# Technical Memo

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Project No. 600048.2

**CC:**

**Date:** December 19, 2016 (Revised September 19, 2019)

**Re:** Task 3: Phillippi Creek Channel System Classification

## 1.0 BACKGROUND AND OBJECTIVES

The Phillippi Creek watershed has an extensively modified drainage network, largely consisting of canals constructed along the former wetland strands and sloughs that occurred prior to development. The canal system has improved drainage in support of residential and commercial land use, but has had some unintended environmental consequences concerning downstream water quality impacts, excessive sedimentation, and extensive natural aquatic and wetland habitat losses. Most of the canals are trapezoidal in cross-section and lack woody vegetation on their banks. These unnatural conditions lack an energy-dissipating floodplain, which when coupled with banks held together by low-strength grasses instead of plants with stronger roots masses, makes the channels more susceptible to erosion than a natural stream. This erosion is associated with a significant amount of Sarasota County's open channel maintenance budget.

The primary purpose of the overall project (Tasks 1-10) is to provide procedures most likely to reduce the long-term operation and maintenance costs of the canals. In other words, to enable the channel systems to become more self-sustaining. Investments that reduce the perennial maintenance and operation costs and that will concurrently improve downstream water quality, reduce sedimentation, improve fish habitat, and create recreational/aesthetic conditions for public benefit will be conceived and described. In essence, the design philosophy is to migrate canal corridor conditions closer to those of natural riparian corridors without compromising the primary flood protection mission of the drainage network. Florida riparian corridors often naturally include patterns of in-line wetlands, strands and sloughs as well as open stream channels.

To meet the overall project goal of providing cost-effective channel improvement recommendations, a channel classification system must be developed. The specific objectives of this **Task 3** technical memo is to describe the methods used to derive a channel classification system and summarize data analysis results.

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The framework for a classification system is presented for use with watershed data and channel data. The classification system was developed to meet the needs of the County for an overview of watershed and channel data in the Phillippi Creek watershed on a basis that helps prioritize improvement projects in a logical and transparent manner. The proposed system uses features of existing widely used classification systems that are amenable to watershed data derived from GIS. It is left open-ended so it can be flexible to meet specific needs. The information acquired and used to develop the classification system is interrelated and will aid in understanding the complex dynamics that drive the physical and biological structure and processes of the canal systems.

Following this technical memo in future project tasks, high-functioning alternatives will be proposed as part of the overall project, which will typically require investments associated with reconfiguring canal shape, dimension, control structures, shoreline, bank and corridor vegetation. A matrix of cost, co-funding potential, risks, and benefits will vary not only in terms of the functional gains sought, but will depend on the intrinsic and extrinsic characteristics of each canal segment related to channel condition and location. This level of complexity suggests value in developing a prioritization matrix derived from a conceptual model with good geographic portability around the watershed and similar areas across the County. The main project deliverable that will be developed later is not going to merely be a static checklist of ranked canal segments, but a management system (MS) that can be applied in a more flexible manner as conditions and understanding change over time. The 'existing channel type and current conditions' were incorporated into the channel classification framework that will influence much of the rest of the MS. The MS will be hierarchical in structure, with improvability, cost, and co-funding options differing among certain high-level categories such as canal type and landscape setting. The MS will account for and compare channel factors including:

- Existing channel type and current conditions (canal type),
- Landscape setting and corridor condition (fragmented versus contiguous with high-functioning areas, upstream and downstream eco-linkages, watershed condition),
- Improvability (sedimentation, nutrient water quality, aesthetics, fishery habitat, fish passage, drainage, wildlife corridor),
- Routine management costs of the channel ($),
- Erosional status and susceptibility (risks to external infrastructure – roads, buildings; risks to canal stability and hydraulic capacity; sedimentation risks to nature and downstream navigability),
- Maintenance and management logistics (accessibility, remoteness, equipment needed, crew safety),
- Costs of improvements ($),
- Co-funding potential ($).

First knowing the watershed and valley setting in the upper tier of a canal classification will thus aid in honing in on the available and best solutions for each canal segment.  Conversely, some of the factors related to risk, key linkages, and logistics might vary independently of the classification (like how accessible the reach is from a public road, or the location of a barrier to fish passage) and such variables may best be conceived as index adjusters acting outside of the classification structure, thus enabling their use on an 'as applicable and as needed' basis. The MS will be accompanied by a guidance manual describing:

- The various kinds of existing open channel types and corridor settings (**Task 3**),

- A map of channel segment types in the Phillippi Creek watershed,
- A review of the existing maintenance program, its costs, and suggested near-term improvements to reduce costs (if any),
- Management and design concepts to reduce long-term maintenance activities while achieving various functional improvements and their unit costs; by improvement category as applicable for each channel type and setting,
- An overall investment cost model comparing existing program costs versus those necessary to achieve self-maintaining systems (with a breakeven analysis),
- DSS flow chart and scoring criteria,
- A prioritization of 12 projects to serve as a working example of applying the MS, as a jump-start toward high-level benefits.

## 2.0 CHANNEL SYSTEM CLASSIFICATION METHODS

The classification system was developed from desktop and field condition information. The central scientific discipline relied upon was fluvial geomorphology, which is the study of how flowing water shapes land. It is largely forensic work, relying upon the weight of evidence provided from multiple lines of investigation. Our team led the development of a classification system for natural Florida streams and applied a similar approach to the Phillippi Canal classification (Kiefer et al. 2015, Amec 2013). This approach is hierarchical in scale, incorporating information from the watershed, valley, and channel reach. It is also inter-disciplinary; using variables in hydrology, biology, and soil science that often associate with key processes controlling geomorphic patterns, stability and sediment transport, fish and wildlife habitat, and channel dimension in riparian corridors.

The larger overall channel network system was classified into smaller groups using multiple watershed and channel parameters such as drainage area, stream order, channel dimension, shape, flow, sediment, habitat, etc. In this section and the following sections, the methodology used to develop the canal classification system will be discussed and a summary of the results will be presented. The general idea is to have a modular classification and ranking system. The proposed system is hierarchical in scale in that it starts with an understanding of how canals vary based on position in the drainage network, valley form, and watershed characteristics before adding considerations within a canal reach such as bank configuration, in-stream fish habitat, riparian corridor vegetation, and erosional status.

The system is modular to facilitate objectives that vary with scope and scale. For example, at its most basic level the system can be used to rank canals for priority actions based solely on reach scale variables (especially bank instability and maintenance costs). This scale can be prioritized because it is the one most directly addressing the maintenance problems and costs determined in **Task 2**. This is a retrospective statement as the methods deployed for **Task 3** included a determination that the primary erosional stressors were derived from local bank conditions and management approaches operating at the reach scale, not at the watershed scale. However, watershed scale considerations are important when seeking benefits related to habitat connectivity and water quality. Therefore, the reach-scale rankings can be adjusted based on a suite of broader objectives related to different combinations of fish passage, downstream pollution abatement, upstream stormwater management, and the development of terrestrial wildlife corridors.

Opening the classification and ranking system up to include network scale considerations also has the benefit of helping to identify where canal management and multiple Sarasota County objectives may intersect. These could include enhancing the recreational fishery; providing nature and bird watching opportunities; contributing to nutrient criteria, TMDL and MS4 compliance; and protection of the tidal portion of Phillippi Creek and Sarasota Bay from excessive sedimentation. For these reasons, watershed-scale classifiers could be used to prioritize entire segments of canals prior to ranking them based on reach scale problems. This has the value of working toward holistic means while recognizing that budget limitations may require working in a somewhat piecemeal fashion over time.

For hypothetical example, the County may wish to establish a combined fish habitat and terrestrial wildlife and pedestrian corridor connecting two currently fragmented habitat nodes such as the Celery Fields Park and Pinecraft Park. Potential connecting routes would be identified and the canal segments along the selected route could then be ranked for enhanced maintenance priorities and/or capital improvements based on their erosional status and riparian corridor characteristics, including cost savings from reduced maintenance activities as part of the ranking. Canals near small 'hinge-point' projects necessary to meet biological objectives, such as new sediment traps or removal of barriers to fish passage, could be weighted more heavily so they could be highly prioritized and thus incorporated into the smaller construction projects thereby enlarging the project to create more favorable economies of scale for contractors bidding on such work.

In another example, the County has identified the junction between canals Main A and Main C near I-75 as a high-maintenance area greatly affected by powerful flow surges and sedimentation from upstream sources. The costs and benefits of placing a sediment trap at that location, controlling erosion sources upstream, and implementing other canal improvements to service water quality, habitat, or recreational goals could be explored in part by describing and ranking all the canals contributing flow to that junction. These two examples illustrate the implementation of a stratified ranking system, whereby logical subsets of canals are first placed into objective-based groups and then subsequently are ranked for funding priorities and scheduling order. This kind of arrangement drives piecemeal work inexorably toward achieving the necessary scope and scale thresholds required to make tangible functional gains in the system.

## 2.1 Study Area and Canal Segment Locations

**Figure 1** provides the location of the study area and the canal segments evaluated in the Phillippi Creek watershed. The canals are located on the west coast of Florida in Sarasota County. Twenty-one canal segments were evaluated as part of this study. However, one of the canal segments was not included in the classification effort due to saltwater intrusion found in that segment. The entire study area encompasses 56 square miles, with 20 individual sub-basins associated with the canal segments.

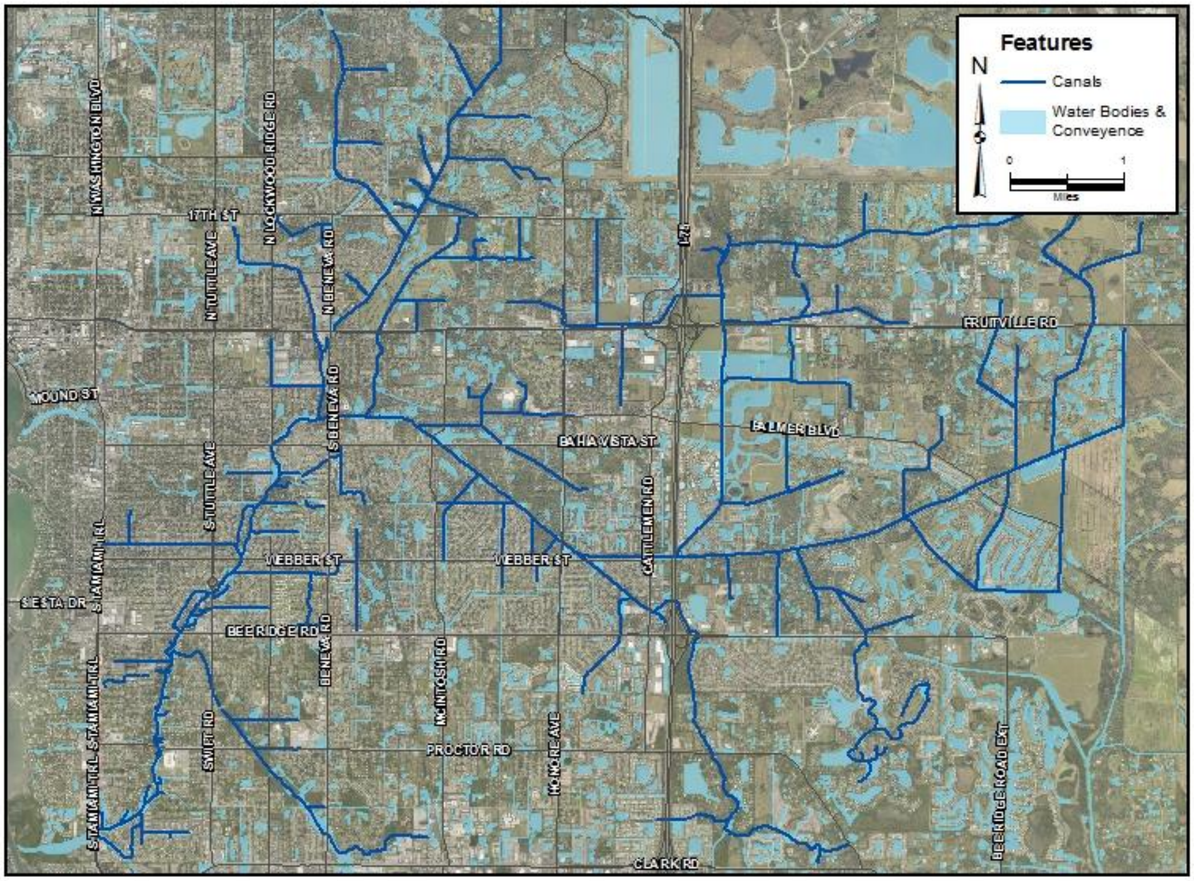


**Figure 1. Phillippi Creek Canals**

## 2.2 Data Acquisition and Compilation

GIS data, other relevant data and documents were provided by the County. In addition, field visits were conducted in May 2016 to collect additional field information for each canal segment. All of the information gathered for the project was compiled into a database and used for data analysis and to develop the canal classification system.

The following GIS layers were acquired and assembled into a working MXD (with source in parenthesis):

- Canal I.D. Maps (Sarasota County)
- LiDAR (Sarasota County)
- Easements (Sarasota County)
- Land Use (Sarasota County)
- Vegetative Cover (Sarasota County)
- Aerials (1995-present) (Sarasota County)
- Utilities with Valve Size (Sarasota County)
- Soils (SSURGO)
- TMDL WBIDs (FDEP)

- NPDES MS4 and Point Source Discharges (Sarasota County)
- Flood-prone areas or level-of-service deficiencies (Sarasota County)
- Areas of recurring maintenance activities (Sarasota County)
- Drainage area of sub-basins (calculated by Amec Foster Wheeler)
- Longitudinal Valley Slope along canal segment (calculated by Amec Foster Wheeler)

The following relevant information was received from the County and reviewed: the Roberts Bay North Watershed Management Plan (Sarasota County 2011), sediment sump design reports and plans (Sarasota County), channel cross-sections (Sarasota County), and Canal O&M Activities/Protocols and associated tracking data of labor, materials, equipment (via Maximo) and other available and related expenses (Sarasota County).

Field surveys were conducted at each canal segment. Cross-sectional, longitudinal, and in-stream habitat surveys were completed along a minimum reach length of 300 ft. Bankfull width, depth, and top of bank dimensions were recorded. Cross-sectional profiles were derived from the survey data. During the field visits, photographs and field notes were recorded to document the physical, stream habitat and hydroecological characteristics of each canal segment. The field assessment for each canal segment included documentation and calculations of the following specific channel and associated parameters:

- Channel shape, dimension (bank and bankfull width/depth)
- Bank condition (degree of erosion: absent, grade control loss, bank loss – and type of failure, etc.), vegetative cover, density and composition
- Bed condition and substrate (cover and composition)
- Instream habitat (vegetation or other)
- *In-situ* water chemistry (temperature, specific conductance, salinity, dissolved oxygen, pH)
- Corridor condition, vegetative cover, composition, accessibility
- Palustrine habitat and buffers
- Workable Easement Width
- Bank slope
- Bank height
- Bank height ratio (= top-of-bank height/bankfull depth)

Additional calculated variables were made to compare departures of canal condition from natural channels in Florida, using regressions developed in Kiefer et al. (2015) to compare channel dimension to drainage area. Variables calculated included:

- Active floodplain width for natural Highlands streams
- Active floodplain width for natural Flatwoods streams
- Bankfull channel dimensions (width, thalweg depth, cross-sectional area)
- Zone of confidence for alluvial versus vegetated channels (valley slope versus drainage area)

### 2.3 Canal Classification Matrix Development

The compiled database that included the field data, GIS data, and other relevant data was used to develop the canal classification matrix. To create the matrix, qualitative data were transformed into categorical units and then used to rank each of the canal segments. In addition, quantitative data were also transformed into ranks to develop the matrix. The idea was to create a ranking system that operated primarily at the canal reach scale and accounted for canal needs, prioritizing those requiring routine maintenance activities and that cause environmental or infrastructural harm. Once such ranks are established they were then modified by factors related to logistics, economics, restoration potential, and watershed scale objectives. Thus, the ranking system was designed to be hierarchical in a way that should facilitate a science based approach to prioritizing work, while allowing portability and professional judgement in its application. The categorical units derived from the qualitative data were also used for other data analyses as described below.

## 2.4 Data Analysis

A total of 33 parameters compiled from the field data, GIS data, and other relevant data were compiled for 20 canal segments into a database and were used for multivariate data analysis (**Table 1**). Qualitative data were transformed into categorical units to provide numerical data necessary for these analyses in developing the classification system. Additional bank stability parameters were derived from field measurements and used in the geomorphic assessments to aid in the development of the classification and ranking system (**Table 2**).

**Table 1. Parameters for Multivariate Analyses**

| Watershed and Drainage Network Variables | |
|---|---|
| Parameter Name | Description |
| STRAHLER | Stream order in the drainage network. Headwater streams are low order and downstream canals are higher order |
| DA_SQMI | Canal's drainage area in square miles |
| VS_PERC | Canal's longitudinal valley slope in percent (V/H distance x100) |
| A | Percent well drained soils in the canal's drainage area |
| B | Percent moderately well drained soils in the canal's drainage area |
| D-Combined | Percent poorly drained soils in the canal's drainage area. Includes D, A/D, B/D, and C/D soils thus representing the pre-development conditions. |
| 200+300 | Percent grasslands in the canal's drainage area |
| 500 | Percent open water in the canal's drainage area |
| 100+800 | Percent developed land in the canal's drainage area |
| 400+600 | Percent native upland forest and wetland in the canal's drainage area |
| TOTAL%IMP | Percent total impervious area in the canal's drainage area |

**Table 1 continued**

| Reach Geomorphic Variables | |
|---|---|
| Parameter Name | Description |
| Bed Condition | Stable or unstable (aggrading, degrading) |
| Bed Substrate | Vegetated, unvegetated, mixed |
| Left Bank Condition | Stable or unstable (rills and gullies; toe scour; shallow plane failures/face erosion; massive gravity failures/slab failure/scalloping) |
| Left Bank % Raw | Percent actively eroding bank surface (0-25%, 25-50%, 50-75%, >75%) |
| Right Bank Condition | Stable or unstable (rills and gullies; toe scour; shallow plane failures/face erosion; massive gravity failures/slab failure/scalloping) |
| Right Bank % Raw | Percent actively eroding bank surface (0-25%, 25-50%, 50-75%, >75%) |
| Bankfull Width | Width of alluvially active open channel in feet |
| Top of Bank Width | Canal top width in feet |
| Bankfull Depth | Depth of alluvially active open channel in feet |
| Top of Bank Depth | Canal top depth in feet |

| Canal Bank and Riparian Corridor Vegetation[1] | |
|---|---|
| Parameter Name | Description |
| Left Bank Vegetation | Heavy tree canopy, mixed tree canopy/shrubs, mixed tree/unmowed herbaceous groundcover, mixed tree/mowed groundcover, heavy shrubs, unmowed groundcover, mowed groundcover, mowed turf grass |
| Right Bank Vegetation | see above |
| Left Bank Density | Closed canopy, mixed trees and open, scattered trees, open |
| Right Bank Density | see above |
| Left Corridor Access | Mowed right-of-way, no terrestrial access |
| Right Corridor Access | see above |
| Left Corridor Veg. | same categories as for bank vegetation |
| Right Corridor Veg. | same categories as for bank vegetation |
| Left Corridor Veg. Comp | Native, non-native, mixed |
| Right Corridor Veg. Comp | see above |
| Left Corridor Density | same categories as for bank density |
| Right Corridor Density | same categories as for bank density |

[1] The vegetation was assessed in two positions within the canal right-of-way, plants on the canal banks from top-of-bank to the toe versus plants growing above top-of-bank in the terrestrial part of the riparian corridor

**Table 2. Additional Variables**

| Parameter Name | Description |
|---|---|
| ROW_W | Right-of-way width estimated from field observations and GIS |
| BHR | Bank height ratio. Top-of-bank height divided by bankfull depth |
| FPL_W | Active floodplain width of a natural stream. This is the wet season channel that fully floods during most years. |
| XSA | Bankfull channel cross-section area |
| SS | Canal bank side slope. Feet horizontal divided by feet vertical |
| Mowed | Categorical variable for banks that are routinely mowed (1) versus those that are not (0) |
| Woody | Categorical variable for banks that are heavily forested by trees and woody shrubs (1) versus those that are not (0) |
| Stable | Categorical variable for banks or canals that are stable (1) versus those that are actively and excessively eroding (0) |

The analysis consisted of three main pieces. The first piece consisted of field reconnaissance. This **Task 3** memo provides the results and interpretation of field variables used to document the kinds of problems observed and diagnose causes of stability and instability in the system.

The second piece of analysis used data collected at the reach, valley and watershed scales of each canal to assuage the degree to which canal fluvial geomorphology, corridor geometry, and riparian plant communities vary throughout the drainage network. The variables are similar to those used in a natural stream classification system for peninsular Florida streams (Kiefer et al., 2015), referred to as a hydrobiogeomorphic classification. This approach recognizes that streams belong to their watersheds and that their stable patterns, dimensions, and riparian habitats are all inter-related. The dominant processes are fluvial and biological, which vary along gradients related to drainage area, soil drainage, valley morphology, and groundwater sources. The main reason for doing this is that headwater streams do not function the same way as streams lower in the drainage network, thus it is important to understand where main differences are likely to occur. Regressions were developed relating various aspects of canal dimension to drainage area and these were visually compared to similar regressions developed for natural peninsular Florida streams in an effort to interpret and describe how the canal fluvial geomorphology departs from natural systems in the region. Multivariate, exploratory statistics including Principal Components Analysis (PCA) and Hierarchical Cluster Analysis (HCA) were used as classification aids.

PCA was employed to investigate the parameters which caused variations in the observed dataset. PCA was used to determine which of the 33 parameters were the most important and accounted for the highest variability across the canal segments. The technique is useful in the analysis of dependence between more than two variables. It can also be used when multiple variables include both dependent and explanatory variables. PCA can simplify a highly complex dataset and make data easier to understand and interpret.

Performing PCA is an iterative process. First, eigenvalues (variances) and principal components were computed. Then the components that cumulatively account for at least 90% of the total variance were determined. After those components were identified, then the number of parameters were reduced in preparation for rotating the variables to obtain new variables and maximize the percentage of variance accounted for by the smallest number of components. The varimax rotation technique was used in this study, which includes an orthogonal rotation. Essentially, the unimportant components (and associated parameters) found by the varimax rotation were eliminated and the most important variables are retained.

Cluster analysis was performed to cluster the parameters and canal segments into groups. Another reason for conducting cluster analysis was to support or refute PCA results in reducing the number of parameters that are important to the structure of the canal segment dataset. Cluster analysis uses a hierarchical clustering procedure. The number of parameters and/or canal segment locations are reduced or classified into smaller groups by combining parameters based on similar characteristics. At each amalgamation step, two clusters' variables are joined until only one cluster remains. The similarity or distance between the clusters is provided as a resulting factor, which is also based on the linkage method selected, which can include complete or Ward linkage. For the final partition into clusters, it is best to have large similarity levels or low distance between the joined clusters.

The third part of analysis invoked bivariate comparisons of variables likely to associate with bank stability and erosion. Statistical tests included comparisons of means (t-test) when the data fit parametric distributions, comparison of medians when the data was non-parametric (Mann Whitney test), and chi-square analysis with Fischer's exact test for differences between actual and expected occurrences among categorical variables. The bank erosion statistical analyses explored differences among stable and unstable banks regarding mowing, woody vegetation, bank height, bank slope, and bank height ratio.

## 2.5 Canal Segment Inventory

Data derived from the classification system that was developed using the results of the matrix and data analyses were used to provide a tabular inventory of the Phillippi Creek basin channel segments including their Legacy ID, GIS Identifier, Classification Matrix, and Ranking Table. The Legacy ID is the existing County nomenclature for each channel and the GIS Identifier was created by Amec Foster Wheeler based on physical or biological change points within each Legacy segment, as applicable. For example, a segment (Legacy ID) may be divided into two reaches (GIS ID) at a tributary junction or at a point between two differently sloped areas within the segment.

## 3.0 RESULTS

### 3.1 Field Assessment

Various forms of erosion were observed on 11 (28%) of the 40 canal banks investigated, affecting 9 (45%) of the 20 canals visited. Erosion occurred across much of the watershed, including a variety of large and small canals. Our team noted that more forms of erosion and greater frequency of erosion occurred on mowed versus forested banks. This was particularly striking because in many instances one bank of a canal was mowed or otherwise non-woody and unstable, while its opposite partner was wooded and stable (**Figure 2**). In almost all cases where such pairs were observed and the mowed bank was eroding, the woody bank was stable.


**Figure 2. Stable Woody versus Unstable Non-Woody Banks (Canal 302).**

Bank instabilities included shallow plane failures, rills, gullies, and toe scour (**Figures 3 and 4**). The form of erosion and position on the bank indicated that the majority of the erosion was caused by gravity failure and by pluvial forces (direct precipitation and overland flow across the top of the bank toward the stream). These kinds of erosion indicate banks that are not adequately internally reinforced by strong vegetation roots, are poorly armored by vegetative cover, or are too heavy to support their own weight (often due to unsustainable combinations of bank height and slope).

Toe scour is erosion caused by fluvial (riverine) forces where the bank meets the channel bed. This is where shear stresses from flow are greatest on the bank. Streams naturally create some toe scour, forming ‘overhanging banks’ and exposed root masses that are excellent fish habitat. Thus it is important to distinguish between desirable and undesirable degrees of scour. Basically, if the toe scour appears to be associated with gravity failures above it, then it is problematic. If the vast majority of the bank is stable above the toe scour, then it is likely acceptable. Unacceptable toe scour was typically only observed on banks also suffering shallow gravity failures high up on the bank surface and those due to pluvial erosion, suggesting that the toe scour was a secondary stressor. In two cases toe scour was observed in association with massive (as opposed to shallow) ‘scalloped’ bank failures (**Figure 2**). In such cases the toe scour is likely to be a primary stressor. This distinction is important because situations where toe scour is a primary stressor indicate hydromodification in the watershed as an important driver for channel erosion, while non-fluvial forms of erosion indicate the bank geometry and materials are the problem.

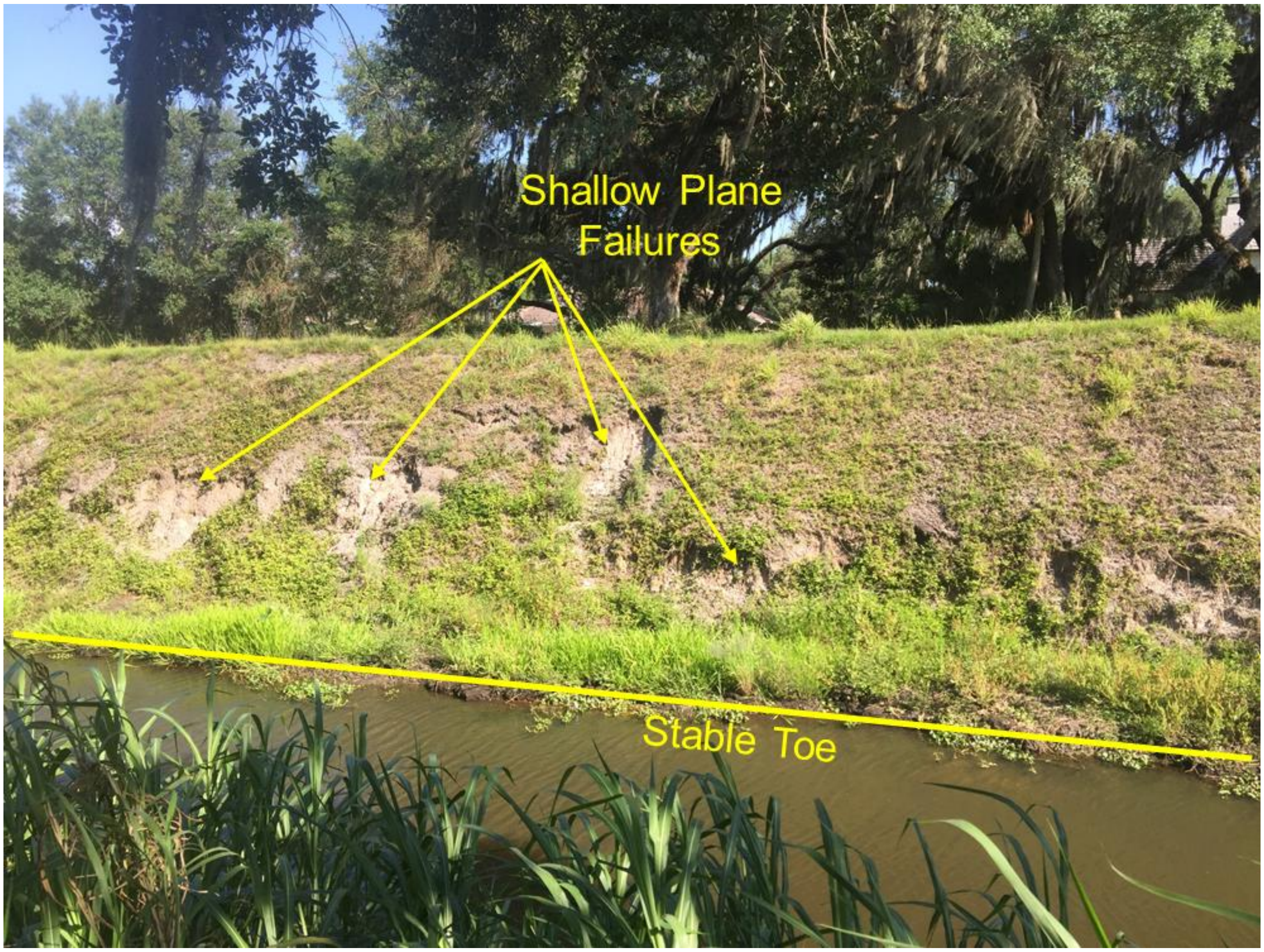


**Figure 3. Pluvial Erosion (Canal 15).**

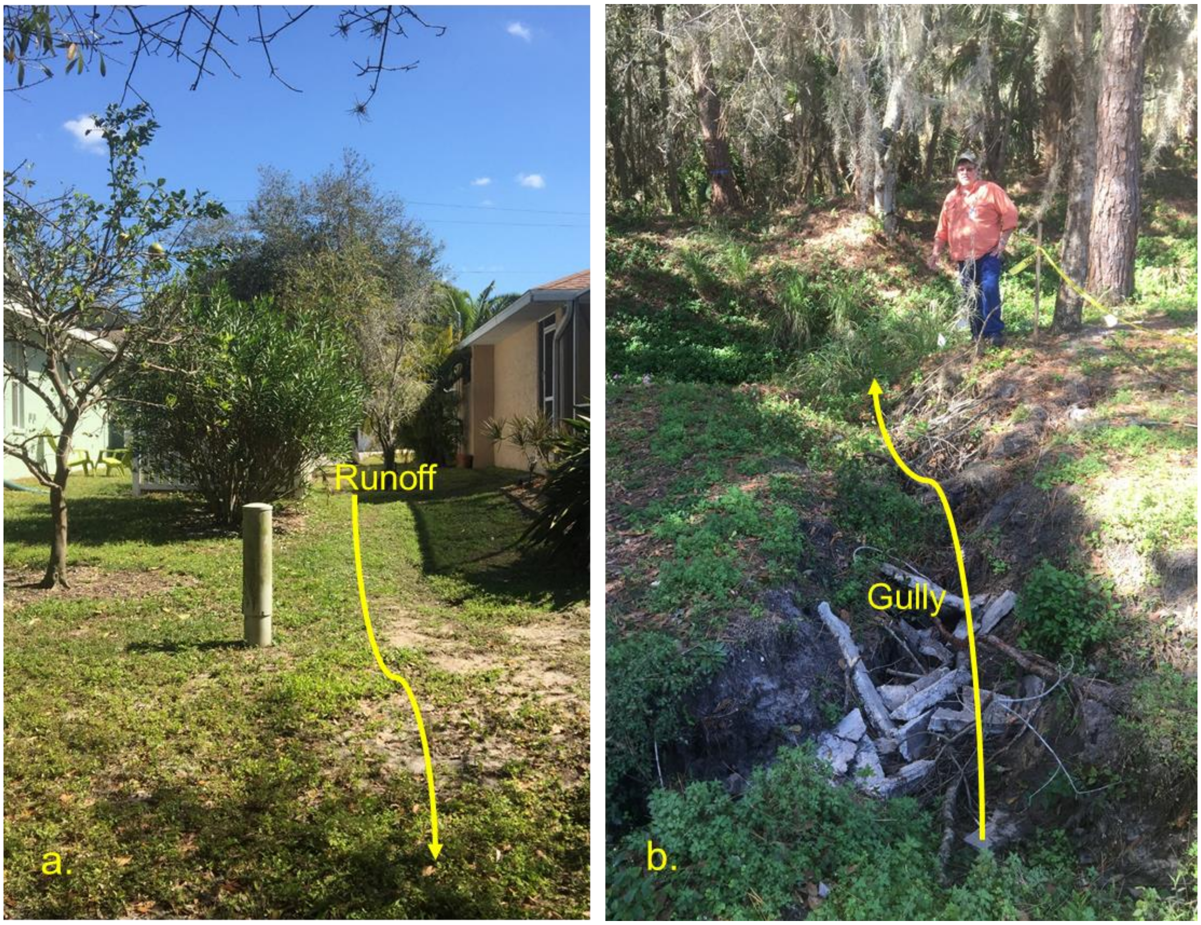


**Figure 4. Pluvial Erosion (Lake Sarasota Canal).**
a. Path of concentrated roof runoff to canal
b. Resulting gully erosion on canal bank immediately downstream of roof runoff path

Notably, bed scour (degradation) was only observed on one canal. Channel degradation is a serious issue and grade control treatments should be deployed rapidly to contain such erosion before it can destabilize both banks as it migrates upstream. This was implemented in the canal where it was observed using riprap (**Figure 5**). Bed scour is indicated by channels with combinations of exposed resistant layers, rather ubiquitous massive gravity failures, and migrating knickpoints. Since degradation is also characteristic of hydromodification effects, its general absence suggest hydromodification is not an issue in most of the drainage network, thus reinforcing the observations of bank condition in that regard.

Some canal beds indicated sediment accumulation (aggradation) (**Figure 6**). Aggradation is almost a given in the main stem canals located in the lowest and flattest areas in the drainage network. It means the canals receive more sediment than they can routinely transport. This could be caused by certain kinds of water withdrawals or by excessive sediment yields from stream or watershed erosion. Based on what is known about the watershed and our team's direct observations, excessive sediment yield is an issue and the SEU has implemented sediment trap projects accordingly. Two such traps were observed and appear to be working well.

Phillippi Creek's sediment loads are mostly from bank erosion, but reliable evidence of sediment transport was also observed from sparsely vegetated lawns to canals at 2 of the 20 studied canals. Canals receiving stormwater from dense lawns did not have such loads. Aggradation is problematic because sediments can clog culverts at road crossings, raise floodwaters, bury and simplify aquatic habitat, and carry pollutants downstream (**Figure 7**).


**Figure 5. Degradation with Migrating Knickpoint (Canal 15).**


**Figure 6. Aggradation and Sediment Plume**
**(Phillippi Creek downstream of Pinecraft Park)**


**Figure 7. Aggradation Associated with Aquatic Habitat Simplification (Phillippi Creek at Pinecraft Park)**

Geomorphic and vegetation data collected in the field was used in the fluvial geomorphic and bank analyses described below.

## 3.2 Fluvial Geomorphic Data Analysis

**Table 3** provides the results from the varimax rotation for the Principal Components Analysis (PCA). The top 11 extracted components (from the original 33) cumulatively accounted for 90.6% of the data variance. Based on the component loadings, 18 parameters are grouped accordingly with their designated components for parameters as follows (in order of importance):

- Component 1: A and D-type soils
- Component 2: Left Bank Density, Left Bank Vegetation, Left Bank Condition
- Component 3: Right and Left Bank % Raw
- Component 4: LU Code 400+600 (Upland+Wetland)
- Component 5: Bed Condition, Right Bank Vegetation
- Component 6: Bankfull Depth
- Component 7: Right Bank Condition

- Component 8: Top of Bank Width, Left Corridor Vegetation
- Component 9: Left Corridor Accessibility
- Component 10: LU code 500 (Water)
- Component 11: Bed Substrate

The 18 parameters shown above and in **Table 3** are considered to be the parameters most likely driving the variability across the 20 canal segment sites. Nine of the eleven components did not have dimensional variables loading on the component. In other words, the latent variables driving canal classification using PCA were influenced most heavily by dimensionless variables.

**Table 3. Rotated PCA Loading Matrix**

| | Component | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Variable** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| A-type soils | 0.978 | | | | | | | | | | |
| D-type soils | -0.979 | | | | | | | | | | |
| Left Bank Density | | -0.92 | | | | | | | | | |
| Left Bank Vegetation | | -0.637 | | | | | | | | | |
| Left Bank Condition | | -0.633 | | | | | | | | | |
| Left Bank % Raw | | | -0.872 | | | | | | | | |
| Right Bank % Raw | | | -0.935 | | | | | | | | |
| LU Code 400+600 (Upland+Wetland) | | | | 0.885 | | | | | | | |
| Total % Impervious | | | | -0.892 | | | | | | | |
| Bed Condition | | | | | 0.83 | | | | | | |
| Right Bank Vegetation | | | | | -0.886 | | | | | | |
| Bankfull Depth | | | | | | 0.913 | | | | | |
| Right Bank Condition | | | | | | | -0.885 | | | | |
| Top of Bank Width | | | | | | | | -0.384 | | | |
| Left Corridor Vegetation | | | | | | | | 0.917 | | | |
| Left Corridor Accessibility | | | | | | | | | -0.914 | | |
| LU code 500 (Water) | | | | | | | | | | -0.924 | |
| Bed Substrate | | | | | | | | | | | -0.877 |
| **Eigenvalue** | 2.2599 | 2.0854 | 2.0612 | 1.9016 | 1.6342 | 1.3519 | 1.3101 | 1.2989 | 1.1666 | 1.0851 | 1.0685 |
| **Total Variance %** | 11.9% | 11.1% | 10.8% | 10.0% | 8.6% | 7.1% | 6.9% | 6.8% | 6.1% | 5.7% | 5.6% |
| **Cumulative Variance %** | 11.9% | 23.0% | 33.8% | 43.8% | 52.4% | 59.5% | 66.4% | 73.2% | 79.3% | 85.0% | 90.6% |

Hierarchical Cluster Analysis (HCA) was used to determine if canal segments grouped together using the watershed and channel parameters. The dendrogram of the observed canal segment locations dataset was generated using distance as a Ward Linkage with Distance as a factor. Two major clustering groups were observed for the canal segment sites as follows:

| Canal Group | Canal Segment |
| --- | --- |
| 1. | 12, 15, 44, 68, 73, 161, 219 |
| 2. | 22, 45, 46, 48, 76, 95, 158, 184, 202, 218, 250, 302 |

Each cluster group may represent different hydrologic and ecologic forcing functions that are clearly represented in the data. Although not shown, for the most part, PCA results supported the results for the 2 canal segment groups that were also identified by cluster analysis as shown in **Figure 8.** The final separation between the canal segment sites following the varimax rotation was also very similar to what was found with cluster analysis. A scatter plot of canal bankfull[2] width versus drainage area shows that canals assigned to Group 1 in the PCA and HCA analyses were uniformly wider and drained larger watersheds versus those in Group 2 **(Figure 9**). When 3 groups are assigned from the HCA results, canals continued to be divided along a size gradient (**Figures 10 and 11**).

**Figure 12** shows each of the canal segments that fall within either Group 1 (a) or 2 (b) on a map including their respective sub-basins and landuse categories. From the map it can be seen that Group 1 (a) canal segments all fall on or adjacent to the main stem of Phillippi Creek. Group 2 (b) segments are all smaller tributaries or lateral canals. Canals sort strongly into 2 to 3 groups along gradients associated with system size and position in the drainage network when watershed and reach variables are considered holistically. This gradient does not extend to 4 groups, after which the divisions do not appear to offer further insight regarding canal or watershed conditions.

Canals draining greater than 8 square mile watersheds were assigned to a different group than those draining smaller basins in the two cluster assessment. The three cluster assessment offers that canals draining less than 2 square mile watersheds are clearly and fundamentally different from those draining 20 square mile basins, with an intermediate canal type in between. As reported in the Conclusions and Recommendations section, both of these conceptualizations offer useful insights based on our field observations and potential objectives for canal improvements.

[2] 'Bankfull stage' refers to a water level generally associated with conducting most of the work to maintain an open channel. It is typically greater than baseflow and less than flood flows, occurring several times a year in wadable Florida streams and is equaled or exceeded during the majority of the wet season in large Florida rivers. It can be interpreted using field indicators such as prevailing scour lines associated with bank inflections and the elevation of lateral bars along the channel margins. It can be difficult to assign bankfull stage in actively eroding streams, so the results reported here are approximate.

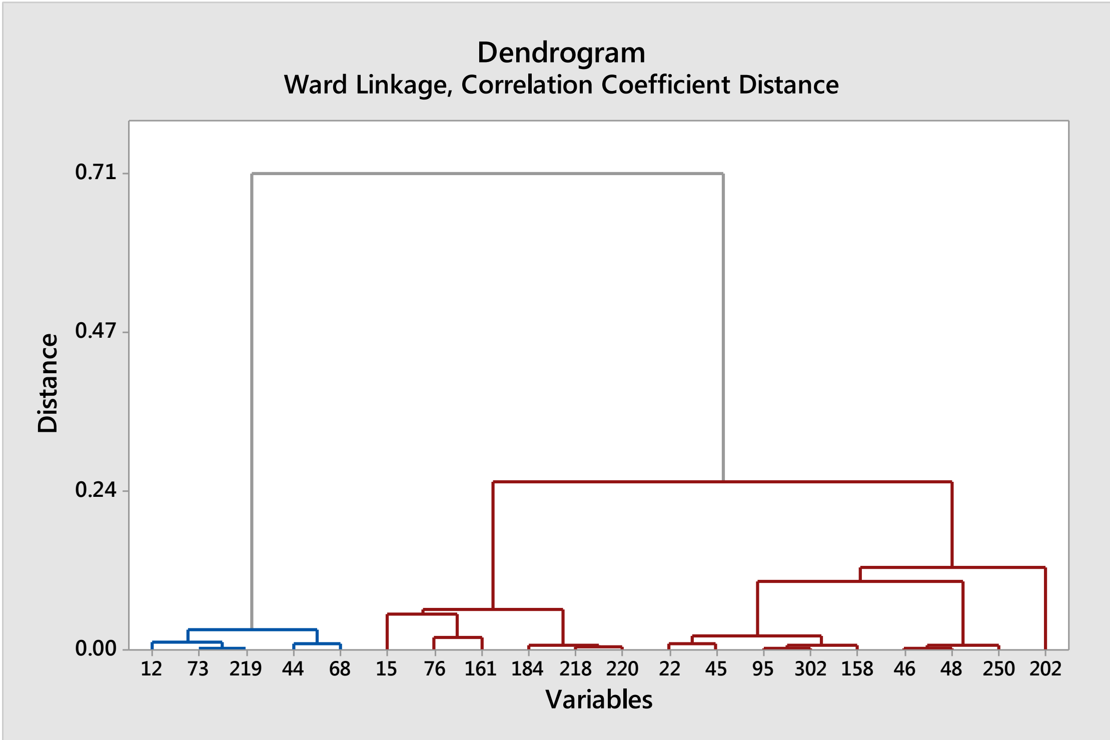


**Figure 8. HCA Dendrogram for 20 Canals (2 Clusters).**

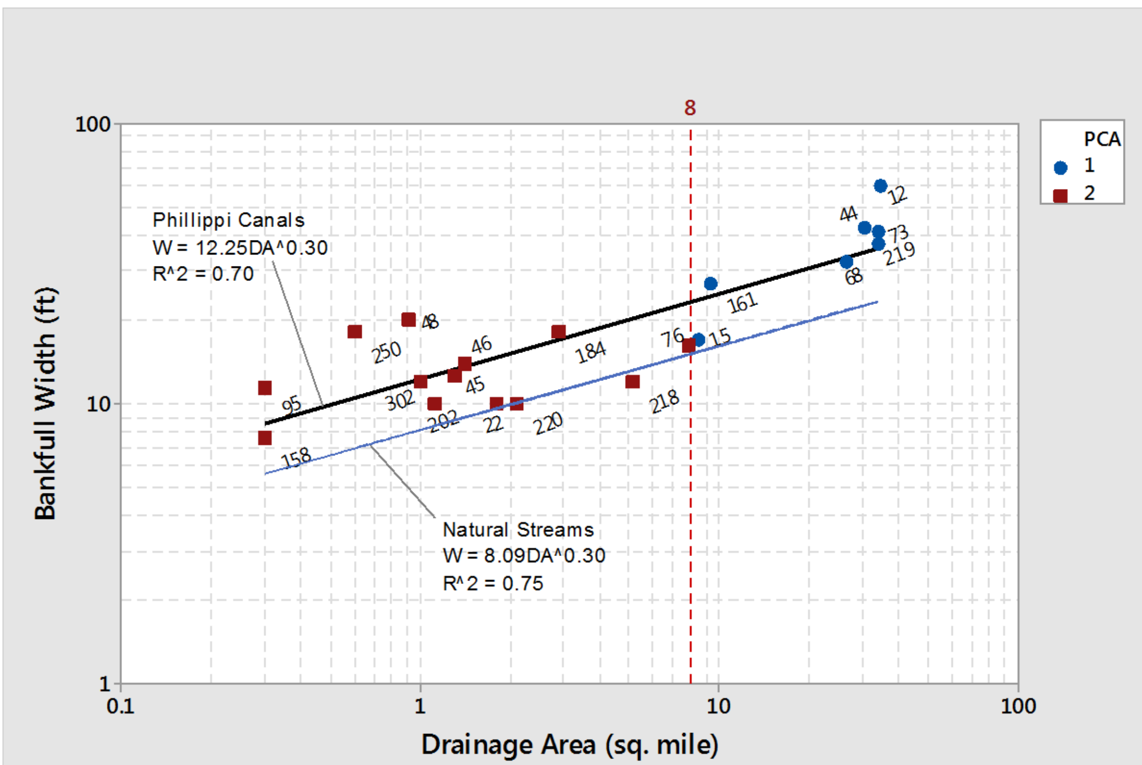


**Figure 9. Canal Bankfull Width versus Drainage Area (2 Clusters).**

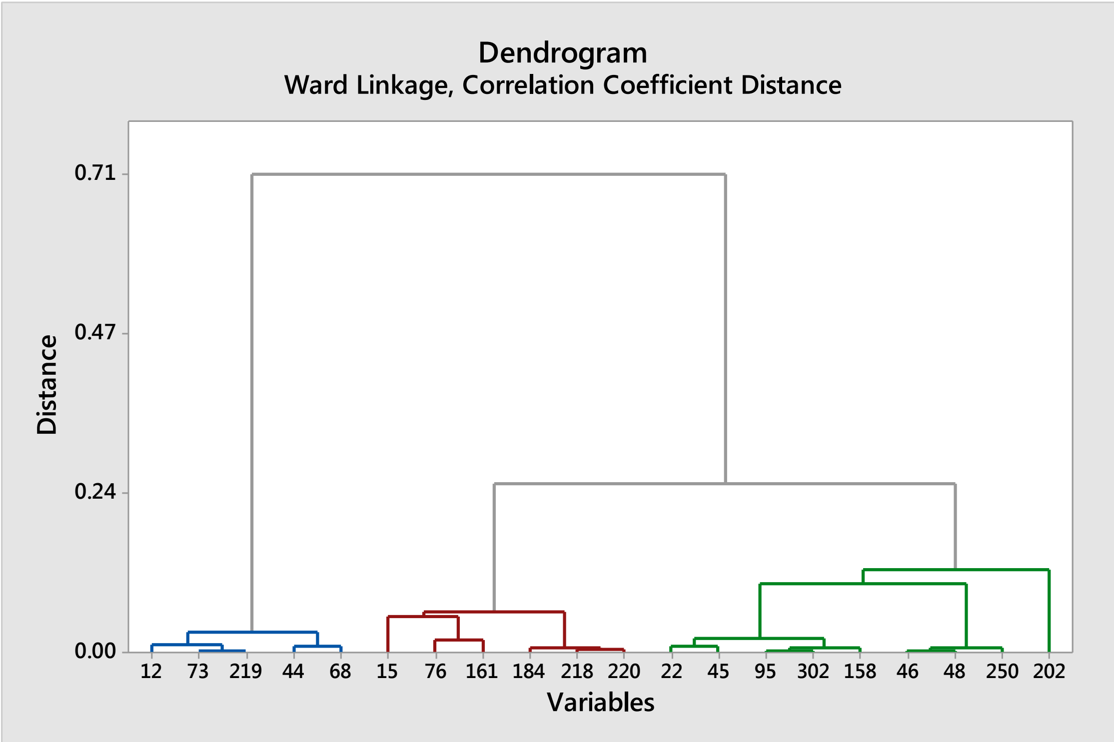


**Figure 10. HCA Dendrogram for 20 Canals (3 Clusters).**

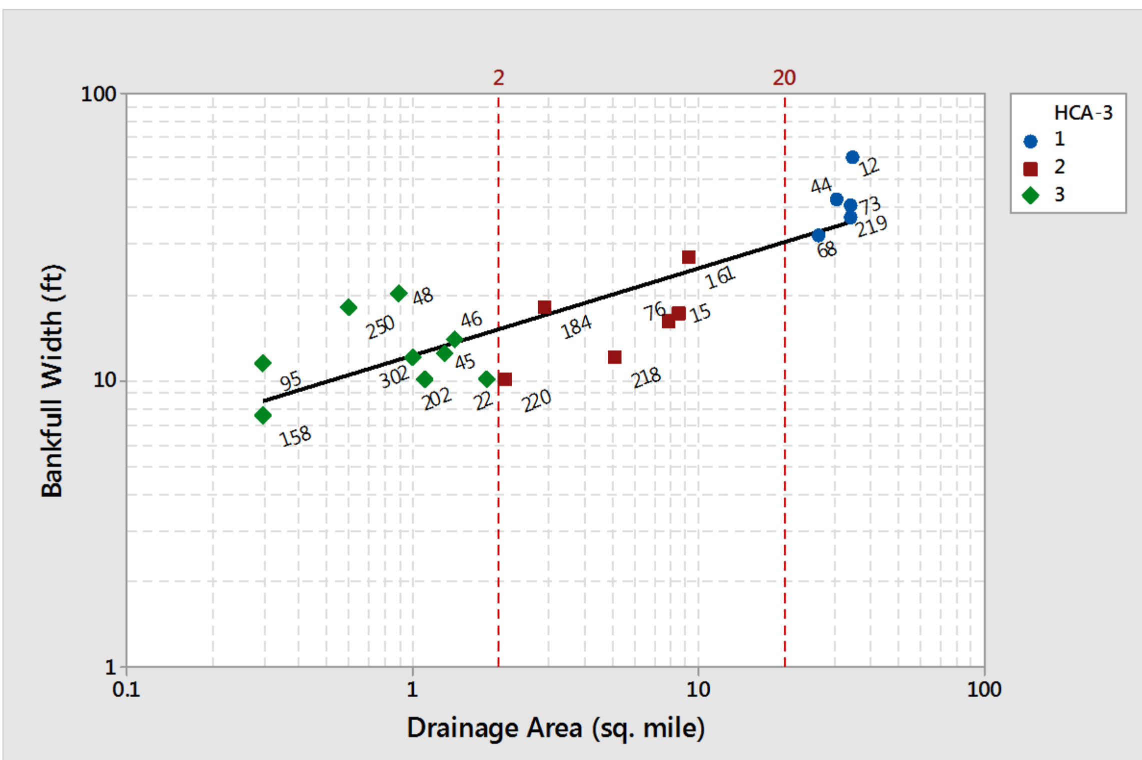


**Figure 11. Canal Bankfull Width versus Drainage Area (3 Clusters).**

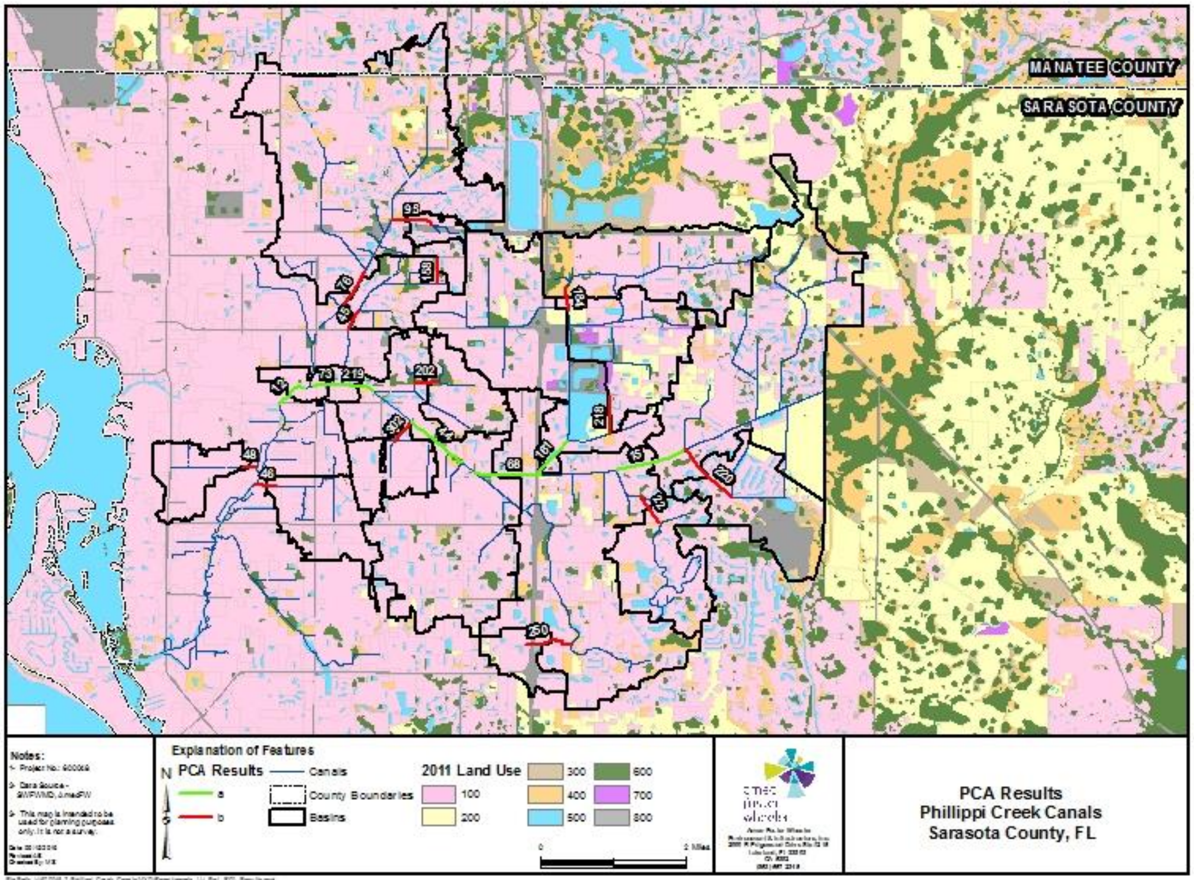


**Figure 12. Phillippi Creek Canal Segments, Land Use and Sub-Basins (2 Clusters).**

An array of regression comparisons were made to help understand canal condition and how it departs from natural conditions. The small group of Phillippi canals observed had a lot of variability in their bankfull cross section area, contributing to a lower $r^2$ value (0.66) when regressing bankfull channel dimension against drainage area versus that of natural streams in the same hydrophysiographic region (0.86) (**Figure 13**). Further, although overlap occurs, the Phillippi canals averaged larger bankfull channel sections than natural channels draining similar sized watersheds, especially the larger canals. Keep in mind that bankfull dimensions are being compared. This aspect of channel dimension represents the outcome of geomorphic processes associated with how channels adjust to the sediment and water volumes delivered from their watersheds. It usually takes at least two decades for bankfull dimension to evolve and achieve equilibrium after valley construction, which most of the canals appeared to have had time to accomplish.

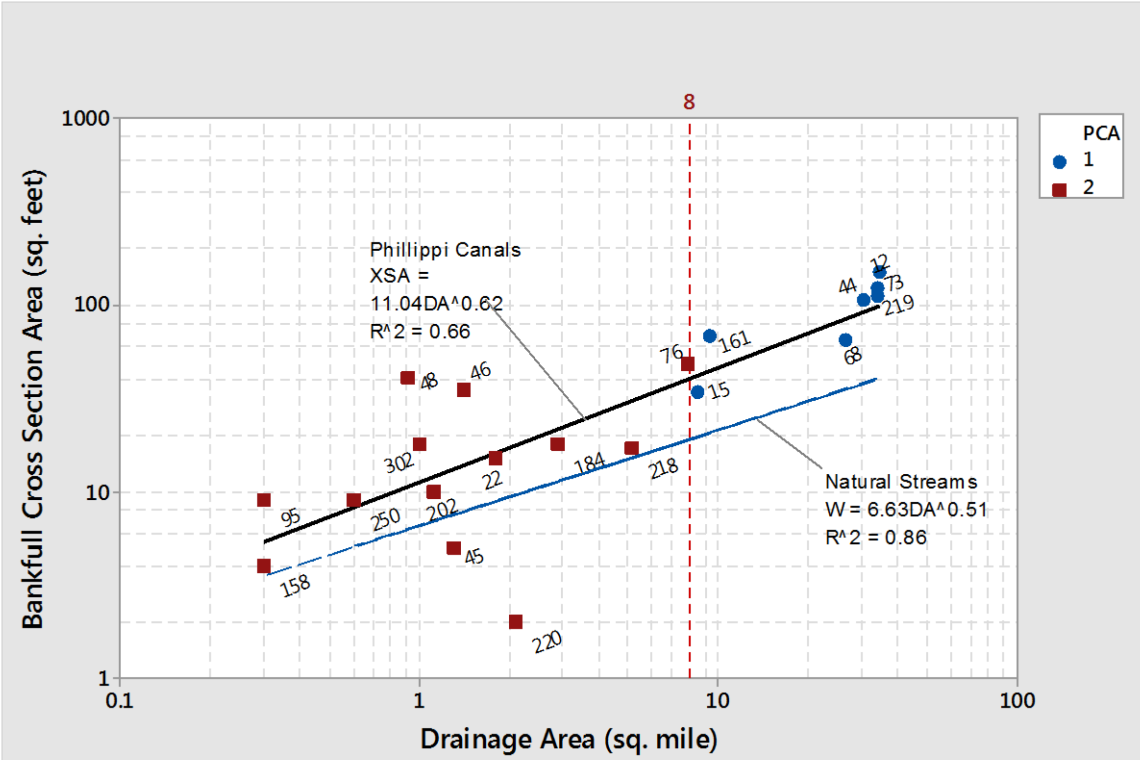


**Figure 13. Bankfull Cross Section Area versus Drainage Area.**

Phillippi canals increase in bankfull width versus drainage area at a rate similar to natural streams, but consistently average larger dimension (**Figure 14**). The variance in width versus drainage area of the Phillippi canals approaches that of natural conditions, with $r^2$ values of 0.70 and 0.75 respectively. This suggests that Phillippi canal bankfull widths are approaching their equilibrium.

Phillippi canal bankfull depth was highly variable (with a low $r^2 = 0.43$), especially for small systems (**Figure 15**). The dimensional variability was greater than that of natural streams for which the association between depth and drainage area had an $r^2 = 0.76$. Canal bankfull depths overlapped substantially with natural streams, and it does not appear that they differ systematically. The two regressions converge at the larger watersheds.

When considering bankfull area, width, and depth collectively it is apparent that the greater variance in cross-section area versus that of natural channels stems mostly from variance in depth versus width. Depth appears to be in considerable flux and is unlikely to represent an equilibrium condition. From field assessments, it is clear that such flux is at least partially associated with excessive sedimentation and the variability of spatial and temporal movement of sediment slugs through the drainage network.

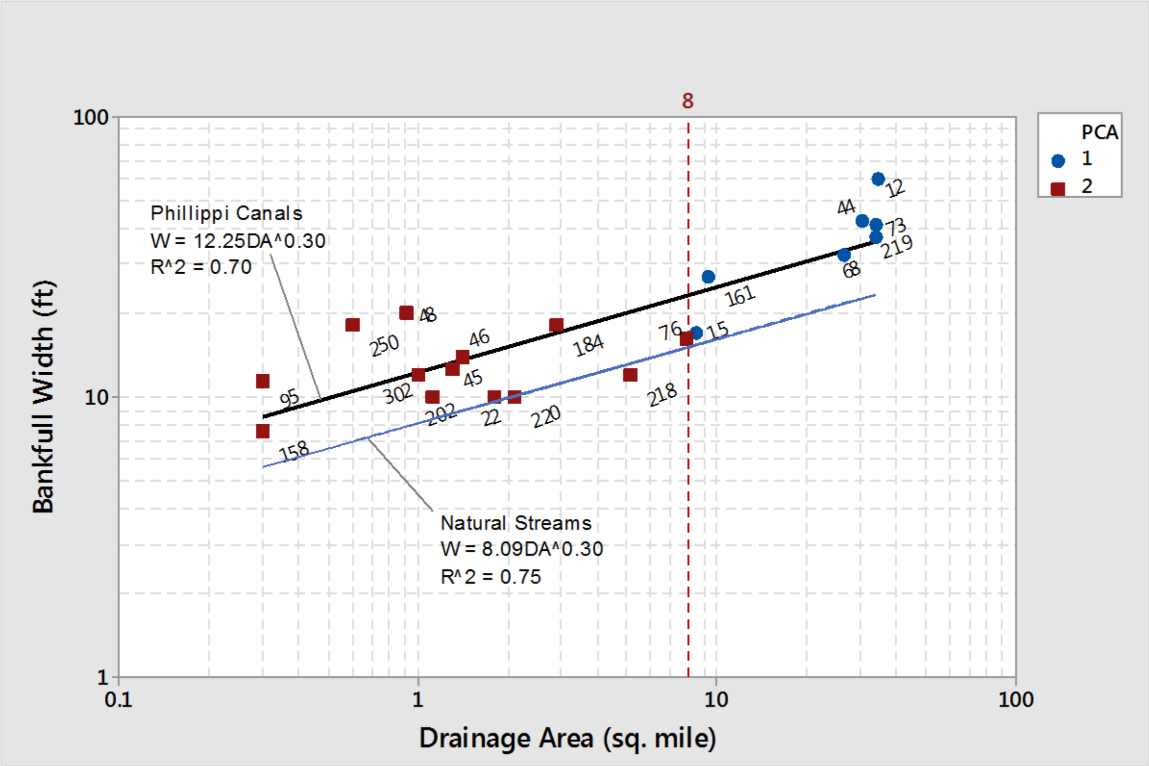


**Figure 14. Bankfull Width versus Drainage Area**

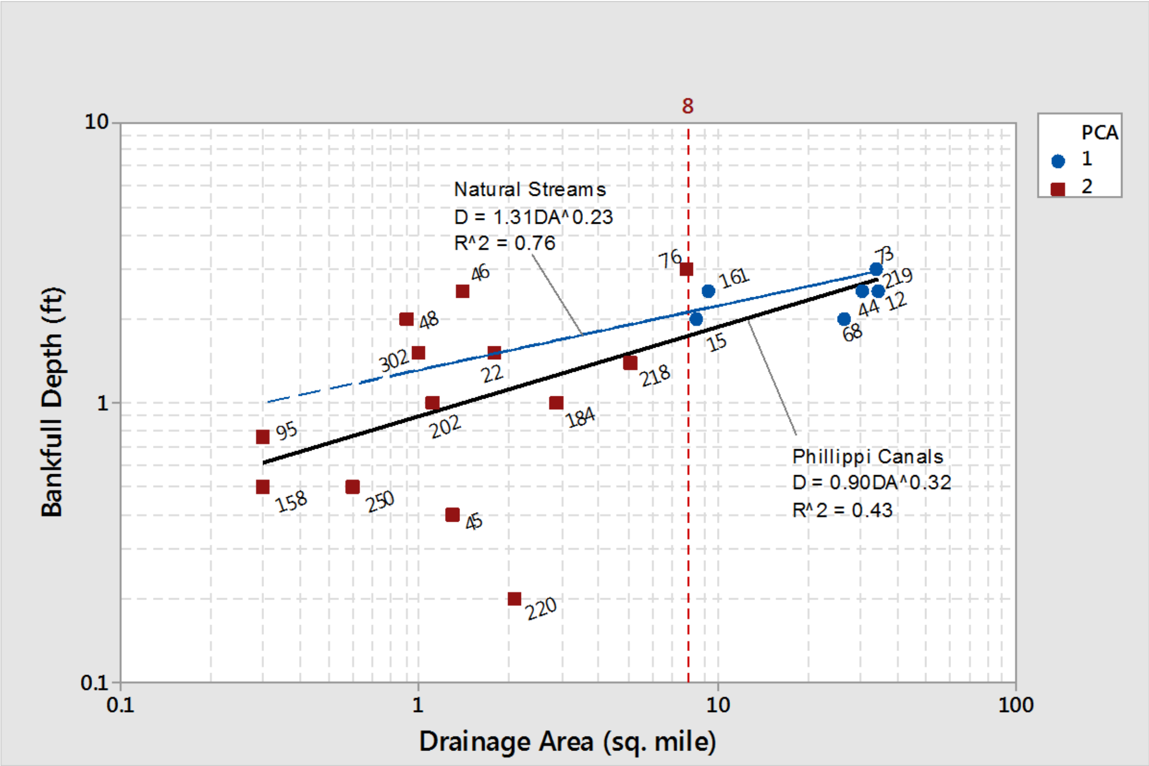


**Figure 15. Bankfull Depth versus Drainage Area**

The larger average bankfull channel dimension in the canals versus natural streams derives mainly from larger canal width. This is consistent with a drainage system delivering greater than natural sediment loads and fluvial forces. The greater sediment yields retard channel deepening, forcing any fluvially driven enlargement to occur by widening. Widening happens more rapidly in weak and high banks because they erode easier than strong low banks. As will be seen, the canal banks are often weak and high. As a result, sediments appear to be predominantly sourced from bank erosion. The trapezoidal shape of the canals increases tractive forces during wet season flow versus the two-stage open channel and floodplain configuration of natural systems. The canals are shaped in ways that focus fluvial energy and natural floodplains dissipate such energy. Therefore, it appears that the canals adjusted to become wider to maintain equilibrium with their watershed deliveries.

Trapezoidal canals serve as their own open channel and floodplain. This can place unnaturally high forces on the stream bed and lower parts of the channel banks unless the canal is comparatively wide with gradual side slopes. Therefore, canal top-of-bank and right-of-way widths were compared to natural active floodplain widths to assist with an understanding of how far conditions depart from nature and the potential for re-patterning the canals to more self-sustaining forms.

Canal top-of-bank (TOB) widths are close to natural alluvial floodplain widths in natural Florida streams (**Figure 16**). Small canals are similar in floodplain width to natural streams draining watersheds with at least 60% poorly drained soils, referred to as 'Flatwoods Streams' in Kiefer et al. (2015). Larger canals have top widths similar to natural streams draining moderately-well to well drained watersheds with at least 40% of the drainage area comprised of such soils (Kiefer et al. 2015). To put this in context it is necessary to understand that natural Flatwoods streams produce more wet season runoff per unit area than Highlands streams, and accordingly evolve larger floodplains to accommodate greater flood pulses.

The floodplain, as defined here, represents the lateral limits of active alluvial surfaces in the river corridor. Alluvial surfaces are those formed by fluvial forces and sediment transported by river flow, as opposed to colluvial surfaces that form by hillslope processes or karst surfaces derived from groundwater dissolution of limestone. By 'active' we mean geomorphic surfaces that were formed and maintained under recent climate conditions (e.g. those occurring for roughly the last few thousand years) and that are still being maintained or re-worked today, as opposed to 'relict' or 'abandoned' surfaces that were formed in the more distant past and are no longer maintained by the existing flow regime. Examples of relict surfaces include the many former marine shoreline escarpments that are found around Florida. In the case of the canals, any active alluvial surfaces present are no older than several decades, making them very young and subject to further alluvial work. **Figure 16** suggests that the canals are dimensioned with TOB widths large enough to handle normal wet season floods without suffering from systemic instability.

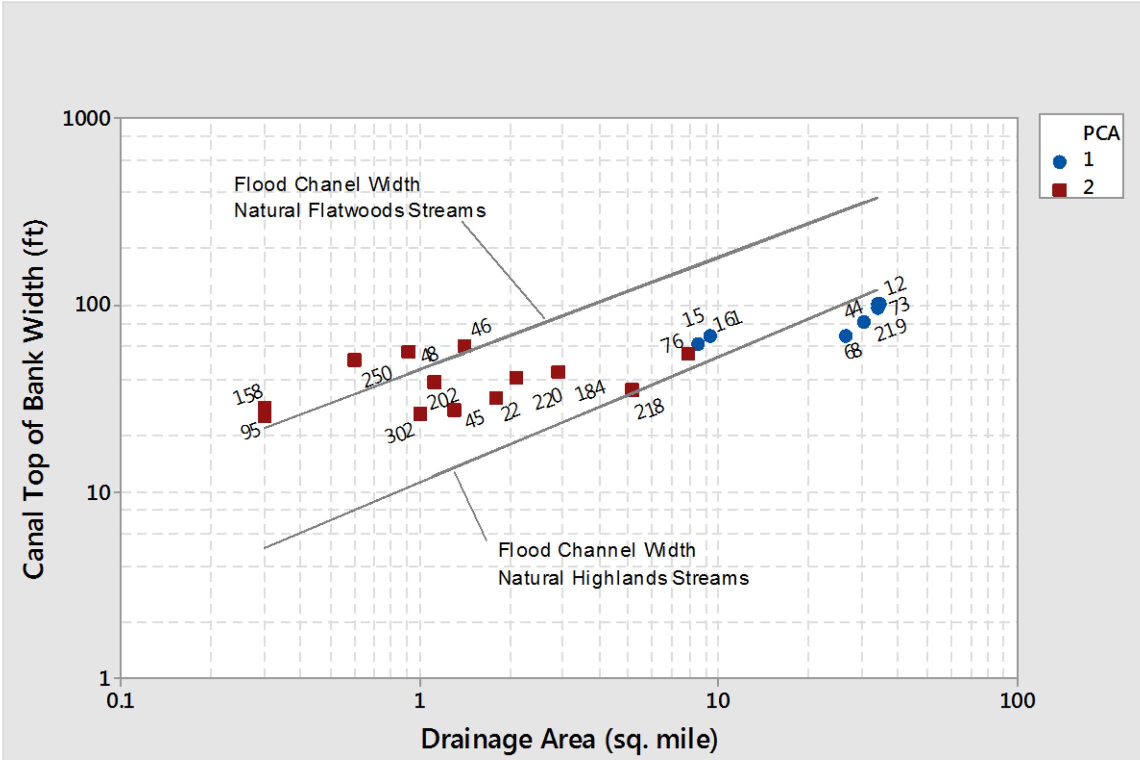


**Figure 16. Canal Top-of-Bank Width versus Drainage Area, Compared to Active Floodplain Width of Natural Streams**

The previous discussion categorized canals using the 2 Group concept. It is useful to also examine the available corridor width data using the 3 Group concept. Doing so, it appears that most Group 3 canals draining small watersheds (less than 2 square miles) have accessible ROW widths more than ample to create headwater streams similar to their natural analogues (**Figure 17**). This includes fully meandering plan forms as well as natural floodplain width. Group 2 canals draining intermediate basins ranging from 2 to 20 square miles could generally be restored at the small end of natural Flatwoods stream corridors or have ample room to accommodate the full dimension and pattern of two-stage natural Highlands streams. The largest canals, Group 1, could not support Flatwoods sized corridors, but appear to generally be large enough hto support Highlands corridor dimensions and pattern.

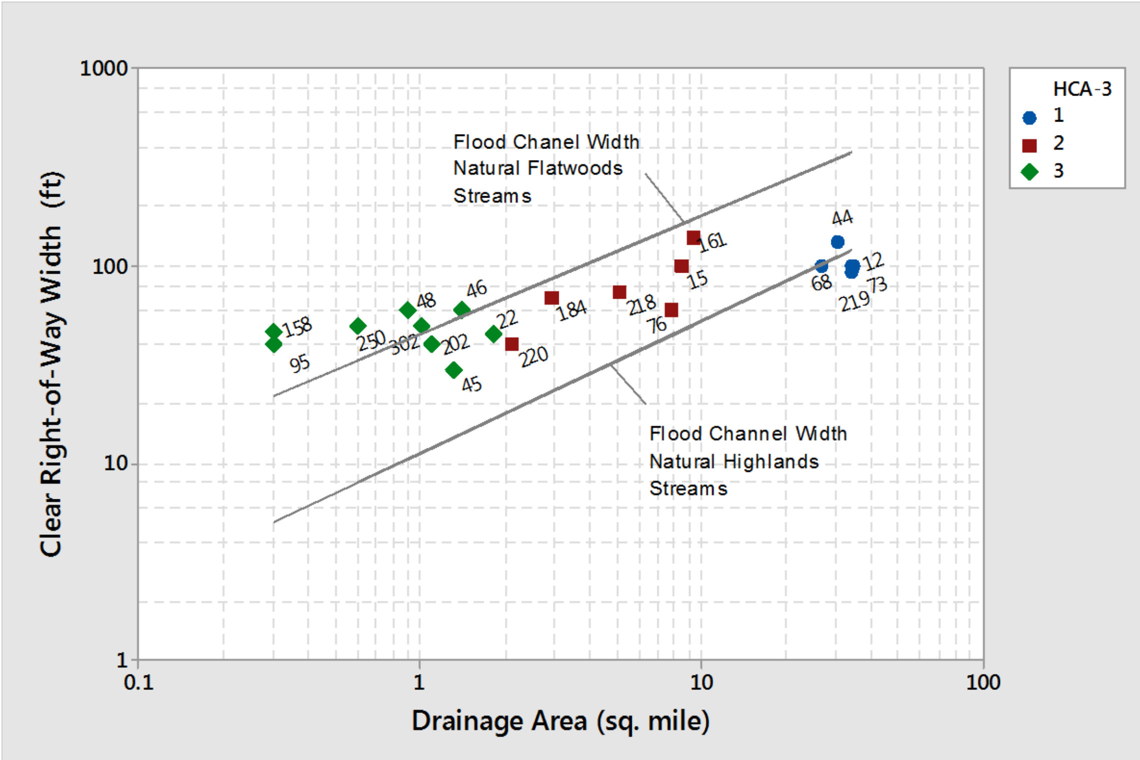


**Figure 17. Canal Right-of-Way Width versus Drainage Area, Compared to Active Floodplain Width of Natural Streams**

Corridor width is not the only consideration for natural riparian corridor design. Valley gradient is also important because natural streams require minimum stream power for their formation and sustenance that is associated with combinations of valley slope and drainage area. The steeper the slope and larger the watershed, the more power is delivered. Fully vegetated streams such as forested strands, herbaceous sloughs, and anastomizing (braided) channels occur at lower valley slopes than well-defined open alluvial channels at a given drainage area because it takes more fluvial energy to erode and maintain an open channel than a vegetated one.

Most of the large canals (Group 1) do not occupy valleys steep enough to maintain an open bankfull channel, while smaller (Group 2) systems more generally do (**Figure 18**). The Group 1 canals fall into a range that typically would support channels that are either completely vegetated or with multiple open channels coursing through a reticulated pattern of vegetated islands. Management activities (e.g. clearing and herbiciding), higher than natural wet season fluvial forces on the streambed, and excessive sedimentation probably combine to retard vegetation establishment. However, almost all of the large canals were observed to have at least some algae or aquatic bed vegetation on an otherwise sandy bed, but the vegetation was typically ruderal (weedy, fast growing) species and patchy.

This distribution of canals means that most of the small systems not only have enough lateral space, but also have enough energy to support meandering open channels and their floodplains in very natural ways. It also suggests the largest canals may actually occupy landscapes more supportive of fully vegetated channels, braided channels, or alternating segments of short open water channels chaining together longer in-line vegetated sloughs or strands. The natural analogues to the latter condition are referred to as 'chains-of-sloughs' in Kiefer et al. (2015).

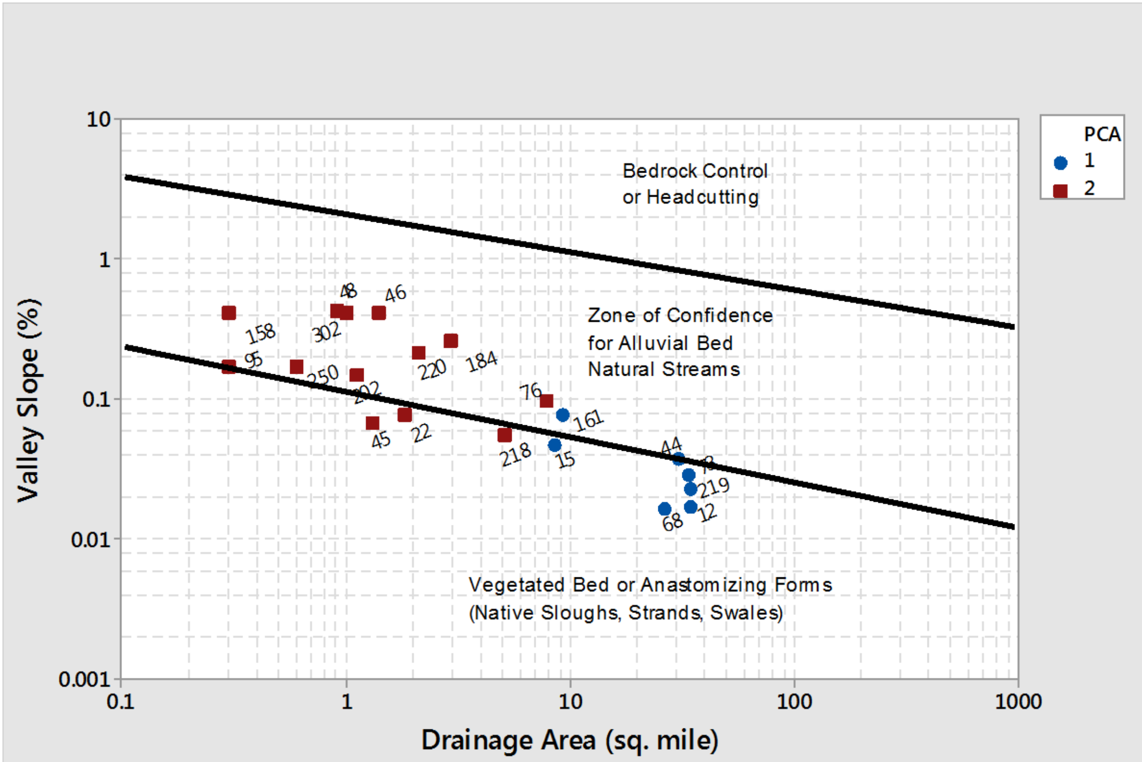


**Figure 18. Zone of Confidence for Natural Open Channel Streams with the Valley Slope and Drainage Area Positions of Phillippi Canals**

Streambed vegetation requires sufficient light penetration. Generally channels must be wide enough to prevent closed canopy bank forests from completely shading the channel. Amec (2013) reported that Florida bankfull channels less than 35 feet wide were typically shaded too much to support copious emergent or submerged aquatic vegetation on the streambed making them heterotrophic. **Figure 11** indicates this generally occurs where Phillippi canals drain less than 20 square mile watersheds (thus including Groups 2 and 3 in the 3 group HCA). Thus, the largest (Group 1) canals are the only ones intrinsically wide enough to preclude shading and thus become more autotrophic. The large streams are not only wide enough, but as previously described, tend toward lower valley gradients conducive to supporting vegetated strands and sloughs. These factors combine to raise the potential that extensive vegetative treatment of baseflow and wet season flow could be established by restoring the Group 1 canals to be more like natural sloughs, strands, braided channels, and/or chains-of-sloughs.

**Figure 15** suggests natural channels, on average, are deeper than the Phillippi canals but this varies tremendously on a site-specific basis. On average, it takes approximately 8 square miles of Phillippi drainage area to achieve bankfull depths achieved by natural streams draining natural watersheds of 4 square miles. This is notable because two major natural stream groups differ at or near 4 square miles (Kiefer et al. 2015). In a series of DeSoto County streams, smaller headwater streams draining less than 4 square miles supported mostly a shallow-water, wetland fish assemblage, while significant species additions and inclusion of larger bodied specimens occurred in the larger streams (Amec-BCI 2011). Thus, canals draining at least 8 square mile watersheds may have greater potential to support larger bodied fish taxa, requiring different expectations and approaches to restoring such habitat versus that of smaller headwater canals.

While not explicitly documented, the field team observed that the canals generally lacked the diversity of fish habitats found in natural streams draining analogous landscape positions. Deep pools and a variety of slack water and riffle flow areas where generally absent or greatly reduced. The potential to apply natural channel design treatments aimed at recovering these kinds of features seem high given the results of the fluvial geomorphic analyses.

It appears that threshold differences using the 2 Group clusters may have value for guiding fish habitat strategies, while the 3 Group clusters may be more useful for guiding general geomorphic restoration goals aimed at self-organizing and stability concepts as well as the potential for a densely vegetated streambed. In both cases, many of the canals appear to have high restoration potential, which is not common in most urban settings.

### 3.3 Bank Stability Analysis

Canal instability appeared to be associated with mostly non-fluvial processes during field observations. The fluvial geomorphic analysis also suggested that watershed conditions and canal dimensions were not highly sensitive to urban hydromodification as a primary cause of the erosion.[3] Thus, an investigation focused on understanding what aspects of bank conditions were most greatly associated with erosion was conducted.

Bank slopes had a normal distribution and a t-test indicated statistically significant differences between the mean slopes of stable and unstable banks ($p = 0.031$). Almost all of the unstable banks were steeper than 2.5:1 (H:V), which is the angle of repose of sand. In other words, the slopes were below the threshold at which a pile of unvegetated or non-reinforced sand will rest. Slightly more than half of the stable banks were also steeper than the angle of repose. Despite the differences between the means, the range of stable and unstable bank slopes greatly overlap suggesting this is a contributing, but by no means the sole factor, in erosional differences among canals banks (**Figure 19**).

Bank heights were non-normally distributed and Mann Whitney tests indicated differences of the medians between stable and unstable banks at $p = 0.063$. This could be rejected as being nonsignificant above the customary $p < 0.05$ level, but only has a 6.3% chance of representing a false difference. Unstable banks averaged 11.5 feet high, while stable banks averaged 8.0 feet high. To put this into perspective, our team commissions a geotechnical engineer's opinion for stream banks greater than 6 feet high to help assure stability in our restoration designs because that is a customary threshold for assuming some risk of gravity failure. More than half the stable banks were as high as the unstable banks and about 3/4$^{th}$ were greater than 6 feet. It is apparent that bank height is a contributing, but not a defining or sole factor, for erosion differences among the canal banks (**Figure 20**).

Bank height ratio (BHR), which is the TOB height divided by the bankfull depth gives an indication of the bank mass above the common water levels exerting the most overall work on the open channel. High BHR can indicate susceptibility to massive gravity failures induced by toe scour. Despite rather universally high BHR, it did not differ significantly in any way between stable and unstable canals ($p = 0.565$, Mann Whitney test for non-normal distribution) (**Figure 21**). This lack of BHR difference is consistent with other evidence pointing to non-hydromodification factors as the primary erosional drivers.

[3] There are likely to be exceptions to this in some canals.

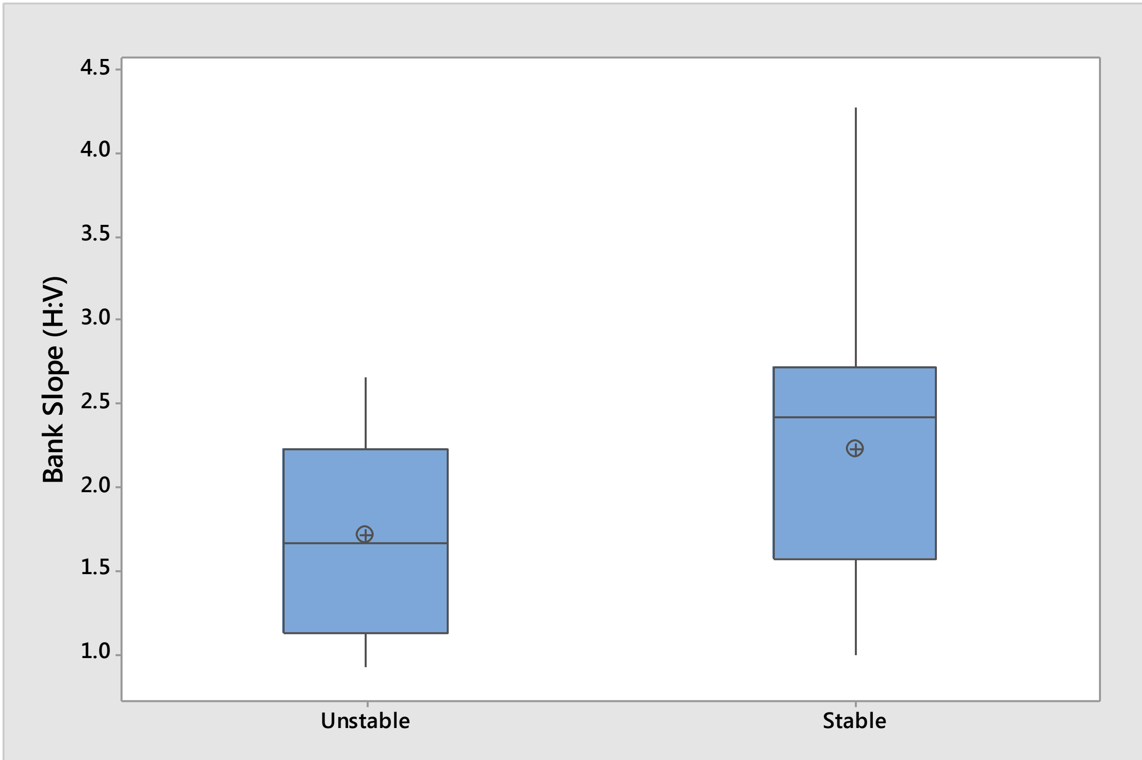


**Figure 19. Side Slopes of Stable and Unstable Canal Banks**

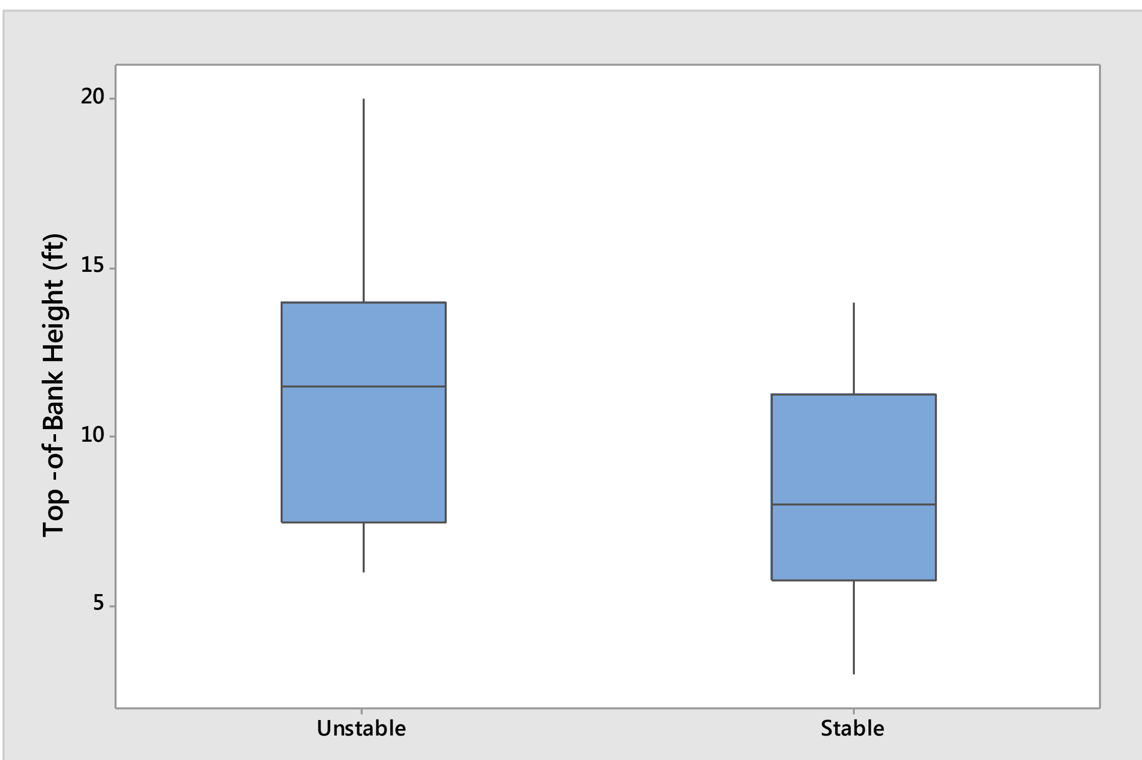


**Figure 20. Top-of-Bank Heights of Stable and Unstable Canal Banks**

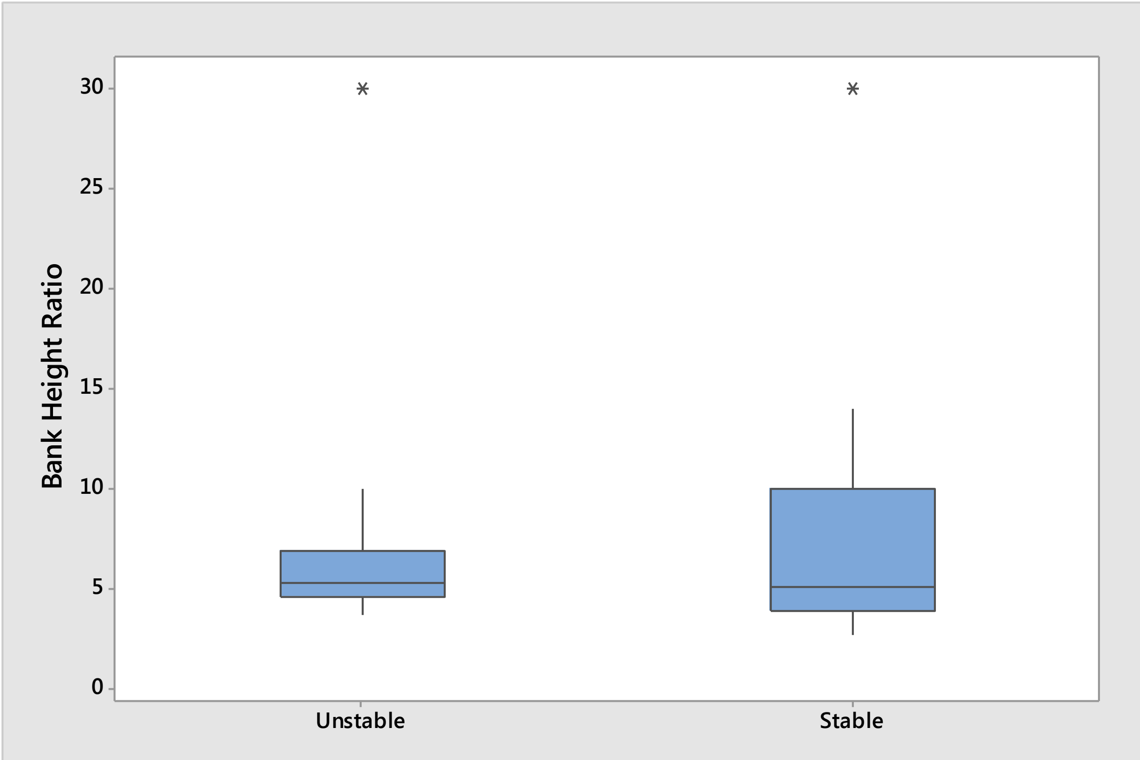


**Figure 21. Bank Height Ratio of Stable and Unstable Canal Banks**

Fisher's exact test was used to explore proportionality differences between the stability of mowed and unmowed banks and forested versus non-forested banks because field observations suggested such differences were likely to exist. Unmowed and mowed banks did not have the same proportionality between stable and unstable condition, with mowing showing a clear association with unstable conditions (statistically significant at $p < 0.0000$) (**Table 4**). Conversely, forested and woody shrub banks showed a clear association with stable banks (statistically significant at $p = 0.001$) (**Table 5**).

**Table 4. Mowing and Bank Stability Proportions**

| | Stable | Unstable | Total |
|---|---|---|---|
| Mowed | 1 | 10 | 11 |
| Unmowed | 28 | 1 | 29 |
| Total | 29 | 11 | 40 |

**Table 5. Woody Cover and Bank Stability Proportions**

| | Stable | Unstable | Total |
|---|---|---|---|
| Woody | 20 | 1 | 21 |
| Nonwoody | 9 | 10 | 19 |
| Total | 29 | 11 | 40 |

Because mean or median bank height and side slopes were more severe on unstable than stable slopes, these variables could be confounding factors when comparing the effects of woody versus mowed banks. Therefore, a subset of the data was explored using only banks that are most susceptible to gravity failure, namely those that are at least 6 foot high and have side slopes less than 2.5. The proportionality of unstable banks associated with mowed sites was significantly greater than that of woody banks (Fisher's exact test, $p = 0.00004$), for the banks most susceptible to gravity failure. Of these susceptible banks, 91% (10 of 11) of those being mowed were failing versus only 8% (1 of 13) with woody cover (**Table 6**). This strongly suggests that internal bank reinforcement is critical to maintaining stability. Forest and woody shrub cover is much more likely to provide this threshold of reinforcement than the comparatively shallow rooted grasses and weeds that can survive routine mowing.

**Table 6. Mowed versus Woody Cover on Banks Most Susceptible to Gravity Failure**

| | Stable | Unstable | Total |
|---:|---:|---:|---:|
| Mowed | 1 | 10 | 11 |
| Woody | 13 | 1 | 14 |
| Total | 14 | 11 | 25 |

## 4.0 CANAL CLASSIFICATION SUMMARY AND PRELIMINARY RANKING SYSTEM

### 4.1 Canal Description and Classification Summary

Canals grouped into 2 or 3 classifications along a size gradient that appear to be useful for planning restoration activities as part of a long-term maintenance reduction scheme. Further divisions did not reveal any categorical utility regarding restoration potential, water sources, susceptibility to erosion, or other interpretable stressors or conditions.

The 2 group classification distinguished between comparatively small and shallow lateral canals draining watersheds less than 8 square miles, versus generally deeper and wider main stem canals supported by larger and more complex drainage networks. This categorization is likely to be useful when planning fish habitat restoration projects. The lateral canals tended to be dimensionally consistent with natural headwater streams that normally support mostly small-bodied fish tolerant of low water levels, and the main stem canals were more likely to be at sustained water depths that can support larger bodied specimens and additional species relying on deeper waters.

The 3 group classification distinguished between headwater canals draining less than 2 square miles and large high-order canals draining more than 20 square mile watersheds, with an intermediate mid-order category between those two extremes. This categorization appears to be useful for general stream corridor restoration and how to best invoke what is known about natural stream fluvial geomorphology in peninsular Florida for setting realistic goals for the achievement of self-sustaining channel stabilization, wildlife corridor development, and in-stream vegetation establishment based on canal position in the drainage network.

The headwater canals generally have sufficient right-of-way to create direct meandering channel and flood channel analogues to the kinds of natural headwater streams draining Flatwoods watersheds (poorly drained watersheds that generate significant wet season runoff). These stream channels typically meander through narrow forested riparian corridors. The high-order canals typically have sufficient right-of-way to support two-stage channels patterned after natural streams draining Highlands watersheds (comparatively well-drained systems with greater baseflow and reduced runoff versus Flatwoods watersheds). The mid-order canals are positioned between these two kinds of systems, meaning they have more than ample room for patterning after Highlands stream analogues, but are on the low end to unacceptably narrow range of conditions natural for Flatwoods drainages. Thus, the distinction between these two drainage categories takes on some importance for strategic planning of environmental and self-sustaining canal improvements. Highlands drainages have at least 40% NRCS hydrologic soil group (HSG) A, B, and C soils, while Flatwoods basins are less well-drained and are more clearly dominated by HSG D soils (Kiefer et al. 2015).

All 20 Phillippi canals studied were dominated by HSG D soils with an artificial drainage modifier (e.g. A/D, B/D, C/D). This kind of soil, ranged from 65% to 100% among the canals, with an average of 95%. The modifier means the soil can be flipped from a poorly drained condition (D) to a more well-drained condition (A, B, or C) with artificial drainage improvements. Given the high density and depth of the canal network, it seems plausible that the soil potential is more like that of a Highlands basin today. However, untreated impervious surface, especially directly connected impervious area, may counter the over-drainage effect thus making the basins behave more like natural Flatwoods systems. This can be tested by integrated groundwater and surface water modeling.

The high-order canal types have valley slopes and bankfull channel widths that are particularly conducive to streambed vegetation establishment, which opens them up for some unique habitat restoration and water quality improvement objectives. They could be re-patterned to establish forested terrestrial corridors and floodplains with braided or semi-open channels carrying most of the flow. The mid-order channel types could be restored to a wide variety of conditions with forested corridors, open and semi-vegetated water channels, and complex channel morphology supporting a variety of bends and pools beneficial to fish and wildlife. The headwater and mid-order canal types are also amenable to specific in-stream treatment techniques designed to reduce nitrogen loads in heterotrophic streams (e.g. regenerative stormwater conveyances). The bottom line is that all three categories of canals can contribute to multiple habitat and water quality objectives in different ways, thus migrating their functions closer to natural stream systems which are inherently self-organizing and self-sustaining (and therefore nearly cost free).

About 20% of the canal banks studied were actively eroding. Sedimentation is known to be a substantial issue in the Phillippi basin and bank erosion appears likely to be the dominant source. Bank erosion seems to be associated mostly with local-scale stressors as opposed to watershed scale hydromodification. In other words, the canals appear to be large enough to accommodate the water and sediment loads delivered by the urban landscape that dominates the basin without needing to evolve larger forms. Instead, the eroding banks generally appear to be overly steep and high, with insufficient internal reinforcement to sustain their configurations. His implicates gravity as opposed to fluvial forces as the primary driver of erosion. Many different approaches can be used to stabilize the banks, each varying in cost, benefits, and applicability to site specific conditions. However, it is abundantly evident that forested banks are much more stable than mowed banks in the watershed, with woody root systems evidently providing shear strength within and protection from rain on the banks that the closely cropped grasses and mowed weeds do not.

Canals should therefore be classified hierarchically, first determining their group assignment as Lateral versus Main Stem channels for fishery purposes and into Headwater, Mid-Order, or High-

Order groups for geomorphic, riparian habitat, and water quality purposes. These aforementioned categories generally only require knowledge of the canal's drainage area. Once placed within those groups then each canal bank should be categorized as stable or unstable, and wooded versus mowed. For example, Canal 15 is a Main Stem, High-Order system with Left Bank Stable/Unmowed and Right Bank Unstable/Mowed.

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