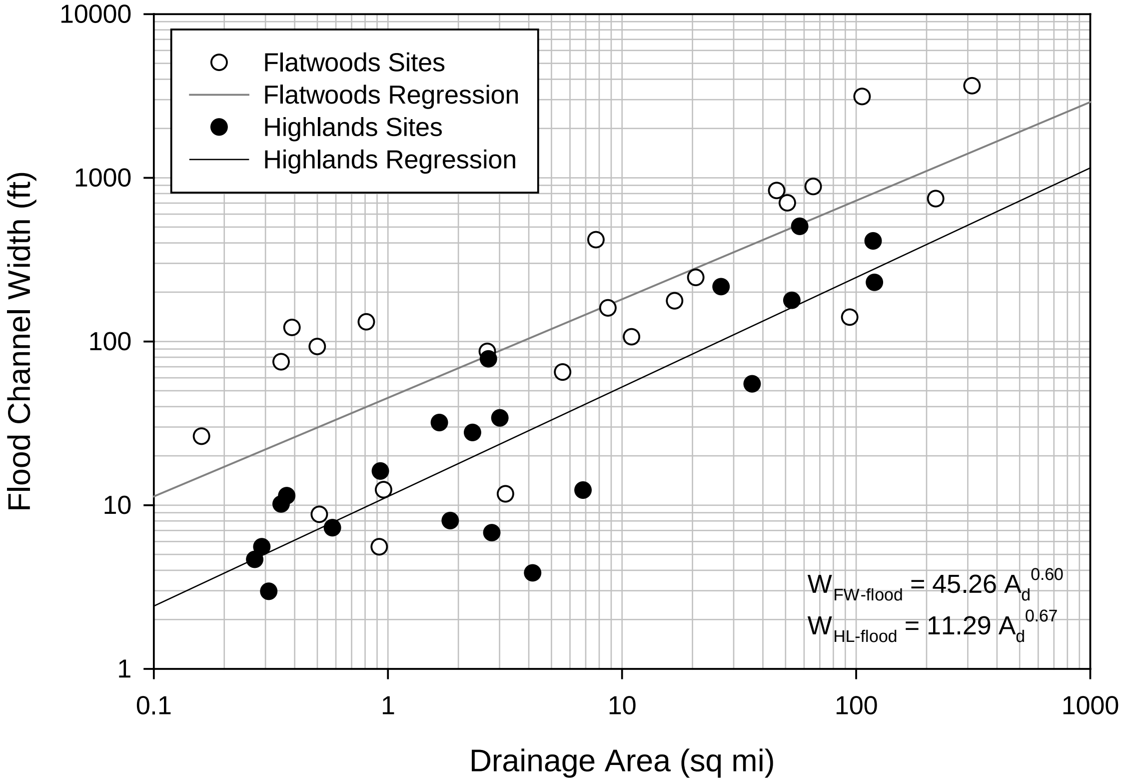


Figure 5.15. Flood Width Versus Drainage Area for Blackwater Streams.

The karst flood width relationship with springshed area is comparatively weak. This is consistent with the fact that the recharge area geography may be variably disjunct and remote from the local surficial drainage to the spring run. This, plus variability in the drainage capacity of subterranean conduits in the limestone, is likely to be creating highly variable lag times not typically present in surface water basins.

Floodscape depth regressions are greatly confounded by stream type and valley confinement. Therefore, simple linear regression of depth associated with drainage area is comparatively weak and is not provided. From a design perspective, flood discharge is the most important aspect to consider. A wide variety of floodplain width and depth configurations exist in nature for a given drainage area, so hydraulic modeling of the alluvial flood discharge is recommended to assure velocities compatible with a stable, depositional surface. Assessment of a variety of standard engineering design storms (e.g., mean annual, 25-year, 100-year floods) is also recommended.

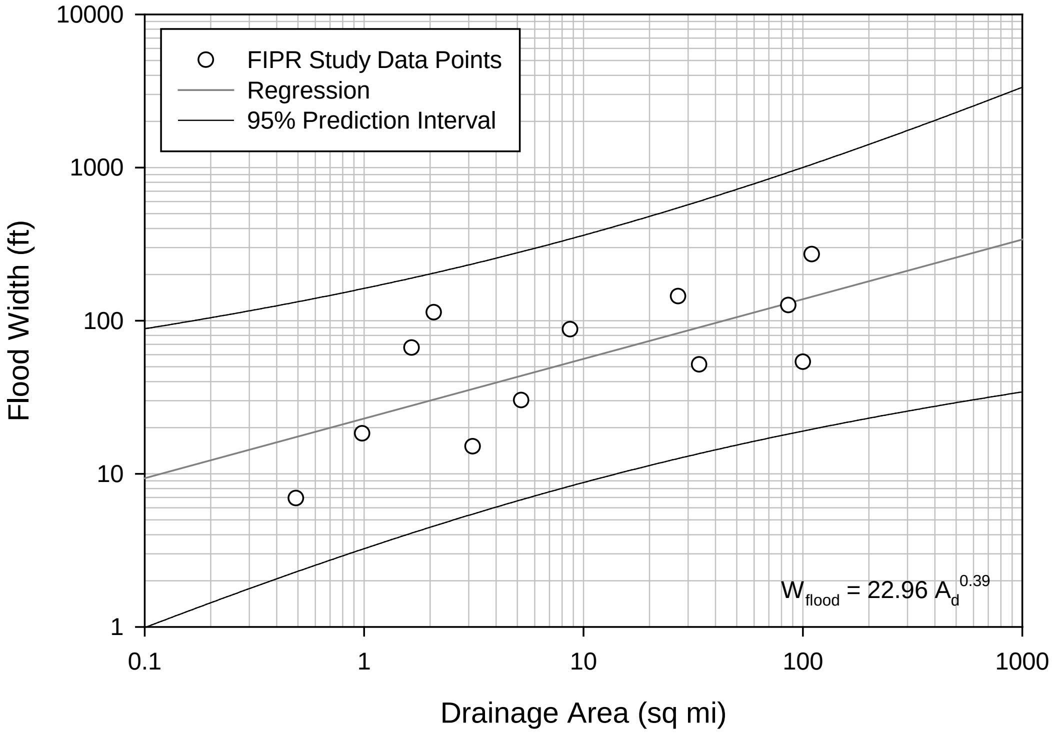


Figure 5.16. Flood Width Versus Springshed Area for Karst Streams.

Bankfull Sediment Load

Relationships for bankfull sediment load as a function of drainage area for first- and second-order blackwater systems are shown in Figure 5.17. The linear regression equation provided a better fit than the power function. Its corresponding coefficient of determination (R^2) and sample size are:

$TPD_{BKF} = 0.049 + 0.046\ A_d$ $R^2 = 0.82$ $n = 7$ (19)

where TPD = total bankfull sediment load (tons/day), and A_d = watershed drainage area in square miles. Total sediment load is directly related to drainage area, with 82% of variability in transport for blackwater streams explained by drainage area. This curve, based on only seven sites, with four collections per site, should be considered preliminary. For example, the regression, if extrapolated beyond its lower limit of data (0.4 square miles), indicates some transport occurring from a drainage area of 0 square miles (a physical impossibility). Aside from a good lesson on not extrapolating regressions beyond their data limits, this suggests room for improvement or that the relationship is not actually linear.

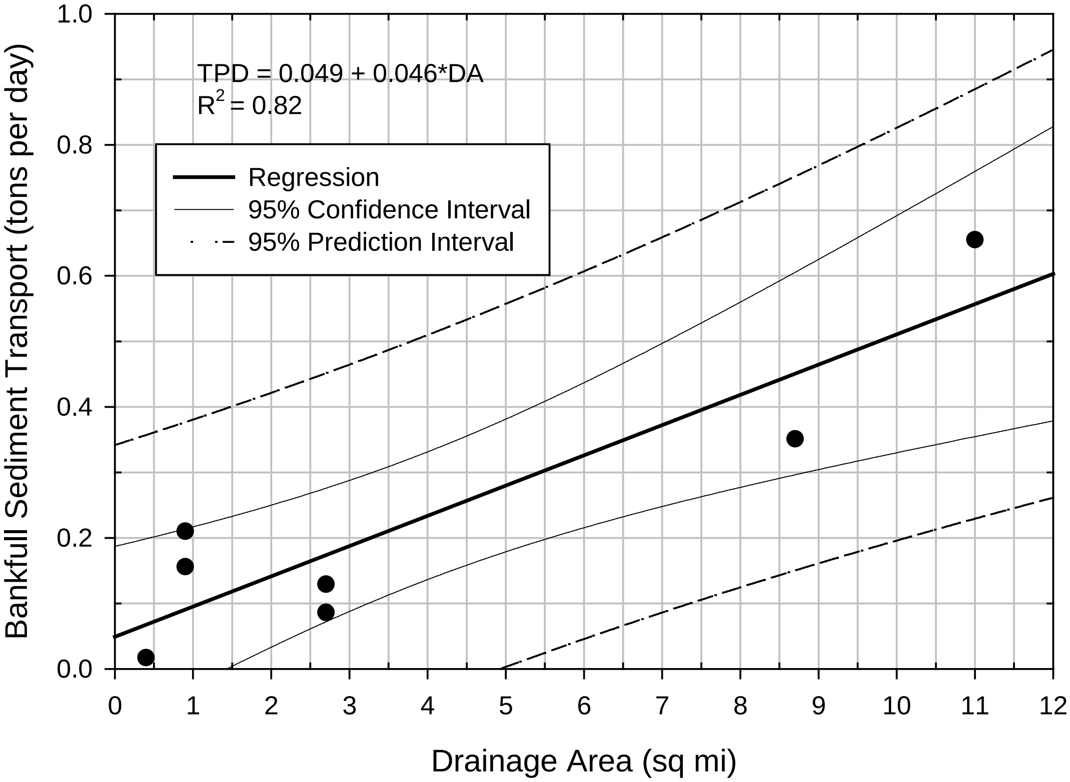


Figure 5.17. Preliminary Sediment Load Versus Drainage for Low Order Streams.

Sediment yield averaged 20.3 tons per year (tpy) per square mile (range 12.4 to 30.4 tpy/sq mi) (Table 5.3). The sites averaged 12.3 tpy/sq mi of suspended load (range 9.6 to 16.3), with an average suspended sediment concentration of 7.8 mg/L (range 4.8 to 12.4). Thus, an average of 64% of the total load was transported as suspended sediment (range 41% to 79%) with the remainder as bedload. Most of the transported material by mass was sand, with median grain size averaging 0.23 mm among sites (range 0.20 to 0.28 mm).

Table 5.3. Sediment Transport and Yield Data for Low-Order Streams.

Site Name	Phys.	DA (Sq. Mi.)	D_{50} (mm)	Bankfull Load (tpd)	Average SSC (mg/L)	Average Total Yield (Tpy/Sq. Mi.)	Average Suspended Yield (Tpy/Sq. Mi.)	Percent Total Yield as Suspended
Lower Myakka UT 3	FW	0.4	0.20	0.02	10.7	--	--	--
East Fork Manatee UT 1	FW	0.9	0.20	0.16	6.5	--	--	--
Lower Myakka UT 2	FW	2.7	0.20	0.09	7.9	12.4	9.6	78
Grasshopper Slough	FW	8.7	0.24	0.35	6.2	15.8	10.7	68
Morgan Hole Creek	FW	11.0	0.23	0.66	12.4	20.5	16.3	79
Tiger UT	HL	0.9	0.25	0.21	4.8	22.4	12.3	55
Jack Creek	HL	2.7	0.28	0.13	6.3	30.4	12.5	41
AVERAGE			0.23	0.23	7.8	20.3	12.3	64

DA = drainage area.
D_{50} = median grain diameter.
Phys. = basin physiography.
FW = flatwoods, HL = highlands.
SSC = suspended sediment concentration.

Differences Among Florida Regions

Metcalf and others (2009) published regional curves for northeast Florida and northwest Florida (the Panhandle), including sites in Georgia and Alabama. An objective of this study was to develop regional curves for peninsular Florida, as this part of the state is quite different in terms of its physiography, geology, rainfall and evapotranspiration patterns. For example, the Panhandle receives 20% more rain on an average annual basis than the peninsula, which almost doubles the mean annual discharge. Panhandle rainfall is more equitably distributed throughout the year with proportionately more winter precipitation due to large frontal-based storms coming off the mainland, while the peninsula receives proportionately more summer precipitation due to convective storms occurring from the convergence of Gulf of Mexico and Atlantic Ocean sea breezes (Henry 1998). Northeast Florida receives similar to slightly larger annual rainfall volumes versus the peninsula, has rain distributed more equitably throughout the year, and does not have the same intensity and duration of maximum seasonal moisture deficits caused by low rainfall during relatively high potential evapotranspiration (pET) in the spring as the peninsula. This means that peninsular watersheds have an even greater difference in the potential between wet- and dry-season discharges than the rainfall variability among the regions alone would dictate.

Peninsular Florida is topographically low and comparatively young since its last sea level submergence. The drainage network consists not only of streams but includes variable frequencies of in-line lakes, springs, and wetlands. Conversely, the drainage networks on the continental land masses tend to lack such in-line punctuations and are inherently more dendritic where the karst is thickly mantled by clay layers under surficial sands. This leads to what appears to be higher drainage densities where streams are found off the peninsula. These differences in climate, relief and network patterns set up the peninsula to have less sediment yield and transport than the other two regions. Based on these differences in sediment and water delivery regimes, differences in bankfull discharge and dimensions would seem likely. In all three regions, areas with karst exposures have diffuse, often internally drained networks.

When Metcalf and others' (2009) Northwest and Northeast Florida bankfull regressions were compared through multivariate regression testing to peninsular Florida bankfull regressions for blackwater streams, the following results were found (based on use of $p < 0.05$ as the threshold for describing a difference):

- Bankfull discharge increases at the same rate (regression slope) with increasing drainage area for all three Florida hydrophysiographic regions, however each region consistently differs in the magnitude (regression constant) of such discharge (Figure 5.18, Table 5.4). Northwest Florida streams had the greatest bankfull discharge while peninsular Florida had the least. This result is in accord with the rainfall volume and pET differences among the regions.
- Cross-section area magnitude differed for all regions and was greatest for Northwest Florida streams while peninsular Florida had the least. Cross-section area increased with drainage area at the same rate for the two northern regions, but the peninsula increased at a smaller rate (Figure 5.19, Table 5.4). In other words, Northwest Florida streams were generally larger than those of the other two regions, while those of peninsular Florida were the smallest. This pattern is consistent with the regional differences in stream flow.
- Bankfull width increased at the same rate with increasing drainage area among the three regions. The Northeast and peninsular regions exhibited statistically similar width magnitude with drainage area, but the Northwest streams were consistently wider than those of the other two regions (Figure 5.20, Table 5.4).
- Bankfull hydraulic depth (or average cross-section depth) differed among all three regions, with Northwest streams being the deepest and peninsular streams the shallowest. Northeast Florida streams deepened at a steeper rate with increasing drainage area than those in the other two regions (Figure 5.21, Table 5.4). This regression slope difference may indicate differences in sediment transport capacity along the drainage networks of Northeast Florida versus the other two regions.

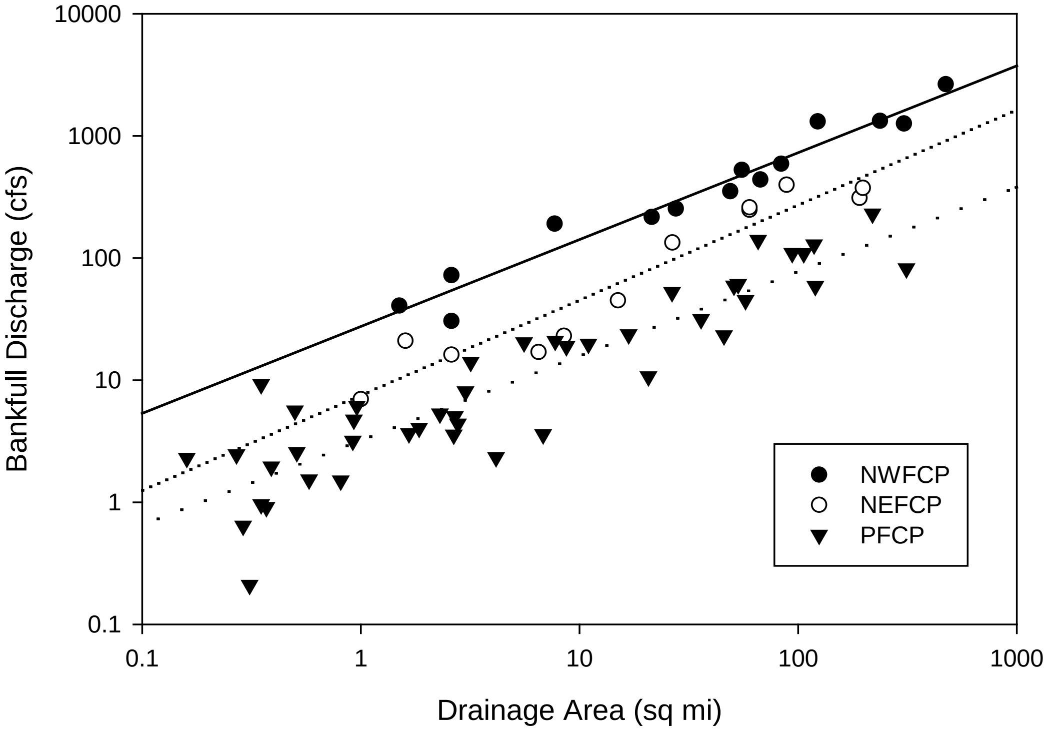


Figure 5.18. Comparison of Bankfull Discharge Regional Curves in Florida.

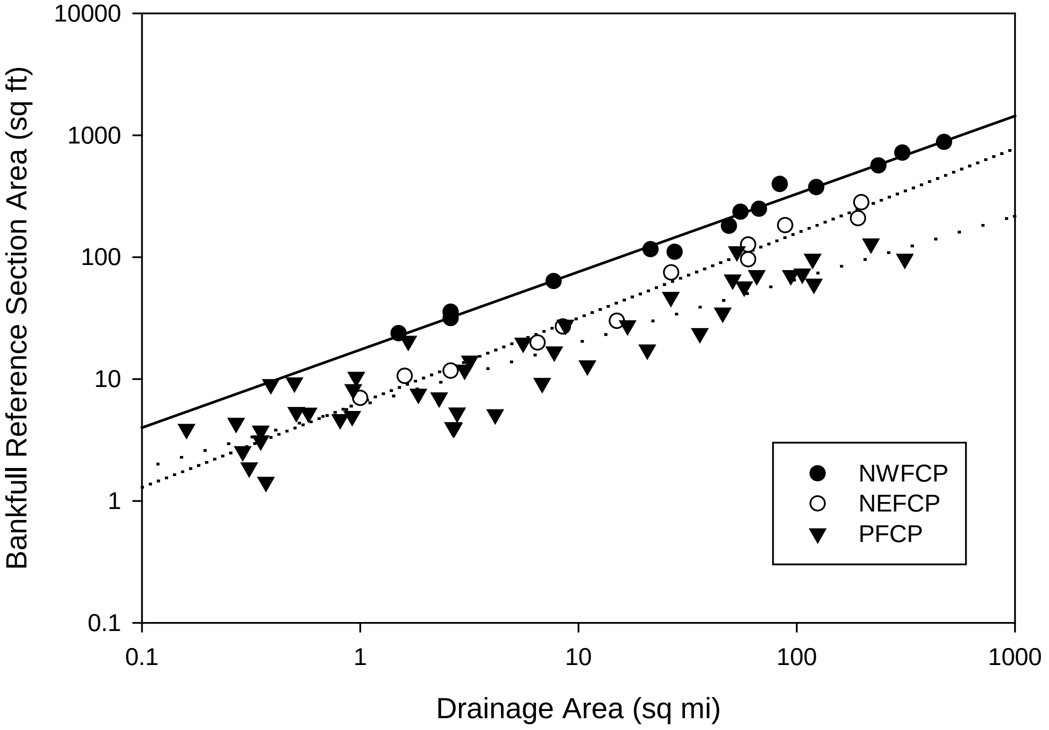


Figure 5.19. Comparison of Bankfull Area Regional Curves in Florida.

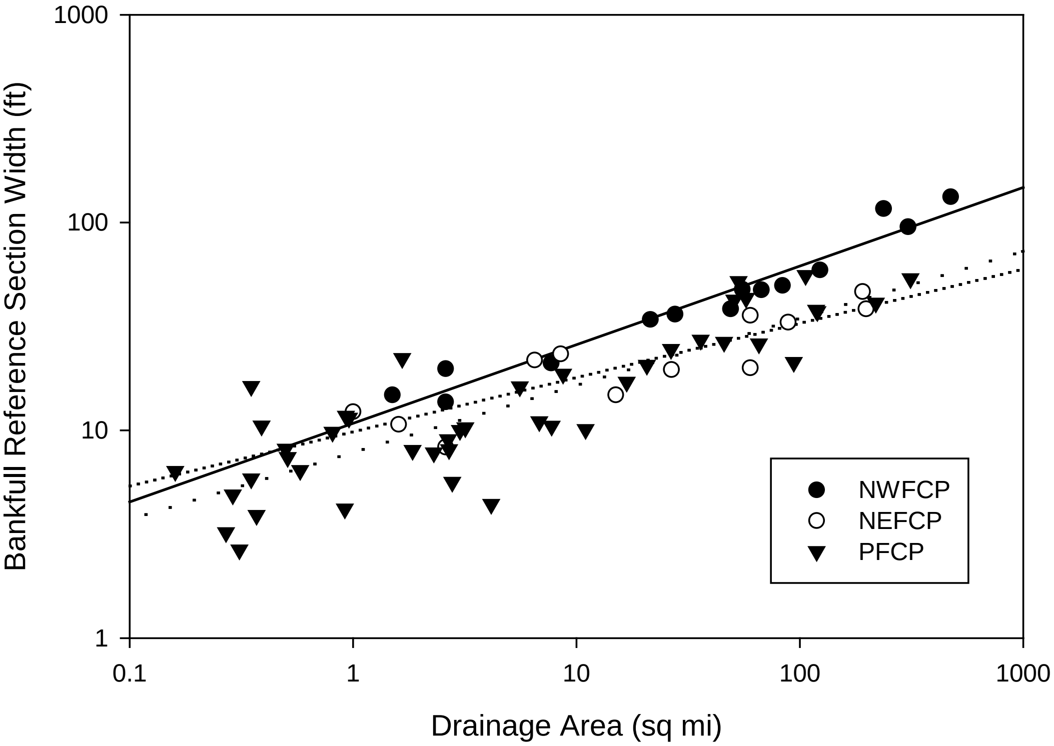


Figure 5.20. Comparison of Bankfull Width Regional Curves in Florida.

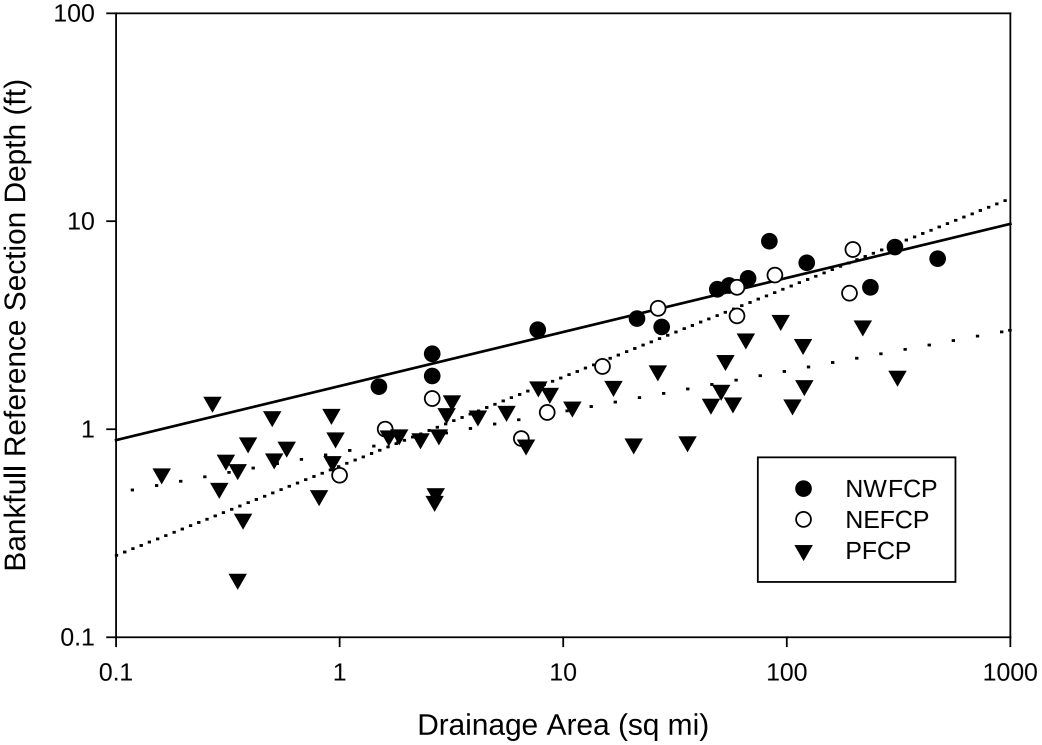


Figure 5.21. Comparison of Bankfull Hydraulic Depth Regional Curves in Florida.

Table 5.4. Pairwise Comparisons of Regional Curves for Florida Regions.

Variables		B Constant			p > F			B Slope			p > F		
IV	DV	NW	NE	P	P NE	P NW	NW NE	NW	NE	P	P NE	P NW	NW NE
Log(DA) ctr	Log(Q)	2.214	1.726	1.265	0.000	0.000	0.000	0.712	0.776	0.657	0.189	0.512	0.557
	SE------->	0.075	0.073	0.038	Sig	Sig	Sig	0.083	0.090	0.040	NS	NS	NS
Log(DA) ctr	Log(XSA)	1.937	1.566	1.361	0.001	0.000	0.000	0.639	0.692	0.486	0.007	0.029	0.549
	SE------->	0.062	0.060	0.031	Sig	Sig	Sig	0.068	0.073	0.033	Sig	Sig	NS
Log(DA) ctr	Log(W)	1.446	1.277	1.277	0.994	0.003	0.013	0.379	0.260	0.292	0.624	0.162	0.140
	SE------->	0.055	0.053	0.028	NS	Sig	Sig	0.060	0.055	0.029	NS	NS	NS
Log(DA) ctr	Log(D)	0.490	0.290	0.084	0.000	0.000	0.000	0.260	0.428	0.195	0.001	0.271	0.032
	SE------->	0.053	0.051	0.027	Sig	Sig	Sig	0.059	0.063	0.028	Sig	NS	Sig

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

NW = Northwest FL CP, NE = Northeast FL CP, P = Peninsular FL CP.

DA = drainage area, Q = bankfull flow, XSA = bankfull section area, W = bankfull width, D = bankfull hydraulic depth.

All of the Northwest Florida streams used in the Metcalf and others (2009) regressions met our inclusionary criteria, while six in Northeast Florida did not. These were typically draining extensive areas under cotton cultivation and other tillage in Georgia, usually with large center-pivot irrigation systems. One was affected by local urban drainage systems. The streams draining the Georgia tilled soils had statistically significantly greater W/D ratios and more widely distributed floodplain alluvium than systems in Florida without such tillage, suggesting larger amounts of watershed sediment yield (AMEC 2013). For that reason, we suggest using some caution when applying the Northeast Florida curves to Florida's areas not under such tillage, especially to systems draining less than 10-square-mile watersheds (the range where the most significant differences based on land use seemed to occur).

Also, the Northwest Florida streams sampled by Metcalf and others (2009) only included sites draining highlands basins, lacking streams of the flatwoods. AMEC (2013) found that flatwoods streams occur, but are comparatively uncommon in that region. They appear to have different alluvial surfaces than their highlands counterparts (e.g., very rough floodplains with pronounced alluvial ridges and chutes) and may also differ in their channel dimensions and patterns. Without further verification, it does not seem prudent to extrapolate use of those curves to flatwoods basins in that region.

CONCLUSIONS

As previously mentioned in the methods section, bankfull channel geometry parameters were based on the average value of the two smallest cross-sections (based on cross-sectional area) surveyed during the reference reach survey conducted at each study site; however, six detailed cross-sections were surveyed for each stream, and the range of variability within bankfull indicator parameters among cross-sections could be highly variable. For example, the range of variability among cross-sections (maximum bankfull measurement minus minimum bankfull measurement) was as high as 187 square feet for bankfull area at Horse Creek near Arcadia, 50 feet for bankfull width at Tiger Creek near Babson Park, and approximately 3 feet in bankfull depth at Horse Creek near Arcadia. Further, Wolman (1955) recognized that local variations in cross-sectional form are a possible source of scatter in downstream hydraulic geometry relations. Clearly, the cross-section chosen for development of the regional curves can have a significant effect on the ultimate regression. The two smallest cross-sections were thus ultimately chosen and their parameters averaged for use in development of peninsular Florida regional curves based on previous work by USGS and based on the notion that the smallest cross-section represents the stream's hydraulic control (Chaplin 2005).

Return intervals were estimated using annual maximum series from a Log Pearson Type III distribution and these characteristically approached a value of 1 year (ranging from <1.01 to 1.4), which is more frequent than the average 1.5-year return interval often reported in the literature (Dunne and Leopold 1978; Leopold 1994), but consistent with findings from other southeastern United States Coastal Plain studies (Sweet and Geratz 2003, Metcalf and others 2009). These findings have important implications, as they indicate that peninsular Florida streams are overtopping their banks more frequently than “textbook” regions. Because annual maximum series cannot determine return intervals of less than one year, partial duration frequencies were calculated. Partial duration series assessments indicated that perennial streams on the peninsula typically achieve bankfull discharge, on average, about 20 times per year. Non-perennial streams typically equaled or exceeded bankfull discharge about four times per year on average.

Peninsular Florida streams differed in their bankfull discharge, cross-sectional area, and depth from the Northwest and Northeast regions, and in bankfull width from the Northwest region. Peninsular streams also differed in their rate of change in cross-section area, having the lowest such rate among the regions. Instead, peninsular streams carry much of their wet-season discharge in their floodplains, leading our team to develop floodplain curves. In aggregate, these differences confirm that Florida has at least three distinctly different hydro-physiographic regions that have substantial effects on watershed and channel geomorphology associations. Most of the differences are consistent with the variability among regions in their rainfall and runoff volumes and seasonal water deficits. The peninsula generates the lowest bankfull volumes and has the smallest channels.

Northeast streams differed in their rate of change in depth with drainage area from the other two regions, with a greater rate. The differences in sensitivity (regression slope) of channel depth with drainage area for the Northeast region may be an artifact of the differences in rural land-use patterns in that region. Several of the smallest Northeast region’s drainages were under heavier cultivation than other streams in the study and their stream valleys had a larger amount of sandy alluvium. This sand may have been excessively sourced to the valley from eroding farms, thus sedimenting and shallowing the lower-order Northeast streams. We observed three headwater streams in Northeast Florida without such cultivation in their watersheds and these sites were all narrower and deeper than the Metcalf and others (2009) regressions would indicate.

In this study, regional curves were developed for peninsular Florida streams. Measurements collected during reference reach surveys at 56 study sites and gage data obtained from the USGS and measured during this study were used to determine bankfull discharge and channel geometry (cross-sectional area, width, and maximum depth). These parameters were then plotted against drainage area (or against bankfull discharge in the case of karst systems) to develop regional curves (Figures 5.1 through 5.12). Table 5.2 summarizes discharge and channel geometry data used in peninsular Florida regional curve development. Equations 1 through 12 summarize power function regression equations, corresponding coefficients of determination (R^2), and sample sizes for various bankfull parameters versus drainage area or bankfull discharge.

Bankfull parameters and discharge varied directly with drainage area. Data were further analyzed to determine whether significant differences exist between streams draining different physiographies (flatwoods, highlands, karst) and geographies (northern versus southern peninsula) in terms of bankfull parameters, as these systems have different water delivery systems: runoff dominated for the flatwoods, groundwater influenced for the highlands, and groundwater dominated for karst. The bankfull channel did not vary significantly between flatwoods and highlands sites, even though these physiographies have much different water supply systems and flow regimes, with the flatwoods sites exhibiting much flashier discharges. Karst system channel size was more dependent upon bankfull discharge than drainage area, thus bankfull dimensions for these sites were plotted versus bankfull discharge. Bankfull discharge and channel area did not vary between sites in the northern versus southern peninsula.

Bankfull discharges in 20 peninsular Florida sites gaged by government agencies were equaled or exceeded for an average of 24% of the gage record for perennial non-karst streams, indicating that bankfull discharge is a common occurrence and the floodplain could be viewed as a vegetated wet-season channel. Eight first- and second-order blackwater streams gaged for this study, seven of which were not perennial, equaled or exceeded bankfull discharge for 9% of the record, and 19% of the flow days, also indicating that even for non-perennial systems bankfull discharge is commonly exceeded. Regional curves were thus developed for the active floodplain in addition to the bankfull conditions (Figures 13 through 16, Equations 13 through 18).

Sediment transport was measured in seven of the eight low-order streams gaged for this study. This work was exploratory, garnering up to four samples per site bracketing bankfull discharge. Bankfull sediment transport was a linear function of drainage area (Figure 5.17), with an average of two-thirds of the total sediment yield being transported as suspended sediment versus bedload. Average yields of 20 tpy/sq mi and suspended sediment concentrations averaging 7.8 mg/L were of similar order of magnitude, but nevertheless lower than the median effective discharge yields of 47 tpy/sq mi and suspended sediment concentrations (SSC) of 11.5 mg/L reported for the Southern Coastal Plain ecoregion (Simon and others 2004). The Southern Coastal Plain spans an area subsuming the entire PFCP and NEFCP, plus much of the NWFCP and the entire Georgia coastal plain. This suggests that the PFCP low-order streams generate some of the lowest yields and SSC within the region. Since the Southern Coastal Plain is the lowest yielding region in the United States, this makes the PFCP systems perhaps the lowest yielding streams in the country. For comparison, coastal plain ecoregions centered along the Texas Gulf, the mid-Atlantic seaboard from South Carolina to Maryland, and the New Jersey pine barrens produced median SSC ranging from 22 to 363 mg/L, with yields ranging from 151 to 1540 tpy/sq mi (Simon and others 2004).

This result is consistent with peninsular Florida's densely vegetated landscapes with nearly year-round growing seasons stabilizing inherently low-relief topography, often punctuated with a deranged drainage network with sporadic to numerous in-line waterbodies that can function as sediment traps. Undisturbed Florida watersheds and valleys effectively resist erosion and retain much of the transported soil and sediment in alluvial floodplains and in-line waterbodies. Vegetative controls, in concert with seasonal flow regimes, contribute to comparatively small open channels flanked by larger heavily vegetated wet-season channels at higher elevation. This outcome places peninsular Florida streams closer in concept to lowland tropical flood-pulse streams with a normal-flow open channel and a floodplain wet-season channel versus most temperate North American streams with more sporadic and short-duration floodplain discharge. In Florida, the stream is often more correctly viewed as a riverine landscape consisting of a two-stage channel system (with bankfull and flood channels) as opposed to focusing solely on the bankfull channel.

Because the physical environment largely controls species composition and abundance of stream-dependent fauna (Allan and Castillo 2007, Gordon and others 2004), restoring stream channels and their active floodplains to dimensions fitting watershed conditions is a high priority. The regional curves were developed to better inform practitioners attempting to do so.

CHAPTER 6
IN-LINE WATERBODY TRANSITIONS

INTRODUCTION

Peninsular Florida streams often occupy deranged networks, whereby the channel network is routinely punctuated by non-fluvial and non-alluvial waterbodies such as lakes, wetland depressions, sloughs, and seepage slopes. Transitions between in-line waterbodies and the streams connecting them are little studied, which is unfortunate because these junctions can offer significant control on the drainage characteristics and hydroperiod of the in-line waters and the water flow and sediment transport of the stream channels. Since the 1930s, many chains-of-wetlands have been ditched through such transitions, greatly altering their form and function. The result has been a homogenization of the longitudinal habitats, turning the chain into a continuous, over-dimensioned channel variably flanked by wide and narrow wetlands of diminished hydroperiod. This contrasts with the original pattern of alternating energy-dissipating depressions with longer hydroperiods linked together by small, energy-focusing channels with seasonally to erratically pulsed flow patterns. The pre-disturbance conditions represent greater longitudinal aquatic habitat complexity along the valley and greater complexity in hydraulic conditions as well.

This research aims to provide a descriptive library of intact sites with natural and common transitions. Unditched reference sites can be uncommon on many rural Florida properties, rendering the availability of these descriptions quite valuable to those interested in creating or restoring natural geomorphic and vegetative analogues in the landscape in lieu of creating potentially overly simplistic or artificial control structures.

Several community types are described and their geomorphology was measured by detailed ground survey as part of the description. A variety of upstream and downstream junctions were measured. Most of the focus was on first- and second-order streams draining less than four-square-mile watersheds because these systems have been very heavily altered during the last few decades and they once comprised the most common stream and interconnected wetland sequences in the landscape. Several kinds of transitions were examined, including the upstream and downstream connections between depressional waterbodies and streams; the upstream and downstream connections between streams and in-line seepage slopes; an alternating slough and stream complex; and a junction between a chain-of-wetlands stream outlet channel with a larger stream channel. Each of these transitions appeared to be representative of conditions observed in the many intact landscapes we observed for this body of research, but we caution that greater variability may be present, and that the sites measured simply represent a series of case studies that serve as a starting point of discovery for the conditions of low-order stream and in-line waterbody transitions.

METHODS

Eleven transition sites were selected from among the 56 streams observed for this study. The sites were selected from among the non-karst watersheds and were restricted to first- and second-order streams. Transitions located upstream or downstream of the stream reaches surveyed for this study were examined for study inclusion. Transitions were selected to include downstream and upstream connections between streams and wetland depressions, seepage slopes, and sloughs. Streams met the general definition used for this study, with a continuous, single-thread channel consisting of well-defined banks and a dominance of inorganic alluvial bed materials. Wetland depressions included fully vegetated doline features (generally ovoid or circular depressions) lacking an unvegetated open channel and dominated by organic bed materials. Sloughs were distinguished from stream channels based on the presence of organic substrates as the dominant bed material and presence of wetland vegetation across most of the channel. Seepage slopes were defined as systems that lacked continuous channels with well-defined banks and were dominated by wetland plants known to be common associates of groundwater discharges, such as various species of bay trees (e.g., loblolly bay, sweetbay) or cutthroat grass growing on non-alluvial soils with significant organic material (e.g., muck, peat, mucky sand, sandy muck).

Topographic survey utilized a Leica Total Station and consisted of variably spaced transects running perpendicular to the valley's flow-line, situated about 20 to 40 feet apart. Transects were placed within the non-stream waterbody, across the entire transitional area, and within the stream channel. The typical survey involved about 20 such transects, spanning longitudinal distances on the order of several hundred feet. When nearby, the transition survey was tied to the same benchmarks as the previous stream channel survey and was appended to it. Surveys were conducted during the wet season and most streams were flowing at the time of survey. The present water line was surveyed along selected transects.

Some transects spanned the upland-wetland ecotone along the valley hillslope and were a few dozen to several hundred feet long. Stations were typically surveyed 5 to 50 feet apart along each transect, depending on the apparent slopes in the survey area. Thalweg, top-of-bank, islands/hummocks, and bottom-of-bank breaklines were surveyed where encountered. Ecotones were also selectively surveyed to supplement the basic geomorphic information collected along the transects. Ecotones included the upland/wetland boundary and the boundaries between distinctly different wetland types when present.

ArcGIS 9.3 was used to create a gridded land surface representing the survey area on 0.1 foot vertical interpolations. First a triangular irregular network (TIN) was created from the survey point data. The surveyed breaklines were used to refine the TIN around the channel margins. Half-foot contour intervals and a DEM using 0.1 foot vertical increments were derived from the TIN surface. The GIS was attributed with the ecotone and present water level point data. The DEM, half-foot contours, present water level point data, and ecotone point data were used to derive the locations, elevations and distances necessary to calculate slopes and dimensions of transition and waterbody features.

RESULTS AND DISCUSSION

Zones of Confidence

Because a single valley can be occupied by repeatedly alternating segments of lotic systems with alluvial beds (streams) and those with vegetated/organic soil beds (wetlands), a simple predictive tool was sought to segregate valley and watershed conditions by which these kinds of waterbodies could be determined. For streams to occur, certain thresholds of tractive forces related to flowing water (such as stream power, shear stress or velocity) must occur at some combination of frequency, magnitude, and duration to create and maintain an open channel in competition with plant community colonization and resistance to erosion. Major controls on the flow regime and the concentration of its forces are strongly associated with watershed and valley characteristics. The drainage area supplies water volumes and the energy of that delivery can be concentrated or dissipated by valley width and relief.

Relationships for valley slope as a function of drainage area for blackwater and karst systems are shown in Figures 4.6 and 4.7. Power function regression equations, corresponding coefficients of determination (R^2), and sample sizes are:

$VS_{blackwater} = 0.49\ A_d^{-0.45}$ $R^2 = 0.74$ $n = 44$ (20)
$VS_{karst} = 0.28\ A_d^{-0.44}$ $R^2 = 0.70$ $n = 12$ (21)

where VS = valley slope in % and A_d = watershed drainage area in square miles.

Valley slope is indirectly related to drainage area, with 74% of the variability in valley slope for blackwater streams and 70% for karst streams associated with drainage area. It was determined that single-threaded, alluvial channels fall within a certain range of valley slope and drainage areas. The regression was developed using field surveys of valley slope at the reach scale, and the zone of confidence is the envelope curve of a larger range of data scatter created from the field measurements plus some valley slopes calculated on larger stream segments using LiDAR-derived topography (AMEC 2013). The envelope curve is similar in its capture to the 95% prediction interval limits of the regression. In other words, there is less than a 5% chance that a valley configuration outside that zone would contain a natural single-thread alluvial channel. Generally, sites below this range do not have the slope necessary to support sediment transport and tend to classify as a slough, strand or swale, while sites falling above this range are generally unstable systems. This valley slope to drainage area relationship is useful for helping to determine if ditched systems (where there is no longer any evidence of a meandering channel) could have historically been a natural stream.

The association is also likely to be process-based, related to thresholds in stream power necessary to move sandy alluvium and create shear stresses at magnitudes, frequencies and durations necessary to displace or preclude vegetation establishment in an open channel. Stream power is essentially the product of the flow magnitude (volumetric discharge rate) and the vertical distance the water drops (relief). Watershed size is a strong correlate of the long-term flow volume delivered to the valley and valley slope incorporates relief as one of two variables in its derivation (the other is length). Therefore, drainage area and valley slope serve as readily measurable surrogates for a system's latent variable of "overall stream power regime above the channel maintenance threshold." In other words, the zone of confidence provides an idea of the watershed and valley conditions necessary to deliver a meaningful threshold of power to create and maintain an alluvial stream channel. Nature provides upper and lower limits for stability. If insufficient power is provided, a diffuse to nonexistent channel system lacking a dominance of alluvial bed materials will result and if too much occurs, the valley grade and banks will erode in a progressive manner until a stable slope is achieved.

Transition Descriptions

Streams and Wetland Depressions

Six transitions between stream channels and waterbody depressions were observed. Four included waterbodies upstream of the channel and two examined streams entering in-line wetlands downstream. The in-line waterbody types included herbaceous wetlands (marshes), forested wetlands (swamps), and a small lake fringed by swamp and marsh zones. All of this group of streams were non-perennial and coursed through colluvial valleys draining small watersheds ranging from 0.4 to 2.7 square miles.

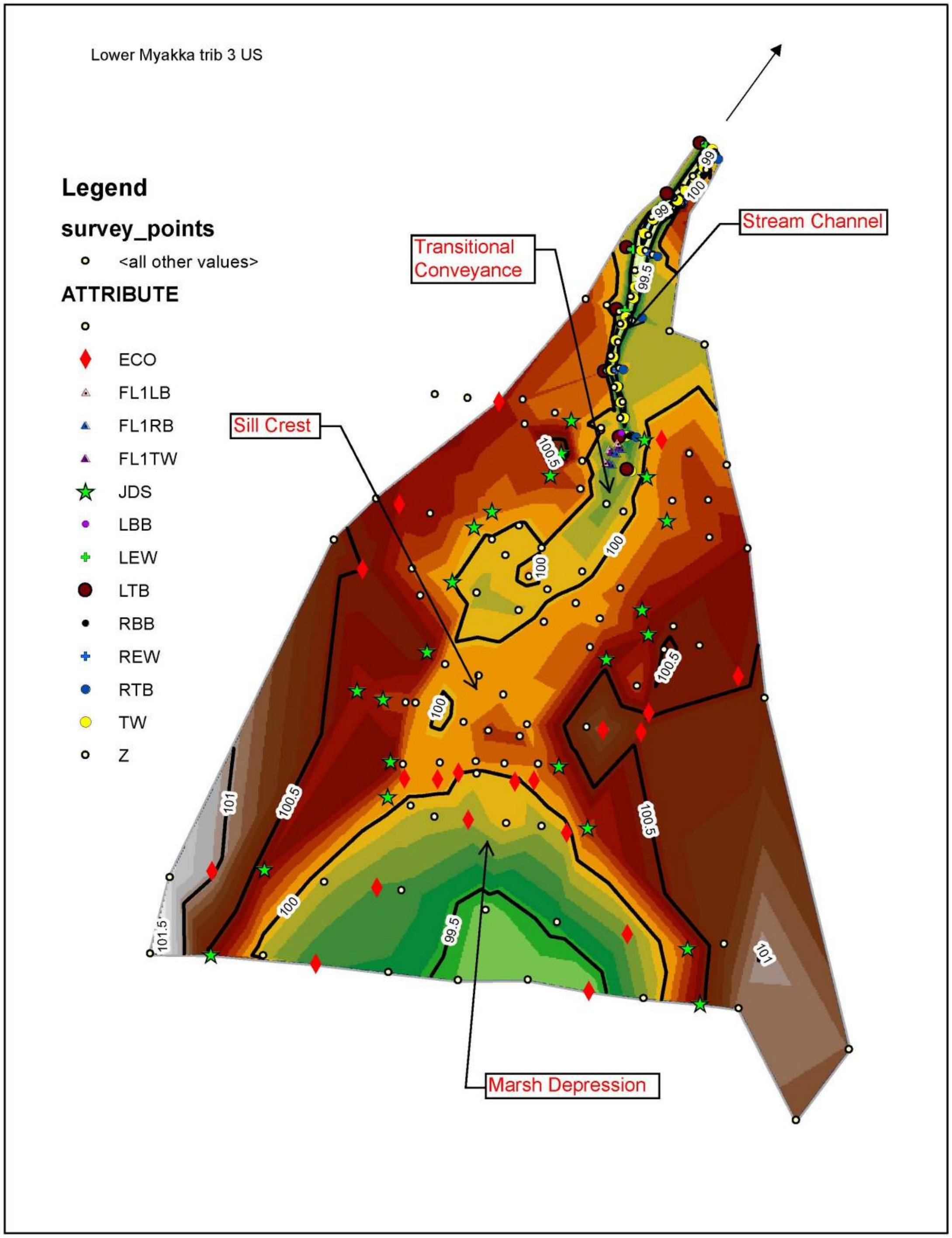
Lower Myakka River Unnamed Tributary 3. The stream channel of Lower Myakka River UT3 is an interior link within a chain of doline marshes and swamps. Dolines are shallow circular to ovoid depressions, common in the flatwoods. This link connects an upper depressional marsh to a lower depressional swamp as part of a lotic system flowing to the Myakka River. The stream segment in the study area is about 1,600 feet long and the sample location drains a 0.4-square-mile watershed. The survey extended from within the interior zone of the depressional marsh laterally to its upland edge, downstream across the transitional surface to its wetland edge, and tied directly into the Lower Myakka River UT3's stream reference reach survey, thus characterizing the transitional outlet from an in-line marsh to a FW-CV-WC stream system.

Four main surfaces comprise the survey area: (1) the in-line marsh depression, (2) an overflow sill that functions like a broad-crested weir for marsh outflow, (3) a declination from the sill forming a transitional conveyance toward the stream channel, and (4) the alluvial stream channel (Figure 6.1). Several community surfaces were apparent within this transition, including two within the marsh depression. The deeper zone of the marsh was dominated by maidencane growing on several inches of muck over fine sand. The shallower fringe of the marsh consisted of a more diverse assemblage of wet prairie plants growing in a one to four inch veneer of mucky sand over sand. These surfaces occurred on slopes declining toward the interior of the marsh. The marsh outlet was funnel-shaped in planview, and supported a hydric hammock dominated by cabbage palm and laurel oak with scattered palmetto and Fakahatchee grass. The outlet soils were fine sands with stripped matrix and a discontinuous 2-inch muck layer at the surface. Fire scars were on all the palms. The vegetation and soils indicated a seasonally wet landscape subject to frequent dry-season fires. The hydric hammock was flanked by a narrow and discontinuous live-oak and cabbage palm gallery forest in a broad expanse of pine and palmetto savanna. The stream channel formed abruptly at the downstream terminus of the unchanneled outlet hammock.

The marsh overflow consisted of a topographic crest, or sill, spanning the outlet hammock 51 feet from the marsh edge. The sill consisted of three surfaces, including a relatively level lower base in the interior flanked by two side slopes extending laterally upslope to the upland/wetland boundary. The land sloped downward longitudinally away from the sill in both the upstream and downstream directions. This means that the sill created a hydraulic threshold that controlled the elevation at which water can flow out of the marsh. Such surfaces function much like a complex broad-crested weir and the base of the sill is sometimes referred to as a “popoff” because the upstream marsh does not discharge until its water levels rise above the base surface of the sill.

The sill’s popoff elevation was about 0.4 feet below the marsh’s seasonal high water line as evidenced by the upland-wetland vegetation boundary elevation and soils. The popoff was 62 feet wide (perpendicular to the flow path) and 50 feet long (parallel to the flow path) at that elevation. The sill’s valley side slopes rose from the popoff about 0.4 vertical feet to the upland edge over distances on the order of 15 to 25 feet on either side (side slopes ranging from 42:1 to 55:1 horizontal:vertical). Thus the total sill width was about 100 feet. The transition from the popoff’s downstream edge to the upper edge of the stream channel was 166 feet long. Overall, the sill consisted of a 51-foot-long rise from the marsh to the popoff, a 50-foot-long popoff, and a subsequent 166-foot-long declination to the stream channel, giving a total transition length of 267 feet. The entire transition was rather fully vegetated without any discernible open channels.

The valley slope of the unchanneled declination was 0.24%, just falling within the zone of confidence for an alluvial channel for the 0.4-square-mile drainage area. Thus the 166-foot-long area represents the lagged distance over which the water gained sufficient momentum to carve and sustain an open single channel after exiting the rather quiescent waters of the wetland depression.



Lower Myakka UT 3

Figure 6.1. In-Line Marsh-to-Stream Transition.

Grassy Creek Unnamed Tributary. The stream channel of Grassy Creek UT is an interior link within a chain of marsh and swamp depressions and seepage slopes. This link connects an upstream depressional marsh and swamp to a lower cutthroat seep as part of a lotic system flowing to Grassy Creek, which in turn is part of a large chain-of-lakes on the Lake Wales Ridge. The stream segment in the study area is about 400 feet long, draining a 0.8-square-mile flatwoods watershed with substantial highlands inclusions. The transition survey extended from within the interior zone of the depressional wetland laterally to its upland edge, downstream across the transitional surface to its wetland edge, and tied directly into the Grassy Creek UT's stream reference reach survey; thus characterizing the transitional outlet from an in-line marsh to a FW-CV-WC stream system.

The main upstream surfaces were similar to those in the previous example (Figure 6.2). Several ecological communities were apparent within this transition, including two within the wetland depression. The wetland interior zone was dominated by loblolly bay growing on organic hummocks. The shallower marsh fringe was dominated by maidencane growing on at least 12 inches of muck. The marsh surface occurred on a slope declining toward the interior of the wetland and the loblolly bay forest occupied the deeper flat at the interior. The marsh outlet was a low-lying hydric pine strand less than 100 feet wide, dominated by slash pine with dense marsh groundcover, including Virginia chain fern, redroot (*Lachnanthes caroliana*), maidencane, and cutthroat grass. The pine strand ran the length of the stream. The outlet soils were zero to six inches of muck on fine sand. Fire scars were on all the pines. The hydric pine strand was flanked by a broad expanse of cutthroat grass flats starting at about 0.7 feet higher that the strand interior. The higher flats were vegetated with a comparatively scattered open canopy of slash pine and many dense patches of woody shrubs such as shiny lyonia, gallberry, and blueberry, with scattered palmetto on the higher ground. The vegetation and soils indicate a seasonally wet landscape with significant groundwater and surface water interaction and frequent fires.

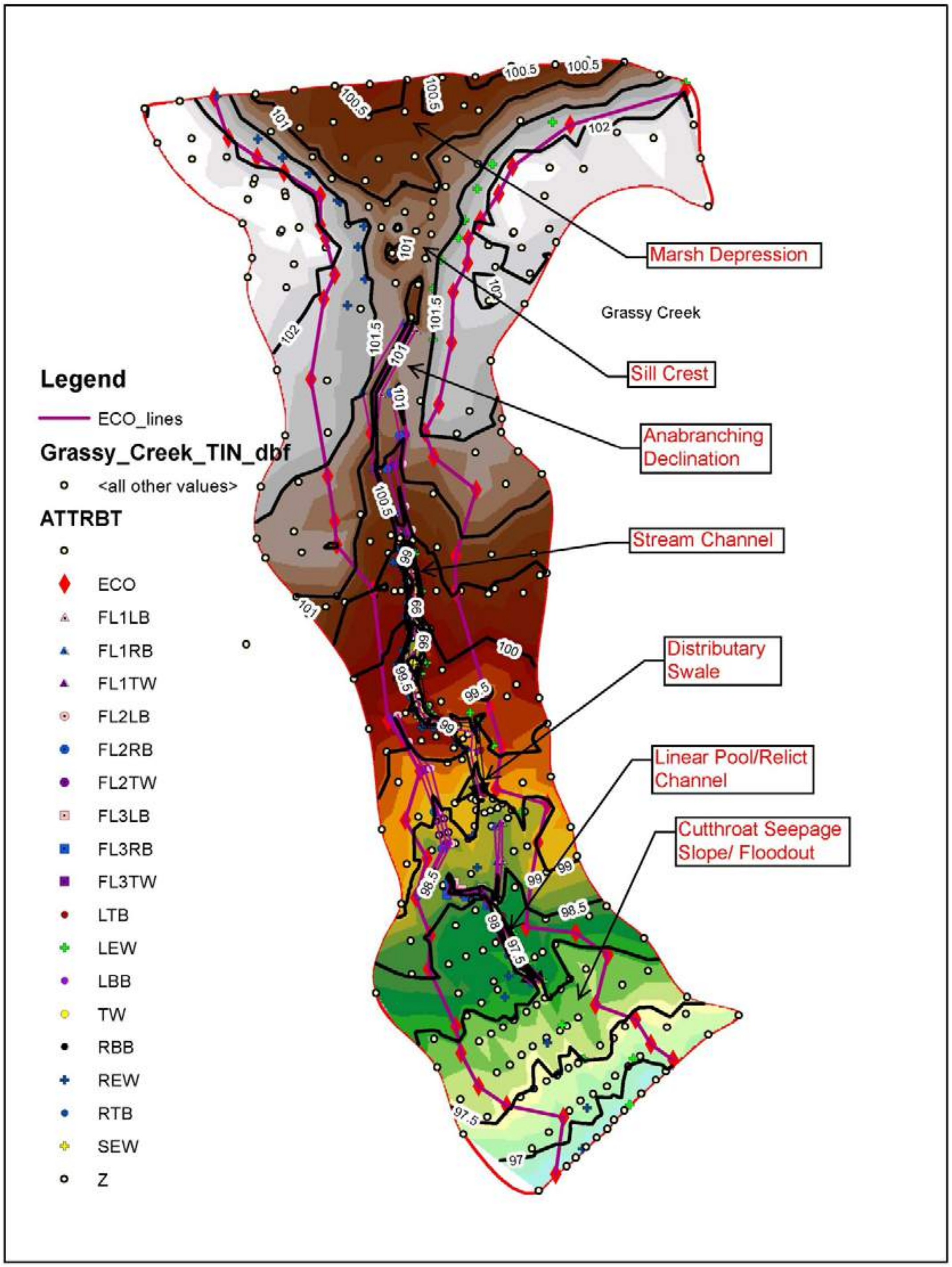
The marsh overflow consisted of a topographic crest, or sill, spanning the strand 38 feet downstream of the marsh edge. The sill consisted of three surfaces, including a popoff flanked by two side slopes extending laterally across the pine strand to its higher cutthroat flat edge, essentially forming an asymmetrical trapezoid cross-section as in the previous case. The land sloped downward longitudinally away from the sill in both the upstream and downstream directions. The sill's popoff elevation was about 0.7 feet below the marsh's seasonal high water line, as evidenced by the upland-wetland vegetation boundary elevation and soils. The popoff was 26 feet wide and 14 feet long at the controlling elevation. The sill's valley side slopes rose from the popoff about 0.7 vertical feet to the strand edge over distances on the order of 30 to 45 feet on either side (side slopes ranging from 38:1 to 61:1 horizontal:vertical). Thus the total sill width was about 100 feet. The transition from the popoff's downstream edge to the upstream edge of the stream channel was 180 feet long. The sill consisted of a 38-foot-long rise from the marsh to the popoff, a 14-foot-long popoff, and a subsequent 180-foot-long declination to the stream channel giving a total transition length of 232 feet. The stream channel formed as a gradual coalescence of two shallow branches along the declination. The anabranches commenced at grade on the upper surface of the 180-foot-long declination from near the popoff and progressively deepened to their junction at the main channel. The main channel thalweg was about 0.9 feet below the adjacent grade.

The valley slope of the anabranching declination was 0.33%, falling within the zone of confidence for an alluvial channel for the 0.8-square-mile drainage area. Thus the 180-foot-long area represents the lagged distance over which the water gained sufficient momentum to carve and sustain an open single channel after exiting the rather quiescent waters of the wetland depression.

Cypress Slash Creek Unnamed Tributary. The stream channel of Cypress Slash UT is an interior link within a chain of lacustrine and wetland depressions and seepage slopes, draining a highlands landscape on the Lake Wales Ridge. This link connects an upstream lacustrine depression, Submarine Lake, to a lower regional cutthroat seepage percoline that intersects the small stream valley. This stream forms the upper segment of a complex chain of wetlands tributary to Cypress Creek. The stream segment in the study area is about 600 feet long and the sample location drains a 0.4 square mile watershed dominated by rolling topography with xeric flatwoods and scrub above the percoline. The transition survey extended from within the lacustrine wet prairie fringe laterally to its upland edge, downstream across the transitional surface to its wetland edge, and tied directly into the Cypress Slash UT's stream reference reach survey, thus characterizing the transitional outlet from an in-line lake-marsh to an uncommon ephemeral HL-RSC stream system.

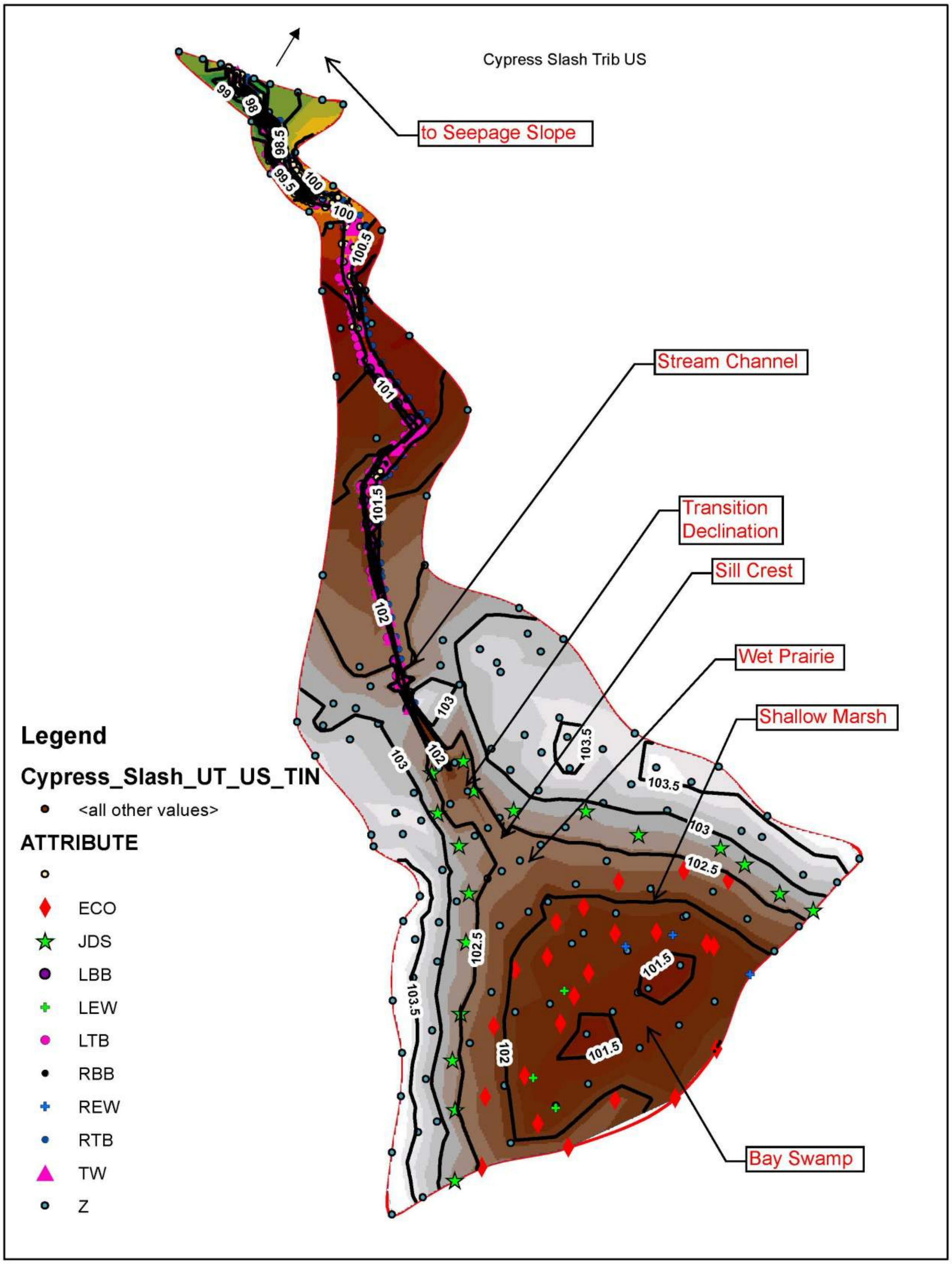
Major surfaces were similar to the previous examples (Figure 6.3). Several communities were apparent within this transition, including four within the lacustrine depression. The deeper zone consisted of open water, which was ringed by a bay swamp growing on 6 to 12 inches of muck over sand. At the lake outlet, the bay swamp was in turn fringed by a funnel-shaped shallow wetland and wet prairie dominated by sand cordgrass and a wide assortment of forbs and sedges growing in fine white sand with organic nodules and some deeper pockets with mucky sand. The wet prairie surface encompassed the sill, with opposing slopes declining toward the interior of the bay swamp and toward the stream. The wet prairie was flanked by a broad expanse of virtually treeless scrubby flatwoods dominated by dense palmetto and various low-growing woody shrubs. Numerous scattered charred pine stumps suggest a crown fire in a xeric flatwoods community. The stream channel formed abruptly at the downstream terminus of the unchanneled wet prairie outlet.

The wet prairie popoff elevation was about 0.3 feet below the upstream wetland boundary elevation. The popoff was 19 feet wide and 33 feet long. The sill's valley side slopes rose from the popoff about 0.3 vertical feet to the palmetto edge over distances on the order of 10 feet on either side (side slopes ranging from 30:1 to 36:1 horizontal:vertical). Thus the total sill width was about 40 feet. The transition from the popoff's downstream edge to the upstream edge of the stream channel was 80 feet long. The sill consisted of a 20-foot-long rise from the bay swamp to the popoff, a 33-foot-long popoff, and a subsequent 80-foot-long declination to the stream channel, giving a total transition length of 133 feet. The entire transition was rather fully vegetated without any discernible open channels.



Grassy Creek UT

Figure 6.2. Stream between Marsh Depression and Cutthroat Seepage Slope.



Cypress Swamp UT

Figure 6.3. Stream Downstream of Swamp/Lake Depression.

The valley slope of the unchanneled declination was 0.25%, just falling within the zone of confidence for an alluvial channel for the 0.4-square-mile drainage area. Thus the 80-foot-long area represents the hydraulic momentum distance necessary to carve and sustain an open channel after it exited the rather quiescent waters of the lacustrine depression.

Coons Bay Branch. The Coons Bay stream channel is an exterior link of a first-order chain of marsh and swamp depressions to a larger mid-order stream floodplain, Payne Creek. This link is about 8,500 feet long draining a 0.5-square-mile flatwoods watershed. The transition survey extended from within the interior zone of the depressional wetland laterally to its upland edge, downstream across the transitional surface to its wetland edge, and terminated a few dozen feet into the alluvial stream channel downstream; thus characterizing the transitional outlet from an in-line swamp to a FW-CV-NC stream system.

Major geomorphic surfaces are similar to the three previous cases (Figure 6.4). Several communities were apparent within this transition. The swamp depression was dominated by laurel oak, red maple and sweet bay, with some canopy gaps allowing dense groundcover by maidencane, duck potato, wax myrtle, lizard's tail, and Dixie iris (*Iris hexagonia*). The wetland depression communities were growing on six inches of muck over sand. The sill and its declination toward the stream were dominated by the same tree and shrub species as the wetland depression, with a groundcover commonly dominated by lizard's tail. This surface was on variable soils ranging from a veneer of muck over fine white sand to 12 inches of mucky fine sand. The swamp outlet was a comparatively low-lying strand less than 150 feet wide. The strand was flanked by broad expanses of alternating mesic live oak hammock and pine flatwoods ecotones. The vegetation and soils indicated a seasonally wet landscape with a declining frequency of growing season fires. Aerials from the 1940s, 50s, 70s, 90s, and 2010s confirm that the forest observed was progressively developing under a reduced fire regime since the 1950s. For example, the upstream swamp/marsh depression was once fully a marsh.

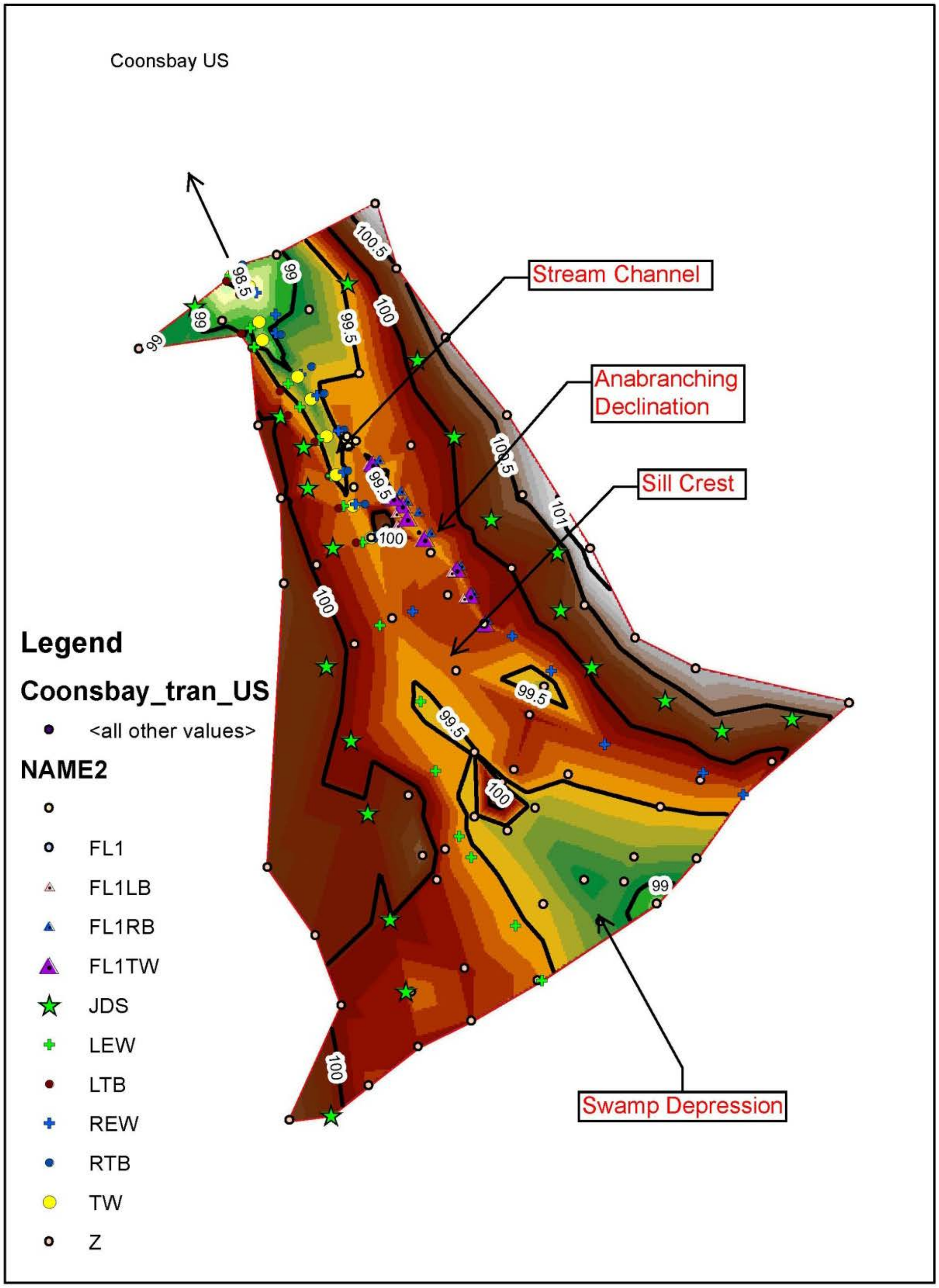
The swamp overflow consisted of a popoff 82 feet downstream of the apparent swamp depression edge. The term "apparent" is used because the swamp community of the sill and depression are very similar. The apparent edge was determined by extrapolating the arc of the depression swamp's boundary across the system's outlet. The sill consisted of three surfaces, including a popoff flanked by two side slopes extending laterally across the hardwood strand to its upland edge. The land sloped downward longitudinally away from the sill in both the upstream and downstream directions.

The sill's popoff elevation was 0.5 feet below the swamp's seasonal high water line as evidenced by the upland-wetland vegetation boundary elevation and soils. The popoff was 19 feet wide and 24 feet long at the controlling elevation. The sill's valley side slopes rose from the popoff about 0.5 vertical feet to the strand edge over distances on the order of 45 to 85 feet on either side (side slopes ranging from 90:1 to 168:1 horizontal:vertical). Thus the total sill width was about 150 feet. The transition from the popoff's downstream edge to the upstream edge of the stream channel was 118 feet long. The sill consisted of an 82-foot-long rise from the swamp to the popoff, a 24-foot-long popoff, and a subsequent 118-foot-long declination to the stream channel, giving a total transition length of 224 feet. The stream channel formed as a gradual coalescence of two shallow branches. The anabranches commenced at grade on the upper surface of the 118-foot-long declination from near the popoff and progressively deepened to their junction at the main channel. The main channel thalweg was about one foot below the adjacent grade.

The valley slope of the anabranching declination was 0.20%, barely falling within the zone of confidence for an alluvial channel for its 0.5-square-mile drainage area. Thus the 118-foot-long area represents the distance over which the water gained sufficient momentum to carve and sustain an open single channel after exiting the rather quiescent waters of the wetland depression.

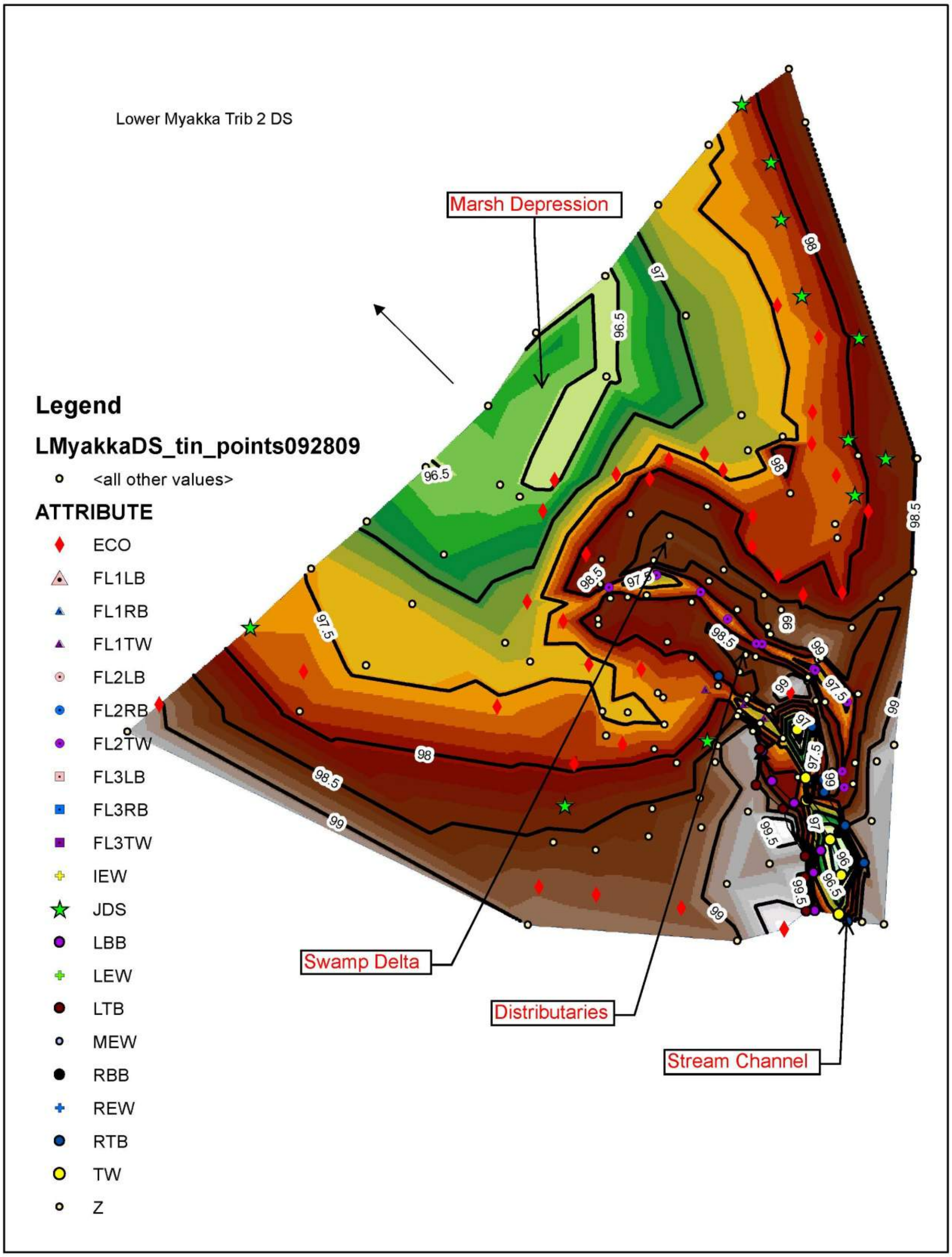
Lower Myakka River Unnamed Tributary 2. The Lower Myakka UT 2 stream channel is an interior link of a first-order chain of doline marshes which connect downstream to the Myakka River. The stream link is about 1,800 feet long draining a 2.7-square-mile flatwoods watershed. The transition survey extended from the alluvial stream channel system and its overbank areas, downstream across the transitional surface to its wetland edge, and terminated downstream within the depressional wetland laterally to its upland edge, thus characterizing the transitional outlet from a FW-CV-WC stream system to a lower in-line marsh depression. The surrounding landscape carries frequent fire and is extensively inundated with sheetflow after thunderstorms during the wet season.

Several surfaces were apparent within this transition, including (1) the alluvial stream channel, (2) a distributary channel system crossing an alluvial delta, and (3) the in-line receiving marsh depression (Figure 6.5). Complex communities occupied the varied surfaces in this landscape. The first surface was the colluvial valley of the stream consisting of a mesic hammock dominated by live oak, palmetto, cabbage palm and wax myrtle. Its soils were loamy sand with a surface layer of up to two inches of muck. It was traversed by a low W/D alluvial channel about 8 feet wide at bankfull flow. The hammock formed a gallery forest about 70 feet wide within a broad expanse of sandy pine savanna. The main channel in the gallery forest quickly divided into a series of anabranches of variable widths and depths downstream as it crossed the receiving depression’s bed, with two main threads functioning as distributaries to the marsh. These anabranches crossed a small delta that deposited about one foot of sediment in the marsh. The delta sediment consisted of fine sands occupied by a hydric hammock dominated by laurel oak with common cabbage palm and wax myrtle. The adjacent lower marsh bed consisted of at least 12 inches of muck dominantly growing maidencane. Parts of the delta also flanked the outer wet prairie zone of the marsh depression. The wet prairie was vegetated by sand cordgrass, spikerush (*Eleocharis* sp.), and various sedges growing on two to four inches of muck over loamy sand.



Coons Bay Branch

Figure 6.4. Stream Downstream of Swamp/Marsh Depression.



Lower Myakka UT 2

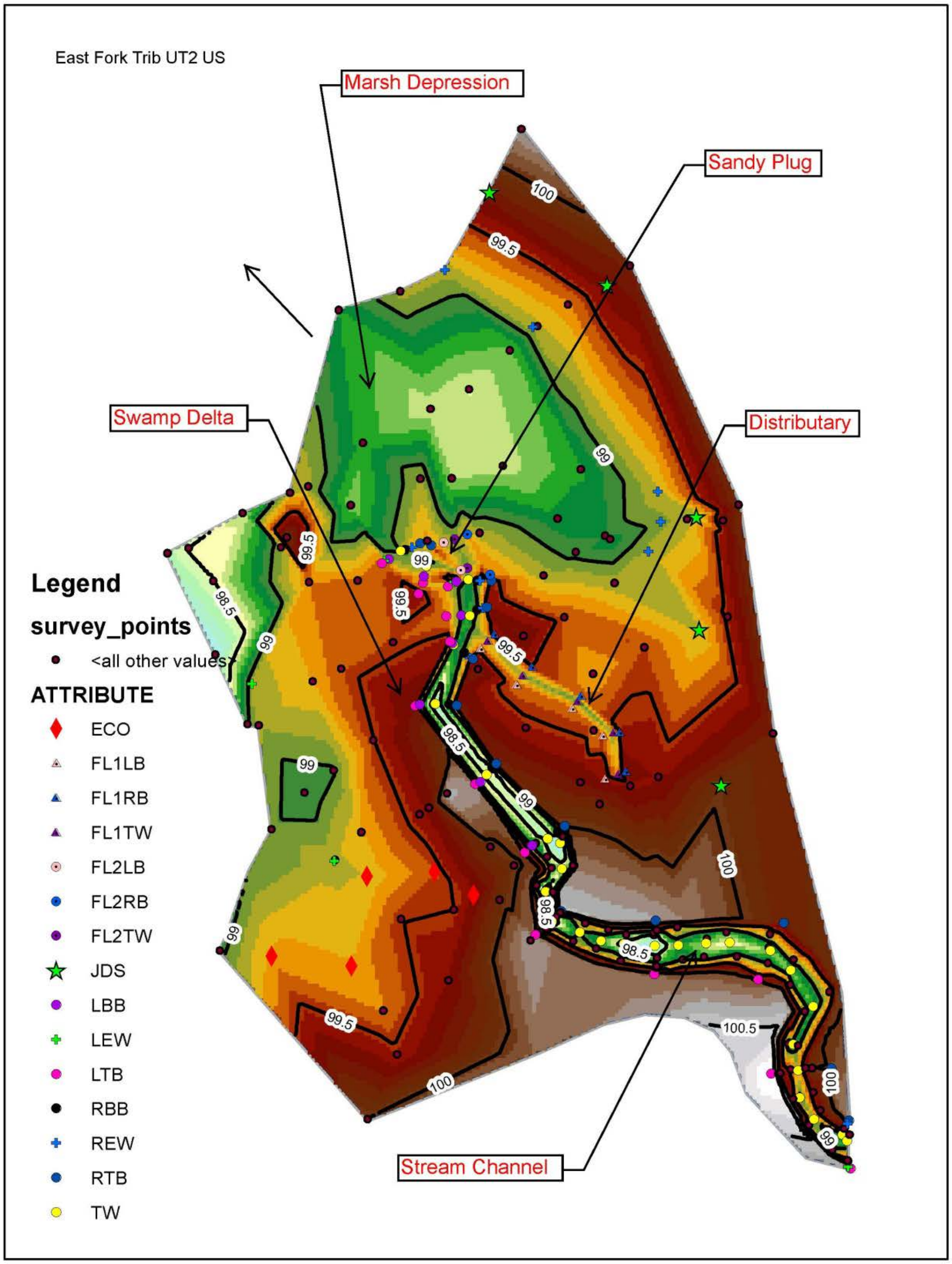
Figure 6.5. Stream Outlet to In-Line Marsh Depression.

The distributary's anabranches had nearly level banks as they crossed the delta. It terminated abruptly. The stream system was non-perennial and would typically be carrying its largest sediment yields when the receiving marsh is maintaining a nearly level pool of quiescent water during the wet season. This pool served to dissipate the fluvial forces, allowing most of the sediment load to settle quickly. The delta was 180 feet long and 126 feet wide.

East Fork Manatee Unnamed Tributary 2. The East Fork UT 2 stream channel is an interior link of a first-order chain of doline marshes and swamps which connect downstream to the East Fork of the Manatee River. The stream link is about 650 feet long draining a 0.4-square-mile flatwoods watershed. The transition survey extended from the alluvial stream channel system and its overbank areas, downstream across the transitional surface to its wetland edge, and terminated downstream within the depressional wetland laterally to its upland edge, thus characterizing the transitional outlet from a FW-CV-WC stream system to an in-line swamp depression. The surrounding landscape carries frequent fire and is seasonally wet.

Surfaces were similar to those of the previous example (Figure 6.6). Several communities were apparent within this transition. The first community was the colluvial valley of the stream consisting of a hardwood swamp strand dominated by laurel oak, red maple, slash pine, dahoon, blackgum and wax myrtle. Its soils consisted of 12 inches of sand with organic nodules and stripped matrix. It was traversed by a low W/D alluvial channel about 10 feet wide at bankfull flow. The strand formed a gallery forest about 120-250 feet wide within a broader expanse of hydric and mesic pine savanna. The main channel in the gallery forest divided into a couple of anabranches of variable widths and depths as it crossed the delta on the receiving depression's bed. These branches rejoined just prior to exiting the delta. Their outlet had a sandy vegetated plug several inches thick at its mouth, partially embaying the stream discharge in the upstream channel. The delta deposited about 0.7 feet of sediment in the wetland depression consisting of up to an inch of muck over at least several inches of gray sand. Delta vegetation was similar to that of the gallery strand. The adjacent lower wetland bed consisted of at least 12 inches of muck dominantly growing a hardwood swamp of red maple, dahoon, and blackgum on organic hummocks with buttonbush dominating the low spots between the hummocks.

The distributary's anabranches had nearly level banks as they crossed the delta, which terminated rather abruptly in the depression. The stream system was non-perennial and would typically be carrying its largest sediment yields when the receiving swamp was maintaining a nearly level pool of quiescent water during the wet season. This pool served to dissipate the fluvial forces, allowing most of the sediment load to settle quickly. The delta was 89 feet long and 64 feet wide.



East Fork Manatee UT 2

Figure 6.6. Stream Outlet to In-Line Marsh Depression.

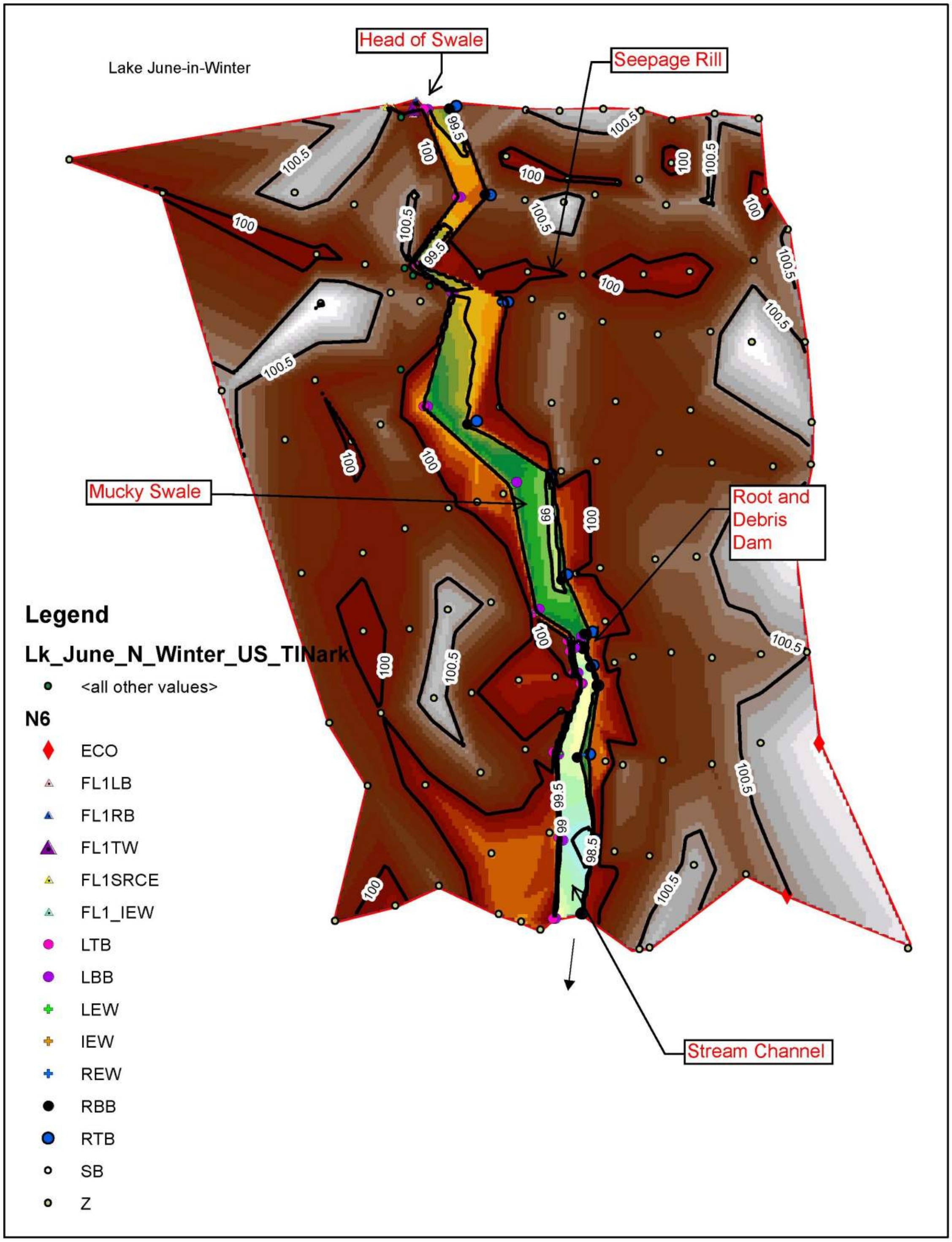
Streams Affiliated with In-Line Seepage Slopes

Lake June-In-Winter Unnamed Tributary. This unnamed tributary links a headwater seepage swamp to Lake June-In-Winter, draining a highlands landscape on the Lake Wales Ridge. The stream segment in the study area is about 1,800 feet long and the sample location drains a 0.6-square-mile watershed dominated by rolling topography with sandy scrub. The transition survey extended across a 180-foot-wide area within the seepage swamp interior, downstream across the transitional surface, and extended into the stream channel; thus characterizing the transitional outlet from a headwater seepage swamp to a HL-RSC stream system (Figure 6.7).

The primary surface along this transition consisted of a longitudinal seepage slope dominated by bay trees growing on peat and sapric organic soils at least a foot thick. All other surfaces described were flanked by this seep slope and ran parallel to it. The concept of a sill does not apply very well to this kind of system. Instead, the transition started with the abrupt appearance of a seepage swale about 9 feet wide just a few inches deeper than the surrounding swamp soils. At the time of visit, water was seeping from the swamp into the head of the swale and along it via short rills in the peat and under dense root masses bordering the swale. The 131-foot-long swale was blocked by root jams and contained 1 to 2 feet of soft flocculant muck on its bed. Parts of the swale were colonized by hummocks with small bay trees. At its terminus the swale had a large log and debris jam, downstream of which the channel bed material became abruptly deeper and sandier.

The valley slope of the transition was 0.30%, falling within the zone of confidence for an alluvial channel for the 0.6-square-mile drainage area. The 131-foot-long swale appeared to represent a somewhat dynamic area that may sometimes support an open channel, perhaps during sustained multi-decadal wet periods such as those encountered during the mid-1930s through 1960s. The swale is blocked by roots and debris during drier decades like the region has experienced since the mid-1960s. The reference reach of the HL-RSC channel that drains this system has a much steeper valley slope (1.1%) than the transition, which evidently has been able to maintain an alluvial bed during the full range of climate fluctuations this century. The transition is a gradual one, lacks a well-defined sill, and is greatly influenced by groundwater interactions with biological grade control and bank development.

Grassy Creek Unnamed Tributary. This is the downstream end of the system of the same name described in the “Streams and Wetland Depressions” subsection (Figure 6.2). The FW-CV-WC stream discharges into a broad and extensive cutthroat grass seepage percoline that perpendicularly crosses the channel.



Lake June-In-Winter

Figure 6.7. Seepage Swamp Outlet to Stream Channel.

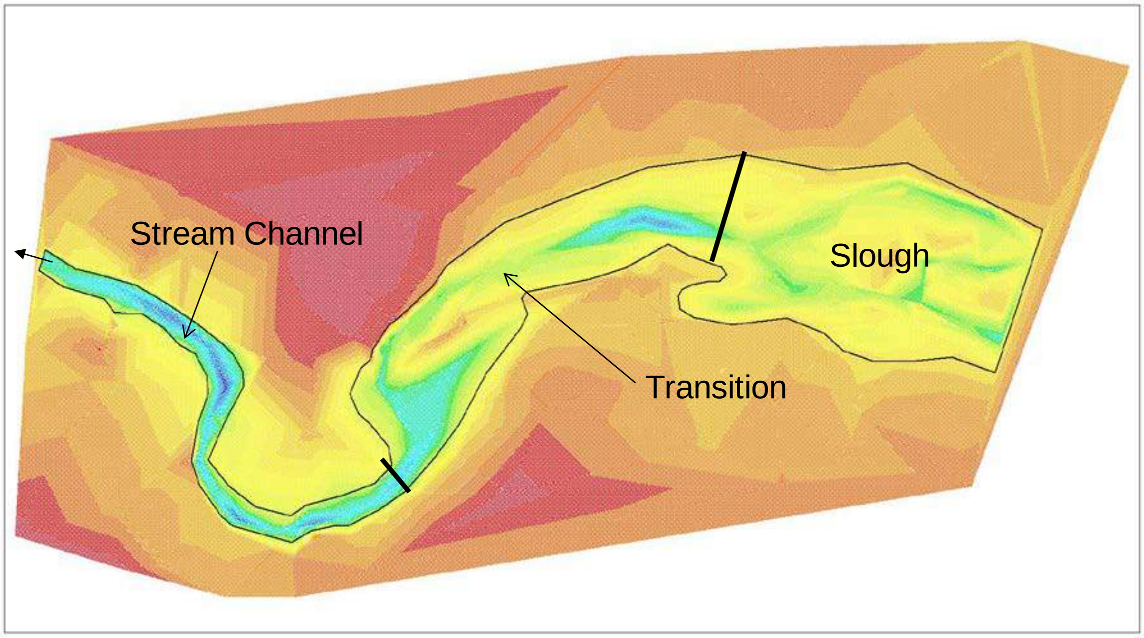
Thus the transition crossed a portion of a much wider and longer regional seepage slope dominated by cutthroat grass, gallberry, and slash pines on mucky sands at least a few inches thick. The transition between the stream channel and the unchanneled downstream seepage slope consisted of a 172-foot-long, 67-foot-wide fully vegetated swale up to a few inches deeper than the adjacent seepage face. The swale vegetation was dominated by dense tussocks of cutthroat grass with scattered slash pines and patches of Virginia chain fern, red-topped panicum, and sedges. A similar seepage slope swale formed the downstream terminus of the Cypress Slash UT stream, with like vegetation plus some scattered pitcher plants. It also intersected a portion of a much larger regional seepage face. Under this arrangement, the runoff from the channel simply floods out across the seepage slope and may actually seep back into the ground at times, depending on antecedent water levels. These wide regional seepage slopes appeared to serve as major lateral energy dissipaters.

The seepage swale at Grassy Creek UT contained an isolated open water pool almost 40 feet long, 1 foot deep, and about 10 feet wide that may have been a relict channel. The pool was discontinuous with the upstream channel, separated from it by more than 70 feet of vegetated swale. Perhaps it represented the lower limits of the channel system as it occurred under the wetter climate period, which has subsequently filled in with soil and vegetation during the antecedent drier climate the region has experienced during the last few decades.

The valley slope of the transition was 0.90%, falling within the zone of confidence for an alluvial channel for the 0.8-square-mile drainage area. The 172-foot-long seepage swale appeared to represent a somewhat dynamic area that may sometimes support an open channel. The transition is a gradual one and is greatly influenced by groundwater interactions with vegetation and organic soil development. In some key respects, this downstream seepage slope transition with the stream channel is a mirror image of the geomorphology exhibited by the upstream seepage slope transition examined at the Lake June-In-Winter UT site, except it is occupied by a fire-adapted wet savanna versus a bay swamp.

Streams Affiliated with In-Line Sloughs

Grasshopper Slough. As defined by FNAI (2010) slough marshes are lotic but weakly flowing, vegetated wetland systems that flow seasonally to intermittently. They have poorly defined banks and discontinuous to no alluvium on their beds. Grasshopper Slough consists of an almost 5-mile-long valley occupied by a series of well-defined open alluvial stream channels alternating with slough marshes and other in-line wetlands. The stream segment in the study area is about 3,000 feet long and the sample location drains an 8.7-square-mile predominantly flatwoods watershed from near the southeastern end of the Lake Wales Ridge to the Kissimmee River valley. The slough marsh upstream of the stream channel is also several thousand feet in length. The transition survey extended across a distance up to a 250-foot-wide area and about 1000 feet long, encompassing about 650 feet of slough (and slough transition) and 350 linear feet of stream channel (Figure 6.8).



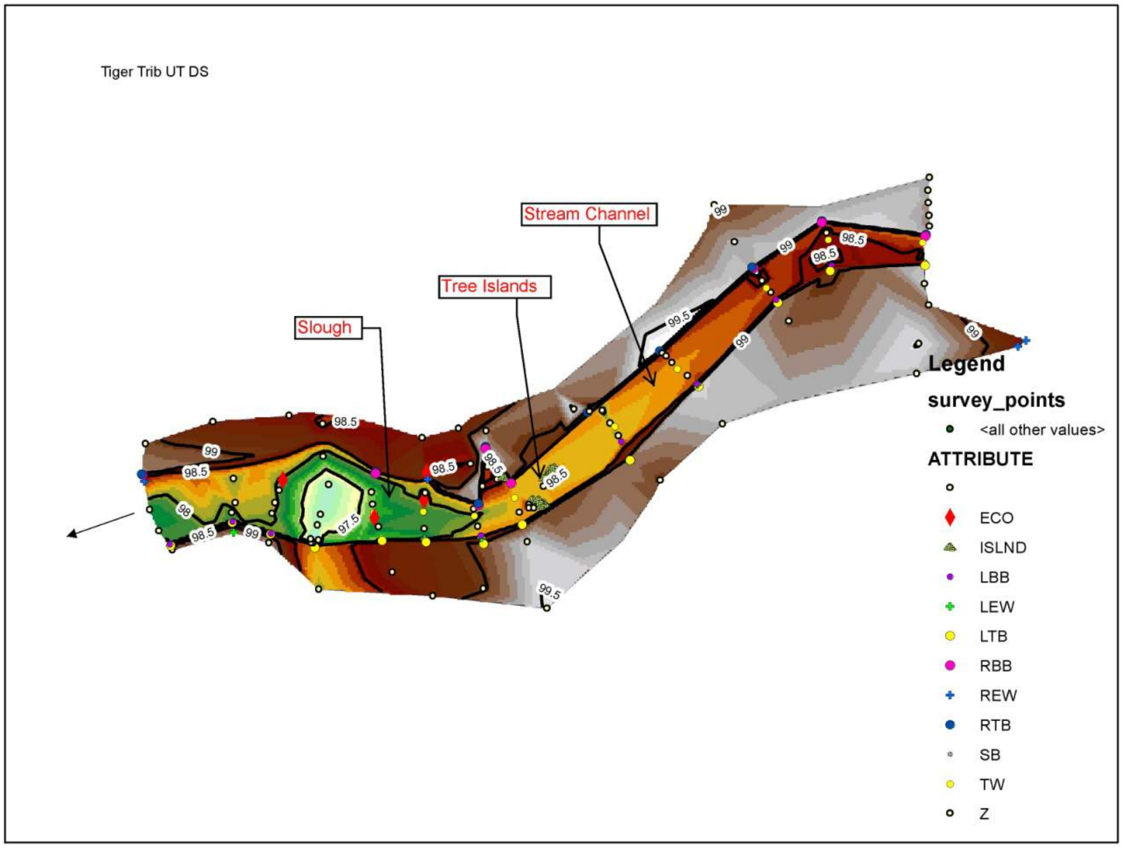
Grasshopper Slough

Figure 6.8. Chain-of-Sloughs Transition.

The alluvial stream channel was a bit unusual for a drainage area that size because it lacked multiple alluvial floodplain features, with just a subtle alluvial ridge. The sloughs immediately upstream and downstream of the study reach were thickly vegetated and had dually threaded (anastomosing) channels with meandering sandy beds and collections of small bars often with roughly two-inch bands of alternating white sand and muck. The densely vegetated portions of the slough generally had muck deposits in excess of 5 inches thick at the land surface. The sloughs appear to be trapping sediments transported from upstream channels, perhaps preventing their routine availability for lateral overbank deposition along the steeper channel stream linkages. In other words, the steeper segments formed comparatively hydraulically efficient channels with better defined banks and sandy open beds that maintained continuity of sediment transport, but that had limited material available for overbank deposition because sediment was being trapped by the flatter sloughs. While nominally an FW-AF-CC system, from a process related standpoint this site represents an intermediate condition between FW-AF-CC and FW-CV-WC systems, seemingly as a result of the sediment-trapping capacity related to the frequency and magnitude of the in-line waterbodies. Each of the several in-line slough marshes were typically on the order of 2,000 to 3,000 feet long and cumulatively comprised about half the total valley length.

The valley slope in the survey area was 0.016% along the slough and it inflected abruptly convex to 0.069% downstream. The greater slope falls within the zone of confidence for systems supporting alluvial channels and the smaller slope does not for the 8.7-square-mile watershed. The slough was dominated by maidencane growing on mucky sand or muck. The bankfull discharge in the slough is spread across a width of 80 to 200 feet and funneled down almost instantly to a width of 20 feet in the open channel segment. Vegetation on the channel banks and adjacent area was dominated by live oak, pines and cabbage palms with a palmetto understory on higher ground and maidencane on lower surfaces. Despite the rather abrupt transition in valley slope and channel width across the threshold for the support for single-thread alluvial channel systems, the most-upstream 180 foot section of the steeper valley was transitional and still supported a slough community. Once again, it appears that momentum effects are operating over that kind of distance as the gentle flow regime transitions to a more concentrated fluvial condition.

Tiger Creek Unnamed Tributary. Tiger Creek UT is an HL-BFC stream channel about 2,000 feet long draining a 0.9-square-mile highlands watershed. It connects a headwater seepage swamp to the floodplain of Tiger Creek. The alluvial stream is punctuated by at least one slough several hundred feet in length. As defined by FNAI (2010), sloughs are lotic vegetated wetland systems that flow most of the year and are deeper than slough marshes. They lack alluvial bed features. The transition survey extended across a 50-foot-wide by 200-foot-long area, encompassing about 150 feet of slough and 50 linear feet of stream channel (Figure 6.9).



Tiger Creek UT

Figure 6.9. Stream Outlet to In-Line Slough.

The stream channel was about 13 feet wide at bankfull discharge, and abruptly expanded to 27 feet wide at the slough. The entire system traversed a seepage swamp bottomland dominated by sweetbay, red maple, wax myrtle, laurel oak, and swamp dogwood with dense cinnamon and royal fern cover growing on muck and thick root masses. The stream channel was sandy until it reached the slough, where it was covered with a 5-inch layer of loose muck. The slough was moderately canopied but supported dense patches of golden club, wild rice (*Zizaniopsis miliacea*), and alligator weed (*Alternanthera philoxeroides*).

The valley slope was 0.17% along the stream and it tilted abruptly concave to 0.08% downstream in the slough. The greater slope falls within the zone of confidence for systems supporting alluvial channels and the smaller slope does not for the 0.9-square-mile watershed. A brief 30-foot-long transition occurred between the alluvial stream and the slough consisting of a sandy channel segment bifurcating around a couple of tree islands (large organic hummocks 10 to 15 feet long and about 5 to 8 feet wide).

Low-Order to Mid-Order Stream Junction

This case study provides an example where a stream channel directly joins a larger channel system in a dendritic fashion. The unnamed tributary of the East Fork of the Manatee River (East Fork UT) drains a 0.9-square-mile watershed in the flatwoods, comprising the exterior link of a chain-of-wetlands to a larger stream channel, the East Fork of the Manatee River (East Fork). The East Fork UT system classified as an FW-CV-NC system, which is typical of streams in its landscape position. The receiving waterbody, the East Fork, drains about a 12-square-mile watershed at the junction of the two streams and classifies as an FW-AF-CC system.

The East Fork UT channel crosses a portion of the alluvial floodplain of the East Fork before joining its open channel. The survey area included the left bank and thalweg of the East Fork channel, the entire area where the East Fork UT meanders across the East Fork backswamp, and a portion of the East Fork UT channel where it crosses the valley hillslope along the larger stream's valley margin. The survey data, coupled with observations of the upper 12 inches of sediment and the vegetation, indicated several kinds of surfaces in the transition and its adjacent areas.

The first surface consisted of the colluvial valley of the East Fork UT, which was a hydric hammock dominated by mucky sands occupied by laurel oak, sweet gum, sweet bay, dahoon and palmetto. A low W/D alluvial channel about 8 feet wide at bankfull flow traversed the surface. This channel quickly divided into a series of anabranches of variable widths and depths downstream as it crossed the East Fork's floodplain, with two main threads functioning as distributaries to the East Fork channel. The anabranches crossed two zones in the floodplain. The upper zone was about 0.7 feet above the adjacent grade, suggesting deposition as a shallow delta in the East Fork's backswamp. The lower floodplain zone was at the prevailing grade of the linear backswamp consistent with sedimentary processes originating from the larger East Fork watershed. These two floodplain surfaces were occupied by a bottomland swamp community dominated by red maple, laurel oak, sweet bay, American elm, pop ash, wax myrtle, buttonbush and Virginia chain fern. The delta surface consisted of laminar deposits of sand, detritus and muck, while the lower backswamp surface consisted of a more uniform loam with some sand and muck.

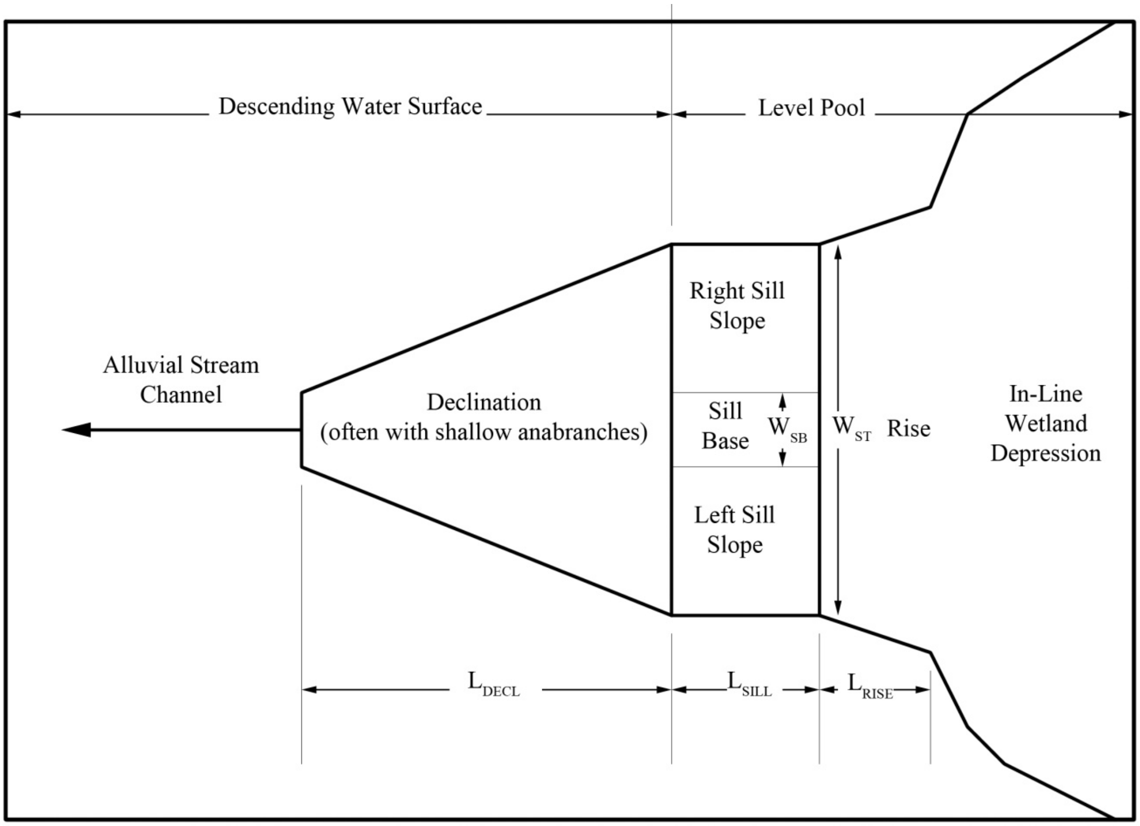
The East Fork UT anabranches became progressively shallow as they crossed the East Fork floodplain, ranging from depths of about 1 foot deep where they coursed through their own delta, to less than 0.5 feet where they carved paths through the East Fork valley alluvium. The East Fork UT channel thalweg entered the floodplain at an elevation approximately 1.2 feet greater than it exited into the larger stream, giving a longitudinal slope of about 0.8%. This slope was sufficient to maintain a single alluvial channel for the drainage area within its own valley, but did not do so upon entry into the larger receiving waterbody's valley. The larger stream valley represented a laterally unconfined zone which dissipated energy for the East Fork UT's flow and sediment. Also, the East Fork UT system was non-perennial and typically would be carrying its largest sediment yields when the East Fork is overbank during the wet season, which further served to dissipate energy as the East Fork UT discharges entered a slowly flowing inundated surface. Therefore the seasonal hydrology and valley geomorphology of the larger FW-AF-CC stream type created an energy dissipation zone that altered the independent effects of the available power of the smaller FW-CV-NC channel joining it, creating an anastomosing planform where an otherwise single-thread channel might occur.

However, despite its comparatively smaller forces, the smaller tributary clearly altered the local geomorphology as it entered the larger stream valley. The shallow delta encompassed the various East Fork UT anabranches and was about 105 feet wide perpendicular to the East Fork UT's flow path (parallel to the East Fork's backswamp flow path). The East Fork UT distributary crossed a 150-foot-wide backswamp, of which the delta occupied the uppermost 65 feet closest to the East Fork's outer valley margin. Thus the transitional feature was about 150 feet long and 105 feet wide. A plunge pool with a thalweg depth of about 4 feet below bankfull stage was measured in the East Fork channel at the main East Fork UT outlet. It is important to note that the tributary did not cut a channel down to the thalweg of its receiving stream, only partially penetrating the larger channel's bank to a depth of about half a foot below the floodplain surface.

CONCLUSIONS

Deranged drainage networks can support complex alternating arrays of functional process zones relying on variably focused fluvial forces. These forces repeatedly cross physical and biological thresholds necessary to support different geomorphic surfaces and the communities occupying them. This series of case studies examined four main kinds of waterbody transitions at stream-to-stream junctions, wetland depression-to-stream junctions, seepage slope wetland-to-stream junctions, and slough-to-stream junctions. These junctions were studied in intact lower-order streams draining colluvial valleys, which have been particularly susceptible to artificial ditching and associated hydraulic homogenization.

Although approached as a series of descriptive case studies, some key unifying concepts are suggested. First, all four outlets of in-line wetland depressions studied flowed over geomorphic surfaces that consistently were configured much like broad-crested trapezoidal weirs. These sills exhibited dimensions, slopes, and relative crest elevations to the seasonal high-water levels of the wetland depression that were rather consistent among the sites, which included marshes, swamps, and a small lake (Table 6.5, Figure 6.10). The sills did not support unique communities, but tended to be vegetated either with species consistent with the adjacent upstream wetland community or by a community more similar to the downstream corridor. The plant communities tended to reflect the fire history of the landscape and can be dynamic over a period of decades.



Surface boundaries represent limits of seasonal high water levels. Sill Base = Popoff.

Figure 6.10. Planview Schematic of Characteristic Wetland-to-Stream Transition.

The two streams discharging into in-line wetland depressions produced small deltas in the depression, akin to a small delta also observed in the floodplain of a larger receiving stream formed by its smaller tributary. These deltas were relatively uniform in their depths and lengths among these three sites. The deltas typically supported vegetative communities that differed from those of the receiving waterbody's bed, and the soils differed between the alluvial deltas and the adjacent non-alluvial bottomlands.

Table 6.1. Wetland-to-Stream Transition Length Dimensions.

Site Name	Upstream In-Line Waterbody	L_{RISE} (ft)	L_{SILL} (ft)	L_{DECL} (ft)	Transition L_{TOTAL} (ft)
Grassy Creek UT	Marsh	38	14	180	232
Coons Bay Branch	Swamp	82	24	118	224
Lower Myakka UT 3	Marsh	51	50	166	267
Cypress Slash UT	Lake Swamp	20	33	80	133

(Refer to Figure 6.10 for further clarification.)

L_{RISE} = Length of incline from nominal edge of wetland depression to edge of sill base.

L_{SILL} = Length of sill when conceived as a broad-crested weir.

L_{DECL} = Length of declination from sill to stream channel at seasonal high water.

Table 6.2. Wetland-to-Stream Transition Cross-Section Dimensions.

Site Name	Upstream In-Line Waterbody	D_{TW} (ft)	W_{ST} (ft)	A_{SHW} (ft^2)	W/D	W_{SB} (ft)	Left Sill Side Slope (H:V)	Right Sill Side Slope (H:V)
Grassy Creek UT	Marsh	0.7	98	43	221	26	61:1	41:1
Coons Bay Branch	Swamp	0.5	130	37	454	19	54:1	168:1
Lower Myakka UT 3	Marsh	0.4	99	32	304	62	38:1	55:1
Cypress Slash UT	Lake Swamp	0.3	39	9	175	19	37:1	30:1

(Refer to Figure 6.10 for further clarification.)

D_{TW} = Thalweg depth of sill at seasonal high water.

W_{ST} = Total sill width at seasonal high water.

A_{SHW} = Sill cross-section area at seasonal high water.

W/D = Sill width to hydrualic depth ratio at seasonal high water.

W_{SB} = Width of sill base (when sill is conceived as a broad-crested trapezoidal weir.

One upstream and one downstream transition at stream-to-seepage-slope junctions were studied. These turned out to be virtual mirror images of each other with discontinuous relict channels occurring between the stream and seepage slope. The transitions were of similar length. Very different vegetative communities were present on each slope type, one dominated by grass and one by hardwood trees adapted to seepage conditions. In addition to the dissipative effects of these groundwater-dominated portions of the landscape, the seepage zones appeared to exert different forms of biological controls on their geomorphology that served to armor the land surface and add shear strength to its soils.

One upstream and one downstream transition at stream-to-slough junctions were studied. These also turned out to be akin to mirror images of each other. The presence or absence of sloughs versus streams appeared to depend primarily on the valley slope.

Transitions between the stream and slough were abrupt, with bankfull discharge widths at least doubling or increasing more than fivefold in the sloughs versus the streams over longitudinal distances of less than a few dozen feet.

The six sites studied where an energy-dissipating waterbody discharged to an alluvial stream channel exhibited transitions 80 to 180 feet long downstream of the sill crest (popoff) on valley declinations that sloped sufficiently to support an alluvial channel, but did not. These areas likely represent a hydrodynamic transitional zone of a characteristic streamline length necessary to accelerate from nearly stagnant velocities to those associated with tractive force thresholds necessary to overcome the stabilizing effects of vegetation and erode and maintain an open channel. In other words, they are brief segments of the landscape where the system shifts gears from a depositional environment and gains enough momentum to erode a fully dimensioned open channel.

In general, the transitions studied offered a complex milieu of alluvial and colluvial surfaces with a diversity of habitats that seldom presented as smooth gradients, but instead occurred in rapid transition. Thus the transitions are small and complex. Some of these surfaces perform key hydrologic functions affecting the hydroperiods and water levels of the in-line waterbodies and are therefore critical to understand when engaged in natural channel design of deranged networks. The in-line waterbodies also clearly serve as foci for sediment trapping, which in turn is likely affecting the channel dimension and discharge carrying capacity of the streams in the network. This detailed look at 11 transitions has emphasized the importance of conceiving many peninsular Florida streams as longitudinally complex lotic systems comprised of often repeating zones serving to abruptly and alternatively dissipate and concentrate fluvial forces in different geomorphic configurations (as FPZs). Many Florida headwater (low-order) stream valleys are best conceived as chains-of-wetlands that differ from their better-studied dendritic network counterparts in most of the rest of North America.

CHAPTER 7
DESIGN CONCEPT

PURPOSE AND OBJECTIVES

Chapters 8 through 11 of this document describe a restoration approach for the major reconstruction of lotic systems of peninsular Florida, with particular emphasis on their fluvial geomorphology and associated biological zones. Attention to these aspects of the landscape will help to assure success in providing viable and sustainable ecological and hydrological functions. For the purposes of this document, "lotic systems" include alluvial stream channels, their meander belts, and the lateral and longitudinal wetland systems to which the stream channels connect. Project objectives can vary but are typically expected to include:

- Creation and preservation of an ecologically complex drainage network.
- Replacement of artificially ditched streams with natural channels.
- Development of self-sustaining fluvial systems compatible with on-site hydrology and sediment texture. Particular emphasis is on placing streams in landscape positions with appropriate combinations of valley slope and drainage area to sustain stable longitudinal gradients.
- Provision of longitudinal and lateral wetland-to-stream connections appropriate for the property's position in the drainage network. This will result in proper large-scale habitat connectivity within the lotic system between streams and their floodplains, their in-line wetlands, and headwater wetlands.
- Taking a holistic approach to provision altered sites with suites of characteristic discharge, sediment type, channel dimension and bedforms, channel planform, floodplain dimensions and vegetation, and in-stream habitat diversity and abundance. The included stream classification provides guidance on the appropriate combinations of these variables in nature and thus describes the genome of the stream to be restored.
- Deployment of proven, cost-effective construction techniques to rapidly create stable and complex channel and floodplain geomorphology with appropriate biological habitat.
- Improvement or protection of the native aquatic fishery or macroinvertebrate community.
- Improvement of aspects of water resource values, including those related to the residence times in contact with surfaces that improve water quality and the transport of sediment, detritus, and solutes downstream.

The proposed approach explicitly provides design details concerning not only the stream channel reach, but also fits these channels to the landscape based on a hierarchical association of channel form and function as it relates to valley and watershed processes. This tactic recognizes that Florida stream environments are comprised of a series of longitudinal and lateral habitat zones that are inherently self-sustaining based on the aforementioned hierarchy of scale and associated fluvial and ecological processes. A related “functional process zone” (FPZ) concept has been described for its utility across the globe, and is the primary subject of a recent textbook promoting improved stream characterization, management, and restoration approaches (Thorp and others 2008). Under the FPZ approach, channel classification (e.g., Rosgen classification) is only one of several interrelated factors evaluated in determining the restoration approach. Descriptions of the existing lotic systems may also include artificial drainage features, such as ditches and canals, where they have disrupted or adversely affected the natural fluvial functions of the property (Thorp and others 2008).

BASIC DESIGN APPROACHES

Two fundamentally different approaches are generally employed to establish dimensions for stream channels reclaimed at surface mines in the United States: (1) tractive force, and (2) regime (Toy and others 2000). Tractive force approaches focus on the hydrodynamic relationships among flow velocity, shear stress, and bed materials. Designers typically rely on evaluations of synthetic design storms to create trapezoidal channels that are non-erosive for the design event(s). This approach has been increasingly criticized for its ecological oversimplification, high establishment and maintenance costs, unpredictability of actual long-term stream adjustments, and poor integration with upstream and downstream waterbodies (Myers 2000, Rosgen 1996, Knighton 1998).

Regime designs focus on the dynamic equilibrium between erosive and depositional forces affecting channel dimension and the dominant discharge that maintains this equilibrium. Streams in this state of equilibrium are “in-regime,” while degrading or aggrading streams are not. Three basic techniques can be used for regime designs (also frequently referred to as “natural channel design”): analog, analytical, and empirical (Skidmore and others 2001).

Analog design is a simple mimicry of stream channel shapes. Frequently, this approach uses the geometry of reaches upstream and/or downstream of the restoration reach as the design template. The use of upstream/downstream reference reaches is most appropriate for restoring short disturbed segments of streams assumed to be in-regime with their watersheds. For example, this might be appropriate for removing disturbances on the scale of pipeline, road, or dragline crossings. Mimicry also makes sense in cases where the bedload materials and watershed conditions in the restored reach, especially those related to sediment load and hydrology, are close to identical to those of the reference reach. Analog approaches could also be called design by case study. Where appropriate, the 56 sites studied could be used as a library of reference reaches from which to draw such cases. This technique applies well to the HL-RSC channel types. However, solely applying the data using analog approaches would limit its utility to a small number of sites.

To overcome such limited utility, the data was systematically collected to support more broadly applicable empirical design methods. Empirical design is based on statistical associations, usually regressions that relate various channel characteristics as dependent variables against independent variables that may be derived at the channel, valley, or watershed scales. These equations are typically derived from many streams in an equilibrium condition. Regional curves are one such set of equations. One of the primary aspects of our research has been to derive the necessary empirical equations to utilize this approach in peninsular Florida. This approach can be applied to all the stream types encountered, but like all regressions should be extrapolated with caution to conditions that differ from those under which the range of associations were observed.

Analytical designs rely on the solution of physically based equations. They can represent relatively simple static-channel hydraulics or more complex deformable-channel hydraulics. Non-deformable solutions are tantamount to a tractive force approach. A more genuine analytical approach allows for channel deformation and rather explicitly accounts for sediment transport and deposition. Due to the complex physics of deformable natural channels, analytical designs typically rely on computer models. More unknowns than equations often occur, and these methods are usually data-intensive. Sediment transport calculations are notoriously prone to large errors, rendering this approach a major exercise in professional judgment, despite the mathematical basis. It is often used in conjunction with other approaches, especially as a design check where watershed conditions are not anticipated to be in equilibrium with historic channel condition.

Part 653 of the National Engineering Handbook (Stream Corridor Restoration) recommended restoration approaches that draw primarily from empirical and analog methods, using analytical approaches to check the desired effects (FISRWG 1998). This is essentially the approach embodied by our guidance. Additional works also describe hierarchical and multidisciplinary design approaches that rely on empirical regime relationships supplemented by analytical assessments (Knighton 1998, Gordon and others 2004). Part 654 of the National Engineering Handbook (Stream Restoration Design) greatly supplements the conceptually based Part 653 with more detailed methods and provides several separate design approach chapters, including Threshold Channel Design, Alluvial Channel Design, Two-Stage Channel Design, and Rosgen Geomorphic Channel Design (NRCS 2007b).

Threshold channel design is centered on tractive force analyses, which are especially useful for systems with erosion-resistant boundaries and relict surfaces that can no longer be changed by modern forces. The sediment transport capacity greatly exceeds the sediment yield from the watershed in a threshold channel. Certain kinds of Florida streams or portions of the lotic system fit this description well. Conversely, alluvial channel design is recommended for systems where the stream is free to migrate and freely exchange bed and bank material with the incoming sediment load, which can be described empirically or analytically. Most Florida stream types at least partially fit this concept, but do so under one of the lowest sediment yields among the humid regions of North America. Where bends migrate, they do so very slowly. These factors indicate that peninsular Florida lotic systems generally function under processes that hybridize threshold and alluvial channel effects.

Two-stage channel design is meant to serve as a way to obtain some natural channel functions from drainage ditches, by retrofitting them with small floodplains. This approach has significant merit for application in Florida, especially since most of the state's natural channels have been ditched as single trapezoidal replacements for more complex surfaces that historically exhibited frequent overbank discharge. In fact, many of the design concepts we have embodied conceptualize perennial Florida streams as two-stage channels, including a low-flow or bankfull open channel that typically contains the dry season and normal discharges (about 75% of the time), and a high-flow floodplain channel that carries the wet season discharges (about 25% of the time).

Rosgen geomorphic channel design seeks to restore the dimension, pattern, and profile of disturbed streams by emulating those configurations found in stable natural channels. It is largely shape-based, focusing on observations made in the channel, working under assumptions that dimensionless ratios of channel shape strongly associate with key stream processes. This can be a reasonable assumption for readily deformable streams, especially those under a dominance of alluvial control. Rosgen design methods rely on measurements taken at reference reaches, an analog concept. The method also requires using the empirically derived Rosgen universal stream classification system to characterize the desired condition for the sites, and then scales the site-specific design dimensions based on dimensionless ratios related to bankfull conditions for the appropriate stream class. The approach also includes the use of dimensionless sediment transport equations as an analytical component, therefore the approach is a blend of analog, empirical, and analytical methods. This synthesis has inspired and guided many stream restoration projects across North America.

However, peninsular Florida has few Rosgen stream types; the types that do occur exhibit a convergence of form with distinctly different underlying processes, and many radically different kinds of natural Florida streams are lumped under single Rosgen stream types. Like with Rosgen methods, our design approach was inspired to seek balance among channel dimension, pattern, and profile with watershed conditions. However, it was necessary to derive an expanded viewpoint and a new system tailored to include the geomorphic and stream habitat outcomes based not only from alluvial controls, but also on Florida's intense biological and karst controls. These regionally specific processes are not intrinsic to the more fully alluvial derivation behind Rosgen approaches. We also sought to derive a system with less reliance on dimensionless channel variables, which turned out to be problematic delineators among most natural kinds of Florida streams. The recommended system subsumes and includes some Rosgen classification concepts, and some of the recommended habitat treatments and classification measurements incorporate or adapt Rosgen methods. In other words, we do not recommend designing Florida stream restoration projects solely relying upon Rosgen methods, but see merit to considering such methods as part of a more comprehensive approach.

Although NRCS (2007b) presents each of these design approaches much like separate and complete items on a *table d'hôte* menu, they contain subcomponents that the recommended approach selects and synthesizes in a more *à la carte* fashion, taking the most applicable of multiple proven approaches to get the best overall result. It is important to note that Part 654 of the NEH contains a number of graphs and equations derived from interregional studies or specific landscapes exclusive of Florida conditions. The use of such information may be problematic in Florida and is not recommended.

This guidance manual for Florida stream design is based on systematic and intensive study of Florida streams as systems with functions and values relying upon their sources of water and their hydrologic pathways, biological interactions with fluvial forces, sediment sources, lateral and longitudinal interactions with adjacent waterbodies, and related processes operating among major hierarchical components at the watershed, valley, channel reach, and habitat patch scales. For that reason, the classification and design approaches refer not to stream types, but to stream system types.

Based on these definitions, the recommended approach is typically empirical with tractive force design checks. In some cases, analog design is acceptable or even necessary, also with simple analytical design checks. Such approaches are broadly, but by no means universally, applicable.

APPLICABILITY

The guidance provided in this manual is most applicable to systems where the watershed is stable and functions like a rural basin in terms of its water and sediment delivery. Excessive groundwater pumping, large flow diversions from ditches and canals, farming or silviculture with poor soil and stormwater management, and urbanization without implementation of low-impact designs for stormwater management can all present altered conditions that exceed the bounds of the empirical basis for the design. The further the system departs from a stable rural condition, the greater the need to vet the empirically based design using analytical tools. In other words, this approach is readily applicable in situations where natural processes can be largely maintained or reconstituted at meaningful thresholds. In situations where they cannot, then it will be necessary to attempt to create new kinds of stream systems rather than patterning them after nature.

Stream system restoration can occur in the waterbody and watershed. Designs aimed at both can be most successful, and are essential for success in phosphate mine reclamation. This guidance was developed to restore streams at phosphate mine settings and the methods described are tailored to the characteristics of customary mining and reclamation practices and available materials. However, the tools also have significant application in other rural settings without mining impacts. Few analytical design checks may be required in situations where the reaches immediately adjacent to the project upstream and downstream have a stable grade and lack water control structures, ditches, or canals. Watershed conditions requiring little analytical work would also have less than

20% urban cover (with less than 10% directly connected impervious area), less than 20% of the non-urban basin is ditched, and less than 10% of the basin encumbered by artificial impoundments, including isolated open mine pits or closed basin reservoirs. Watersheds with combinations of such stressors should probably have less than 25% of their total cumulative area affected to rely on the empirical data. Any departures above these thresholds indicate use of significant analytical work to support the design decisions. The nature of the analytical support will differ among settings and is beyond the scope of this manual to recommend, but will typically invoke hydrology monitoring and modeling. The analytical approaches recommended for phosphate mining would be overkill for many simpler situations where the surficial aquifer is undisturbed, nor are they the only conceivable approaches for such mine sites. Drainage ditches in rural settings often cross rather flat landscapes, requiring significant hydrology modeling to assure the restoration will not worsen offsite flooding, especially upstream of the work.

This guidance applies only to freshwater systems and was not developed for use in tidal streams. It applies across the peninsula from the Santa Fe River basin south to the Caloosahatchee and St. Lucie River watersheds. Extrapolation beyond that range may be possible, but not recommended without additional site-specific research. Streams draining more than 500-square-mile watersheds are likely to encounter a mixed regime of highlands, flatwoods, and karst influences and are well outside the range of the regression data. Further, such streams are comparatively uncommon, and for all those reasons should be treated as case studies rather than as systems lending themselves to the categorical design approaches developed for this manual.

Further, stream restoration in urban settings is a matter of significant professional judgment and generally requires knowledge not covered in this manual. The value of attempting to create natural streams in urban watersheds is an open question and a subject of active research and much debate.

We encourage designers to use this categorical guidance as advice and food for thought rather than as a prescription. It is intended to stimulate thinking, not turn it off. We may not always follow it in all circumstances ourselves. Instead of rigid protocols, stream restoration design requires rigorous scientific understanding of process as well as form. It is also a creative endeavor. Each site is an original work and few projects will lend themselves entirely to a paint-by-numbers mentality. It helps to have some constructive self-doubt. Work hard at perfecting your own designs by questioning them in concept and in detail. After all, Heraclitus (c. 500 BC) has told us, “No man ever steps into the same river twice, for it is not the same river and he is not the same man.”

APPROACH OVERVIEW AND DOCUMENT STRUCTURE

Streams are complex ecosystems, but can be broken down into convenient planning hierarchies to facilitate their restoration and management. The first planning level, the landscape, includes the watershed and the aquifers interacting with the stream network. Knowledge of landscape level variables related to soil drainage, karst terrain, contributing area, valley slope, and position in the drainage network enable predictive classification of stream system type. These landscape variables associate strongly with top-down processes structuring the stream corridor surfaces and their dimension. Hydrology, geology, and physiography are the most critical disciplines at this level. Key analytical assessments and management items for the landscape are described in Chapter 8.

The next planning level includes the creation of fluvial surfaces in the riparian corridor, including alluvial floodplain features, the open alluvial channel (bankfull channel), and stream junctions with in-line paralotic and paralentic waterbodies. Various combinations of such surfaces can occur, creating a variety of functional process zones (FPZs) along the valley. The empirical design considerations necessary to be successful at this planning level are centered heavily on the applied discipline of fluvial geomorphology at the reach scale. For many practitioners, this is considered to be the primary component of stream restoration, as it is where the channel and floodplain features are patterned and dimensioned to fit their watershed and valley condition. Chapter 9 provides empirical and analytical guidance for reach design.

The riparian corridor surfaces create template conditions and enter into biologically mediated feedback loops that characterize the habitat potential and associated flora and fauna of the riparian corridor. Particular biological communities tend to associate with the various FPZs and are absent or unlikely in others. These communities distribute along lateral and longitudinal gradients in the riparian corridor with abrupt transitions between them. The habitat occurs in distinct patches that form the ecological pieces of the reach. Biology and soil science are the key disciplines to facilitate the establishment and recovery of these patches as a self-sustaining whole. Chapter 9 provides information on what patches apply best to each stream type and how to sensibly distribute them within the reach. The applied disciplines of soil bioengineering and fishery enhancement structure design are useful here and some Florida adaptations are discussed in Chapter 9.

Conceptualization and design are critical to the success of a restoration project, but are just two of the four legs under the table. Proper construction and adaptive management are the others. Chapter 10 provides some case studies regarding construction approaches tested in the phosphate industry. These techniques are application to a variety of non-mining settings as well. Chapter 11 discusses the need for goal-setting and adaptive management plans, including monitoring during project maturation to help inform the need for maintenance activities and for use as outcome measures defining project success.

CHAPTER 8
LANDSCAPE-LEVEL DESIGN

LANDSCAPE CONSIDERATIONS AND STREAM CLASSIFICATION

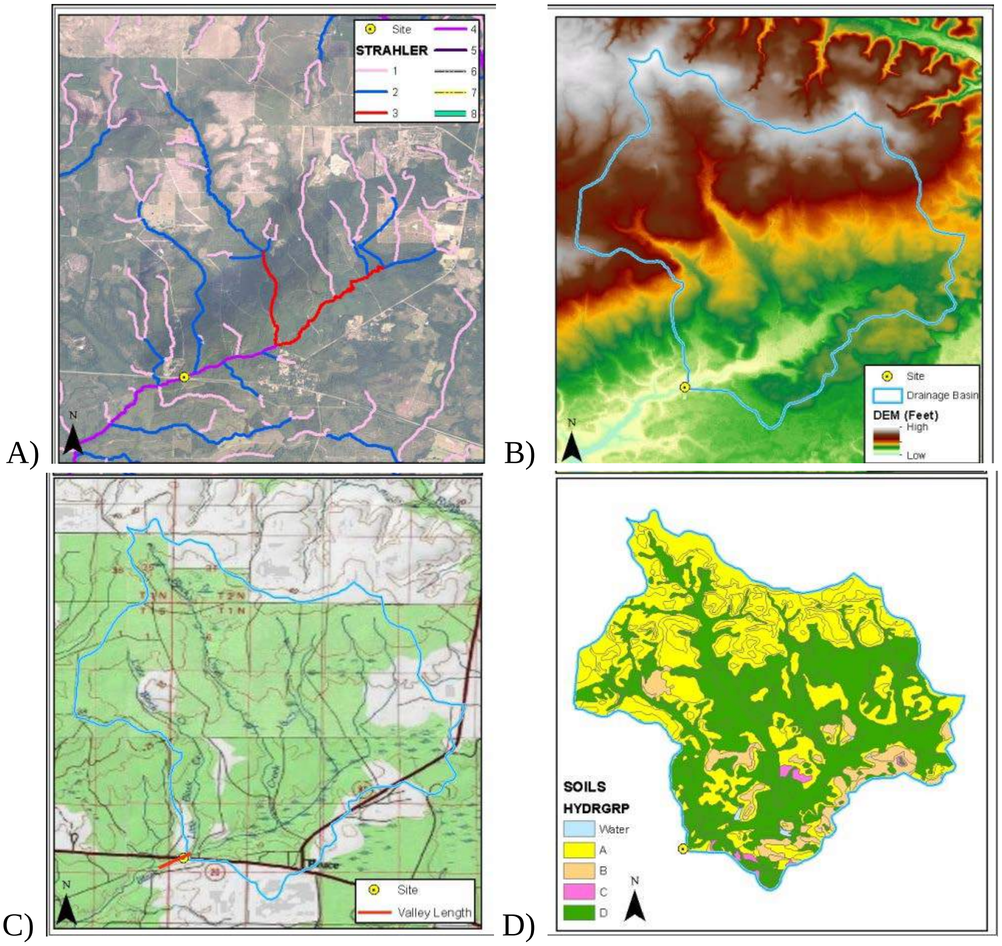
The first step is to conceptualize whether stream restoration is appropriate for the project area, and if so, what kinds of streams are supportable. These questions are best addressed by examination of the prospective stream's primary support systems: the watershed, aquifer, and valley. Important data sources include topographic maps of sufficient detail to map the watershed, aerial photographs from the 1940s through the present, relatively recent LiDAR-derived topography or other sources providing a two-foot contour interval or better for the valley, and NRCS hydrologic soil group maps. This information aids in describing how the land use, topography, and drainage networks have been altered in ways, and at thresholds, likely to impact stream process and function.

Since the classification system requires knowledge of drainage area and valley slope, the following algorithm is provided for making these calculations. Valley slope varies along its axis and provides a scale-dependent solution. Therefore, it is important to exercise careful judgment in following the recommended means to make the slope calculations.

The first step is to delineate the portion of the watershed contributing discharge to the project area. Basin delineation can be completed in the GIS using various information sources, including:

- The National Hydrography Dataset (NHD) layer can be used as your basic hydrological feature layer.
- The Florida Fish and Wildlife Conservation Commission (FWC) has developed a Stream Layer that can be used to assist in determining how far upstream the watershed goes. Symbolizing the drainage segments with the Strahler Order attribute aids in rapidly identifying which sub-basins to aggregate when calculating drainage area for larger watersheds.
- FDEP WBIDs and FDEP_Drainage_Basins_Areas_1997 (or FDEP's updates to this) with the HUCS symbolized can be used to assist in watershed delineation and contributing watersheds.
- LiDAR and USGS 1:24000 topo quads can be used to fine-tune the watershed boundaries (Figure 8.1).

Note that watershed delineation can be complicated when there are canals within the basin that cross the topographic drainage divides. Oftentimes, the purpose of a study is to determine what the natural stream "should" be like; therefore, in these cases one would ignore the canals and delineate the basin based on topographic divides. Once the basin has been delineated in GIS, GIS can then be used to calculate the pre-disturbance drainage area for each site in square miles. For design, however, it is important to base calculations on the actual watershed conditions that will be in place. For drainage divides altered by canals, or those otherwise indeterminate, it may be necessary to model the system to estimate the effective divide at bankfull and flood discharges.



A) Aerial imagery and FWC Strahler classification; B) LiDAR-derived Digital Elevation Model (DEM with NHD basin); C) USGS topo quad; D) Soil hydrogroups

Figure 8.1. Various GIS Information Sources Used for Stream Classification.

The watershed shapefile can then be used to determine each basin's soil characteristics, as these greatly affect how water is delivered to the stream (Figure 8.1). The USDA classifies soil hydrographs as A (well drained), B (moderately well drained), C (moderately poorly drained), and D (poorly drained). To characterize soils for stream classification purposes, one can use GIS to determine the percent of A, B, C, and D soils occurring within the watershed, as follows:

- Acquire soil GIS layers that cover the watershed area of interest.[6]
- After the watershed has been delineated in the GIS, the Intersect Tool should be used to clip the soils of interest within the watershed.

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[6] For Florida soils, the Florida Geographic Library and Water Management Districts Data were used, which originated from NRCS/SSURGO, published in 2006.

- Make a new column in the attribute table to calculate the new intersected areas in square miles.
- If there are soil types that have more than one Hydrological Group associated with the soil type, (e.g., A/D) then the natural group should be chosen for determining pre-disturbance stream type. The natural condition is described by the second letter (which would be 'D' in this example). For design analyses, if the soil drainage has been successfully increased, then their modified condition (designated by the first letter) should be used in the model. To determine the percentages, change Hydro groups that have double letters to single appropriately, and sum by letter.
- Select all polygons that have A and C and export as a new shape file and calculate the percentage of the watershed for each.
- Sites with greater than 40% A+C soils are classified as "highlands." Sites with less than 40% A+C soils are classified as "flatwoods."

Valley scale variables such as valley slope can affect stream variables such as alluvial features, habitat, and channel dimension. Valley slope is a major stream system classifier for a wide range of drainage areas, resulting in different stream types based on valley slope versus drainage area relationships.

Valley slope should be calculated using the best available topographic data. Nothing beats a special-purpose ground survey. If ground survey is used, it is important to begin and end the stations on typical riffles and record bankfull stage at multiple intervening stations at normal riffles as well. However, ground survey is not always available or warranted and reasonable estimates can usually be obtained using available remote sensing data or maps in the GIS. To determine valley slope using existing map data, select a point both upstream and downstream of your site. The location of upstream and downstream points should be chosen at a sufficient distance apart to generate a 5 to 15 foot elevation drop, based on the scale of the map. This is not always possible for small headwater streams connecting chains of wetlands. In that scenario, the seasonal high water elevation of the upstream wetland and of the downstream wetland can be used to calculate the drop. Seasonal high water is determined by finding the approximate edge of wetland elevation. There is some best professional judgment that needs to be used when determining upstream and downstream valley slope location points, as the drop should be fairly uniform across the valley and should not include too many tributaries (ideally none).

Carefully assess digital elevation maps to assure they are not representing a water surface on one panel and bare earth on another, or that they are not otherwise compilations of separate surveys with grossly incompatible characteristics in time or quality that would cause significant errors. In such cases, the USGS 5-foot contour maps are likely to be a superior resource.

The lowest elevations of upstream and downstream points are extracted and the distance between the two points are measured. These values are then plugged into the following equation to calculate the valley slope at each site:

Valley Slope % = 100 × (Upstream Elevation – Downstream Elevation)/
(Distance Between US and DS Points)

For some stream systems, valley slope determination is the final piece for classifying a stream based on the HBG classification system. For all streams, it provides valuable information regarding the potential for a valley to even support a single-thread alluvial channel.

Figures 4.6, 4.7, 4.9 and 4.45 provide nomographs useful for determining the likelihood of an alluvial stream in the project area. Once that is confirmed, then the most likely stream type can be determined following the classification procedure of Chapter 4. By the very way in which stream types were developed, understanding the appropriate type for the landscape helps to assure a proper conceptual framework is engaged to provide sustainable alluvial surfaces and habitat assemblages for the project area. The way to assemble and dimension these surfaces varies by stream type and the means to do so is described in Chapter 9.

Watershed condition should be assessed. If the watershed is in good condition compared to impact thresholds, then no further work in the watershed component of the design is likely to be necessary. The empirical design criteria used at the next two phases of design should apply in a very direct fashion. If the criteria are not met, then watershed improvement design should be explored. A primer in watershed management is beyond the scope of this document, but the ideal goal would be to eliminate the effects of extensive ditching, pavement, and excessive soil loss to develop sediment yields, infiltration and runoff responses with reasonable similarity to a pre-disturbance condition. Particular attention should be paid to delivery of runoff at or near bankfull flow. If a sufficient approximation of pre-disturbance hydrology cannot be established, then the empirical design details espoused in this manual become diminished in their application and a much more analytical approach will be warranted in order to be effective.

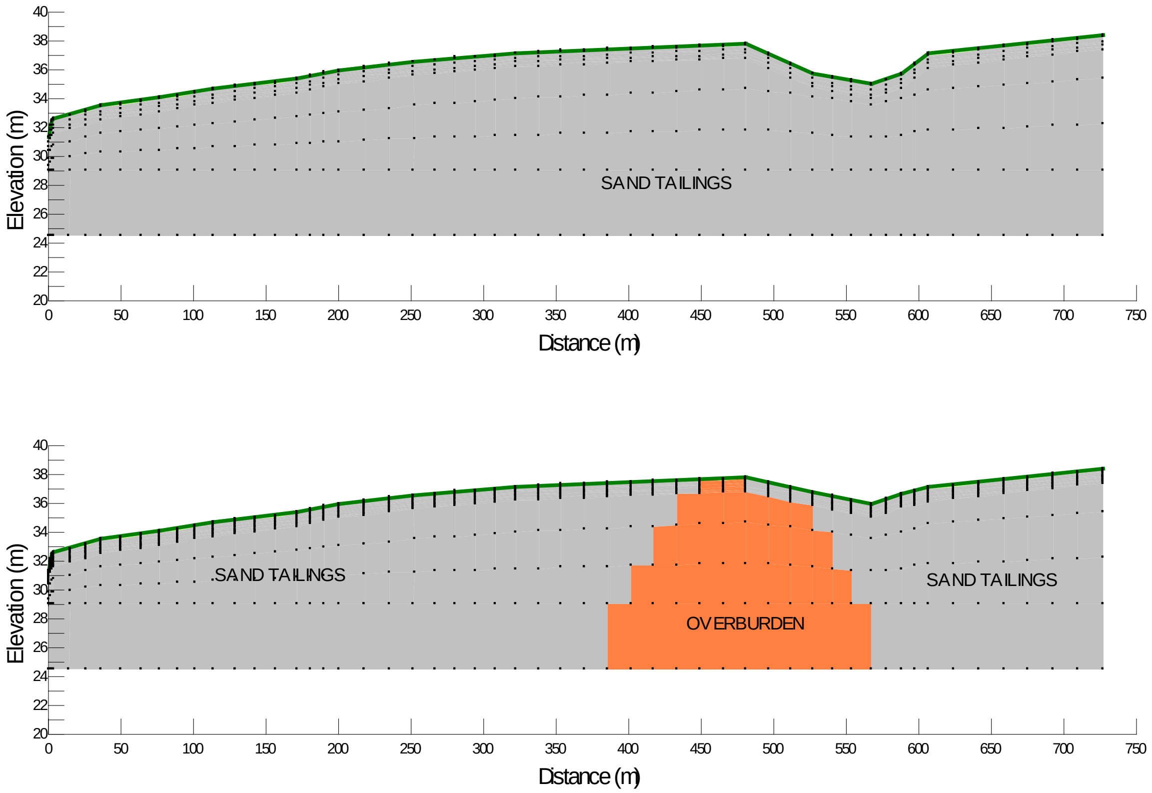
CATCHMENT DESIGN AT PHOSPHATE MINES

Phosphate mining greatly alters the landscape, but key hydrologic functions necessary for stream support can be developed with the prudent re-distribution of the available reclamation materials (overburden, sand tailings, clay tailings, and native topsoil) within the watershed. The drainage area must produce runoff and baseflow that combine to deliver seasonally appropriate flow to the valley. If seasonal high water tables and land surface gradients fall within the desired norms for either highlands or flatwoods basins for most of the watershed, then natural kinds of stream flow can typically be supported. Some amount of groundwater and surface-water modeling during the design process is typically necessary to assure this occurs at phosphate mines. Tightly coupled, fully distributed integrated groundwater-surface water models such as DHI’s MIKE SHE or other models that dynamically represent the overall water balance such as the FIPR Hydrology Model, can provide the required information to test preliminary watershed and aquifer designs to assure adequate streamflow regimes. These are just examples of applicable software, as other appropriate codes are available.

The design concept starts quite literally with a bottom-up tactic aimed at providing subgrading of available sand tailings, loamy overburden, and clay lenses and layers to guide the elevations and directional gradients of groundwater movement toward the stream valley. This is typically accomplished by (1) providing a layer of sandy material near the land surface to accept rainfall and allow some fraction of it to infiltrate vertically into the soil, (2) providing mine cut directions or overburden subgrading configurations to promote saturated groundwater flow in the desired direction (typically perpendicular to the stream valley), and (3) to provide subgrading of overburden lenses and saddles to balance the horizontal hydraulic conductivity so appropriate baseflow is delivered to the stream without excessively dewatering the palustrine wetlands to be created or preserved in the landscape (Figure 8.2).

The thickness of the sandy surface layer will depend on its hydraulic conductivity and the gradients desired and usually must be determined by numerical simulations invoking unsaturated zone physics. Most integrated hydrology models provide such routines. The continuous daily output from integrated models also allows the development of flow duration curves and spells analysis that can be used to confirm statistical flow distributions related to categorical flow regimes (ephemeral, intermittent, perennial) and to calculate the likelihood of continuous flow spells useful for aquatic fauna to complete their life cycles, as well as being able to calculate overbank flow durations and riparian wetland hydroperiods. If a spatially distributed model is not used, then infiltration and groundwater flow sufficiency can be examined by slice models such as Hydrus 2D, mHelp, or Vadose/W. General water table elevations and gradients across the watershed can be assessed either within the integrated model, slice model, or by use of a 3-D groundwater model such as MODFLOW. If an integrated model is not run, then the duration and seasonal frequencies of water table elevations calculated by the groundwater model should be compared to the stream bed elevation as a means for determining the potential baseflow characteristics. The intersections of the groundwater table with the bed could then be taken as an approximation of flow days, but will not quantify the discharge.

Bankfull discharge is critical to maintaining an open channel system and is a function of drainage area. Appropriate bankfull discharge can be predicted using Equations 1 and 2 in Chapter 5, or Figures 5.1 and 5.2. Predicted runoff from the reclamation area can then be benchmarked against the bankfull flow of a natural watershed of the same size by use of an integrated model, or can be simulated separately in flood event routing models such as MIKE 11, HEC-RAS, ICPR or SWMM. If the integrated model is used, a synthetic daily flow record becomes available that can be used to check bankfull frequencies and cumulative exceedance durations in comparison to the range of natural conditions for those variables, as described in Chapter 2. This is the most robust way to confirm appropriate stream hydrology. Numerous combinations of antecedent moisture conditions, rainfall volumes, and storm durations create bankfull discharges, which makes the use of an event model an exercise in substantial professional judgment when attempting to verify bankfull discharges. An integrated model run for at least a 10-year daily climate record with daily stream flow output covers an excellent statistical distribution of such variable conditions, enabling a more robust assessment.



Graphic extracted from Vadose/W integrated hydrology model, Gilshey Branch

Figure 8.2. Overburden Subgrade Used to Alter Groundwater Gradient.

If an integrated model is not used, then an event model should be used to determine at least one representative site-specific design storm producing bankfull discharge for the premining conditions of the project area. Once a pre-mining bankfull storm resulting in regionally applicable bankfull discharge for the project area has been determined, it can be applied to the proposed post-reclamation watershed. The drainage network configuration, topography, soil textures, and land cover classes can be iteratively redesigned until the reclaimed basin provides bankfull discharges from the design storm within some average tolerance limit of the pre-mining bankfull discharge. The bankfull discharges for each reclaimed watershed should fall within the 95% prediction intervals of Figure 5.1. These prediction intervals offer a wide range of natural variability, but it is likely best to design toward the central tendency of the bivariate association to maximize the potential for success. Professional judgment concerning watershed conditions should be exercised when deviating from the regression line.

If event modeling is used, it might be prudent to vet the watershed design further by deriving more than a single bankfull design storm. Most bankfull discharges will occur during the wet season with lentic wetlands at brimful conditions or higher. The base event could follow customary stormwater modeling practices in southwest Florida using an average antecedent moisture condition (AMC II) with a 24-hour duration. On a couple of project areas where this approach was used, a 1.0- to 1.5-inch modified Florida Type-II rainfall distribution provided bankfull discharge. Do not use these results as blanket values; they only apply to the specific sites from which they were derived.

In addition to the AMC II, 24-hour event, exploration of reclaimed watershed response to a series of pre-mining storms with wet antecedent conditions (e.g., AMC III) and perhaps using longer or shorter storm durations than 24 hours, could be used to supplement the base storm evaluation. This would provide greater assurances that the watershed runoff is functioning in a sufficiently natural way. The mean annual event (2.33 year return interval) can sometimes be a good event to test runoff applicable to floodplain maintenance discharges. It is far too large and infrequent of an event to evaluate bankfull discharge in peninsular Florida.

CATCHMENT DESIGN AT URBAN SETTINGS

The regional curves and reference systems included in this report were intended for use at phosphate mines and in rural watersheds. They are not intended for use in urban settings except perhaps as tools for determining just how far an urban system has departed from natural norms. Without deliberately designing the urban landscape to perform otherwise, the increased impervious cover can so greatly alter the watershed’s water and sediment yields that the use of empirical data from stable rural streams in such settings is not likely to be appropriate and would likely fail. The prudence of investing in urban stream restoration remains a complex and open question (Walsh and others 2005, Findley and Taylor 2006). Watersheds with more than 10% directly connected impervious area, or with more than 20% total urban cover, are subject to substantial stream erosion likely to affect the physical and biological integrity of the system (Center for Watershed Protection 2003, Booth and Jackson 1997). Cuffney and others (2010) found that watersheds with even less than 5% impervious cover can adversely affect aquatic fauna in streams, given the wide array of water quality and hydrology alterations in urban systems. Geomorphic effects can take decades to unfold through a sequence of channel evolution phases that often go unnoticed until the late stages of the process.

To invoke natural channel design approaches that use non-urban reference streams, it is necessary to provide stormwater management systems that more closely mimic unpaved landscape hydrology. These techniques generally invoke reducing directly connected impervious areas by use of low-impact development (LID) techniques aimed at increasing groundwater infiltration or widely distributed, small-scale detention storage. Examples include systematic use of infiltration basins, rain gardens, rain barrels, pervious pavement, and vegetated swales, among other treatments. Such systems can be pre-planned in growth areas or retrofitted in areas already developed. Even so, simply restoring the hydrology in a developed watershed will not necessarily prevent (or reverse) the effects of urbanization because the sediment yield can remain altered. Therefore, taking a natural channel design approach to restoring urban streams not only requires advanced watershed stormwater management, but likely also requires the development of regional curves using only stable urban streams. Even if such curves are available, urban stream renewal and protection will require ample analytical assessments to support a restoration design.

In some cases, knowledge of the HBG classification system can be useful for conceptualizing urban stream rehabilitation. For example, based on its watershed size and pre-disturbance soil types, an urban stream in Pinellas County, Bee Branch, was likely a baseflow channel draining a sandy highlands watershed (HL-BFC) prior to development. Such systems lack an alluvial floodplain. Houses were built throughout the watershed, including along the low bluffs adjacent to the bankfull channel. The system responded to increased impervious surface by first deepening and then widening. The widening took the form of building a floodplain bench where one had not historically occurred, undermining the back yards, decks, and swimming pools of the adjacent home sites. The once highland stream's watershed was effectively converted to something more like a flatwoods watershed, and accordingly was building a new floodplain to accommodate the larger flood pulses. Basically, the streamside home sites were in the path of the newly developing floodplain surface.

The solutions therefore could be conceptualized into three alternatives: (1) obtain easements along the stream and rehabilitate the channel and floodplain more akin to a flatwoods system (e.g., FW-AF-CC), (2) rehabilitate the watershed to once again function as a highlands system, perhaps providing temporary in-place stabilization along the stream as the stormwater retrofits were designed, permitted, and implemented, and then restoring the stream to its historic type (HL-BFC), or (3) stabilizing the stream in place and mitigating for its lost ecological functions offsite. Which of those three approaches would be implemented depends on a variety of social and economic factors determined by the community and their elected officials. In this case, the erosional effects were so advanced that the lead times necessary for options one and two were too long and the only viable option was the third one.

This case study is an excellent example of the value of advanced planning tools, such as a county-wide or watershed-wide inventory of stream erosion status and directly connected impervious cover levels, to increase the options for viable solutions before they become emergencies subject to a narrower range of remedies. Such inventories enable local governments to more effectively prioritize their watershed and waterbody management activities.

CATCHMENT DESIGN AT AGRICULTURAL AREAS

Many of Florida's rural landscapes have been affected by land clearing and drainage ditches necessary to promote agricultural use. These hydrologic alterations can be remedied by comparatively straightforward ditch plugging and re-vegetation efforts that restore the runoff capacity of the landscape to something close to a pre-disturbance condition. Once this is accomplished within a stream's watershed, the regional curves and classification system developed for this report are quite applicable restoration guidance tools. Also, the valley slope-drainage area zone-of-confidence graph will provide a good basis for assessing the stream restoration potential of a plowed or ditched valley segment.

Ditches and canals can be providing flood relief to upstream landowners. Therefore, designs must be carefully assessed for their effects on the level of service available to such landowners. Flood event modeling should be conducted for a variety of storm events to assess if offsite flood impacts will occur as a result of the proposed project. A typical basic array of design storms would minimally include the 2.33-, 25-, and 100-year, 24-hour events applied to the existing and proposed conditions for comparison. The model domain needs to extend far enough beyond the project boundary to simulate flow and water levels upstream of the project. Any increase in flood levels offsite is subject to regulatory requirements. In such cases landowners can sign waivers, grant flood easements, or the project's scope can be reduced until such effects become negligible or absent.

If only a subset of a watershed's ditches can be plugged, then surface water event modeling should be conducted using a design storm that provides bankfull discharge and another that provides active floodplain inundation under presumed unditched conditions. Appropriate design storms could be iteratively derived by inputting a pre-disturbance watershed condition without ditches, with its natural NRCS soil drainage characteristics and land cover classes to derive the curve numbers. The drainage network could be approximated using historic aerials and topography maps. Pre-disturbance channel dimension could be estimated using the regional curves. The model could then be used to explore a series of rainfall volumes and durations for those resulting in bankfull and flood discharges for the reaches of interest. Once those two storms are established, they could be used to dimension restored or reconstructed channels to pass the proposed bankfull and floodplain flow volumes as simulated under the proposed partially ditched landscape with its ultimate combination of existing and proposed land use designations. This approach can work well for any watershed that remains sufficiently rural (e.g., less than 10% directly connected impervious area).

Another major consideration for restoring streams in ditched agricultural landscapes involves the base level changes that have occurred in the downstream and lateral connections to the restored channel. These can be too low to support the original channel elevations, requiring a system to be at least partially entrenched. Transitions between deep ditches and restored streams may require special engineering considerations. Another key consideration is the presence and density of livestock in the restored riparian corridor. Best management practices should be followed to protect the restored corridors. Ideally, cattle would be excluded from the restoration area completely as it matures.

Sprayfields, wastewater residuals application, septic systems, and nitrogen-based fertilizers can affect water quality in karst streams sometimes very remote from the pollutant source. Springshed protection and best management practices to prevent or reverse cultural eutrophication of springs are a major consideration for assuring the biological integrity of karst streams, which, in turn, can also strongly associate with their physical integrity.

Secondary effects on streams can occur due to groundwater or surface water withdrawals for agricultural irrigation, municipal supply, and industrial uses. Most major stream systems are protected directly through minimum flows and levels (MFL) adopted by the Florida Legislature. However, the vast majority of mid- to low-order streams are not, and most major aquifers were over-allocated prior to MFL adoption. More continuous hydrology gaging of small “sentinel” streams is warranted, as these systems are most vulnerable to landscape alterations and are likely to show impacts before they appear in larger systems.

VALLEY DESIGN

This section focuses on how to select from among a suite of potential geomorphic surfaces within the valley that carry flowing surface water, forming lotic systems. Common assemblages of stream channel types, floodplain surfaces, and adjacent in-line waterbodies are associated with specific aquatic and vegetative communities into self-sustaining landscape combinations. These assemblages form distinct FPZs. It is important to note that FPZs are process-based descriptions of land surfaces that can be readily identified in the field. This is predominantly a fluvial geomorphic design component, but one that ultimately sets limits on the kinds and distribution of habitat. Certain combinations of FPZs are more common in particular watershed size ranges and positions in the drainage network. Thus, conceptualizing the valley setting and associated FPZs are critical initial design steps preceding the selection and dimensioning of various surfaces in the riparian corridor and concurrent designation of biological habitat components.

Chapter 3 provides information related to valleys. Five valley types were characterized based on valley confinement (seepage ravines, upland confined, wetland confined, unconfined, and well-adjusted). These features are variably, but not randomly, occupied by the 15 different kinds of alluvial streams described throughout Chapter 4. Some non-alluvial FPZs also form important components of lotic systems in Florida’s deranged networks. These non-alluvial systems could be described as lentic, paralentic or paralotic in terms of their hydrogeomorphology. They include in-line sloughs, wetland depressions, lakes, lagoons/billabongs, floodouts on seepage slopes, and spring vents. Certain non-alluvial FPZs associate more strongly with certain stream types. Therefore, it is convenient to initially determine the right stream type for a valley segment, and then proceed to the alluvial and non-alluvial valley-type associations appropriate for its lateral and longitudinal boundaries. Natural combinations of HGB stream type, valley type, and adjacent colluvial features can be used to conceptualize FPZs for each valley segment.

Consistent with the recommended design concept and design sequence, characteristic combinations of FPZs are described for each stream type. Stream types are organized into their watershed types and then their position in the drainage network. Stream type can be identified using field procedures, if the stream has not been obliterated or otherwise damaged, or can be predicted using soils data, watershed size, and valley slope. Once the desired stream type and the project's existing valley condition are known, the designer can conceive appropriate FPZs.

The riverine landscape can be viewed as a lotic system comprised of an open channel (riverscape) and a vegetated floodplain (floodscape) (Thorp and others 2008). These are unique geomorphic surfaces. For design purposes, it is convenient to view the riverscape as being equivalent to the bankfull channel dominated by sediment transport. This definition is consistent with those of Rosgen (1996) and USFS (2003). Above the bankfull channel, sediment transport is greatly and rapidly diminished. In an alluvial floodplain, sediment deposition dominates the floodscape and in a colluvial floodplain alluvial transport and deposition is minimal to absent. The floodscape can have wetland or upland vegetation, depending on a variety of factors, and a sharp geomorphic transition is not present along all floodplain margins in Florida. Therefore, the floodscape is defined as the surface within the meander belt for design purposes. The surfaces bordering the exterior of the meander belt can be alluvial or colluvial and can consist of a wide array of habitat types. In some cases the valley hillslope upgradient from the floodscape can be a critical component of the riparian corridor, offering important control on the sediment and chemical loads to the lotic system. In such cases, we have offered some design concepts for the valley hillslope outside the meander belt. Therefore, the design surfaces are organized into riverscape, floodscape, and riparian buffer components.

CHAPTER 9
REACH-SCALE DESIGN

DESIGN METRIC OVERVIEW

Every stream segment requires a complete set of specifications to assure appropriate channel habitat complexity and stability, based on the existing and historic on-site conditions. Stream dimensions are typically described from three perspectives: cross-section, profile, and plan view. Collectively, these perspectives define the stream geometry in three dimensions. These dimensions provide the most fundamental basis for the design. They also work in concert; changing a variable in one perspective typically changes variables in others. Some of the metrics function as construction specifications and others serve as analytical checks on the suitability of the construction metrics being prescribed. Each parameter typically included in the master design table at the reach scale is explained below. Suggestions for applying the segment design metrics to each stream type follows.

SEGMENT DESIGN

Planview Components

Stream-Channel Length and Sinuosity Ratio

This is the total length of stream channel to be created. It is an essential construction specification and permitting metric. It also must be in accordance with the valley length regarding acceptable ranges for sinuosity (Sr) and channel slope. Sinuosity is the length of channel divided by the valley length. It is also the valley slope divided by the slope of the channel. Segment-scale sinuosity ratios of PFCP blackwater streams were characteristically about 1.3 to 1.5 (Table 9.1). Sinuosity ratio is a design guide with a fair degree of flexibility, except in some cases where the sinuosity is an important design factor in assuring proper channel friction and/or slope to slow down velocities to acceptable levels in areas with steep valley slopes. We have seldom found this metric to be a prime driver for reach-scale design in peninsular Florida because of the wide range of conditions presented by nature and usually apply it as a design check rather than a construction specification.

The means for all metrics provided in Table 9.1 are based on a limited number of measurements (n = 1-6 per stream type) and the ranges are modestly extrapolated from the limits of the measured data among sites. They are provided to give the designer a sense of how the design compares to some empirical information.

Table 9.1. Segment Design Metrics by HBG Stream Type.

Stream Type	S_R	R_C (ft)	R_C/W	MBW (ft)	D_{TW} Pool/Riffle Ratio	W/D	BHR
FW-CV-WC	1.33 (1.05-2.10)	13 (8-20)	1.4 (0.9-2.0)	45 (30-75)	2.0 (1.4-2.7)	18.6 (12-40)	1.1 (1.0-1.4)
FW-CV-NC	1.35 (1.10-2.10)	13 (8-20)	1.8 (1.2-3.0)	54 (25-75)	1.5 (1.3-2.0)	7.0 (3-11)	1.2 (1.1-1.5)
FW-AF-CC	1.47 (1.10-2.10)	30 (10-60)	2.0 (1.2-3.0)	103 (75-200)	1.6 (1.3-2.0)	10.2 (6-15)	1.2 (1.0-1.6)
FW-AF-WF	1.42 (1.05-2.10)	43 (25-80)	1.7 (1.0-3.0)	155 (75-250)	1.5 (1.3-2.3)	23.9 (15-70)	1.0 (1.0-1.1)
FW-AFS-LG*	1.30 (1.05-2.10)	44 (30-100)	1.1 (0.8-2.0)	257 (150-450)	1.8 (1.3-2.3)	36.2 (15-100)	1.0 (1.0-1.1)
FW-AFS-HG	1.26 (1.05-2.10)	60 (30-100)	2.0 (1.2-3.0)	253 (140-400)	1.3 (1.2-2.0)	9.7 (5-14)	1.4 (1.1-1.8)
HL-RSC	1.23 (1.05-1.80)	10 (5-20)	1.9 (1.0-5.0)	32 (15-70)	2.4 (1.5-4.0)	7.6 (2-15)	1.6 (1.1-2.8)
HL-BFC	1.38 (1.05-1.80)	13 (6-25)	1.4 (0.8-2.0)	56 (30-90)	1.8 (1.3-2.3)	12.4 (3-40)	1.2 (1.0-2.0)
HL-AFS	1.31 (1.05-1.80)	50 (20-100)	1.3 (0.8-3.0)	186 (100-300)	1.5 (1.3-2.0)	23.2 (12-40)	1.3 (1.0-2.1)
K-LM	1.09 (1.03-1.20)	13 (5-30)	1.0 (0.6-1.4)	34 (15-75)	1.8 (1.4-2.3)	32.5 (6-70)	1.9 (1.1-3.0)
K-MM*	1.04 (1.01-1.20)	132 (30-250)	3.7 (1.0-6.0)	67 (40-100)	1.4 (1.3-2.0)	23.6 (6-80)	1.3 (1.0-2.0)
K-HM*	1.10 (1.03-1.40)	135 (30-250)	2.7 (1.0-6.0)	138 (100-200)	1.8 (1.3-2.3)	32.0 (10-100)	1.3 (1.0-1.8)
K-GM-WC*	1.06 (1.01-1.20)	**	5.8 (2.0-6.0)	504 (150-600)	1.3 (1.2-2.0)	131.0 (40-200)	1.6 (1.0-1.8)
K-GM-DC*	1.12 (1.05-1.40)	86 (40-120)	1.8 (1.0-4.0)	202 (150-250)	1.5 (1.3-2.0)	33.3 (10-100)	1.1 (1.0-1.8)
CV-CG*	1.42 (1.05-2.10)	17 (6-30)	2.1 (1.0-3.5)	76 (20-130)	1.3 (1.2-1.5)	8.3 (3-12)	1.6 (1.2-1.8)

Values are the mean among sites (with recommended ranges in parentheses).
S_R = Sinuousity ratio at the reach scale. Valley scale sinuousity is typically larger.
R_C = Average reach radius of curvature.
R_C/W = Mean reach radius of curvature divided by mean reach bankfull width.
W = Bankfull width.
MBW = Meander belt width at reach scale. Valley scale is typically wider.
D_{TW} Ratio = Thalweg depth at average pool divided by average riffle depth in reach.
W/D = Bankfull width divided by bankfull hydraulic depth.
BHR = Bank height ratio, thalweg depth at top-of-bank divided by bankfull thalweg depth at riffle.
*Recommended range is preliminary due to small sample (n<3).
**Very gradual bends with curvature on order of 1,000 ft.

Number of Bends and Radius of Curvature

Bends provide velocity gradients that create microhabitat opportunities for macroinvertebrates and fish, dissipate energy, and create complex foci for sediment transport and deposition. Bend geometry, particularly radius of curvature (Rc) and the ratio of Rc to bankfull width (Rc/W), vary along the stream and also by stream type and size (Figure 9.1). Typically, 3 to 4 bends per 20 bankfull widths occur. A bend must have an Rc/W less than 6, else it is defined as a straight run.

Streams should be restored with bend geometries that fall within the normal and natural range of Rc/W ratios for their types (Table 9.1). Bends should not curve too severely and some variability in patterns should be created among bends. Few Florida streams have consistent wavelengths and amplitude patterns among bends. The meander patterns tend to be irregular with variably long straight sections alternating with comparatively tight clusters of bends. It is often useful to commence the meander design with a GPS survey of a nearby stable stream of type and scale compatible with the project purpose and then mimic the surveyed pattern in the design (Figure 9.2). The topology can then be checked and rescaled to assure it meets the appropriate range of bends per stream length, and tolerances for Rc and Rc/W. Bends and their associated Rc/W ratios and overall segment sinuosity assure appropriately high ratios of bank length to surface area and a variety of bank slopes, all of which serve to dissipate energy within the bankfull channel.

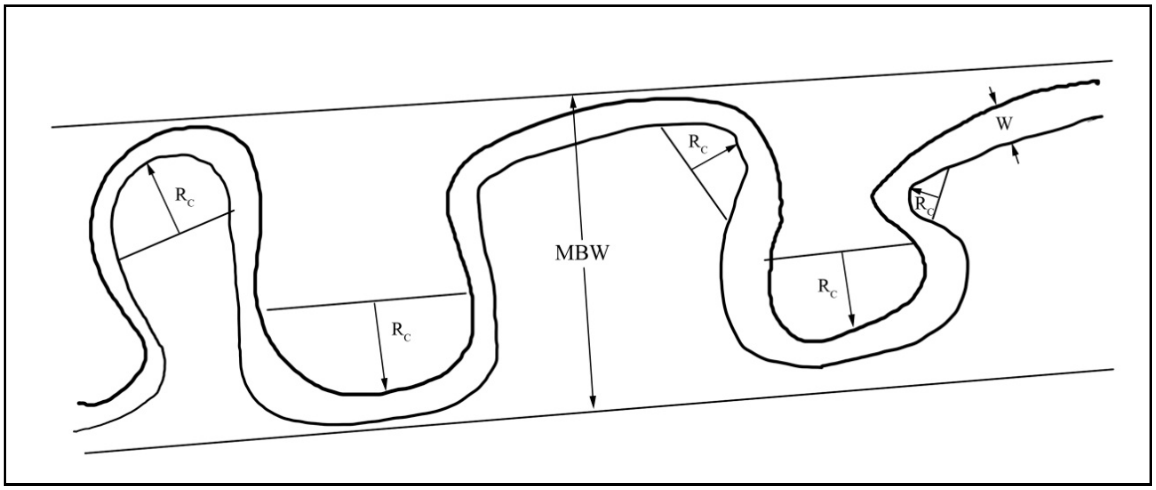


Figure 9.1. Planview Illustration of Meander Belt and Radius of Curvature.

Image flown 2010, post-construction, DB-5 stream reclamation site. Meander pattern copied from a natural site and applied to restoration design.

Figure 9.2. Example of Characteristic FW-CV Channel Meander.

Meander Belt Width and Floodplain

Meander belt width (MBW) is the zone that the stream channel meanders through as bends migrate over long time frames. This can be viewed as the “wiggle room” for the stream (Figure 9.1). The meander belt surfaces are alluvial where bend migration is common, and can be colluvial in streams within upland and wetland confined valleys.

The latter have meander patterns seemingly dependent on rare events with generally fixed channel planform. The genesis of the meander belt surface varies by stream type. Irrespective of the flood frequency and duration, the meander belt represents a zone occupied by the channel system over time, and is an upper-level hierarchical design component. Once the meander belt width is set, then the adjacent surface can be dimensioned. The slopes and elevations of this surface will depend on the valley type and the desired wetland width. The meander belt width also sets some intrinsic limits on bend geometry. Table 9.1 provides information for establishing belt width as a function of stream type.

The horizontal distribution of various alluvial and colluvial floodplain surfaces should be mapped in planview (and cross-section) for the meander belt and its adjacent riparian buffer or valley hillslope (Figure 9.3). This includes surfaces anticipated to exhibit different energy regimes, sediment supply, and vegetative communities. It also includes depiction of the lateral hydraulic exchange locations and invert elevations between the floodscape and riverscape when such junctions are concentrated in small areas as opposed to being laterally diffuse. It is useful to reference surface elevations against bankfull stage in the design process, although elevations and contour lines are to be depicted in standard vertical datums (e.g., NAVD-1988) in construction plans.

Various flood flow ways should be dimensioned (top W, D, bed W, side slopes, long slope). This is mainly required for systems with linear backswamps or secondary floodplain channels (chutes) separated from the main channel by an alluvial ridge. Chutes tend to be connected to upstream inlets and downstream outlets and are narrower and shallower than the bankfull channel. Linear backswamps are wider and shallower than the bankfull channel. They tend to have upstream inlets and downstream outlets in mid-order streams. In major rivers with very gradual riverine water surface profiles and high alluvial ridges (e.g., middle Suwannee River), backswamp-to-riverscape connections may be limited to a single downstream opening in the alluvial ridge, which serves as an inlet to the floodplain during flood rise and an outlet to the river during flood recession.

River water exchanges with valley flats typically occur across broad areas of the shoreline. In such cases, specifying the width and general elevations of the valley flat is sufficient. Oxbows, by definition, are abandoned channels cut off from the main channel that receive river water during floods. Oxbows tend to be similar in width to the bankfull channel, but shallower. Sinkholes can occur in some riverine floodplains. These can be variably mantled by alluvium, with some connected to subterranean conduits allowing complex water exchanges between the river, aquifer, and floodplain surface.

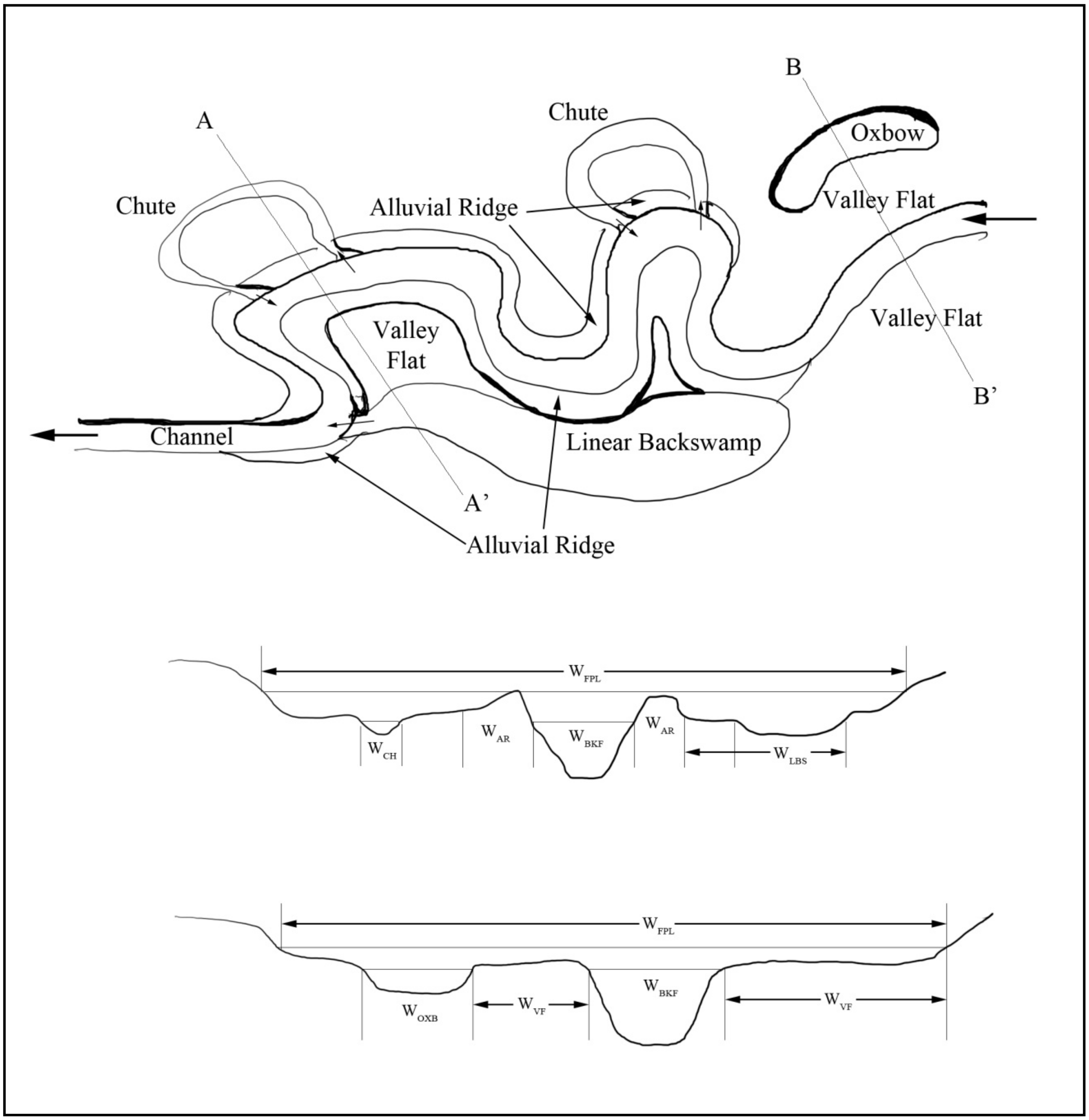


Figure 9.3. Planview and Cross-Section Schematics of Alluvial Floodplain Surfaces.

Longitudinal Components

Inlet and Outlet Inverts

These are the vertical boundary conditions between which the stream is “strung.” The upstream or inlet invert is usually set by the outfall conditions desired in the headwater wetland or other connecting conveyance. If from a wetland or lake, this often functions much like a natural broad-crested weir prior to entering the channel and is often approximated as six inches below seasonal high for the wetland at sites draining less than a few square miles. The downstream or outlet invert is set by a connection point to an existing stream bed or wetland. Sometimes the wetland connection points are depositional areas and a small delta can form at the stream outfall in the wetland at the connection. Chapter 6 provides a library of case studies that could be used to guide wetland-stream transition designs. Because stream profiles vary along riffle-pool sequences, it is important to be sure the invert elevations are measured and specified at the nearest riffle for channel-to-channel connections. Tables 6.1 and 6.2 provide examples of wetland-stream transition dimensions for several low-order stream cases and Figure 6.10 provides a planview schematic useful for designing such transitions.

Key channel inverts can also be located at relatively sharp inflections between two slope regimes along a valley segment or at areas where lateral inflows from the watershed increase substantially (e.g., from a tributary stream or spring vent).

Designs for reaches being tied into ditches or otherwise unnatural or unstable connecting waters require site-specific engineering knowledge beyond the scope of this natural channel design manual. Designs in such settings are unlikely to achieve long-term stability without geotechnical engineering specifications at the transitions between the restored and unrestored reach. In some cases, a simple linear transition can be made from the entrenched connection point upgradient along the design channel if the receiving waterbody is not actively headcutting and the resulting bed and valley slopes are within natural channel norms for the appropriate stream type. These latter two conditions should always be checked thoroughly even if the receiving stream is natural and banks appear to be stable near the connection.

In uncommon cases where new stream valleys are created at mining operations and the connection points are made to the floodplain of a preserved large stream where no connecting channel historically existed, care must be taken in selecting the location of the junction. This can create instability if the edge of the floodplain encompasses a scarp with steeper longitudinal slope than a natural stream valley typically accommodates. Connections at such locations may require geotechnical engineering design and earthwork within the floodplain to prevent headcutting across the scarp and into the reclamation.

Riffle-Pool Sequences

It is highly useful to provide a long profile that traces the vertical pattern of the channel thalweg and identifies the locations of riffles and bend pools using linear stationing to define their apexes and inflections for construction purposes (Figure 9.4). A simple effective design approach is to locate the contoured pools at each bend and place the riffles halfway between the adjacent upstream and downstream bends. For larger stream types with more complex bed materials of rocky or highly cohesive bed materials, it may also be useful to add details regarding glides and runs, but we have yet to find compelling cause to implement such information in peninsular Florida streams with mobile sandy beds.

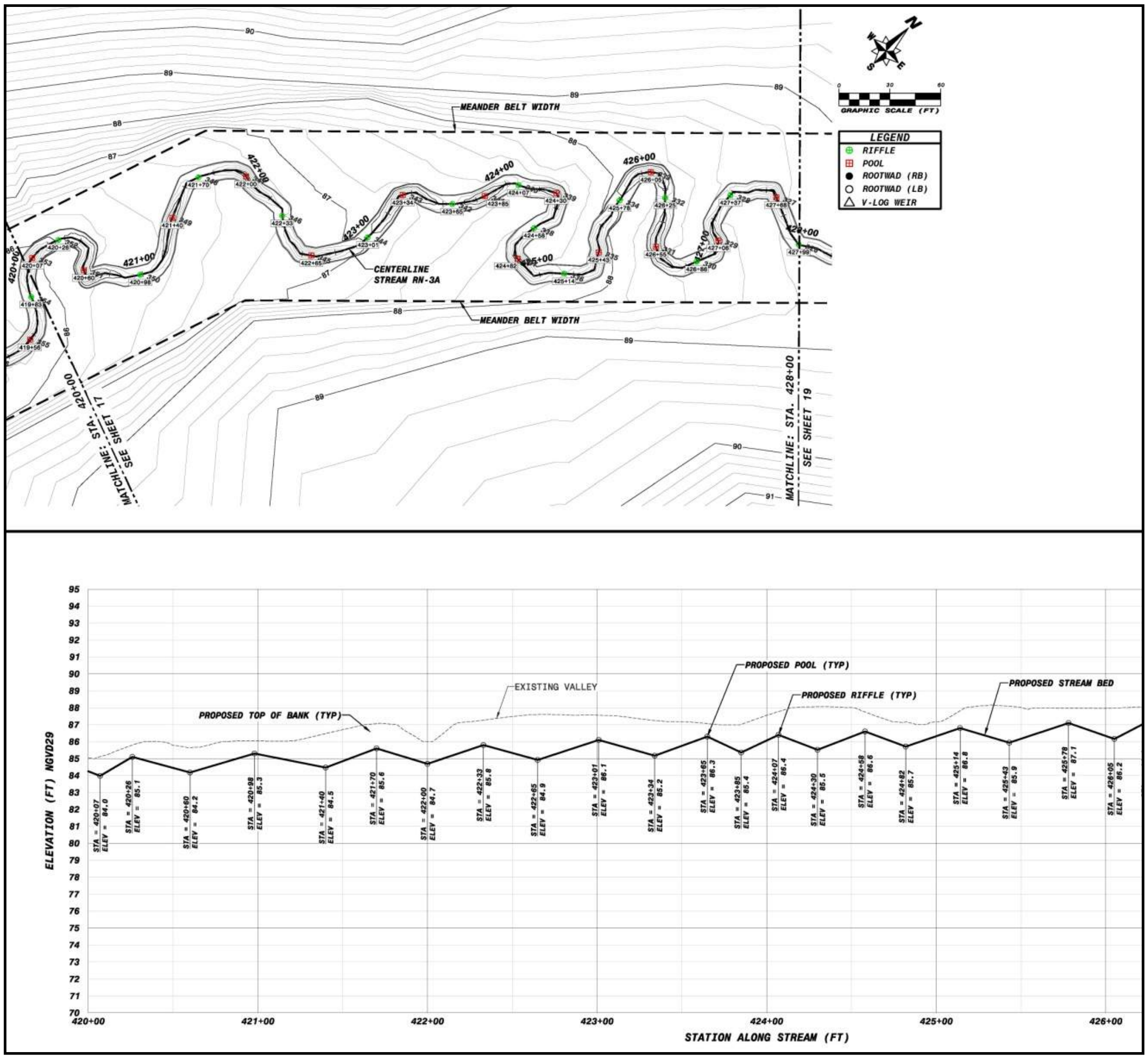


Figure 9.4. Design Example of Planview and Profile for Riffle-Pool Sequences.

A decision must be made concerning whether the top-of-bank will be concordant with the bankfull elevation. This varies by stream type and objectives for the hydrology of the floodplain. For example, some headwater streams are naturally entrenched a few inches and some larger streams have pronounced alluvial ridges along the channel margins. The resulting top-of-bank width and elevation should be depicted on the plan view, profile, and cross-section diagrams as separate breaklines from the bankfull elevations when they are not the same. In profile view, it is important to depict the locations and dimensions of any floodplain inlets and outlets through the alluvial ridge or channel bank. These can be shown in more detail as lateral cross-sections if desired.

Channel Slope

This is a design-check that is a function of the inlet and outlet inverts and contoured stream length. It must be within the typical ranges established for the reference reaches of similar stream classification types. Typically if the valley slope and sinuosity ratios are within natural norms, the bed slope is not necessary to consider because it is the multiple of those two variables. Variations can occur if the valley slope and bed slope were measured at different valley segment lengths. Channel slope should be carefully considered where unusual connections are being contemplated, or where site conditions require a change in slope within the reach for which the valley slope and sinuosity ratio were considered.

Cross-Section Components

Riparian Corridor (Riverine Landscape) Cross-Section

The riverine landscape consists of the open channel (riverscape), floodplain within the meander belt (floodscape), and land surfaces adjacent to the floodscape (which are referred to as terrestrial buffers for convenience, although they can be a variety of surface types). The floodscape and valley hillslope can dwarf the riverscape. Therefore, it is best to provide a set of cross-sections that define the overall valley at an appropriate scale and then to provide a set of supplemental cross-section details of the riverscape.

The riverine landscape sections should depict all alluvial and colluvial surfaces, if any, in the floodscape and buffer. Subtle differences in grade affecting hydroperiod and floodplain community composition are to be depicted. The section should also depict minimum depths of soil layer amendments, if necessary for the project purpose (Figure 9.5).

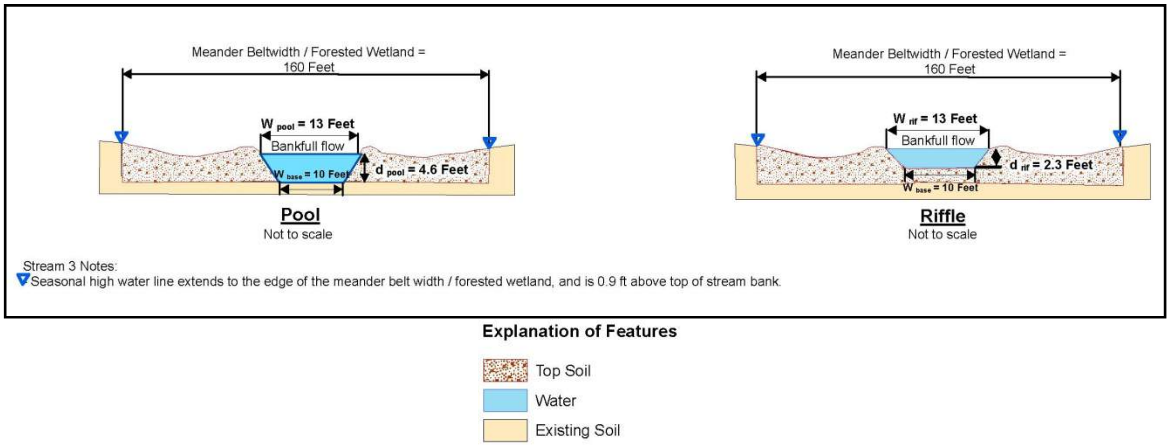
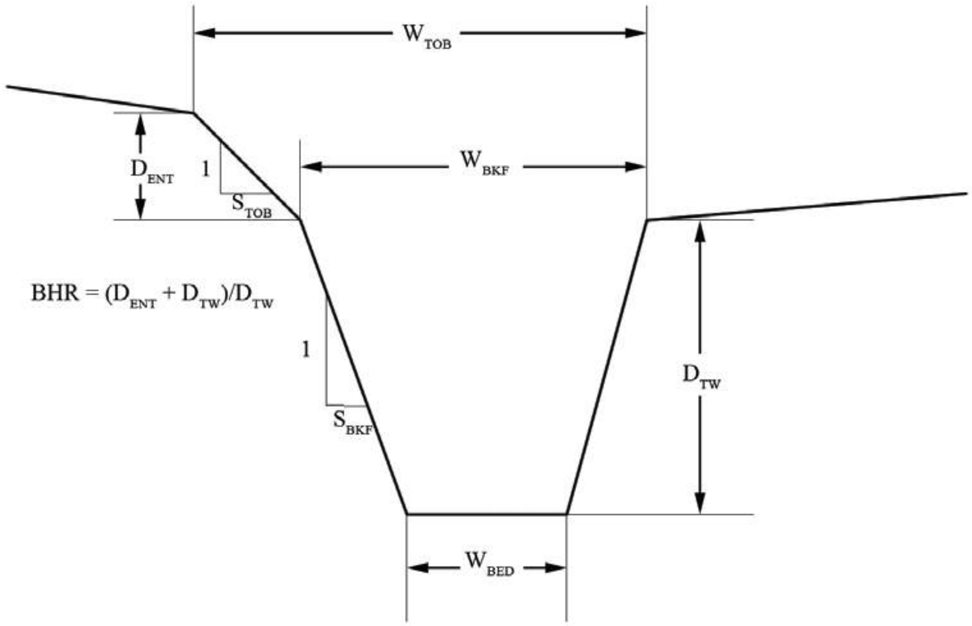


Figure 9.5. Example of Channel and Floodscape Cross-Section Schematic.

Riverscape (Bankfull Channel) Cross-Section

A prototypical cross-section is defined as a trapezoidal channel defined by its entrenchment depth (D_{ENT}), slope of entrenchment (S_{TOB}), top-of-bank width (W_{TOB}), bankfull width (W_{BKF}), thalweg depth (D_{TW}), bank side slopes (SB), and bottom width (W_{BED}) (Figure 9.6). The section is referred to as prototypical because it represents a central tendency form that will self-adjust gradually after construction, likely taking on a more irregular shape. Dimensions are referenced against bankfull stage. Bankfull stage may be nearly level with the floodplain. In such cases, the entrenchment depth (D_{ENT}), slope of entrenchment (S_{TOB}), and top-of-bank width (W_{TOB}) need not be specified.



Notes:
1) Both sides can be entrenched, or neither, depending on stream type and riparian community
2) S_{BKF} is typically steeper than S_{TOB}.
3) Generally W_{BKF} and D_{TW} are established using regional curves and W_{BED} is iterated to match A_{XS} on its curve. Thus, S_{BKF} becomes a dependant variable. Bank slopes can be close to vertical or much more gradual.

Figure 9.6. Schematic of Riverscape Cross-Section.

The design dimensions are calculated from regional curves and regressions provided throughout Chapter 5. It is important to note that the primary design depth used is the maximum depth of a typical riffle cross section (D_{TW}). It is less than the maximum depth in a pool. This prototypical cross-section forms an “anchor” from which construction may deviate within limits set by the fluvial geomorphologist. For example, pool thalweg depths can be designed using a range of pool-riffle depth ratios that vary by stream type (Table 9.1). This approach leads to cross-sections at pools and riffles with appropriately different dimensions and shapes.

Once the initial prototypical cross-section is established, it can be tweaked to assure the dimensions fall within normal ranges appropriate for the landscape setting and stream type for cross-section area and a series of shape factors including average depth (hydraulic depth), width/depth ratio, bank height ratio, and entrenchment ratio.

Bankfull area (A_{BKF}) is calculated using regressions, and the design should be as close to the regression line as possible. Mean bankfull depth (D_{BKF}) is calculated from the prototypical section and can be compared to the regional curve values on Figure 5.21. Then the W_{BKF}/D_{BKF} (W/D) ratio is checked for consistency with the desired Rosgen classification or the natural range for the desired HBG type. For example, W/D less than 12 is a Rosgen E-type. This is important for some HBG stream types and irrelevant to others.

Belt Thickness

This is a metric of importance to phosphate mining areas and is simply the average depth below the ground surface that the sandy and riparian organic substrate material is placed within the meander belt. It is typically similar to or greater than the thalweg depth of the stream (Figure 9.5). Specifying appropriate soil layers within a belt thickness zone could also be useful in circumstances where new floodplains will be constructed at lower elevations than the site's existing grade; for example, when a new stream valley is to be contoured on natural ground in an area that did not historically support a stream, or a two-stage channel is to be constructed where the local base level was lowered by deep ditches and the new floodplain must be built at lower elevation than the pre-disturbance condition.

IN-STREAM HABITAT DESIGN

Boundary Substrates

Stream types in many parts of the world are readily identified based on threshold differences for the transport and supply of different caliber rocks along a longitudinal gradient across physiographies with substantially different valley slopes and associated unit stream power (Rosgen 1996, Montgomery and Buffington 1997). For example, the boundary substrates associated with streams in the mountains (boulders and cobble), piedmont (pebble and gravel) and coastal plain (sand and silt) portions of the watershed are excellent indicators of process-based differences in geomorphic function in such regions. Florida offers no such pronounced gradients, and instead of systems sorting into logical types based on the effects of relief on rocks, the systems sort based on threshold differences in biological versus alluvial processes associated with the magnitude and duration of the relative amount of groundwater versus runoff water sources.

The vast majority of peninsular Florida streams are dominated by bed materials consisting predominantly of fine to medium sands, with 0.25 mm diameters being a characteristic median value. Special cases are presented by groundwater-dominated systems such as root-step channels with important living weirs formed by massive root dams and by autotrophic spring runs where the alluvium is generated autochthonously by detrital processes. Some streams cross limestone outcroppings or have cut to other resistant materials such as stiff clays or iron-cemented sands. These resistant layers form geologic grade controls that can substantially alter bed slopes and channel dimension. The identification of the location of such controls within, upstream or downstream of the restoration reach is important prior to conceptualizing the restoration and determining how to apply the guidance of this document, which is based on systems that are not under dominant geologic control.

Bank materials are more variable by stream type, and can consist of organic soils, colluvial sands, alluvial sands, silty loams, or mixtures of any of these materials. For this reason, it is important to identify the processes that will sustain the near-bank surfaces and, if soil amendments are required, identify a compatible soil composition.

The most important hard substrate for aquatic fauna in southeastern U.S. coastal plain streams consists of large woody debris (LWD) (Benke and others 1986, Benke and others 1984, Thorp and others 1985). LWD for design purposes can be any piece of wood at least 4 inches in diameter and more than three feet long. Because of LWD’s biophysical importance, design guidance is provided for systematically introducing in-stream snags and root wads.

Number of In-Stream Snags

Large roots and snags often induce localized pool and shoal foci that supplement the major pool/riffle patterns associated with channel bends. Thus, LWD provides hydraulic structure as well as hard-substrate habitat for aquatic fauna. The pools and shoals resulting from wood hydraulics are referred to as induced surfaces. Determination of the amount of LWD to be placed in a stream should consider physical and biological functions.

The number of large snags (typically 4-8-inch diameter in headwater stream, with the addition of even larger pieces in larger streams) to be installed in the stream is specified based on the number of pools appropriate for the reach, snag inventories of on-site reference reaches, and snag densities reported from other natural streams in peninsular Florida. Snag densities in peninsular Florida blackwater streams are typically two to four pieces of large woody debris (LWD) per 100 LF of stream, and two to six in spring runs (Table 9.2). Large snags will create localized hydraulic conditions that will facilitate the rapid formation of a rough stream bed/bank profile.

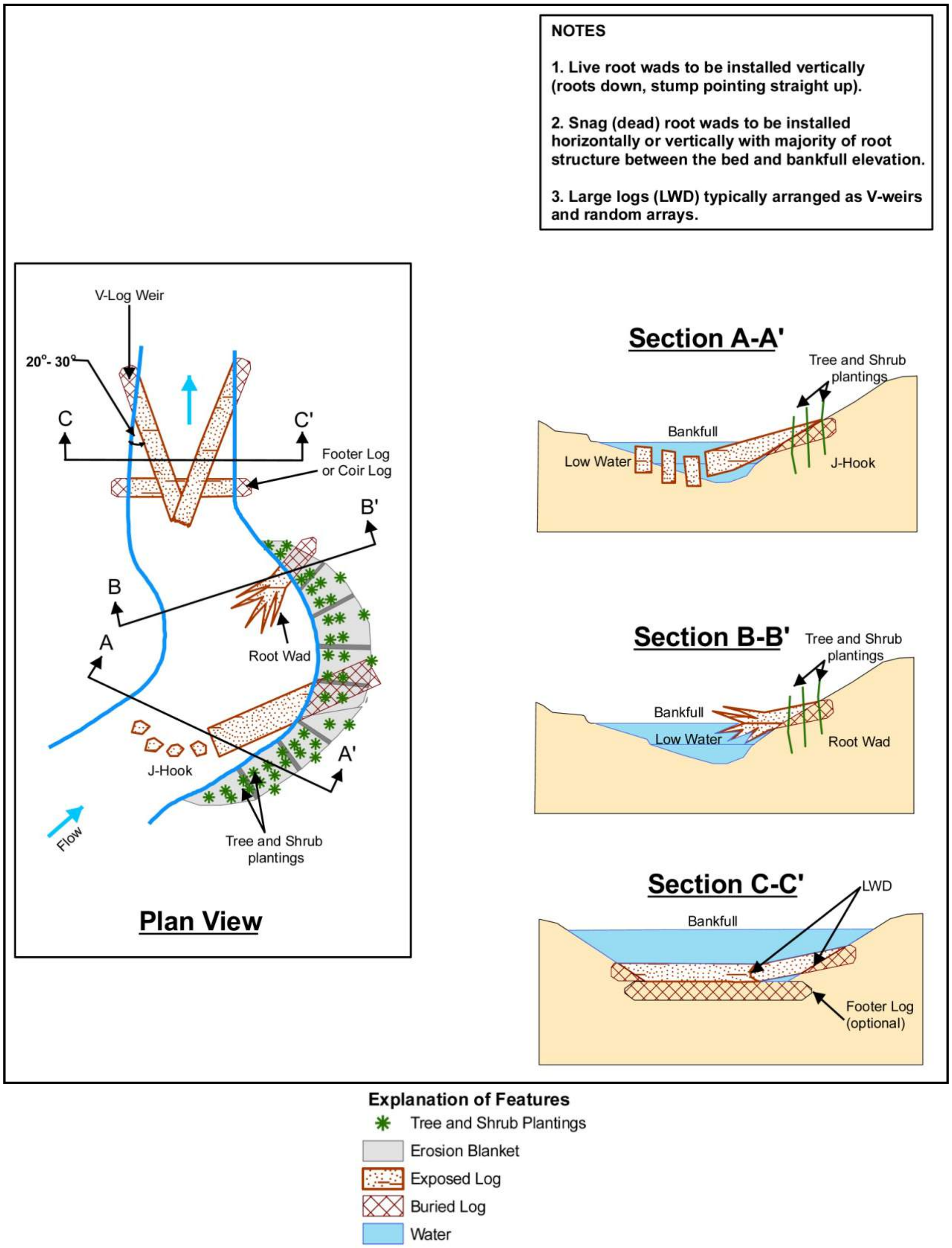
The means for all metrics provided in Table 9.2 are based on a limited number of measurements (n = 1-6 per stream type) and the ranges are modestly extrapolated from the limits of the measured data among sites. They are provided to give the designer some sense of how the design compares to some empirical information.

Table 9.2. In-Stream Habitat Design Metrics by HBG Stream Type.

			Pool Depth Distribution				
Stream Type	LWD/100 LF**	Pools/100 LF	%Shallow (1-2')	%Medium (2-4')	%Deep (>4')	%SAV	%AVEG
FW-CV-WC	2.1 (0.0-4.0)	2.3 (0.1-5.0)	90 (67-100)	10 (0-33)	--	--	8.5 (0-20)
FW-CV-NC	0.4 (0.0-1.5)	1.5 (0.3-2.5)	60 (33-100)	40 (0-67)	--	--	0.4 (0-2)
FW-AF-CC	2.9 (0.5-5.0)	1.9 (0.8-4.5)	--	85 (25-100)	15 (0-75)	--	7.2 (0-20)
FW-AF-WF	2.2 (0.5-4.0)	0.6 (0.4-1.0)	--	67 (25-100)	33 (0-75)	--	22 (1-65)
FW-AFS-LG*	1.9 (0.5-4.0)	1.7 (0.6-3.0)	--	--	100	0.8 (0-2)	13.4 (0-30)
FW-AFS-HG	2.0 (0.5-4.0)	2.4 (0.6-3.0)	--	--	100	--	9.7 (0-30)
HL-RSC	3.7 (0.6-8.0)	1.5 (0.4-4.0)	60 (25-100)	40 (0-75)	--	--	3.7 (0-25)
HL-BFC	3.2 (0.0-6.0)	1.8 (0.5-4.0)	40 (0-100)	60 (0-100)	--	--	0.6 (0-5)
HL-AFS	2.7 (0.6-6.5)	1.8 (0.5-4.0)	--	45 (0-100)	55 (0-100)	6.1 (0-20)	11.3 (0-30)
K-LM	5.5 (2.0-9.0)	0.5 (0.1-2.0)	100	--	--	0.5 (0-5)	4.4 (2-10)
K-MM*	5.9 (2.0-9.0)	0.9 (0.2-2.0)	--	100	--	0.7 (0-5)	26.1 (5-50)
K-HM*	3.8 (1.0-6.0)	1.4 (0.2-3.0)	--	70 (40-100)	30 (0-60)	15.0 (5-30)	10.9 (5-20)
K-GM-WC*	1.2 (1.0-3.0)	***	***	***	***	62	20
K-GM-DC*	2.0 (1.0-3.0)	1.4 (0.6-3.0)	--	--	100	36 (20-60)	8.0 (0-20)
CV-CG*	1.3 (0.6-2.2)	1.8 (1.0-2.5)	50 (0-100)	50 (0-100)	--	--	--

Values are the mean among sites (with recommended ranges in parentheses).
LWD/100 LF = Number of logs per 100 linear feet of channel.
Pools/100 LF = Number of pools per 100 linear feet of channel.
%SAV = Relative abundance of in-stream habitat cover with submerged aquatic vegetation.
%AVEG = Relative abundance of in-stream habitat cover with emergent aquatic vegetation.
*Recommended range is preliminary due to small sample (n<3).
**Values reported for streams with tree-lined banks only.
***Too few pools encountered on single site sampled.

The number of pools offered by the bend density often falls short of the average number of pools in a system because it neglects induced surfaces. At a minimum, LWD treatments targeted to induce the number of additional pools should be specified. Rosgen (2006) offers design guidance for creating stable cross-vanes (V-log weirs) for exactly such a purpose. A typical deployment we have successfully adapted for Florida headwater streams is shown in Figure 9.7. It is important to drive the ends sufficiently into the banks and to anchor the upstream apexes into the footer log with rebar or into the bed using cabled duck-bill anchors. V-log weirs should be placed along the longer straight runs about mid-way between the alluvial riffles and bend pools. Each V-log weir counts as one pool and two snags toward the quantity specifications. Total pool densities within the natural ranges applicable to each stream type (Table 9.2) can be assured by the combined specs of the total number of bends and V-log weirs.



NOTES

1. Live root wads to be installed vertically (roots down, stump pointing straight up).

2. Snag (dead) root wads to be installed horizontally or vertically with majority of root structure between the bed and bankfull elevation.

3. Large logs (LWD) typically arranged as V-weirs and random arrays.

Figure 9.7. Schematic of J-Hook, Root Wad, and V-Log Weir.

If more wood is desired after specifying the V-log weirs to meet local reference reach or regional densities, it can be provided in the form of randomized scatterings of wood into debris fields on the runs or glides between the riffles and pools on surfaces lacking the V-log weirs. The snags can be clustered into groupings of several pieces and as individual logs. Observe patterns in nearby stable streams for ideas on placement. Our observations have been that most wood occurs in clusters as opposed to a more even distribution of individual logs.

Whether to anchor random LWD depends on the length and diameter of the wood relative to bend radii and bankfull thalweg depths and how important it is to prevent navigation hazards. If the wood is longer than the bends and the diameter at least one-third the thalweg depth it does not need to be anchored in non-navigable, wadeable streams. In streams navigable even by kayaks or canoes, LWD placements should be carefully chosen to avoid creating navigation hazards and should be anchored in place. Such placement and the details of anchoring mechanisms for mid- to high-order streams are matters of site-specific engineering judgment beyond the scope of this guidance document. Some anchoring systems and approaches are more permanent than others. Having said that, snags are consumable items that gradually break down and that even when anchored can be transported by large flow pulses. They may need to be supplemented during the management of the system as the forest matures in newly created corridors.

Root Wads and J-Hooks

Root wads are intact, flat root masses attached to a stump. Root wads can be added into the bank at low radius bends (sharp bends) as a habitat amendment to allow for the immediate formation of overhanging banks and exposed large root masses. Root wads for small streams can be left upright (roots down, stump up) and placed in a depression next to the bank with soil packed around all sides except the side exposed to the creek, or the wad can be laid on its side with the stump driven into the bank in larger streams (Figure 9.7). Root masses exposed to the stream will provide habitat and the root wad will form a difficult-to-move bank feature. This could work with live root stumps rescued from clearing activities as well as dead wood. If available, some species (e.g., sweetbay and dahoon) can coppice from stumps with live root masses. Live root wads may therefore provide a double benefit, especially for small groundwater-fed streams.

Rosgen (2006) provides details useful for root wad deployment in larger streams. Root wads can destabilize banks if deployed in entrenched streams (those not of Rosgen type C or E) (Brown 2000). Root wads should be viewed as fisheries habitat amendments and their deployment depends on decisions related to their costs versus fishery habitat needs rather than stream stability.

If additional bend stability is desired, J-hooks are a type of re-directive structure that can be deployed to refract the flow line away from the outer bank of a bend toward the middle of the channel. These can be used as part of an a priori design tool to protect particularly tight bends located along stabilizing floodplain substrates in newly created channels or as an adaptive management tool after construction at bends indicating excessive erosion. We have adapted Rosgen's (2006) combined rock and wood recommendations to an all-wood construction by pounding logs vertically into the bed in lieu of the use of the apex stones (Figure 9.7).

Wing Deflectors

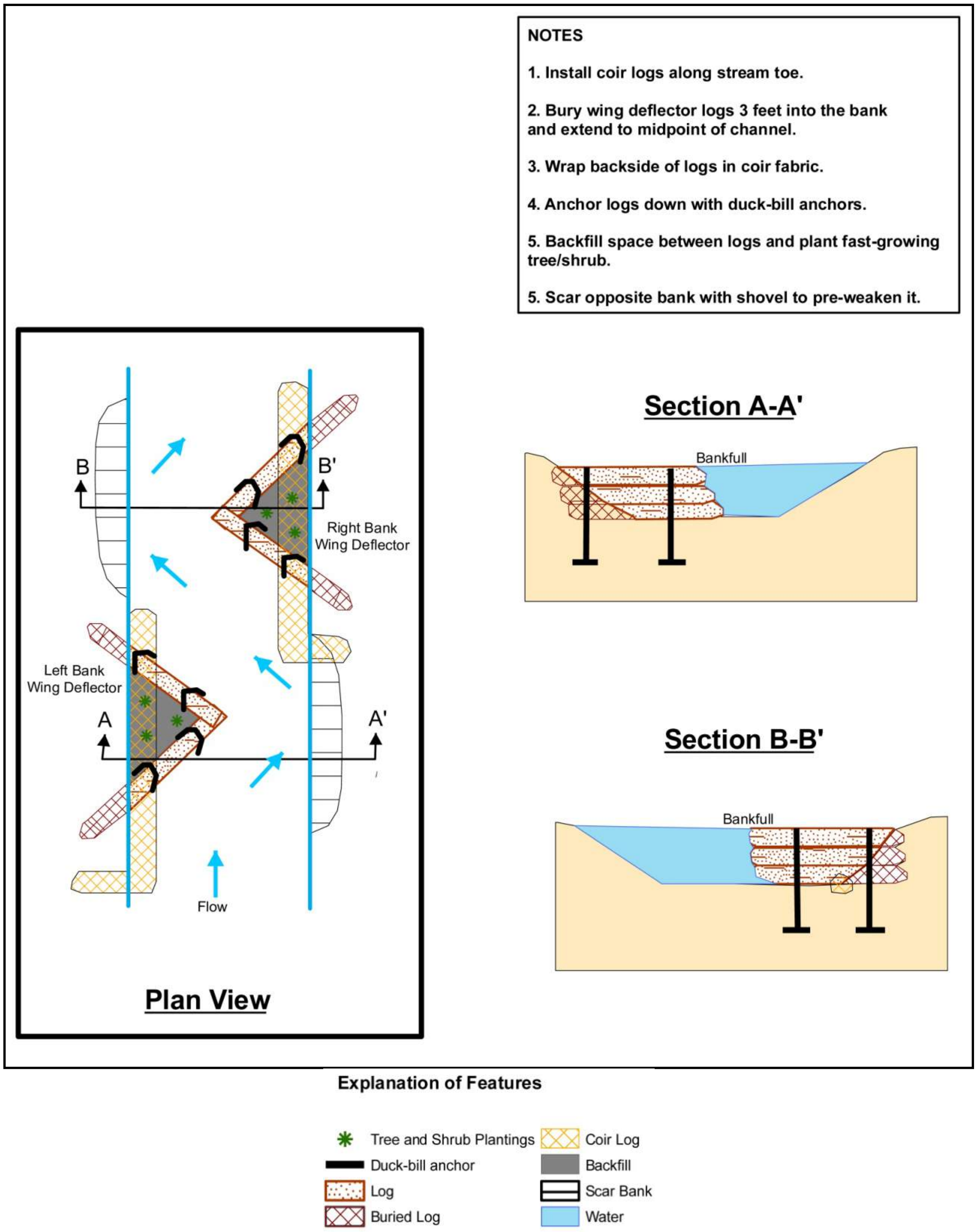
Wing deflectors are triangular or trapezoidal revetments that project into the stream for the purpose of adding sinuosity and tight bends to a system that is too straight. They essentially force erosion to occur on the opposite bank, forming a low radius bend. Wing deflectors are generally an adaptive tool to be deployed after construction as the system matures, but can also be placed a priori as a channel is being constructed. The revetment applies best to low-order streams and consists of a stacked and anchored log face that hard-armors the embankment, which is filled with soil and vegetated. Figure 9.8 depicts a deployment we have successfully implemented in Florida headwater streams.

HYDRAULIC AND SEDIMENT TRANSPORT DESIGN CHECKS

The final design check consists of assessing the tractive forces using mean shear stress, velocity or stream power at bankfull discharge (Table 9.3). The means are based on a limited number of measurements (n = 1-6 per stream type) and the ranges are modestly extrapolated from the limits of the measured data. They are provided for guidance purposes only. They do not, by themselves, constitute verification of continuity of transport or bank stability but at least can give the designer some sense of how the design compares to some empirical information. Bankfull discharge can be calculated based an association with drainage area (Figures 5.1 and 5.2). This discharge can then be routed through a typical riffle design cross-section assuming normal flow conditions (those unhindered by major backwater effects) and applying the channel slope used in the design. One example of software used for such routing that can calculate the pertinent forces is RiverMorph.

The prototypical cross-section must provide for tractive forces within the typical ranges encountered for the appropriate stream types in the region. They must also allow for continuity of sediment transport compatible with the downstream systems. Continuity of sediment transport also depends on sediment supply from the watershed.

More complicated sediment transport equations typically give widely differing calculations of sediment transport rates and resulting stable channel dimension. We examined several such equations offered in the SAMWin software program for potential utility as analytical tools to use in natural channel design, perhaps even in lieu of the empirically based design approach. None of the equations resulted in channel dimension predictions that could be systematically or reliably applied without knowledge of upstream sediment yields that has not been developed for Florida, or that may vary substantially by location.



NOTES

1. Install coir logs along stream toe.

2. Bury wing deflector logs 3 feet into the bank and extend to midpoint of channel.

3. Wrap backside of logs in coir fabric.

4. Anchor logs down with duck-bill anchors.

5. Backfill space between logs and plant fast-growing tree/shrub.

5. Scar opposite bank with shovel to pre-weaken it.

Figure 9.8. Wing Deflector Schematic.

Table 9.3. Tractive Forces by HBG Stream Type.

Stream Type	Mean Shear Stress (Lb./Ft.^{2})	Velocity (Ft./Sec.)	Stream Power (Lb./S)
FW-CV-WC	0.07 (0.02-0.25)	0.5 (0.2-0.9)	0.6 (0.1-2.0)
FW-CV-NC	0.10 (0.05-0.25)	0.6 (0.4-1.0)	0.5 (0.3-0.8)
FW-AF-CC	0.10 (0.03-0.20)	0.9 (0.5-1.5)	1.6 (0.3-2.9)
FW-AF-WF	0.06 (0.03-0.15)	0.8 (0.5-1.5)	2.0 (0.4-5.0)
FW-AFS-LG*	0.03 (0.01-0.05)	0.9 (0.5-1.5)	2.6 (1.0-5.0)
FW-AFS-HG	0.12 (0.05-0.20)	1.6 (1.0-2.0)	6.9 (3.0-10.0)
HL-RSC	0.44 (0.15-0.95)	0.4 (0.1-0.8)	1.5 (0.1-5.0)
HL-BFC	0.12 (0.05-0.20)	0.7 (0.4-1.0)	0.8 (0.2-2.0)
HL-AFS	0.08 (0.05-0.15)	0.9 (0.2-1.5)	2.2 (1.0-4.0)
K-LM	0.05 (0.01-0.15)	0.3 (0.1-0.7)	0.2 (0.05-0.6)
K-MM*	0.07 (0.03-0.15)	0.4 (0.2-0.8)	0.6 (0.2-1.5)
K-HM*	0.08 (0.03-0.20)	0.5 (0.2-1.0)	1.4 (0.5-2.5)
K-GM-WC*	0.06	0.2	4.0
K-GM-DC*	0.12 (0.03-0.30)	1.0 (0.5-1.5)	7.5 (1.0-15.0)
CV-CG*	0.27 (0.10-0.50)	1.7 (1.0-2.5)	4.1 (1.0-7.0)

Values are the mean among sites (with recommended limits in parentheses).
Values are for bankfull discharge at a riffle.

TEMPORARY STABILIZATION

Stormwater Management

Stormwater management is aimed at controlling excessive erosion through the active work area that could destroy the work, present a safety hazard, or pollute downstream waters. It is important to minimize the occurrence and volume of water flowing through the exposed construction zones. Even with such measures, water will enter the project, making it necessary to consider erosion control mechanisms. Runoff through the active construction area needs to be minimized until the initial stabilizing mechanisms are in place and soils are stabilized in the project area. One way to place the odds in the project's favor is to restrict the construction to the dry season. By no means is this a fully preventative measure, as El Niño years reverse the seasonality of precipitation and cold fronts can carry significant rain during the normal dry season. Therefore, even dry-season construction must provide for a risk-based level of service consistent with engineering norms and regulatory requirements.

Engineering approaches to route runoff around the work area can include any combination of hydraulic structures suitable for the site. Conditions are so site-specific that they will usually require design by an engineer experienced in hydraulic systems, stream hydrology, slope stability, and groundwater management (especially in high-bank areas with groundwater seepage through the embankment). However, some basic approaches and tools developed for stream restoration bear note. For example, products creating temporary aqueducts or water-inflated coffer dams can be used to isolate a bank or portion of a bed to be worked upon in a perennial stream. Temporary bypass channels or pipelines can be constructed parallel to a work area requiring construction across the entire cross-section. These can be supplemented by low-head high-volume pumps. One tactic is to split the project into phases, commencing successive work zones only after the preceding zone is stabilized and carrying flow. This places only a subset of the project area in jeopardy at any given time and enables a variety of small-scale bypass approaches to be tailored to short sections of the valley rather than a single construction solution for the entire reach. Another tactic is to keep the time of construction as short as safety and logistics allow. Plan work when the weather conditions are likely to be most favorable, get the site dry, and work efficiently.

Even when following such risk-minimization procedures, water will enter the site. Budget time and materials for weather-related contingencies and patching after storms. For example, despite having substantial hydraulic system controls, two of our three pilot projects had to carry the equivalent of 10-year return interval storm events during construction. At the very least, normal rain will fall directly on the bare surfaces. A wide array of sediment and erosion control best management practices (BMP) can be followed to reduce erosion on exposed surfaces. Water quality controls such as sediment sumps and flocculants can be utilized to prevent downstream impacts. Silt fences should be placed parallel to the banks near the top of bank for the full length of the stream, to prevent the channel from silting-in from rill erosion on the valley hillslope. Likewise, silt fences should be placed at the outer edge of the exposed meander belt to prevent siltation of the floodplain from the adjacent terrestrial surfaces. Larger floodplains can benefit from the placement of silt fences perpendicular to the floodway. This results in a cellular structure that prevents massive amounts of sediment transport. Do not cross the bankfull channel with silt fence, ever. It is at best a waste of money and can create more erosion than it prevents. A properly designed riverine landscape includes a channel that will provide continuity of sediment transport for a wide array of discharge without failing. However, riverscape stability depends on bank cohesion provided by living root masses in most Florida stream types. Therefore a temporary surrogate for this must be provided.

Bank Control

Simple application of biodegradable erosion control blankets (BECB) can be used to temporarily stabilize the banks of headwater streams. Knowledge of a wider array of soil stabilization approaches and river mechanics is necessary when dealing with larger streams and the recommendations offered here are only applicable to headwater streams with riffle bank heights less than a couple of feet. For example, protection of the toe between the bank slope and bed can be of critical concern for perennial streams with bank heights greater than those of headwater streams. Gray and Sotir (1996) provide a seminal text on soil bioengineering approaches to bank stabilization, with a variety of techniques that complement natural channel design approaches quite well.

Two- to three-year rated BECBs are recommended for use on streams with bank angles steeper than the angle of repose of sand or the given bank material. These are usually made from coir (coconut fiber) and come in a variety of weaves and strengths. Note that encapsulation means that bank sediments are placed over a portion of the blanket and that the blanket is wrapped around the face of the bank to the bankfull elevation. An inner straw blanket is recommended across the portion of the BECB face exposed to the bank to prevent sand from sifting through the outer BECB layer.

Stream segments that have side slopes that are gentler than the angle of repose of fine sand can have their BECBs simply staked down in a single layer across the bank surface without encapsulation. These segments are also in gentler sloped valleys with higher groundwater tables and are likely to reach sufficient root densities quickly. Therefore, a one-year rated blanket can be utilized. Either a biodegradable weed-free straw or wood fiber blanket can be utilized.

The recommendations for BECBs assume the use of cohesionless sands in the meander belt. In some cases, the meander belt will be fully amended with combinations of wetland and upland topsoil that have moderate cohesion with a viable seedbank and live plant rhizomes, perhaps rendering the use of BECBs unnecessary. It is important to establish long-term plant materials into the BECB. The BECB is not permanent and sustainable shear strength functions are ultimately supplied by living vegetation appropriate for the near-bank zone.

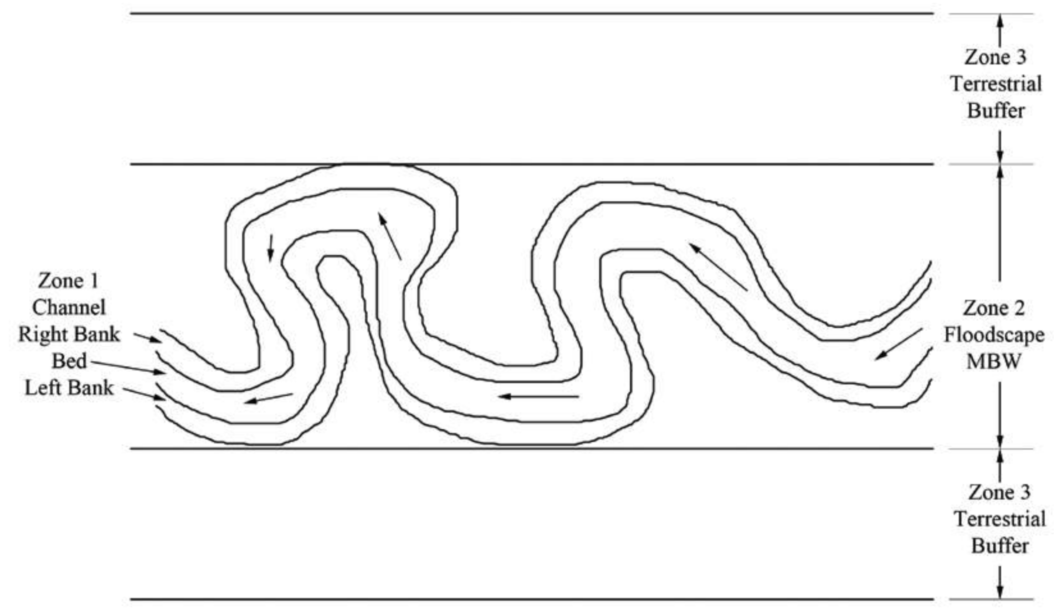
Grade Control

This is not always a major consideration in low-gradient Florida streams, especially for systems lacking an adverse history of hydraulic alterations in the watershed. However, exceptions occur when dealing with connections to artificially entrenched downstream junctions, especially those with active headcutting. Such sites require special engineering knowledge beyond the scope of natural channel design. Also, loss of grade control is a frequent outcome in heavily ditched or urbanizing watersheds, sometimes requiring special measures to stabilize migrating headcuts to prevent them from affecting the project area.

Another exception is in the creation of root-step (HL-RSC) streams, which often hold grades beyond the norms for sandy bed materials, and perhaps for some of the more steeply graded headwater valleys sometimes occupied by the outer links of chains-of-wetlands (FW-CV-NC) or that are near the classifying transition between HL-RSC and HL-BFC stream systems. These conditions and related natural channel design approaches for establishing grade control structures are discussed in the section for HL-RSC streams.

RIPARIAN HABITAT ZONES AND VEGETATION

The riparian corridor extends laterally from the stream channel and for design purposes is defined by three zones, (1) the riverscape, (2) the floodscape, and (3) a terrestrial buffer (Figure 9.9).



Notes:
1) Zone 2 is the floodplain surface within the meander belt, exclusive of the channel (Zone 1).
2) Zone 3 can be an alluvial bottomland beyond the meander belt, a seepage slope, or an upland valley hillsope depending on stream type and FPZ (valley type).
2) If Zone 3 is an extensive bottomland swamp, a small upland buffer (Zone 4) can be added to buffer the swamp, but is typically unecessary to protect the stream.

Figure 9.9. Basic Zones within the Riparian Landscape.

Zone 1: Riverscape

The riverscape is the open channel, including its bed and banks. Emergent vegetation is limited on the bed within this zone due to hydraulic forces, sediment transport and shade, but it can occur in patches. The bed vegetation is comprised mostly of herbaceous plants but can sporadically include trees and shrubs.

A critical sediment-vegetation interface occurs along the channel banks, which are densely lined by combinations of woody and herbaceous plants. There is much overlap in the channel bank species among various stream channel types, but some distinctions are necessary. For example, some species are mainly associates of larger mid-order or high-order streams (e.g., bald cypress, water-locust, and water hickory) and are rarely found in small mid-order and low-order systems. In some headwater streams and on pronounced alluvial ridges, saw palmetto can form very dense cover on the banks. The saw palmettos provide a lot of habitat structure, armoring, and root shear strength.

The streams meandering through well-adjusted valleys often have a mixture of bank vegetation patches depending on whether the channel bank is bordering the upland edge of the meander belt or is interior to the wetland bottomlands. For areas with wetland channel borders, a mixture of fast-growing and climax species should be used to supply both rapid and sustainable shade, leaf packs, and fine root masses to the stream. These plantings should be distributed through the BECB at each segment, working in concert with the BECB to add shear strength to the embankment. Common native species that strengthen stream banks in the region vary by stream type.

Establishing shade over the channel reduces colonization by aquatic invasive and ruderal herbaceous species that can clog the channel bed. Fast-growing, native, early successional species should be planted to rapidly establish shade over the channel and to provide quick sources of allochthonous carbon and live root masses and can include Virginia willow, Carolina willow, elderberry (*Sambucus canadensis*), wax myrtle, and buttonbush. All of these species are commercially available and can be established using small containerized stock or, for some species, stem cuttings on moist soils. Native species with phenology to grow well from bundles of woody cuttings (e.g., buttonbush, and elderberry) are commercially available as live fascine bundles for stream restoration, but may not be suitable accessions for peninsular Florida.

Zone 2: Floodscape

The floodscape includes the wetland or upland areas adjacent to the riverscape, above bankfull stage and extending to the lateral limits of the meander belt. These areas will be planted in accordance with wetland or upland vegetation compatible with project objectives and those associated with the appropriate stream type and FPZ.

Zone 3: Terrestrial Buffer

Stream channels and their near-bank vegetation are susceptible to physical disturbance and other alterations that occur in the adjacent uplands, such as erosion from intense cattle grazing and eutrophication from over-fertilization. Riparian buffers can effectively mitigate or even eliminate such effects. Some of the valley types provide inherently wide stream buffers (e.g., wetland unconfined channels), while others provide a more limited buffer (e.g., upland confined channels). Therefore, terrestrial riparian buffer zones require different considerations regarding FPZ classification of the stream segment and the adjacent existing or projected land use.

Upland confined streams lack any kind of significant wetland floodscape buffer and are typically flanked by a pyrogenic upland community that may or may not include an upland gallery forest. These stream systems are highly susceptible to impacts from the adjacent uplands because they lack extensive lateral wetlands that can trap eroded sediments, can be easily traversable by cattle and off-road vehicles, leading to soil disturbance and local rill erosion, and lack extensive histosols that can promote denitrification of runoff from over-fertilization. Therefore, native cover buffers should be established at least 95 feet wide on both sides of the meander belt of streams in upland confined valleys. The 95-feet width meets the recommended riparian forest and grass buffer commonly adopted by the USDA to assure proper riparian system nutrient processing in agricultural landscapes (Welsch 1991) and exceed the absolute minimum threshold to meet a variety of stream conservation objectives (Wenger 1999). The terrestrial buffer will, whenever practical, be topsoiled with native upland soils to promote rapid establishment of desirable functions related to soil biogeochemistry near these streams.

Wetland confined streams are less susceptible to water quality impacts and are most susceptible to over-trafficking, which occurs where the channel bends migrate close to the wetland/upland ecotone. Most of the channel is inherently well buffered by its adjacent wetlands. Native vegetation buffer widths should be extended at least 60 feet beyond the meander belt for streams coursing through wetland confined valleys. This width is consistent with FDEP "Optimal" conditions for Habitat Assessment stream habitat buffers (FDEP SOP-001/01, Form FD 9000-5).

Unconfined wetland streams are the least susceptible to lateral water quality and trampling impacts because they typically course well within extensive wetland bottomlands. These lotic systems should be buffered with native upland and transitional vegetation along their outer boundaries in accordance with the upland buffer recommended by SWFWMD adjacent to wetlands of 25 feet [BOR 3.2.7(a)]. Topsoiling of the buffer for this valley type is not critical because the wetland belt tends to be wider than a few hundred feet and it is usually topsoiled with a growing medium suitable for forested wetlands, providing ample opportunity for normal wetland soil biogeochemistry to occur.

CONSIDERATIONS PARTICULAR TO STREAM TYPE

The previous sections outline the general design approach and associated metrics. Certain stream types require emphasis on some metrics more than others or otherwise have unique design considerations. Chapter 4 provides overall descriptions of each stream type. These should be understood prior to undertaking restoration design. They are not repeated in the following sections, which merely highlight unique design concepts and metrics of each type on an as-needed basis.

Flatwoods Headwater Streams (FW-CV-WC and FW-CV-NC)

Landscape

Flatwoods headwater streams typically occur within chains-of-wetlands. Conceptualization of FPZs in chains-of-wetlands can depend partly on scale, depending on sources of stress and restoration objectives. For example, aquatic macroinvertebrates do not develop species signals distinct from headwater wetlands in stream channels for several hundred feet downstream of the wetland (T.L. Crisman, personal communication). Many chains have short stream linkages that do not offer enough length to provide significant habitat for rheophilic fauna. For that reason one could simply define the entire chain as the FPZ containing a series of longitudinal surfaces including the headwater depression, its outlet sill (or popoff), the alluvial stream channel, colluvial wetlands lateral to the channel, a channel outlet delta to its receiving waterbody, and in-line wetland depressions. Thus, short stream segments linking in-line wetlands can be conceived as a chain-of-wetlands FPZ with the wetlands and channels viewed as inclusionary surfaces.

As a general concept, we begin to pay more attention to valley lengths occupied solely by stream channels in excess of 1,000 linear feet as surfaces large enough to warrant consideration as separate FPZs even when these streams are parts of chains-of-wetlands. The rationale is that such systems reach a scale where the fauna may not be strictly controlled by the species composition of large lentic waterbodies upstream or downstream of the alluvial channel. At such scales, lotic habitat and associated aquatic fauna can be influenced by valley confinement and alluvial channel features at least as much as by the effects of the nearest in-line lentic wetlands. Therefore, for stream channels greater than 1,000 feet long within chains-of-wetlands, the channel is conceived as being part of an FPZ dictated by its valley type and stream type. Applicable FPZs include wetland confined and upland confined valleys occupied by either FW-CV-WC or -NC streams. The in-line wetlands are treated as separate FPZs along the valley.

Bankfull Surfaces (Riverscape)

FW-CV-WC streams are most characteristically dimensioned using the C5 curves (Figures 5.7 and 5.11), while FW-CV-NC streams are most characteristically dimensioned using the E5 curves for width, depth, and W/D ratios (Figures 5.8 and 5.12). Exceptions occur in nature and can be acceptable, warranting consideration of the effects a deeper channel would have on nearby wetlands (lateral and longitudinal) and the potential for headcutting based on the downstream waterbody conditions.

A decision must be made concerning whether the top-of-bank will be concordant with the bankfull elevation. This is generally the case for FW-CV-WC systems. For some FW-CV-NC systems, especially those that are upland confined to the channel margin (e.g., lined by palmettos), the top-of-bank may be properly set within a few inches above the bankfull elevation. The result is a slightly entrenched bankfull channel. The resulting top-of-bank width and elevation should be depicted on cross-section diagrams (Figure 9.6). This adds two more breaklines to be specified on the plan and profile views.

The channel toe can be selectively protected from erosion by use of a coir roll or ECB. Wide arrays of bank species are possible, depending on the soil moisture regime and expected fire-frequency of the meander belt. Numerous examples of potential dominant and common species assemblages are provided in Chapter 4. One unique aspect of revegetating some of these sites involves the variable use of saw palmetto transplants. The phosphate industry has had good experience supplementing bank planting areas with mature transplanted saw palmettos rescued from areas subject to mining. This technique applies to non-mining settings as well.

Meander Belt Surfaces (Floodscape)

The floodplain is not alluvial and is often a mesic upland. When it is a wetland, the community tends to be narrow and dominated by species that tolerate shallow flooding and short hydroperiod. The stream channel is typically a drain of water from the meander belt, and is less often a source during the year. Examples of potential meander belt communities are discussed in Chapter 4.

Valley Hillslope (Terrestrial Buffer)

These streams are small and shallow. Their meander belt communities are narrow and typically are not naturally buffered by wide wetland bottomlands. These channels contact extensive uplands and wetlands in aggregate, forming the most extensive soil-to-streambank contact within the total drainage network. This makes them susceptible to biogeochemical disruptions associated with adjacent land-use activities, but that can be reduced with adequate buffering. Terrestrial buffers of native vegetation should extend at least 95 feet beyond the meander belt. In areas where cattle grazing will occur, it is prudent to produce a dense shrubby buffer that includes tough, thorny and non-palatable species to discourage herd congregations along the stream.

Flatwoods Intermediate Streams (FW-AF-CC and FW-AF-WC)

Landscape

These stream types occupy landscape positions with watersheds large enough to generate sediment mass and flow volumes sufficient to create and sustain alluvial surfaces in the floodplain, which is a key threshold change versus the chain-of-wetlands and headwater stream types. Their upstream and downstream connections can be direct stream channel junctions akin to those of dendritic networks, but also frequently include in-line wetland depressions, sloughs and strands.

Bankfull Surfaces (Riverscape)

FW-AF-CC types can be C5 or E5 channels. Slightly entrenched forms and those with alluvial ridges tend toward the lower W/D shapes of the E5's (thus warranting application of regional curves Figure 5.8 and 5.12). Sites lacking alluvial levees tend to have the higher W/D ratios (C5) (apply Figures 5.7 and 5.11). The FW-AF-WF channels characteristically have equivalent top-of-bank and floodplain elevation. The channels strongly tend toward C5 shapes, suggesting that sandy alluvium tends to accumulate in the bed (apply Figures 5.7 and 5.11). Bank vegetation for both of these intermediate stream types typically reflects that of the adjacent wetland floodplain community. Channels are efficient and tend to lack vegetation.

Meander Belt Surfaces (Floodscape)

FW-AF-CC systems typically have compact linear backswamps and low-lying alluvial ridges in a frequently inundated floodplain. Since these are the first systems along a drainage network to reach physics thresholds for development of alluvial floodplain surfaces, the floodplain soils are often chaotic distributions of sandy and silty alluvium and organics. Conversely, FW-AF-WF meander belts tend to be comparatively flat with more continuous and ubiquitous presence of fine-grained alluvial deposits. This, coupled with the wide and shallow channel form, indicates that these systems occupy valleys receiving greater overall sediment loads than the FW-AF-CC types. This is consistent with their larger drainage areas and lower valley slopes. The meander belt for either type can be well adjusted or unconfined and characteristically supports wetland communities.

Valley Hillslope (Terrestrial Buffer)

Channels in the unconfined FPZs require little buffering. Buffers should be more carefully considered in the well-adjusted FPZs because the outer bends are in proximity with the upland interface and can receive lateral solute and sediment inputs with little treatment absent a buffer.

Flatwoods Large Streams (FW-AFS-LG and FW-AF-HG)

Landscape

The FW-AFS systems can link to a wide variety of waterbodies, including other stream channels, large in-line wetlands, and shallow lakes. The HG systems occur at greater valley slopes than the LG types. The AFS systems differ from the AF types based mainly in their stream power and resultant scale and depth of alluvial features in their main channels and floodplains. Some of these systems are not wadeable during the wet season. These systems are perennial and generate large, powerful flood pulses creating situations where hydraulic system infrastructure will comprise a considerable amount of the restoration engineering and construction budget.

Bankfull Surfaces (Riverscape)

The FW-AFS-HG systems are often entrenched, typically with pronounced alluvial ridges consisting of fine sands. Channels are deep E5 types and sometimes B5, warranting application of Figures 5.8 and 5.12. FW-AFS-LG systems are rarely entrenched, and have low-lying to nonexistent alluvial ridges with banks occurring at the floodplain elevation. Their forms are rather strongly C5 types with quite high W/D ratios, warranting application of Figures 5.7 and 5.11.

Despite a somewhat open canopy, in-stream vegetation is absent to uncommon in HG systems due to the depth and power of the dominant fluvial forces. Some emergent vegetation and submerged aquatic vegetation can occur in sporadic and discontinuous patches in the shallower and lower-gradient LG streams, especially on lateral and mid-channel bars.

Bank vegetation in the HG systems can differ substantially from that of the floodplain, often including a mixture of mesic and hydric species ranging from cypress and water hickory at the toe to palmetto and live oak on the alluvial ridge. The bankfull elevation makes a convenient point of reference for where the species assemblage shifts. LG bank vegetation typically is similar to that of the adjacent wetland floodplain. Banks in both systems are characteristically well rooted from the top of the bank to the channel toe (at least down to the baseflow or seasonal low stage).

Meander Belt Surfaces (Floodscape)

The HG floodplains are rough, typically supporting a variety of hydric to mesic communities. The LG floodplains typically are dominated by massive bottomland swamps. Both of these systems drain equally large watersheds, presumably receiving similar sediment yields and flow volumes. The difference is in the processing of those materials related to valley slope. The steeper HG slopes concentrate energy that is dissipated by deep bend pools and by secondary channels and chutes in the floodplain. Energy is effectively dissipated across large comparatively flat floodplains in the lower-sloped LG systems. Floodplain building occurs by lateral accretion in both kinds of systems. Vertical accretion is more common in the LG systems and fine inorganic sediments are less likely to accrue in the HG systems. Abandoned channels tend to fill quickly with sandy material in HG systems, but more often can persist as oxbow ponds in LG systems.

Valley Hillslope (Terrestrial Buffer)

Channels in the unconfined FPZs require little buffering. Buffers should be more carefully considered in the well-adjusted FPZs because the outer bends are in proximity with the upland interface and can receive lateral solute and sediment inputs with little treatment absent a buffer. Natural buffers can consist of a wide array of upland communities, including especially flatwoods, dry prairies, and mesic oak hammocks.

Highlands Sapping Ravines (HL-RSC)

Landscape

Special design considerations center on the fact that these streams exist in sapping valleys with ample groundwater discharge. Typically, they drain headwater seepage swamps and discharge to deep waterbodies including lakes, rivers, and large sinkholes.

Bankfull Surfaces (Riverscape)

The critical design surface consists of root-steps. These are living systems that form over time, so a temporary surrogate is required. This could take the form of V-log weirs and coir logs with footer logs. Spacing is variable, getting as dense as three steps per 100 linear feet of channel. A threshold seems to occur when a reach averages at least 0.8 steps per 100 linear feet of channel (Table 4.6). Step depth should be from 0.5 to 2 feet. It is important to create the steps as V-shaped weirs that focus flow lines toward the channel interior versus straight check dams, which are more likely to be bypassed or undercut by erosion. Banks should be lined with tough BECBs and densely planted with sweetbay, loblolly bay, blackgum, and dahoon.

Vertical living root stumps (VLR), which are freshly transplanted root masses oriented with the trunk stump vertical and the roots down as the tree grew, could be planted in the banks along one or both sides of the V-log weir, overhanging some of the weir, with coir logs packed underneath and on at least one side of the overhanging roots to provide a rooting medium. In concept, this could accelerate root weir development but is a matter of some experimentation. The VLRs should be comprised of sweet bay, loblolly bay or dahoon specimens.

One uncommon variant of this stream type exists above the groundwater table most of the time, flowing ephemerally. The root-steps consist of pine and palmetto. Construction tactics using V-log weirs are similar, but the bank species should consist of saw palmetto and slash pine. Large palmetto transplants could be deployed analogously to the VLRs described above.

Meander Belt Surfaces (Floodscape)

These are typically seepage slope swamps with non-alluvial substrates.

Valley Hillslope (Terrestrial Buffer)

The lateral seepage slopes provide outstanding natural buffers for the channel. For the ephemeral form, a protective buffer is important. It should consist of flatwoods, sandhill or scrub upland species.

Highlands Small Streams (HL-BFC)

Landscape

These streams are found in a variety of headwater to mid-order landscape positions. They typically connect to headwater and in-line swamps or other streams. The channels and meander belts contact a very wide array of forested wetland and upland habitats. These streams tend to have long flow durations.

Bankfull Surfaces (Riverscape)

The dominant bed materials are sand with typical alluvial and woody substrates. The streams are typically closed canopy and heterotrophic, although small patches of emergent vegetation can occur in light gaps. C5 or E5 channel shapes are appropriate. Up to a few inches of entrenchment can occur.

Meander Belt Surfaces (Floodscape)

These surfaces are non-alluvial, and because of a high groundwater table characteristically consist of organic soils ranging from sapric muck to peat and sometimes mucky sands. The meander belt is usually a densely canopied and three-tiered hardwood forested or mixed hardwood and pine wetland, but upland pine forests and hydric to mesic hammocks occur.

Valley Hillslope (Terrestrial Buffer)

Valleys can be upland or wetland confined, well-adjusted, or unconfined, often alternating between at least two FPZs repeatedly along the valley. The hillslope communities can consist of a wide variety of mesic to xeric upland forests as well as seepage slopes. Where the valley segment is upland confined or well-adjusted, it is important to provide conservation buffers because these areas are highly susceptible to overgrazing and other forms of encroachment that could adversely affect sedimentation and solute fluxes to the stream.

Highlands Large Streams (HL-AFS)

These streams are found in a variety of mid-order landscape positions. They typically connect to large headwater or in-line lakes, in-line swamps or other streams. Cultural eutrophication of upstream lakes can affect the trophic status and water quality of these streams. The channels and meander belts contact a very wide array of forested wetland and upland habitats. These streams are perennial.

Bankfull Surfaces (Riverscape)

The dominant bed materials are sand with typical alluvial and woody substrates. The canopy is mostly to partially closed and most sites include small patches of SAV and emergent vegetation in light gaps. C5 forms are common in unconfined valleys and B5 channel shapes can occur in tightly confined well-adjusted segments. Up to a few inches of entrenchment can occur.

Meander Belt Surfaces (Floodscape)

These surfaces are at least partially alluvial in genesis, and because of a high groundwater table characteristically also consist of organic soils ranging from sapric muck to peat and sometimes mucky sands. Alluvial ridge and linear backswamps occur with muck, sand, and silt layers of varying thicknesses. The ridge is often discontinuous or sporadic. The meander belt is usually a densely canopied, three-tiered hardwood and/or cypress swamp.

Valley Hillslope (Terrestrial Buffer)

Valleys can be well adjusted or unconfined, often alternating repeatedly along the valley. The hillslope communities can consist of a wide variety of mesic to xeric upland forests as well as seepage slopes. Where the FPZ is well adjusted, it is important to provide conservation buffers because these areas are highly susceptible to overgrazing and other forms of encroachment that could adversely affect sedimentation and solute fluxes to the stream.

Clay Ravines (CV-CG)

Landscape

This is an uncommon stream type that tends to occur in deeply dissected headwater valleys intersecting clay layers, including but not limited to the Hawthorn Formation. They occur in high-relief valleys in the flatwoods or highlands, but are probably more common in rolling highlands landscapes due to their comparatively greater relief. Headwater swamps, sinkholes, and other streams tend to be their connecting waterbodies.

Bankfull Surfaces (Riverscape)

Channels tend toward B5 or E5 forms, with sandy beds and either loamy or cohesive, stiff clays in the banks. Channels are closed canopy.

Meander Belt Surfaces (Floodscape)

The surfaces are non-alluvial and can consist of hydric to mesic hammocks.

Valley Hillslope (Terrestrial Buffer)

These streams are susceptible to erosion and should be well buffered.

Small Heterotrophic Karst Streams (K-LM and K-MM)

Landscape

K-LM and MM systems form downstream of low-volume headwater spring heads. Their downstream connections can be other streams, springs, or in-line swamps.

Bankfull Surfaces (Riverscape)

The dominant bed materials are sand with typical alluvial and woody substrates in LM systems. The streams are normally closed-canopy and heterotrophic, although MM systems can have up to 40% of their bed covered by shade-tolerant emergents such as golden club and lizard's tail. Some snail-hash can be present on the MM bed materials. Virtually any Rosgen sand-bed channel type can occur in the LM systems, while C5 is most characteristic of the MM systems. Up to a few inches of entrenchment can occur. Banks typically consist of discontinuous organic soils tightly woven by living moss and fern root masses between areas with sandy or organic soils unmantled by the biological banks. Coir logs back-planted with such flora could be used to repair biological banks in these systems. Bank vegetation is similar to that of the adjacent floodscape community.

Meander Belt Surfaces (Floodscape)

These surfaces are non-alluvial, and because of a high groundwater table characteristically consist of organic soils ranging from sapric muck to peat and sometimes mucky sands. The meander belt is usually a densely canopied and three-tiered seepage swamp in LM systems. Communities in the MM systems can also include seepage slopes or hardwood and cypress swamp communities.

Valley Hillslope (Terrestrial Buffer)

Valleys can be seepage slopes or wetland confined. These systems tend to be intrinsically buffered from local runoff pollutants by their wet, densely forested hillslopes, but are susceptible to potentially remote sources of pollutants occurring in their recharge areas.

Transitional Karst Streams (K-HM)

Landscape

These systems form downstream of mid- to high-volume headwater spring heads, sometime picking up tributary flow from other small spring runs. Downstream connections can be other streams, springs, or in-line swamps. Autotrophic communities occur at densities sufficient to create some biologically derived sediment, but are not dominant in the riverscape. Water quality problems from karst groundwater sources carrying nitrates and nitrites from remote and local sources are possible.

Bankfull Surfaces (Riverscape)

The dominant bed materials are sand, shells, and organic floc with deep pools, and a typical array of alluvial and woody substrates. These are complex stream channels with alluvial, biological and geologic controls. Limestone outcrops can occur. The streams are partially closed canopy, typically with at least 10% of the bed covered in

SAV, distinguishing them from the smaller heterotrophic runs. Emergent vegetation, especially sawgrass, can occur on lateral bars. Various Rosgen channel forms can occur. These systems often only have a thin veneer of sand on large portions of the bed armoring an underlying organic substrate. Banks typically consist of rather continuous organic soils tightly woven by living moss and fern root masses. Bank vegetation consists of wetland hardwoods and some cypress. Coir logs back-planted with such flora could be used to repair biological banks in these systems.

Meander Belt Surfaces (Floodscape)

These surfaces are non-alluvial, and because of a high groundwater table characteristically consist of organic soils ranging from sapric muck to peat and sometimes mucky sands. The meander belt is usually a densely canopied and three-tiered hardwood and cypress swamp community. Sometimes shallow, muck-filled secondary channels occur parallel to the run.

Valley Hillslope (Terrestrial Buffer)

Valleys can be seepage slopes, wetland confined, or upland confined. Longer runs can alternate among these forms. These systems tend to be intrinsically buffered by their wet, densely forested hillslopes, except at the upland confined FPZs, where a terrestrial buffer should be established. Sources of pollutants carried via spring discharge can readily bypass (flow under) these buffers, however.

Large Autotrophic Karst Streams (K-GM-DC and K-GM-WC)

Landscape

These systems form below very high-volume headwater spring heads, or at areas picking up tributary flow from large spring runs or copious clusters of in-channel springs. Downstream connections can be other streams, springs, lakes, or tidal waters. These systems are highly susceptible to water quality problems from karst groundwater sources carrying nitrates and nitrites from remote and local sources.

Bankfull Surfaces (Riverscape)

The dominant bed materials are sand, shells, and organic floc with deep pools, and a typical array of alluvial and woody substrates. The DC streams are mostly open canopy (at least 70%) while the WC forms are generally completely open. DC streams have patchy SAV communities covering about one-third of the bed, while WC streams typically have at least two-thirds of the bed covered by SAV. Emergent vegetation, especially sawgrass, can occur on lateral bars. Rosgen types include C5 and B5's. WC systems typically have W/D in excess of 50 and DC systems less than 50. Banks typically consist of rather continuous organic soils tightly woven by living moss and fern root masses. Bank vegetation consists of wetland hardwoods and some cypress. Banks are typically high enough to warrant layered BECB encapsulations of peat or muck for repairs (in lieu of the coir log approaches acceptable for smaller spring run types).

Meander Belt Surfaces (Floodscape)

These surfaces are non-alluvial, and because of a high groundwater table characteristically consist of organic soils ranging from sapric muck to peat and sometimes mucky sands. The meander belt is usually a densely canopied and three-tiered hardwood and cypress swamp community. Sometimes shallow, muck-filled secondary channels occur parallel to the run.

Valley Hillslope (Terrestrial Buffer)

Valleys can be seepage slopes, wetland confined, or upland confined FPZs. Runs typically alternate among these forms. These systems tend to be intrinsically buffered by their wet, densely forested hillslopes, except at the upland confined FPZs, where a terrestrial buffer should be established. These terrestrial buffers can readily be bypassed by pollutants carried to the stream via spring discharge flowing in limestone strata beneath the wetland soil layers.

CHAPTER 10
TWO STREAM CREATION CONSTRUCTION TECHNIQUES

INTRODUCTION

Stream channels will develop passively due to natural weathering processes in valleys created for their formation. This process was used in the phosphate mining industry in the 1970s through the early 2000s. The companies would generally contour a floodplain suitable to pass the 25-year 24-hour storm event and allow the low-flow channel to self-carve over time. That process typically took about two decades to reach equilibrium (Figure 10.1). In 2004 the FDEP required greater specificity in stream channel design and construction, aimed in part to accelerate the process. Since then, the industry has engaged in two procedures to build stream systems: (1) mechanical construction, and (2) hydraulic construction. Mechanical construction is rather conventional and hydraulic construction is a more novel technique developed and tested by AMEC in collaboration with Mosaic at the South Pasture and Fort Meade Mines. Both techniques have applicability to non-mining landscapes. More information is provided below. This is not intended to be a step-by-step construction description because the steps will vary among sites. Instead, it is our intention to share some aspects of these two approaches to construction that may be unique to Florida conditions, are otherwise novel, and that have demonstrated successful implementation.

Reclamation Site R-7, North Pasture Mine

Figure 10.1. Example of Stream Created by Natural Weathering.

MECHANICAL CONSTRUCTION

This approach involves the direct construction of the valley and channel topography and soils using a combination of mechanized equipment and manual labor to implement a detailed and highly specified plan set. It is the conventional way most stream restoration projects are built across North America, requiring detailed site plans and specifications with sufficient information to convey and enforce the necessary results with the contractor. This is aided by daily site visits from a construction inspector independent of the contractor who is highly knowledgeable regarding stream restoration and construction. The construction sequence varies, but typically commences with installation of temporary stormwater management systems and groundwater control measures. Working in a dry site is generally safer and more efficient than working in the wet.

For major valley and stream reconfigurations, it makes sense to build the valley to final grade and then excavate the channel in circumstances where the valley materials are fairly uniform at grade and are sandy or would otherwise not suffer from unacceptable compaction or displacement from heavy earthmoving equipment (Floodplain-First Construction). This was done on the Gilshey Branch site, as depicted in Figure 10.2.

A) Floodplain contoured and stream channel alignment staked.

Figure 10.2. Photo Montage of Floodplain-First Mechanical Construction.

B) Channel excavated from the floodplain and banks wrapped in erosion control blanket.

C) Works stabilized with temporary groundcover prior to planting permanent cover.
North Gilshey Branch, Fort Meade Mine

Figure 10.2 (Cont.). Photo Montage of Floodplain-First Mechanical Construction.

In cases where more complex soil layering using materials subject to compaction or displacement are to be established, it makes sense to subgrade the valley to the lower limit of those surface layers, build the channel first above that grade and then backfill the lateral layers adjacent to the channel (Channel-First Construction). This leaves a less-compacted and rutted floodplain behind. That approach was taken on the DB-5 site, as depicted in Figures 10.3 and 10.4.

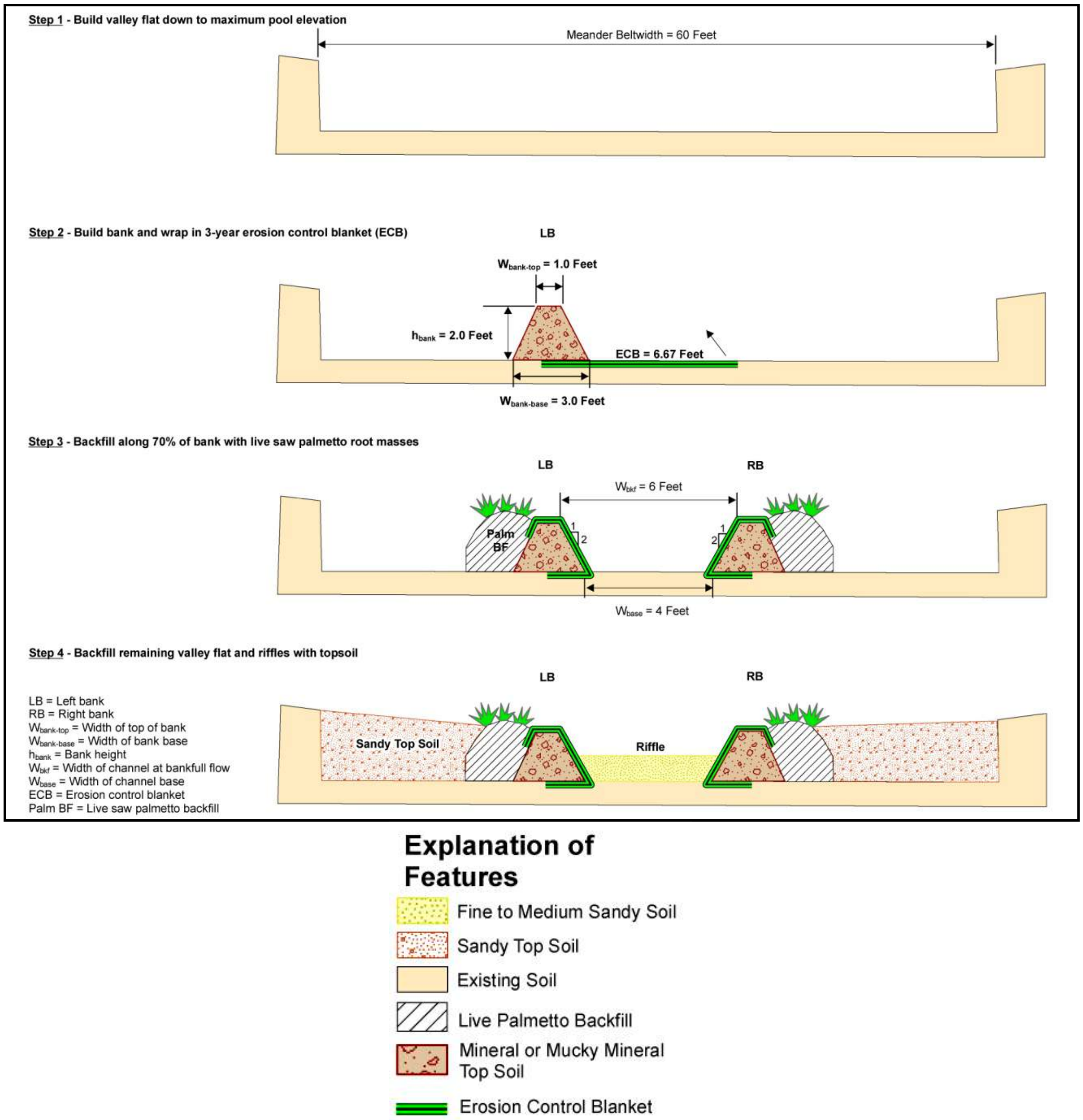


Figure 10.3. Sequence of Channel-First Mechanical Construction.

A) Filled-in existing canal and sub-grading the meander belt.

B) Built right bank above sub-grade and transplanting palmettos along bank.

Figure 10.4. Photo Montage of Channel-First Mechanical Construction.

C) Placing meander belt soils in floodplain adjacent to bank.

D) Both banks completed and all meander belt materials placed.

Figure 10.4 (Cont.). Photo Montage of Channel-First Mechanical Construction.

E) Project overview upon earthwork completion, prior to installing vegetation.
DB-5, South Pasture Mine

Figure 10.4 (Cont.). Photo Montage of Channel-First Mechanical Construction.

Slow-growing palmettos form extensive bank communities along certain Florida stream types. Their growth habits and rates do not lend themselves particularly well to conventional soil bioengineering approaches such as brush layering, wattles, or planting live sticks through the BECBs. However, mature palmettos survive transplanting quite well. AMEC and the Mosaic Company tested incorporation of transplanted palmetto-soil masses to create palmetto-lined banks as part of a soil bioengineering approach to creating a stable channel system at DB-5. The palmettos were moved during the dry season and placed with a front-end loader behind a narrow BECB layered soil mass (Figure 10.4B). They were trimmed back and irrigated for three months (Figure 10.5). Two years later they expressed excellent growth.

A) Head of channel immediately after construction with palmettos trimmed back.

B) Same site, mid channel, three years later.
DB-5, South Pasture Mine

Figure 10.5. Photo Montage of Saw Palmetto Maturation.

For sites with intact floodscapes, but an inadequate riverscape, it is necessary to carefully plan access to the project area to minimize wetland disturbance. Small walking excavators that can work in flowing water or manual labor crews instead of earthmoving equipment can be used to do so. Manual labor alone was used to enhance the bankfull channel form and in-stream habitat on Maron Run, installing root wads, J-hooks, V-log weirs, and wing deflectors (Figure 10.6). Macroinvertebrate monitoring before and after these improvements indicated increased habitat quality and a positive faunal response. V-log weirs and J-hooks were successfully deployed in R-7 (North Pasture Mine) to stabilize bends and pools. These LWD structures have been intact for more than five years to date.

A) Manual labor installing wing deflectors and other LWD habitat amendments.

B) Wing deflector more than one month after installation.

Figure 10.6. Photo Montage of Retrofit LWD Habitat Amendments.

C) Same wing-deflector more than one year after installation.
Maron Run, Fort Meade Mine

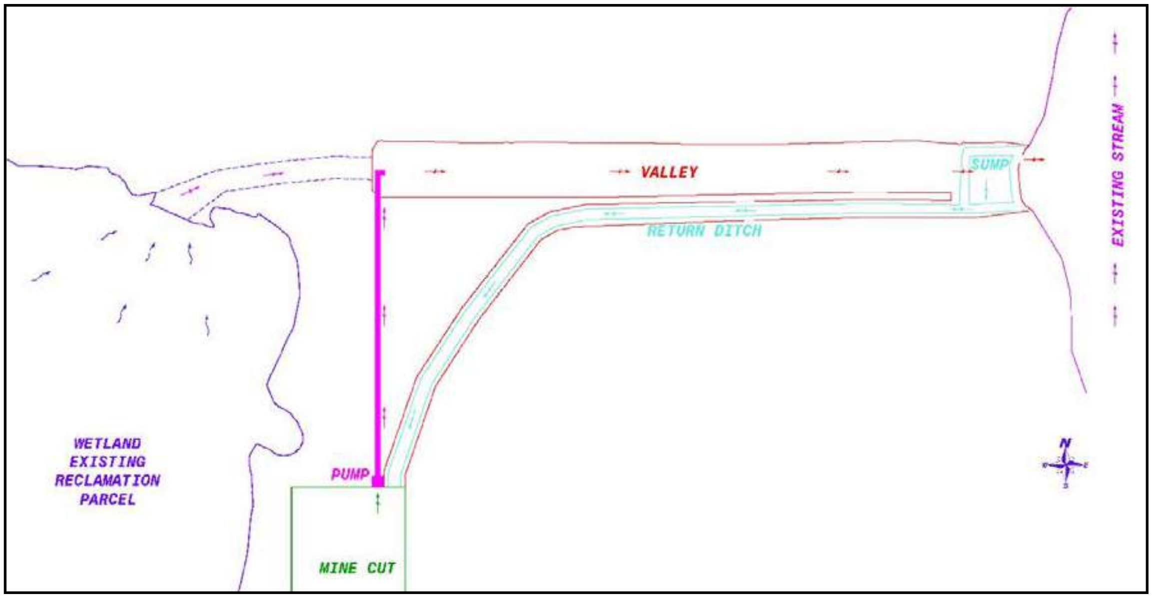
Figure 10.6 (Cont.). Photo Montage of Retrofit LWD Habitat Amendments.

In circumstances requiring sediment transport (either degradation or aggradation), the use of heavy equipment in an intact floodplain can be eliminated or reduced by hydraulic construction as well, whereby water can be pumped to scour aggraded channels and slurries can be pumped to fill degraded ones.

HYDRAULIC CONSTRUCTION

Hydraulic construction involves the use of flowing water, or associated sediment slurry, to construct the stream channel. The design concept invokes two simplifying concepts: the dominant and effective discharge theories. The theory of effective discharge states that a single flow volume can be identified which occurs with sufficient power and overall duration to do most of the work to create and maintain an open channel. Dominant discharge theory states that if the effective discharge is the only flow applied to a valley, a similar stream channel pattern and dimension would result when compared to that of a naturally more variable flow regime. Bankfull discharge is often assumed to represent the effective discharge. It is important to recognize that in nature the effective discharge carries sediment yields from the watershed in addition to in-channel scour. For Florida, the watershed's yields are small, so adding soil to the discharge is not always essential. Therefore, the main design tool for hydraulic carving is to assure the valley slope and drainage area are consistent with Figure 4.6 or 4.7, and then to calculate an appropriate bankfull discharge from Figure 5.1 or 5.2 (or their associated regression equations).

As with mechanical construction, the first step is to isolate the site for stormwater management. The stormwater controls should include a sediment trap at the downstream end of the project area to capture the volume of sediments carved for the channel plus a factor of safety (Figure 10.7). The next step is to establish a water circulation that provides a constant bankfull discharge through the project area, isolated from downstream receiving waters. Because the channel migrates upstream over time as it develops (headcuts), the amount of time to reach equilibrium dimensions is a function of project length as well as the resistance of the soil materials to erosion. For a mixture of unconsolidated sand and organics it took 8 weeks to reach equilibrium on a 1,000 foot long valley on the DB-2 project (Figure 10.8). For a stiff clay and sandy loam substrate about 5,000 feet long, it took about 24 weeks on the South Bowlegs site. Basically, hydraulic carving is similar to natural weathering processes, but takes a matter of months instead of decades.



DB-2, South Pasture Mine

Figure 10.7. Schematic of a Hydraulic Construction Recirculation System.

A) Valley at photo station before hydraulic carving.

B) Valley at same photo station during hydraulic carving two weeks later.

DB-2, South Pasture Mine

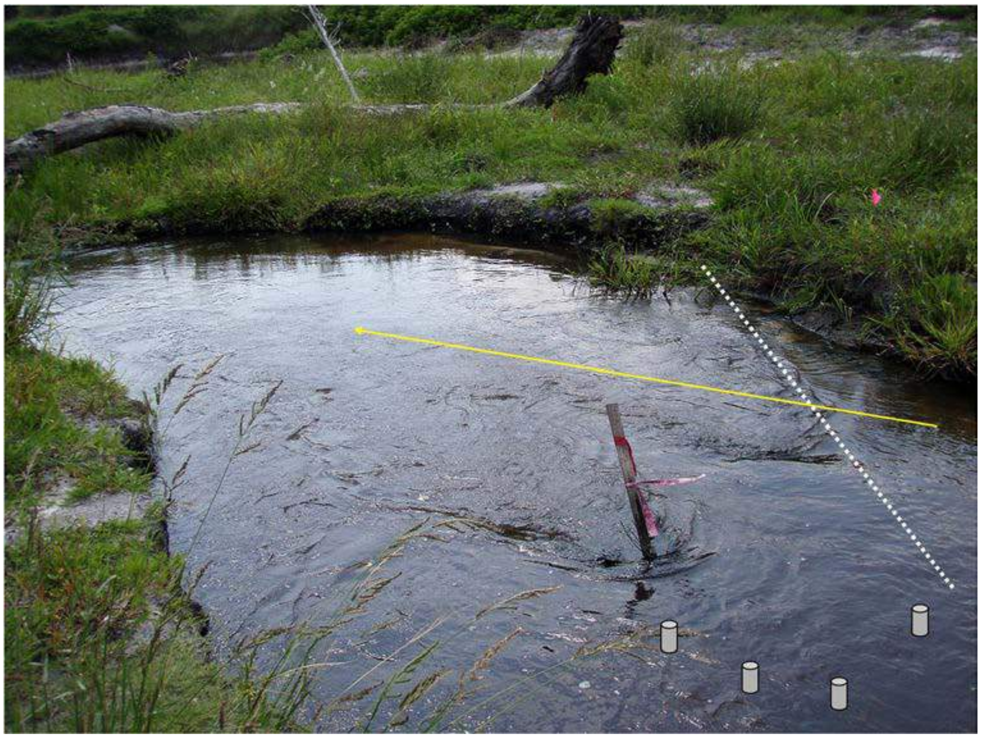
Figure 10.8. Photo Station Comparison Before and During Hydraulic Carving.

Florida's headwater streams typically have intense biological controls on bank stability due to a year-long growing season. Heavy flows are concentrated during a four- to six-month wet season but serve mainly to water-prune roots rather than to undermine trees or shrubs due to the low relief of the peninsula. These factors enable dense woody root masses to become very firmly established in the banks from top to bottom of the embankment which serve to hold the channel meander pattern in place. However, wind storms variably knock down trees, exposing readily erodible bank materials and thus leading to temporally and spatially chaotic meander patterns for most Florida headwater streams. The tree falls also create areas of hydraulic energy foci, inducing bed patterns that would not otherwise occur.

Therefore, the hydraulic carving approach benefits from creating valley substrates with variable resistance to erosion (e.g., of different cohesion), including a good growing medium that allows fast-growing herbaceous wetland plants to grow as the carving unfolds. It also benefits from scattering clusters of large, heavy woody debris across the meander belt prior to and during carving. Once the channel is more than halfway toward equilibrium, pumping can be temporarily suspended to allow some of the LWD to be placed into standard V-log, J-hook, and wing deflector positions as well as random arrays within the incipient channel (Figure 10.9). When keying the LWD into the bank, it is important to do so recognizing the ultimate width the channel will reach and choose pieces long enough to accommodate it. This can be predicted using Figures 5.6, 5.7, or 5.8 depending on stream type, or their associated regression equations. Some of the sharpest bends can be selected for combined root wad and J-hook treatments to preserve them through the process.

A) J-hook placed after 4 weeks of hydraulic carving to preserve bend.

Figure 10.9. Large Woody Debris Deployments Made During Hydraulic Carving.



B) Same J-hook submerged by bankfull discharge at equilibrium dimension. Dashed line shows location of logs and cylinders show location of wood piles driven into the bed. Yellow arrow is flow direction. Note common survey stake with image A).

C) V-log weir placed after 4 weeks of hydraulic carving to induce a new pool.

Figure 10.9 (Cont.). Large Woody Debris Deployments Made During Hydraulic Carving.

D) Same V-log weir submerged by bankfull discharge at equilibrium dimension. Dashed line shows location of logs and yellow arrows depict flow direction.
DB-2, South Pasture Mine

Figure 10.9 (Cont.). Large Woody Debris Deployments Made During Hydraulic Carving.

The base level of the outlet to the downstream sediment sump is an important consideration. If it is set too low, it will lead to an excessively entrenched stream. It is prudent to establish a permanent or temporary resistant layer at the valley mouth before the sump to retard this. This could be a clay layer or a metal culvert through an earthen berm. In the South Bowlegs project the outlet pipe was set too low, leading to an entrenched stream. About halfway through the process, the pipe was raised to the desired invert and the bed materials accumulated at the proper level. This result suggests that sediment slurries could be used to readily fill artificially entrenched channels in urban settings to reactivate their abandoned floodplains if a fixed downstream grade could be established at the desired base level. This approach could likewise be used to fill degraded channels downstream of in-line dams using sediments dredged from the reservoir. In other words, hydraulic construction can be used to carve channels in aggraded streams or newly created valleys, or can be used to transport slurries useful for building higher bed elevations in degraded or over-dimensioned channels.

A benefit of this approach is that channel formation only occurs where it will be sustainable. For example, the South Bowlegs site included a variable valley profile with slopes ranging above and below the lower thresholds observed to support open alluvial channels in nature. The locations of where channels carved and where they did not on the South Bowlegs site were consistent with these thresholds, forming a naturalistic chain-of-wetlands along the contoured valley (Figure 10.10).

South Bowlegs Creek, Fort Meade Mine

Figure 10.10. Chain-of-Wetlands FPZ Response to Hydraulic Carving.

Further, the transitions between the in-line wetlands and stream channels were similar in pattern and size to those encountered in natural systems. Thus, channel system formation is self-regulating along the valley in a very natural way.

One serendipitously discovered benefit of the hydraulic construction technique is that it appears to be robust against intense storms occurring near the end of construction. The South Bowlegs project received more than 4 inches of rainfall in an hour and the DB-2 site 5.4 inches in two hours, when they each were within 80% of construction completion. In both cases, the actual water delivered to the project area from direct precipitation alone was on the order of a 10-year, 24-hour return interval event for the entire watershed, had it been on-line. Largely because natural channel principles and appropriate erosion control BMPs were being followed, the damage was not catastrophic to the works and no pollution events occurred. Reworking was entirely unnecessary in one case and was restricted to a few V-log weirs in another. Channel planform patterns and cross-section dimension remained within design requirements.

Another benefit of hydraulic carving is that it requires a comparatively simple set of plans versus that of mechanical construction and is a largely self-regulating constructor. It is also potentially less invasive in corridors with difficult access for mechanical earthmoving equipment. Conversely, the biggest advantage of mechanical construction is that very exacting channel forms and soil layers can be specified. It is more surgical in concept and execution.

The greatest cost sensitivities of hydraulic construction depend on how many pumps are required, the size of the pumps, and the length of time the pumps need to run. Generally, the low-head high-volume pumps often used in Florida require boosters every 8,000 feet or less, depending on solids content of the slurry and other factors. This means that a 9,000-foot-long project will be roughly double the cost of a 7,000-foot-long one, despite only adding a 28% increase in length. In the 9,000-foot-long scenario, it might make more sense to create the upstream 1,000 feet using mechanical techniques and the downstream 8,000 feet using the hydraulic process to avoid adding a second pump. If the mobilization costs of the heavy equipment to a remote site are very high, then it might be less expensive to simply do the entire project mechanically rather than to pay that premium for a small subset of the valley in addition to pumping costs. This is just food for thought as the actual technique used will depend on project objectives, available equipment and service providers, and site-specific conditions.

CHAPTER 11
MONITORING AND ADAPTIVE MANAGEMENT

INTRODUCTION

It is highly beneficial to clearly state the project goals and set a series of measurable objectives related to meeting the goals (NRCS 2007b). An example of stated goals might be, “Improve upon existing ditched channel conditions by reclaiming a more natural stream channel and riparian corridor system. The reclaimed system will have fluvial geomorphology and riparian habitat patterns akin to those of natural headwater channel systems for the region (peninsular Florida), specifically a FW-CV-NC type with a Rosgen E5 channel. This design will restore headwater wetland hydrology and in-stream aquatic habitat diversity and complexity destroyed by historic ditching.”

The monitoring objectives are to create a series of outcomes measures to document development of geomorphic, hydrologic, chemical, and biological conditions and to provide recommendations for adaptive management practices to ensure that restored stream systems are functioning as desired. Biological monitoring is often neglected, which is unfortunate because ultimately it is a main purpose of the restoration (Roni and others 2008). The biota are really the ultimate outcome measure, while data concerning water quality, geomorphology, and hydrology are top-down process variables that can be used to explain the biological outcomes and guide corrective management tactics if necessary.

Some stream restoration projects are conceived as an exercise in accelerating succession. Various functions will come on line at different rates and some are contingent on others, making them threshold-dependent, as opposed to occurring along a linear gradient through time. Geomorphologists are trained to recognize structural contingencies and their lag times as a critical component to recommending restoration strategies (Schumm 1977). It is important to anticipate the trajectory, consider its potential threshold points, and track where the site is on it.

Biologists also focus on trajectories. For example, Keenan (2007) found differences in water quality, habitat substrates, and macroinvertebrate community indices in 22 streams restored by passive weathering that took about 15 to 20 years to reach equilibrium similar to unmined reference sites. Clewell and others (2000) described a similar chronosequence at a single site, Dogleg Branch, after 20 years of intensive monitoring. A temporal benchmark has been established for headwater streams constructed using passive weathering and the next step is to better understand what construction and management practices sustainably provide biological integrity more quickly and the extent to which the investment in particular practices is justified. Although the previous discussion is focused on headwater streams created at phosphate mines, it is necessary to recognize that lag times will likely vary by stream type and the intensity of the disturbance upon restoration.

The latter point bears emphasis. Streams in need of restoration are typically disturbed twice. This includes the original set of stressors that led to a desire to restore the system, followed by the invasive act of restoration itself. The original set of stressors in streams likely to be restored outside of mining sites often lead to a series of complicated and irreversible series of geomorphic changes that are decades in the making and that rarely can be resolved simply by removing the stressor set. This necessitates physically resetting the in-stream conditions to either fit the new stressed watershed condition, or removing the top-down stressors from an altered watershed while simultaneously resetting the in-stream conditions to something more like a genuinely restored condition. Either way, in-channel work is likely. However, it can be a bit like open-heart surgery and should be minimized to the greatest extent practical. Continuing with the medical practice metaphor, we should be following the basic med-student training concept of *Primum non nocere*, which literally translates from Latin to "first, do no harm" and expresses the desire to consider not only the benefits of treatment but the risks. Go into the valley with as light a hand as possible.

When budgeting stream restoration projects we strongly recommend including monitoring funds for a several-year period. Recognizing that lag times occur, it is not necessary to monitor all things every year except for research purposes. It is more cost-effective to qualitatively inspect the site annually, while reserving more expensive quantitative monitoring to track milestones likely to become apparent after a few wet seasons (typically 3 to 6 years) and again after woody vegetation starts to form a closed canopy (typically 7 to 12 years). We have found that simply monitoring variables in one discipline is unlikely to provide a sufficient picture of project outcome and therefore recommend hydrology, geomorphology, water quality, in-stream habitat mapping, macroinvertebrate, fish, and vegetation monitoring.

MONITORING FOR MANAGEMENT AND OUTCOME MEASURES

Hydrology

Stream systems should have adequate water supply for their type. Staff gages equipped with continuous level recorders record the full variability of water levels. Non-vented pressure transducers with self-contained batteries and internal data loggers are typically the most affordable and hassle-free mechanism. Continuous recording is recommended and flow should be measured during repeat hydrological monitoring using a velocity meter during Year 3, Year 7, and Release Year to adjust stage-discharge rating curves developed during the first year or two after restoration, and to calculate bankfull flows. USGS section-area methods are recommended.

Stream channel wet-season flows should produce bankfull discharge and bankfull tractive forces within the range of values for the desired HBG stream type or project-specific reference streams. The exceedance or frequency of bankfull discharge should also fall within such ranges if they can be established. Further, the long-term flow duration or frequency of years with 90- or 180-day flow spells should meet the ranges exhibited by the desired HBG stream type or site-specific reference conditions.

Geomorphology

The following design objectives have been developed pertaining to the stream channel:

- Channel beds and banks should be stable;
- Channels should be properly dimensioned to transport water and sediment from their basins in a self-maintaining manner;
- Channels should exhibit normal and natural complexity in plan and bed forms (have a normal and natural pattern and dimension of bends, riffles, and pools); and
- Channels should be topographically and hydraulically compatible with riparian wetlands (lateral, headwater, and receiving waterbodies).

Reference reach surveys should be conducted in accordance with Harrelson and others (1994) to monitor channel stability, dimension, and complexity during Years 1, 3, 7 and Release Year. Each year visual erosion and stability inspections of channel segments and their connections to other waterbodies (i.e., wetland-stream transition areas) are required to identify maintenance items. Permanent photo stations should be established and repeat photographs taken during annual inspections. If visual or quantitative monitoring indicates deviance from desired patterns, the climate and other potential causes of the deviation should be contemplated prior to recommending remedies.

The reclaimed streams will be temporarily stabilized until bank vegetation is established to ensure long-term natural channel stability. Natural streams typically have deformable boundaries and beds. “Stabilization” does not mean the stream will not change shape. It just means that it is unlikely to engage in long-term destabilizing trends of bank failures leading to aggradation or channel incision (degradation) that could impair biological function of the stream channel or lead to harmful erosion or shoaling downstream. Therefore geomorphic metrics should be compared to the acceptable ranges for the desired stream type.

The following performance standards have been developed pertaining to the stream channel:

- Channel shape indices, such as Rosgen Level II classification, should be consistent with those forms occurring for the desired HBG stream type;
- Bankfull thalweg depth, width, and cross-section area should be in range with appropriate HBG types or project-specific reference streams in peninsular Florida;

- The association between valley slope and drainage area must be within range of natural stable streams in peninsular Florida;
- The channel sinuosity ratio, number of riffles and pools per unit stream length, and radius of curvature of the bends must be within the range of natural stable streams in peninsular Florida; and
- The slopes and widths across the in-line wetland-stream transitions must be stable and in accordance with the design specifications.

Fauna

Channels should provide a normal and natural diversity and abundance of in-stream aquatic habitat features for aquatic fauna, such as large woody debris, packed leaves, macrophytes, and roots. Rapid habitat assessments, such as the Department of Agriculture (USDA) Stream Visual Assessment Protocols (SVAP) (NRCS 1998) and FDEP Stream Habitat Assessments (HA) (FDEP 2011b), should be conducted during Year 3, Year 7, and Release Year to monitor habitat availability. Created streams should score within the ranges of comparable reference systems, or “Good” or better on SVAP and “Suboptimal” or better on FDEP Habitat Assessment during Release Year.

Macroinvertebrate communities not only form the base of the heterotrophic food web, but can provide good indication of aspects of the water quality and hydrology regime, so FDEP SCI sampling (FDEP 2011b) should also be performed during Year 3, Year 7, and Release Year. It is not acceptable to treat SCI thresholds developed for perennial streams as applicable to non-perennial ones. While perennial streams should score “Healthy” on the FDEP SCI during Release Year, because many biologically intact headwater streams do not have sufficient flow durations or dissolved oxygen levels to routinely pass the SCI, the site’s SCI for non-perennial systems should score within the range of SCI values for applicable reference streams within the HBG type desired until such time as a non-perennial SCI is developed. Alternatively, metrics related to function such as feeding guilds could be assessed and compared to a range of natural conditions in reference streams.

Stream systems should include a diversity and abundance of pools, riffles, and cover that support native freshwater fish species. Fish in Florida headwater streams are poorly studied. Despite substantial overlap in habitat requirements, it is not safe to assume a healthy macroinvertebrate community results in a healthy fishery. For example, BCI (2009) documented passing SCI scores in a deeply entrenched ditched stream in Hillsborough County that supported a fishery overwhelmingly dominated by small-bodied, exotic fish taxa escaped and naturalized from regional fish farms. The main problem was the ditch lacked the necessary pool structure to support native predatory fish.

Fisheries differ by stream type and can be good indicators of impacts. In a case study of several streams in DeSoto County, Florida, AMEC-BCI (2011) found that the fish taxa of unditched FW-CV streams differed in composition and relative abundances from those of ditched channels draining less than 4-square-mile watersheds. The natural CV streams were dominated by small-bodied species common to regional wetlands. Larger, more perennial streams, including FW-AF-CC/WF and FW-AFS-HG systems on the property, had all the taxa present in the smaller stream types with the addition of larger-bodied species, more species relying on sandy alluvial surfaces and deep pools, and species more sensitive to low dissolved oxygen levels.

Because the fishery can indicate separate functions and biological outcomes from the macroinvertebrate community, fish sampling is highly recommended. Fish should be collected using dip nets, electrofishers, and/or seine nets, depending on the channel conditions during Year 3, Year 7, and Release Year. Sampling areas 20-30 times the bankfull width should be blocked with nets at both ends during the collection. A fish Index of Biological Integrity (IBI) has not been developed for Florida streams, but stream health can be assessed examining fish abundance and biomass, taxonomic identification, species richness, pollutant tolerance, life-cycle and longevity characteristics, functional feeding guilds, and reproductive strategies.

Restored streams should provide taxonomic richness in the ranges found in the desired HBG stream types or site-specific reference sites, and the dominant feeding and reproductive guilds should be present as indicators of success until such time as applicable fishery IBIs are developed for Florida streams.

Flora

The riparian corridor should be sufficiently wide and vegetated with a dominance of native forest canopy, shrub, and groundcover plants normally and naturally associated with the riparian corridor community(ies) applicable to the desired stream type and site plans. The vegetation in the riparian corridor will typically be monitored in accordance with a Mitigation Wetland Monitoring Program. Wetlands along and in-line with created streams should meet normal permitting agency wetland performance criteria by release year.

The FDEP has recently developed stream-specific rapid vegetation bioassessment protocols. The Linear Vegetation Index (LVI) measures the biological integrity of the macrophytes in and along the channel (DEP SOP FS 7320). The Rapid Periphyton Survey (RPS) measures the effects of eutrophication on the algal community (DEP SOP FS 7230). The FDEP has offered ranges deemed to be normal and natural for healthy Florida streams, but regional variations and investigations concerning potential variability by HBG stream type may be warranted as refinement before their use as success determinants.

Water Quality

Stream systems should provide adequate water quality specific to the desired HBG type. Created streams can be reconnected to the drainage network upon demonstrating well-vegetated stable channels and floodplains meeting Class III turbidity standards during wet-season discharges. Grab samples should be performed during flowing conditions of standard field parameters, including temperature, turbidity, pH, specific conductance, and dissolved oxygen during Year 3, Year 7, and Release Year. Restored streams should meet existing Class III water standards or otherwise fall within the range of values for reference streams. Water quality monitoring programs should include constituents relevant to the stated restoration objectives. For example, if stream restoration is engaged as part of a TMDL BMAP to assist in reducing downstream nutrient loads for total nitrogen, then upstream and downstream nitrogen loads should also be monitored.

ADAPTIVE MANAGEMENT

The following series of recommendations for responding to site conditions requiring maintenance was developed for a series of headwater streams. It is a case study, more useful as a thought-provoking example as opposed to a generic set of recommendations applicable to all projects. Some of the recommendations are quite universal, however. For example, chronic channel instabilities tend to manifest themselves first at the transitional areas between wetlands and streams and/or at the downstream channel junction near the preserve boundary. Channel erosion typically starts at the downstream end of the site and migrates headward through the system. Inspectors should walk the entire length of the system annually at the end of the wet season until release. The system should be examined for migrating knickpoints at least several inches below design grade.

If such features are confirmed, the knickpoint should be stabilized with grade control techniques using large woody debris, coir logs, or other means deemed necessary by a qualified fluvial geomorphologist. Additionally, the watershed should be examined for opportunities to deliver less flashy runoff, as grade control may benefit from improved stormwater management practices, including ditch plugging, stilling basins, and LID techniques. In general, the closer the watershed improvements are to the restored stream, the greater positive effect they will provide.

Severe storms can cause channel avulsions that bypass tight bends. The annual inspection should note any such avulsions and GPS their location with a submeter instrument. If more than 5 such avulsions occur, the sinuosity ratio of the channel should be measured using a GPS. If this ratio falls out of the natural range, the channel should be retrained to achieve the sinuosity required. This can be accomplished in at least three ways: (1) by adding wing deflectors to portions of the stream opposite areas with sparse trees, (2) by digging more bends at radius of curvatures the site has demonstrated it will support, and/or (3) by rediverting flow to the original construction, filling the avulsion(s) with soil, coir log grade controls, and revegetating them.

Excessive sedimentation from the watershed can fill pools and smother hard substrates such as large woody debris habitat. If the Year 3 or 7 repeat reach surveys and

SVAP procedures indicate that pool frequencies are out of spec, then the cause of sedimentation should be determined. If it is ongoing, the source should be stabilized (if on land owned or controlled by the project manager). Otherwise, additional V-log weirs should be added to promote pool inductions necessary to meet the specifications.

Wind storms can create excessive debris loads into channels, increasing flow friction, trapping sediments excessively and causing the system to eventually avulse. If any debris dams blocking more than 75% of the channel cross-section area at bankfull are observed, they should be partially removed to allow at least 25% clearance. Also, rare floods could rip V-log weirs and root wads from their moorings and could create debris dams downstream of their intended locations. These should be treated as the debris dams listed above.

If pools or large woody debris counts fall below specifications and loss of V-log weirs or root wads is the suspected cause, then additional V-log weirs and root wads should be added to bring the site back within design specifications during Years 3, 7 or prior to release as needed.

If the site fails to provide the minimum abundance and diversity of in-stream habitats to score Good on the SVAP or Sub-Optimal on the FDEP Habitat Assessment during the Year 7 surveys or later, the site should be diagnosed for the cause of such deficiencies and habitat should be added by planting additional in-stream vegetation, adding more woody debris, adding cobble, or other means necessary to achieve success. However, if the system is meeting the fish species specification and is passing the SCI (or is within reference site ranges), these maintenance items are unnecessary.

Normal and customary vegetation management and maintenance activities for forested wetlands should be deployed in the riparian zone to promote tree growth, canopy development and to repress nuisance species.

Cattle and recreational vehicles should be excluded from the riparian zone at least during the establishment period, which may include through release as successful mitigation. Thereafter, a site-specific management plan should be developed, at a minimum, consistent with Florida Department of Agriculture best management practices for beef cattle operations (FDACS 2008).

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Appendix A

FLUVIAL GEOMORPHIC VARIABLE DESCRIPTIONS

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

Physiog: 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).

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

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

Basin Scale Continuous

Drain_Area: 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 Sinuosity.

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 pools/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.

*Dimensionless variable.

Appendix B

HYDROLOGIC VARIABLE DESCRIPTIONS

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 15th and 85th 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 times 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 per 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

GLOSSARY

GLOSSARY

Alluvium: Sediment transported and deposited by fluvial forces. For the purposes of this document, we are referring to modern and ongoing processes operating on a timescale that can be measured in terms of a season, a few years, or perhaps a few decades. This is an important distinction because the upper lithology of much of the Florida peninsula is comprised of ancient sili-clastics that are relicts of past alluvial transport. For the purposes of applied fluvial geomorphology and stream characterization in Florida, when referring to alluvium or alluvial processes, we are typically talking of the modern and on-going re-working of ancient alluvial deposits.

Annually Perennial: Streams flow 95% of the time on a long-term record, and almost continuously receive groundwater baseflow. These systems have 360-day continuous flow spells during most years, and achieve 180-day spells at least 90% of years. (see Ephemeral, Seasonally Intermittent, and Seasonally Perennial for comparison)

Bankfull: The discharge quantity and channel stage indicated by inflections in channel geomorphology, changes in vegetation, and signs of geomorphic work transporting alluvium that differentiates between comparatively routine in-channel flows versus less common floodplain flow conditions. Bankfull stage delineates the physical and biological thresholds that determine the lateral limits between the open channel waterbody and the adjacent floodplain. Bankfull discharge is often presumed to be similar in magnitude and frequency to dominant discharges (see related definitions of Dominant and Effective Discharge).

B_, F_, G_ Rosgen Type II Stream Types: Moderately to extremely entrenched stream cross-sections, often resembling gullies. These systems are uncommon natural associates of undisturbed flatwoods ecoregions in Florida, typically confined to mid-order or larger stream channels occupying valley segments crossing ancient marine escarpments. If found in a different valley type, they are likely indicators of excessive erosion and stream degradation in the flatwoods physiographic regions of Florida. They are more common as natural associates of the highlands sand ridge ecoregions of Florida and can also naturally occur in karst regions along some spring runs occupying carbonate paleochannels.

C5 Rosgen Type II Stream Type: A sandy natural meandering stream channel, typically with pronounced pools and point bars, that has a relatively wide and shallow bankfull cross-section and is only slightly entrenched in its floodprone area (Rosgen 1996). The letter designation ‘C’ defines the channel shape as having a Width to Depth ratio (W/D) greater than 12 and is modified according to the dominant channel boundary material by a numeric designation (in this case, sand = ’5’). For example, a shallow-broad channel (W/D > 12) that is slightly entrenched in its valley (ER > 2.2) is a C-type. If it is bounded by sandy materials, then it becomes a C5. A C6 has a similar geomorphology, but is bordered by silt/clay, whereas a C4 channel is bounded by gravel. The vast majority of natural low-order channels in southwest Florida flatwoods are either

C5's or E5's (see definition below), with C5's exhibiting tendencies to occupy flatter wetland valleys and E5's occupying more confined and steeply sloped upland valleys. However, both types can be encountered virtually anywhere.

Colluvium: Sediments or soils not governed by active riverine processes.

Control: Stream geomorphology can be governed by combinations of alluvial, geological, or biological processes or "controls." Streams under alluvial control have a dominance of forms created and maintained by ongoing sediment transport regimes. Geologic control results from processes associated with the development and weathering of resistant rock layers. Many of Florida's in-line waterbodies located within deranged drainage networks fit this concept well. Biological controls are from the formations of plants and animals. Examples include beaver dams, alligator holes and bed materials consisting of snail shells.

Dendritic Drainage Network: Valleys networks contain continuous stream channels organized in a tree-like pattern, uninterrupted by non-fluvial waterbodies.

Deranged Drainage Network: Valleys with stream channels are frequently punctuated by in-line waterbodies that are non-fluvial such as lakes, sinkholes, wetlands and sloughs. The non-fluvial waters have geomorphic genesis that differ in time and process from those active in the fluvial portions of the valley.

Dominant Discharge: The concept that channel morphology results primarily from a single common discharge and that channel dimension would be similar under a constant flow equivalent to the dominant discharge versus the more variable overall flow condition found in natural streams. See Bankfull and Effective discharge for related concepts.

E5 Rosgen Type II Stream Type: A sandy natural meandering stream channel, typically with pronounced pools and riffles, that has a bankfull cross-sectional width to depth ratio of less than 12 and is slightly entrenched in its floodprone area (Rosgen 1996). The vast majority of natural low-order channels in southwest Florida flatwoods are either C5's (see definition above) or E5's. E5's tend to occupy more steeply sloped valleys than C5's and are more likely to occupy headwater positions in the drainage networks of Florida's flatwoods versus higher-order positions. However, both types can be encountered virtually anywhere.

Effective Discharge: The flow conducting most of the overall sediment transport in a variable discharge regime. See Bankfull and Dominant discharge for related definitions.

Entrenchment Ratio: Ratio of the "Floodprone width" to the "Bankfull channel width" (Rosgen 1996).

Ephemeral: Streams are dry for at least 40% of the time over a long-term record, have a lot of inter-annual flow variability with long dry spells and seldom receive sustained groundwater baseflow. Flow can occur for less than 10% of the time during a long-term record for the smallest of these streams. Some sites may not flow at all during prolonged multi-year droughts. Most of these systems lack 90-day continuous flow spells during most years, and almost never achieve 180-day spells. (see Seasonally Intermittent, Seasonally Perennial, Annually Perennial for comparison)

Flood Flow: The discharge that just fills the alluvial floodplain to its wetland bottomland edges. This discharge is intended to reflect that which occurs at the upper boundary of potential alluviation of the floodplain, or the upper boundary of floodplain-building processes derived from overbank flow. The wetland boundary, so defined, excludes colluvial seepage slopes.

Floodprone Width: The valley width at twice the elevation of the bankfull thalweg depth (Rosgen 1996).

Floodscape: The aquatic and terrestrial components of the riparian zone that is flooded when the stream discharge is above bankfull conditions (Thorpe et al 2006)

Functional Process Zone: A fluvial geomorphic unit, typically smaller than a valley and larger than a reach, with functions related to dynamic physical processes that occur over time and that native biota are adapted to colonize and utilize to sustain their local populations (Thorpe et al 2006). FPZs can be distinguished based on combinations of HBG stream type, valley type, and adjacent colluvial features.

Gallery Forests: Gallery forests form as corridors along streams and wetlands and they project into landscapes that are otherwise more sparsely canopied such as open woodlands, savannas, or grasslands. Gallery forests are able to exist where the surrounding landscape will not support dense forests because the riparian zones in which they grow offer greater protection from fire, are often of higher fertility, and have a more reliable water supply at the root zone. As a result, the boundary between the gallery forest and the surrounding woodland or grassland is usually very abrupt, with the ecotone being only a few feet. Gallery forests are adversely affected worldwide by overgrazing, altered fire regimes, logging, and conversion to agriculture.

Hydraulic Residence Time: The volume of a waterbody divided by its net discharge rate.

Hydroperiod: The cumulative inundation or saturation duration of a waterbody, usually expressed as a percentage or as the average number of months per annum.

Interfluve: A terrestrial or floodplain land area located between two stream valleys.

Lentic Waterbody: Still waters. The water surface profile is nearly level. Water flow is gradual compared to the volume contained within the waterbody, leading to average hydraulic residence times typically at least several days long. Typical examples include headwater and isolated depressional wetlands, ponds, and lakes. Lentic wetlands are mapped as 600-series FLUCCS.

Lotic System: This is the landscape definition for inter-connected flowing waterbodies. It includes all the lentic and paralotic waterbodies that are connected by stream channels (see "lotic waterbody"). A typical lotic system in the flatwoods of Florida will include headwater wetland depressions, in-line wetlands, alluvial stream channels, and riparian wetlands. Sloughs and strands may also be part of the lotic system. The key distinguishing characteristic of a lotic system is flowing water, with at least some of that flow concentrated and conveyed by alluvial channel linkages.

Lotic Waterbody: Synonymous with "Stream." Characterized by running waters with a dominant unidirectional flow controlled by gravity. The water surface profile is noticeably sloped. Residence time is usually very short, less than a few days and often only a few seconds depending on the scale observed. Typical examples include the open bankfull channels of creeks, branches, and rivers. Lotic waterbodies exhibit continuous alluvial features on the channel bed and are bounded by well-defined banks that are held by dense emergent vegetation. They are mapped as 511 FLUCCS when natural or 512 FLUCCS when ditched at the locations of historically natural streams.

Paralentic Waterbody: Nearly lentic. Shallow vegetated or deeper open water depressions with diameters typically in excess of two-orders of magnitude wider than the bankfull channels connected to them. Water slopes are nearly level. Residence times are intermediate between those of lentic and lotic waterbodies and may vary considerably by season. Typical examples include in-line wetlands and in-line lakes. Paralotic wetlands are typically mapped as 600-series FLUCCS, not as 511's or 512's.

Paralotic Waterbody: Nearly lotic. Gently flowing waters that have a multi-directional flow pattern that typically is not organized at sufficient stream power to routinely conduct geomorphic work related to efficient sediment transport. Water slopes are very gradually sloped when flowing. Residence times are intermediate between those of paralentic and lotic waterbodies and may vary considerably by season. Typical examples include in-line sloughs and strands, in-line billabongs (narrow linear lakes found in many Florida rivers), and could also be laterally extended to include some large linear backswamps and oxbows in riverine floodplains. These areas generally lack any continuous and open inorganic alluvial features associated with sediment transport. If alluvium is a major presence, the dominant surfaces are depositional. Paralotic wetlands are typically mapped as 600-series FLUCCS, not as 511's or 512's.

Radius of Curvature: A measure of channel bend dimension corresponding to the length of a chord that approximates half the diameter of a circle that fits tangentially within the bend. Low radius of curvature indicates a tight bend, while high radius of curvature indicates a gradual one. Because larger rivers are expected to have larger bends, comparisons among streams of varying size are facilitated by dividing radius of curvature by channel width. The resulting radius of curvature to width ratio is a useful tool for assessing bend geometry.

Riverscape: The aquatic habitat located within the bankfull channel (Thorp et al 2006).

Sapping: A process of erosion whereby concentrated groundwater flow removes material from a lithological layer below ground. The overburden can subsequently collapse into the void, creating a gully or new valley.

Seasonally Intermittent: Streams tend to flow for at least 40% of the time during a long-term record. Sustained groundwater baseflow is generally absent during the dry season and present during the core of the wet season or sustained periods of weekly rainfall. These systems have 90-day continuous flow spells during most years, and sometimes achieve 180- and 360-day spells. (see Ephemeral, Seasonally Perennial, and Annually Perennial for comparison).

Seasonally Perennial: Streams tend to flow for at least 80% of the time during a long-term record. Sustained groundwater baseflow is generally absent during the dry season and present during virtually the entire wet season. These systems have 180-day continuous flow spells during most years, and sometimes achieve 360-day spells. (see Ephemeral, Seasonally Intermittent, and Annually Perennial for comparison).

Appendix D

CLUSTER ANALYSES DENDOGRAMS

CLUSTER ANALYSES DENDOGRAMS

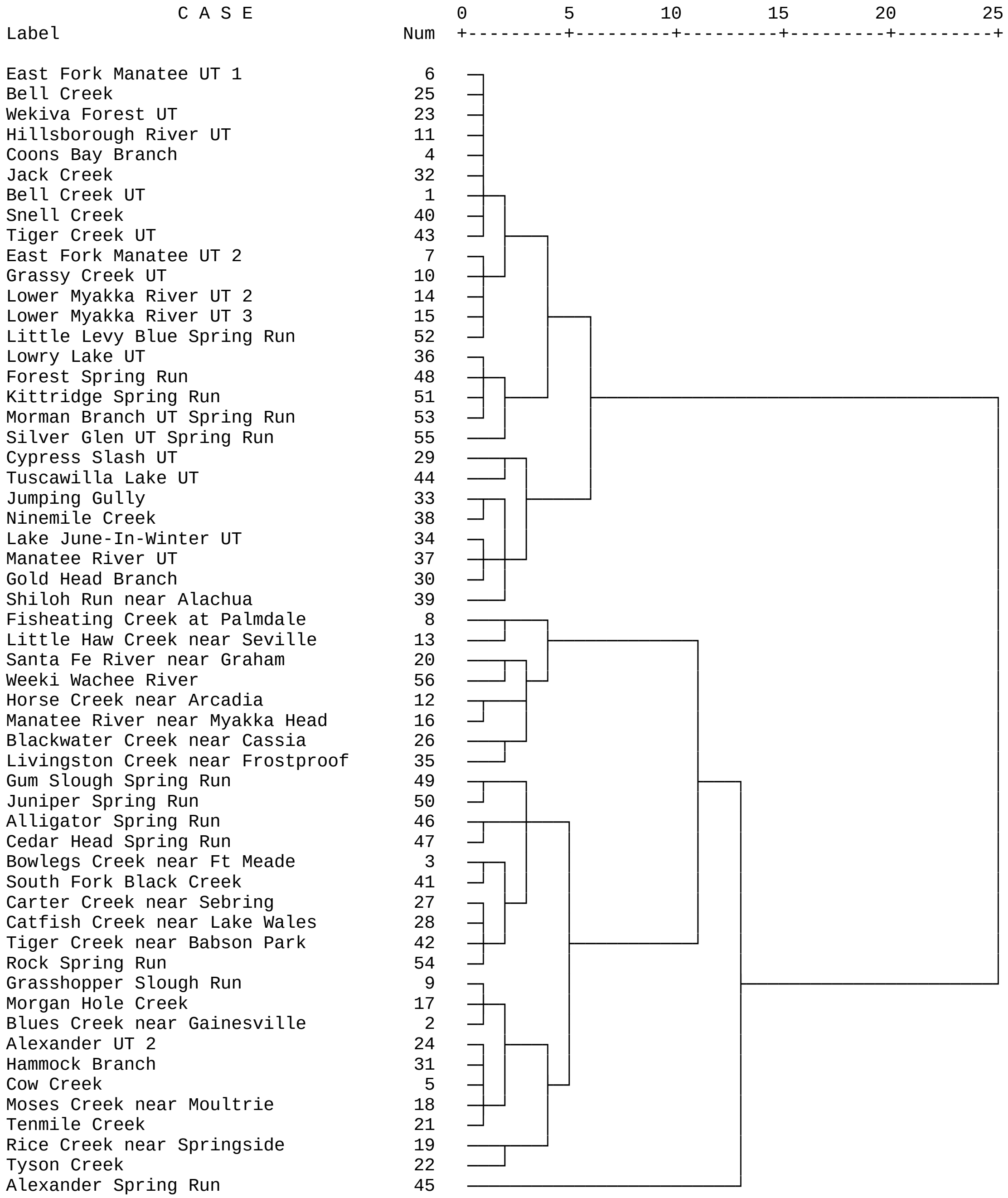
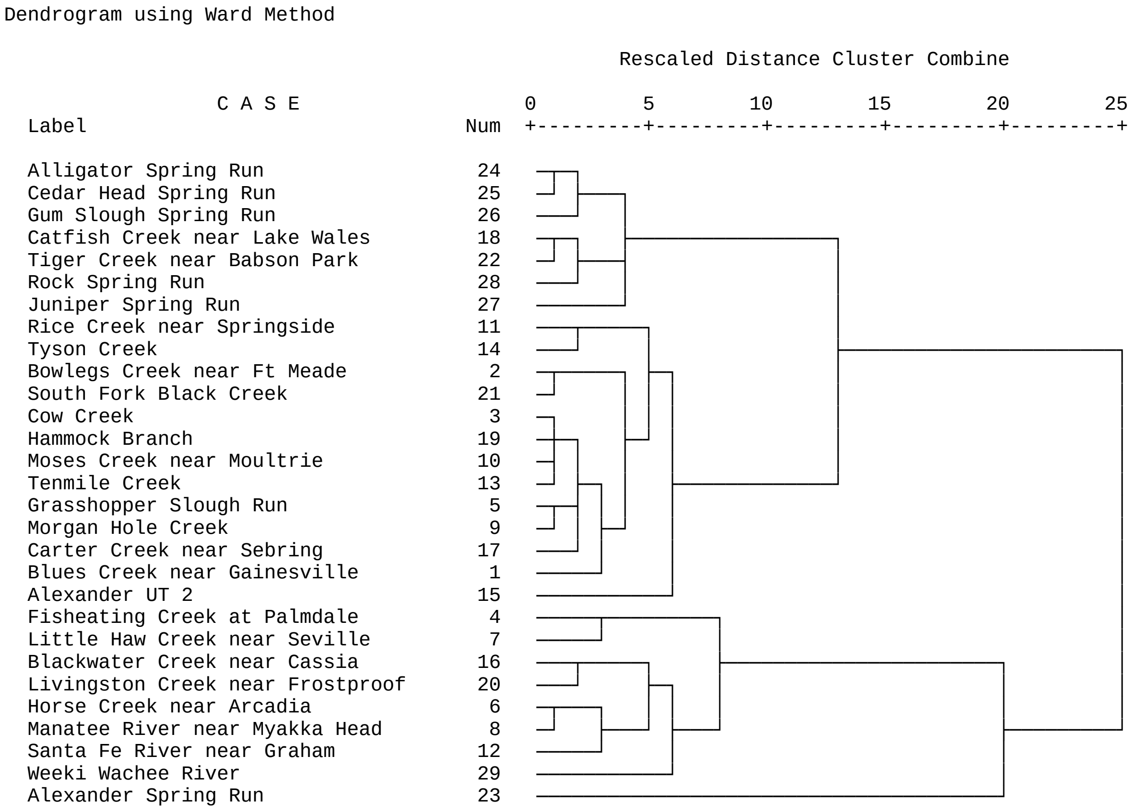


Figure D-1. Dendrogram for All Sites on All Variables.



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Dendrogram using Ward Method

                                        Rescaled Distance Cluster Combine

               C A S E                  0         5        10        15        20        25
  Label                          Num    +---------+---------+---------+---------+---------+

  Alligator Spring Run            24
  Cedar Head Spring Run           25
  Gum Slough Spring Run           26
  Catfish Creek near Lake Wales   18
  Tiger Creek near Babson Park    22
  Rock Spring Run                 28
  Juniper Spring Run              27
  Rice Creek near Springside      11
  Tyson Creek                     14
  Bowlegs Creek near Ft Meade      2
  South Fork Black Creek          21
  Cow Creek                        3
  Hammock Branch                  19
  Moses Creek near Moultrie       10
  Tenmile Creek                   13
  Grasshopper Slough Run           5
  Morgan Hole Creek                9
  Carter Creek near Sebring       17
  Blues Creek near Gainesville     1
  Alexander UT 2                  15
  Fisheating Creek at Palmdale     4
  Little Haw Creek near Seville    7
  Blackwater Creek near Cassia    16
  Livingston Creek near Frostproof 20
  Horse Creek near Arcadia         6
  Manatee River near Myakka Head   8
  Santa Fe River near Graham      12
  Weeki Wachee River              29
  Alexander Spring Run            23
```

Figure D-2. Dendrogram for Large Sites on All Variables.

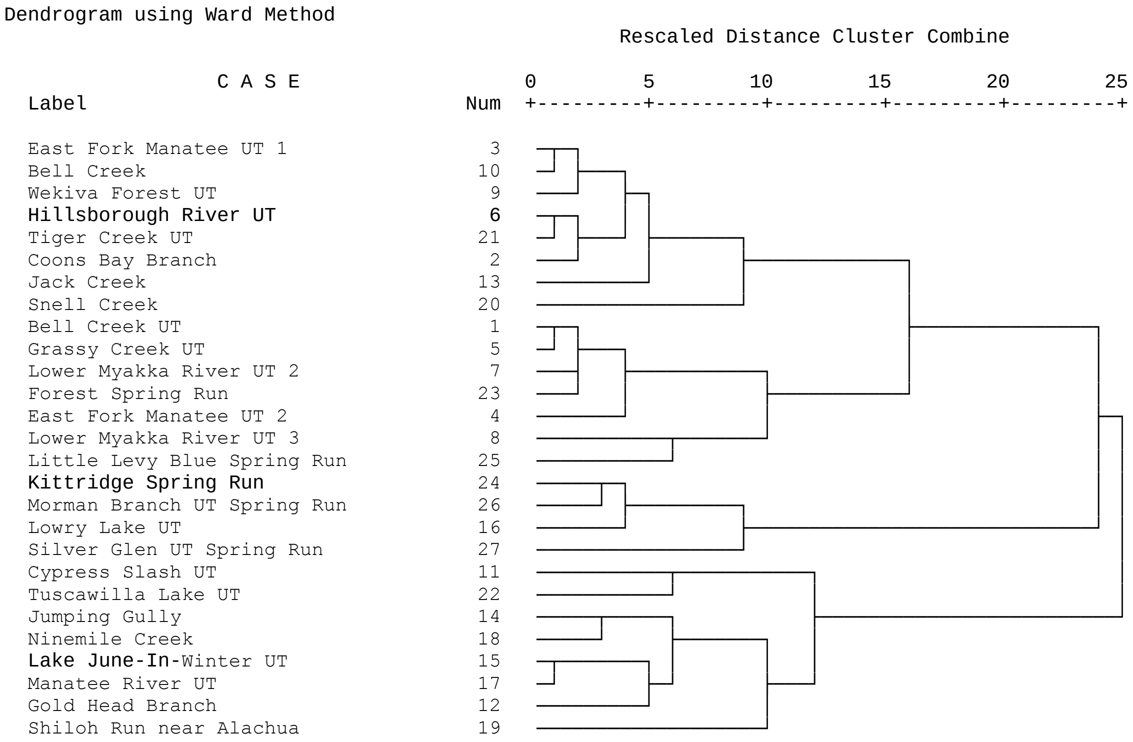


Figure D-3. Dendrogram for Small Sites on All Variables.

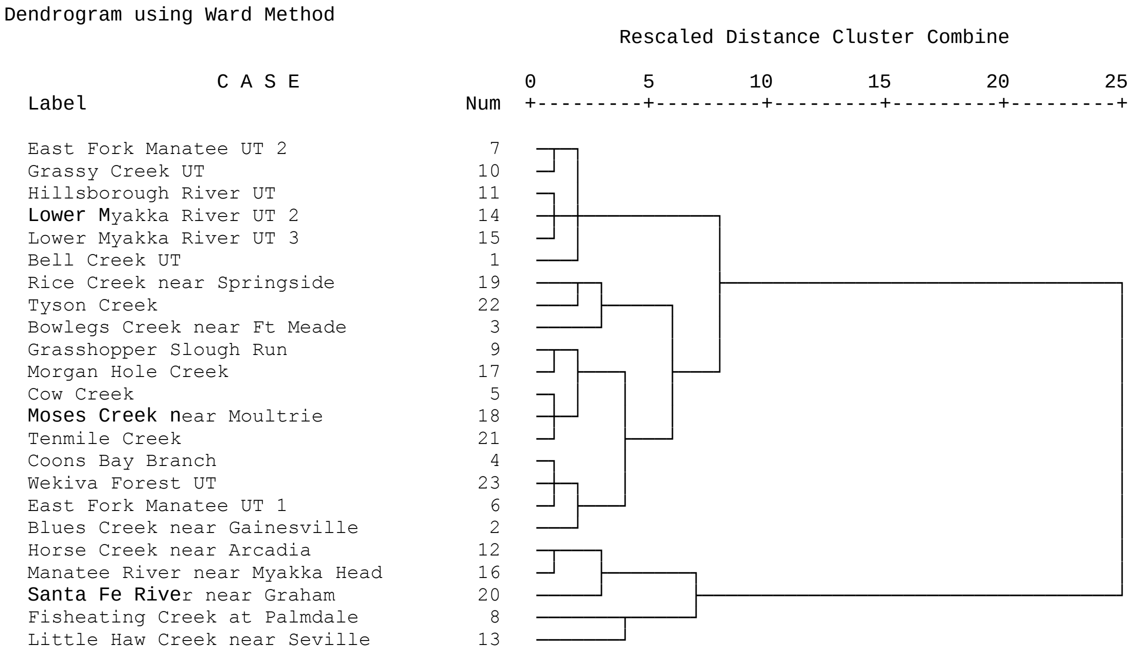


Figure D-4. Dendrogram for Flatwoods Sites on All Variables.

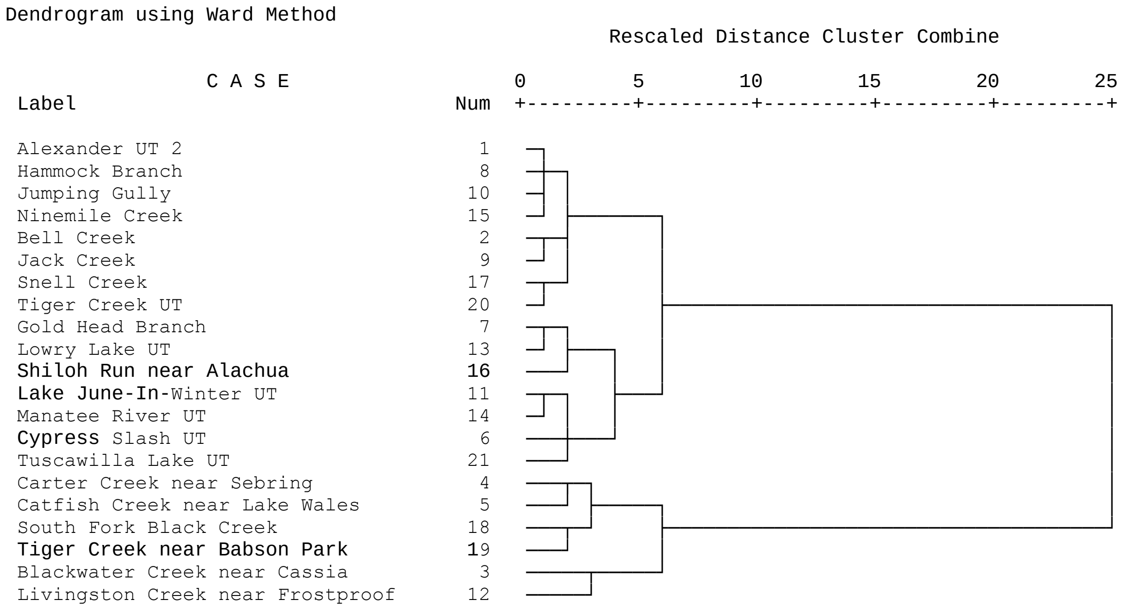


Figure D-5. Dendrogram for Highlands Sites on All Variables.

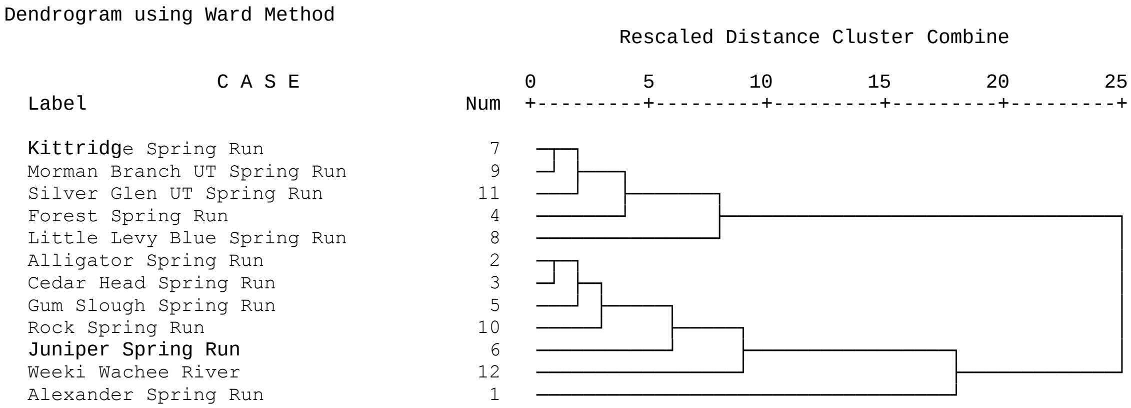


Figure D-6. Dendrogram for Karst Sites on All Variables.

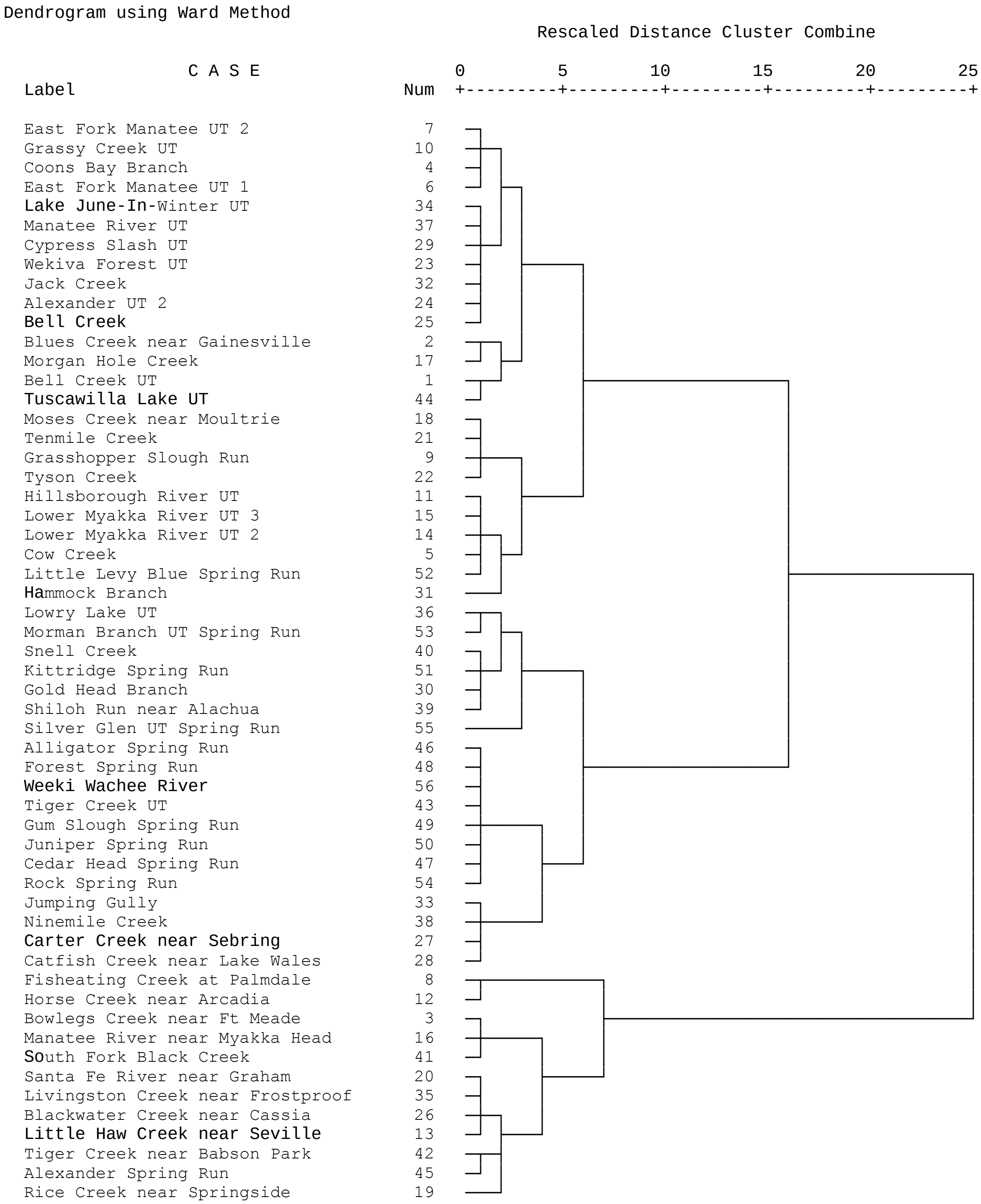


Figure D-7. Dendrogram for All Sites on Watershed Variables.

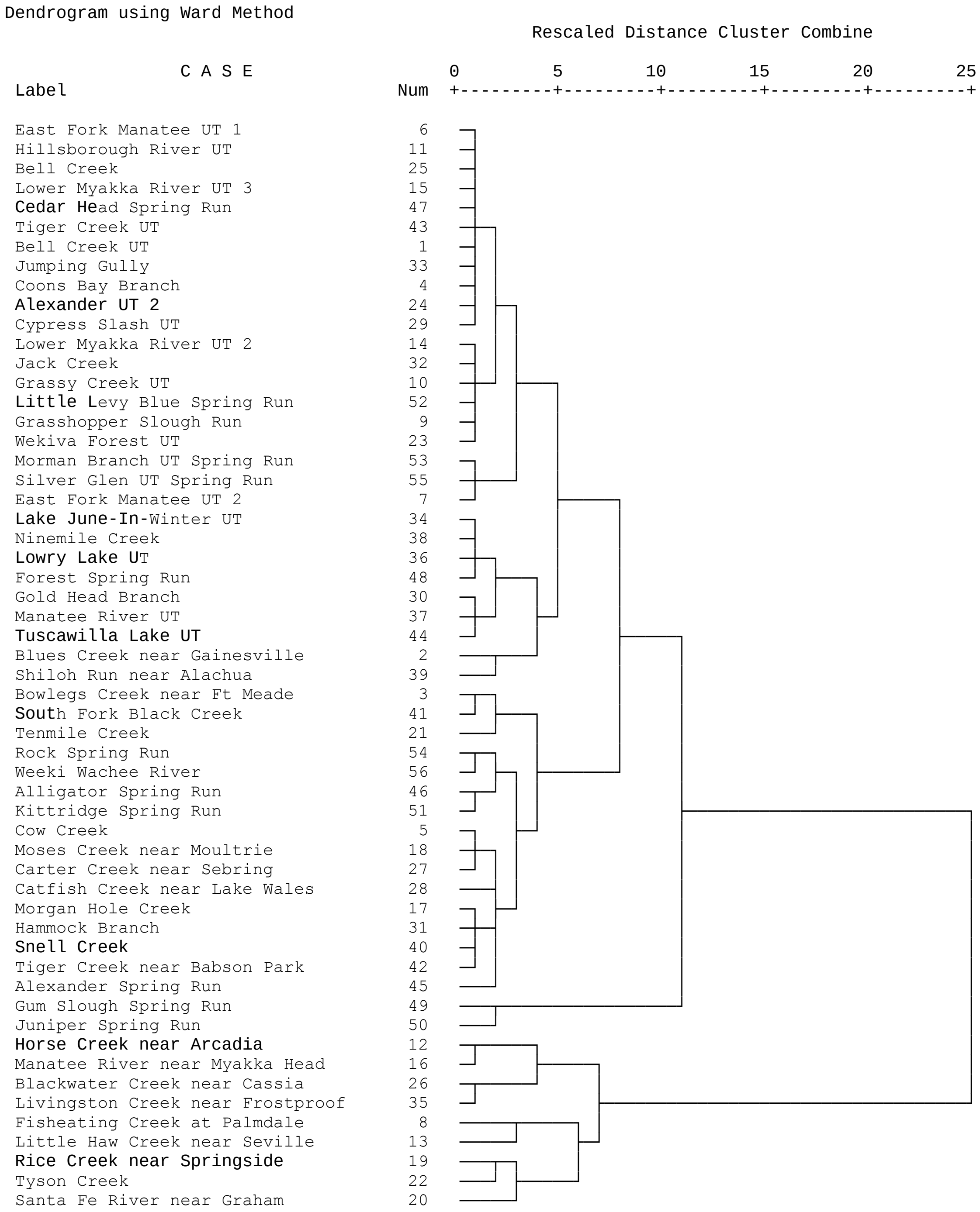


Figure D-8. Dendrogram for All Sites on Valley Variables.

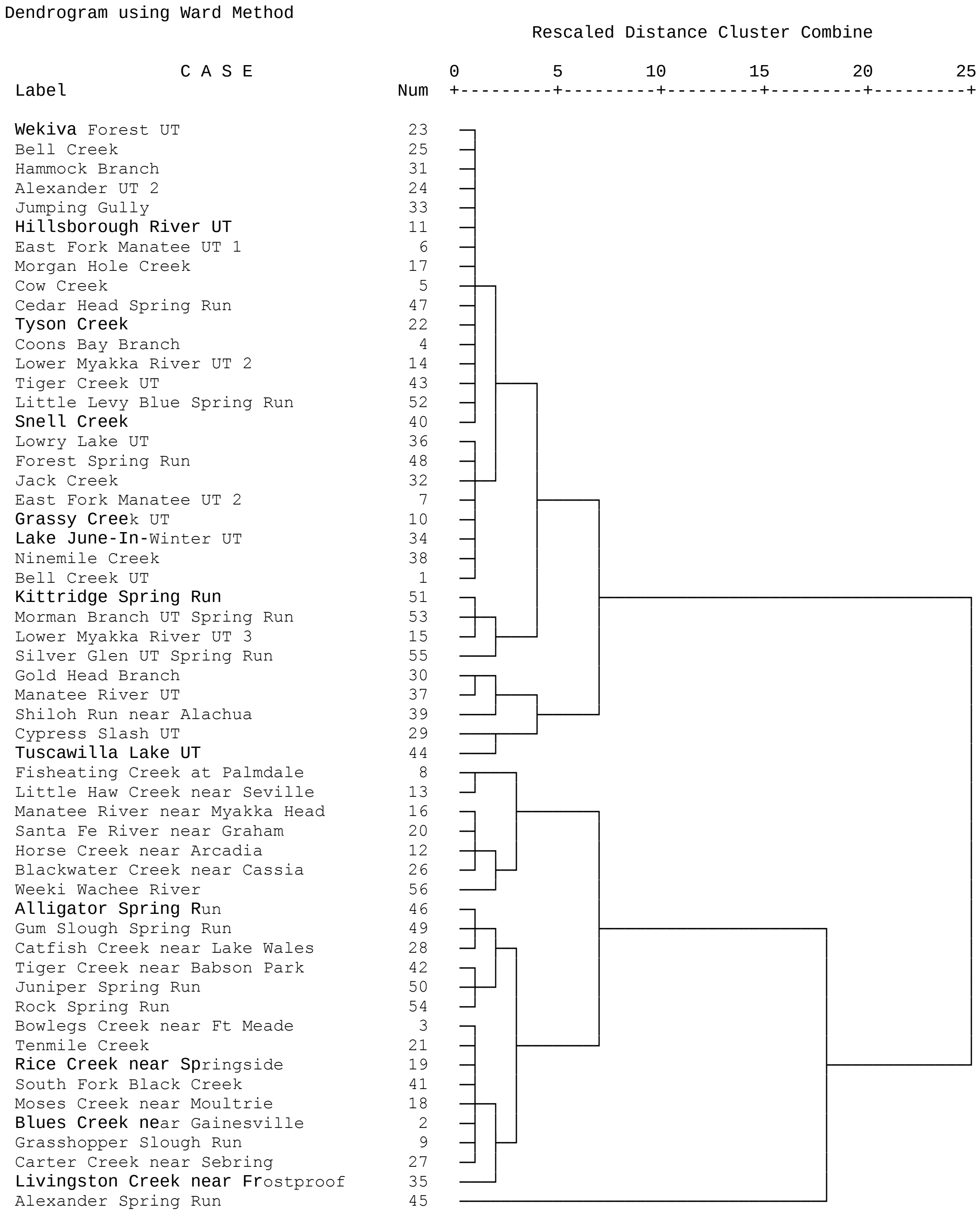


Figure D-9. Dendrogram for All Sites on Reach Variables.

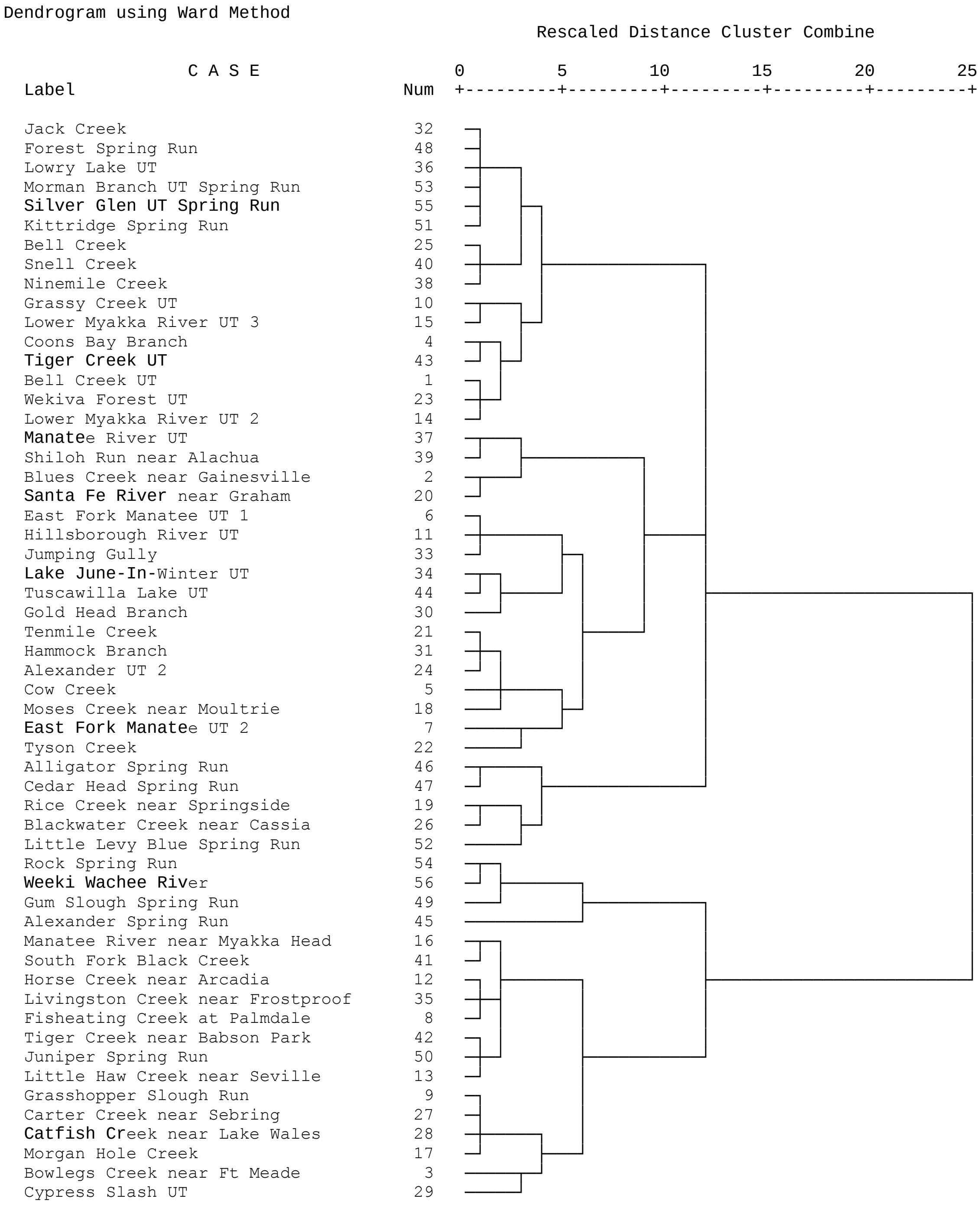


Figure D-10. Dendrogram for All Sites on Habitat Patch Variables.

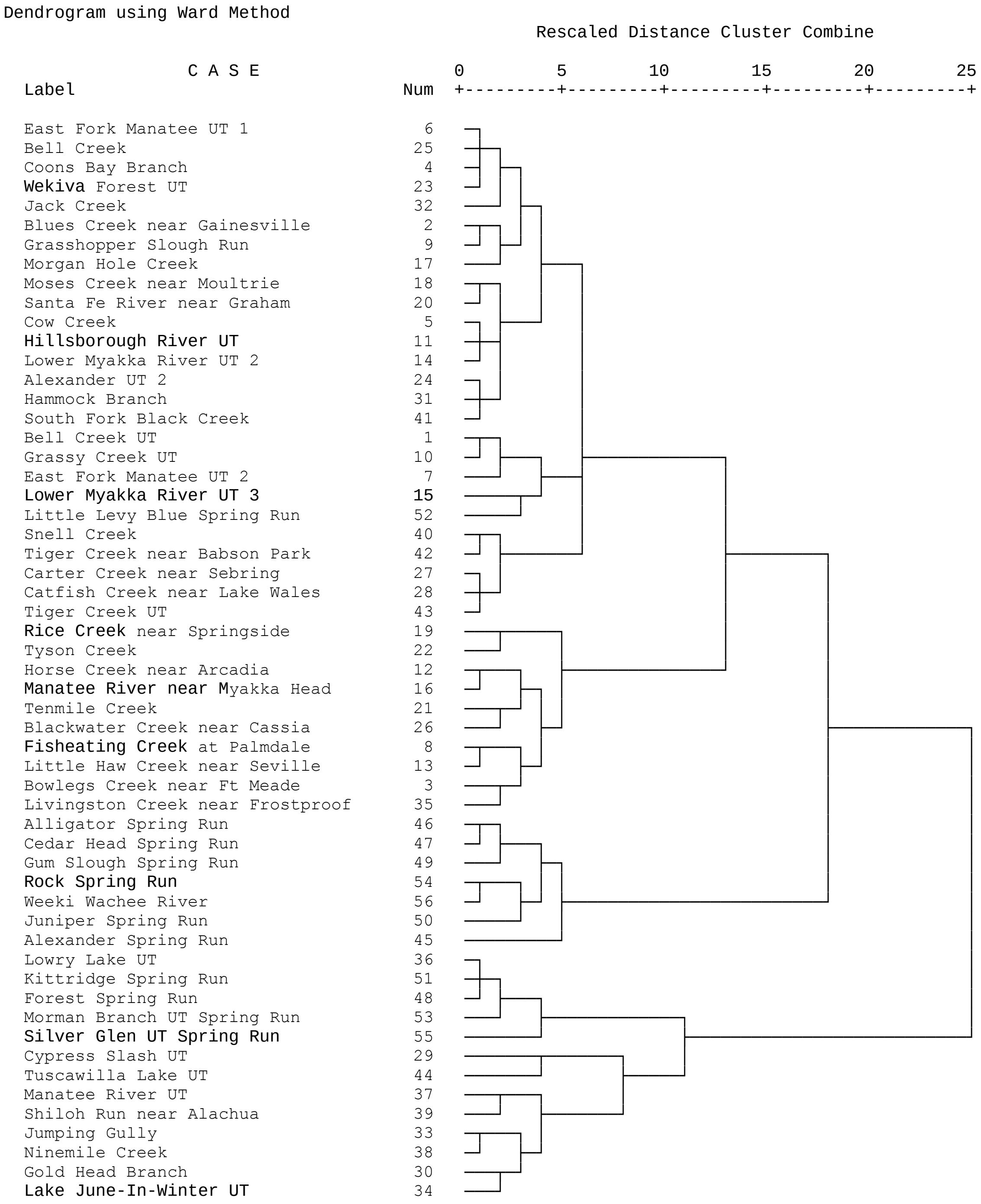


Figure D-11. Dendrogram for All Sites on Dimensionless and Unit Variables.

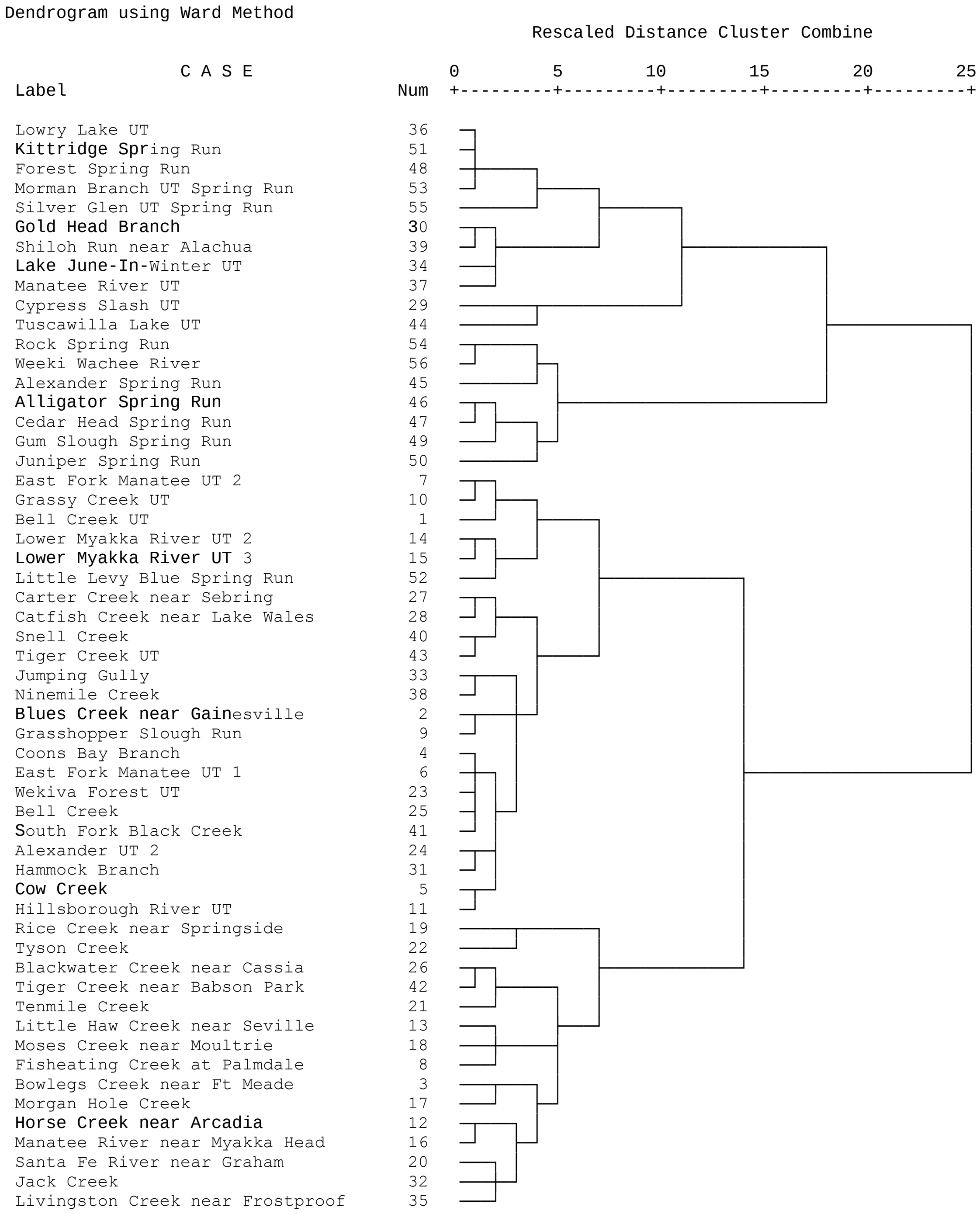


Figure D-12. Dendrogram for All Sites on Dimensionless Variables.

Appendix E

PRINCIPAL COMPONENTS ANALYSIS TABLES

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 (Cont.). All Cases with All Variables, Rotated Component Matrix.

	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 (Cont.). All Cases with All Variables, Rotated Component Matrix.

	1	2	3	4	5
Percent Wetlands			.563		
Valley Width at Flood Line			.562		
Valley Segment Sinuosity 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 (Cont.). Large Sites with All Variables, Rotated Component Matrix.

	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 (Cont.). Large Sites with All Variables, Rotated Component Matrix.

	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 (Cont.). Small Sites with All Variables, Rotated Component Matrix.

	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 (Cont.). Small Sites with All Variables, Rotated Component Matrix.

	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 (Cont.). Flatwoods Sites with All Variables, Rotated Component Matrix.

	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 (Cont.). Flatwoods Sites with All Variables, Rotated Component Matrix.

	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 (Cont.). Highlands Sites with All Variables, Rotated Component Matrix.

	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 (Cont.). Highlands Sites with All Variables, Rotated Component Matrix.

	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 (Cont.). Karst Sites with All Variables, Rotated Component Matrix.

	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 (Cont.). Karst Sites with All Variables, Rotated Component Matrix.

	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 (Cont.). Karst Sites with All Variables, Rotated Component Matrix.

	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 (Cont.). All Sites with Reach Variables, Rotated Component Matrix.

	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

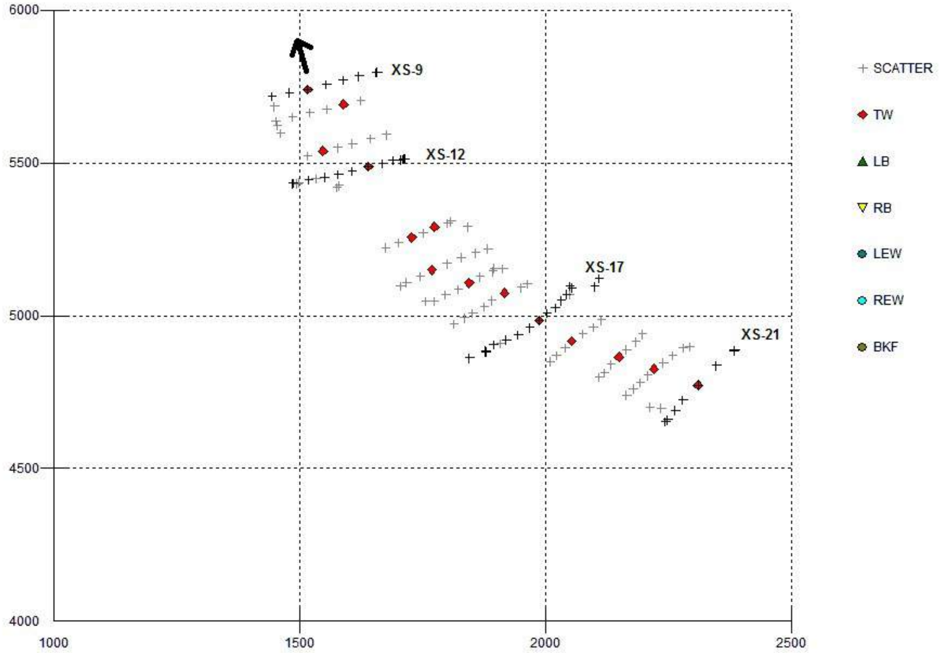
Table E-11. All Sites with Dimensionless Variables, Rotated Component Matrix.

	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

Appendix F

PLANFORM, CROSS-SECTION, AND PROFILE SURVEYS

PLANFORM, CROSS-SECTION, AND PROFILE SURVEYS



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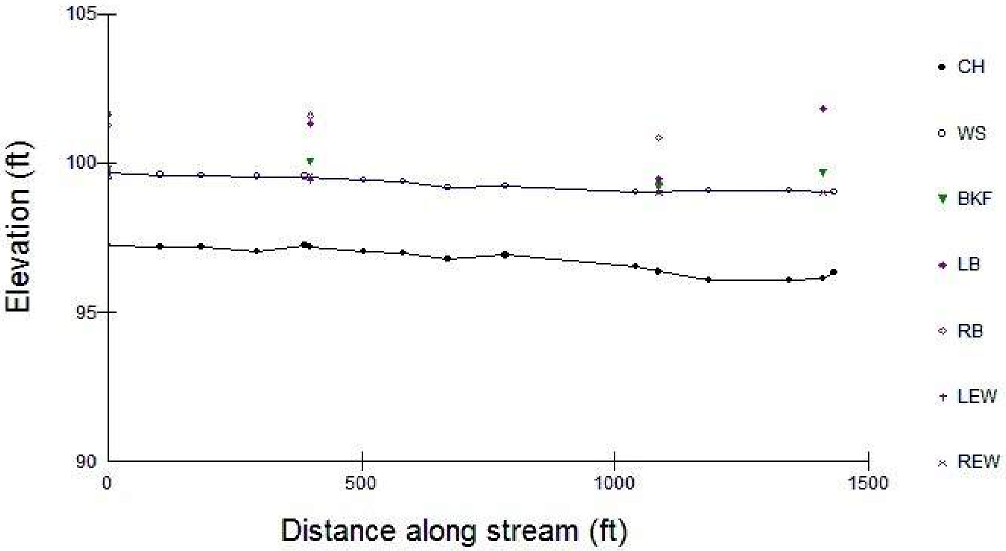


B

Figure F-1. Alexander Spring Run. (A) Plan Form. (B) Longitudinal Profile. (C) Cross-Sections.

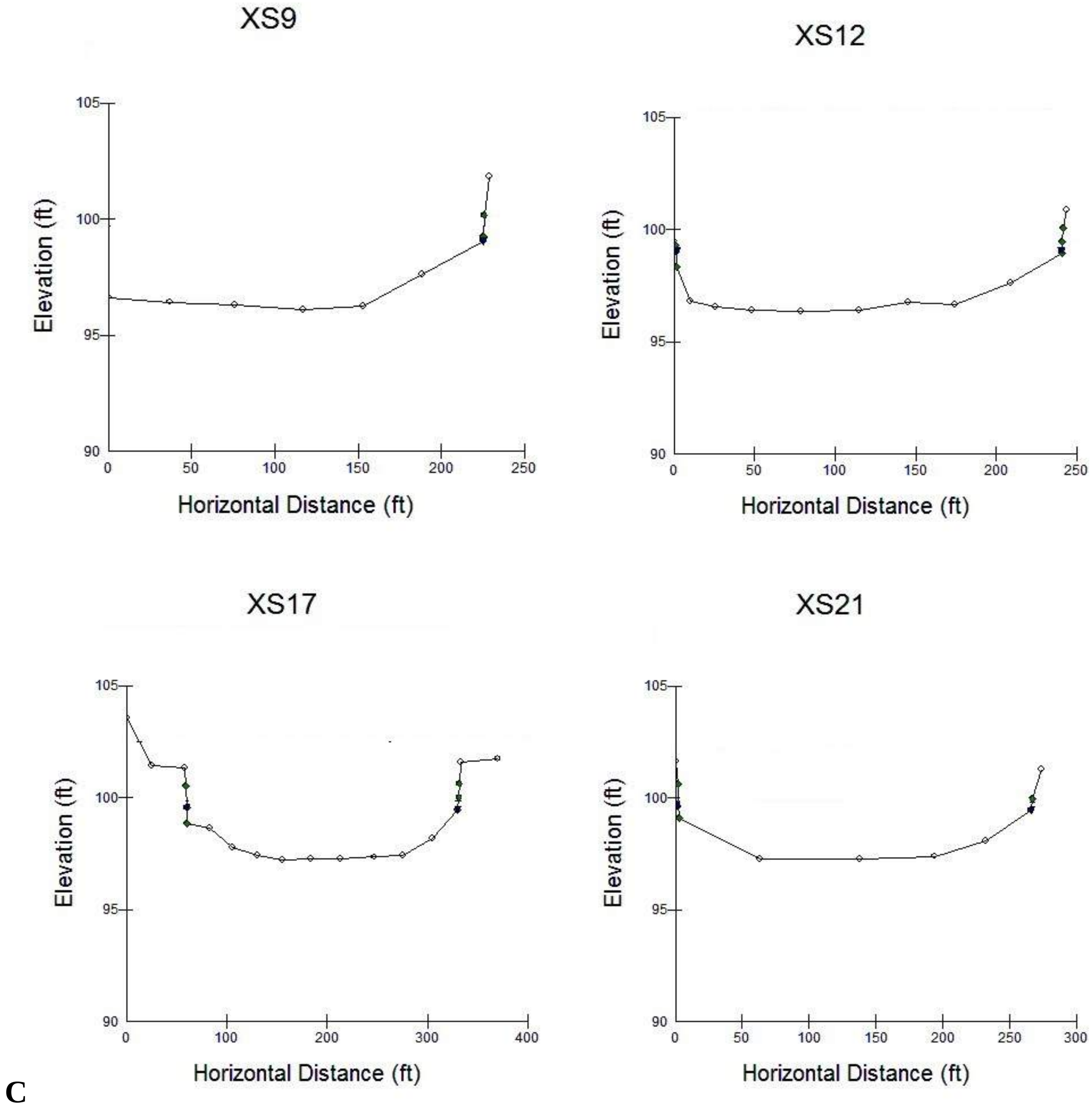


Figure F-1 (Cont.). Alexander Spring Run. (A) Plan Form. (B) Longitudinal Profile. (C) Cross-Sections.

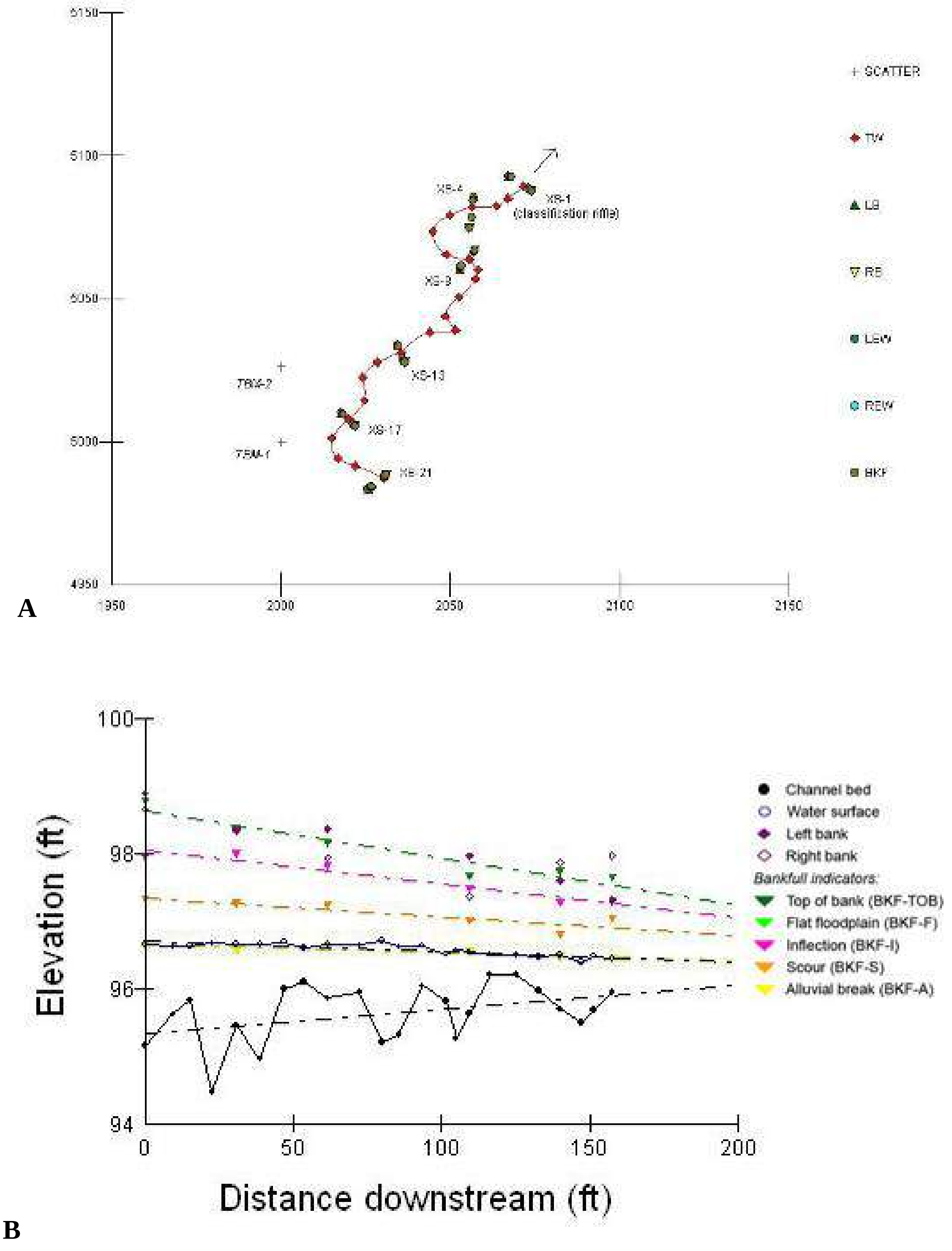
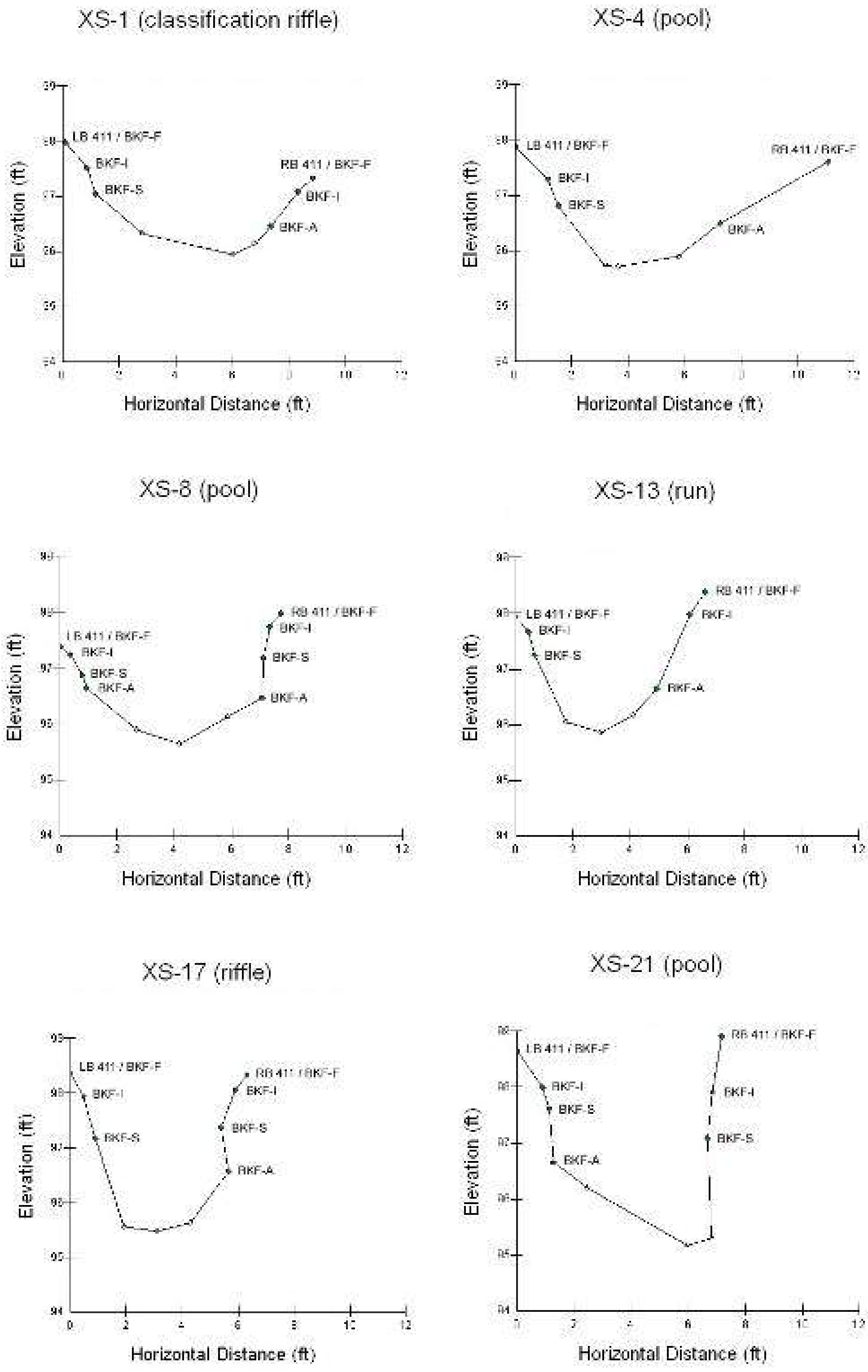
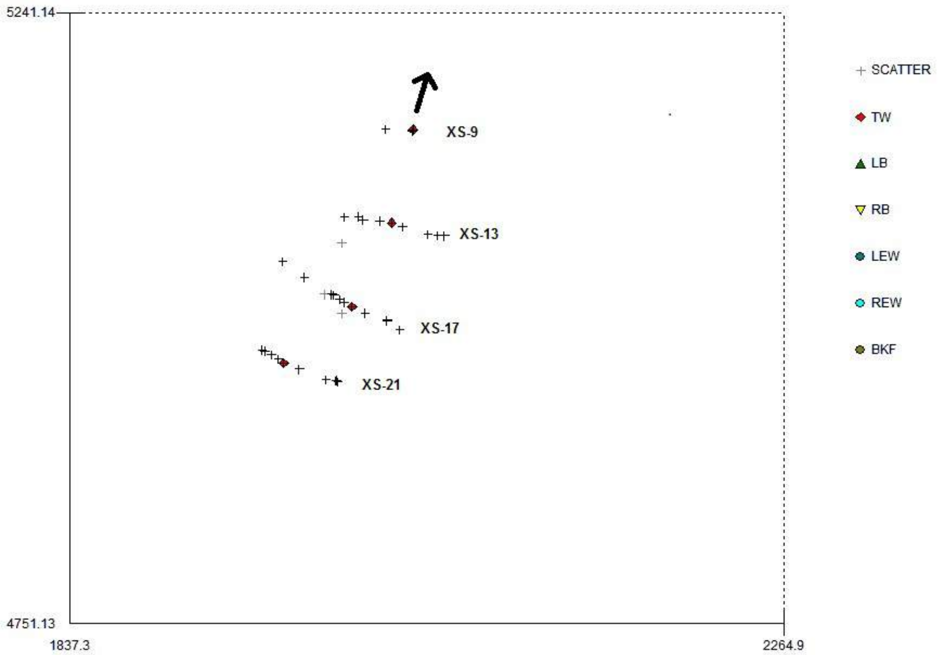


Figure F-2. **Alexander UT2. (A) Plan Form. (B) Longitudinal Profile. (C) Cross-Sections.**



C

Figure F-2 (Cont.). Alexander UT2. (A) Plan Form. (B) Longitudinal Profile. (C) Cross-Sections.



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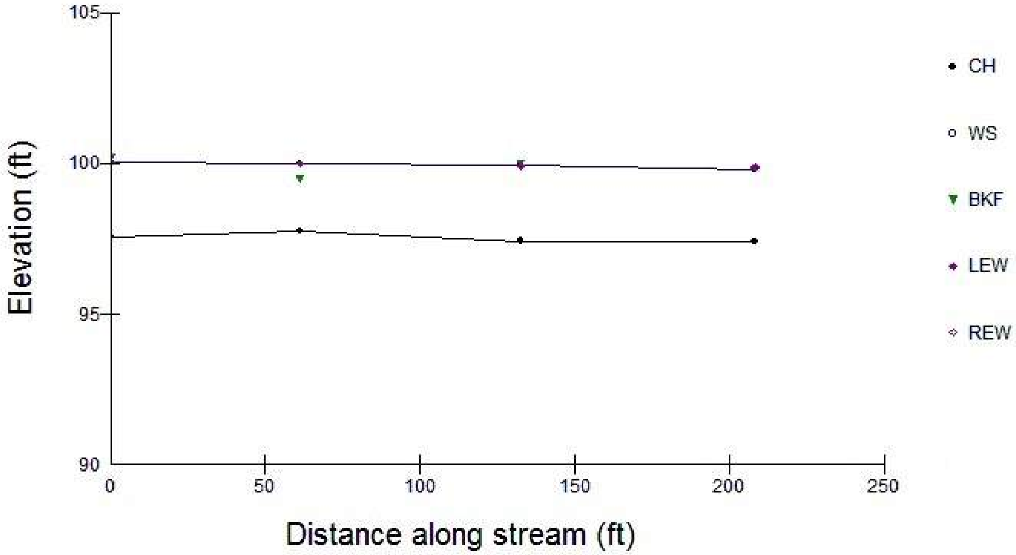
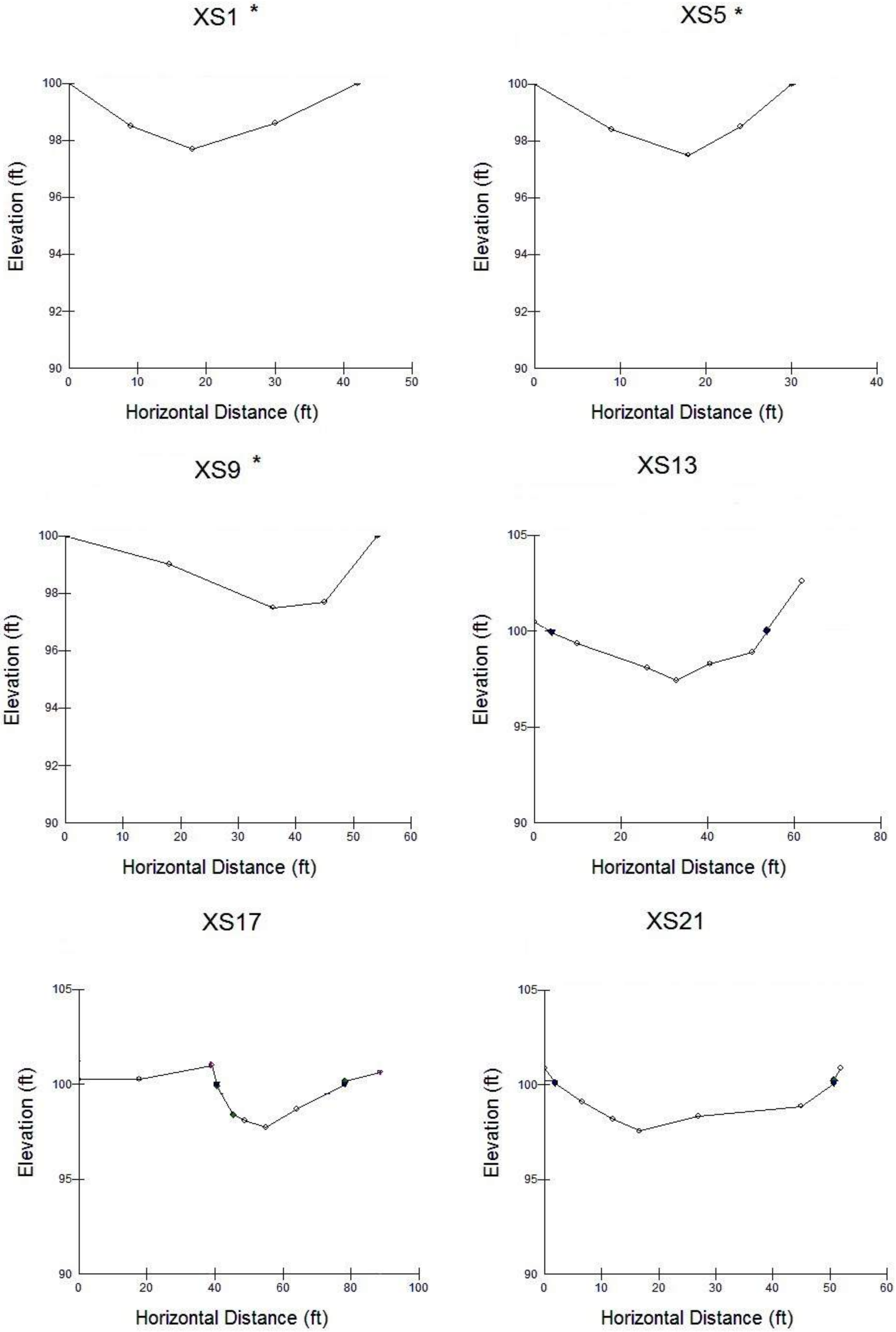


B

Figure F-3. Alligator Spring Run. (A) Plan Form. (B) Longitudinal Profile. (C) Cross-Sections.



C

Figure F-3 (Cont.). Alligator Spring Run. (A) Plan Form. (B) Longitudinal Profile. (C) Cross-Sections. (*Not part of total station survey)

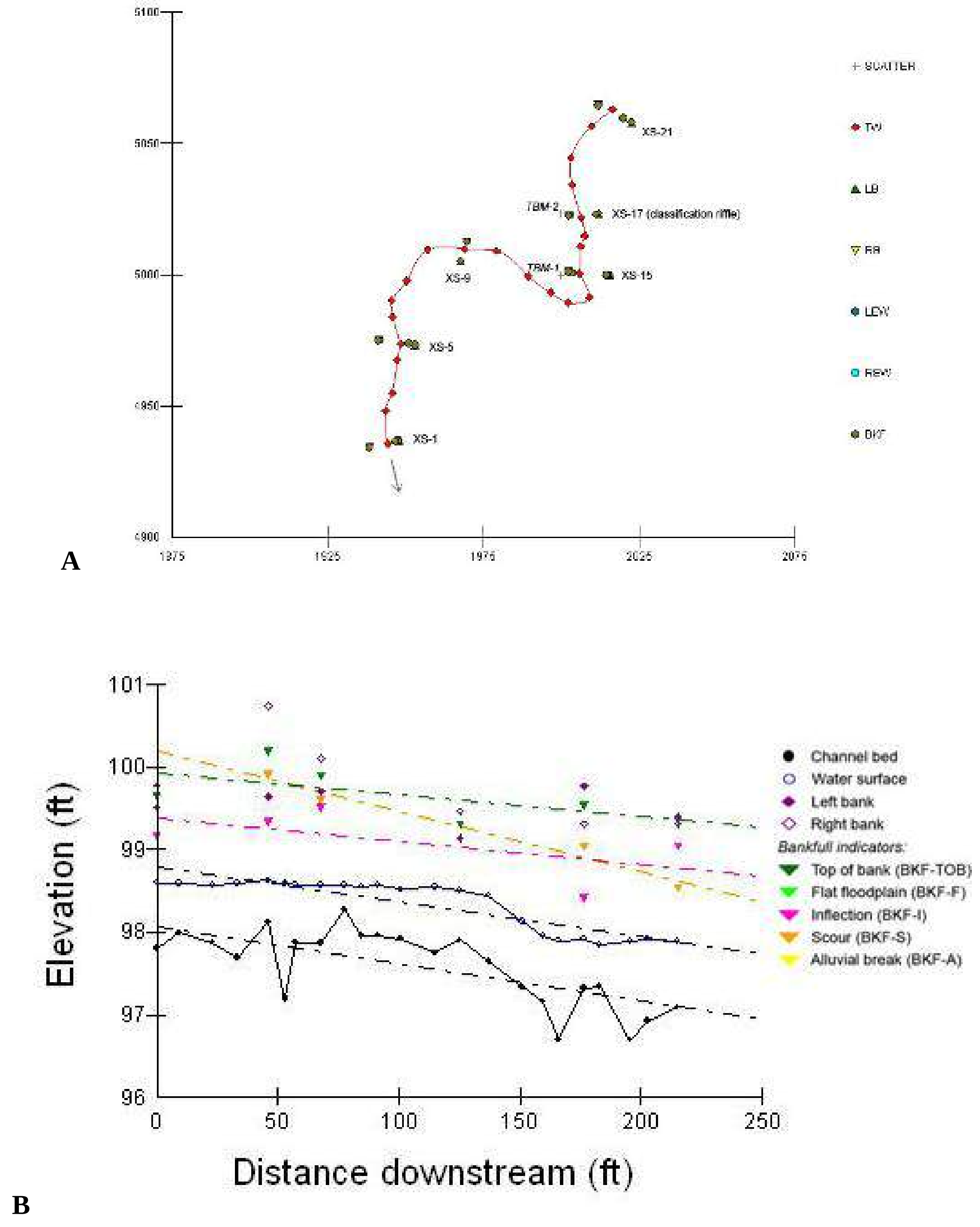


Figure F-4. Bell Creek. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

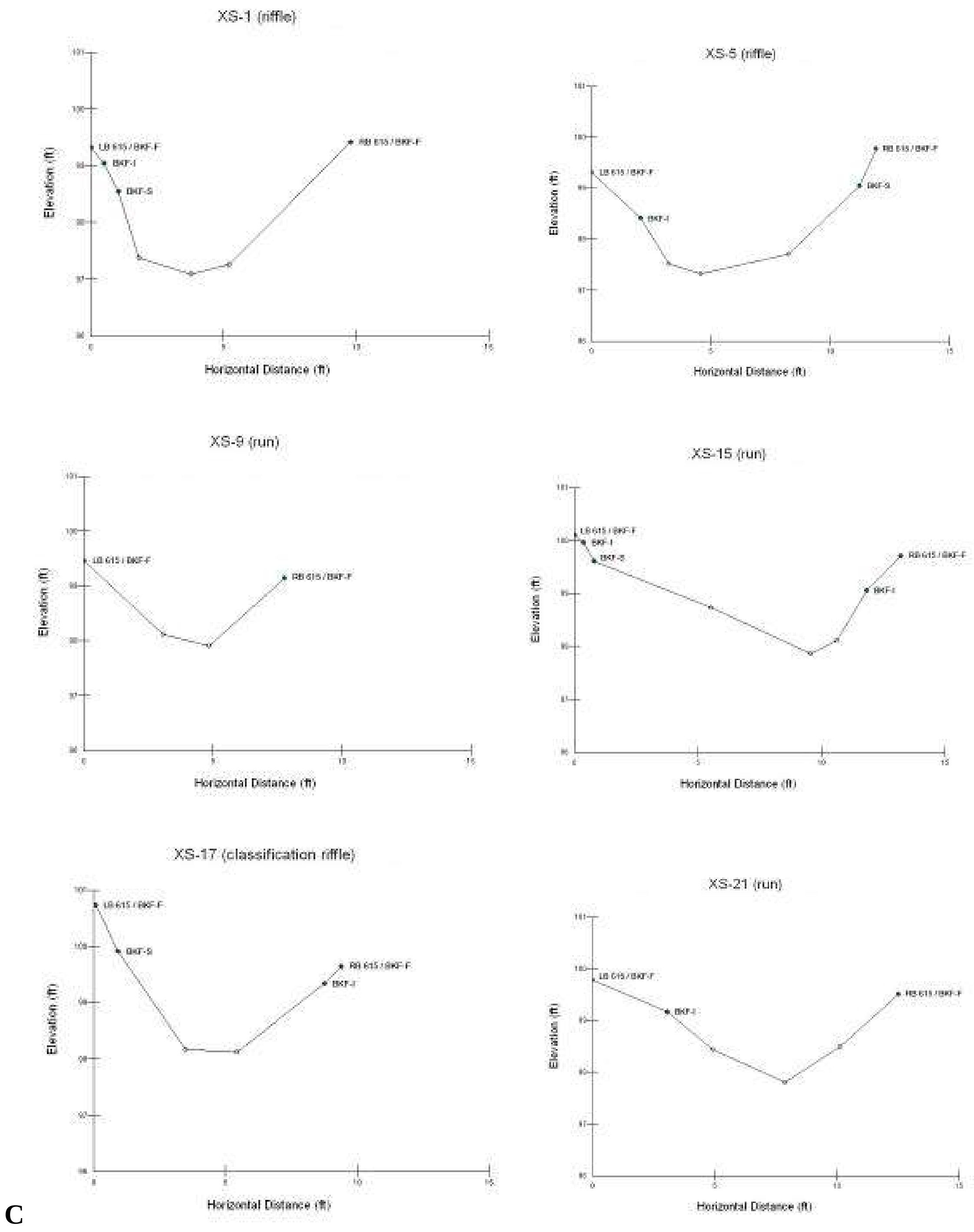


Figure F-4 (Cont.). Bell Creek. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

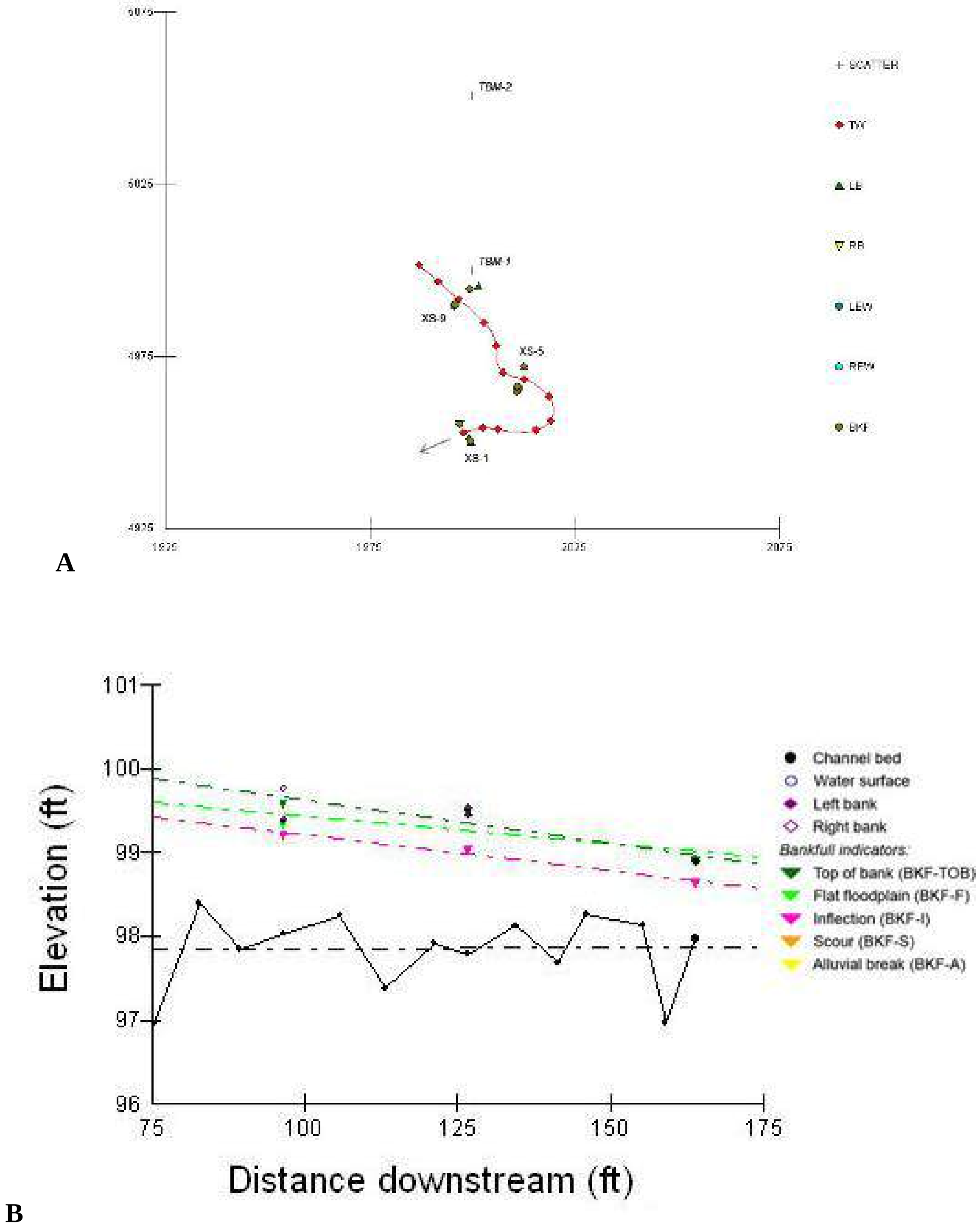
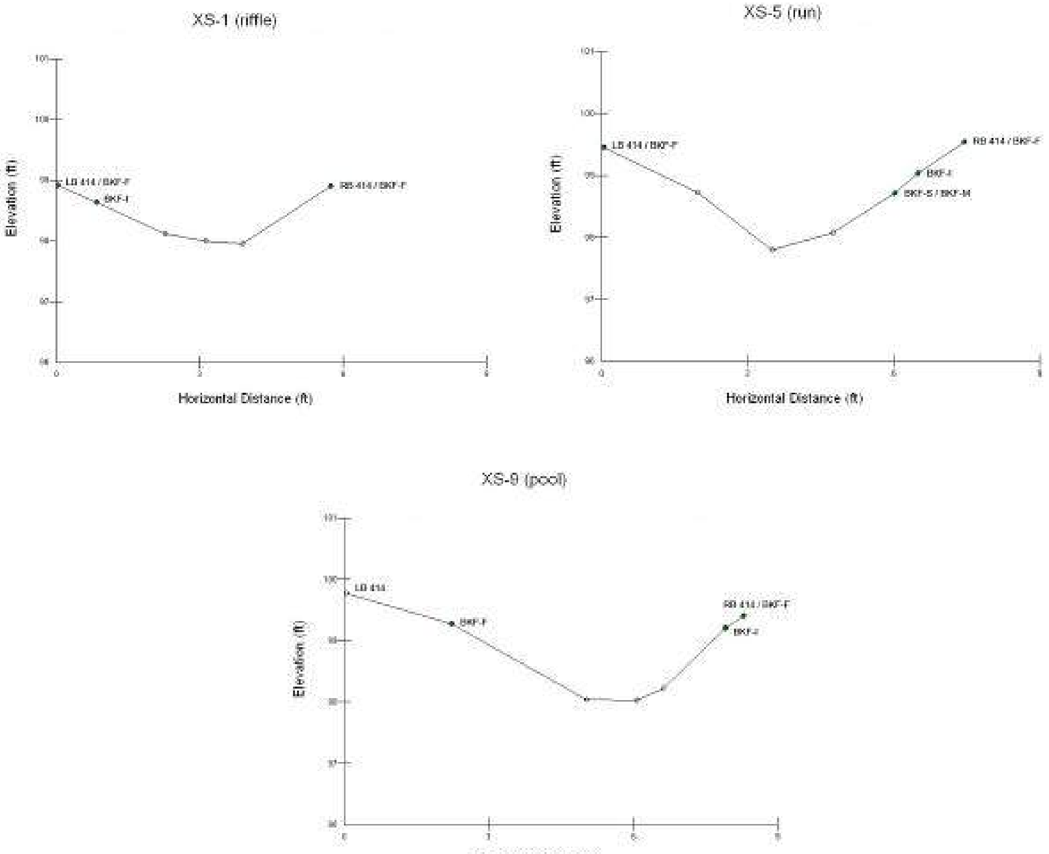


Figure F-5. Bell Creek UT. A) Plan Form. B) Longitudinal Profile.
C) Cross-Sections.



C

Figure F-5 (Cont.). Bell Creek UT. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

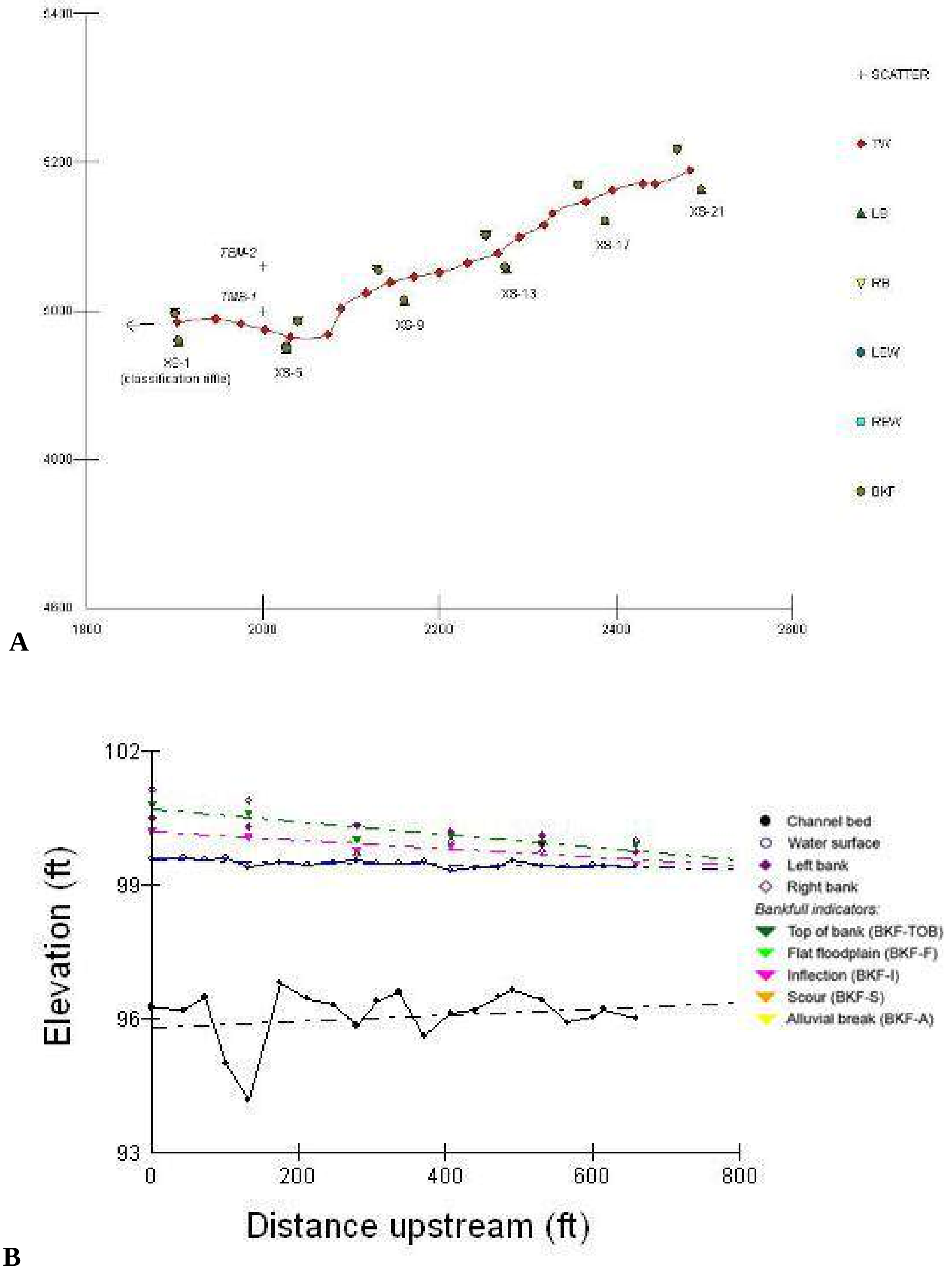
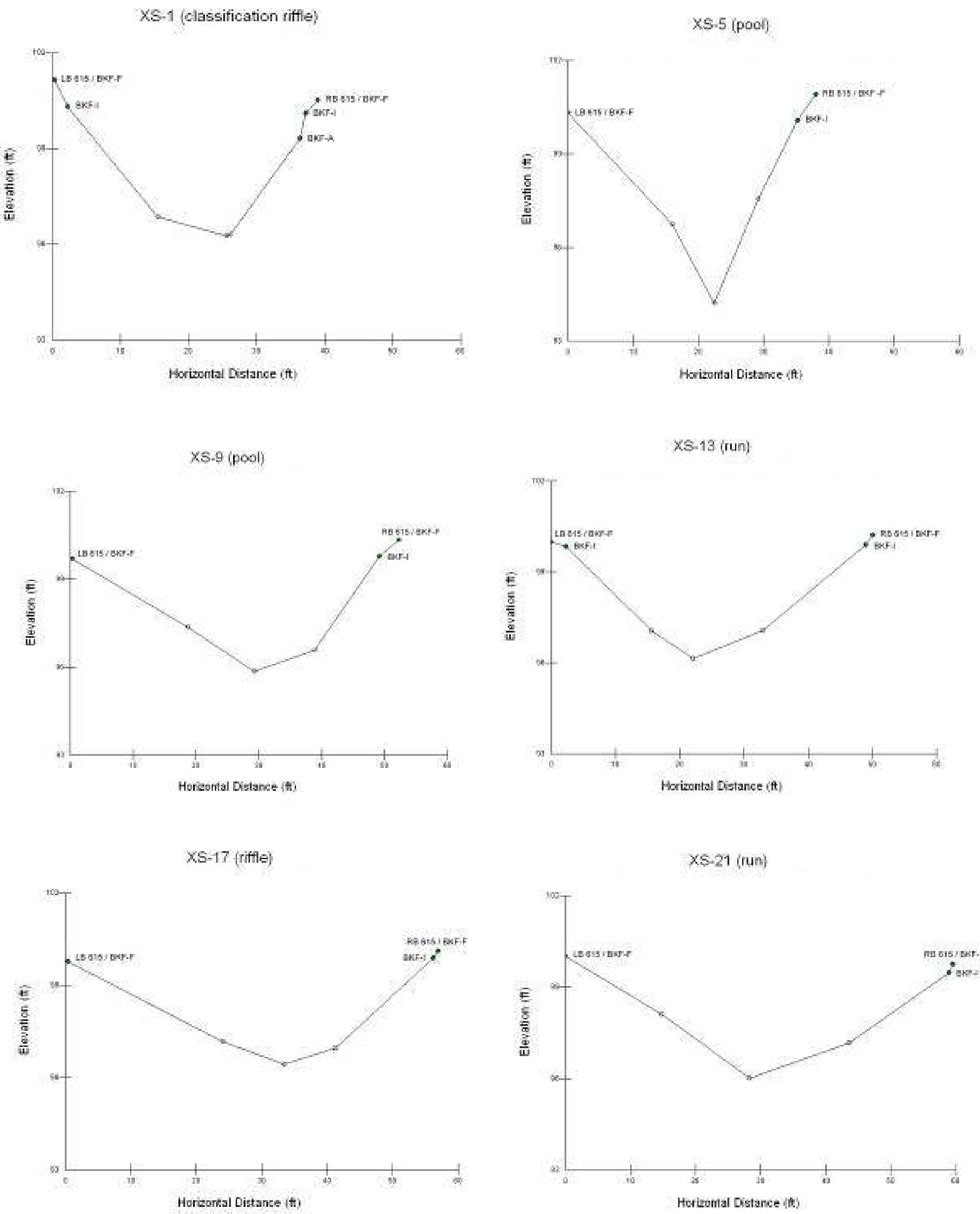


Figure F-6. Blackwater Creek near Cassia. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-6 (Cont.). Blackwater Creek near Cassia. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

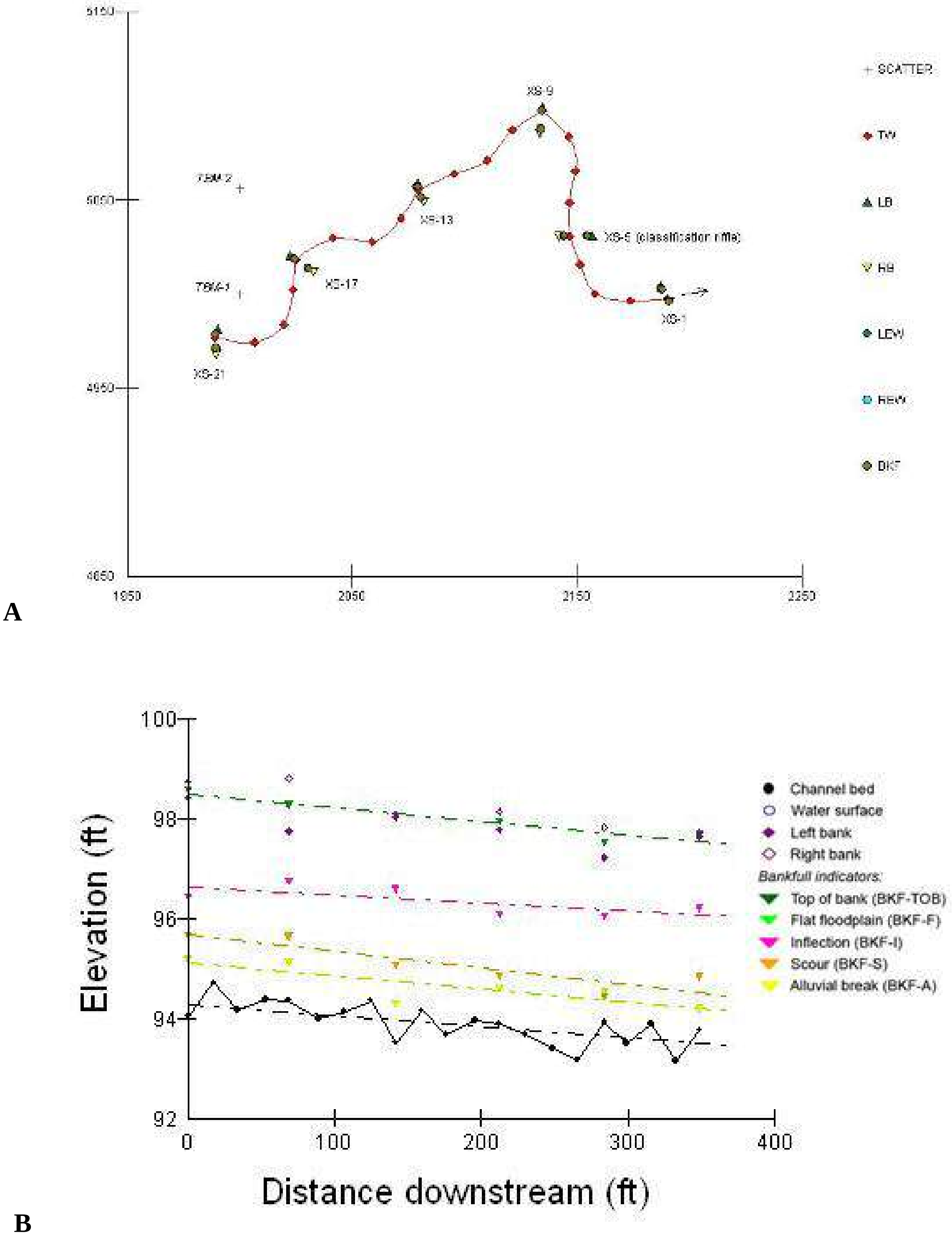


Figure F-7. Blues Creek near Gainesville. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

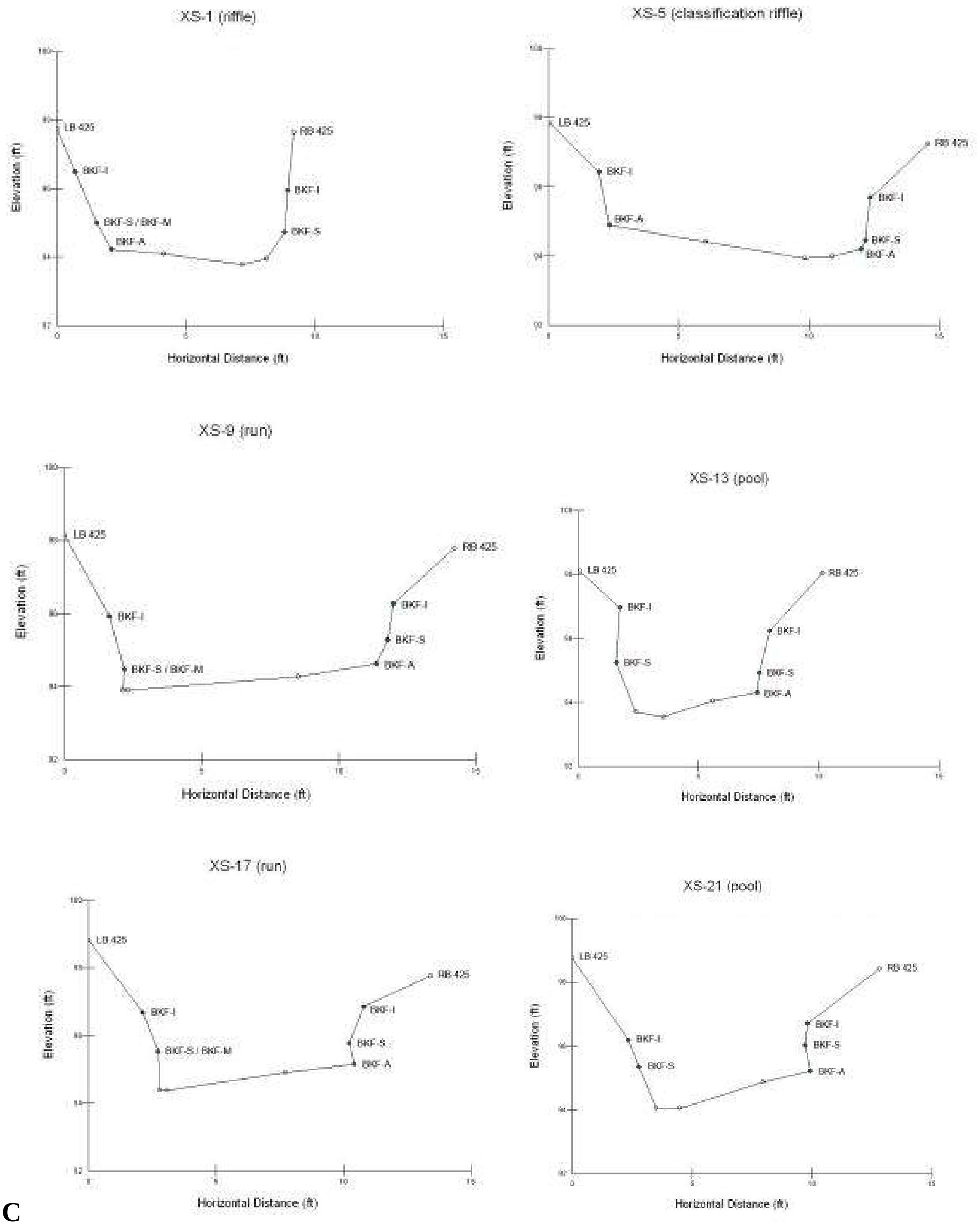


Figure F-7 (Cont.). Blues Creek near Gainesville. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

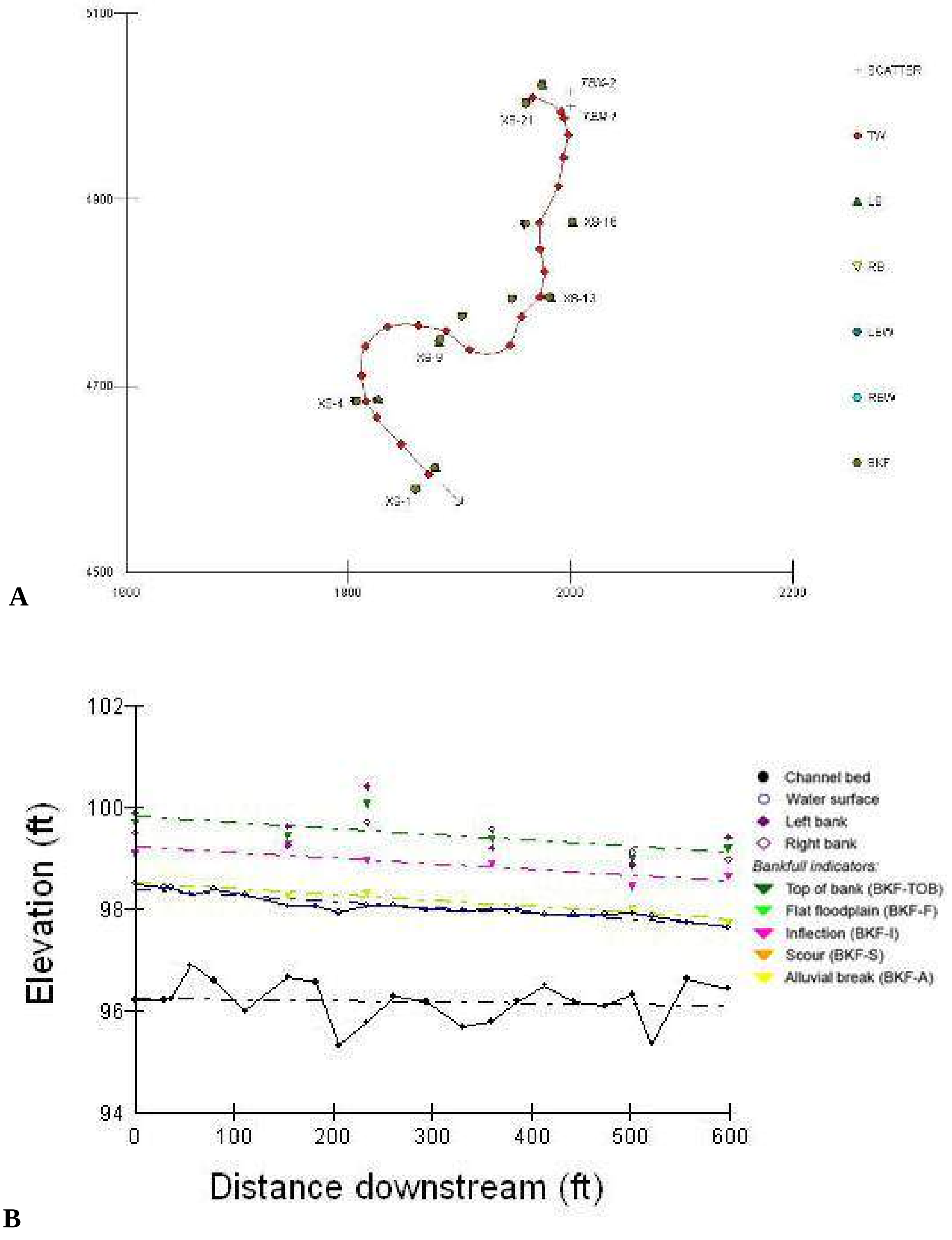
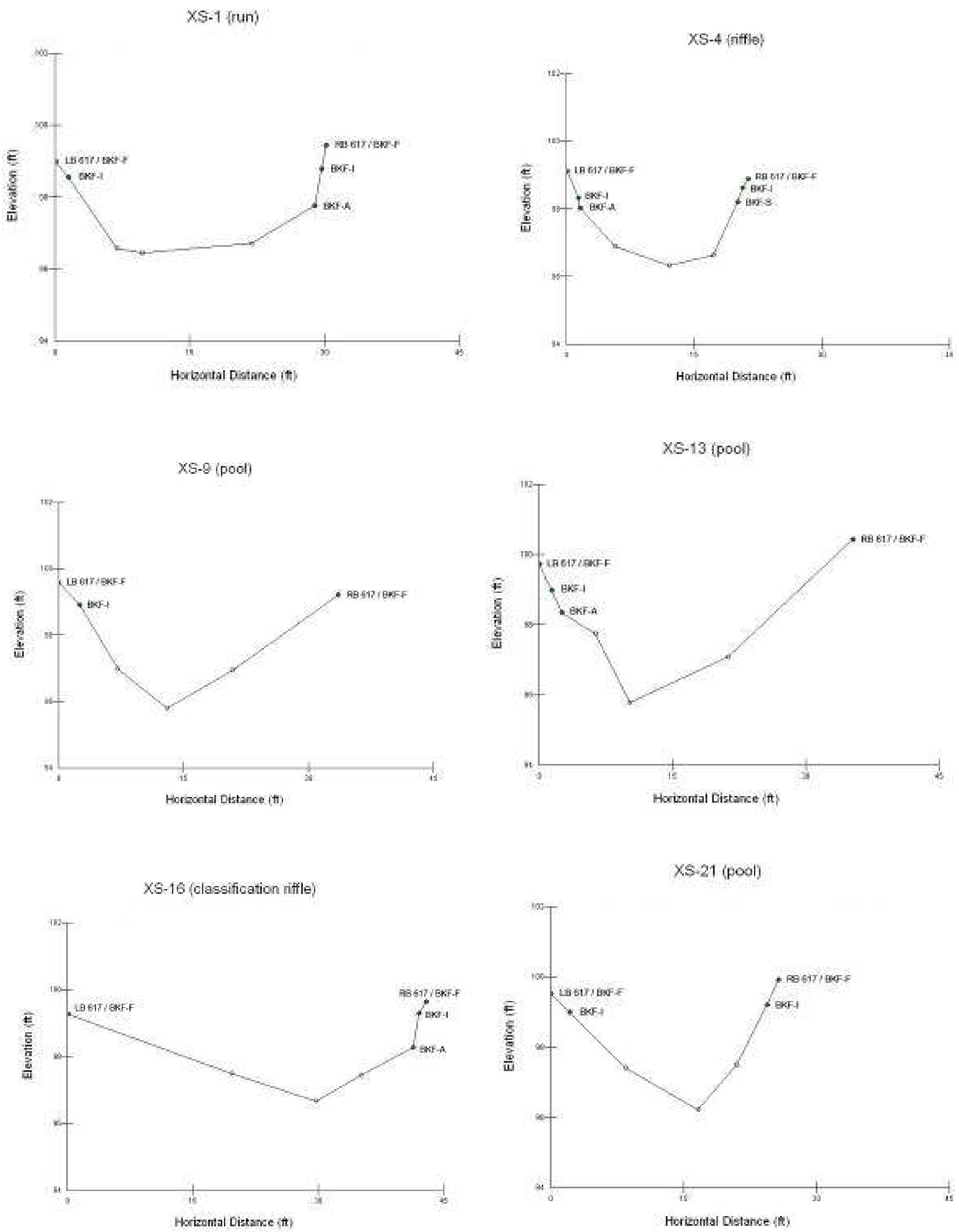


Figure F-8. Bowlegs Creek near Fort Meade. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-8 (Cont.). Bowlegs Creek near Fort Meade. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

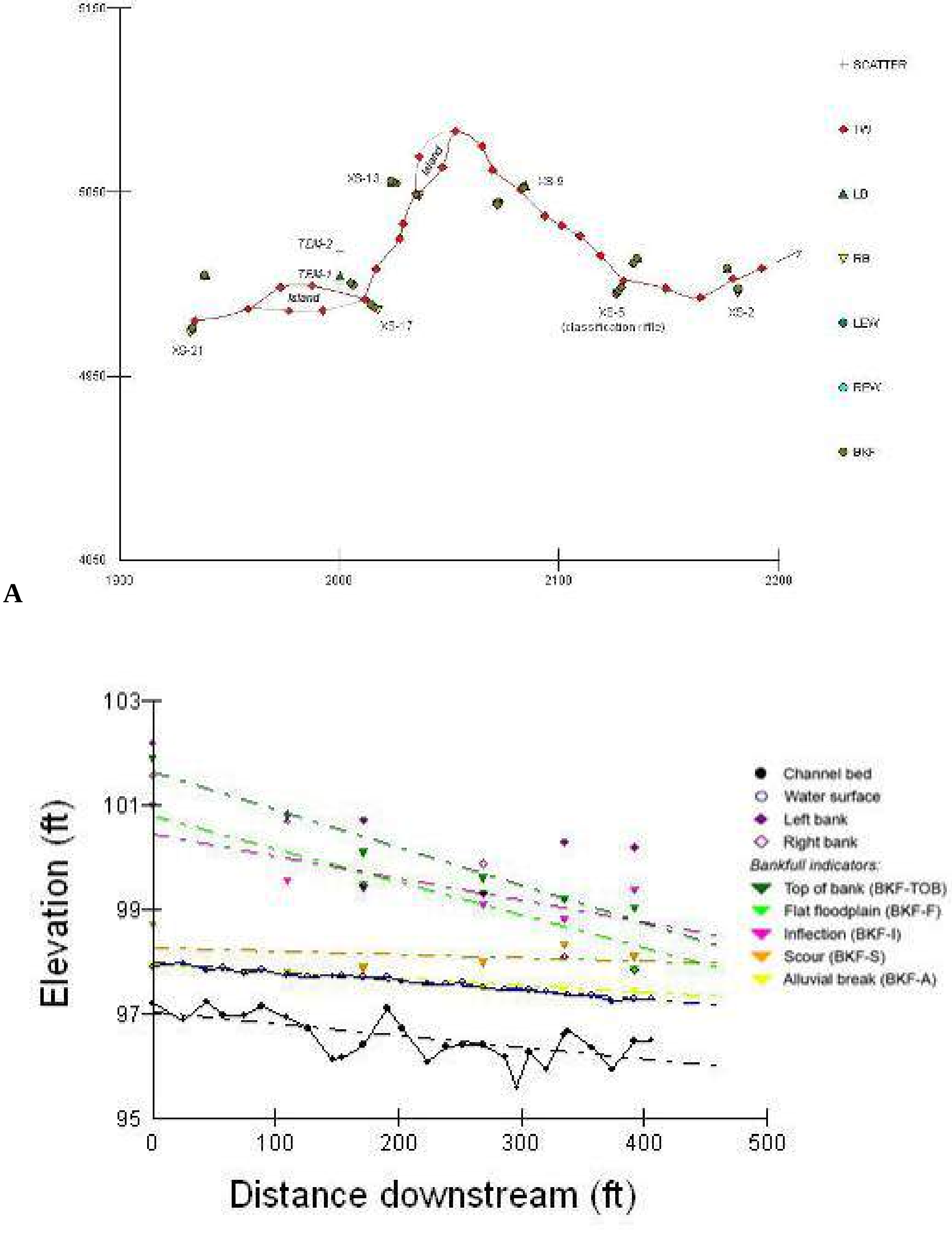
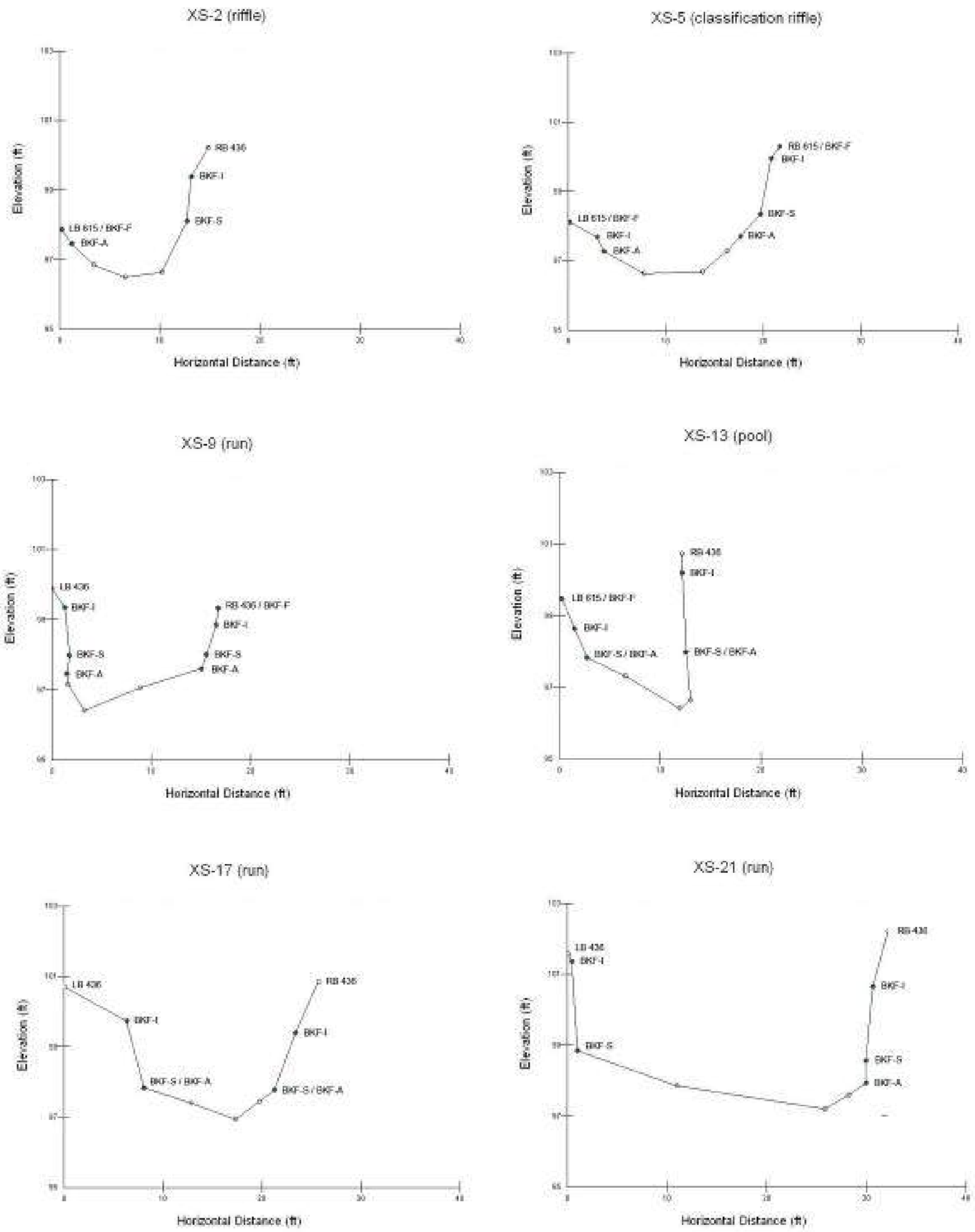


Figure F-9. Carter Creek near Sebring. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-9 (Cont.). Carter Creek near Sebring. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

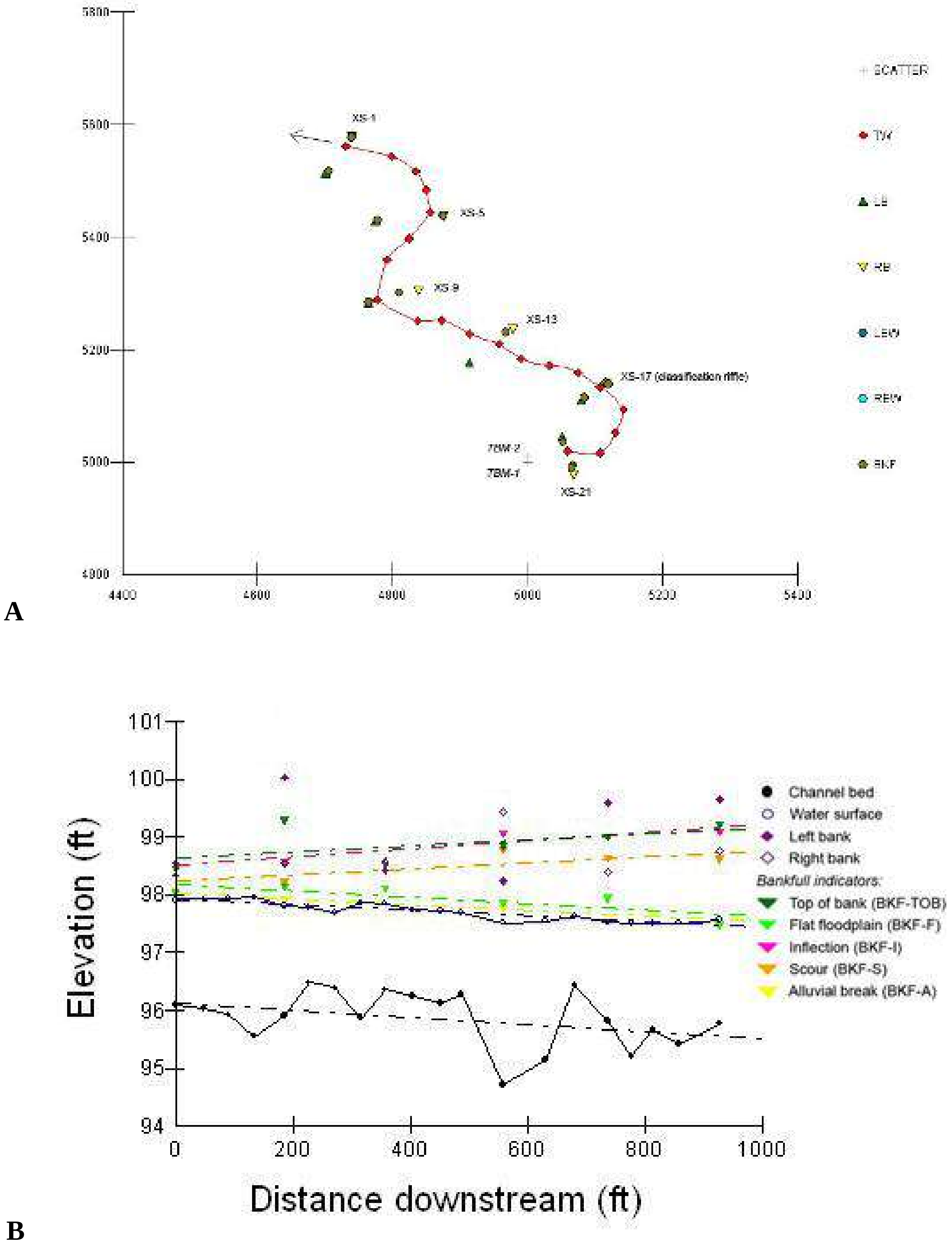


Figure F-10. Catfish Creek near Lake Wales. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

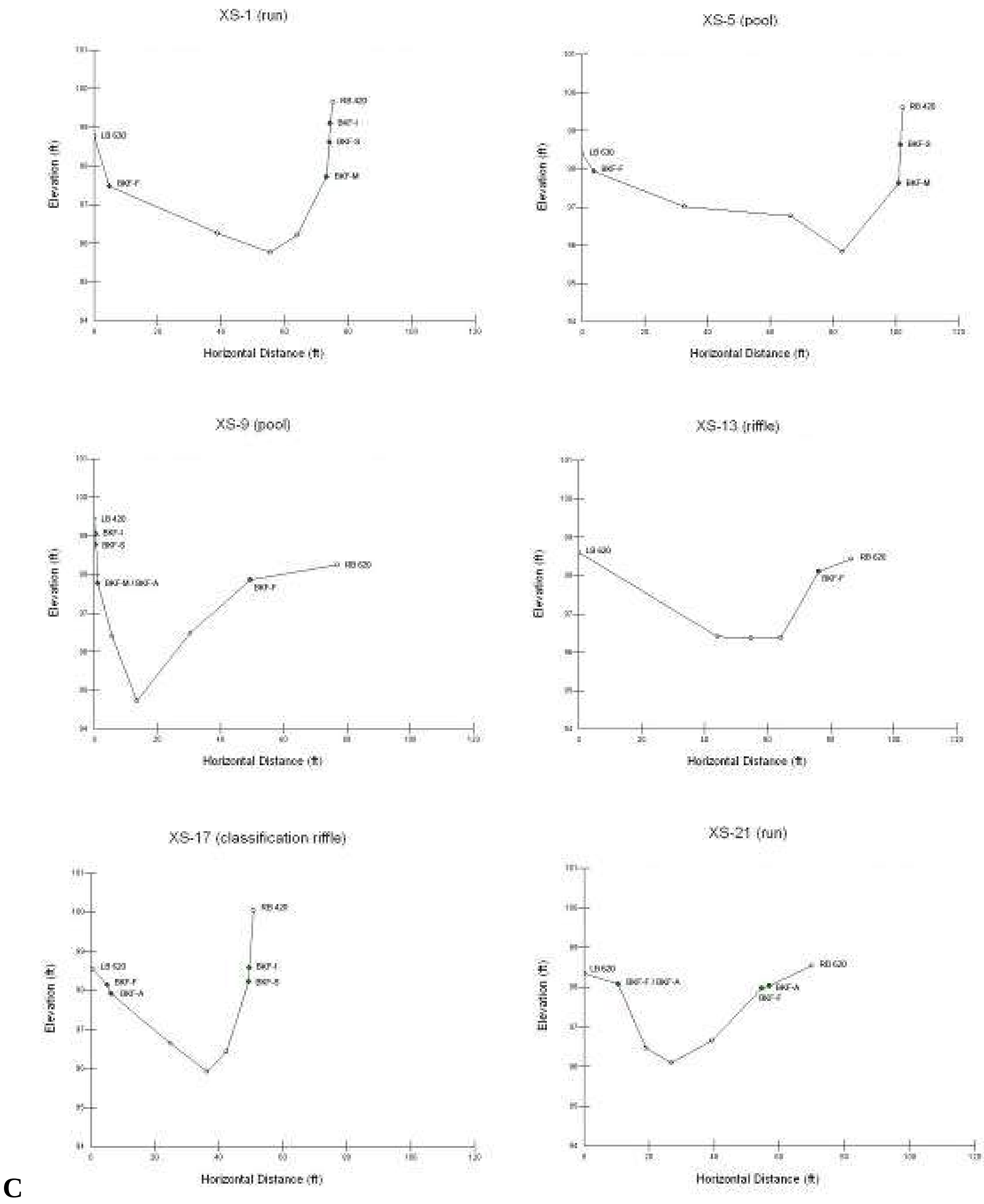


Figure F-10 (Cont.). Catfish Creek near Lake Wales. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

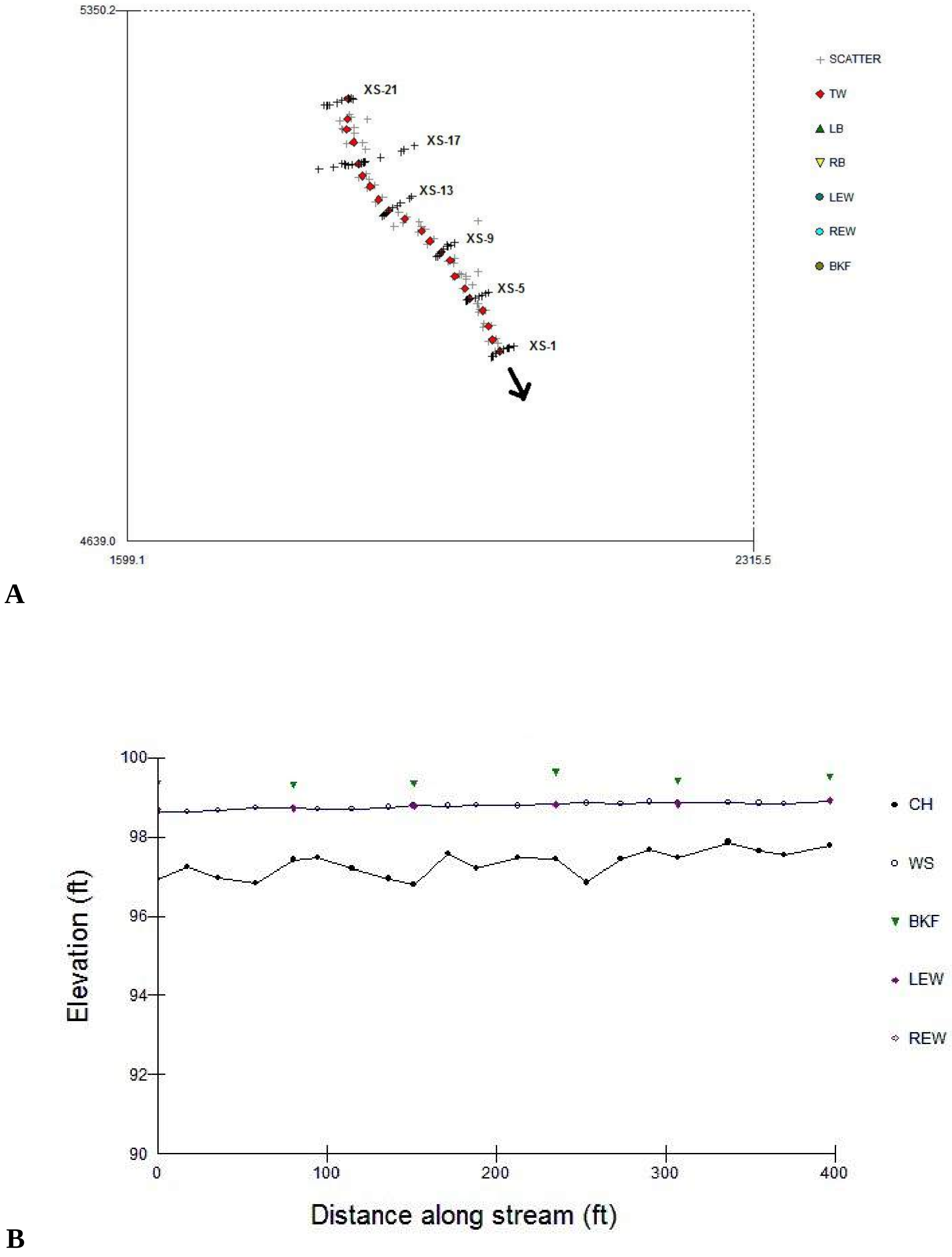
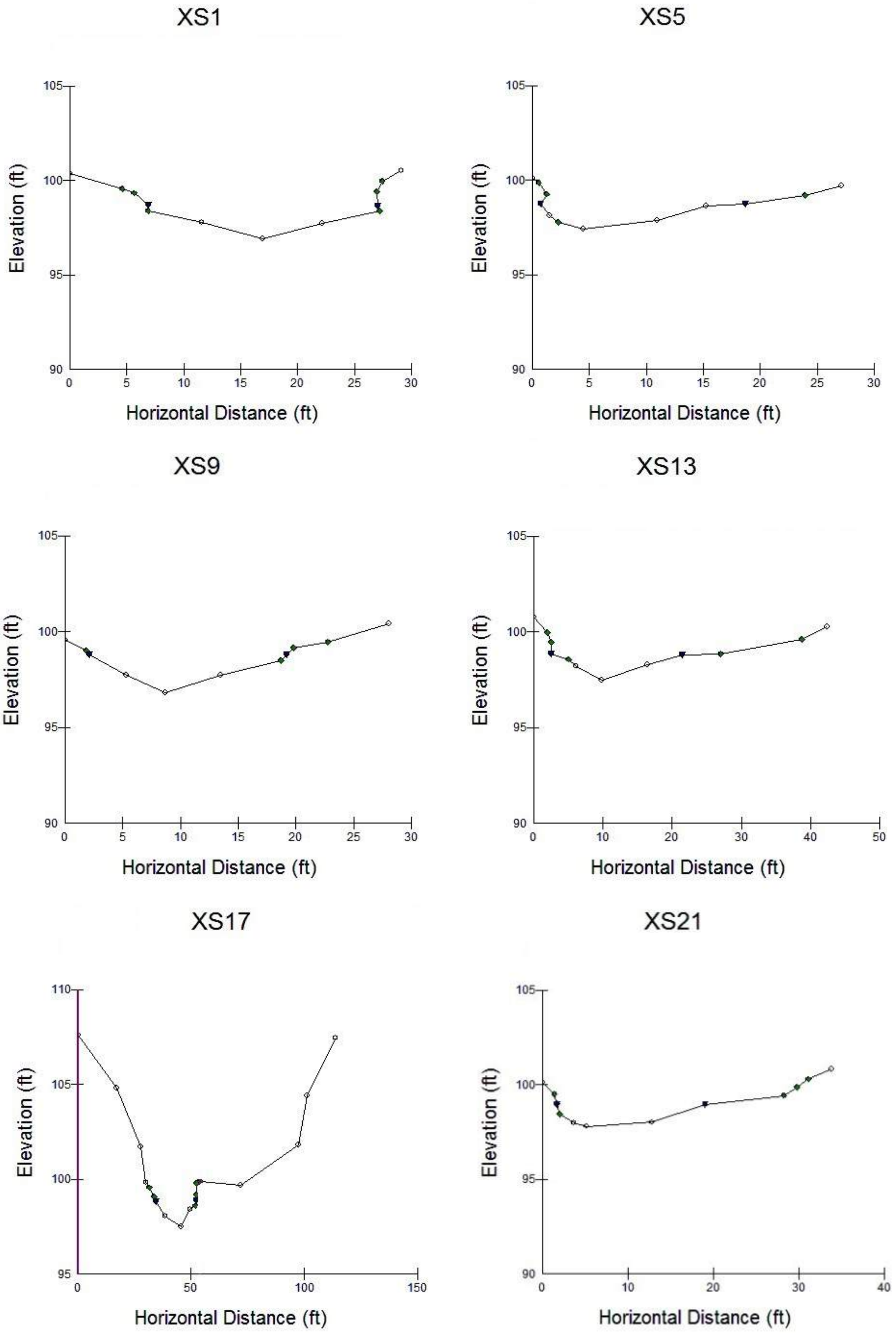


Figure F-11. Cedar Head Spring Run. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-11 (Cont.). Cedar Head Spring Run. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

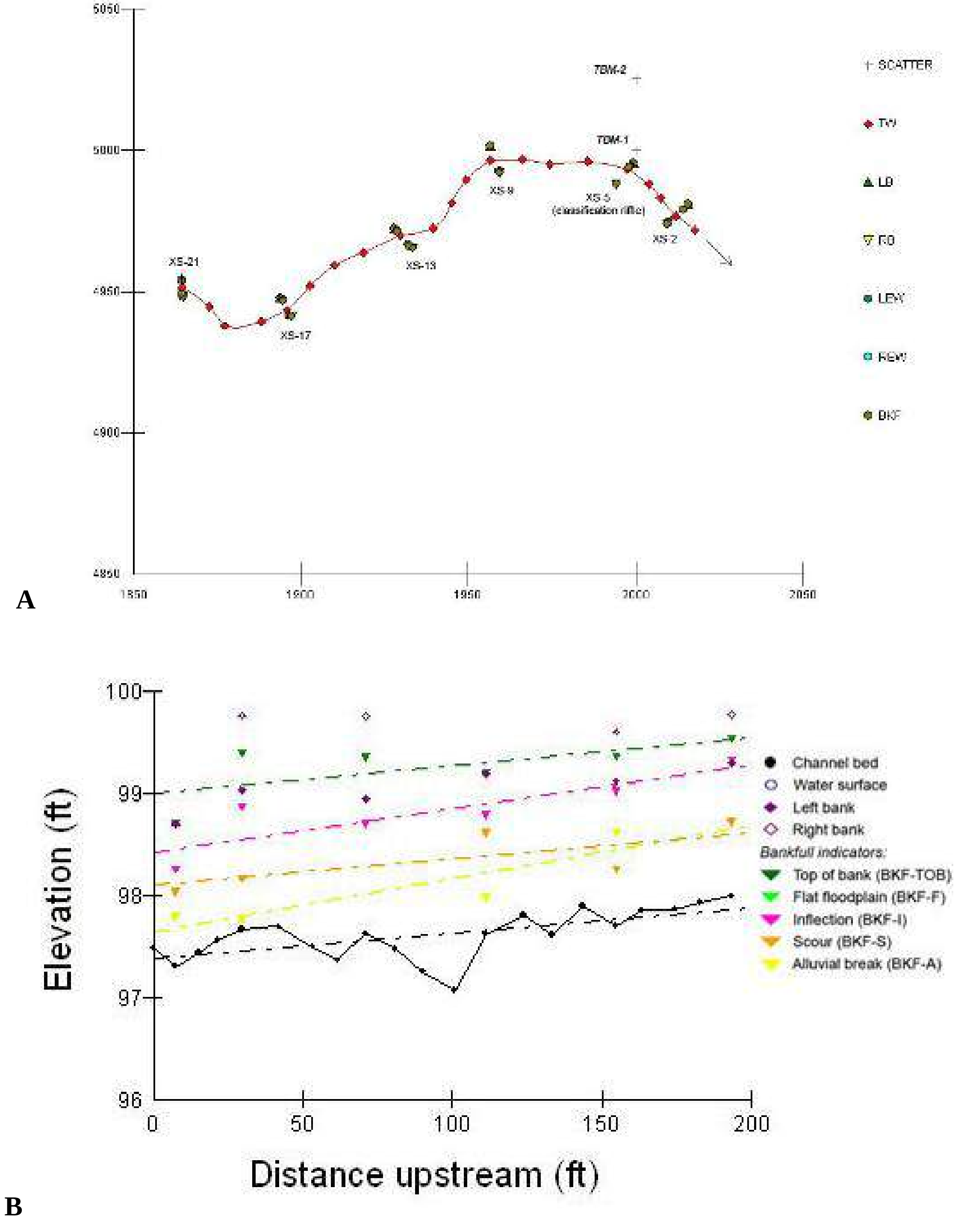
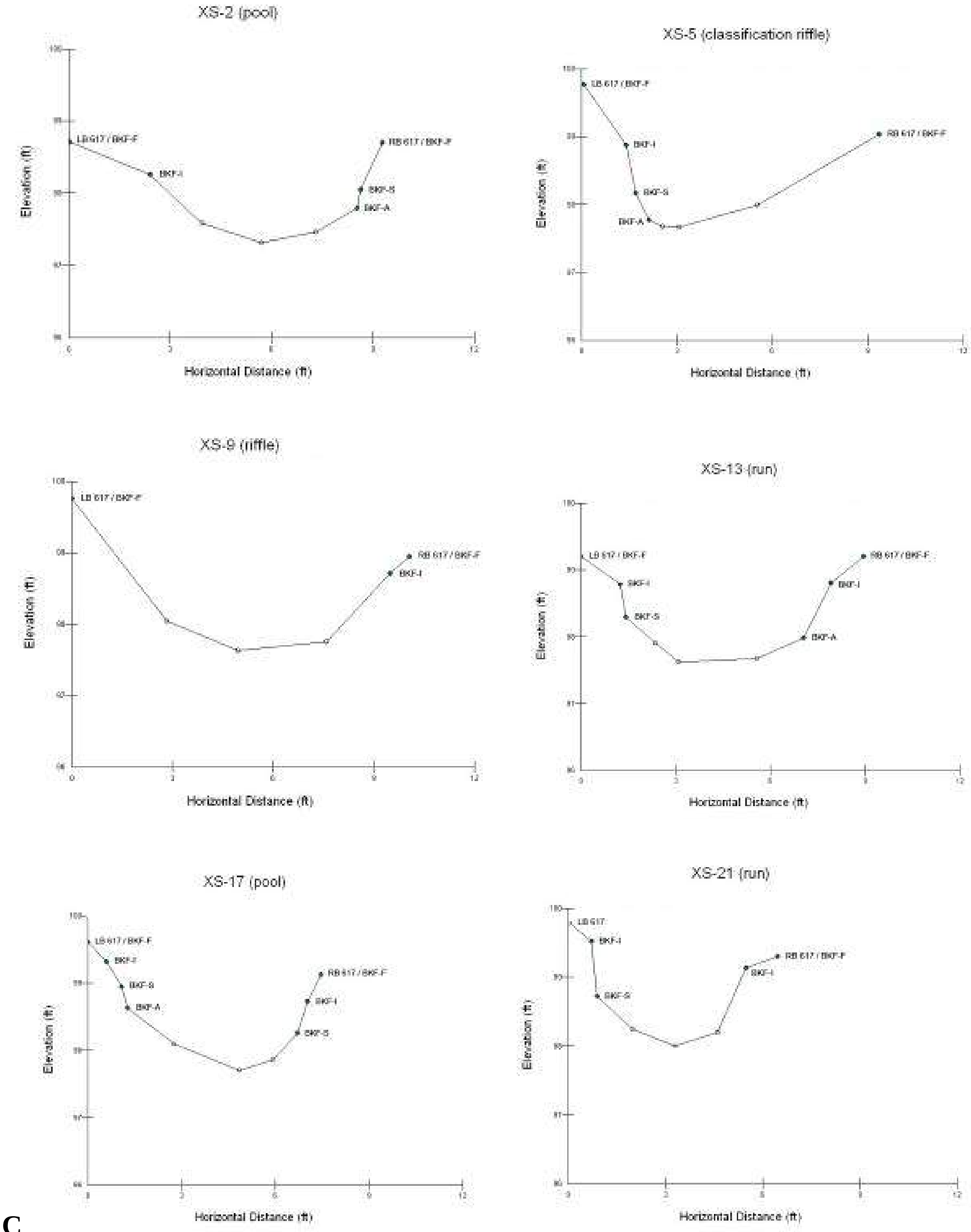


Figure F-12. Coons Bay Branch. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-12 (Cont.). Coons Bay Branch. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

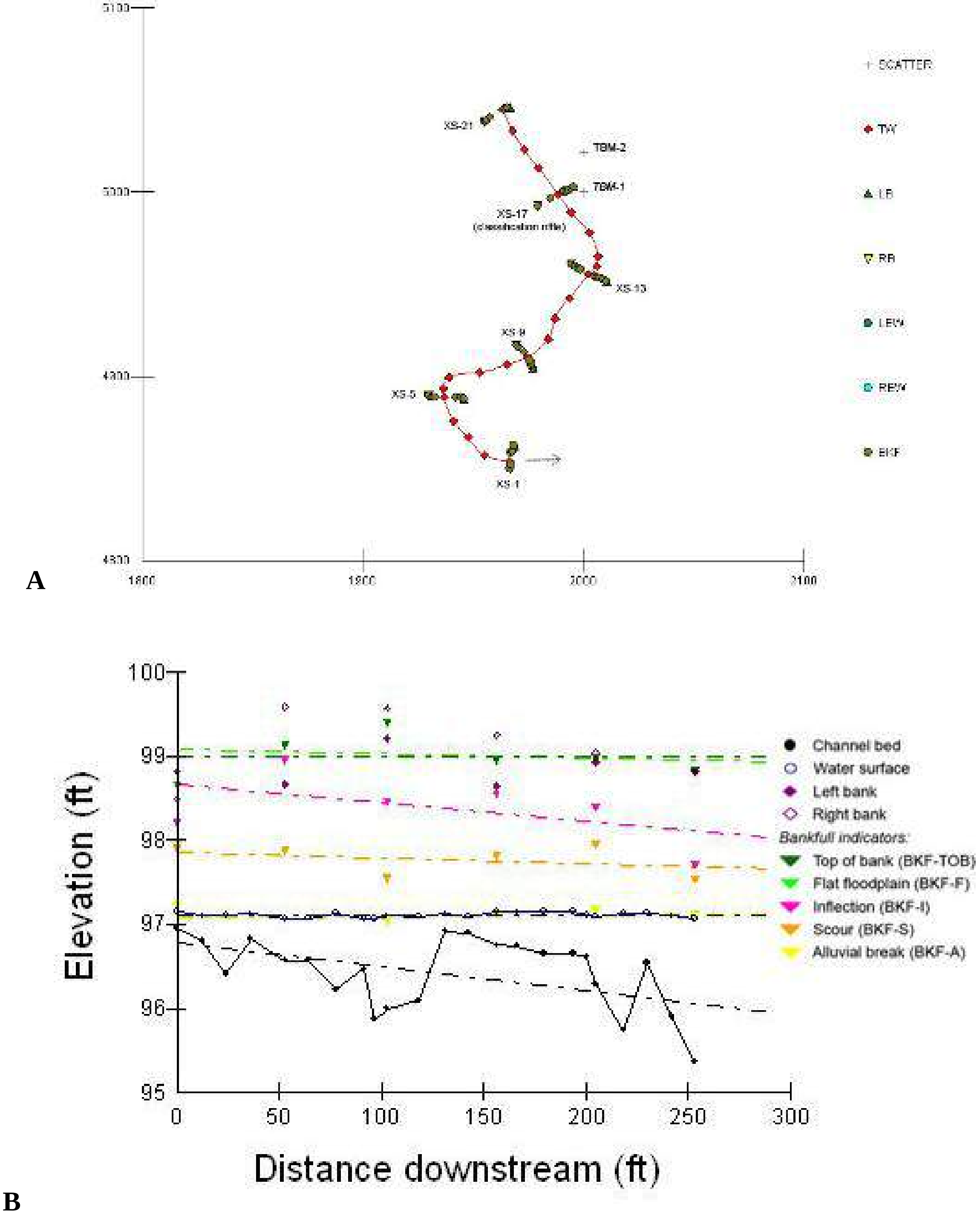
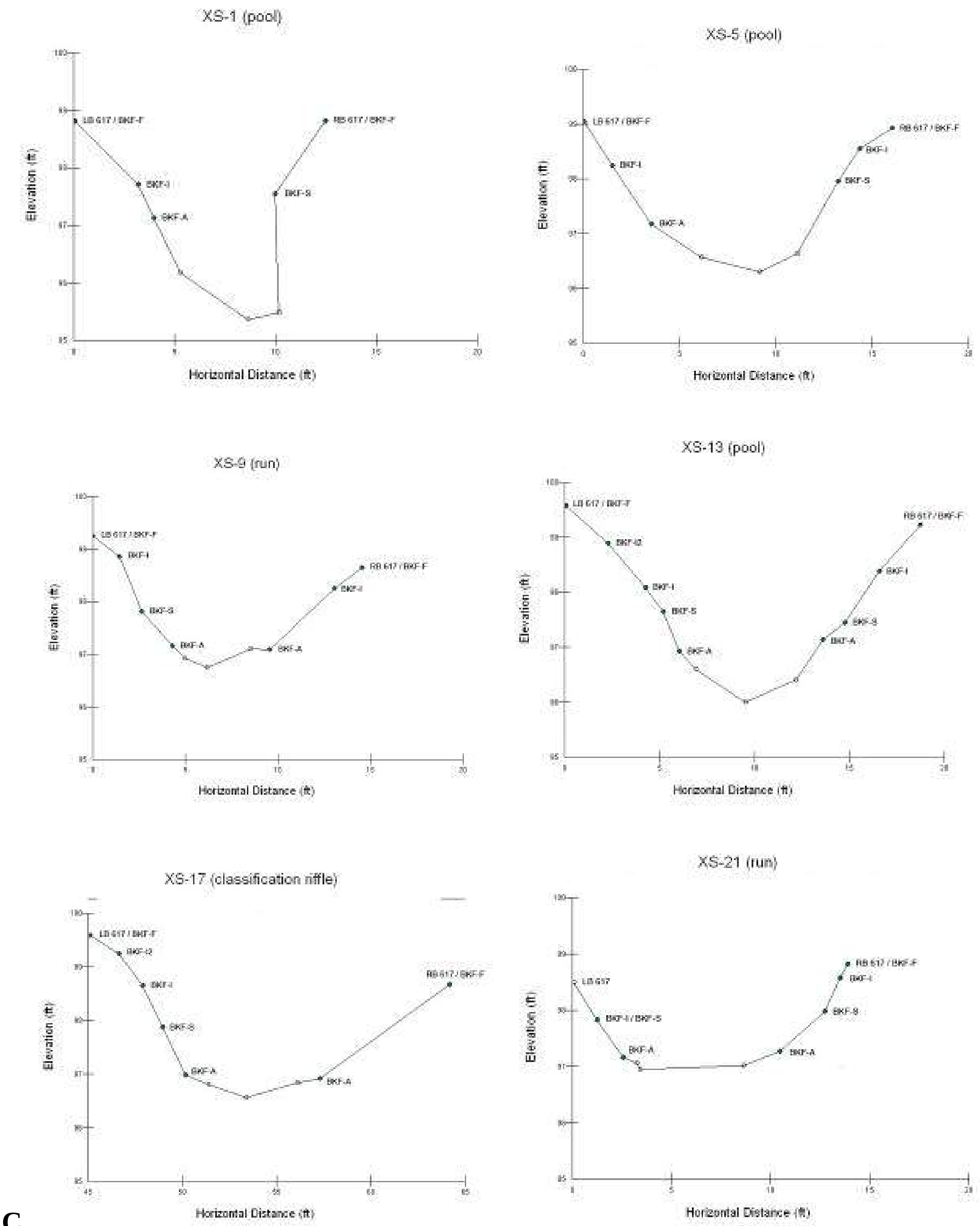


Figure F-13. Cow Creek. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-13 (Cont.). Cow Creek. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

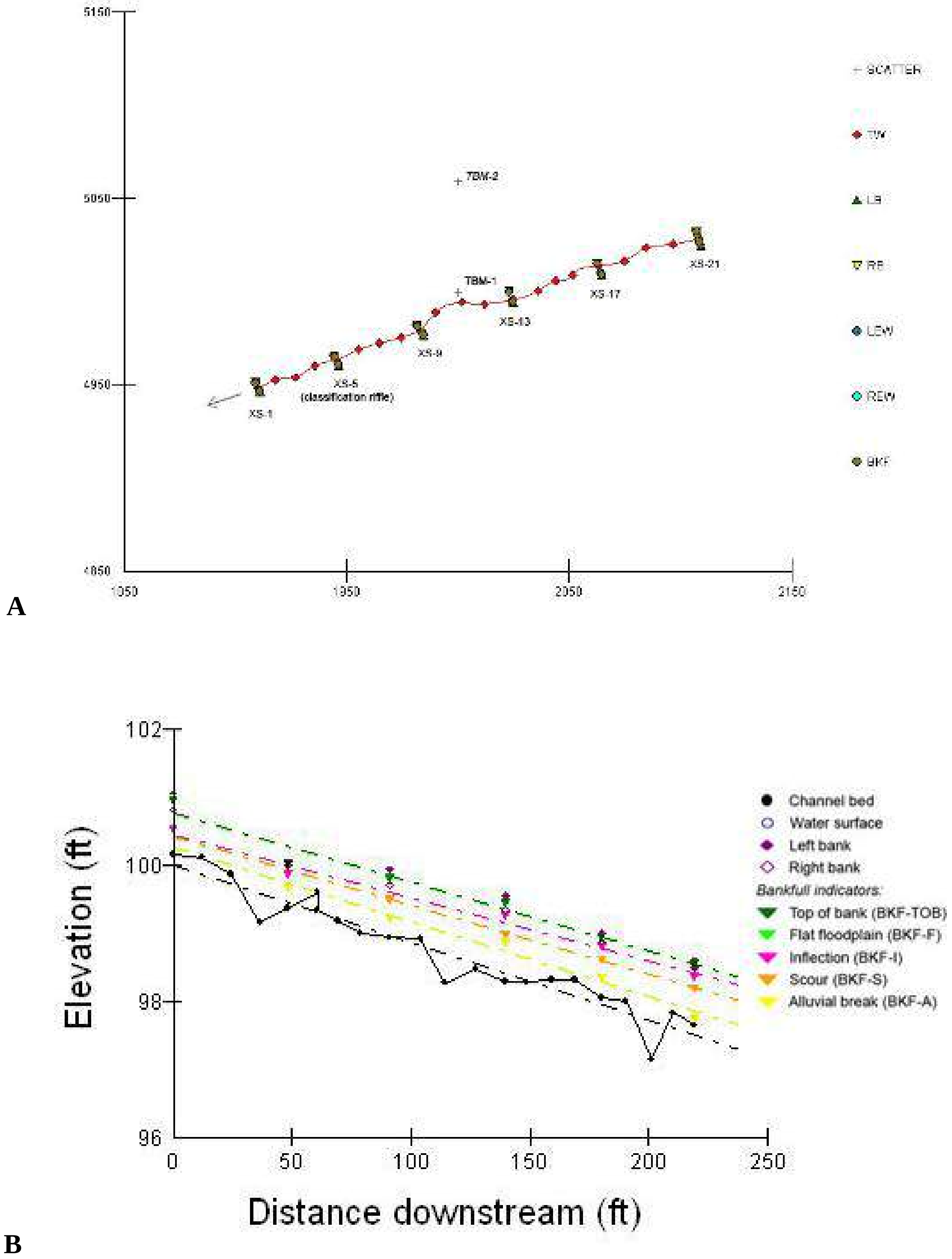
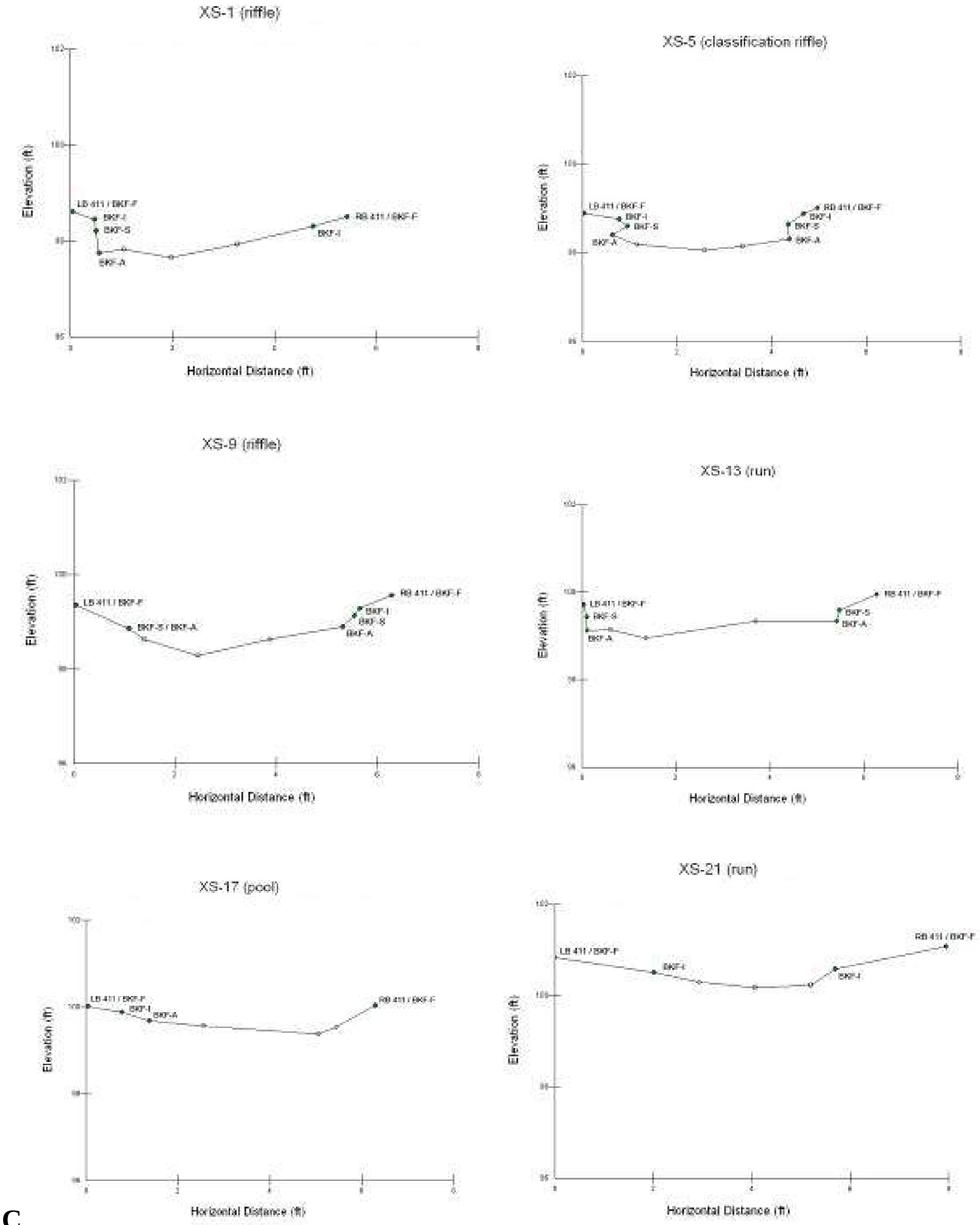


Figure F-14. Cypress Slash UT. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-14 (Cont.). Cypress Slash UT. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

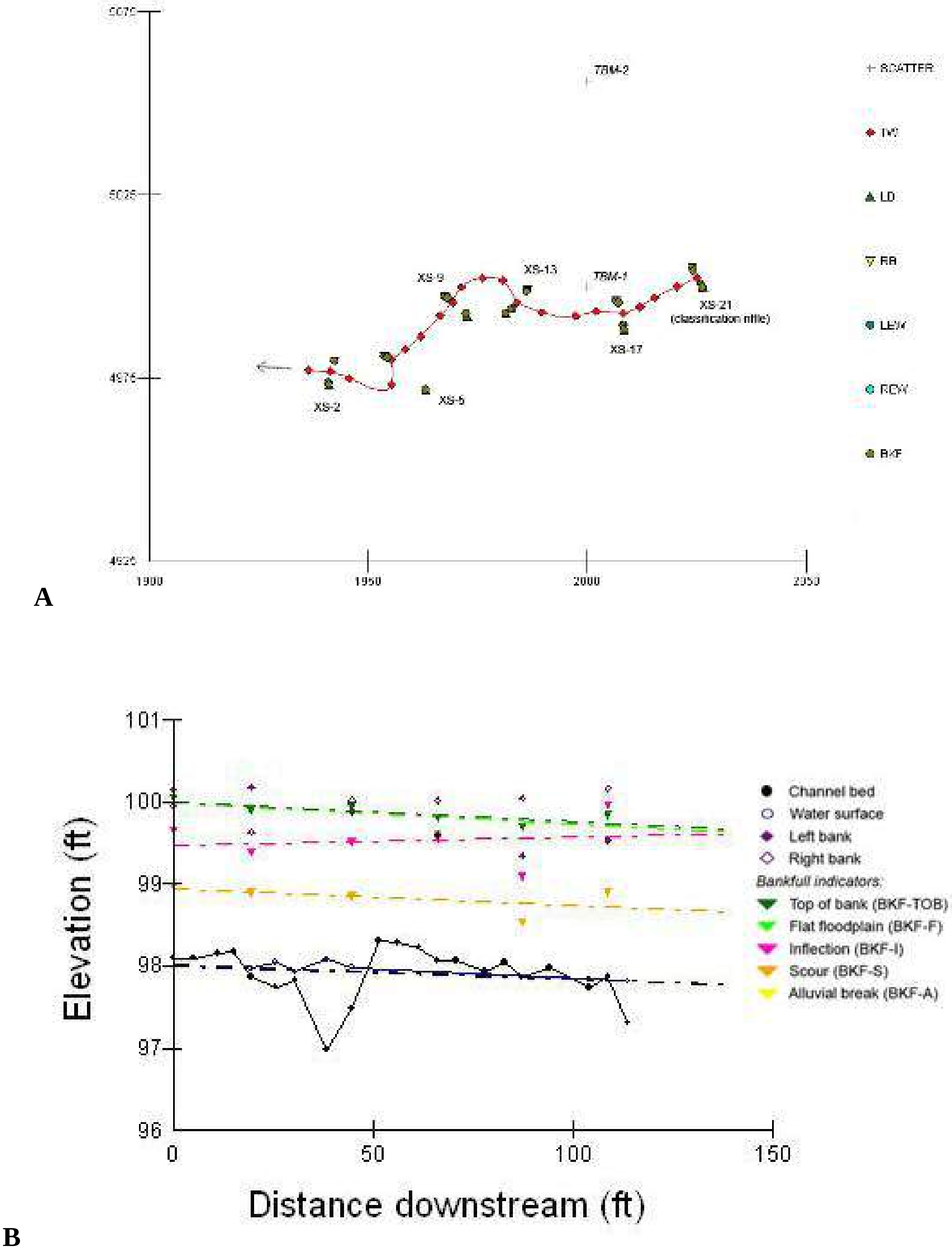
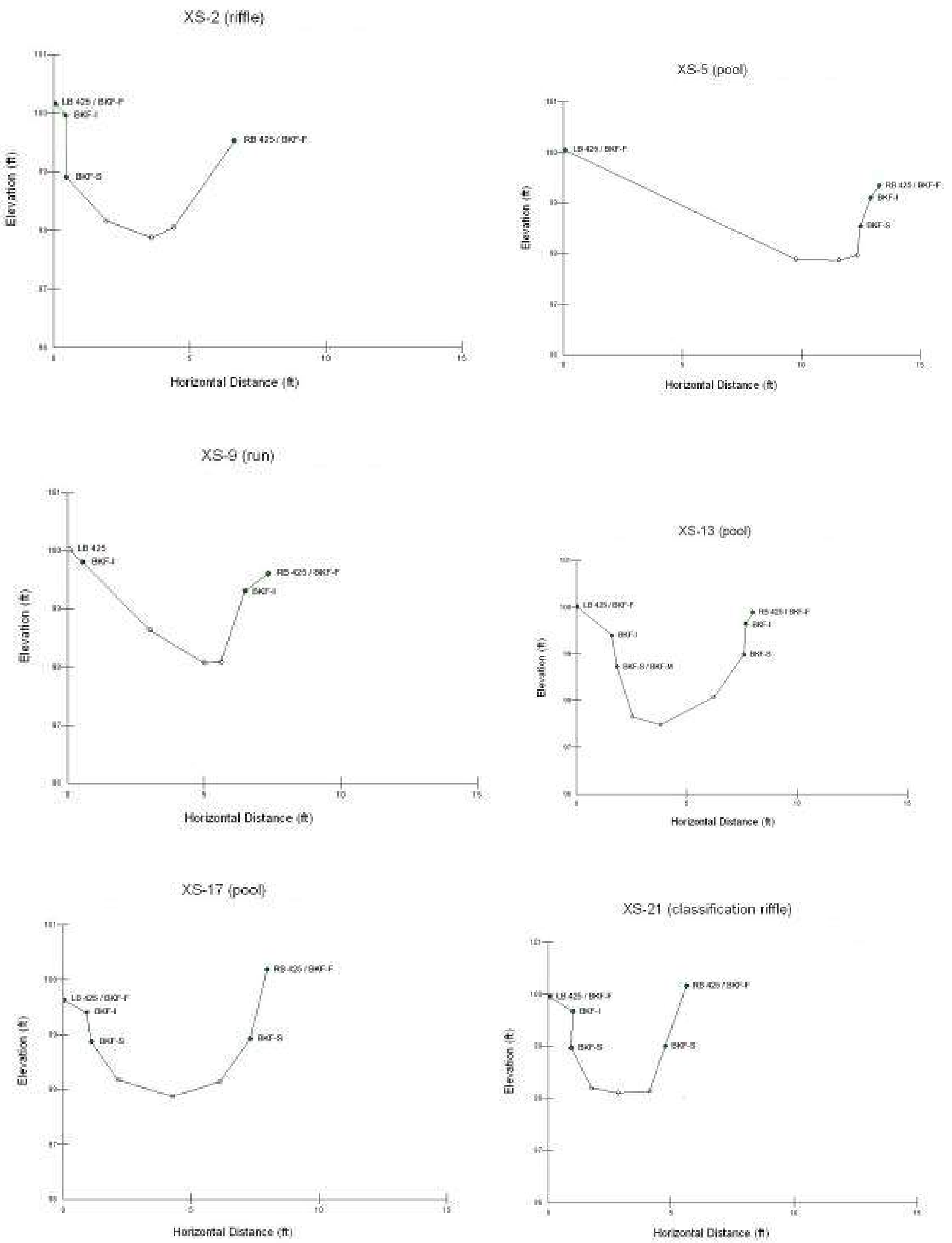


Figure F-15. East Fork Manatee UT 1. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-15 (Cont.). East Fork Manatee UT 1. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

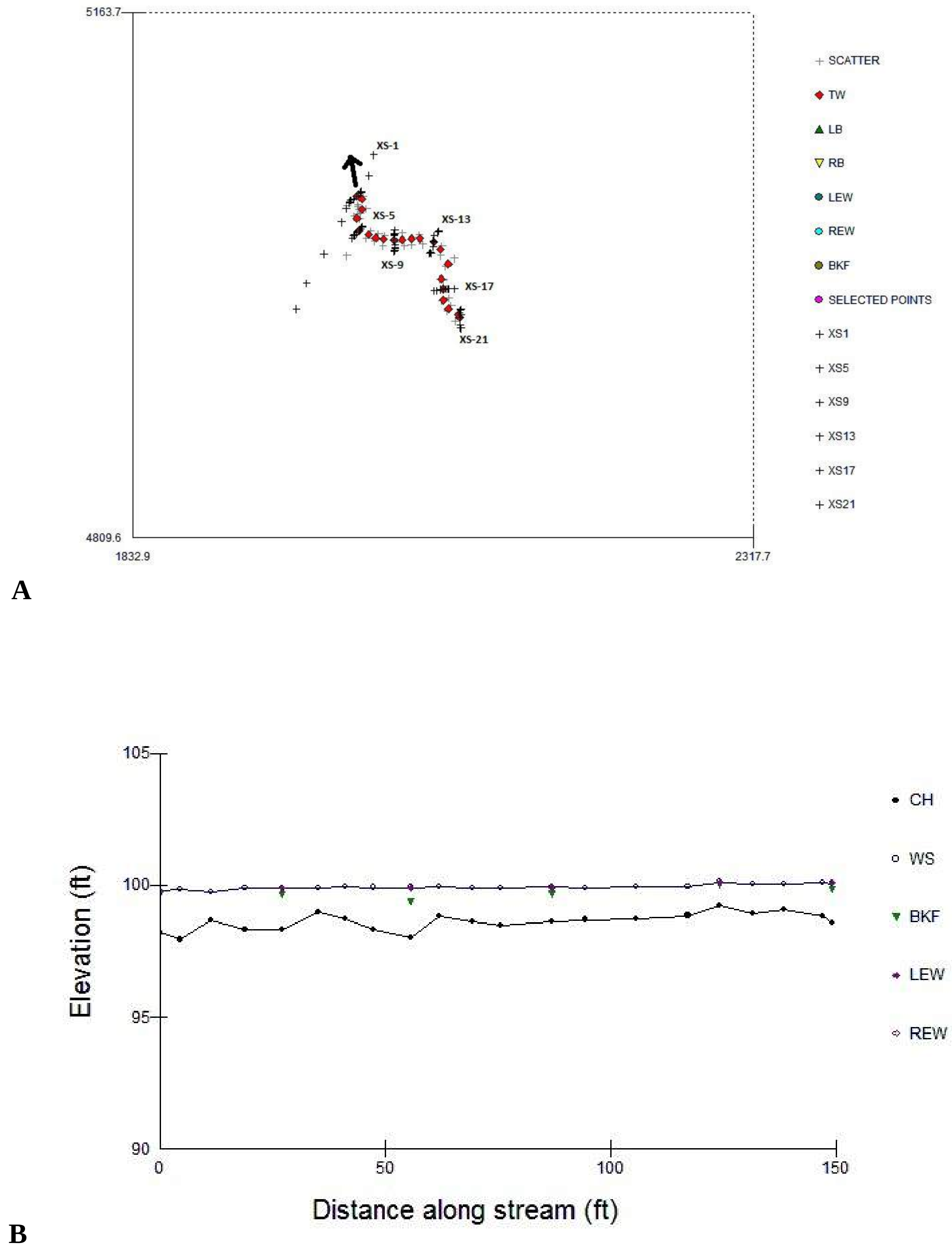
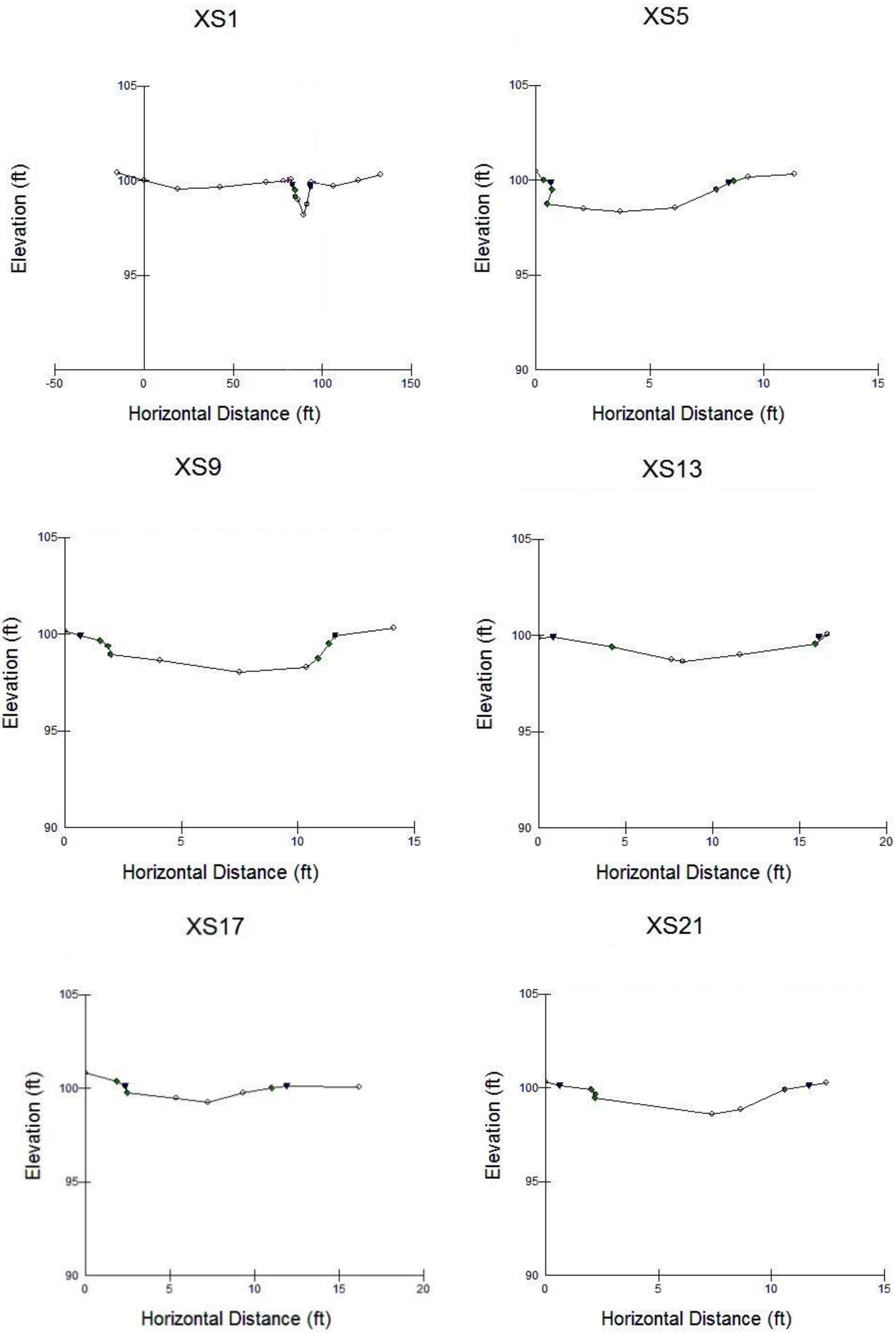


Figure F-16. East Fork Manatee UT 2. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-16 (Cont.). East Fork Manatee UT 2. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

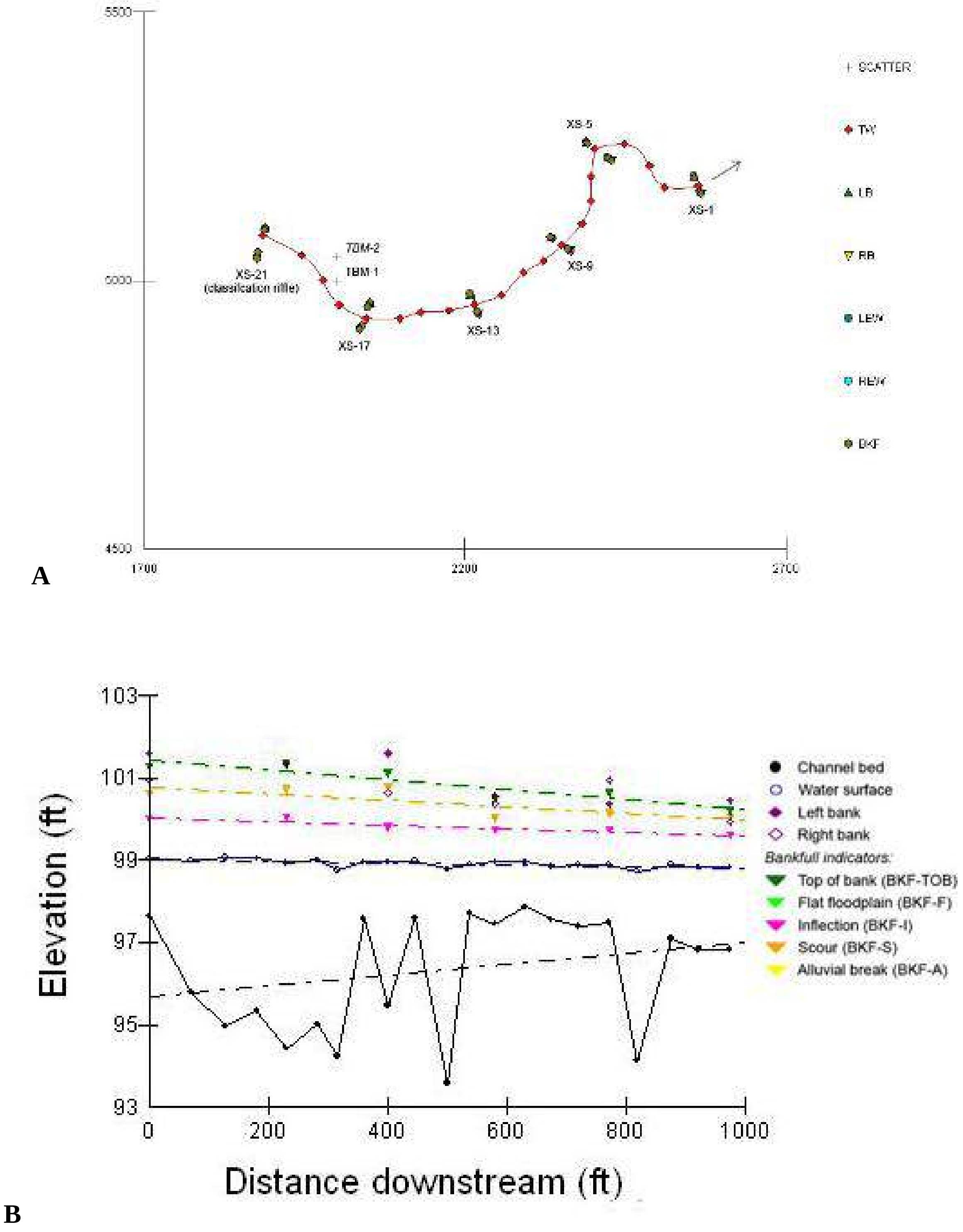


Figure F-17. Fisheating Creek at Palmdale. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

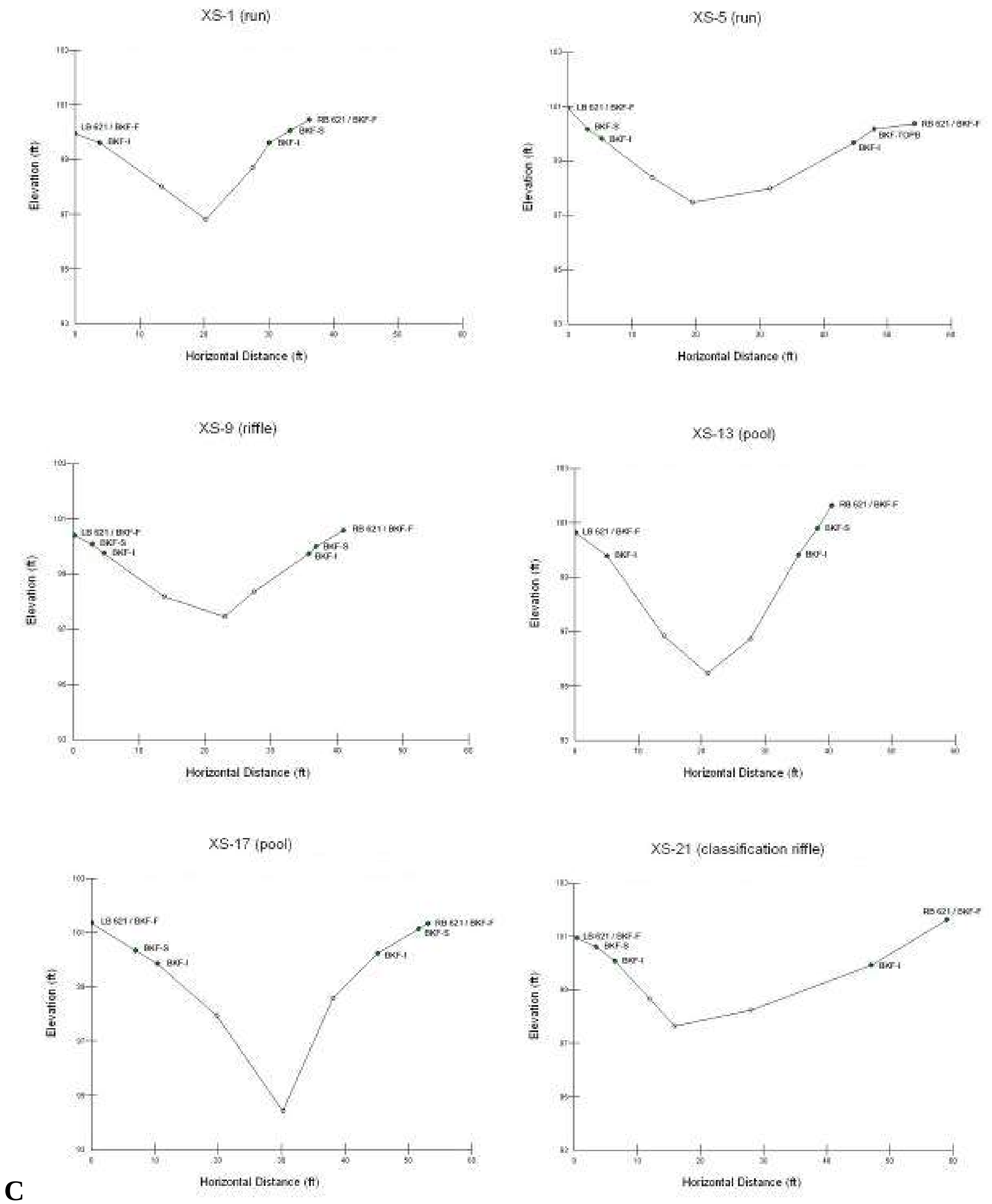
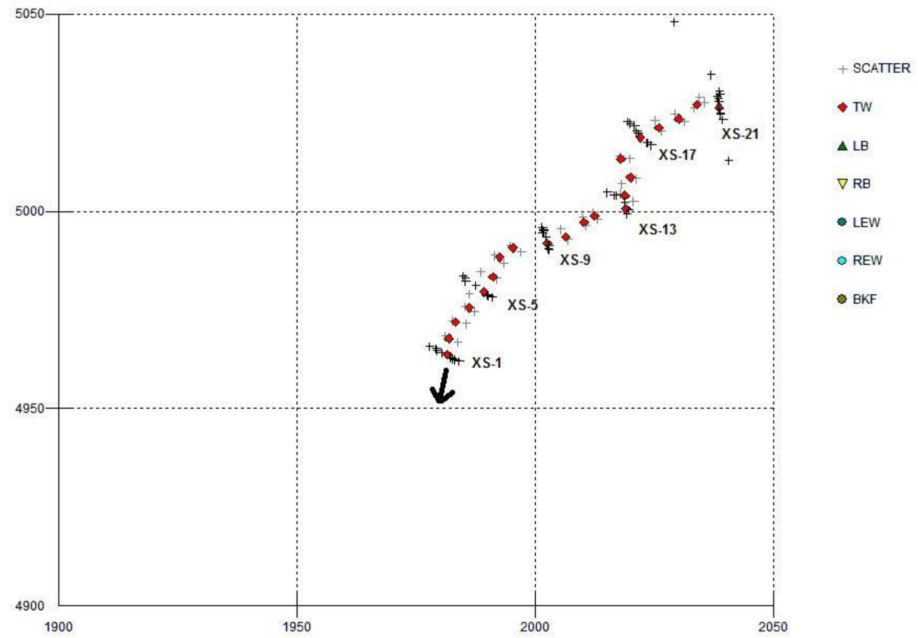
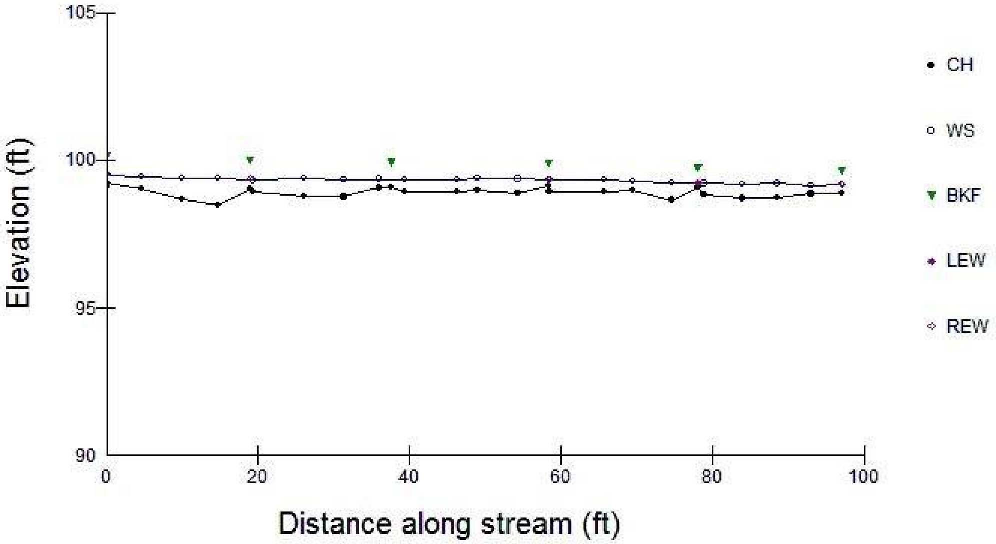


Figure F-17 (Cont.). Fisheating Creek at Palmdale. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

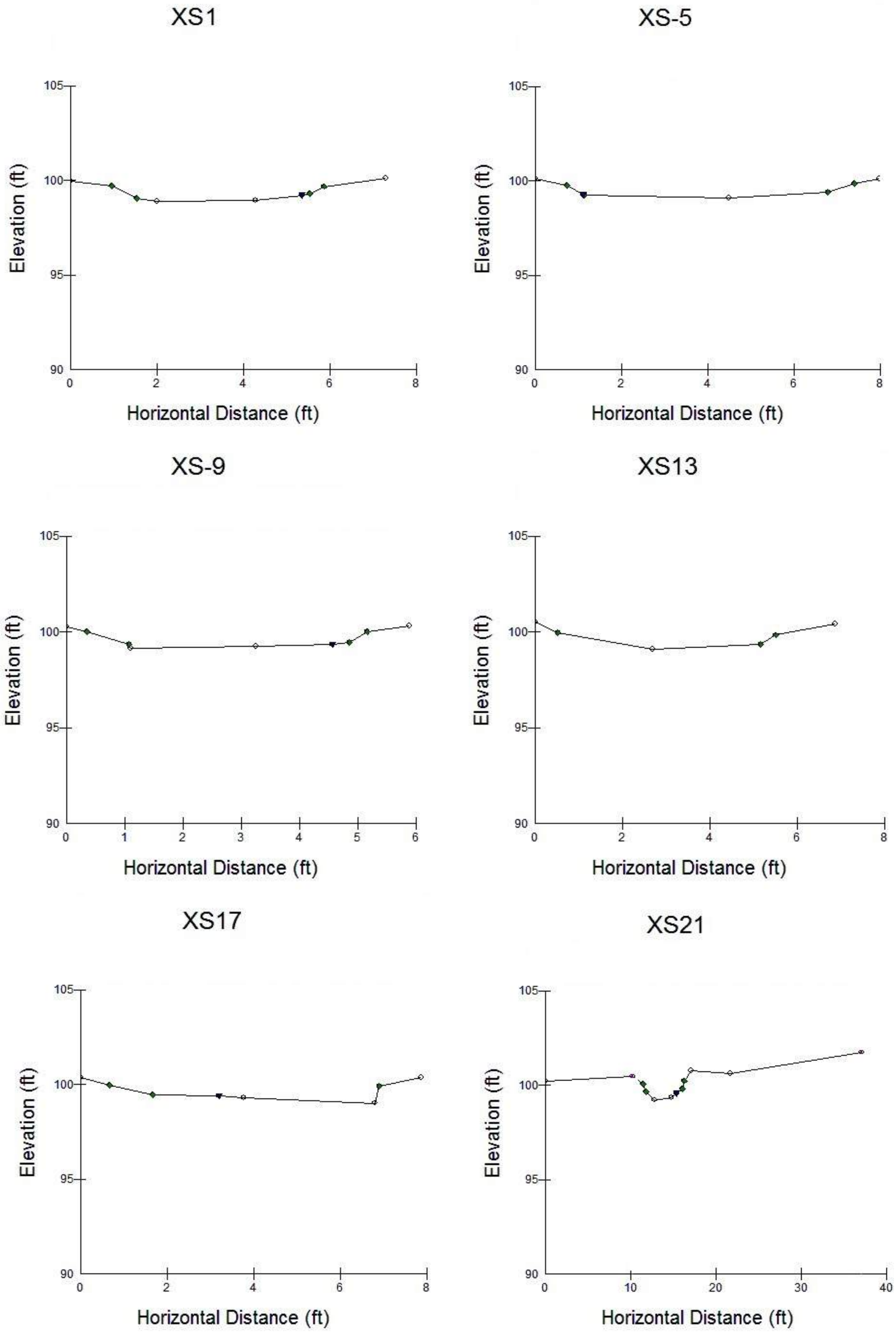


A



B

Figure F-18. Forest Spring Run. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-18 (Cont.). Forest Spring Run. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

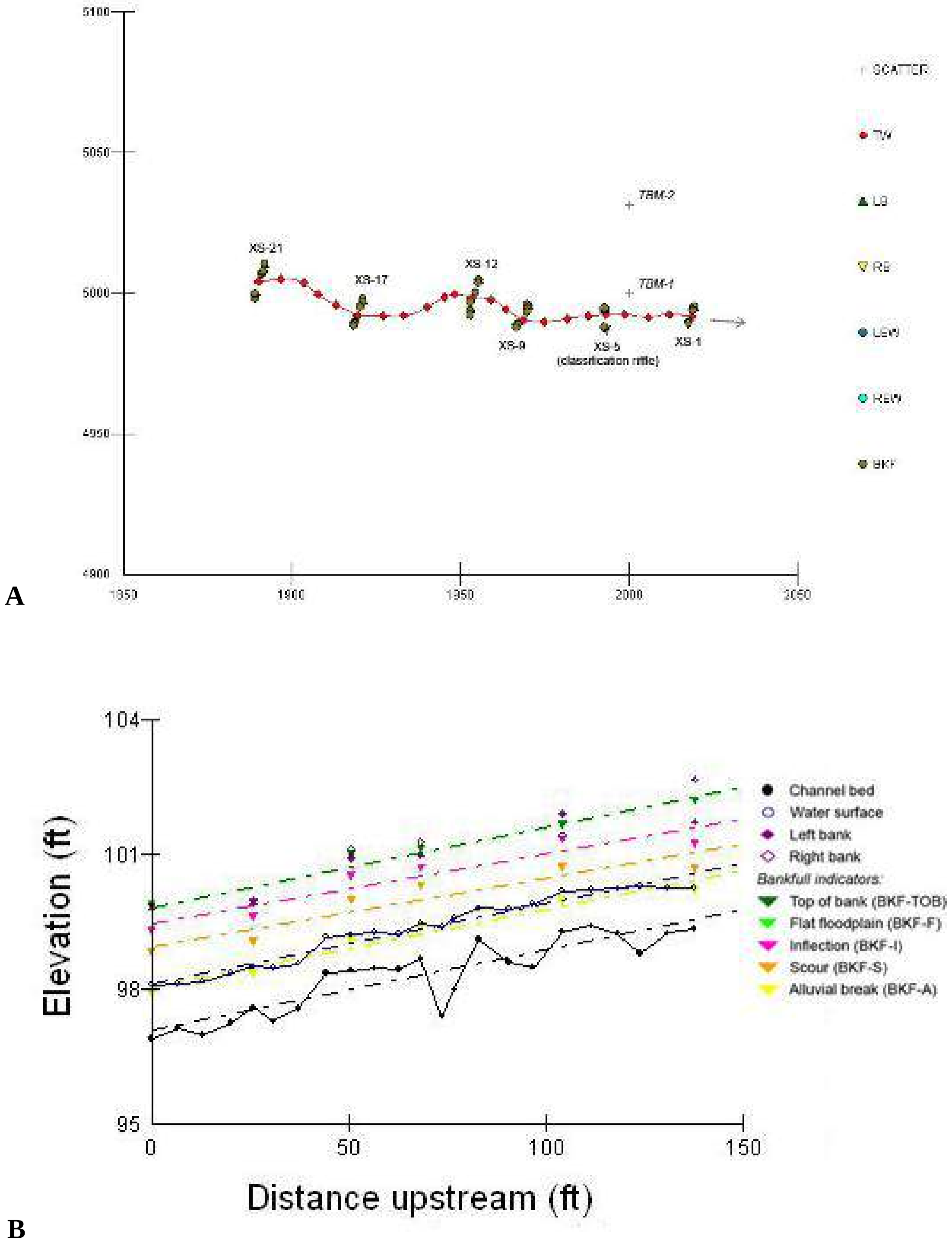
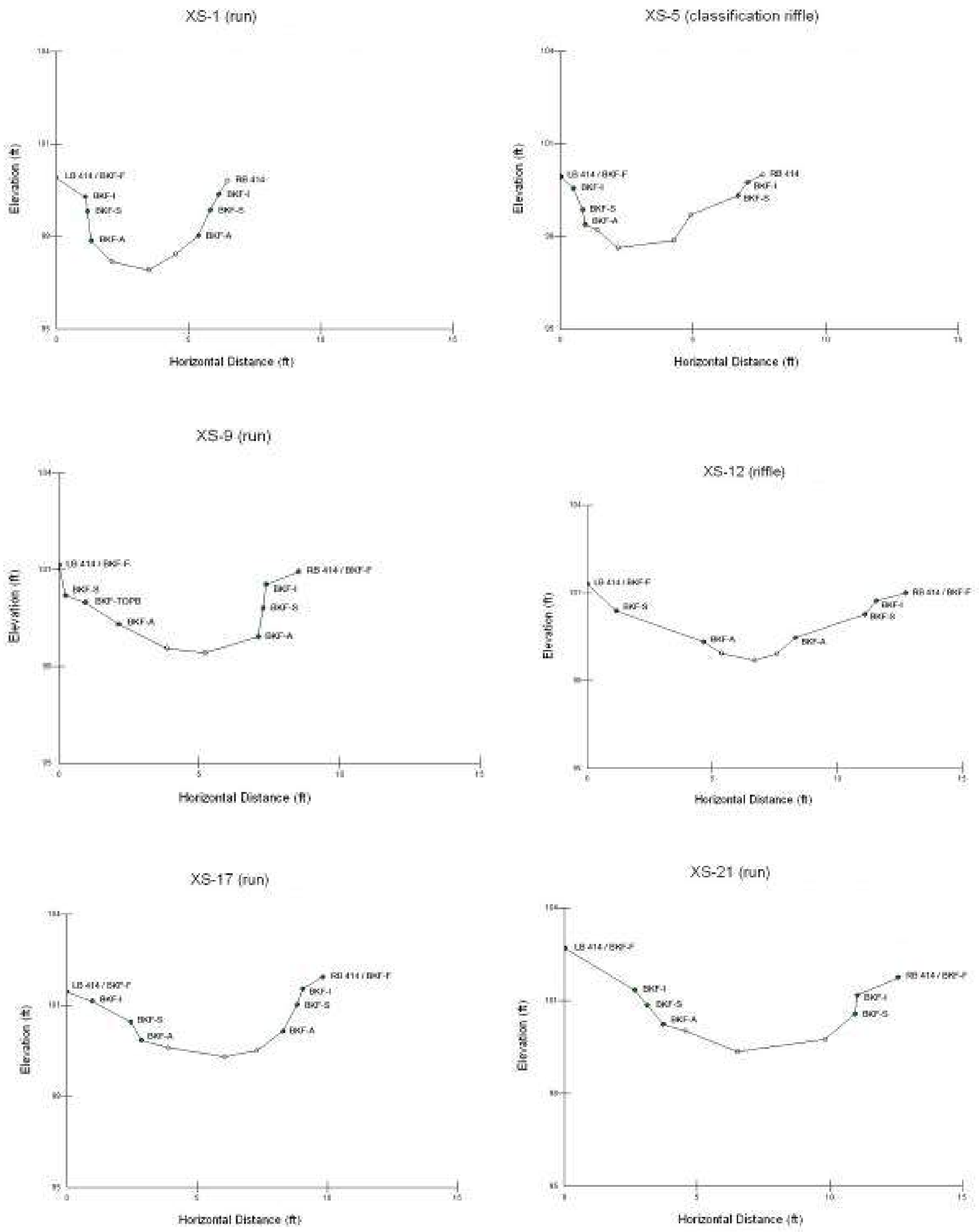


Figure F-19. Gold Head Branch. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-19 (Cont.). Gold Head Branch. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

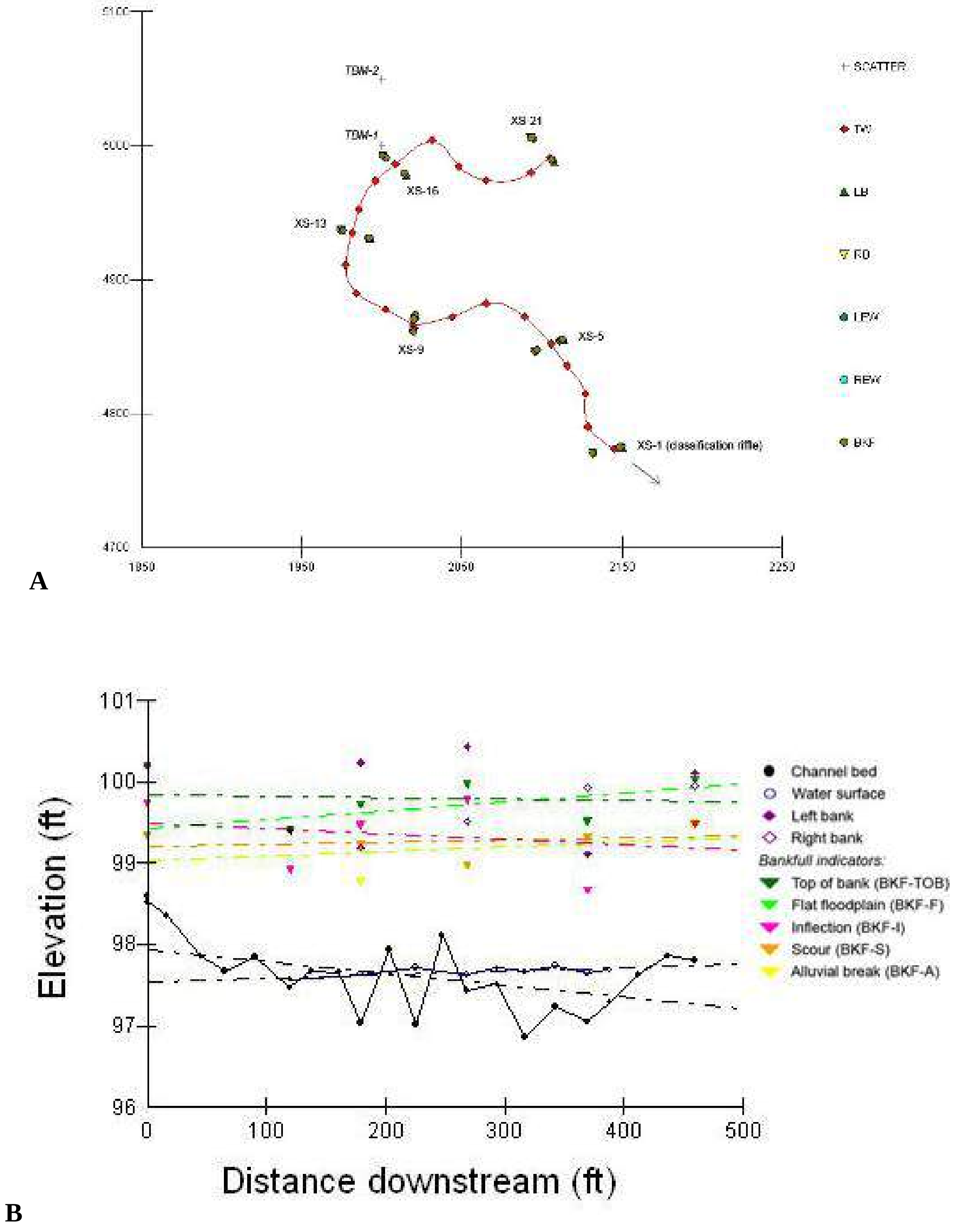
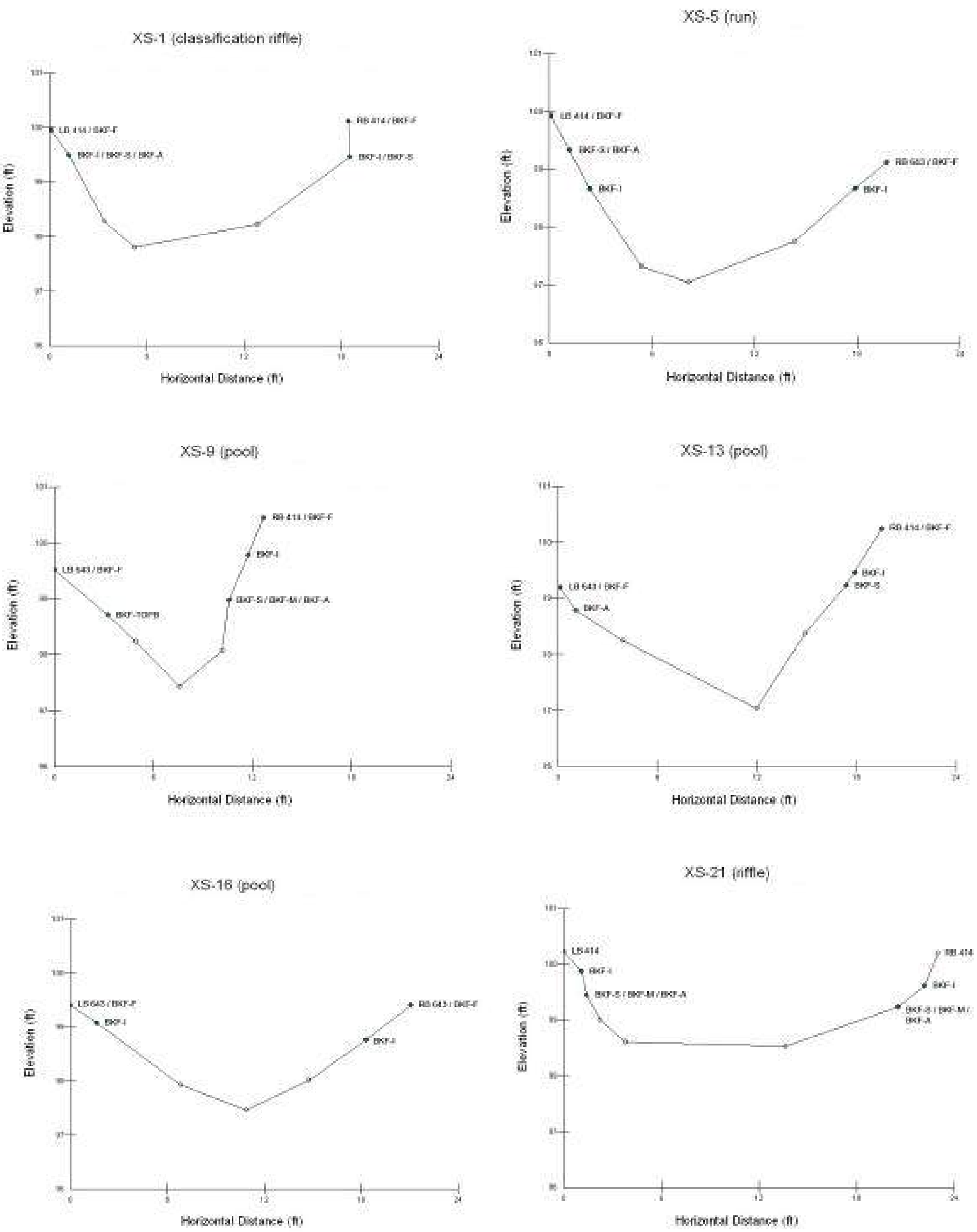


Figure F-20. Grasshopper Slough Run. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-20 (Cont.). Grasshopper Slough Run. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

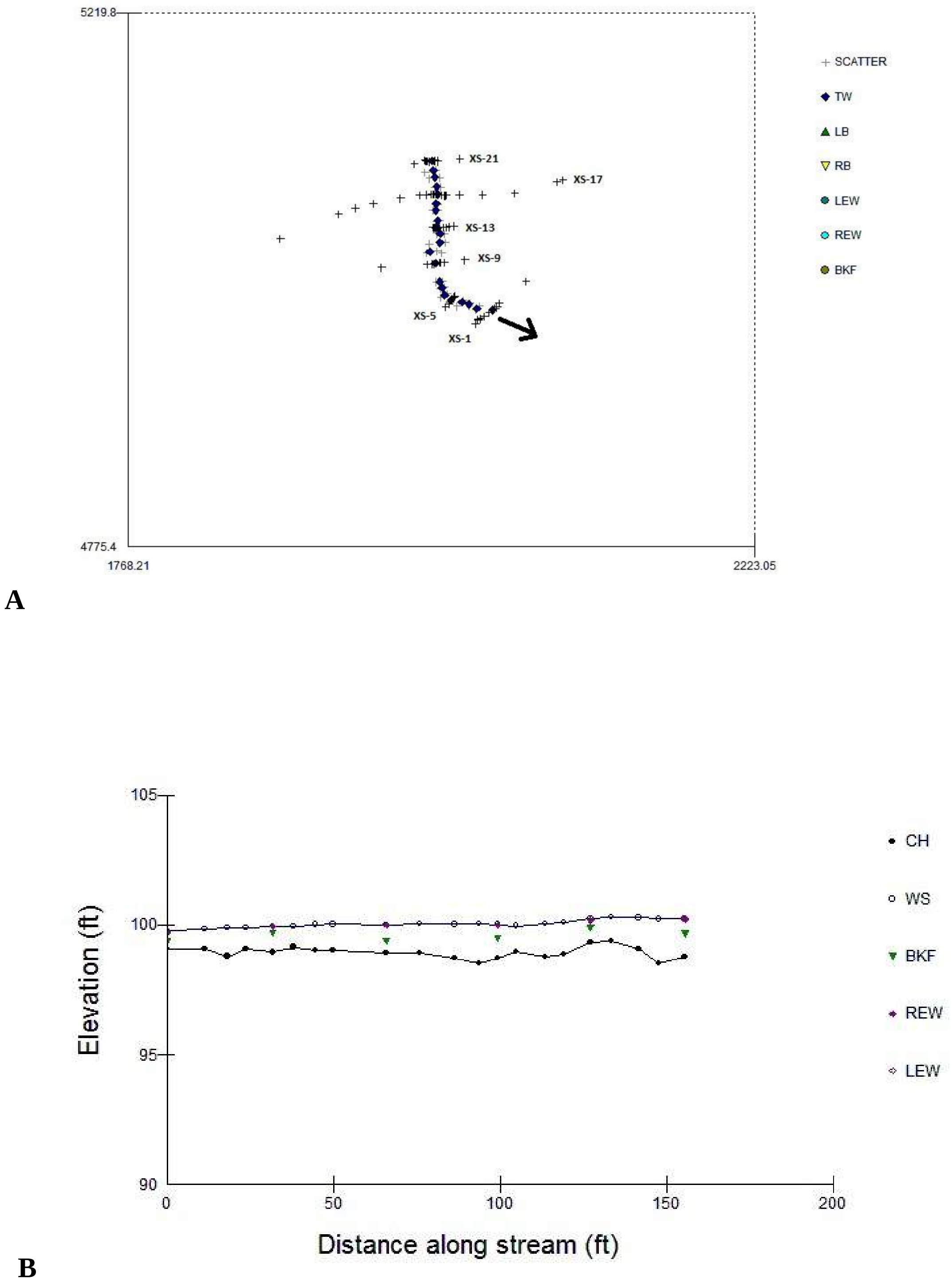
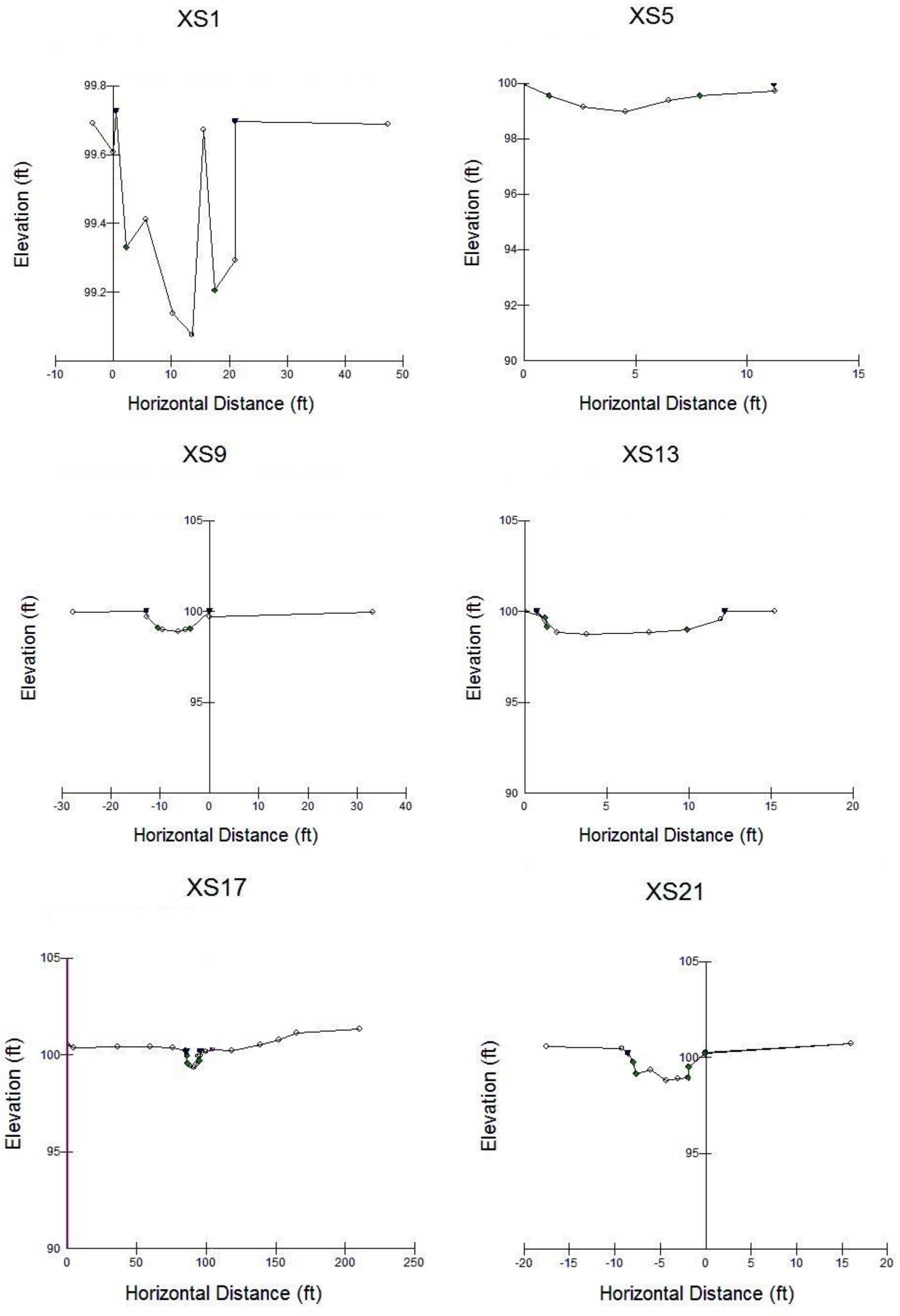
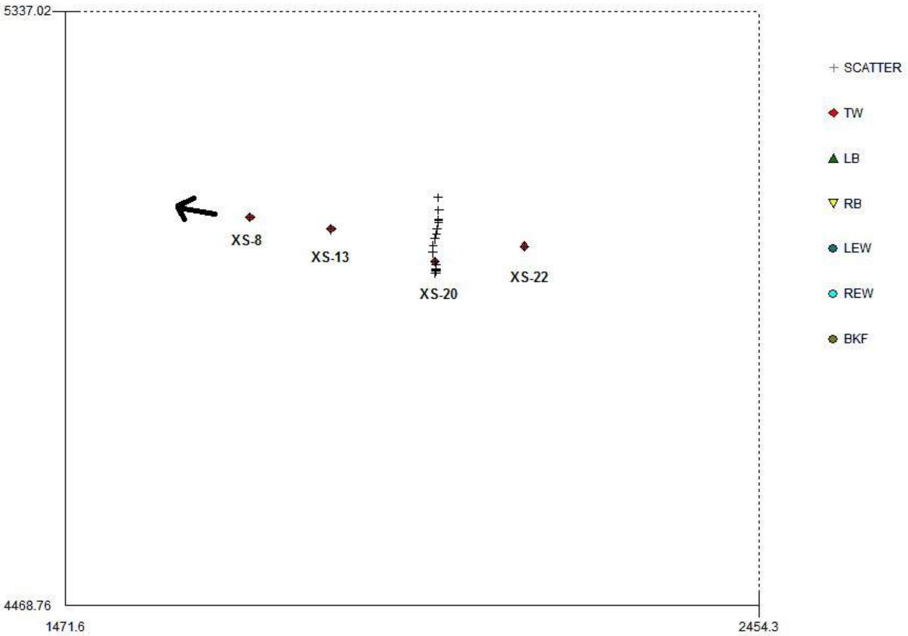


Figure F-21. Grassy Creek UT. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

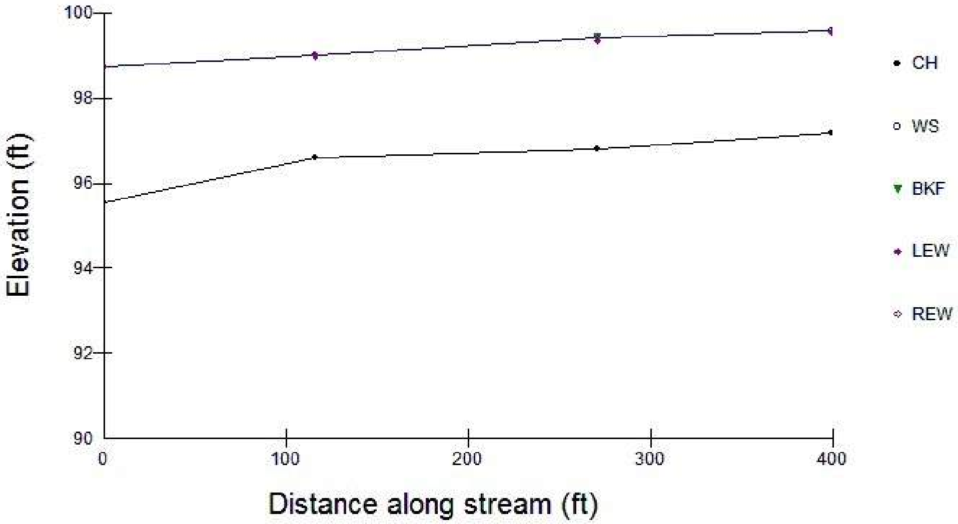


C

Figure F-21 (Cont.). Grassy Creek UT. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

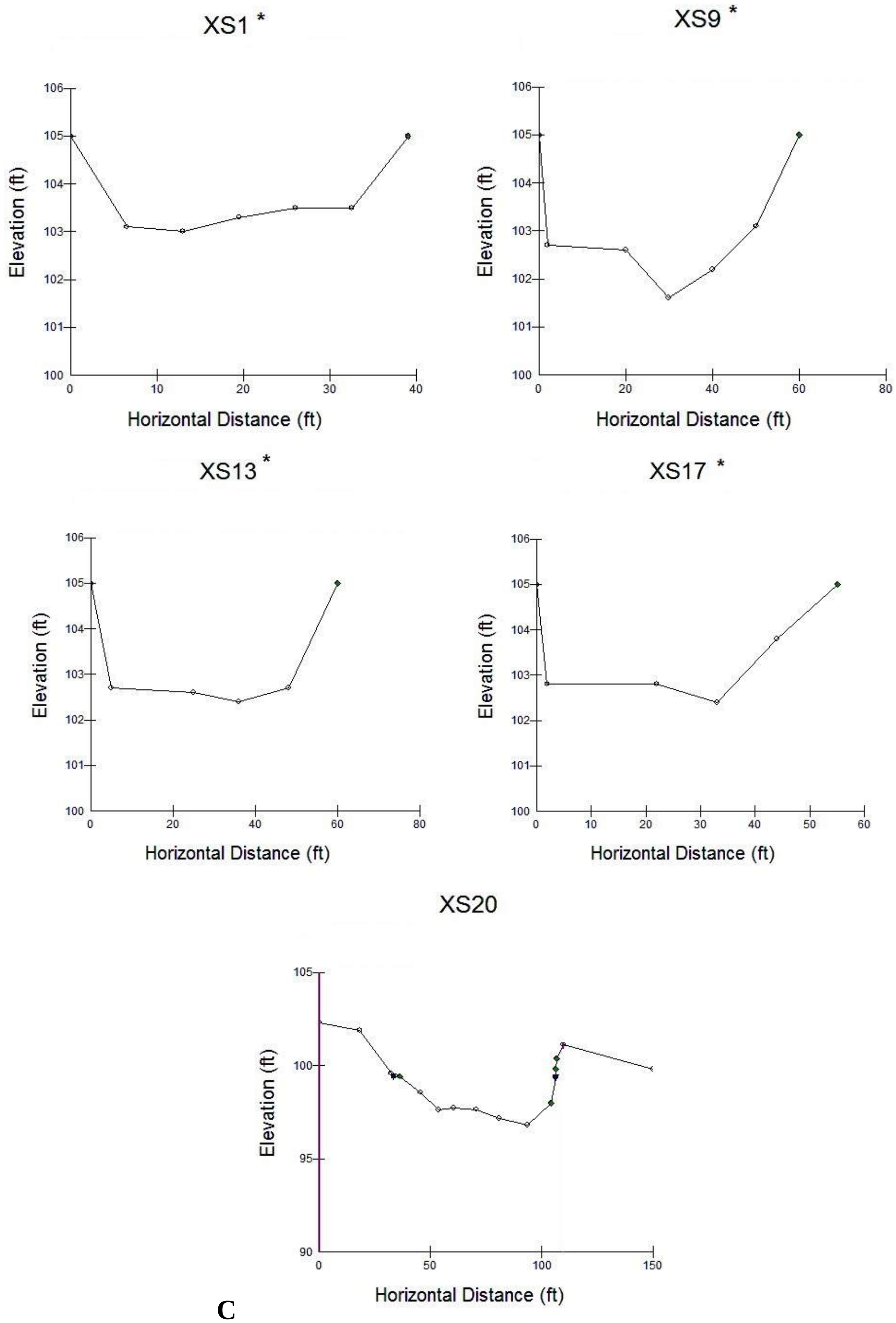


A



B

Figure F-22. Gum Slough Spring Run. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-22 (Cont.). Gum Slough Spring Run. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections. (*Not part of total station survey)

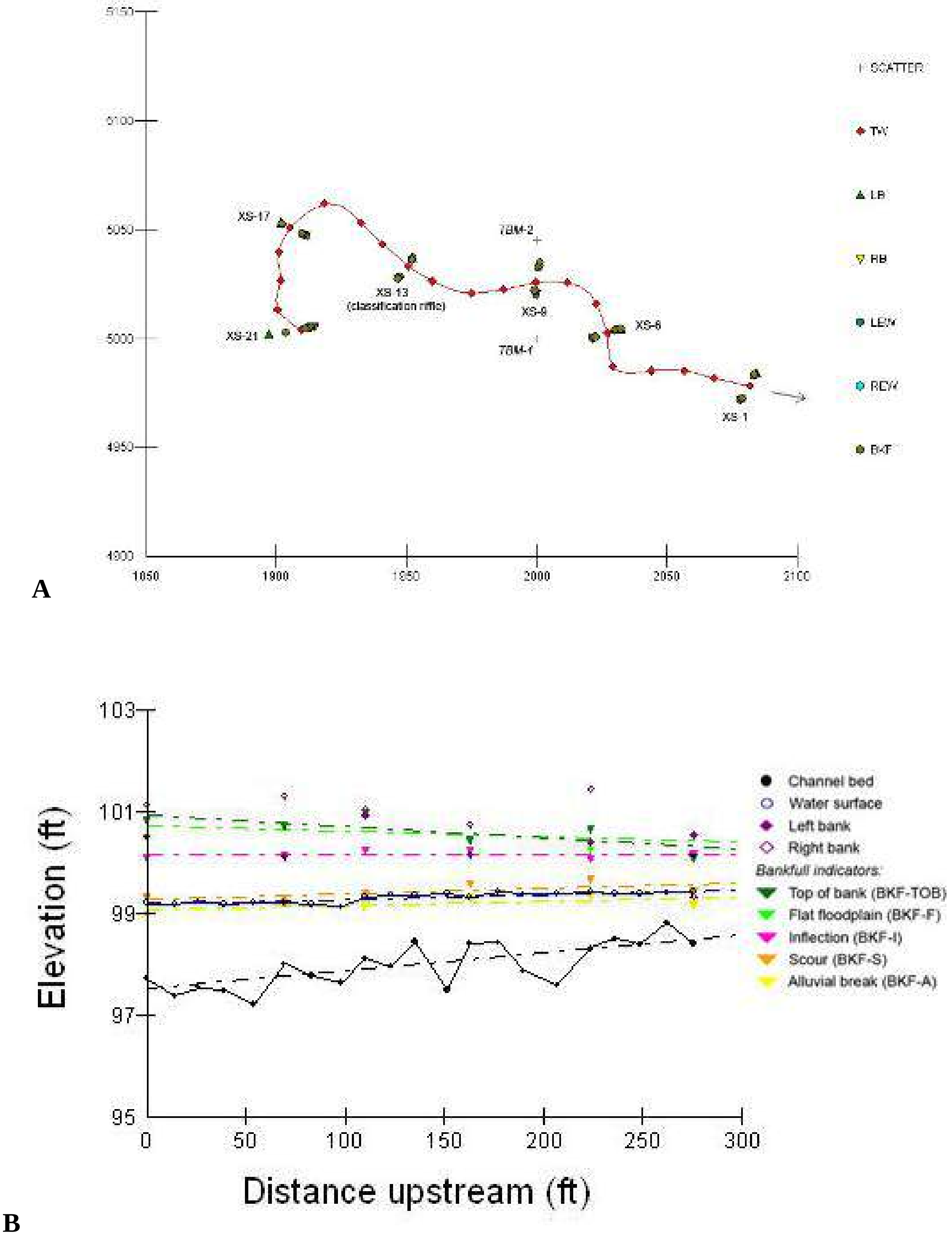


Figure F-23. Hammock Branch. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

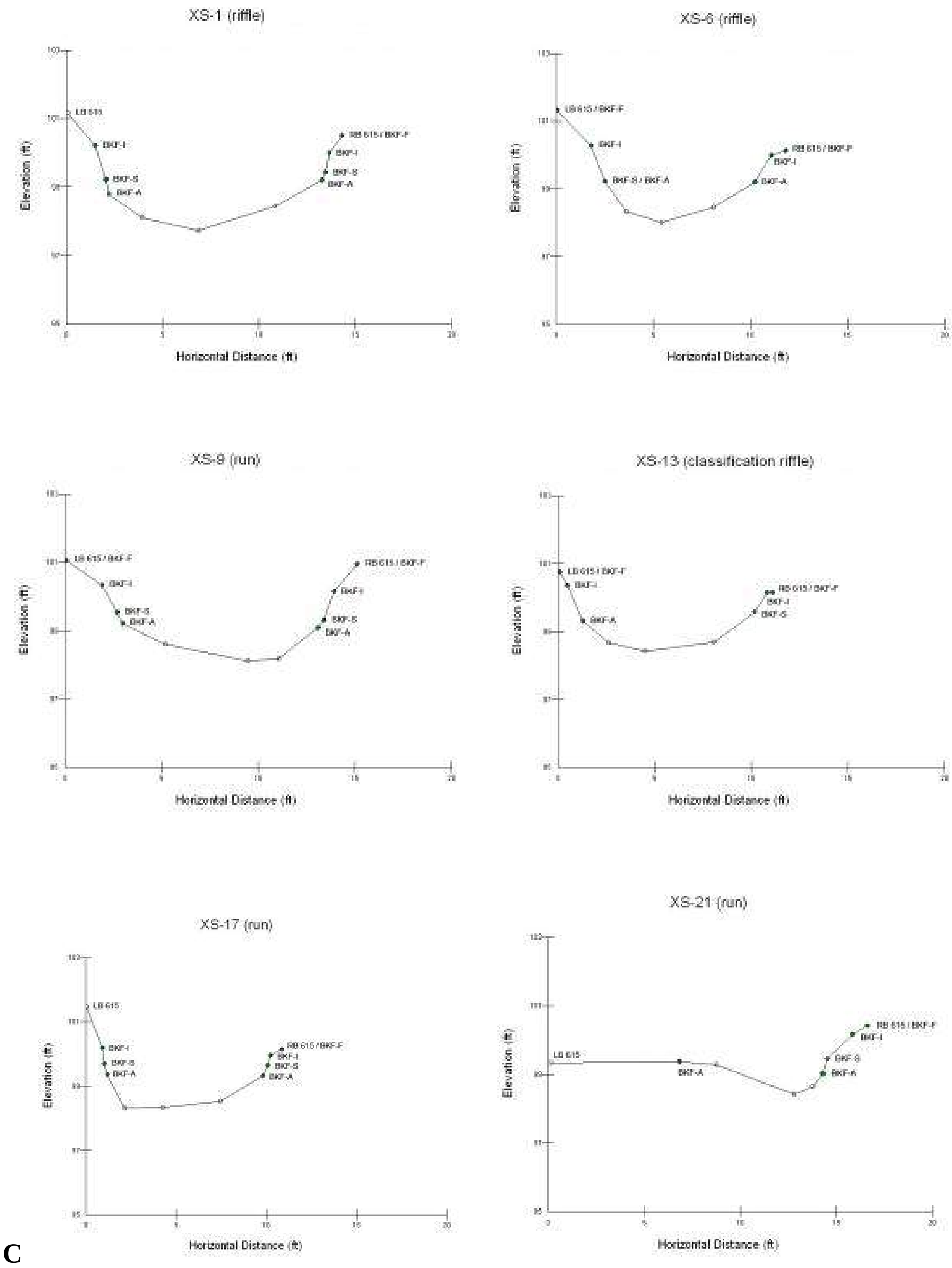


Figure F-23 (Cont.). Hammock Branch. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

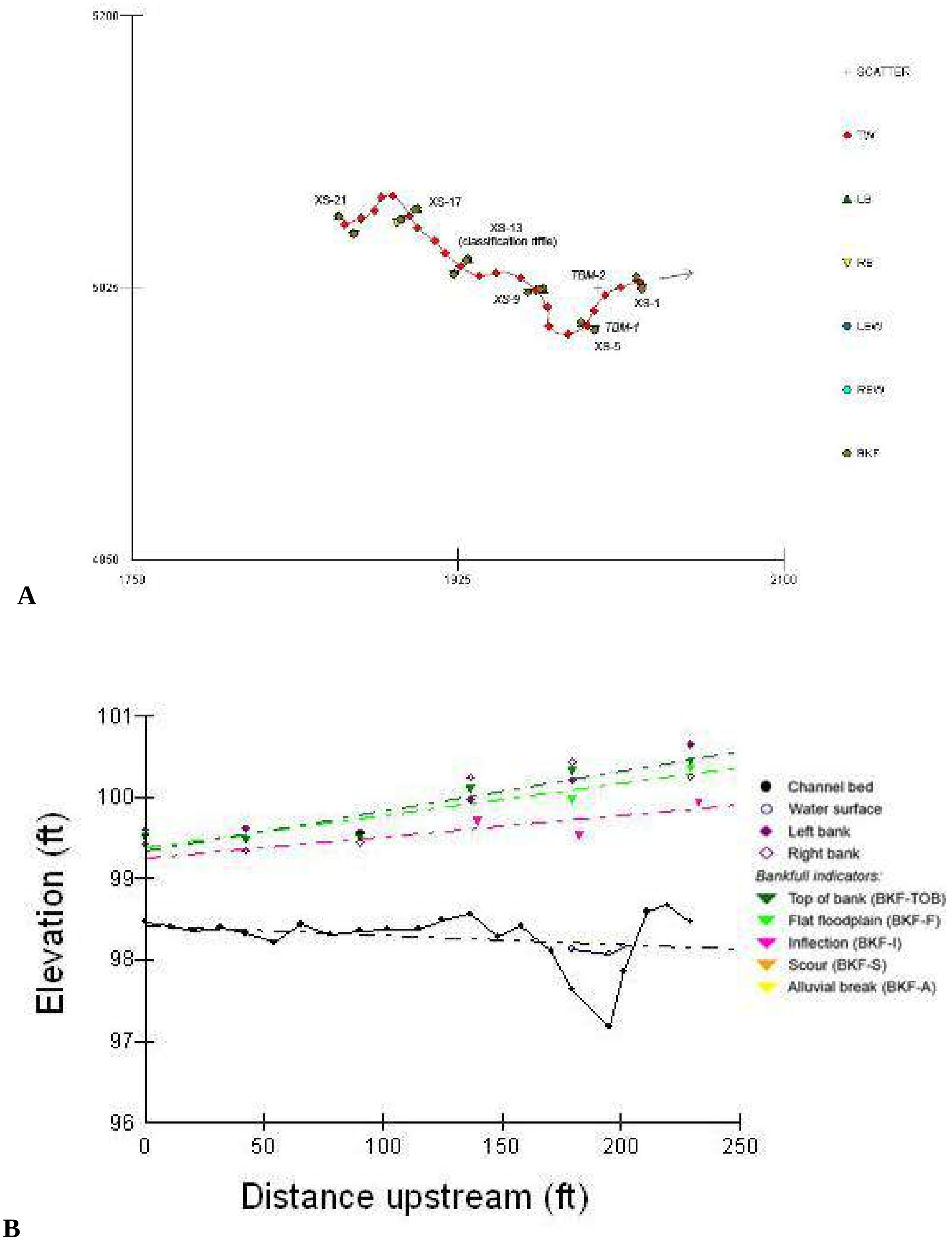


Figure F-24. Hillsborough River UT. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

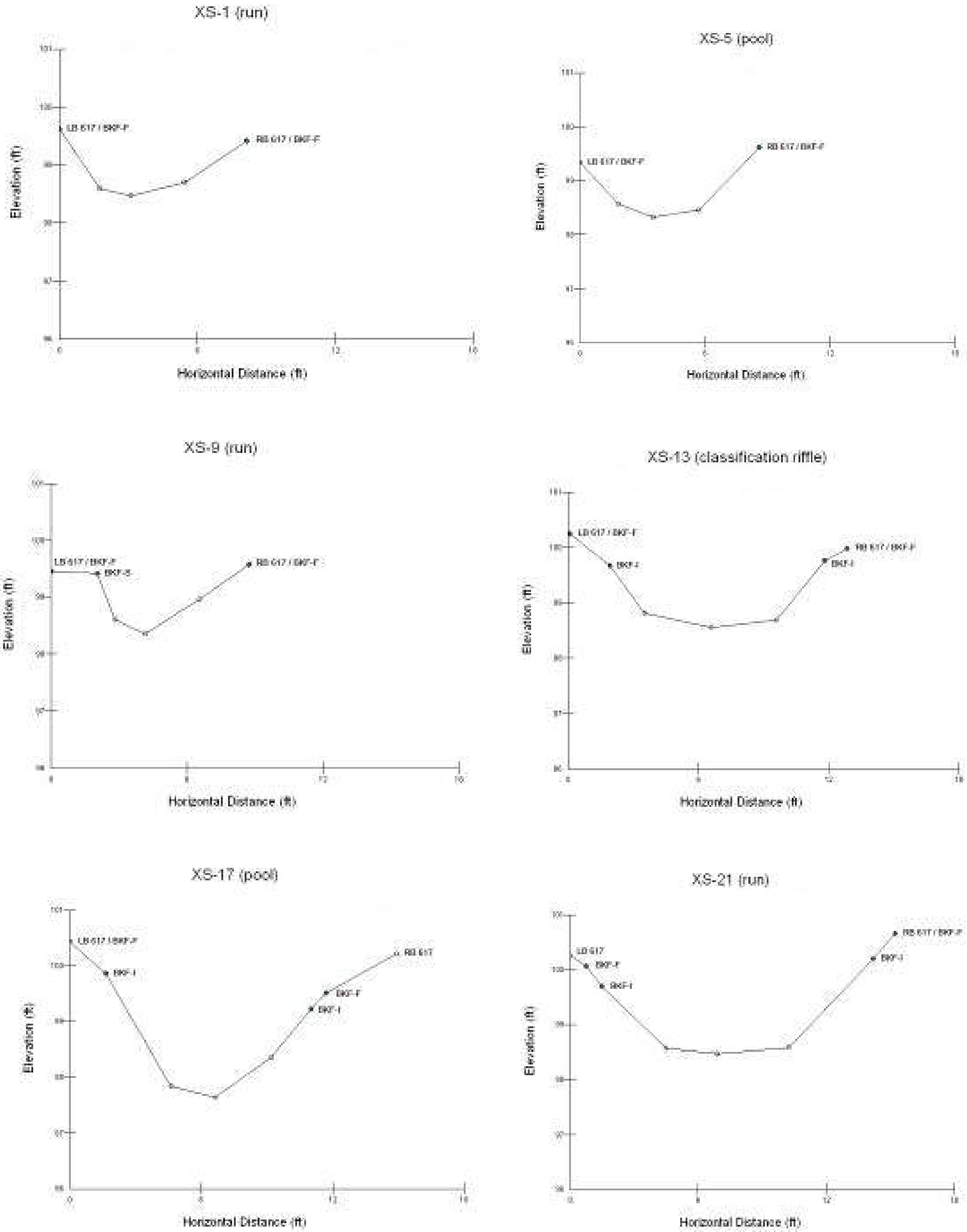


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Figure F-24 (Cont.). Hillsborough River UT. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

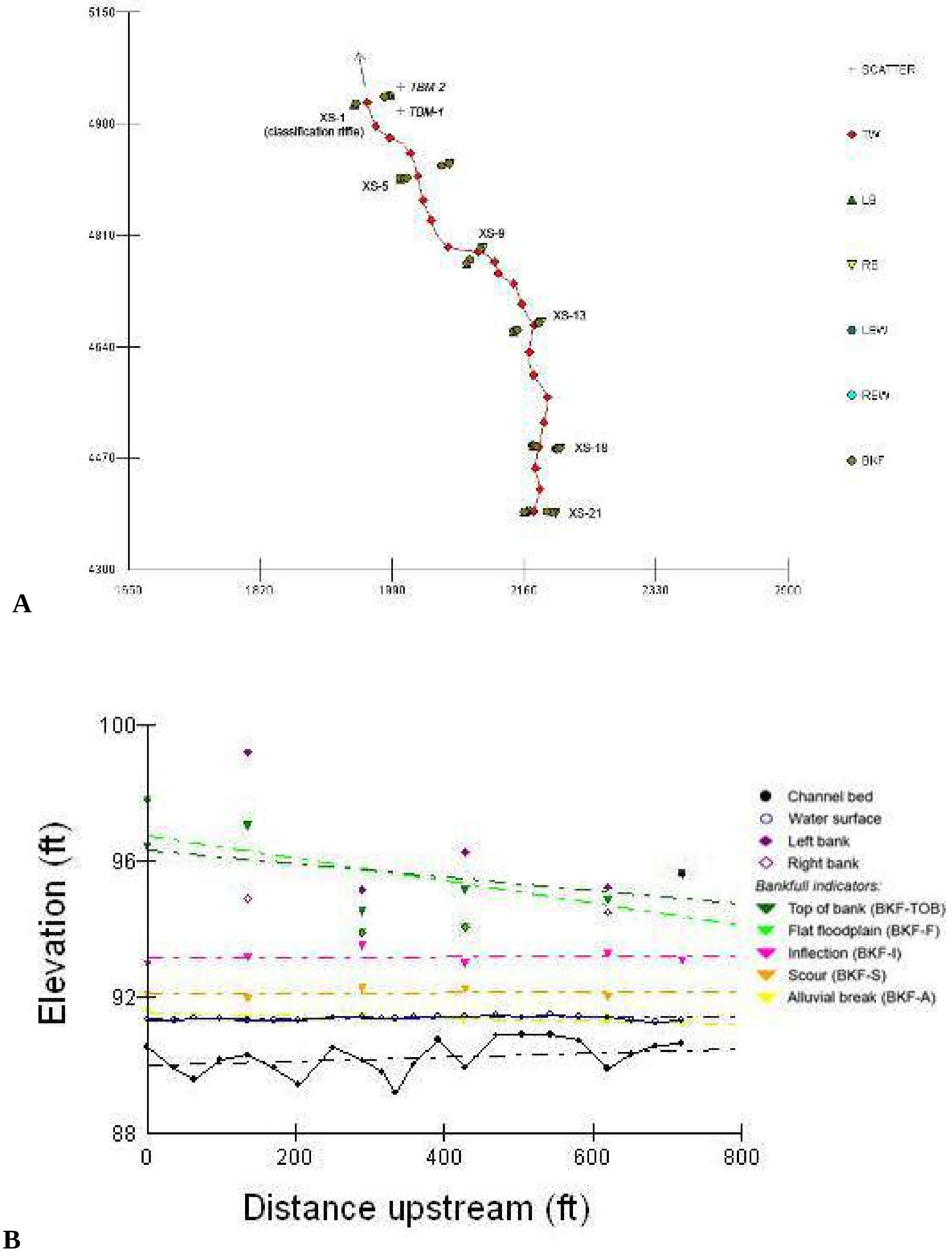
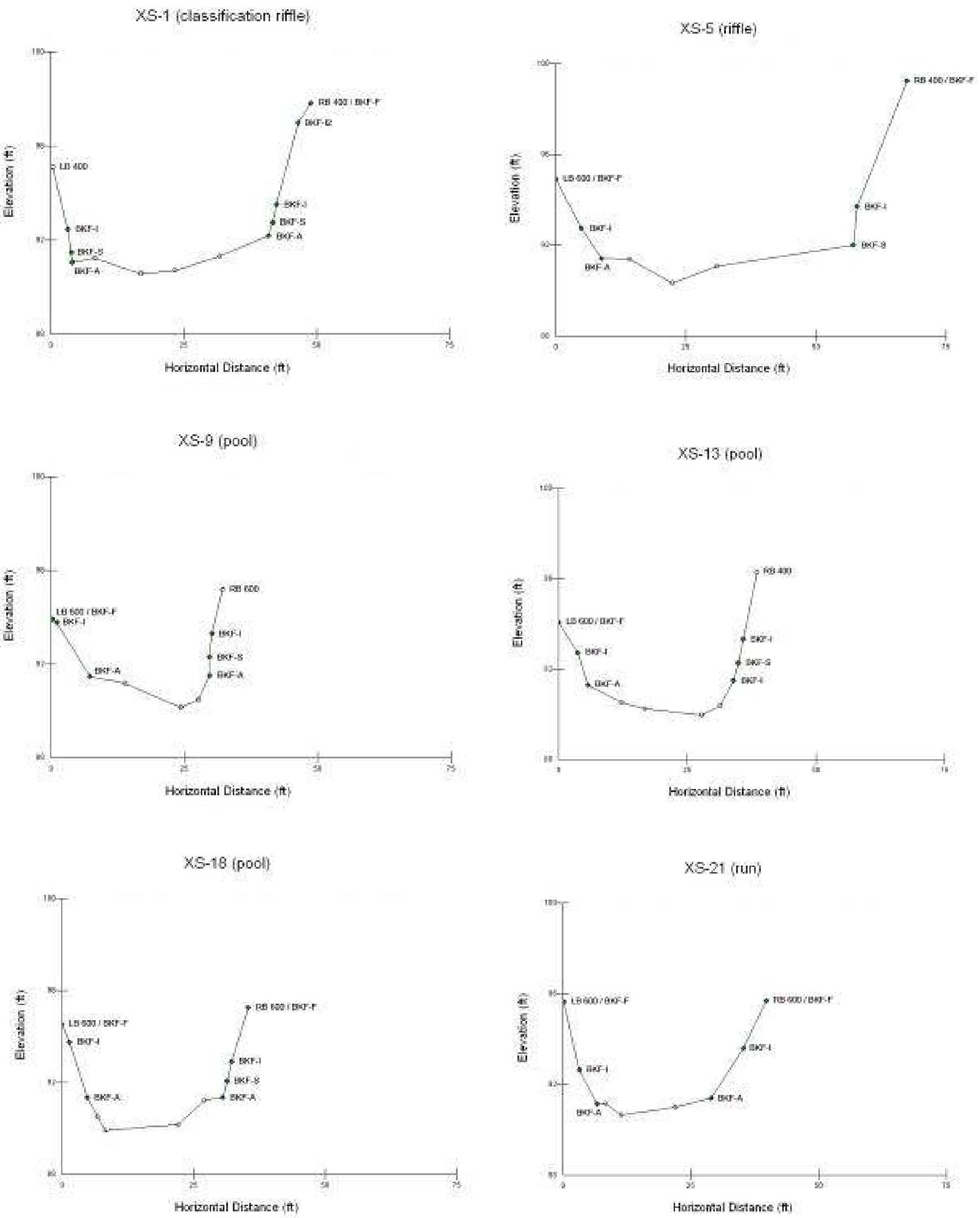


Figure F-25. Horse Creek near Arcadia. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-25 (Cont.). Horse Creek near Arcadia. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

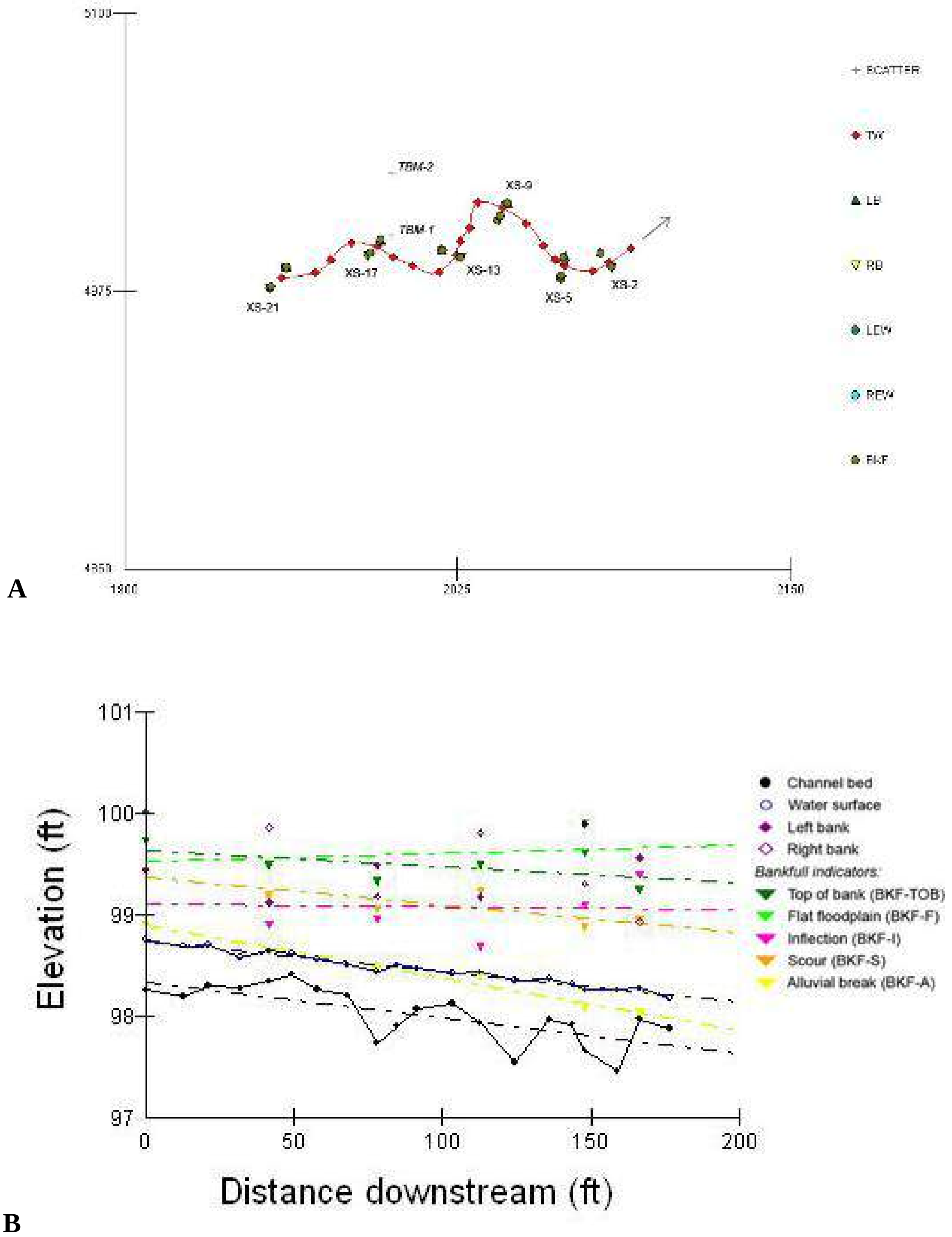
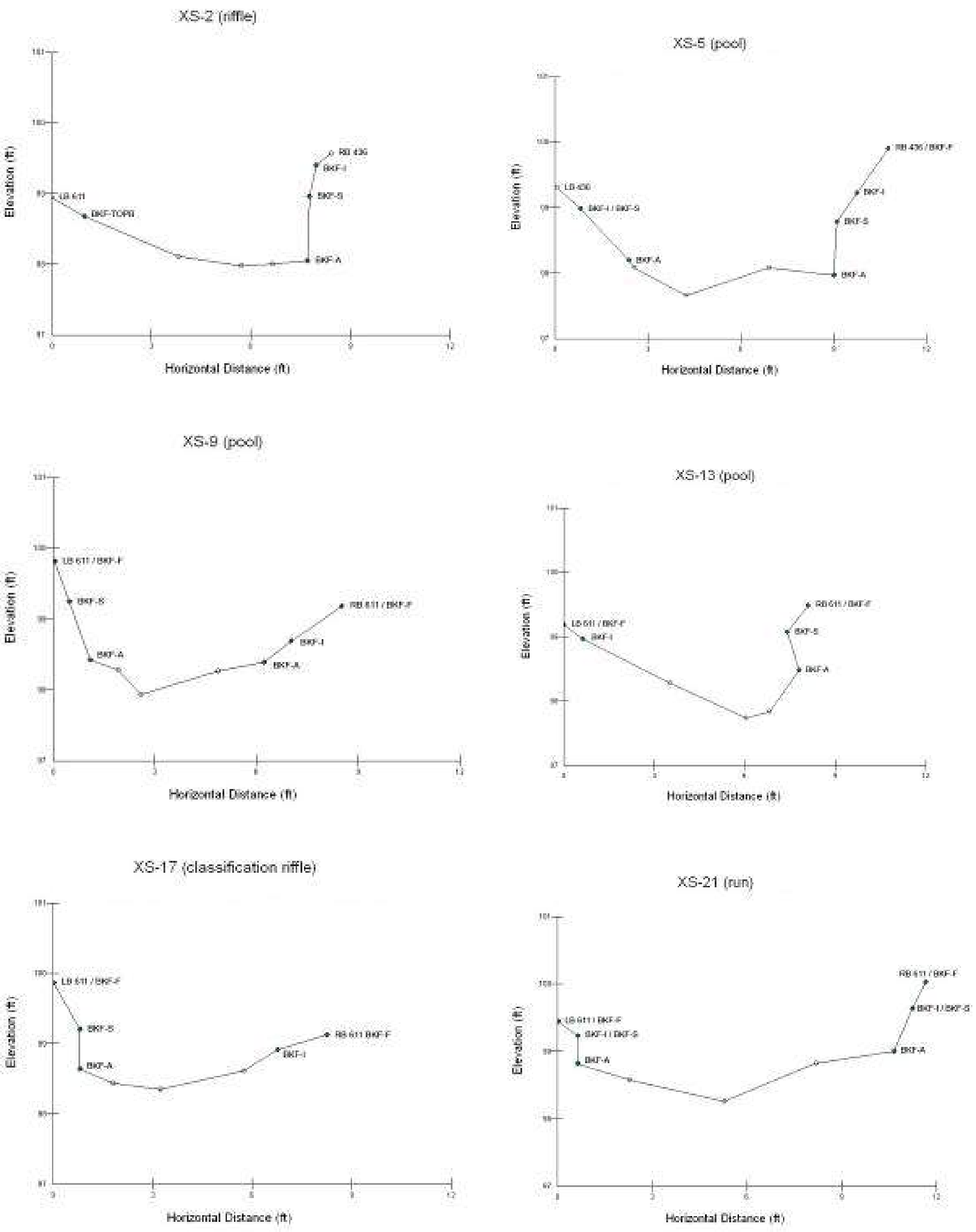


Figure F-26. Jack Creek. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-26 (Cont.). Jack Creek. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

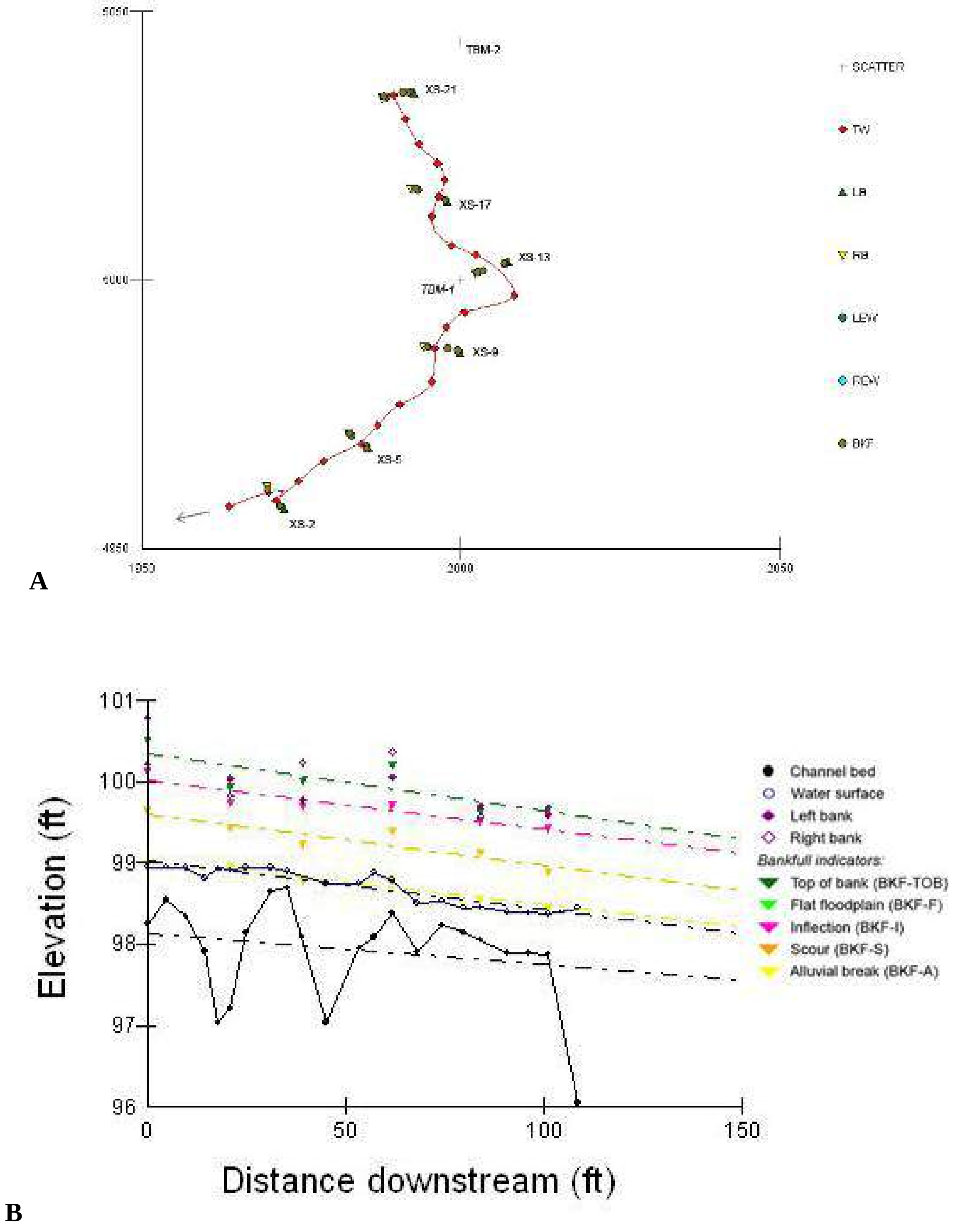


Figure F-27. Jumping Gully. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

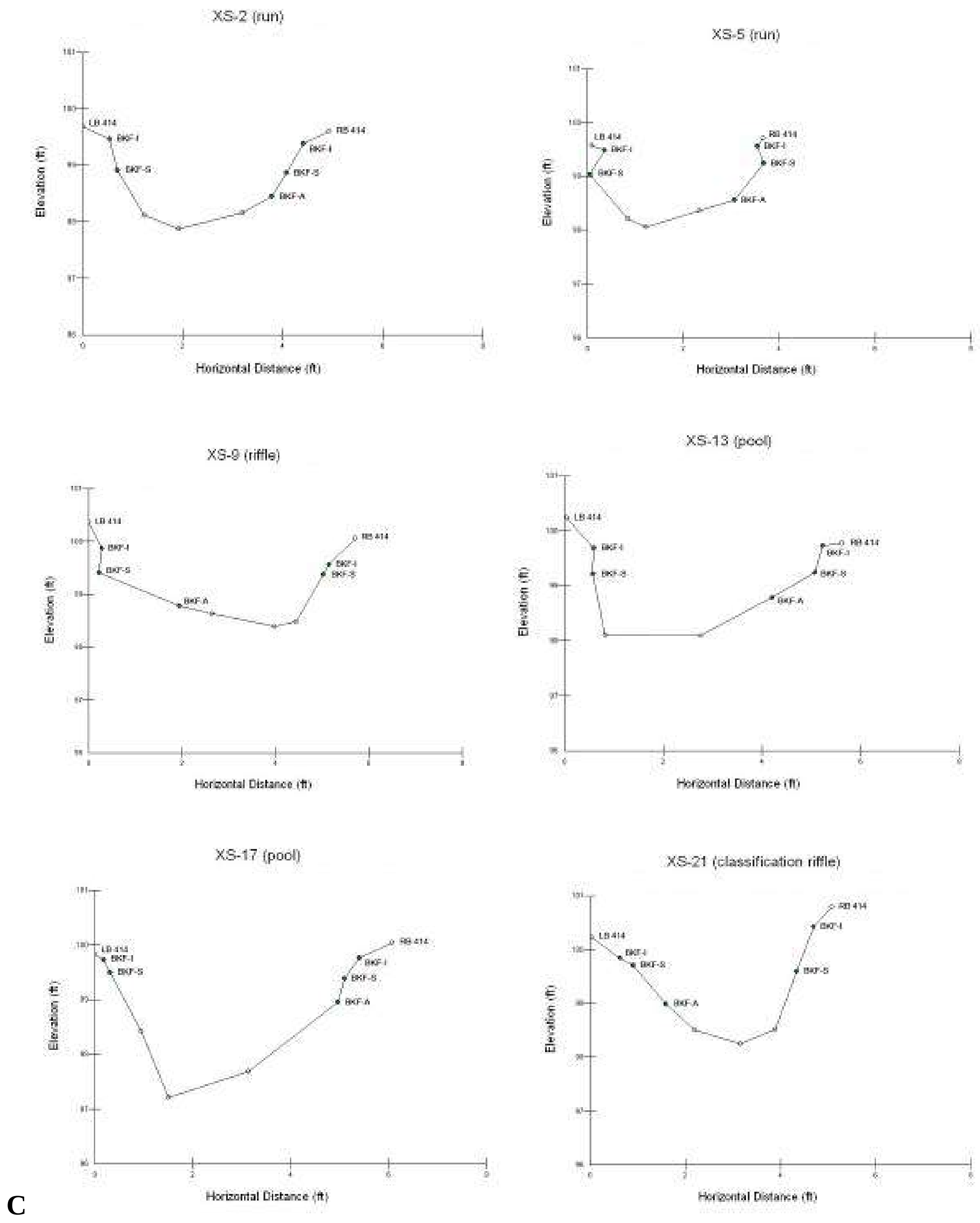
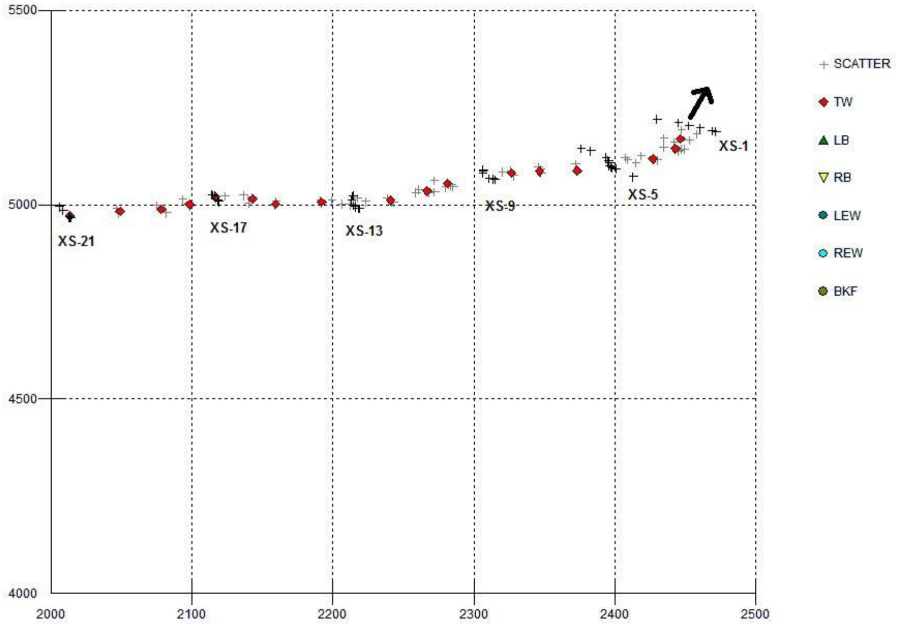
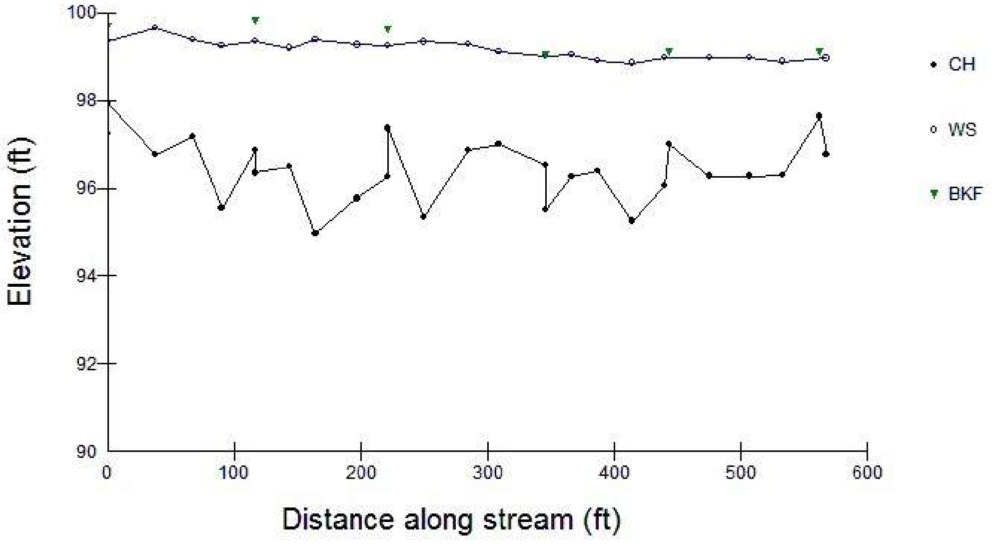


Figure F-27 (Cont.). Jumping Gully. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

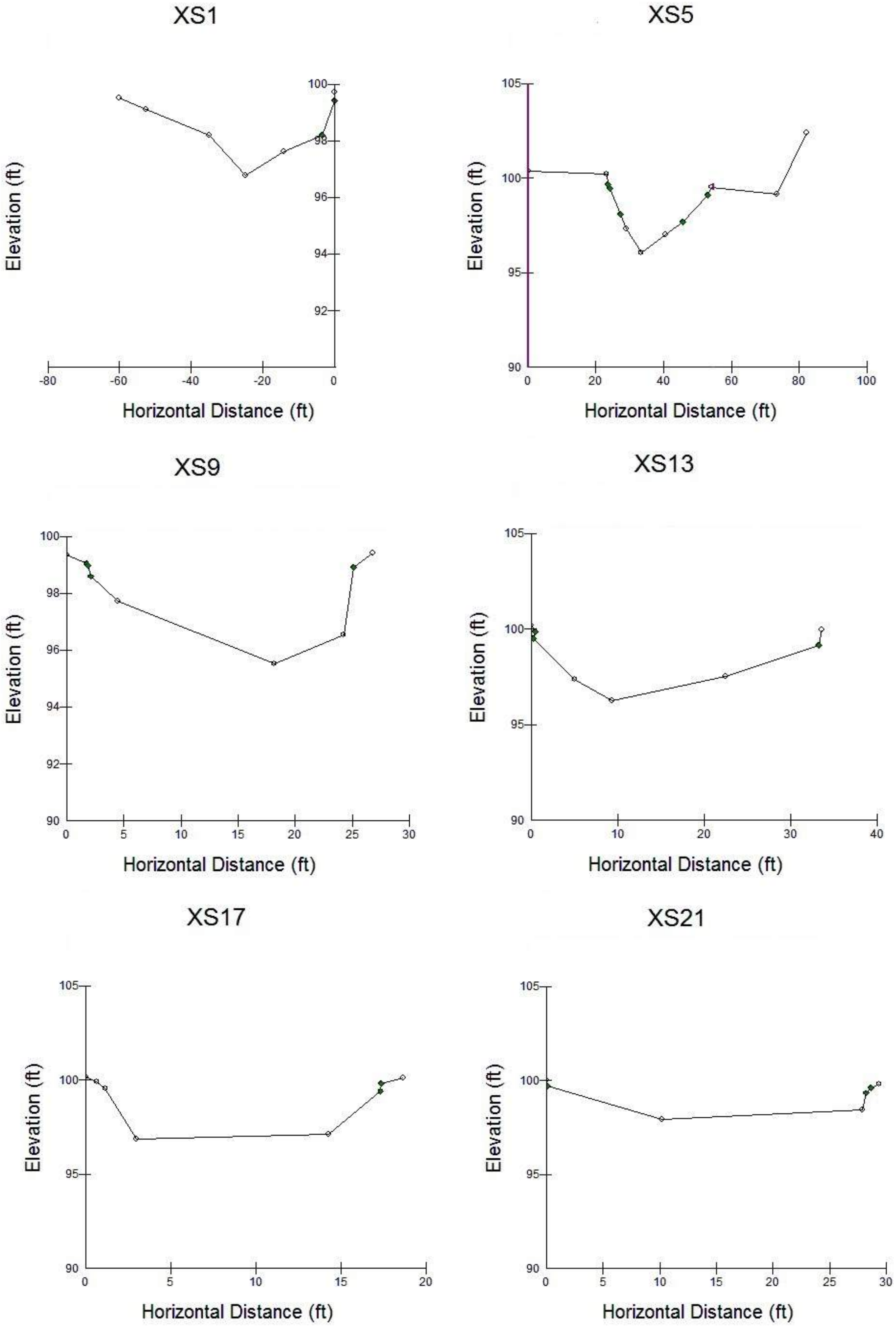


A



B

Figure F-28. Juniper Spring Run. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-28 (Cont.). Juniper Spring Run. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

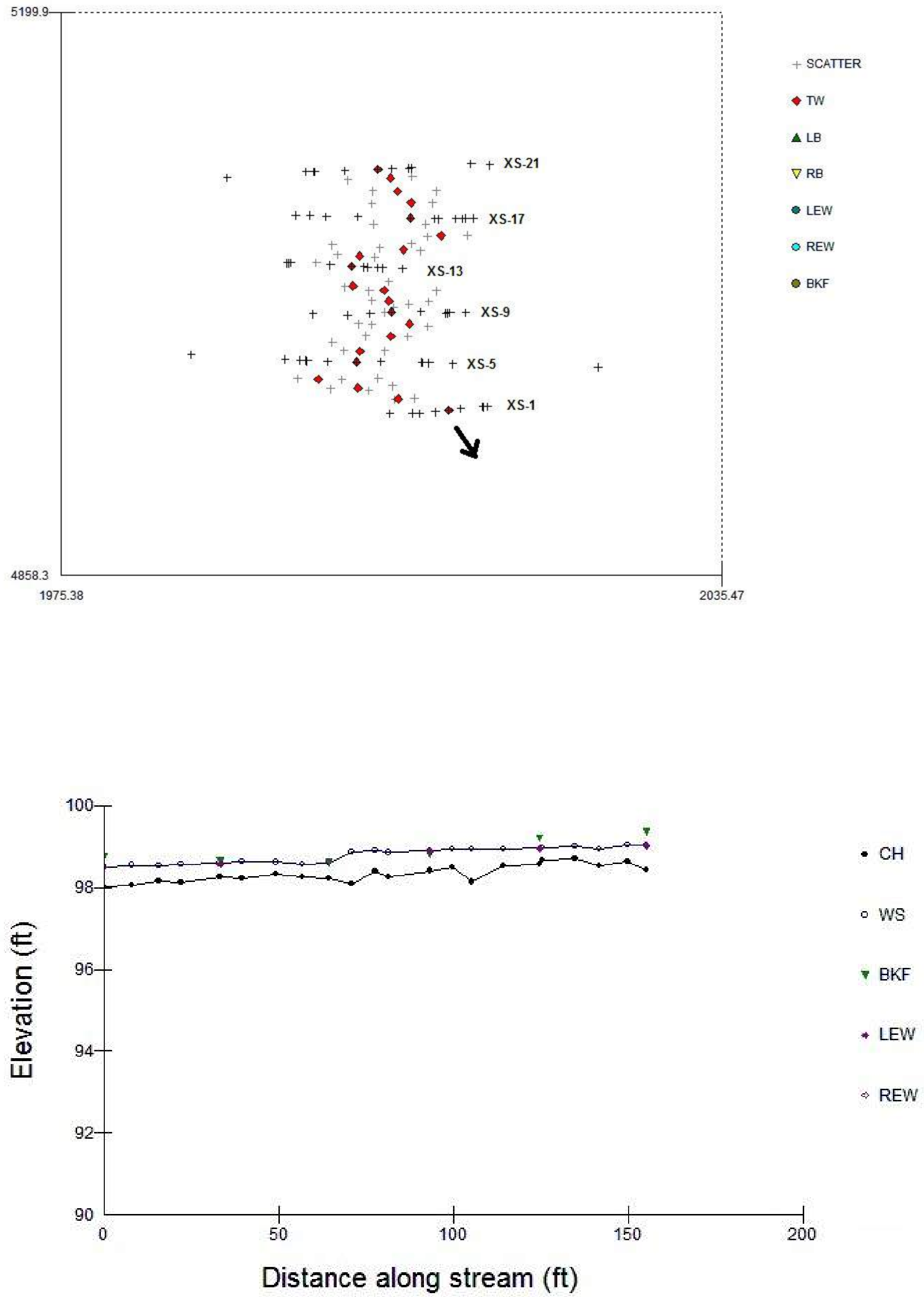


Figure F-29. Kittridge Spring Run. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

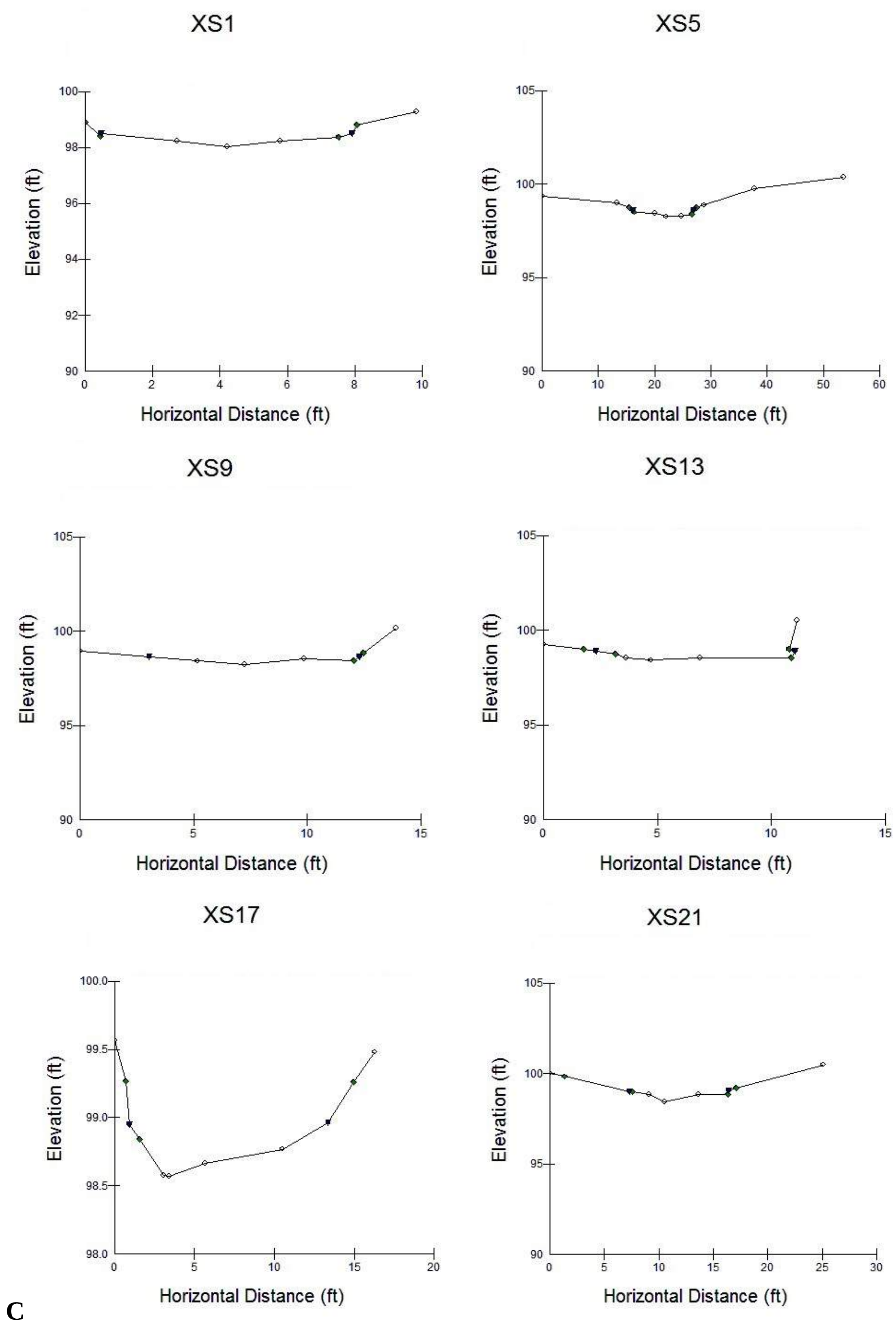


Figure F-29 (Cont.). Kittridge Spring Run. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

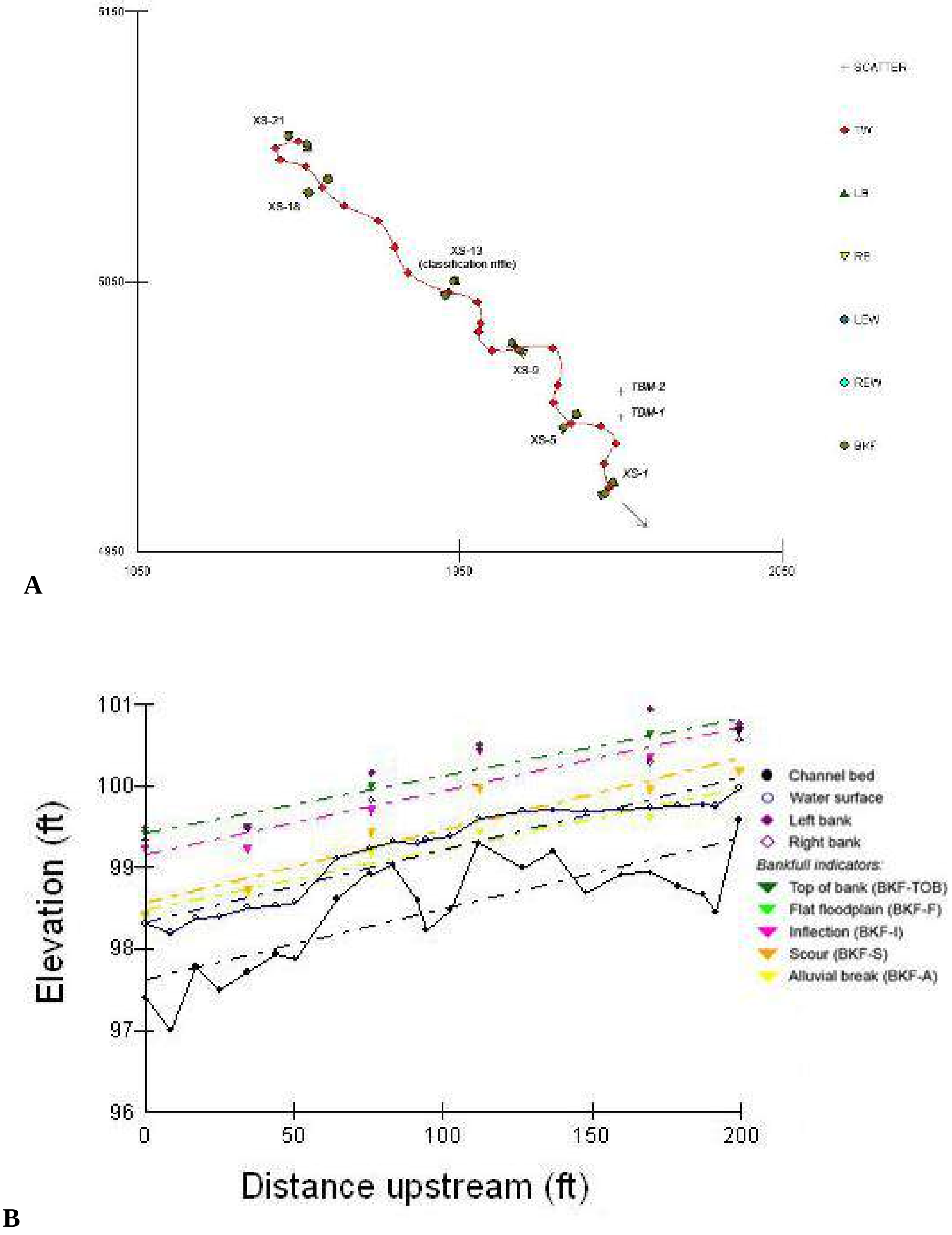
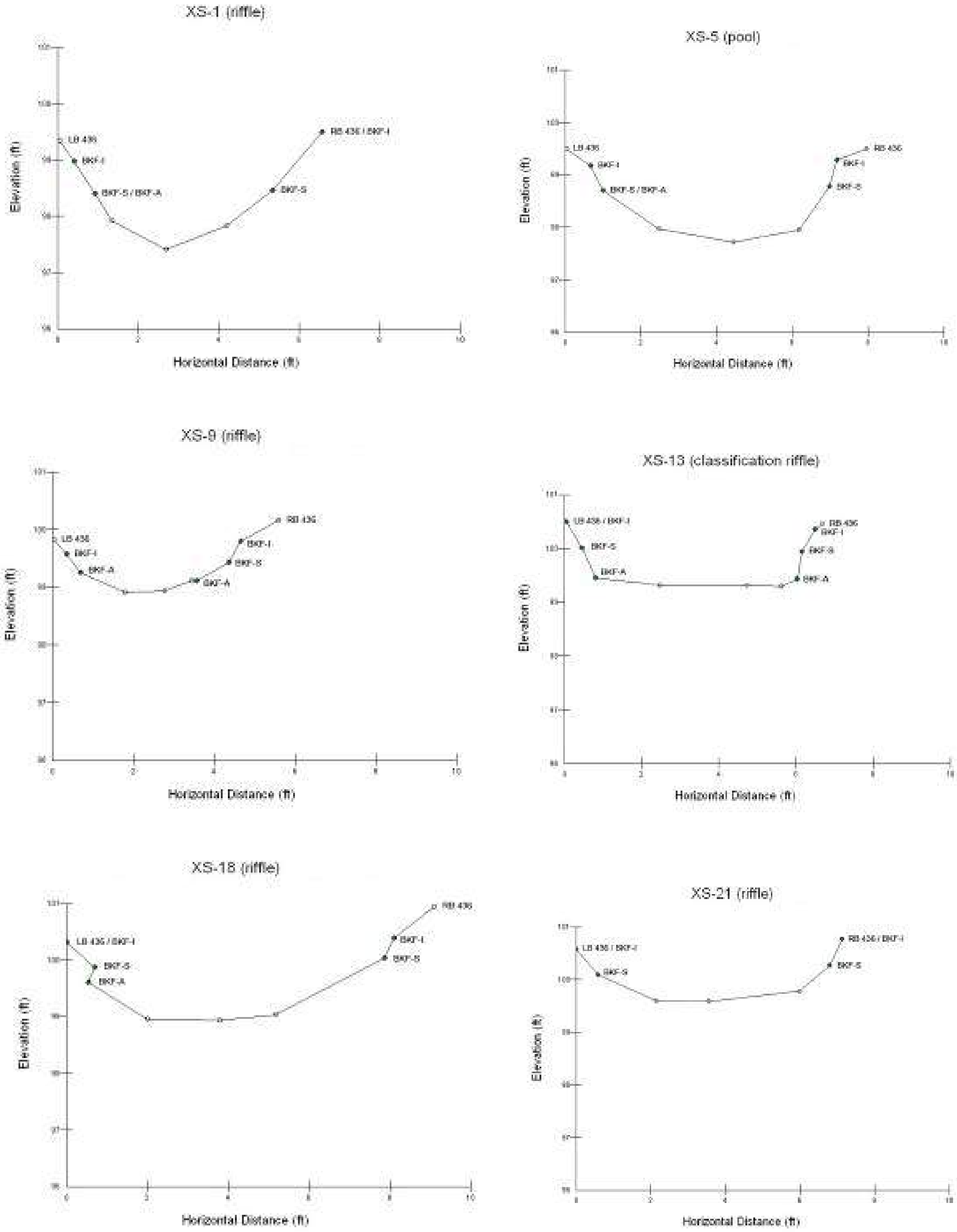


Figure F-30. Lake June-in-Winter UT. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-30 (Cont.). Lake June-in-Winter UT. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

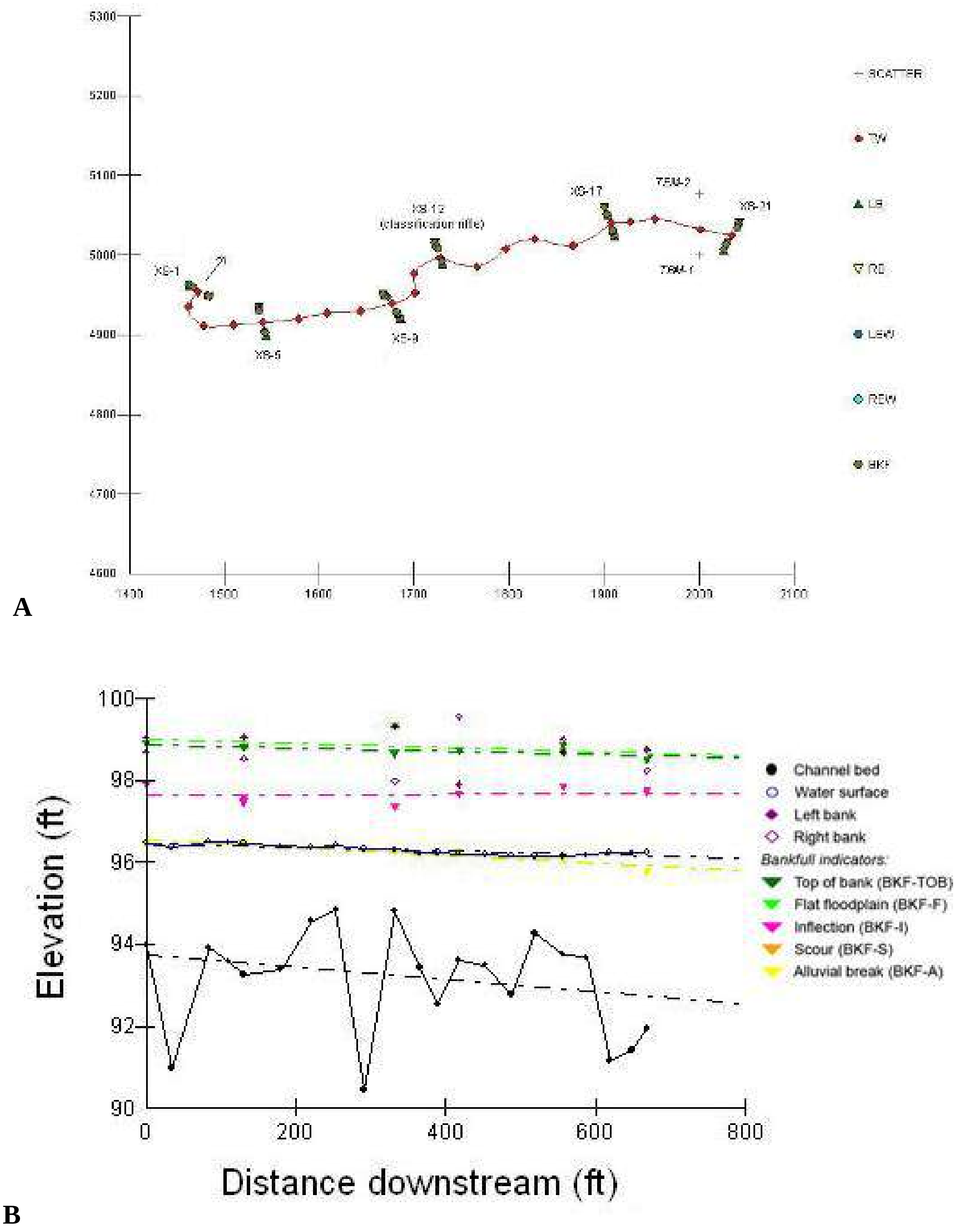
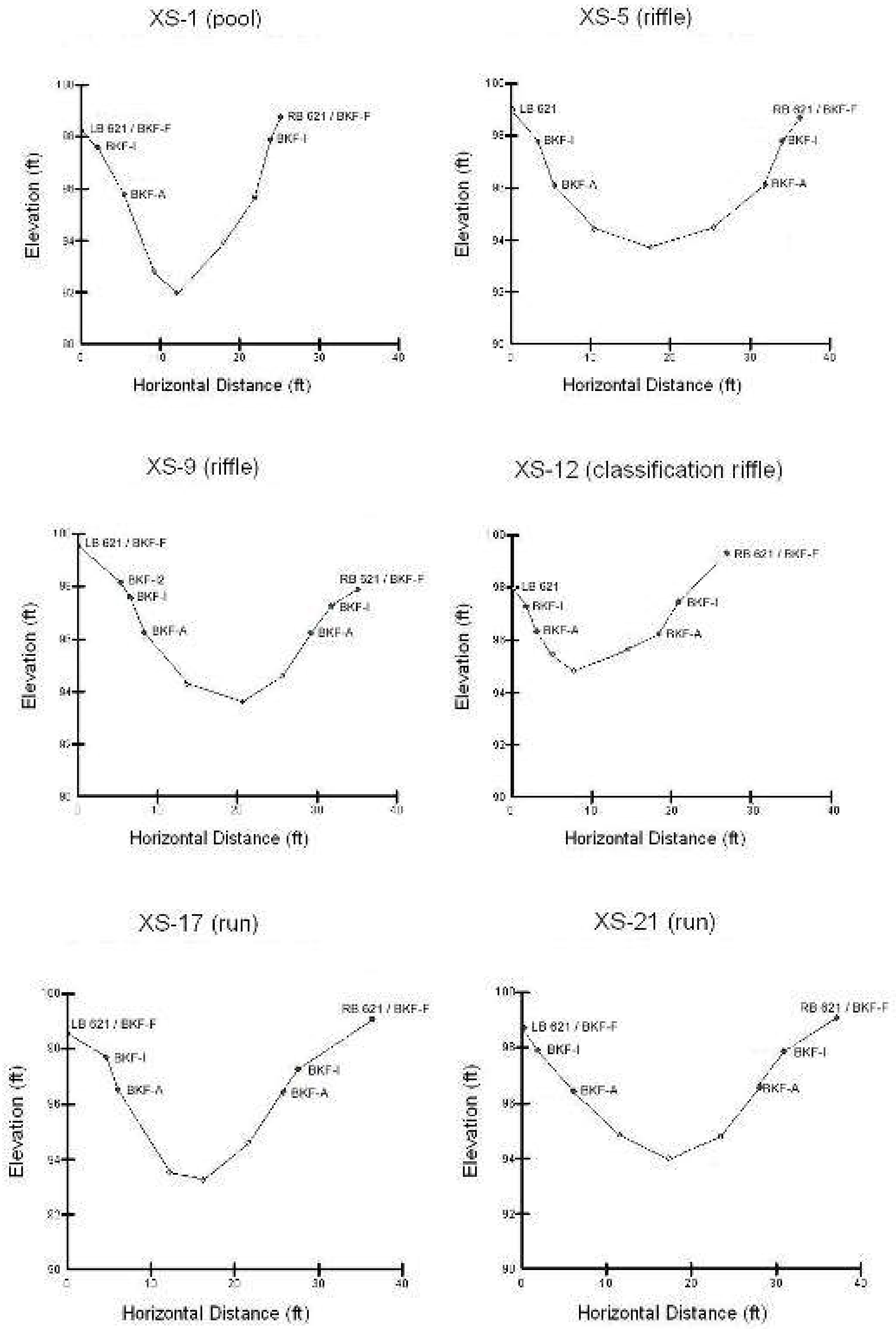


Figure F-31. Little Haw Creek near Seville. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-31 (Cont.). Little Haw Creek near Seville. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

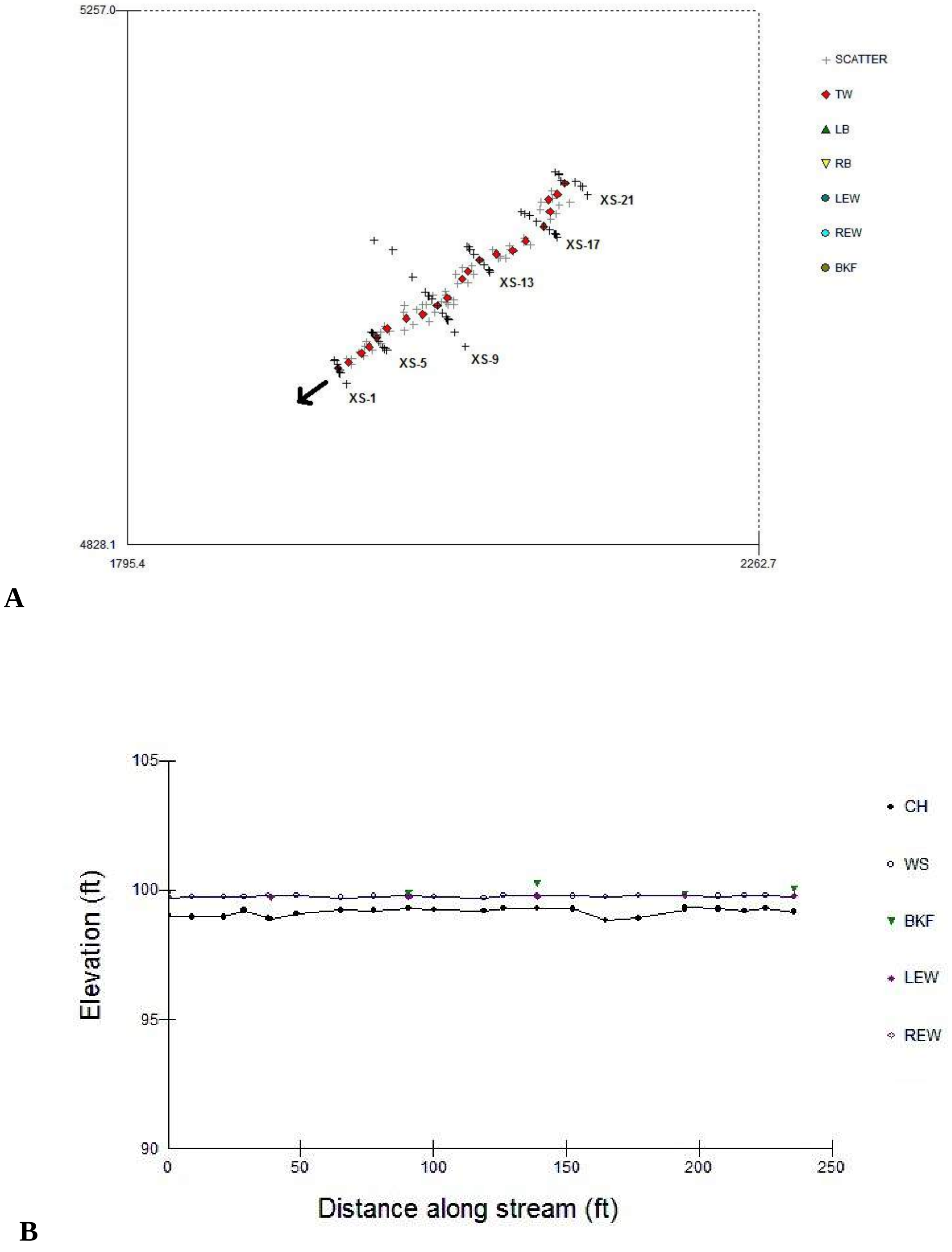
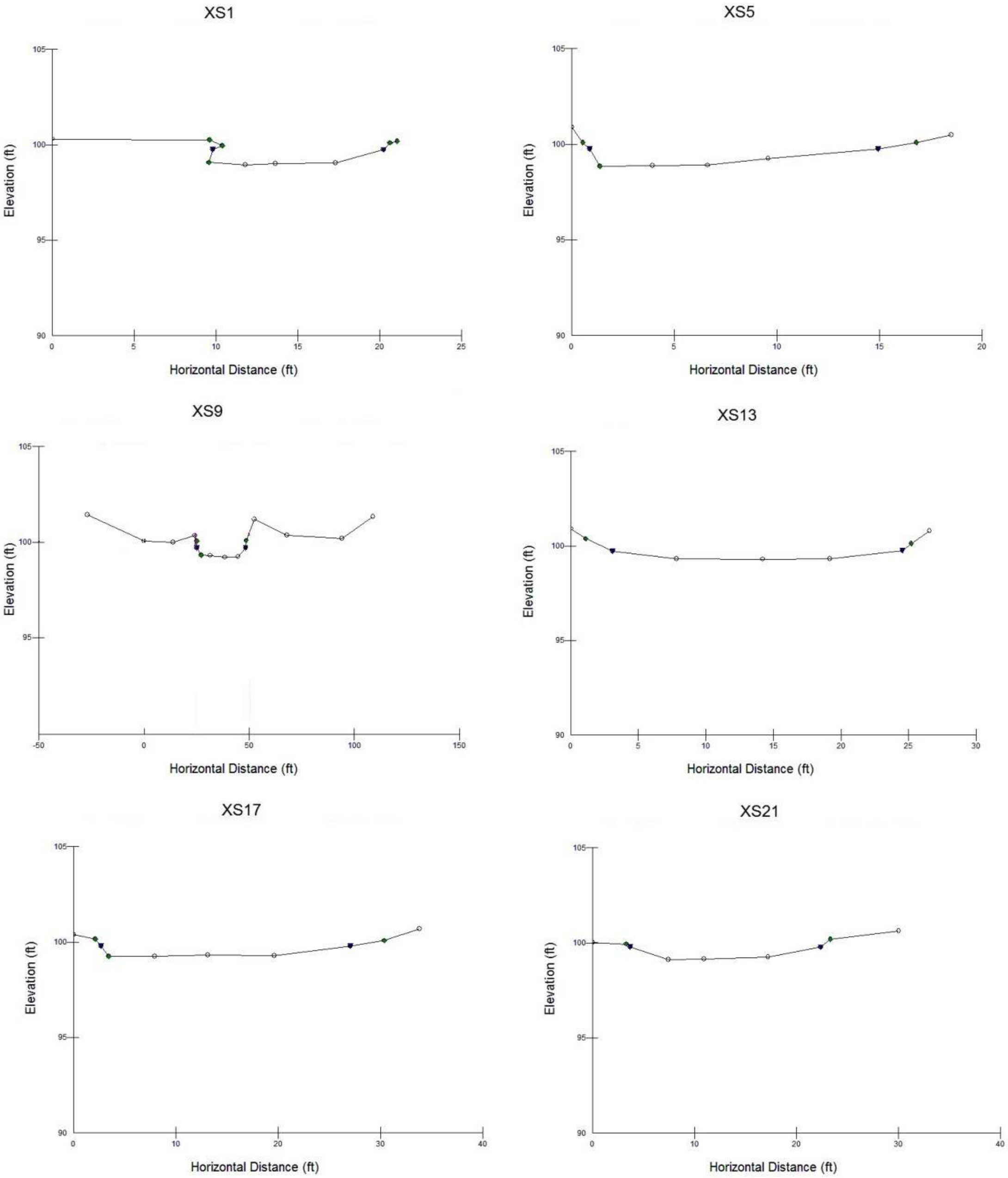


Figure F-32. Little Levy Blue Spring Run. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-32 (Cont.). Little Levy Blue Spring Run. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

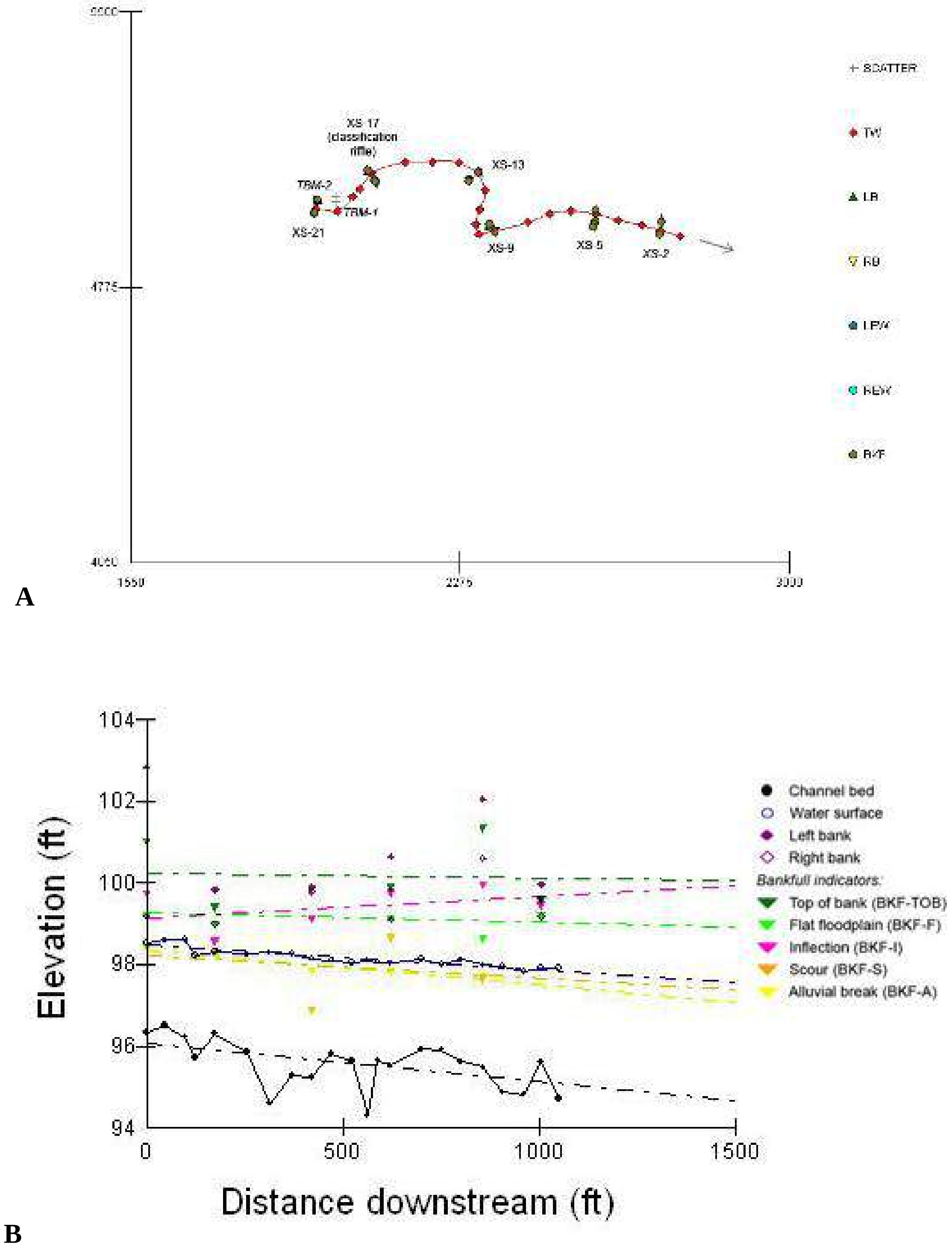
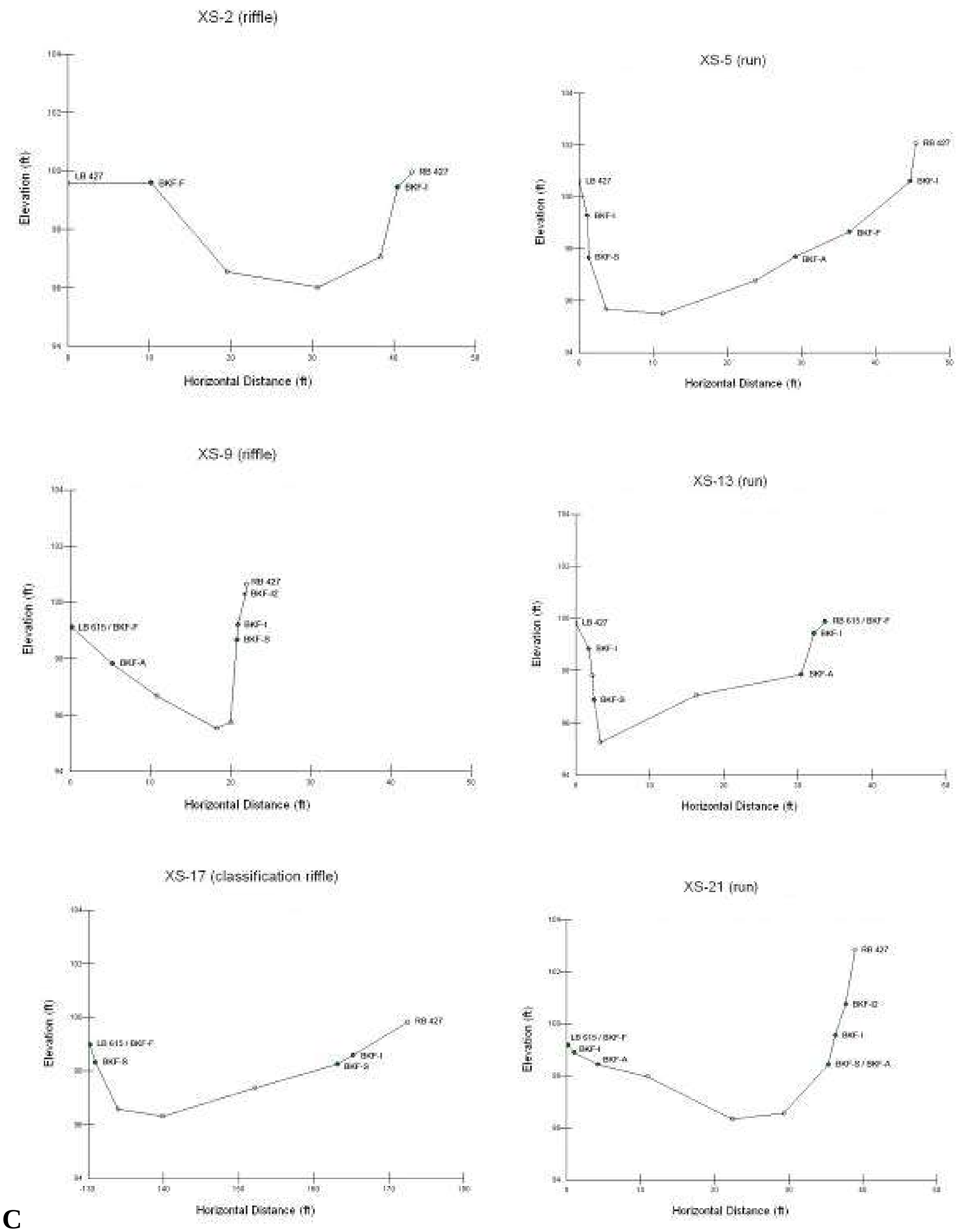


Figure F-33. Livingston Creek near Frostproof. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-33 (Cont.). Livingston Creek near Frostproof. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

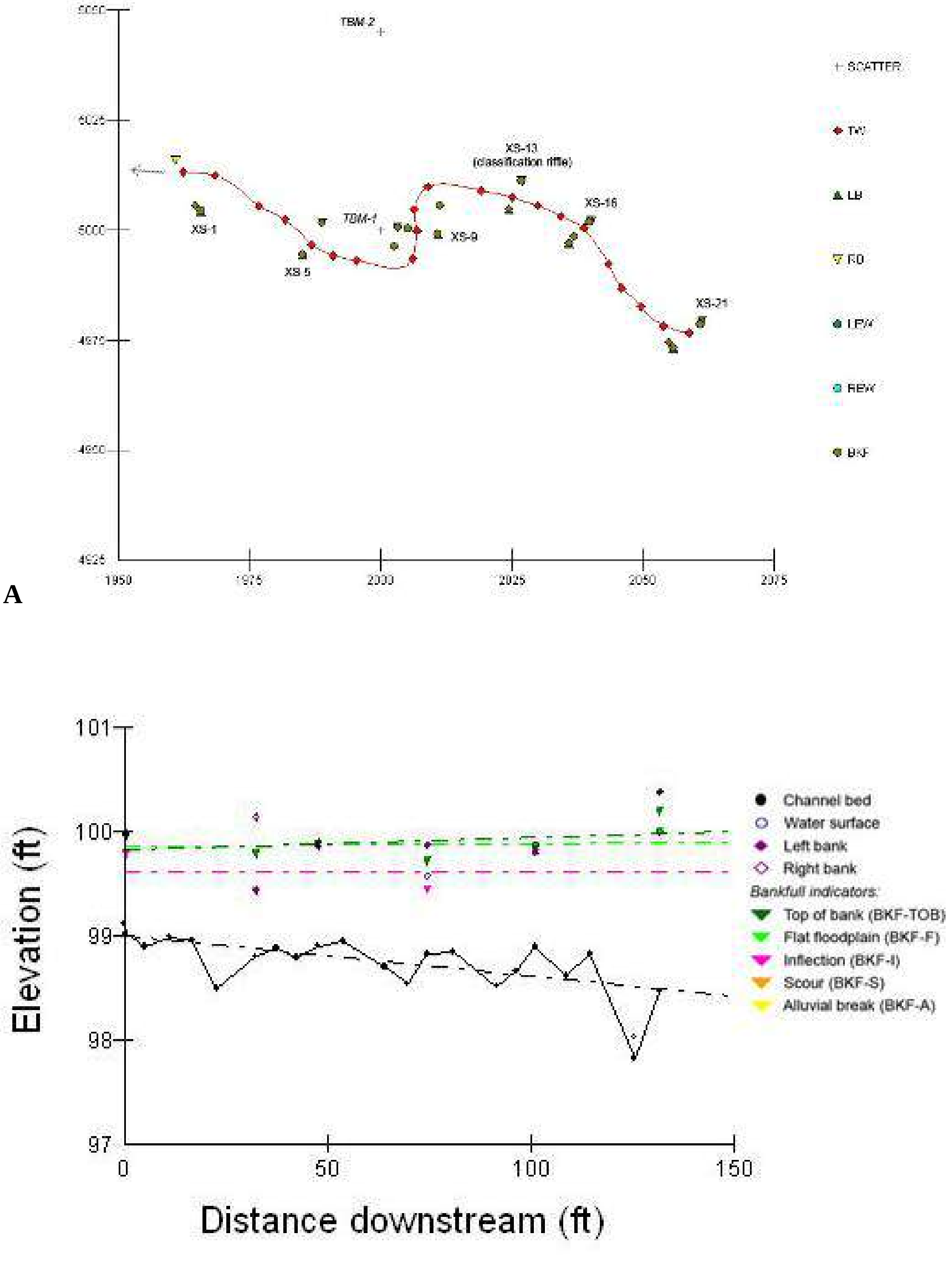
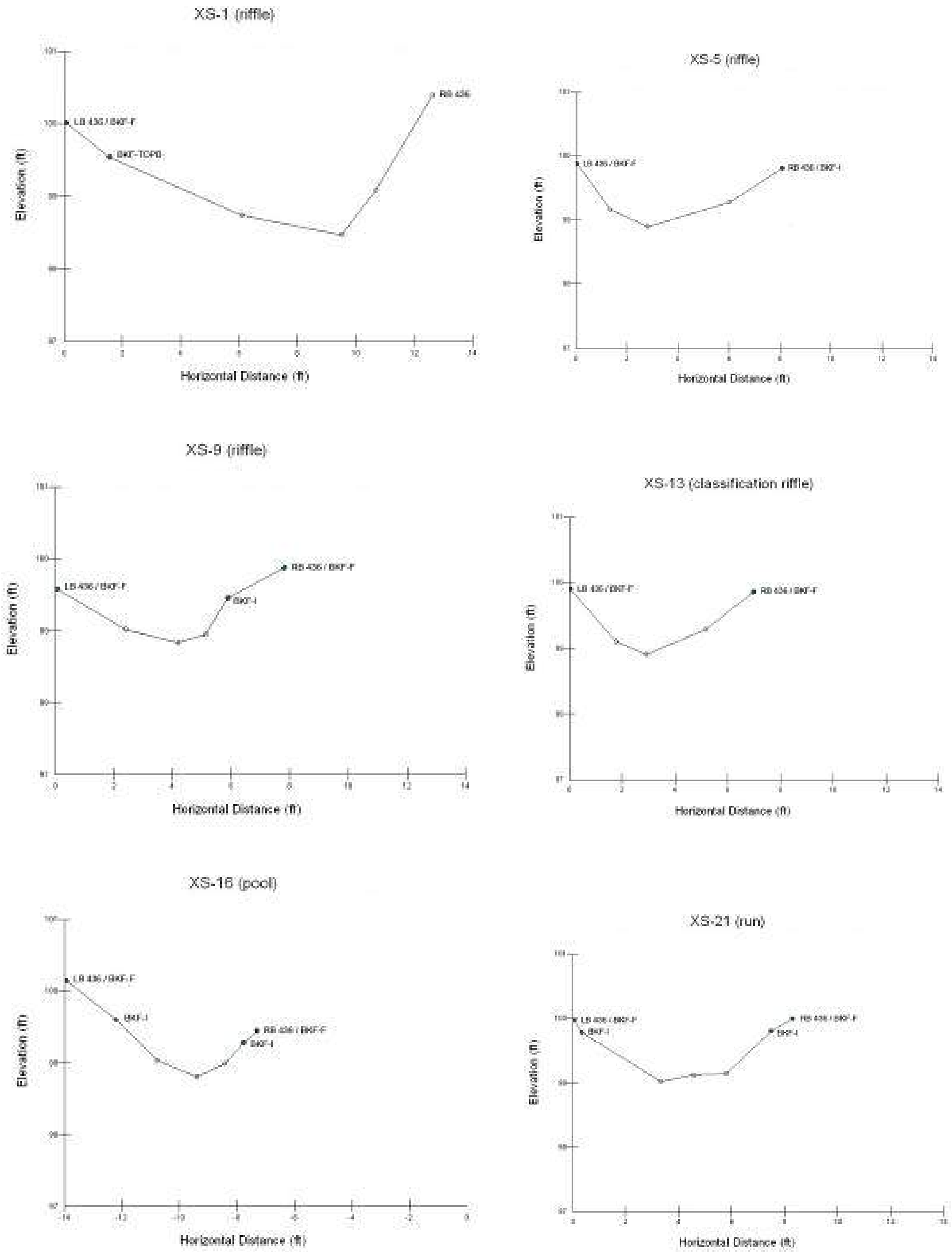


Figure F-34. Lower Myakka River UT 2. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-34 (Cont.). Lower Myakka River UT 2. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

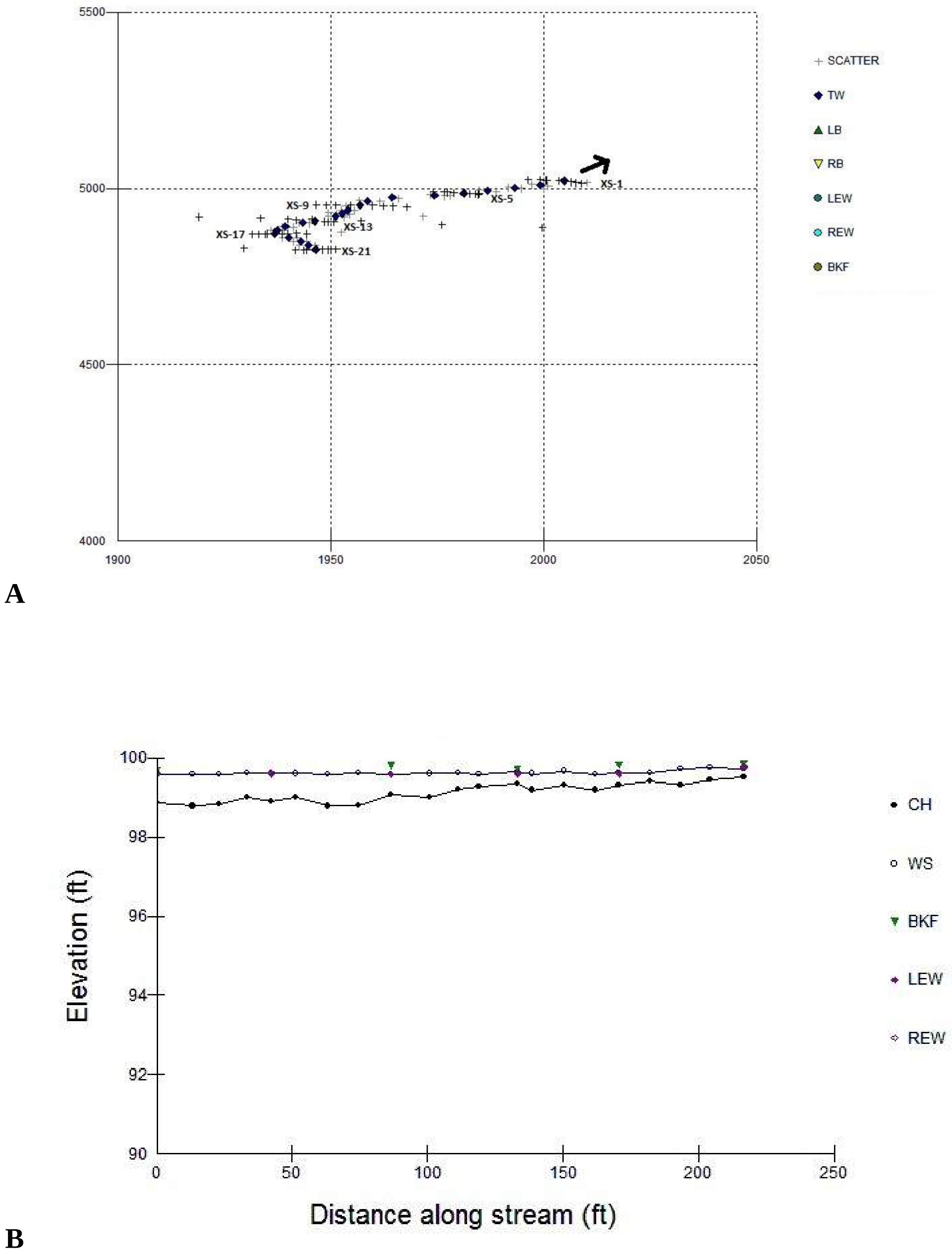
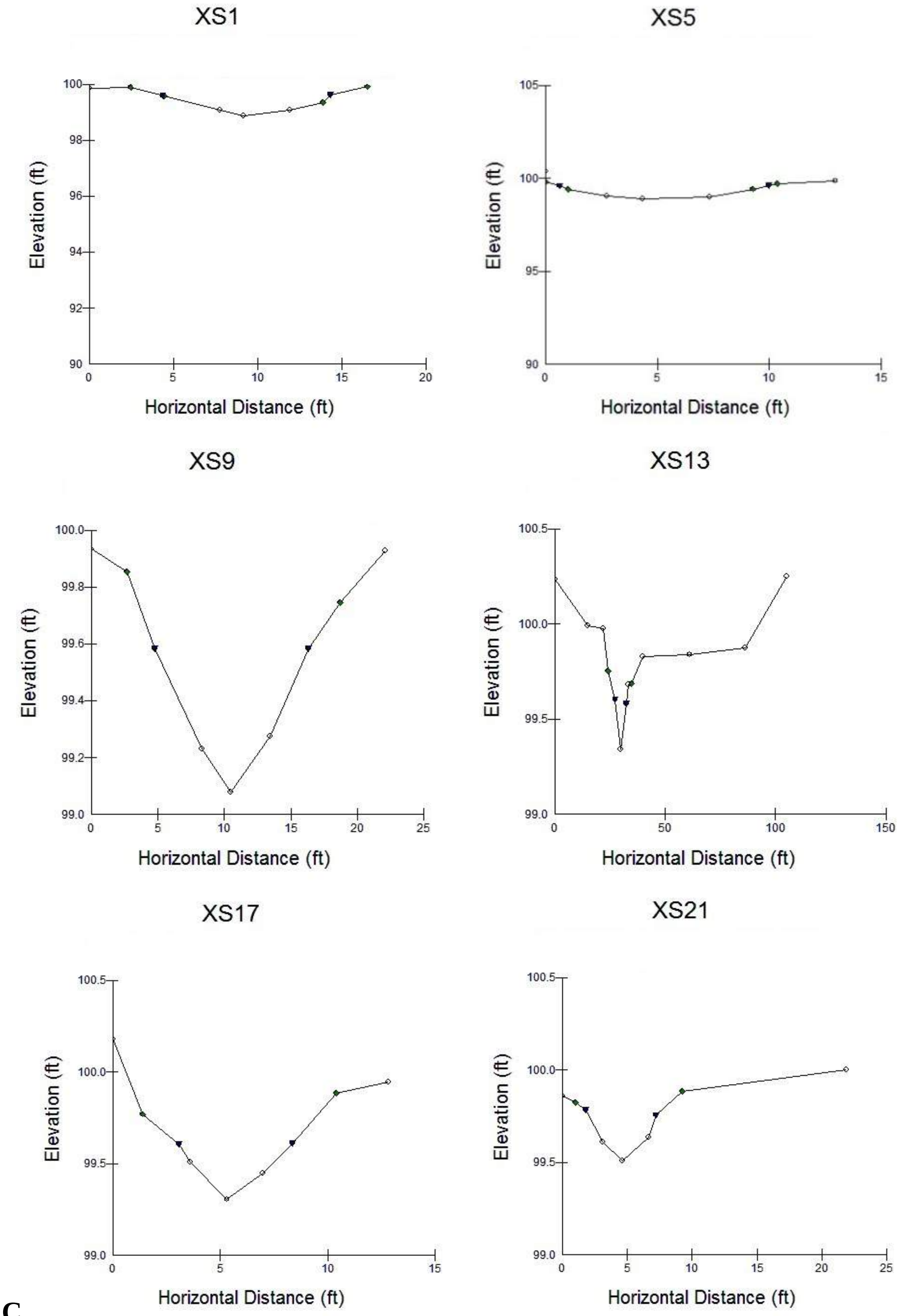


Figure F-35. Lower Myakka River UT3. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-35 (Cont.). Lower Myakka River UT3. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

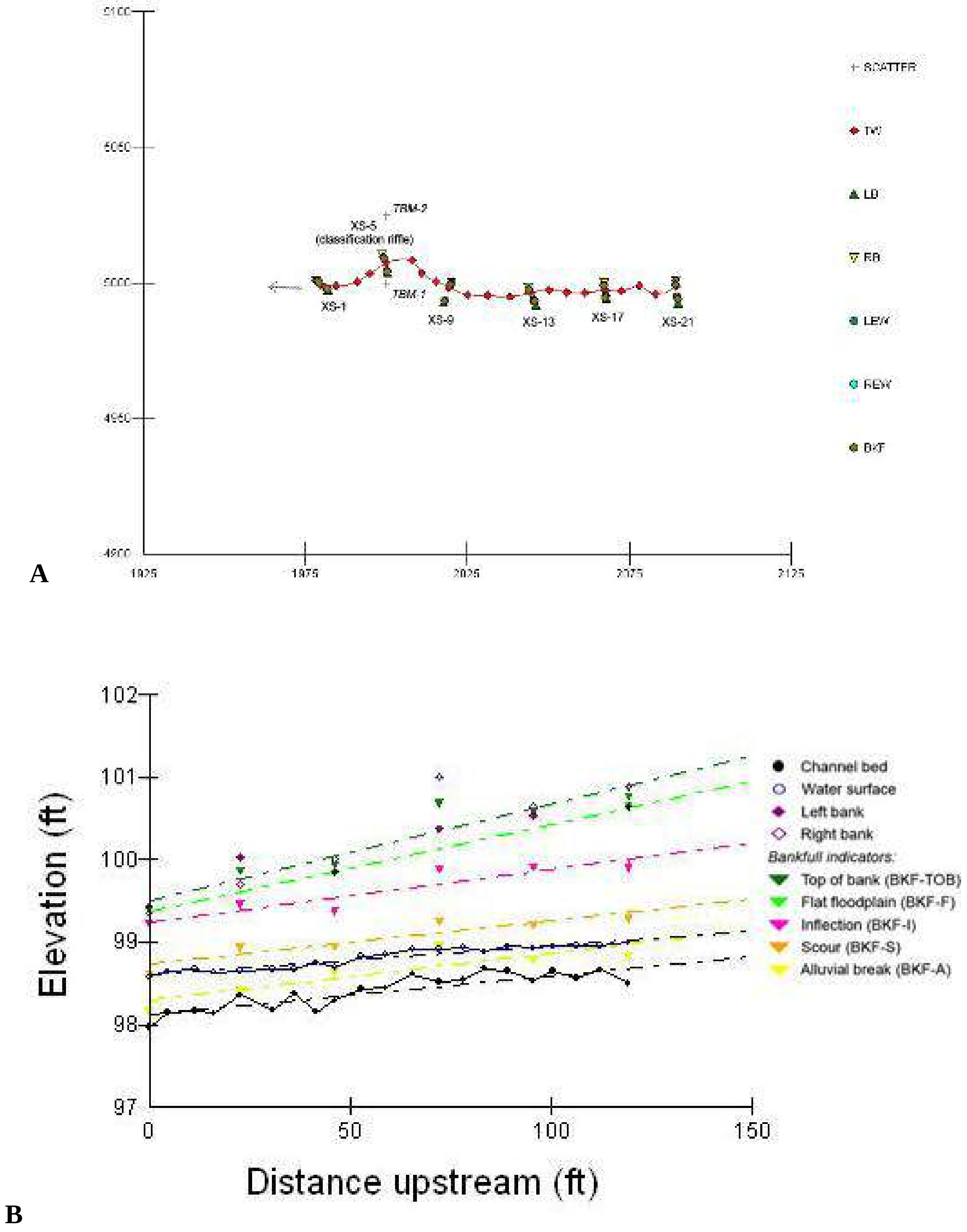
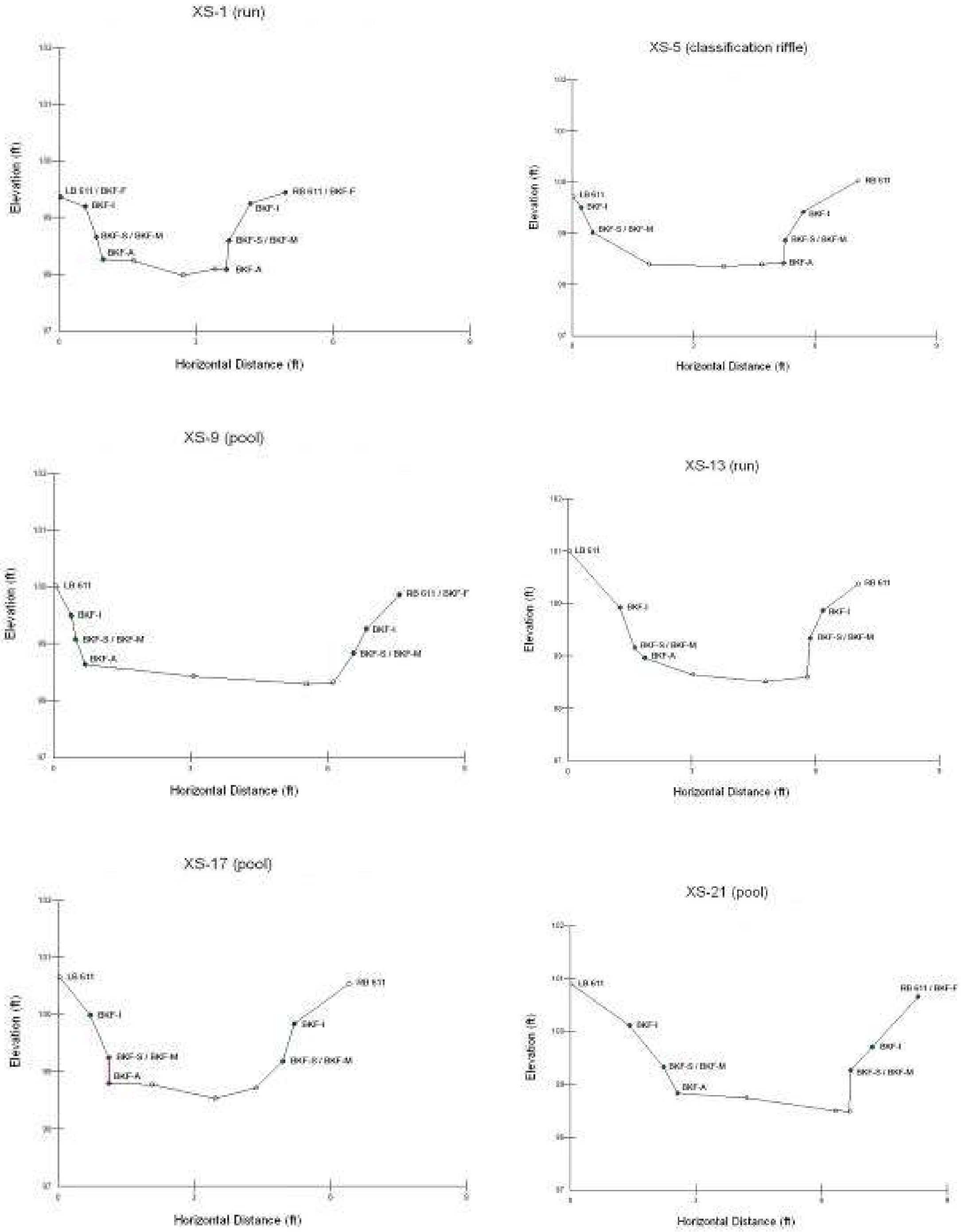


Figure F-36. Lowry Lake UT. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-36 (Cont.). Lowry Lake UT. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

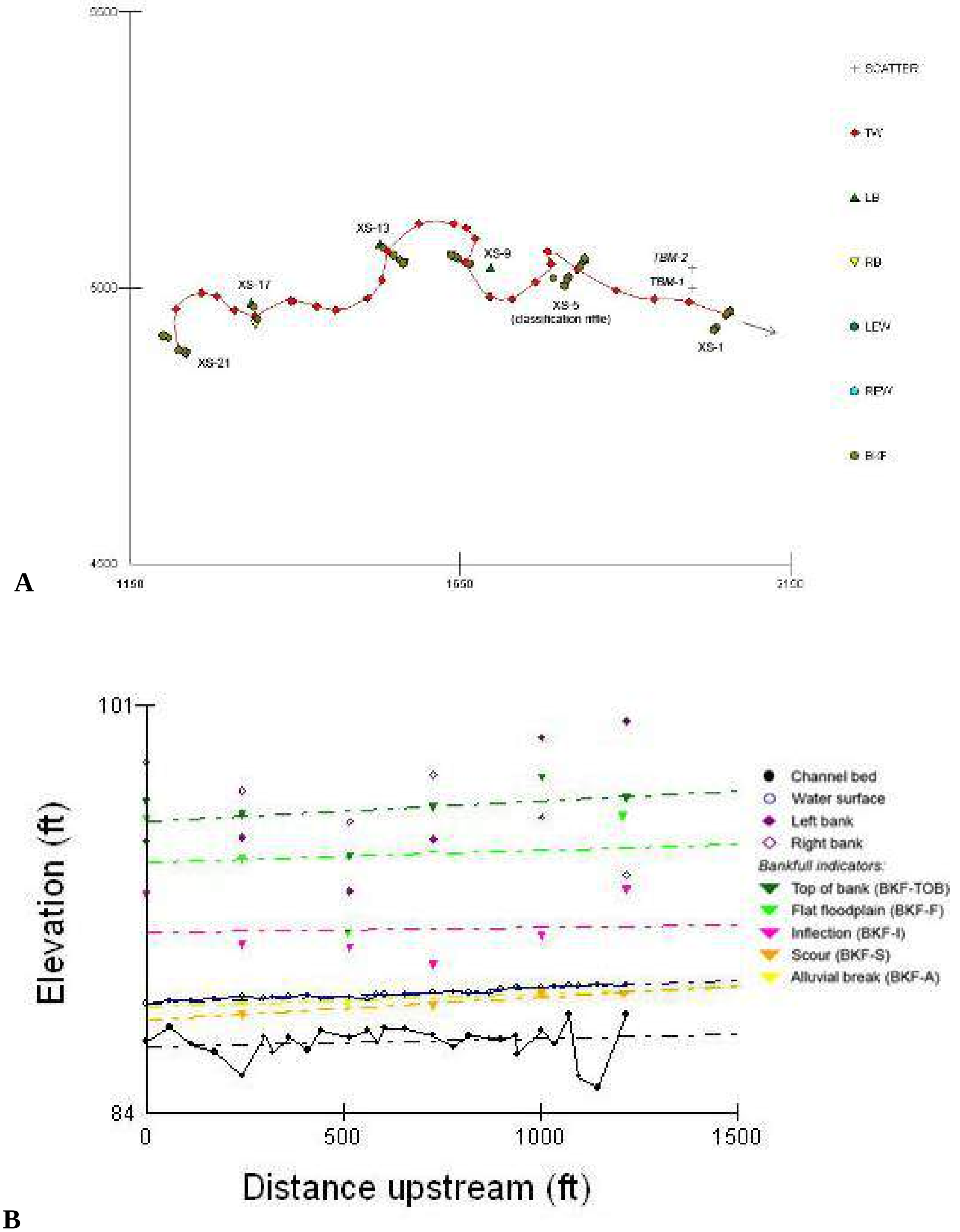
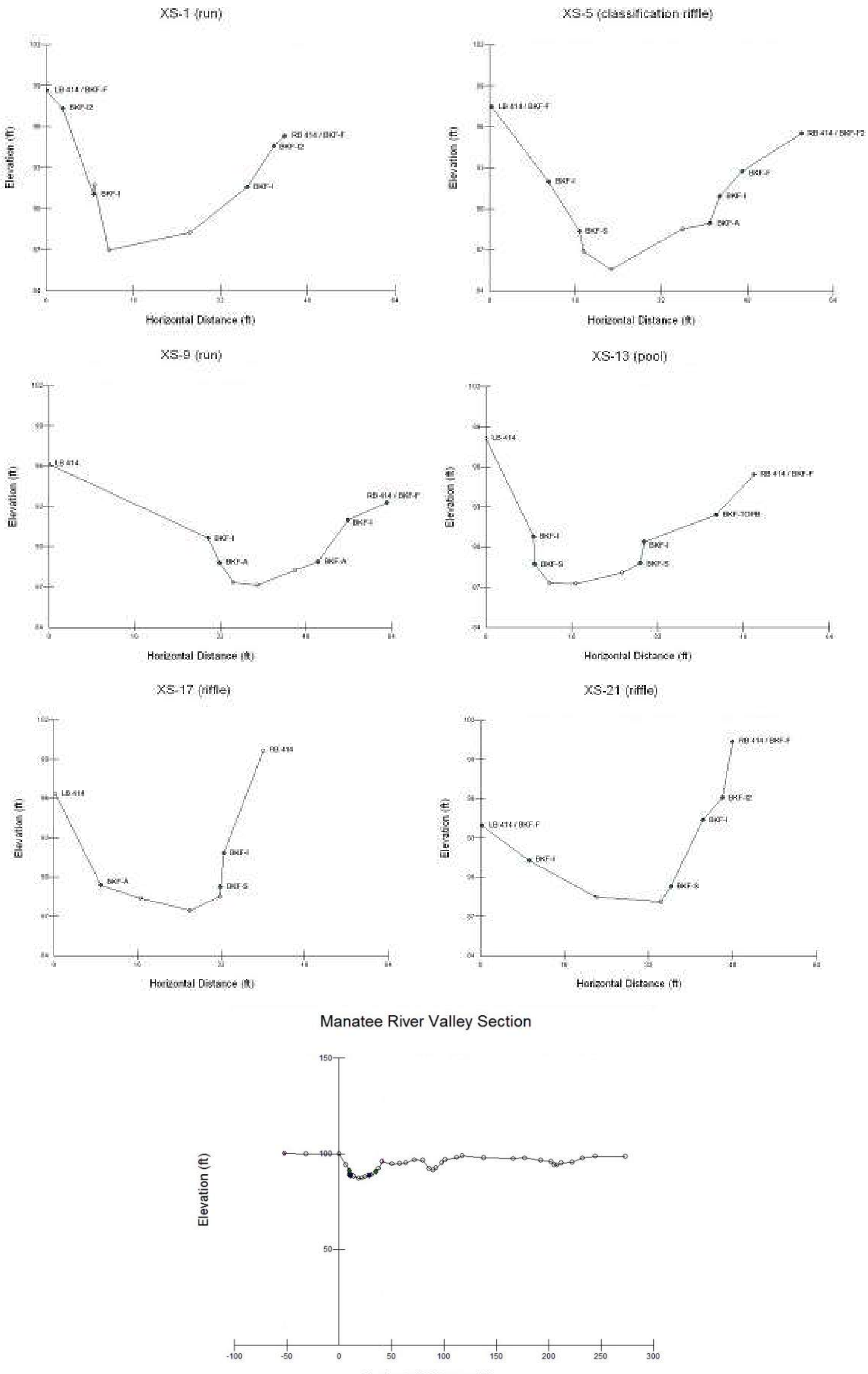


Figure F-37. Manatee River near Myakka Head. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-37 (Cont.). Manatee River near Myakka Head. A) Plan Form.
B) Longitudinal Profile. C) Cross-Sections.

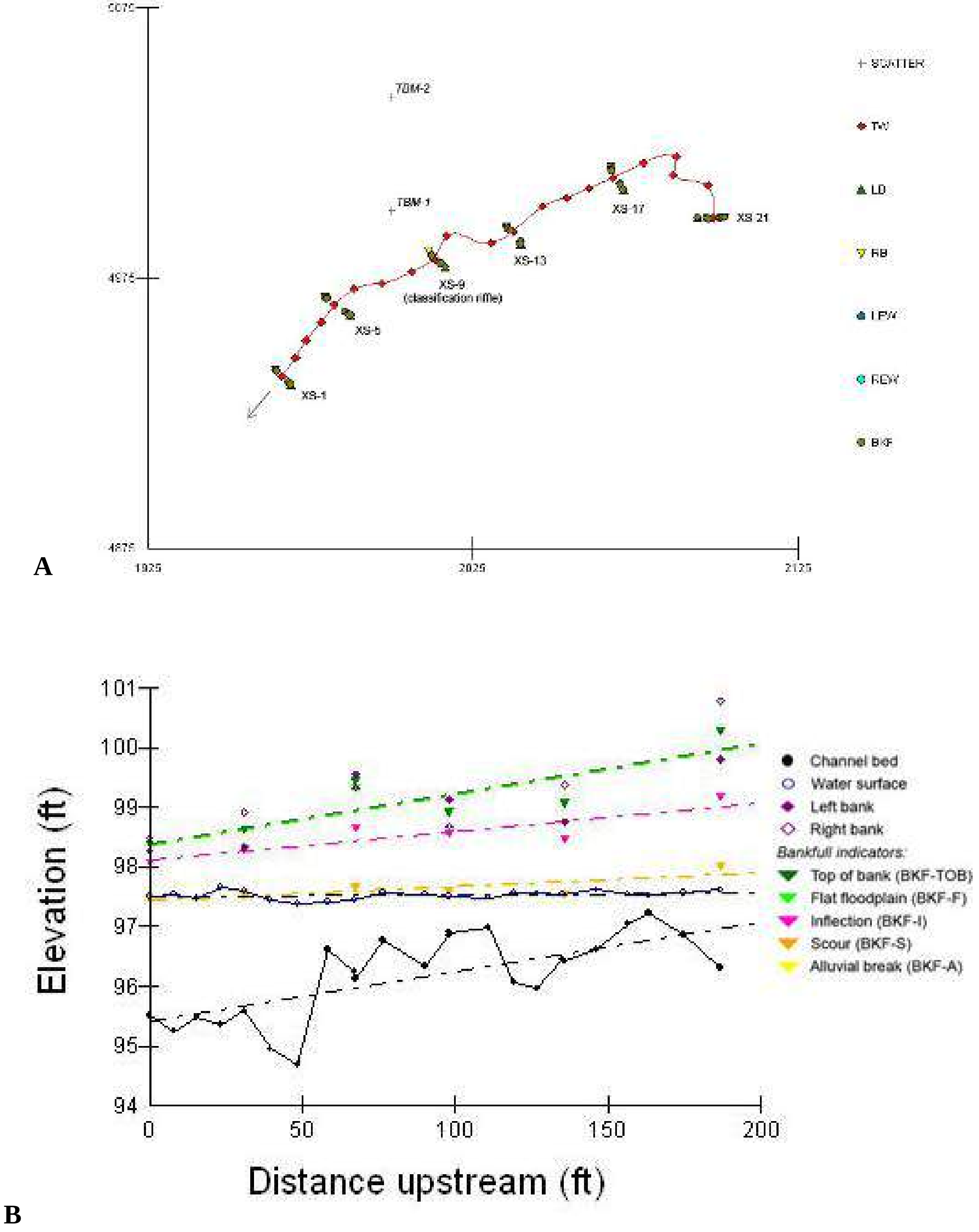
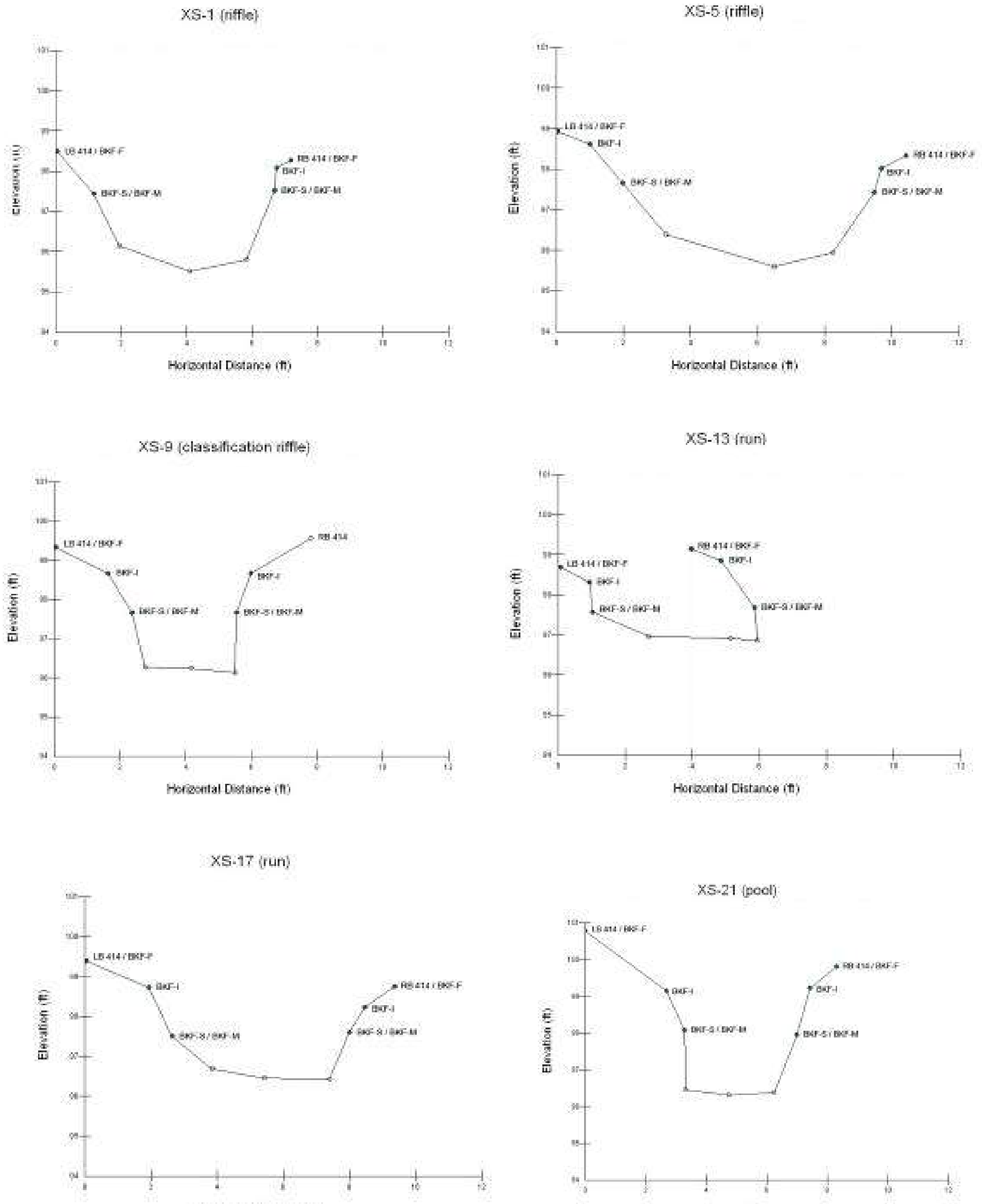


Figure F-38. Manatee River UT. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-38 (Cont.). Manatee River UT. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

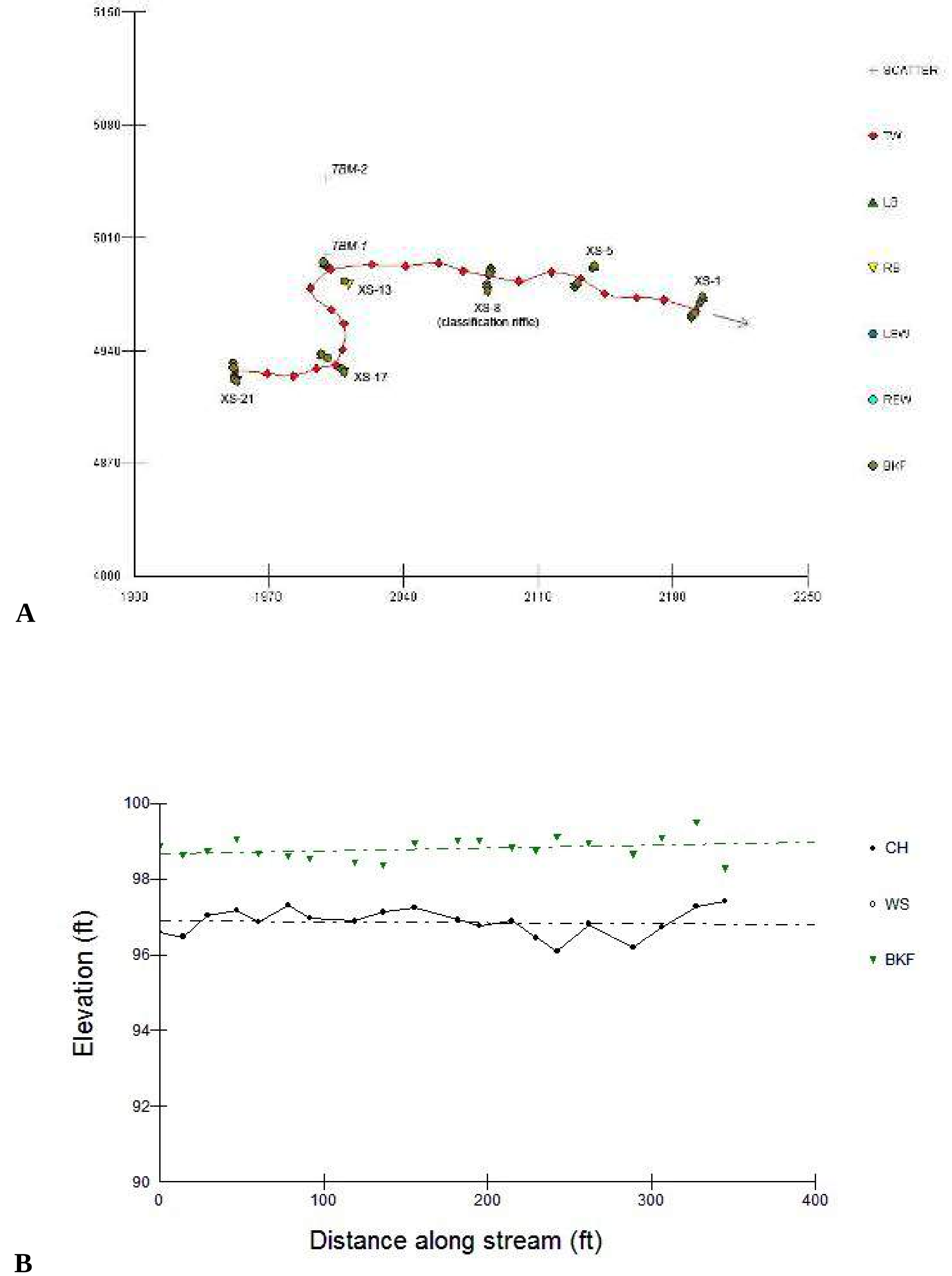


Figure F-39. Morgan Hole Creek. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

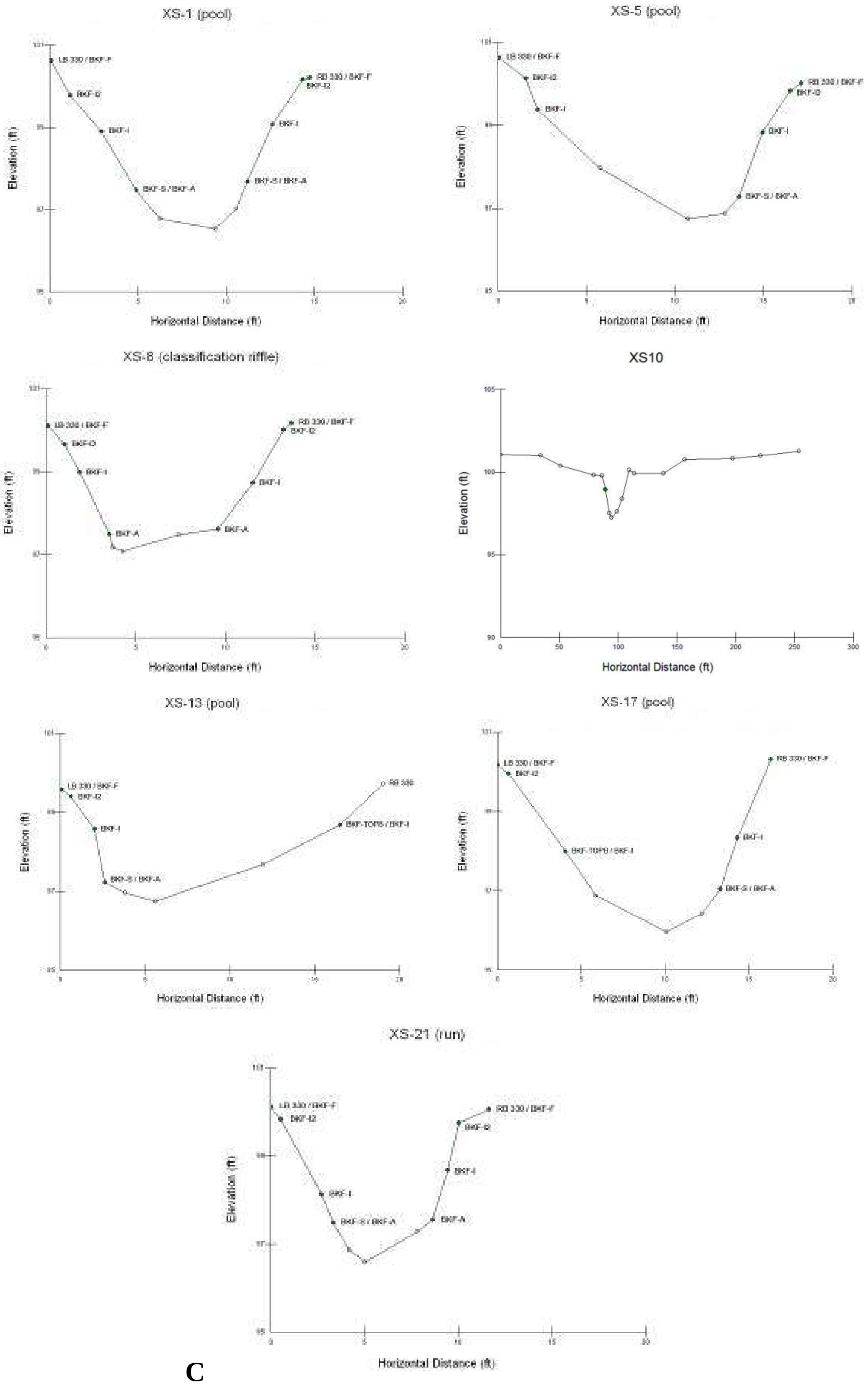
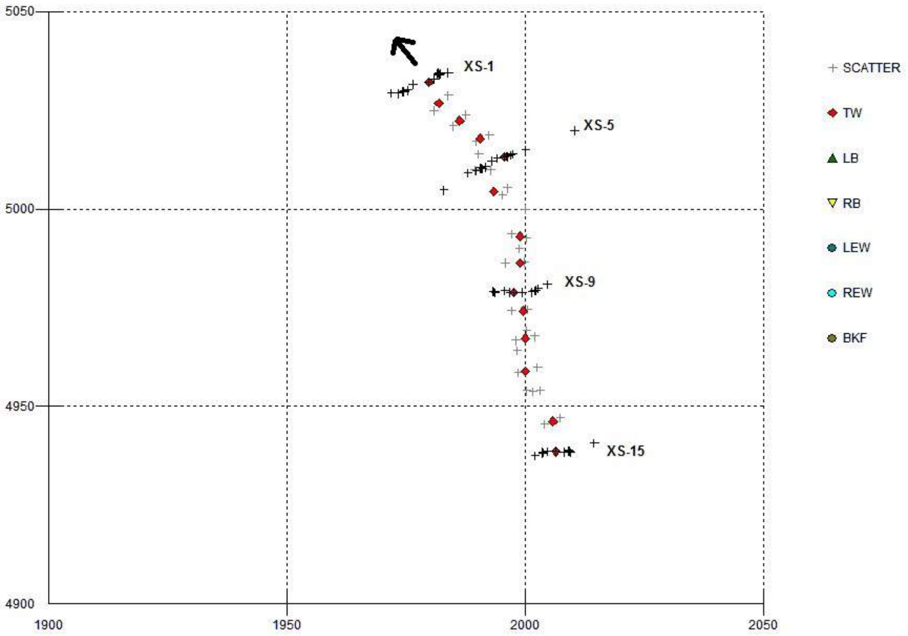
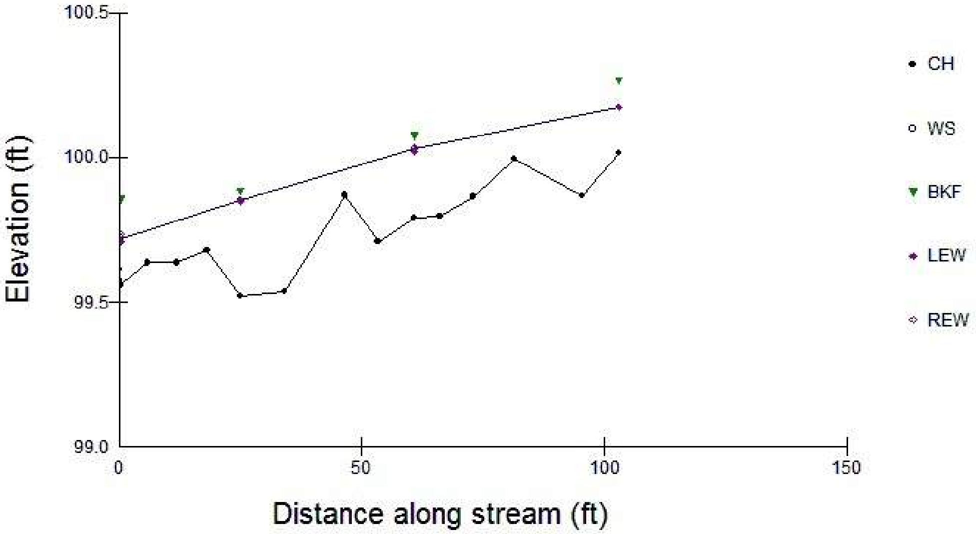


Figure F-39 (Cont.). Morgan Hole Creek. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

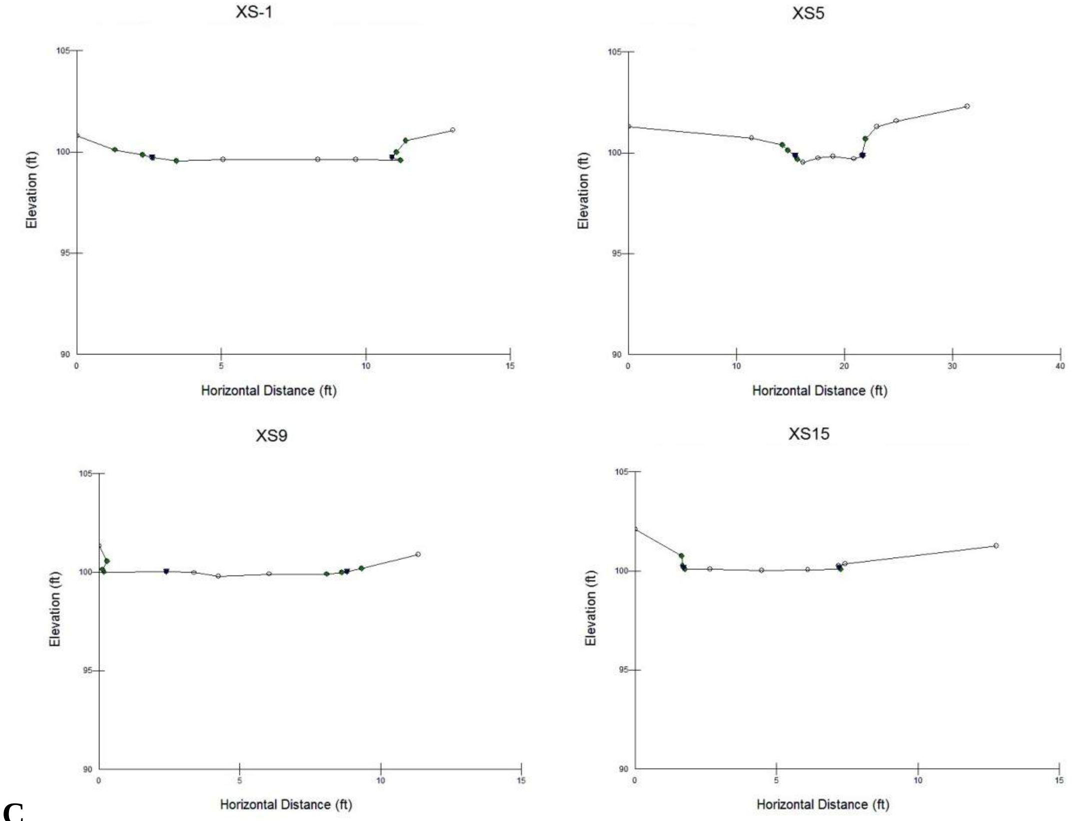


A



B

Figure F-40. Mormon Branch UT Spring Run. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-40 (Cont.). Mormon Branch UT Spring Run. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

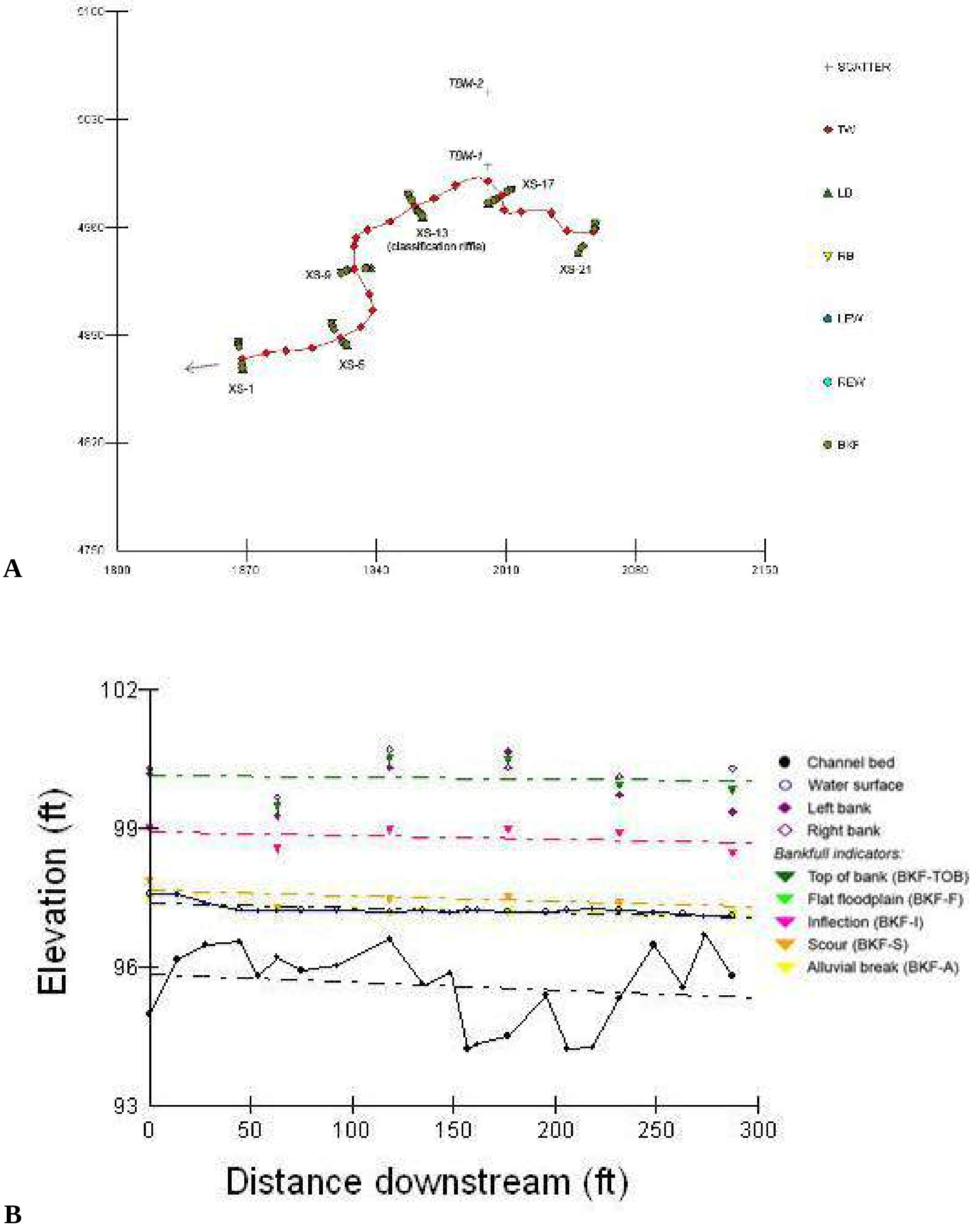
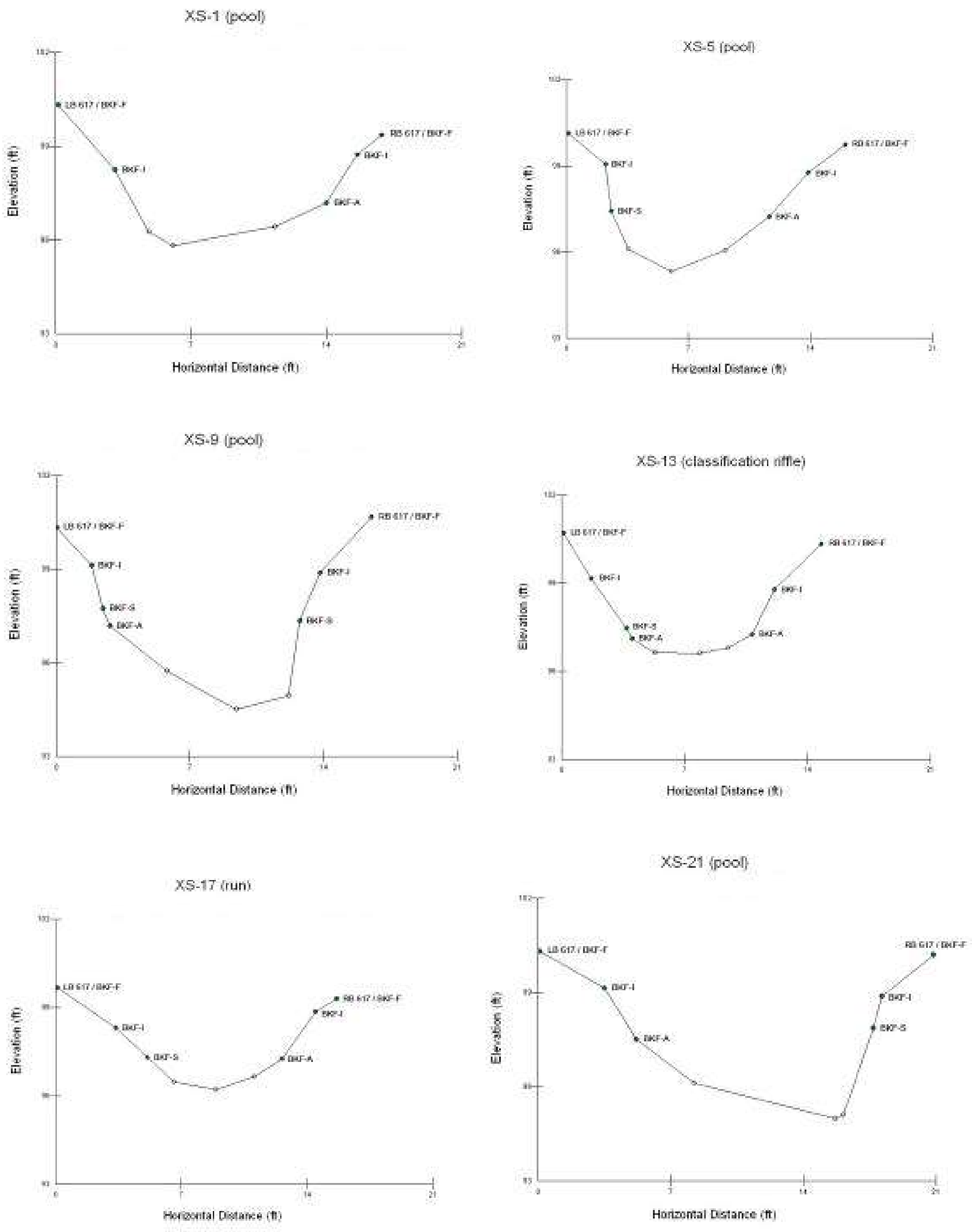


Figure F-41. Moses Creek near Moultrie. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



XS-1 (pool)

XS-5 (pool)

XS-9 (pool)

XS-13 (classification riffle)

XS-17 (run)

XS-21 (pool)

C

Figure F-41 (Cont.). Moses Creek near Moultrie. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

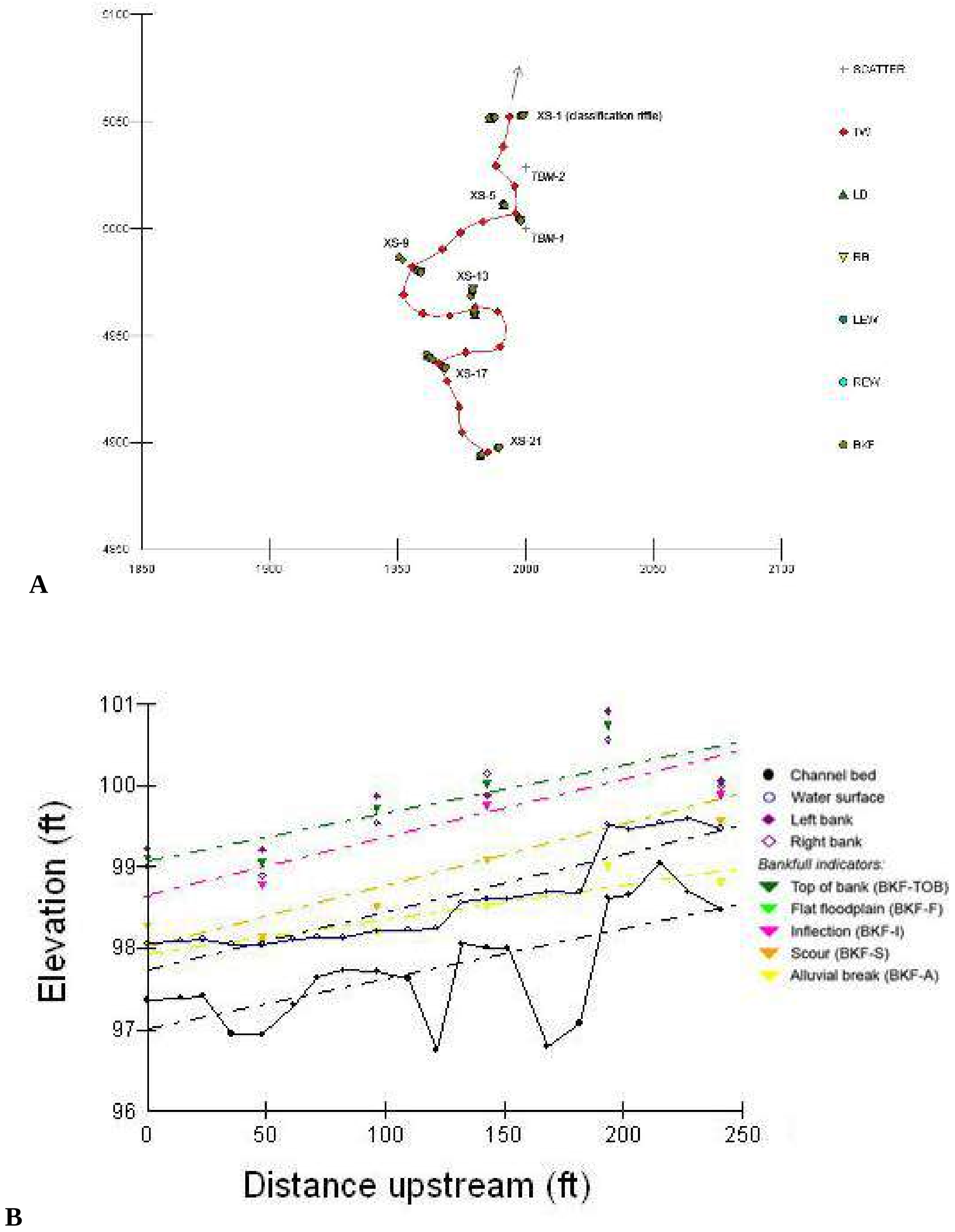
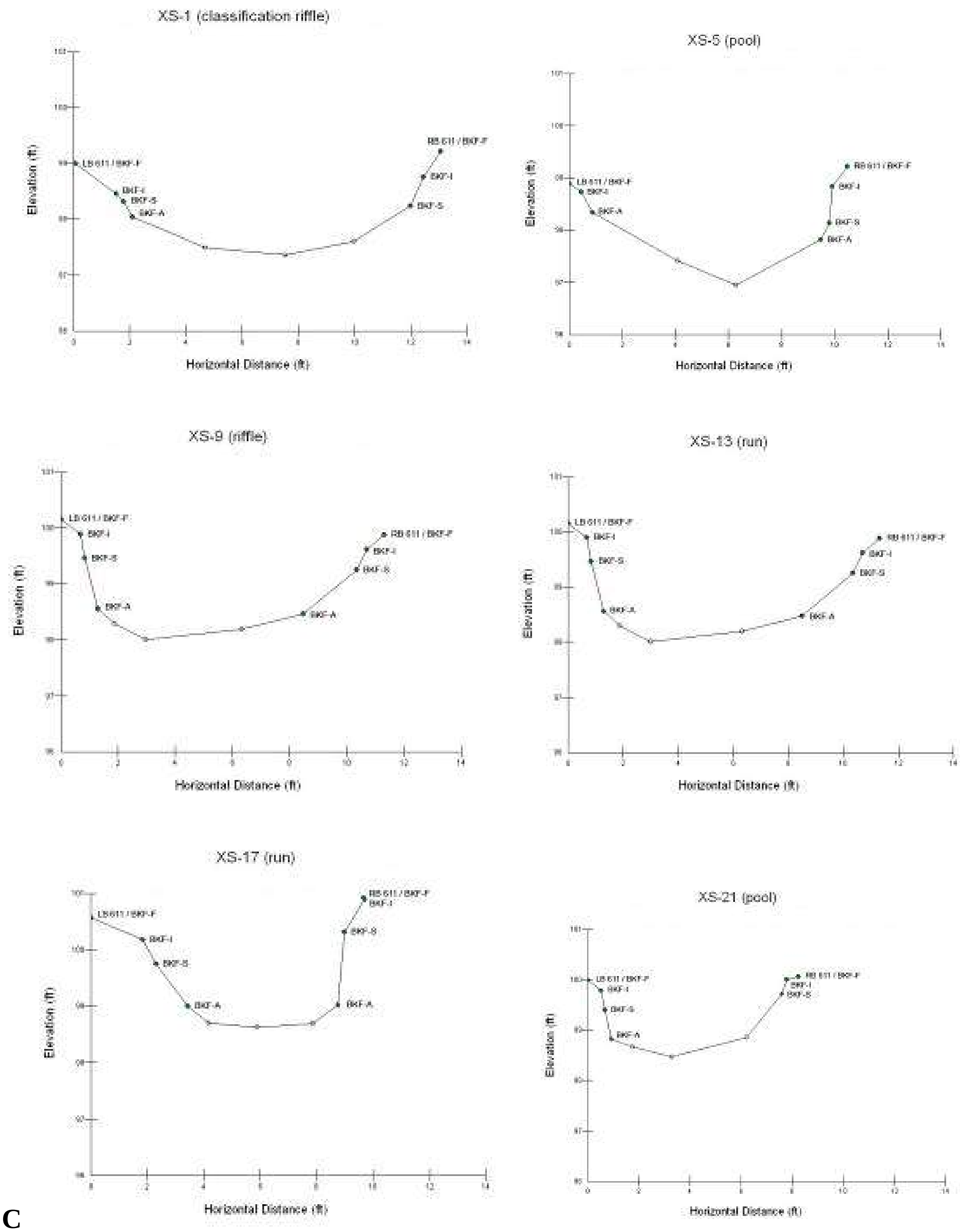


Figure F-42. Ninemile Creek. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-42 (Cont.). Ninemile Creek. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

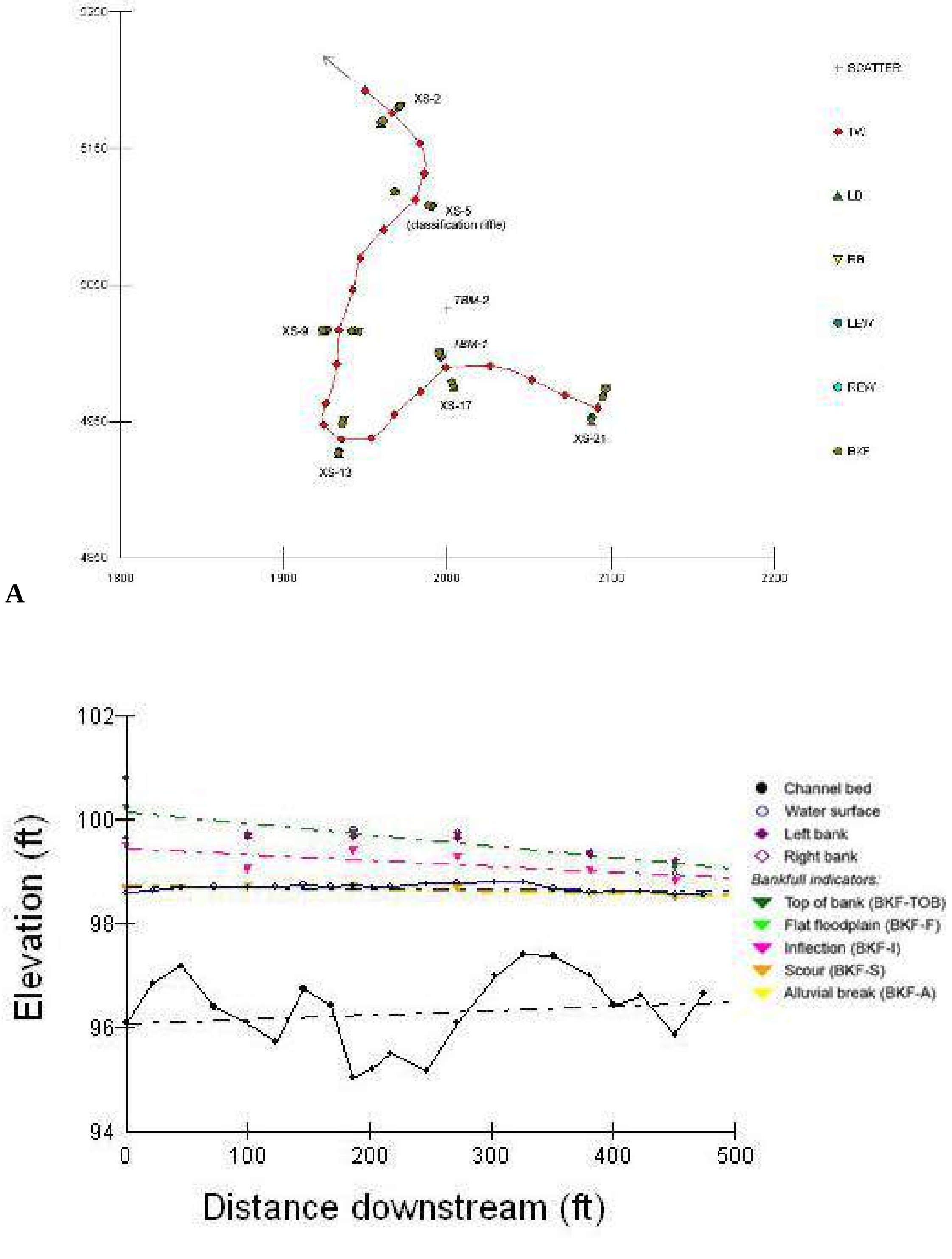
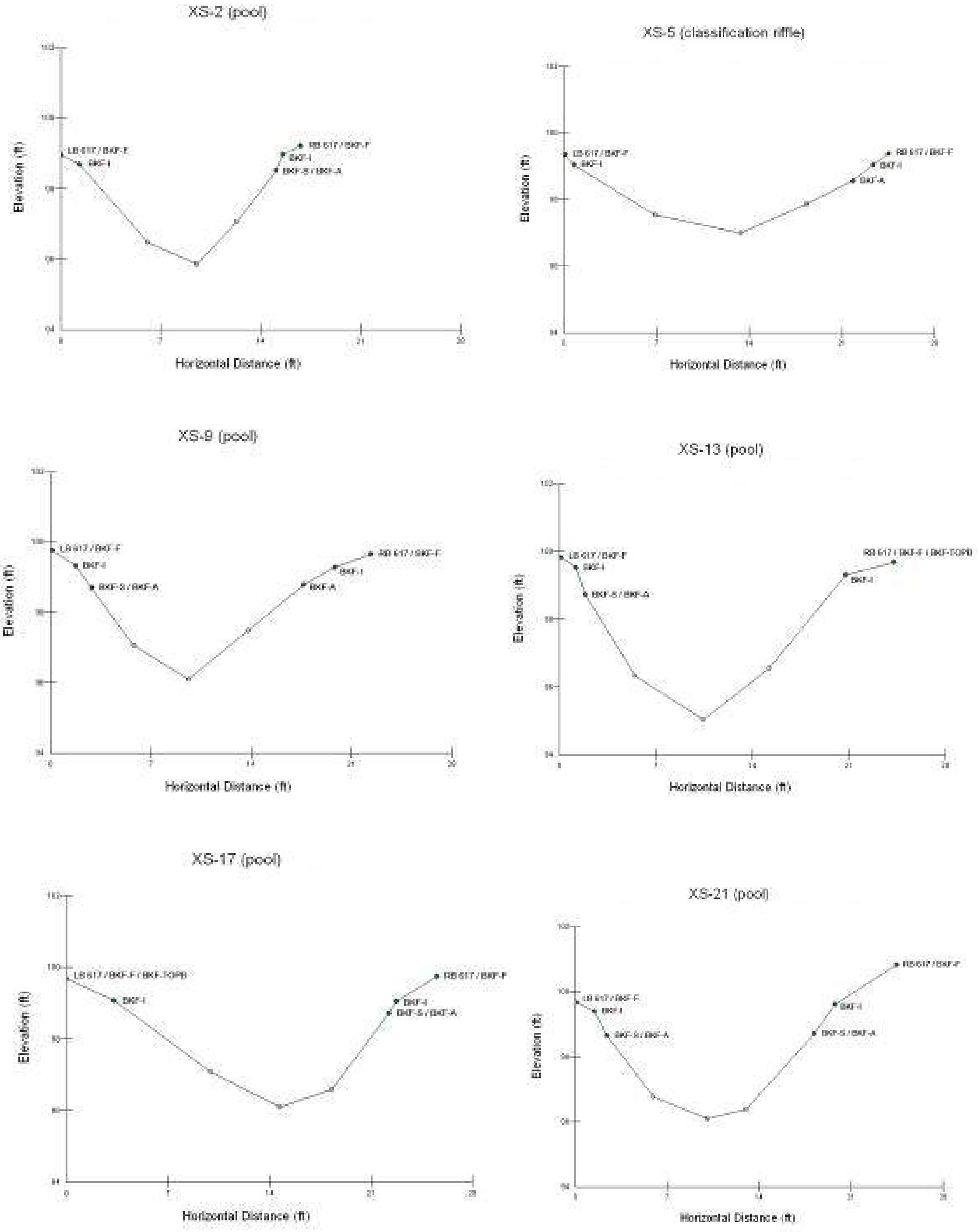


Figure F-43. Rice Creek near Springside. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-43 (Cont.). Rice Creek near Springside. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

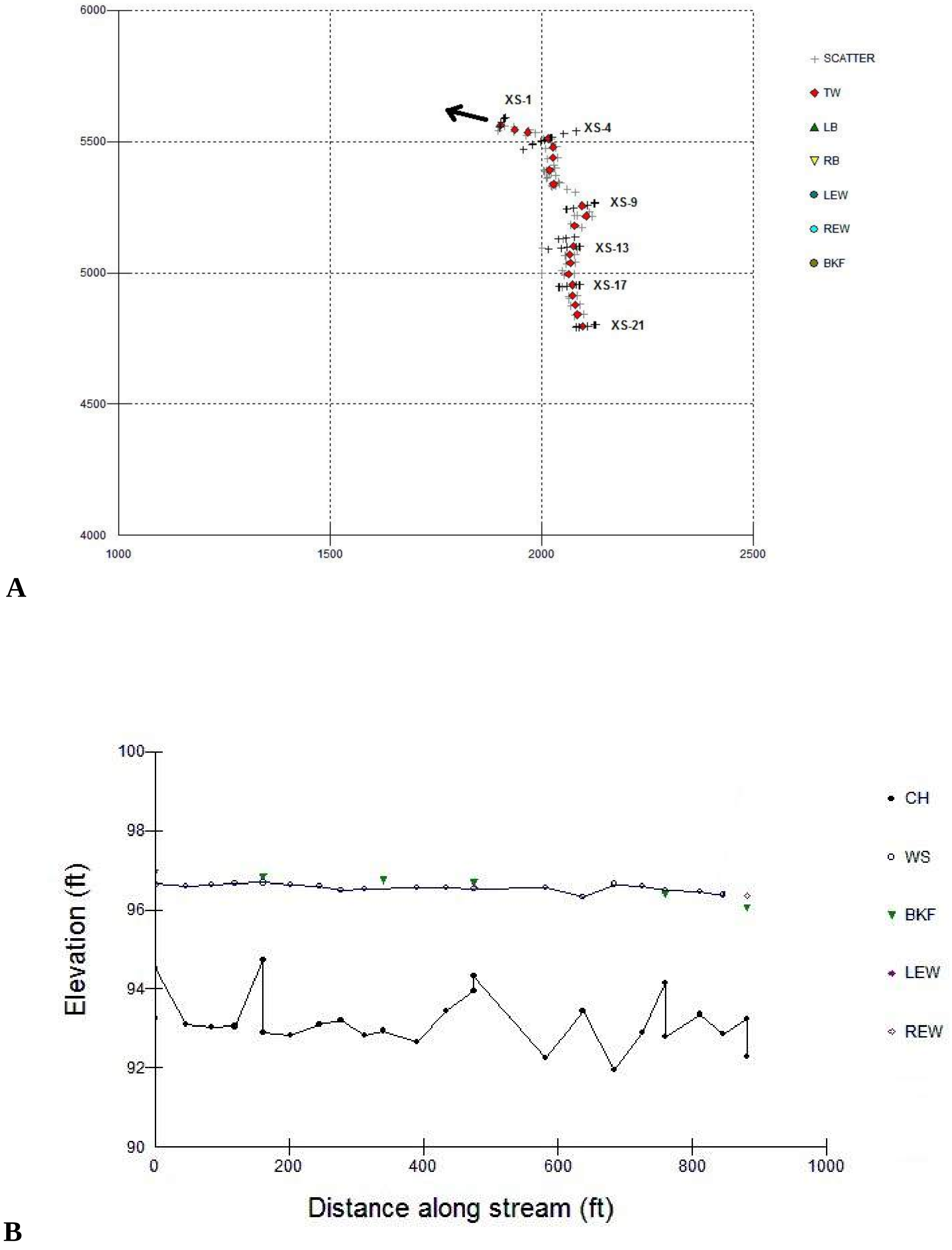
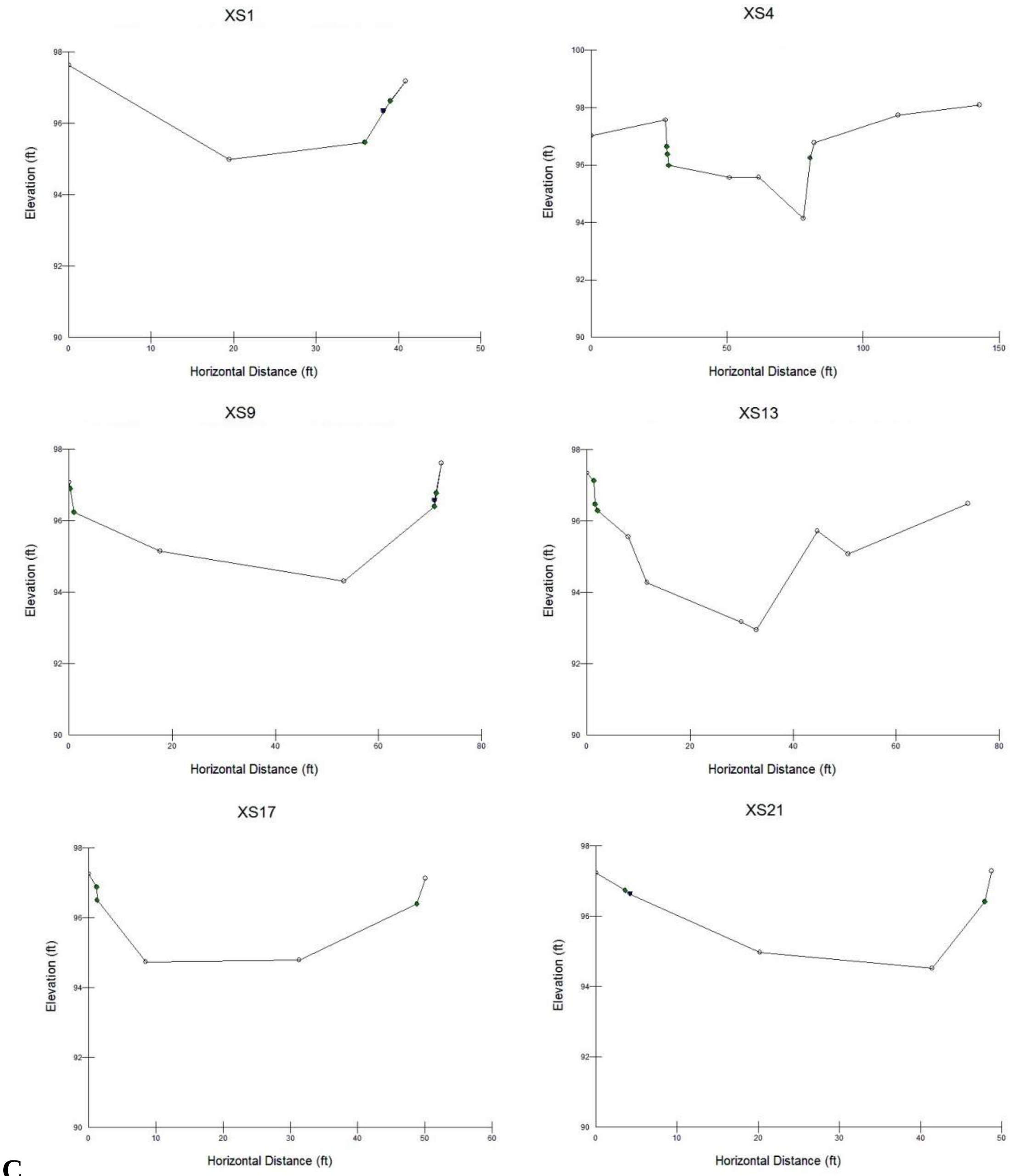


Figure F-44. Rock Spring Run. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-44 (Cont.). Rock Spring Run. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

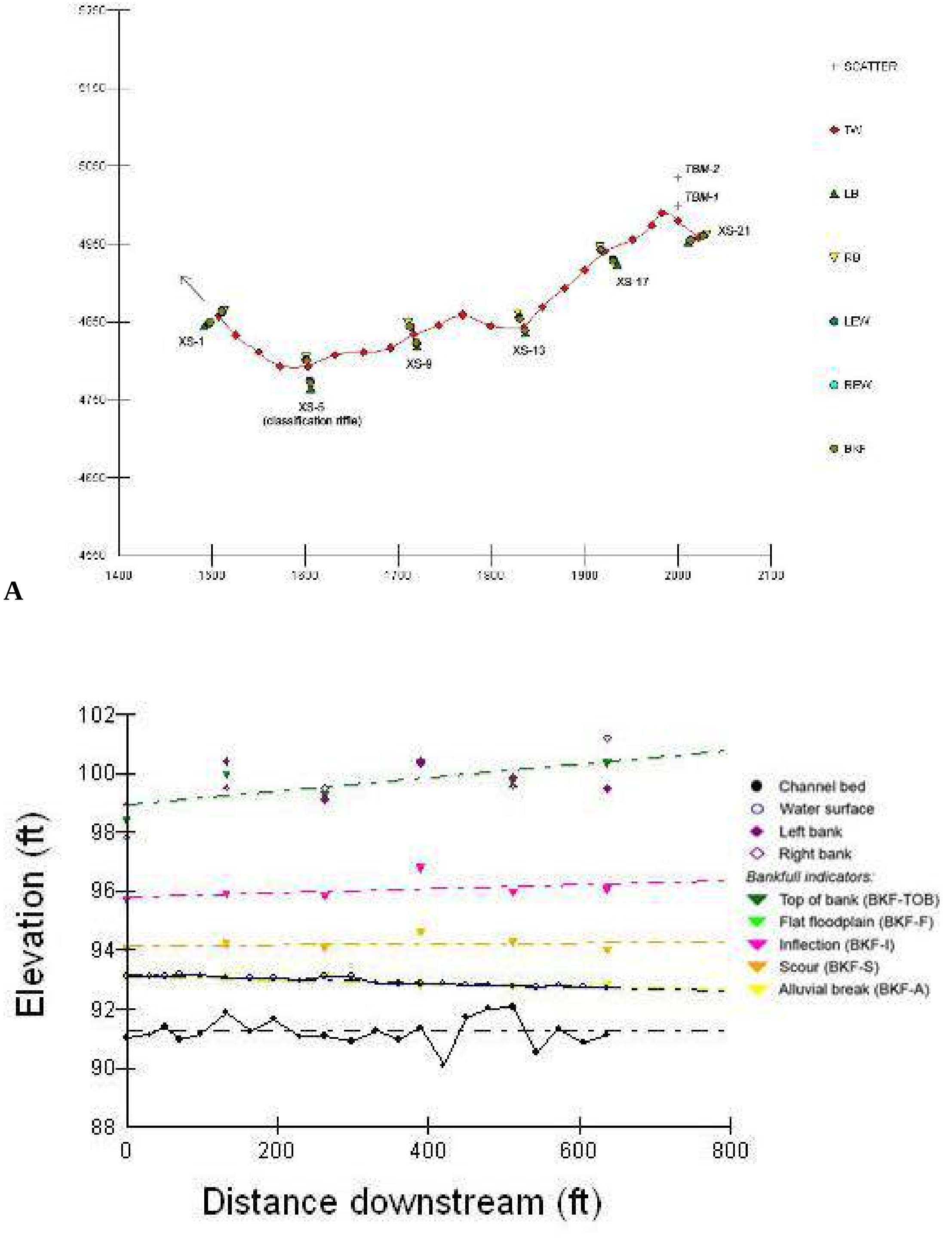


Figure F-45. Santa Fe River near Graham. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

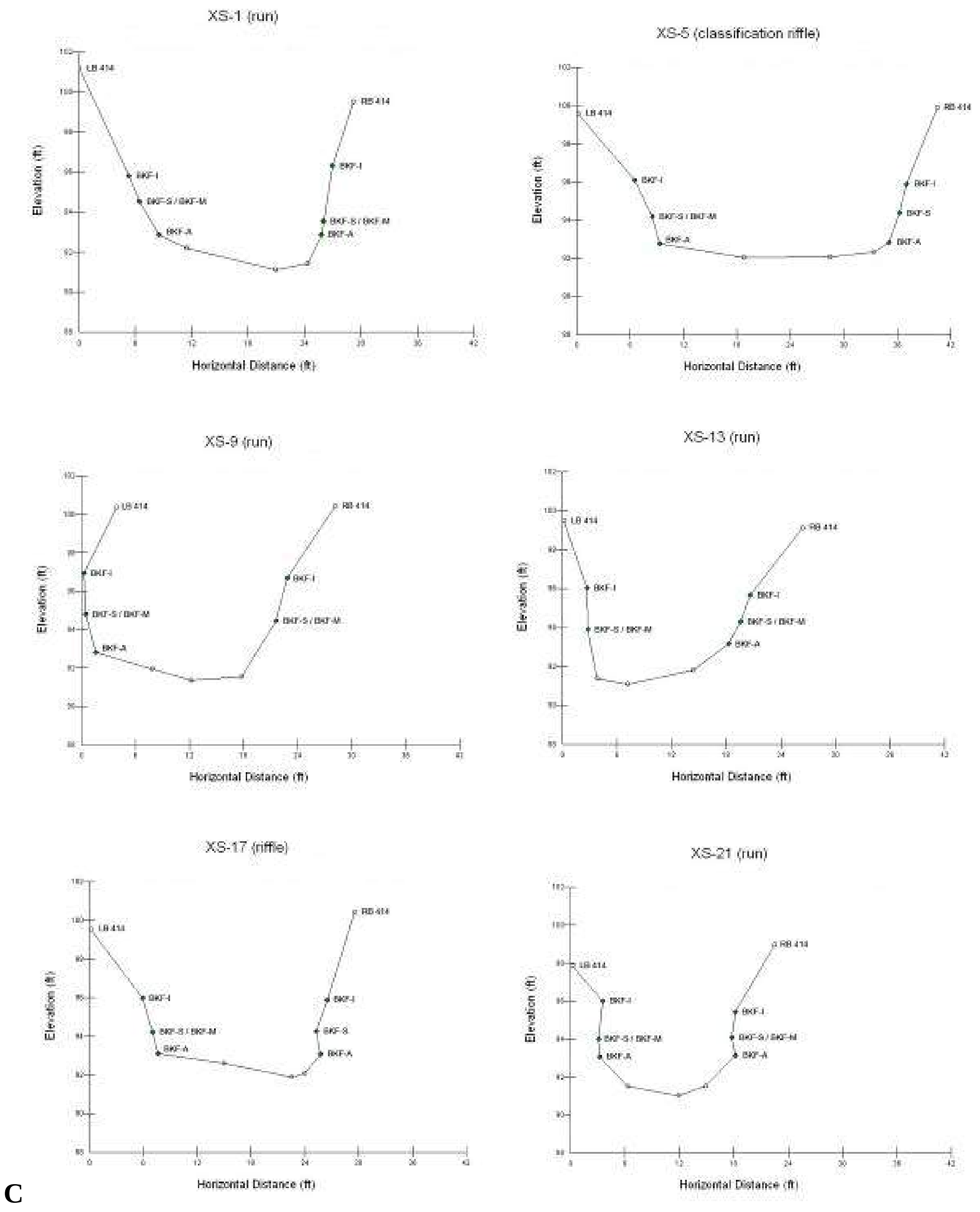


Figure F-45 (Cont.). Santa Fe River near Graham. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

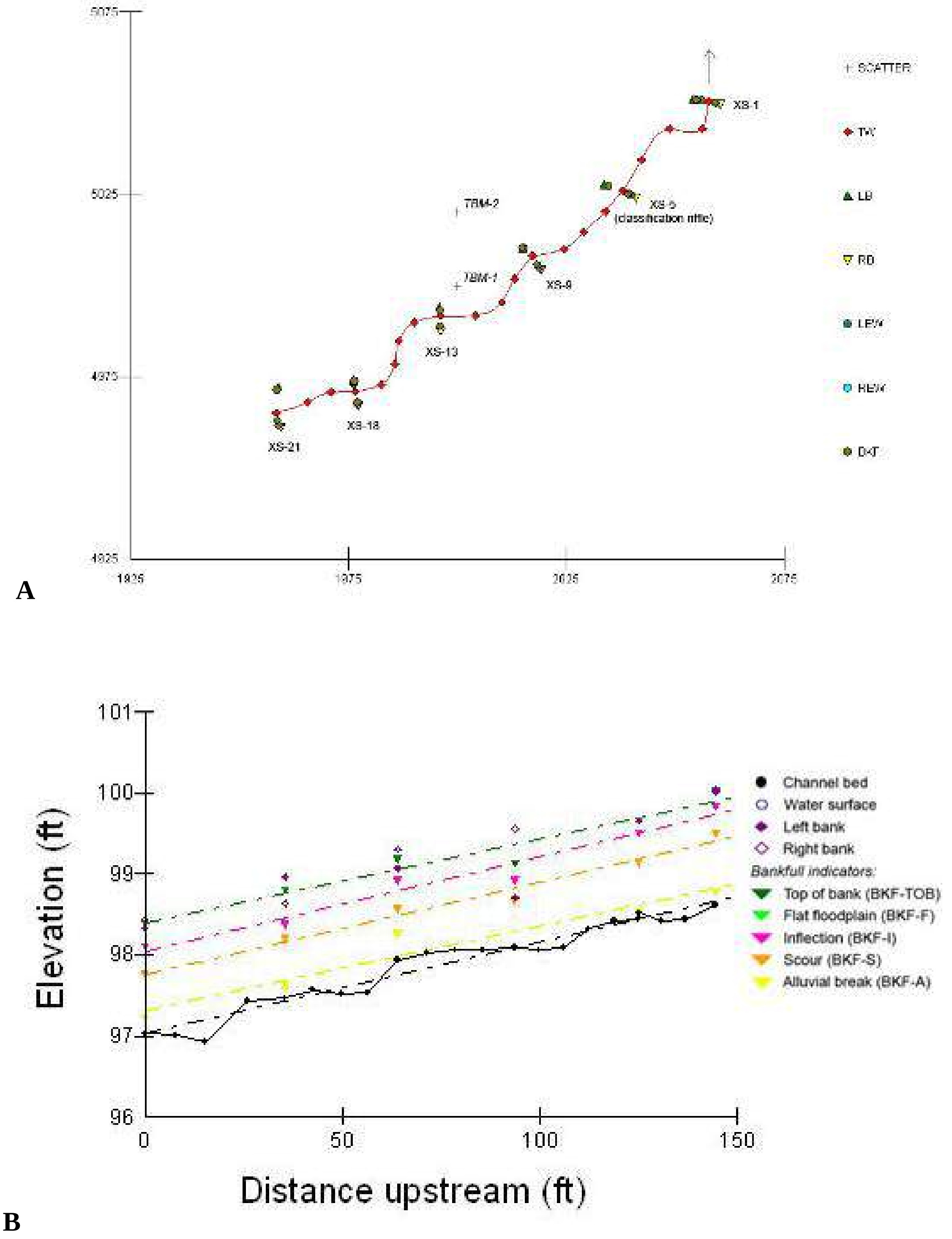
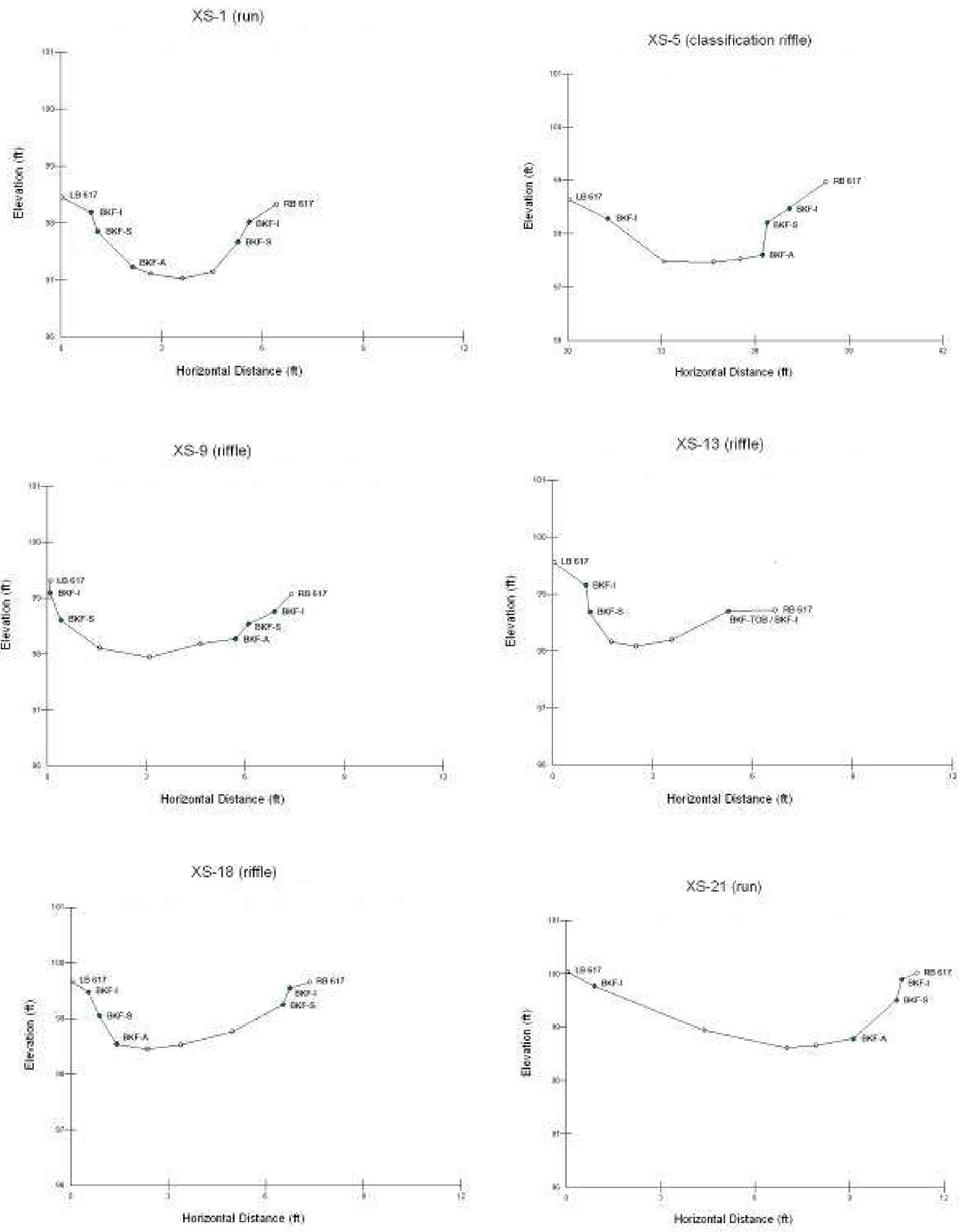
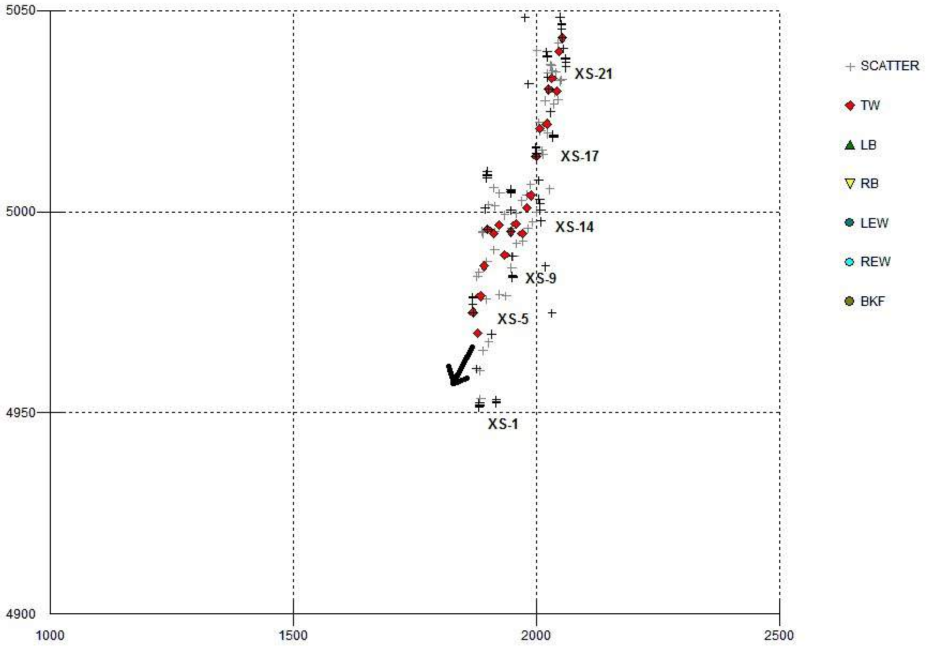


Figure F-46. Shiloh Run near Alachua. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

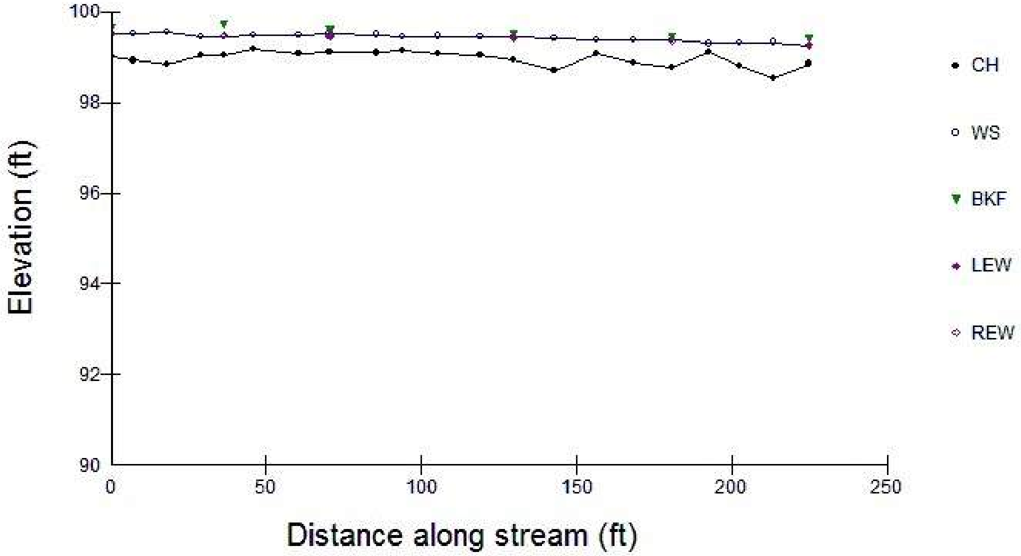


C

Figure F-46 (Cont.). Shiloh Run near Alachua. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

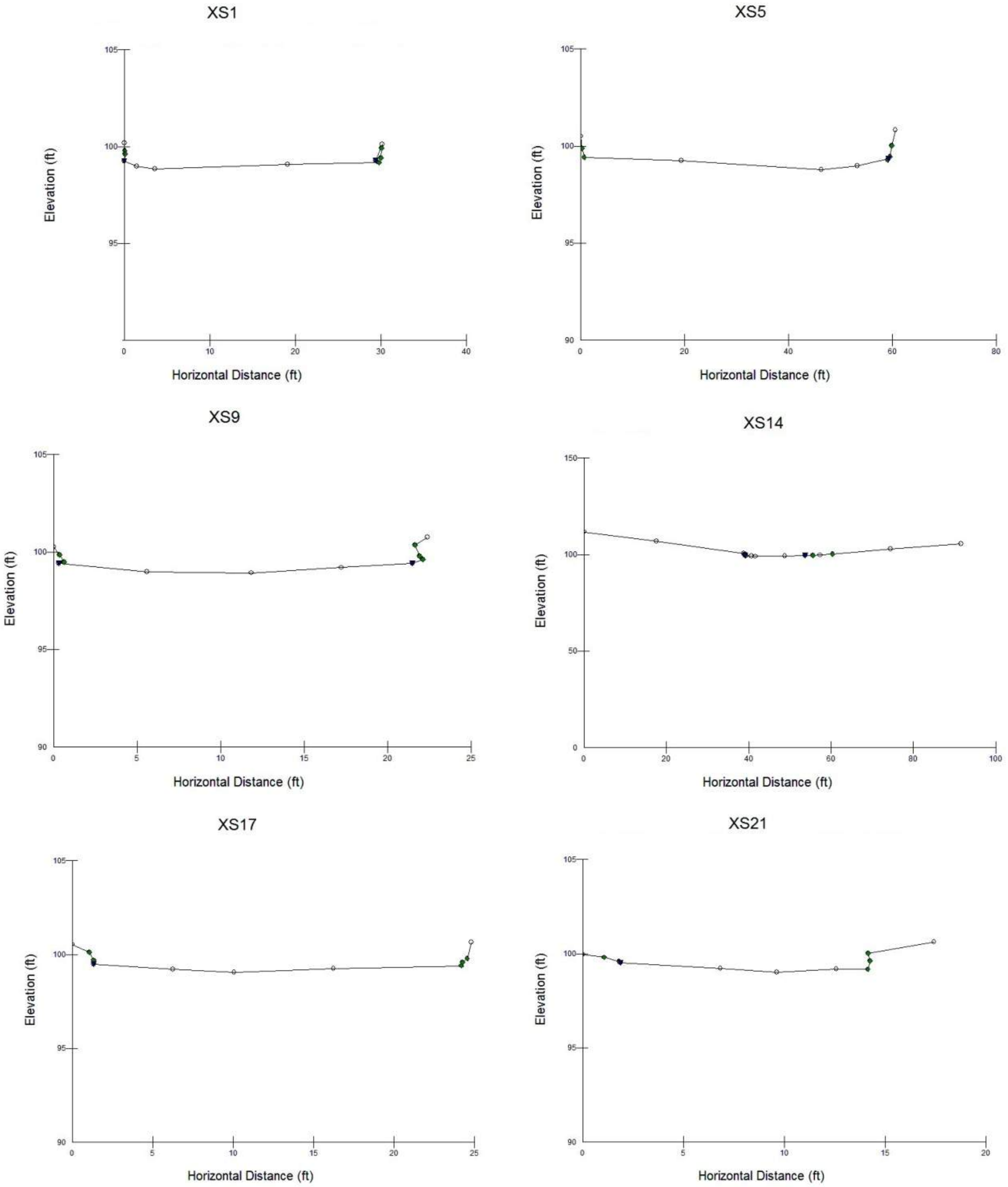


A



B

Figure F-47. Silver Glen UT Spring Run. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-47 (Cont.). Silver Glen UT Spring Run. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

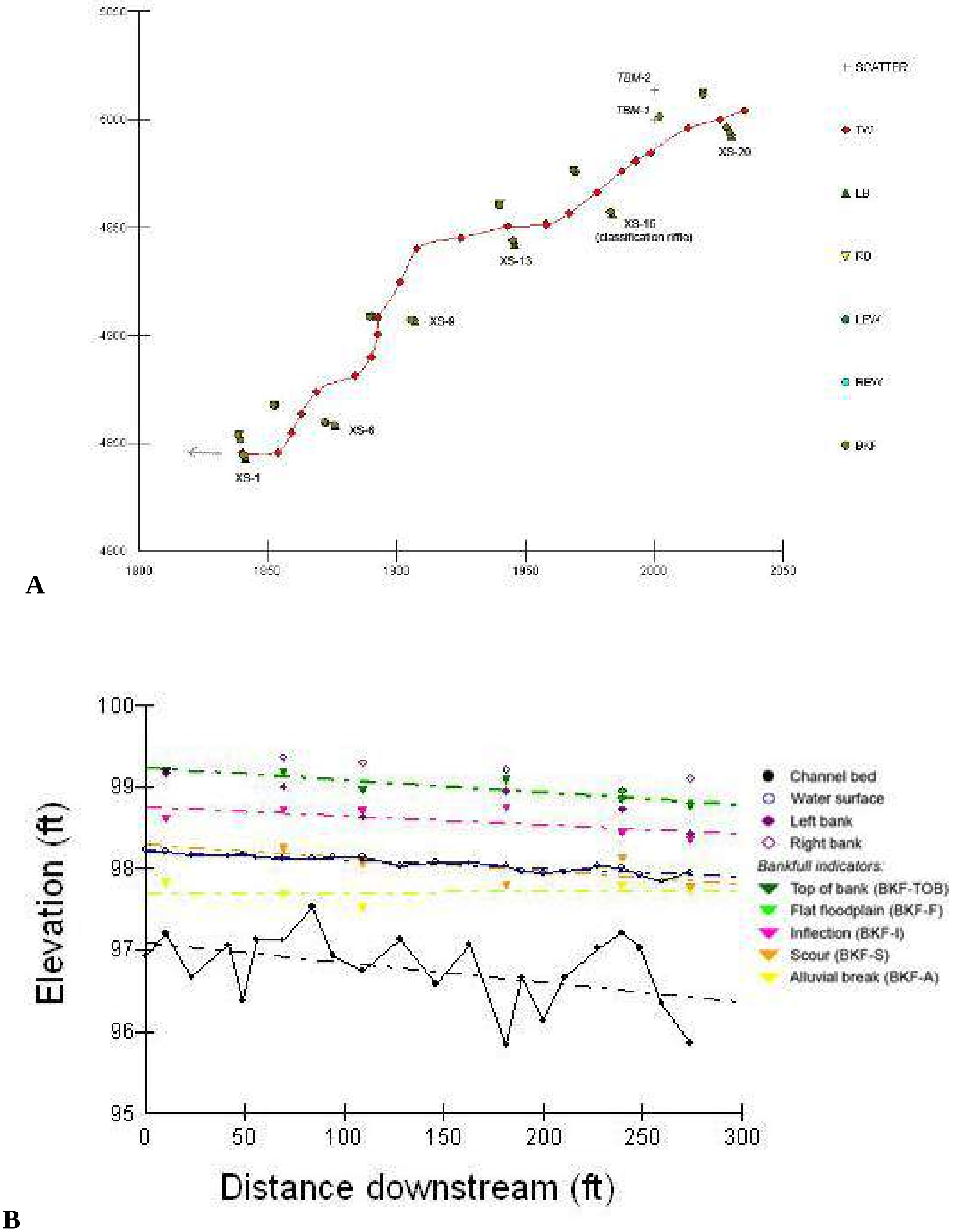
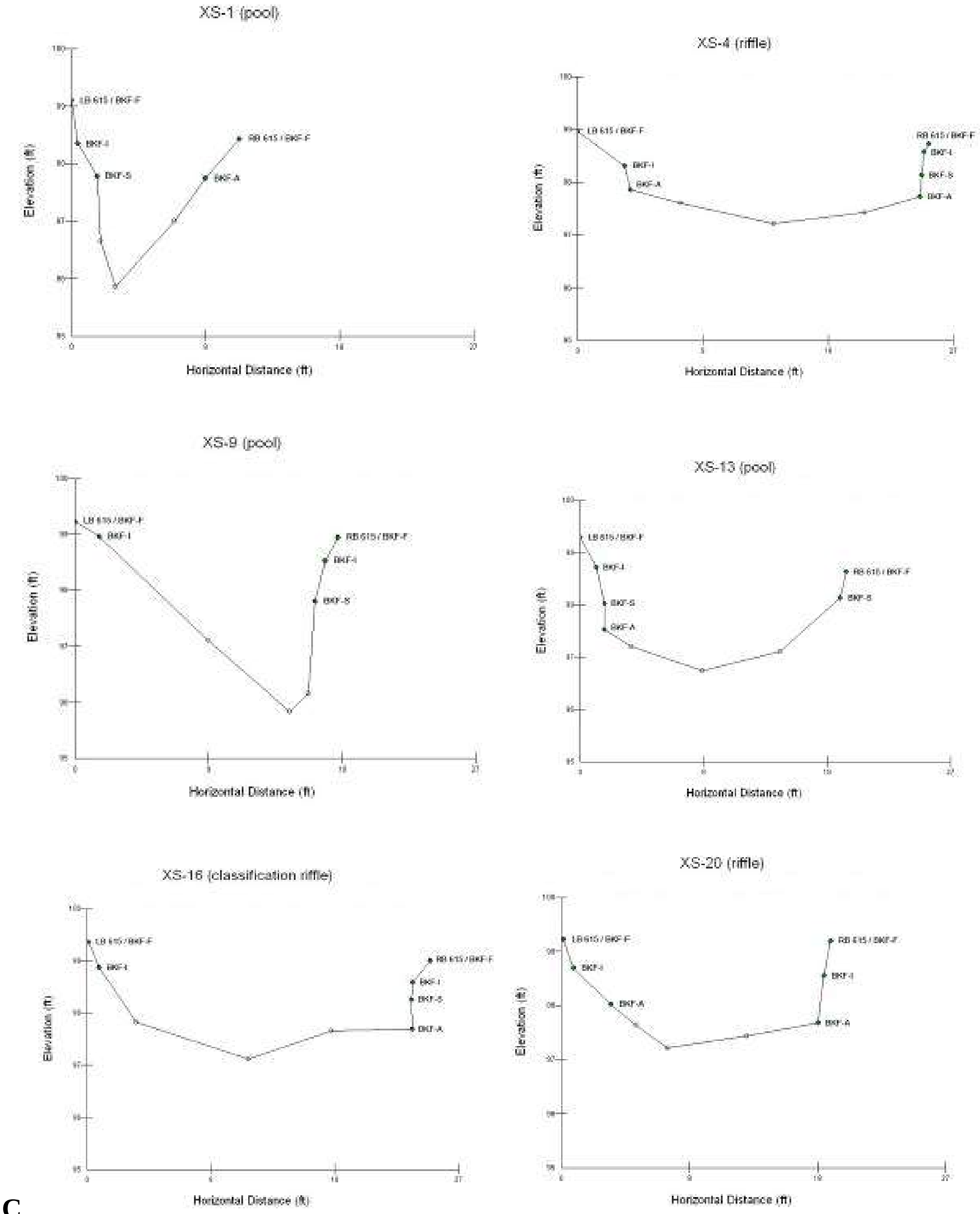


Figure F-48. Snell Creek. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-48 (Cont.). Snell Creek. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

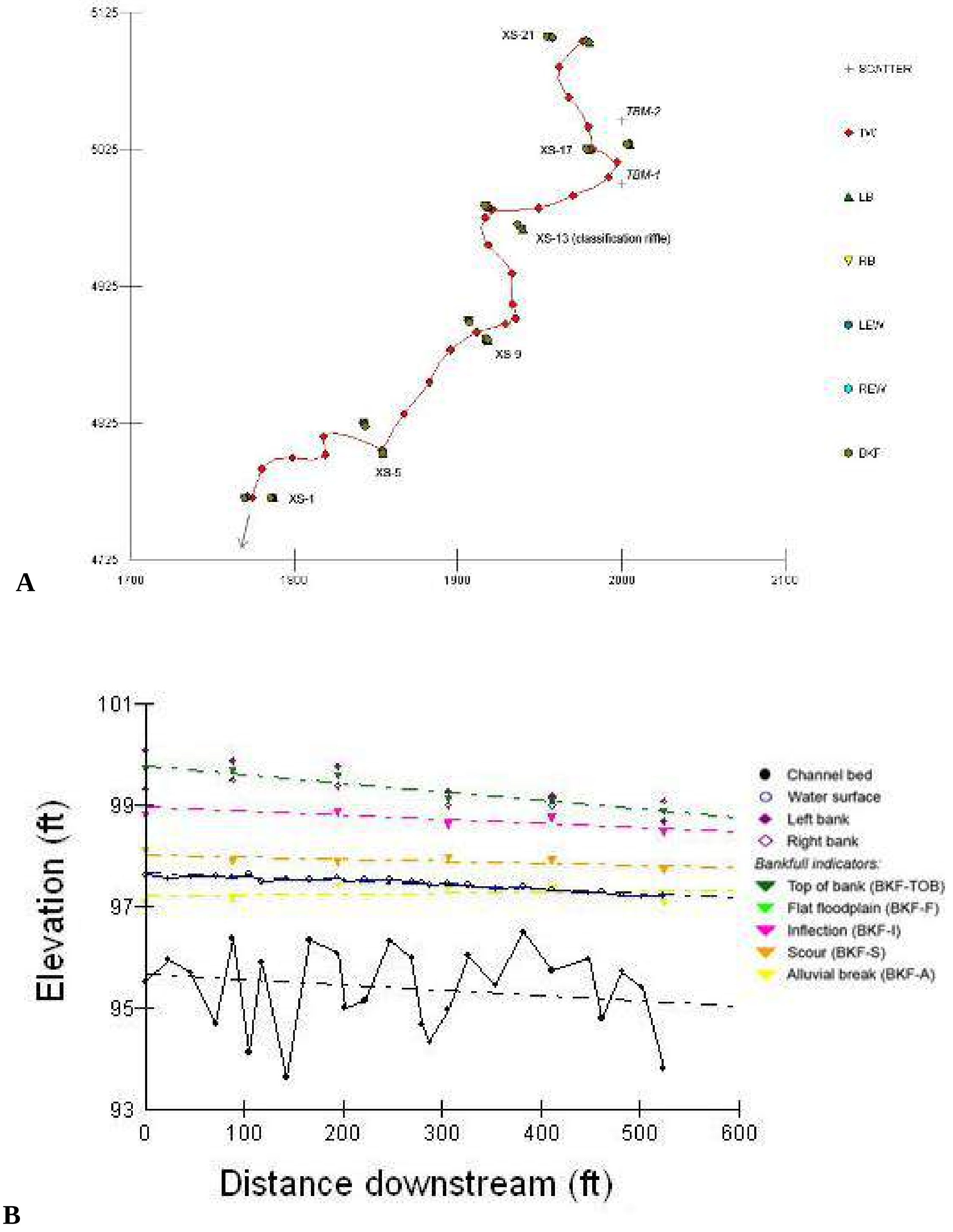
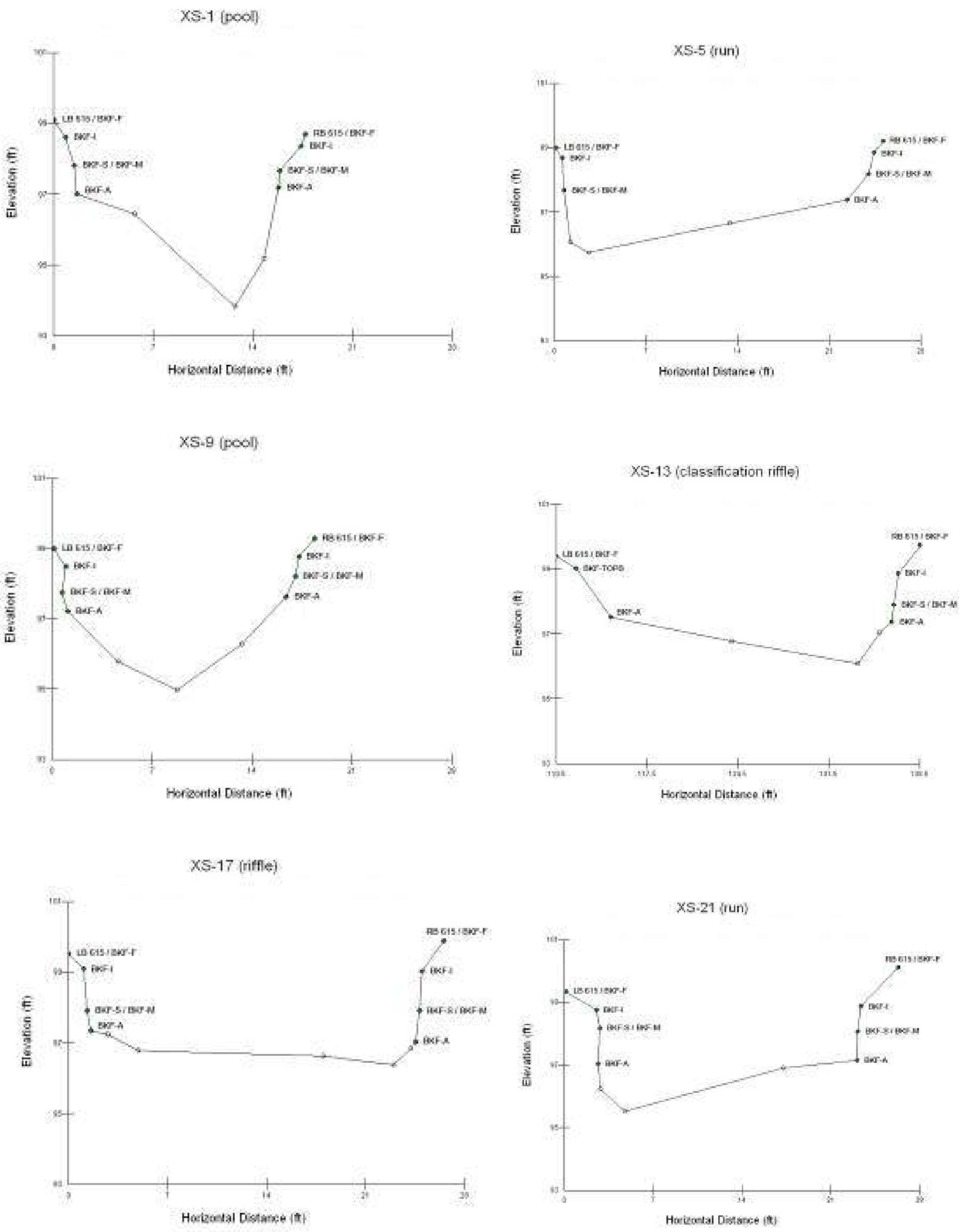


Figure F-49. South Fork Black Creek. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-49 (Cont.). South Fork Black Creek. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

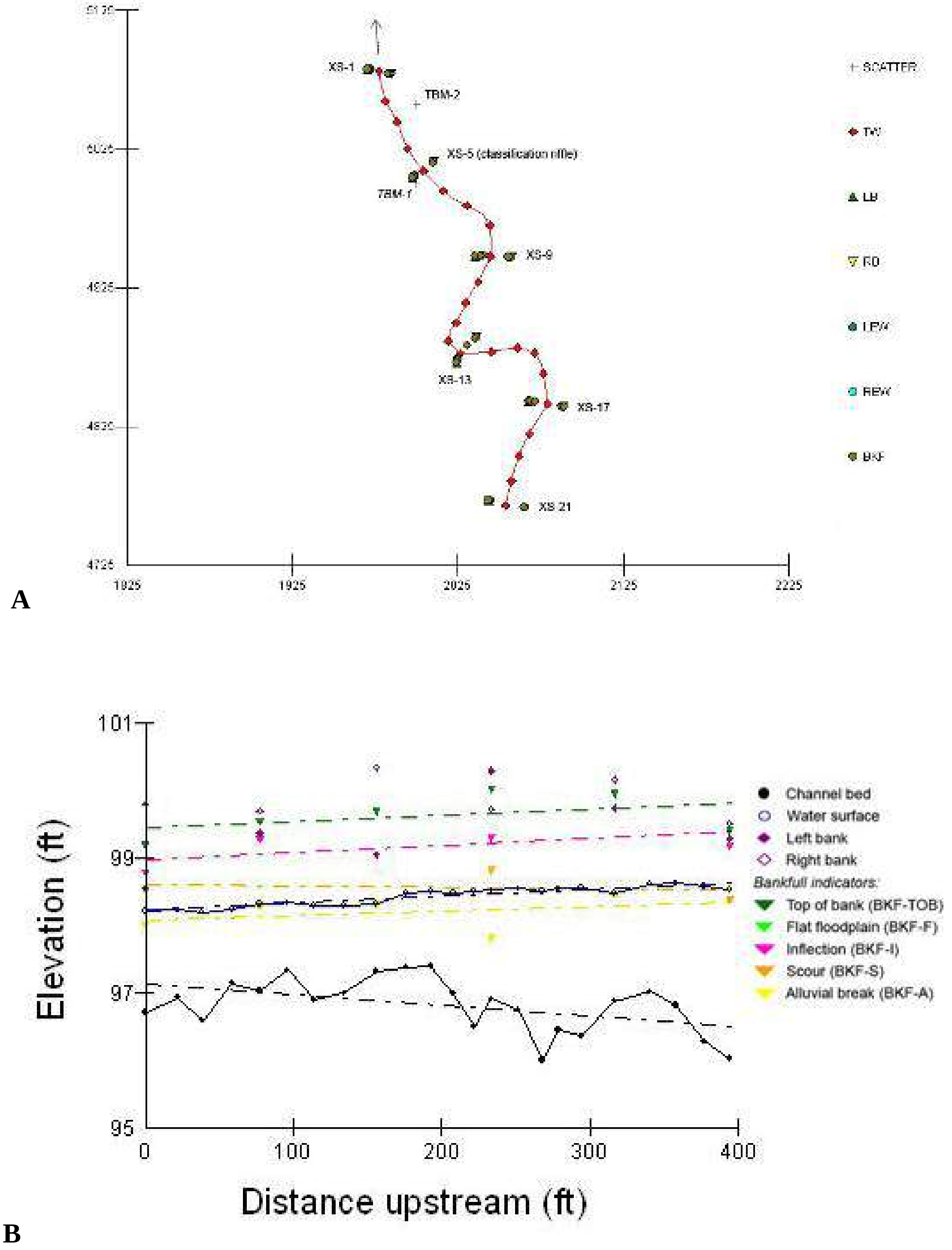
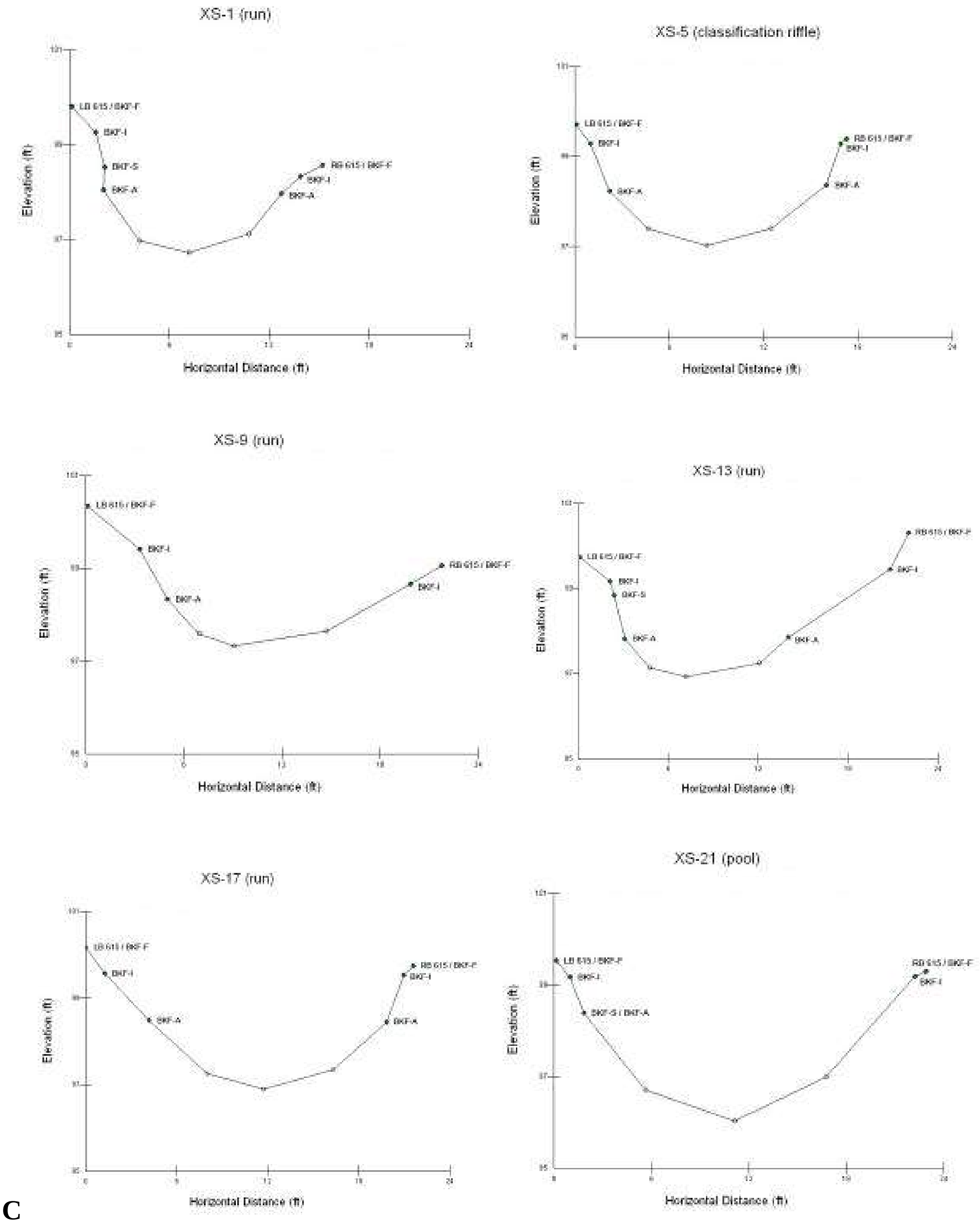


Figure F-50. Tenmile Creek. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-50 (Cont.). Tenmile Creek. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

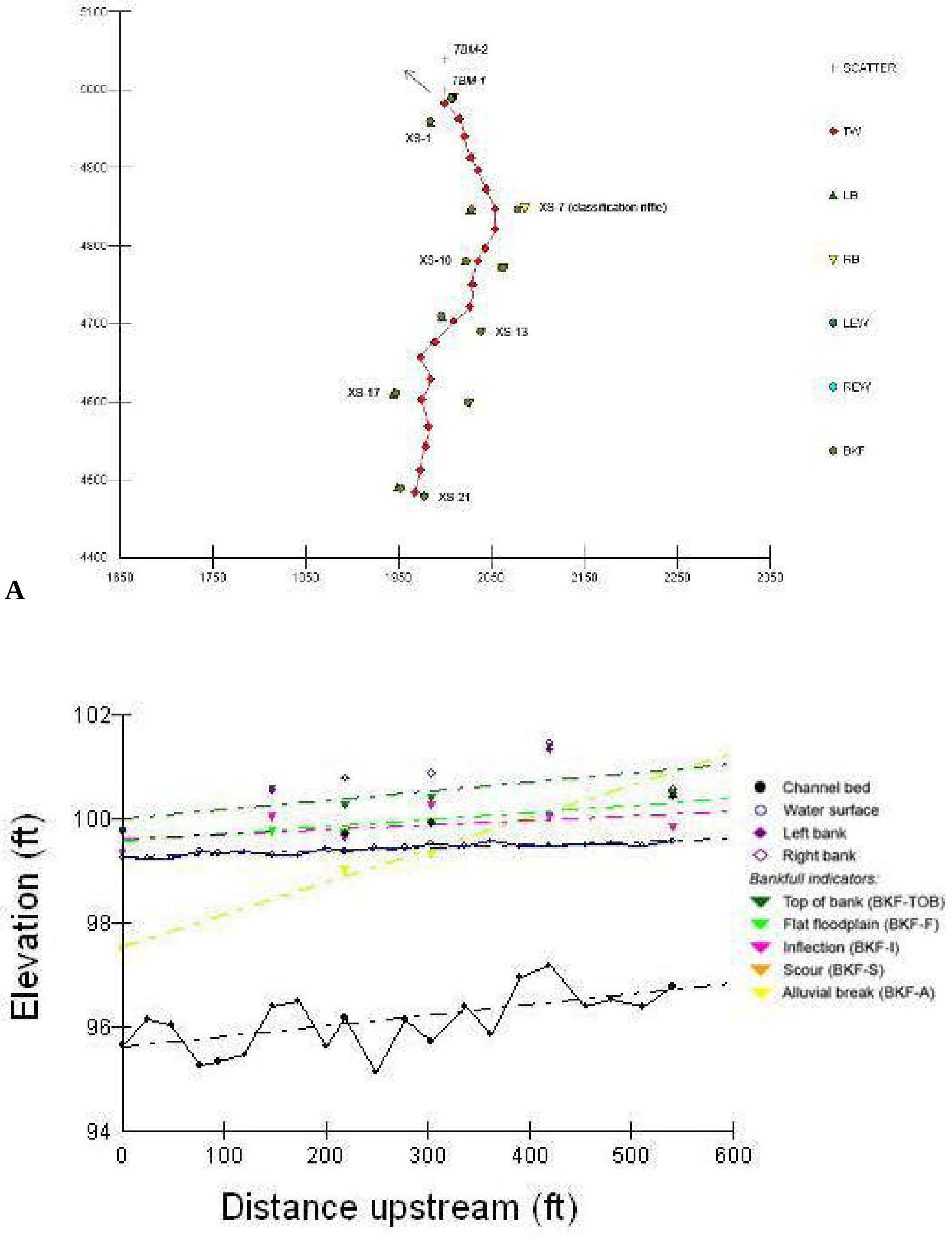
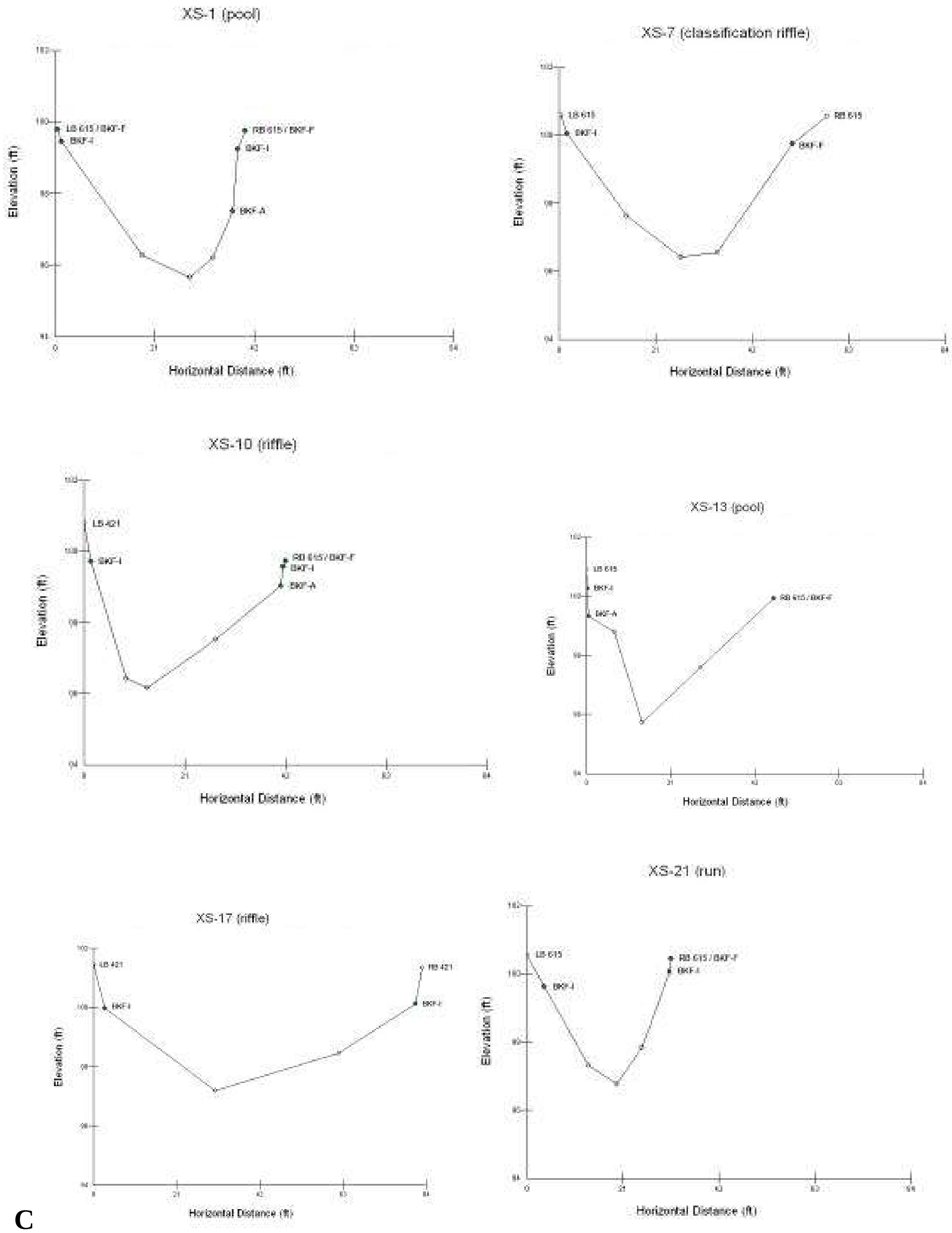


Figure F-51. Tiger Creek near Babson Park. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-51 (Cont.). Tiger Creek near Babson Park. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

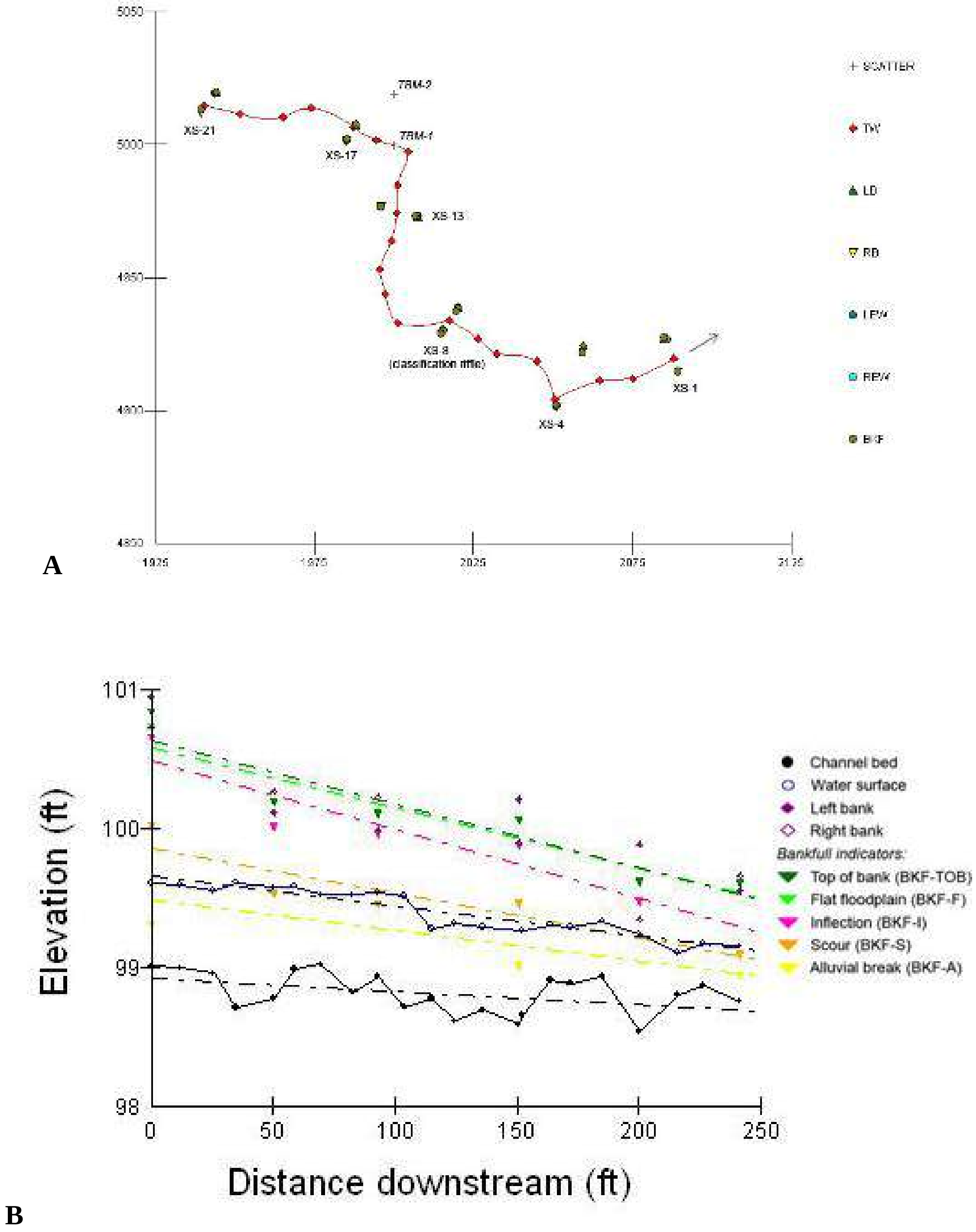


Figure F-52. Tiger Creek UT. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

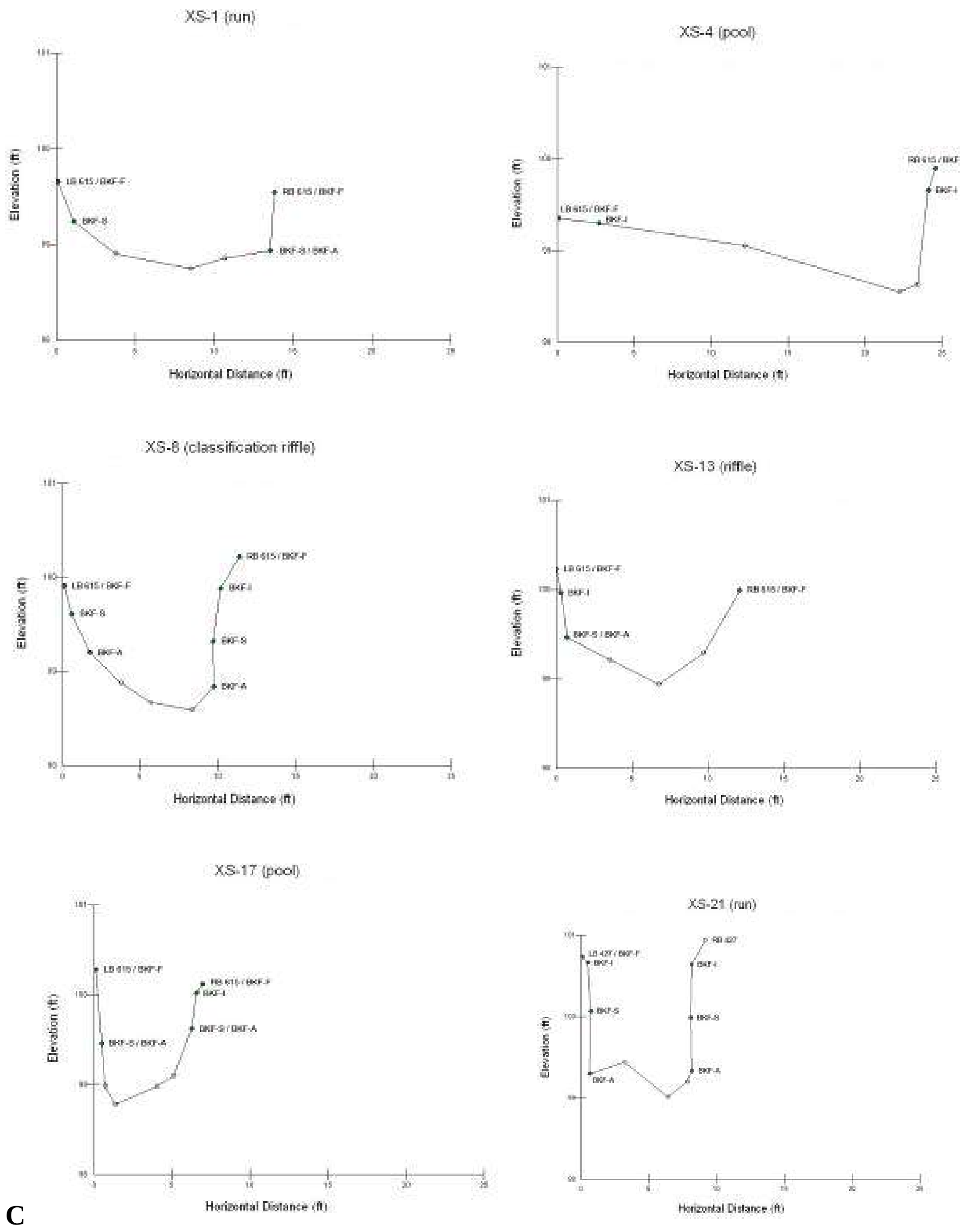


Figure F-52 (Cont.). Tiger Creek UT. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

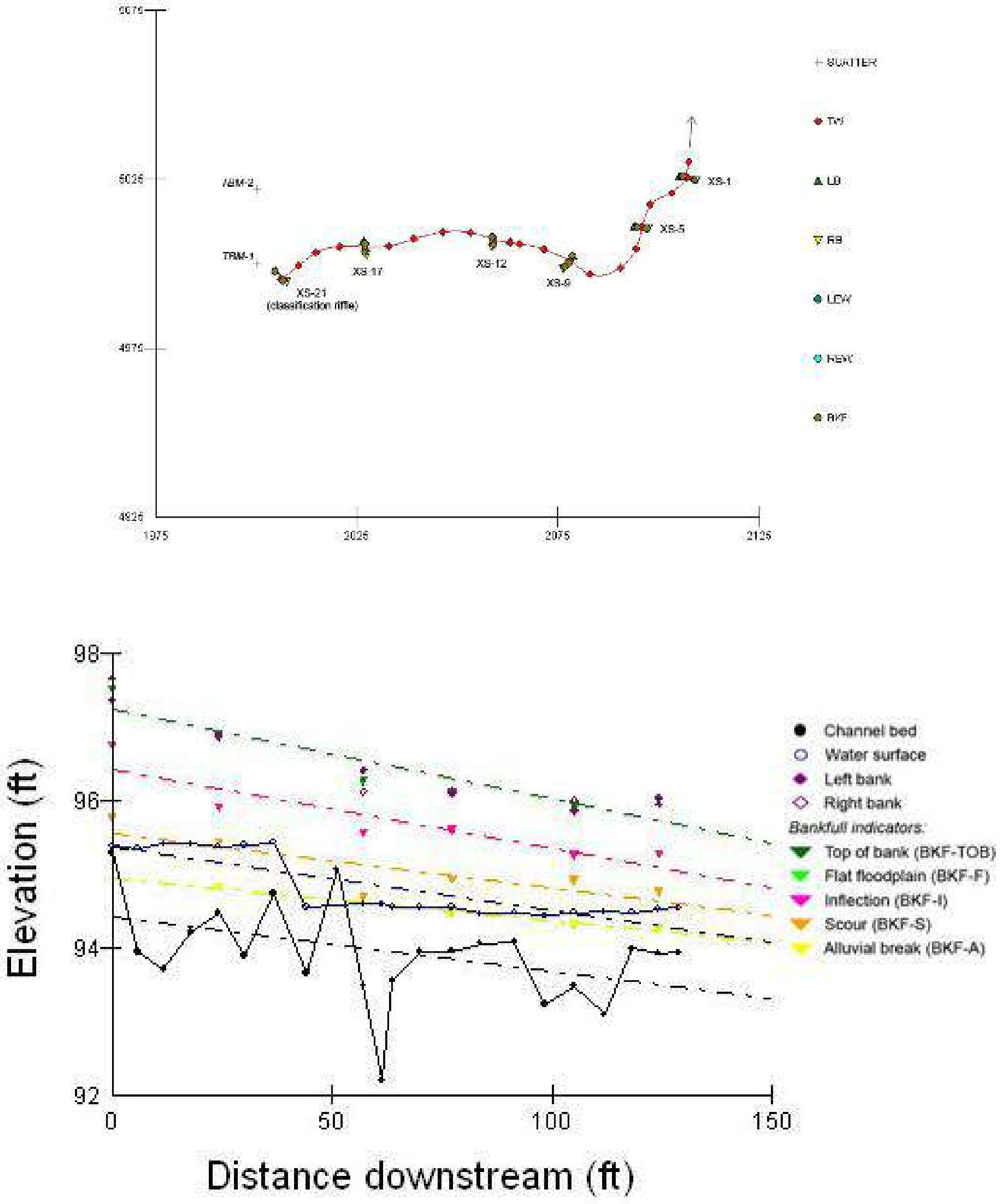
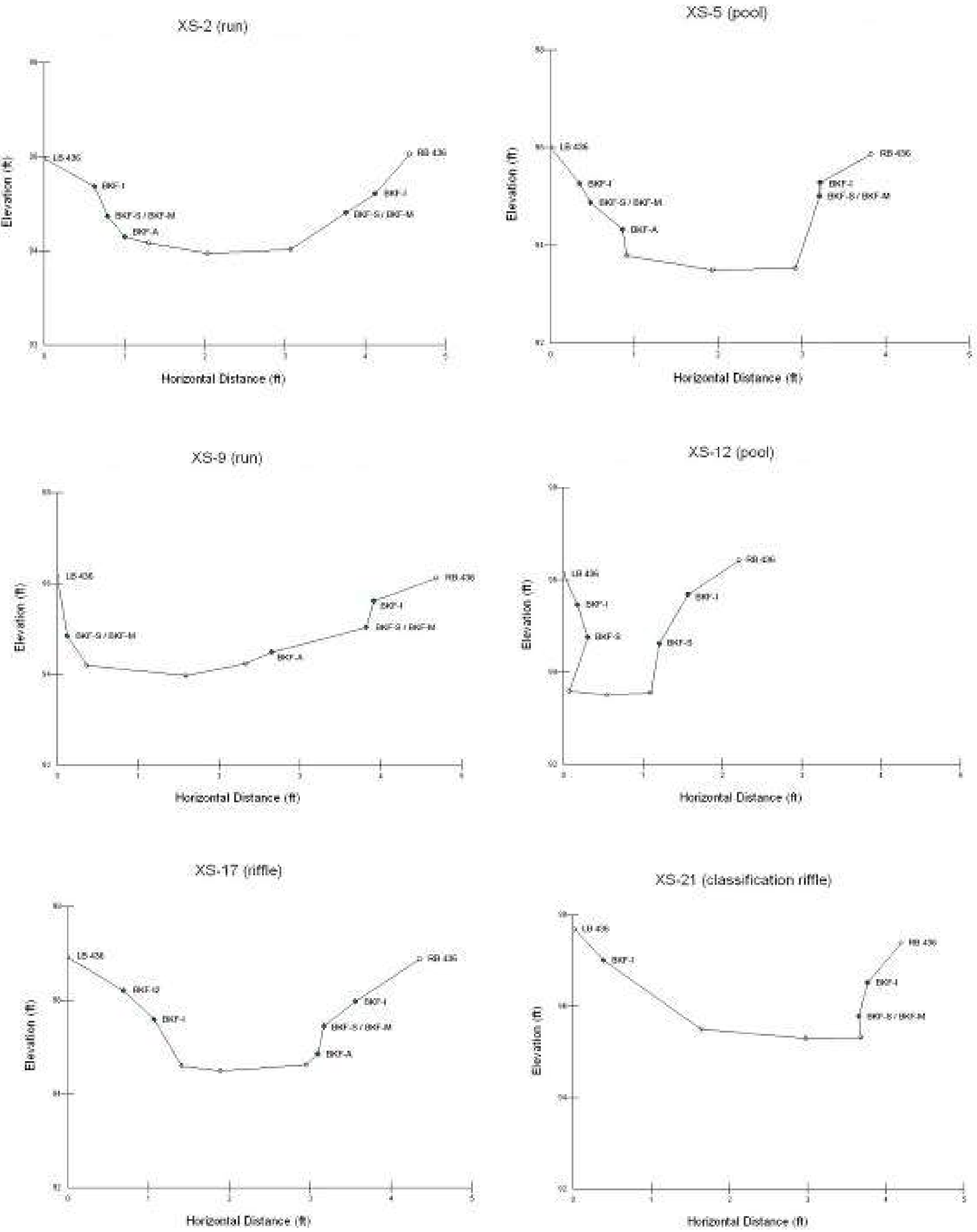


Figure F-53. Tuscawilla Lake UT. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-53 (Cont.). Tuscawilla Lake UT. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

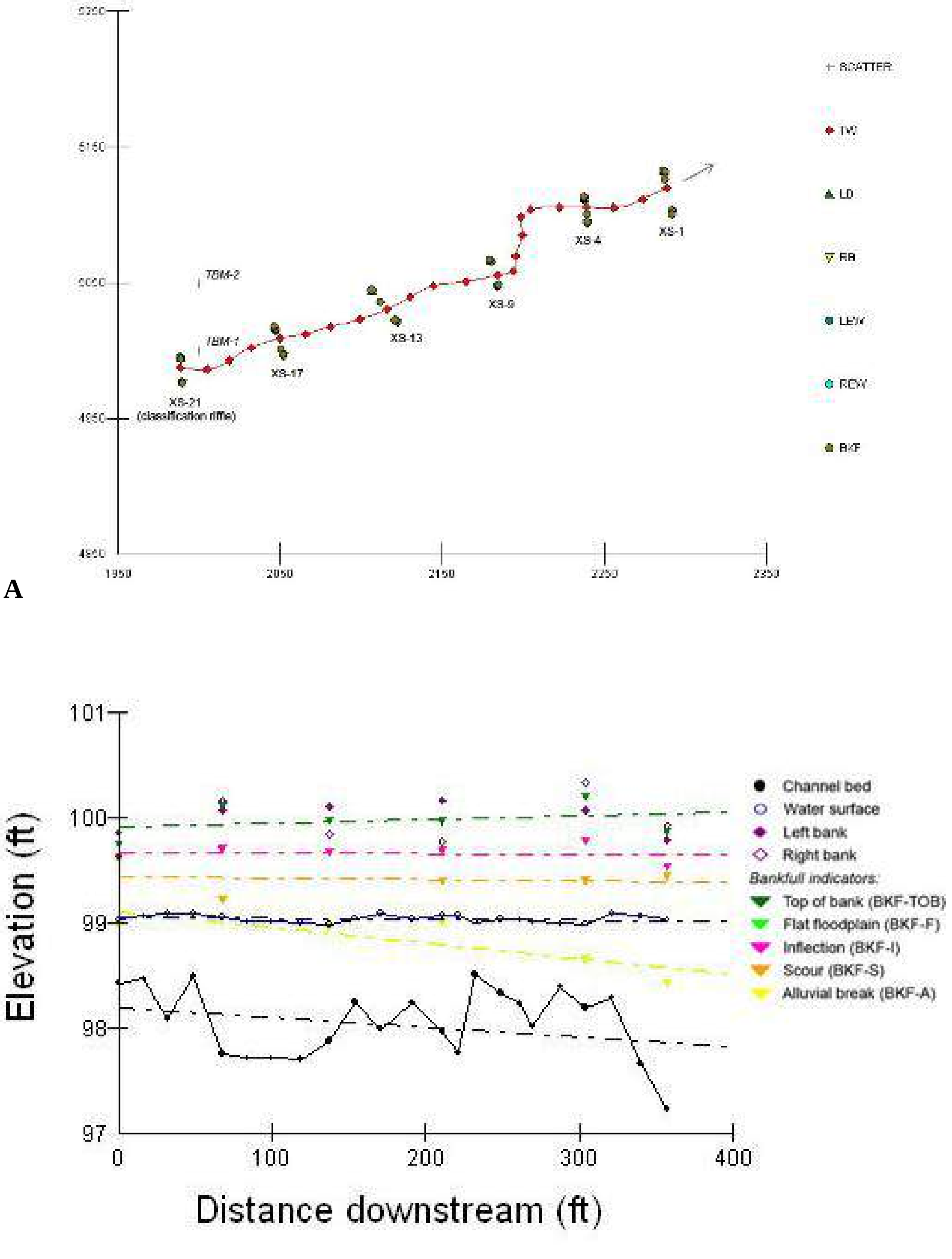
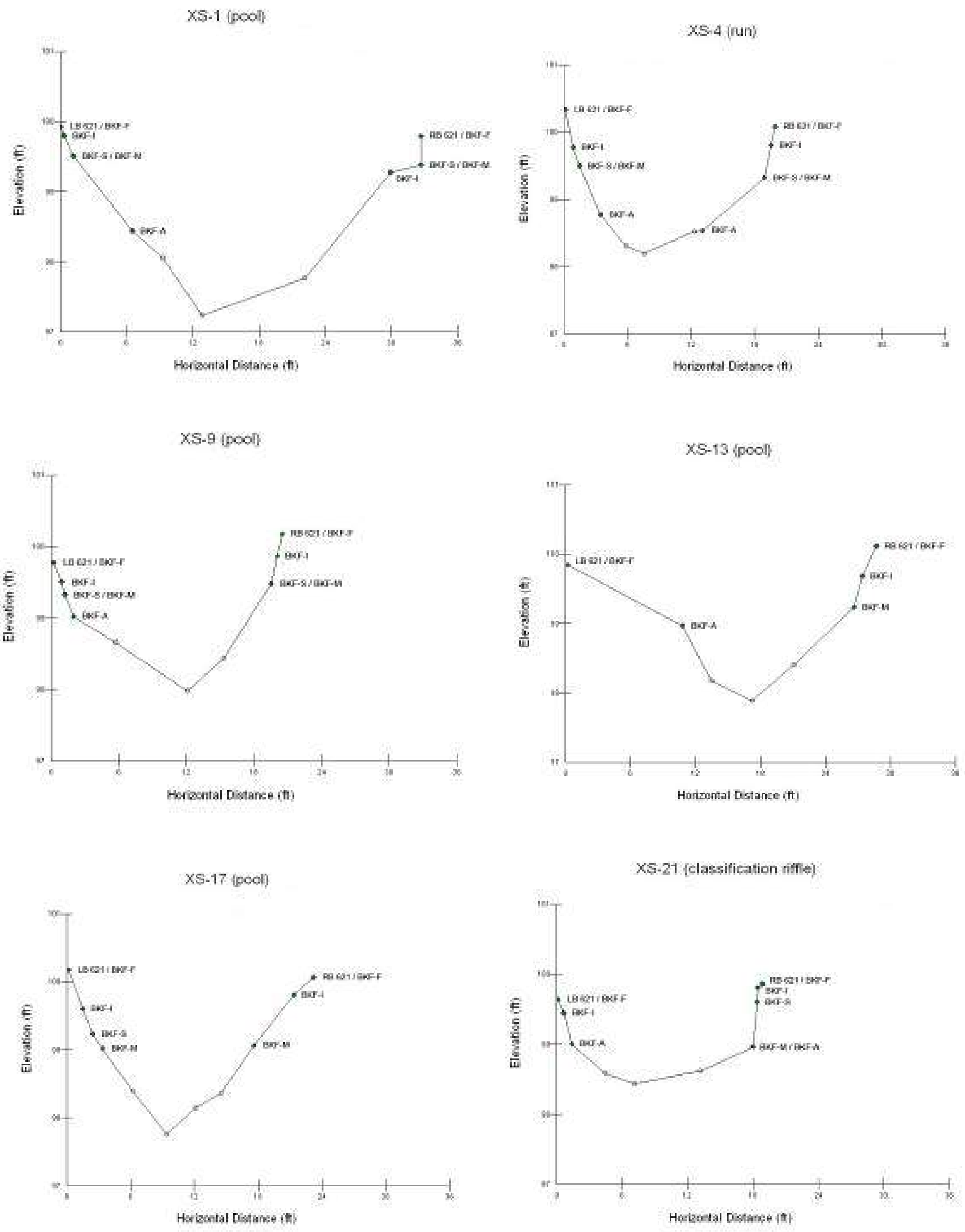


Figure F-54. Tyson Creek. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-54 (Cont.). Tyson Creek. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

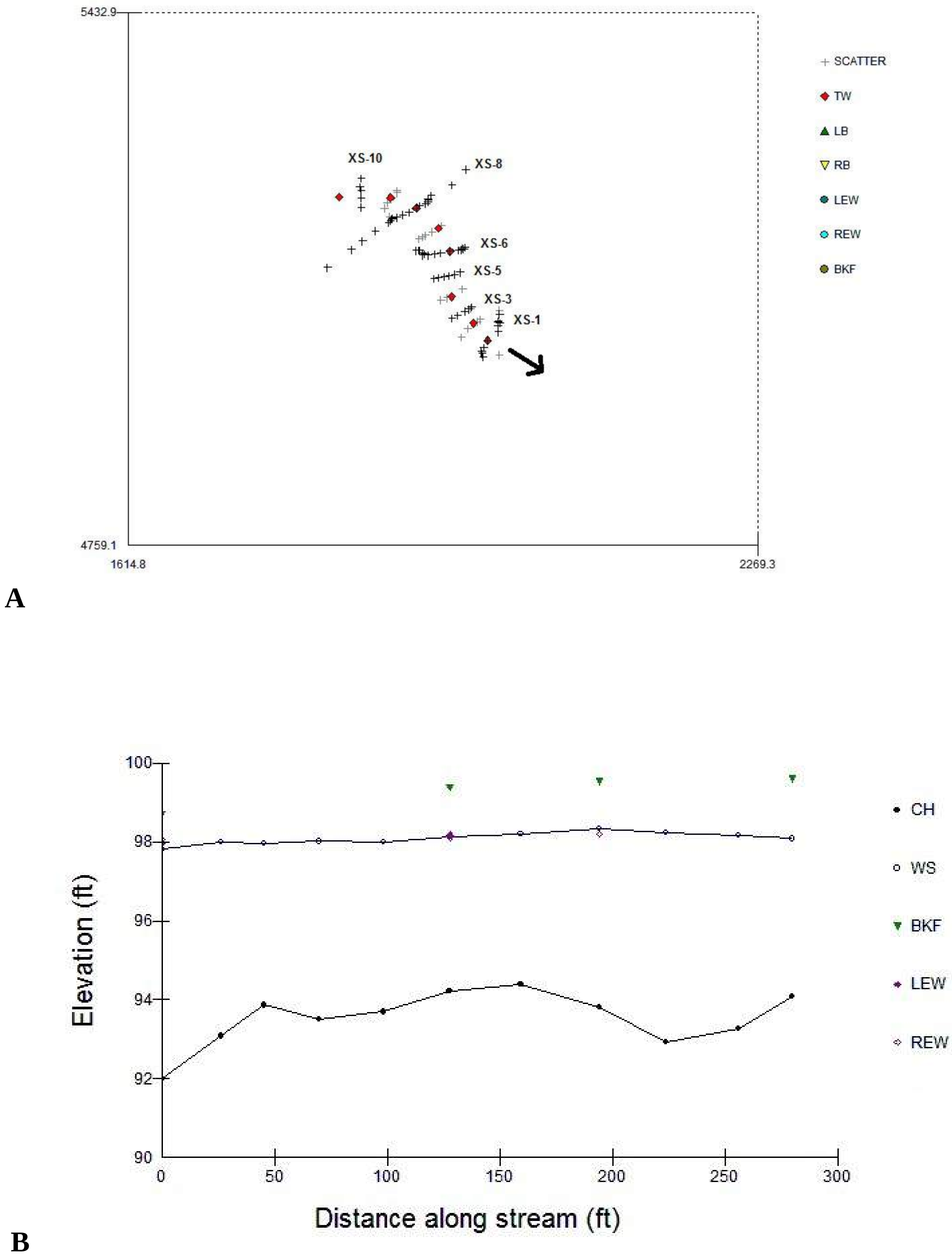


Figure F-55. Weeki Wachee River. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

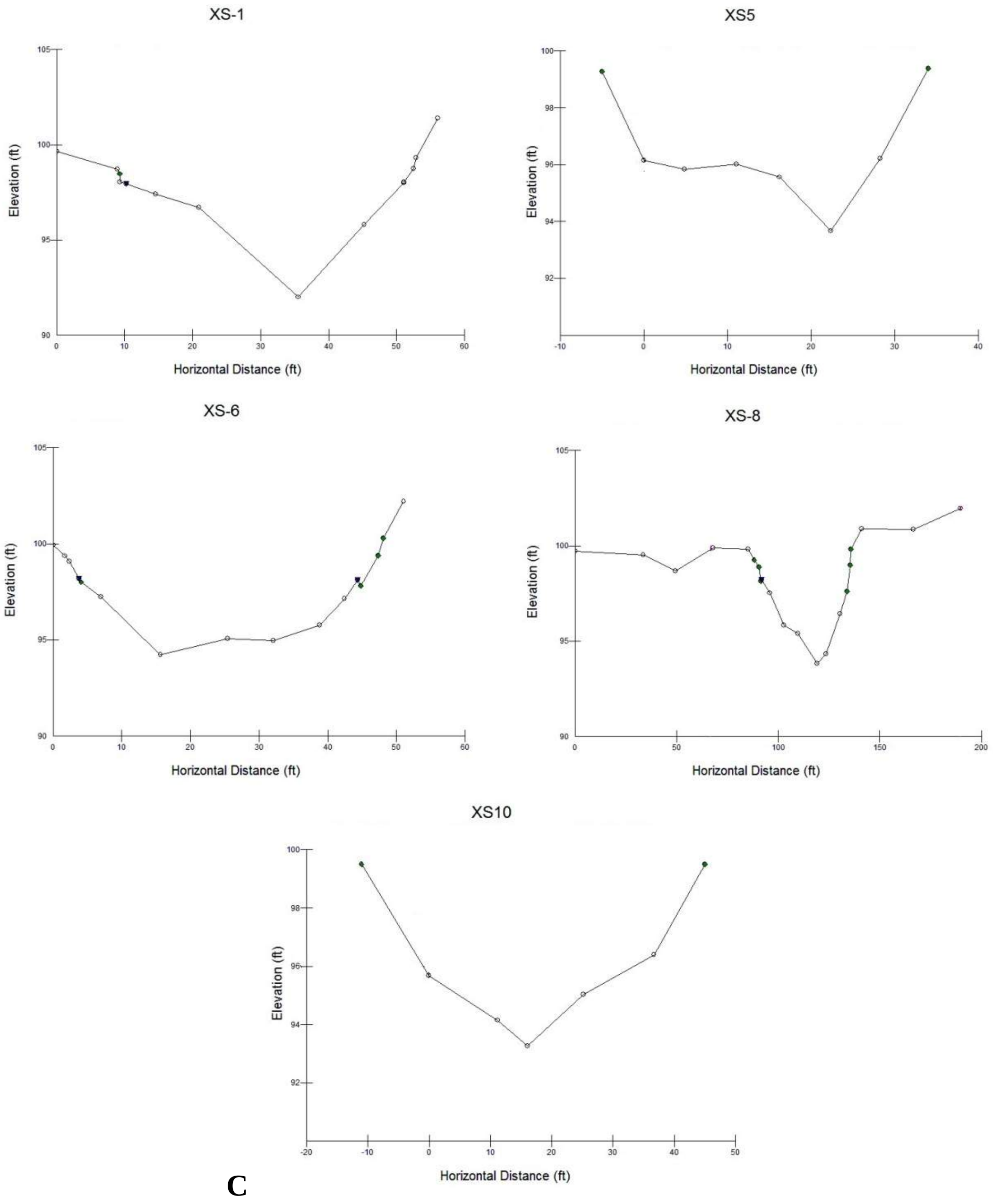


Figure F-55 (Cont.). Weeki Wachee River. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

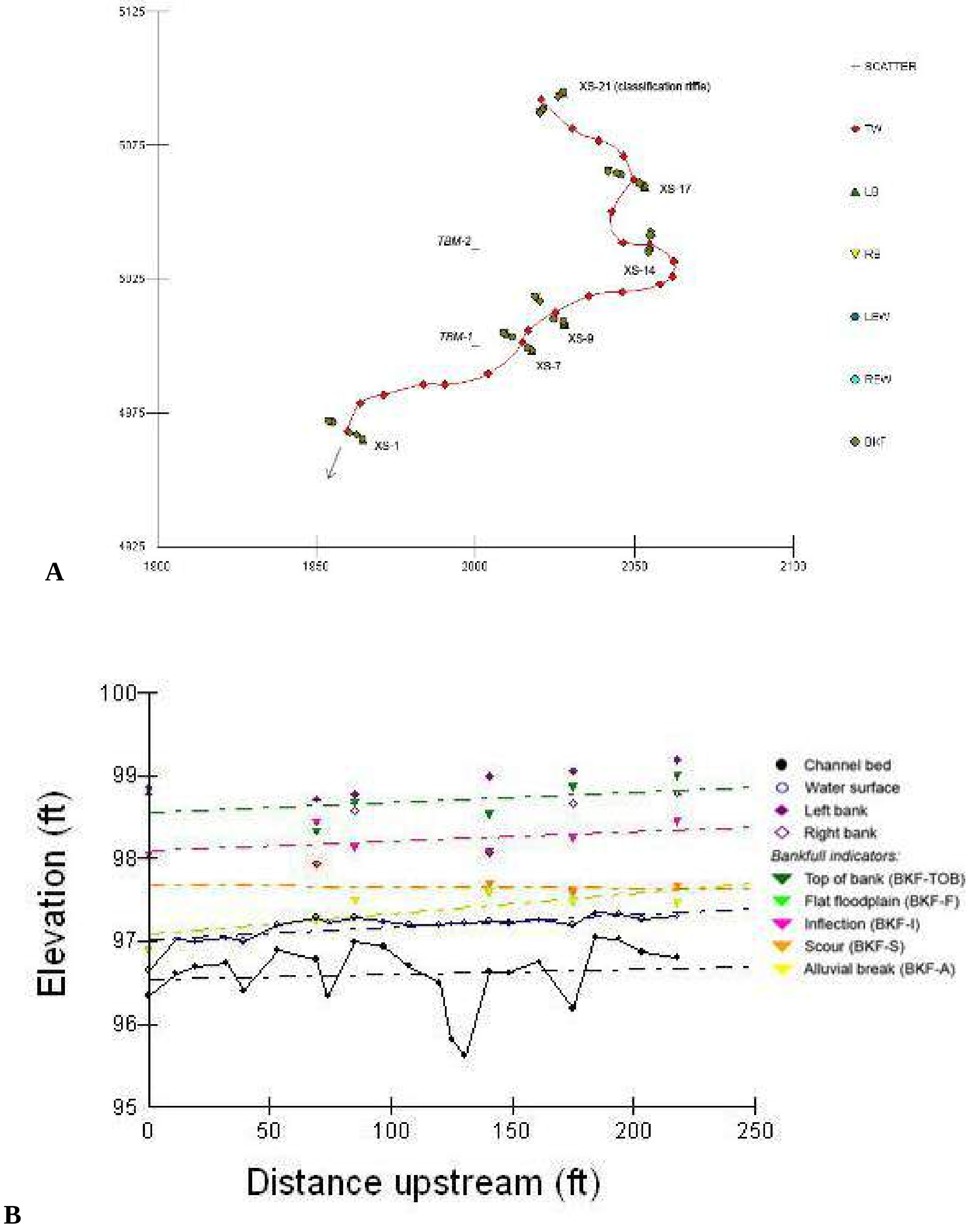
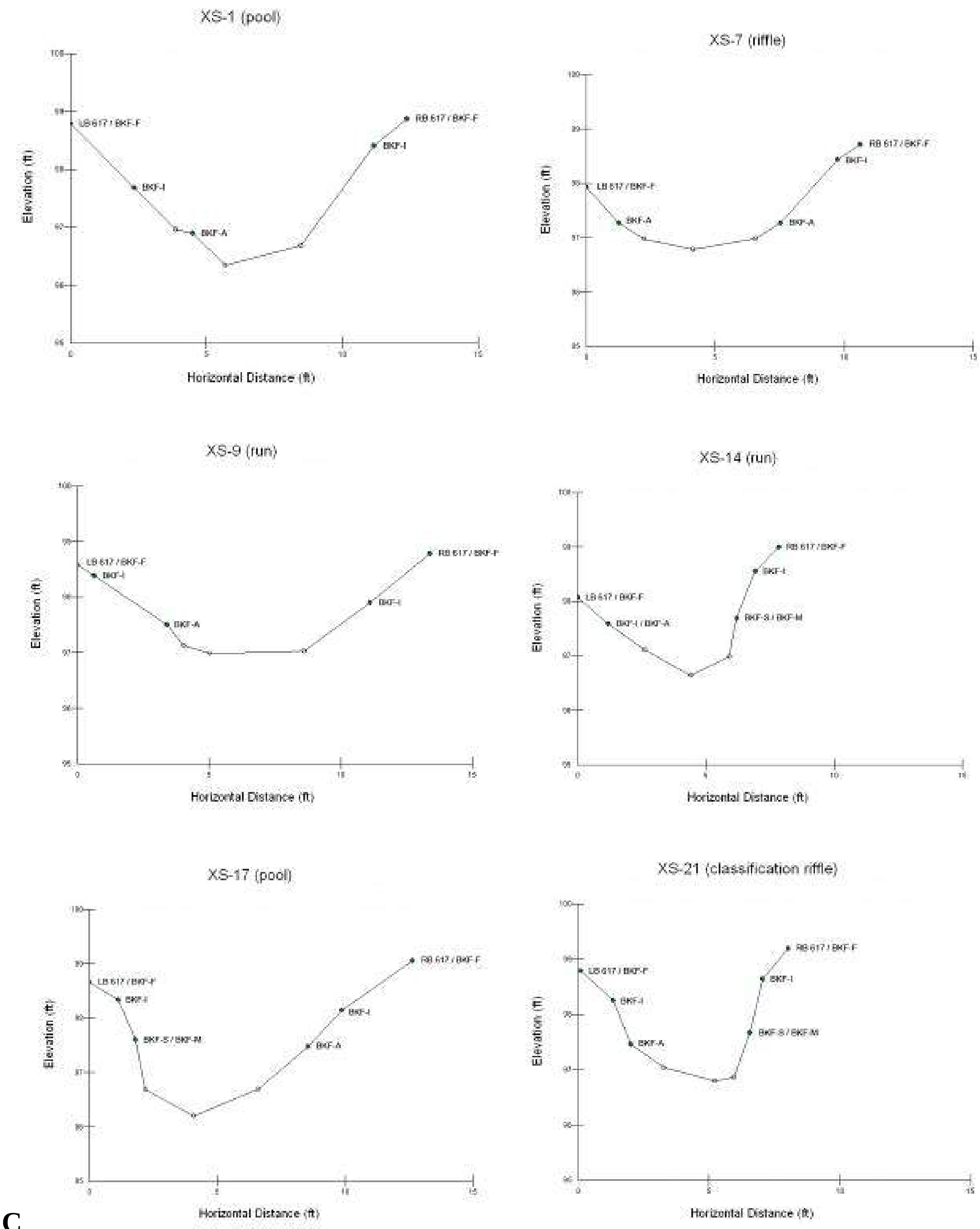


Figure F-56. Wekiva Forest UT. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.



C

Figure F-56 (Cont.). Wekiva Forest UT. A) Plan Form. B) Longitudinal Profile. C) Cross-Sections.

Appendix G

SITE PHOTOGRAPHS

SITE PHOTOGRAPHS

Alexander Spring Run

(March 31, 2008)

DOWNSTREAM

UPSTREAM

RIGHT BANK

LEFT BANK

Alexander UT2
(February 28, 2008)


DOWNSTREAM


UPSTREAM


LEFT BANK


RIGHT BANK

Alligator Spring Run

(September 7, 2008)

DOWNSTREAM

UPSTREAM

LEFT BANK

RIGHT BANK

Bell Creek

(October 4, 2007)

DOWNSTREAM

LEFT BANK

Bell Creek UT

(October 11, 2007)


DOWNSTREAM


UPSTREAM


LEFT BANK


RIGHT BANK

Blackwater Creek near Cassia

(March 3, 2008)


DOWNSTREAM


UPSTREAM


LEFT BANK


RIGHT BANK

Blues Creek near Gainesville
(January 10, 2008)


DOWNSTREAM


UPSTREAM


LEFT BANK


RIGHT BANK

Bowlegs Creek near Fort Meade

(December 3, 2007)

DOWNSTREAM

UPSTREAM

LEFT BANK

RIGHT BANK

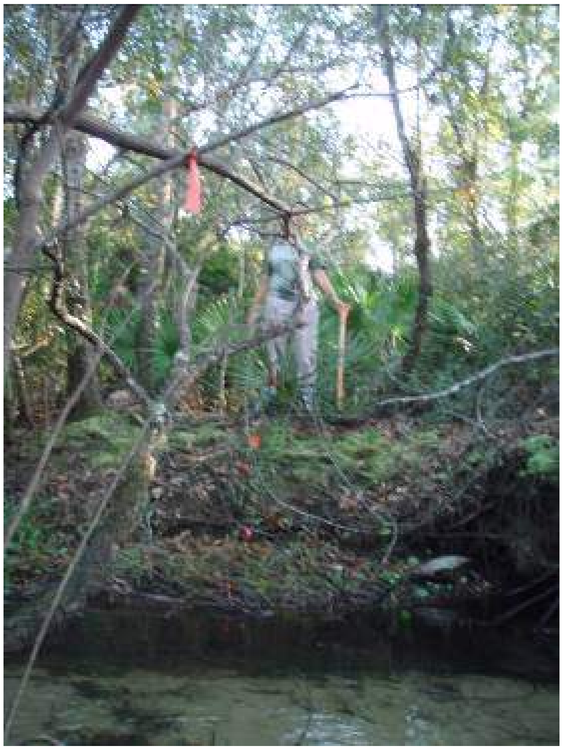
Carter Creek near Sebring

(December 7, 2007)

DOWNSTREAM

UPSTREAM

LEFT BANK



RIGHT BANK

Catfish Creek near Lake Wales

(September 27, 2007)

DOWNSTREAM

UPSTREAM

LEFT BANK

RIGHT BANK

Cedar Head Spring Run

(April 20, 2008)

DOWNSTREAM

UPSTREAM

LEFT BANK

RIGHT BANK

Coons Bay Branch

(November 13, 2007)

DOWNSTREAM

UPSTREAM

LEFT BANK

RIGHT BANK

Cow Creek
(January 3, 2008)


DOWNSTREAM

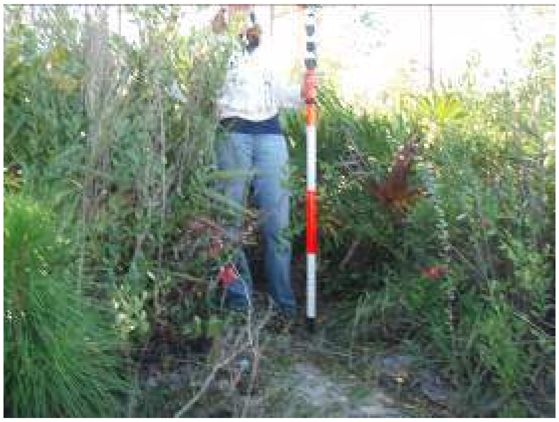

UPSTREAM


LEFT BANK


RIGHT BANK

Cypress Slash UT

(December 17, 2007)



DOWNSTREAM

UPSTREAM

LEFT BANK

RIGHT BANK

East Fork Manatee UT1
(November 5, 2007)


DOWNSTREAM


UPSTREAM


LEFT BANK


RIGHT BANK

East Fork Manatee UT2

(August 31, 2008)

DOWNSTREAM

UPSTREAM

LEFT BANK

RIGHT BANK

Fisheating Creek at Palmdale

(March 20, 2008)

DOWNSTREAM

UPSTREAM

LEFT BANK

RIGHT BANK

Forest Spring Run

(March 28, 2008)


DOWNSTREAM


UPSTREAM


LEFT BANK


RIGHT BANK

Gold Head Branch

(February 8, 2008)

DOWNSTREAM

UPSTREAM

LEFT BANK

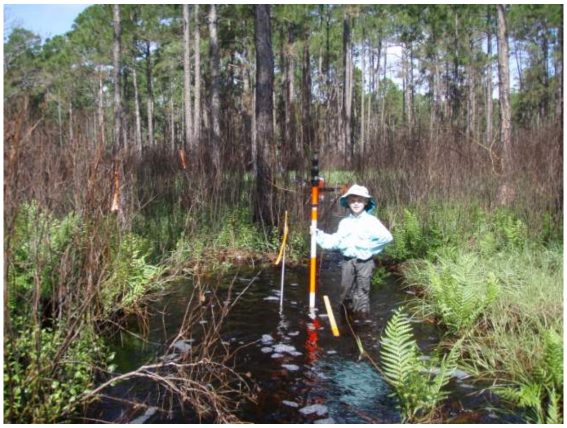
RIGHT BANK

Grasshopper Slough Run
(October 22, 2007)

UPSTREAM

LEFT BANK

Grassy Creek UT
(August 24, 2008)


DOWNSTREAM


UPSTREAM


LEFT BANK


RIGHT BANK

Gum Slough Spring Run

(August 9, 2008)

DOWNSTREAM

UPSTREAM

LEFT BANK

RIGHT BANK

Hammock Branch

(February 18, 2008)

DOWNSTREAM

UPSTREAM

LEFT BANK

RIGHT BANK

Hillsborough River UT

(November 1, 2007)

DOWNSTREAM

UPSTREAM

LEFT BANK

RIGHT BANK

Horse Creek near Arcadia
(March 17, 2008)

DOWNSTREAM

UPSTREAM

LEFT BANK

RIGHT BANK

Jack Creek
(December 13, 2007)


UPSTREAM

Jumping Gully

(February 7, 2008)

DOWNSTREAM

UPSTREAM

LEFT BANK

RIGHT BANK

Juniper Spring Run
(March 22, 2008)


DOWNSTREAM


UPSTREAM


LEFT BANK


RIGHT BANK

Kittridge Spring Run
(September 6, 2008)


UPSTREAM


DOWNSTREAM


RIGHT BANK


LEFT BANK

Lake June-in-Winter UT

(December 10, 2007)

DOWNSTREAM

LEFT BANK

RIGHT BANK

Little Haw Creek near Seville

(February 29, 2008)

DOWNSTREAM

UPSTREAM

LEFT BANK

RIGHT BANK

Little Levy Blue Spring Run

(September 13, 2008)

DOWNSTREAM

UPSTREAM

RIGHT BANK

Livingston Creek near Frostproof

(December 5, 2007)

DOWNSTREAM

UPSTREAM

LEFT BANK

RIGHT BANK

Lower Myakka River UT2
(October 16, 2007)


DOWNSTREAM


UPSTREAM


LEFT BANK


RIGHT BANK

Lower Myakka River UT3

(September 9, 2008)

UPSTREAM

DOWNSTREAM

RIGHT BANK

LEFT BANK

Lowry Lake UT

(February 14, 2004)


DOWNSTREAM


UPSTREAM


LEFT BANK


RIGHT BANK

Manatee River near Myakka Head

(November 9, 2007)

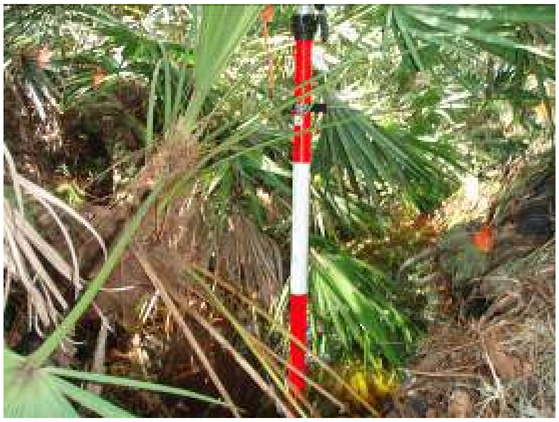
DOWNSTREAM

UPSTREAM

LEFT BANK

RIGHT BANK

Manatee River UT
(November 2, 2007)


DOWNSTREAM


UPSTREAM


LEFT BANK


RIGHT BANK

Morgan Hole Creek
(December 17, 2007)


DOWNSTREAM


UPSTREAM


LEFT BANK


RIGHT BANK

Mormon Branch UT Spring Run

(August 3, 2008)

DOWNSTREAM

UPSTREAM

LEFT BANK

RIGHT BANK

Moses Creek near Moultrie

(January 18, 2008)

DOWNSTREAM

UPSTREAM

LEFT BANK

RIGHT BANK

Ninemile Creek

(March 12, 2008)

DOWNSTREAM

UPSTREAM

LEFT BANK

RIGHT BANK

Rice Creek near Springside
(January 11, 2008)


DOWNSTREAM


UPSTREAM


LEFT BANK


RIGHT BANK

Rock Spring Run

(March 27, 2008)


DOWNSTREAM


UPSTREAM


LEFT BANK


RIGHT BANK

Santa Fe River near Graham

(January 16, 2008)

DOWNSTREAM

UPSTREAM

LEFT BANK

RIGHT BANK

Shiloh Run near Alachua
(January 8, 2008)


DOWNSTREAM


UPSTREAM


LEFT BANK


RIGHT BANK

Silver Glen UT Spring Run

(March 30, 2008)

DOWNSTREAM

UPSTREAM

RIGHT BANK

LEFT BANK

Snell Creek

(November 12, 2007)

DOWNSTREAM

UPSTREAM

LEFT BANK

RIGHT BANK

South Fork Black Creek
(February, 2008)


DOWNSTREAM


UPSTREAM


LEFT BANK


RIGHT BANK

Tenmile Creek

(March 6, 2008)

DOWNSTREAM

UPSTREAM

LEFT BANK

RIGHT BANK

Tiger Creek near Babson Park

(March 14, 2008)

DOWNSTREAM

UPSTREAM

LEFT BANK

RIGHT BANK

Tiger Creek UT
(December 6, 2007)

DOWNSTREAM

UPSTREAM

LEFT BANK

RIGHT BANK

Tuscawilla Lake UT
(January 28, 2008)

DOWNSTREAM

UPSTREAM

LEFT BANK

RIGHT BANK

Tyson Creek

(December 18, 2007)


DOWNSTREAM


UPSTREAM


LEFT BANK


RIGHT BANK

Weeki Wachee River
(June 20, 2008)

UPSTREAM

DOWNSTREAM

LEFT BANK

RIGHT BANK

Wekiva Forest UT
(October 30, 2007)


DOWNSTREAM


UPSTREAM


LEFT BANK


RIGHT BANK