

PHILLIPPI CANAL IMPROVEMENT GUIDANCE MANUAL

Prepared for

Sarasota County Stormwater Environmental Utility



Prepared by

Wood Environment and Infrastructure Solutions, Inc.

wood.

September 2019

Wood Project No. 600048.2



Contact

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1.0 INTRODUCTION

The Sarasota County Stormwater Environmental Utility (SEU) hired Wood Environment and Infrastructure Solutions (Wood) to assess the County’s management activities in the Phillippi Creek watershed’s channels and recommend treatments to end a cycle of repetitive maintenance.

This guidance manual is written for an audience of decision makers, planners, and designers looking to obtain an overview of Wood’s research and recommendations regarding the improvement potential of the Phillippi Creek canals. It is a synthesis of more detailed scientific and economic assessments.



Sarasota County staff visiting the Suwannee River Water Management District’s conversion of the Alligator Creek canal to a natural channel in Starke, FL. Wood designed the project to be fully funded by the Florida Department of Transportation and Florida Fish and Wildlife Conservation Commission. A variety of game fish built spawning beds in the restored stream habitat within a year of project construction. Spawning was concurrently absent in the canal immediately upstream and downstream of the project.

The detailed accounts occur among a series of memos and data compilations that serve as the technical appendices of this guidance document. The following documents are available under separate cover for those seeking more information:

Appendix A – Data Compilation. Digital inventory and ESRI ArcGIS package of the geographic information used in the assessments and the maps Wood derived from these assessments. (GIS data for Tasks 1, 7, and 8).

Appendix B – Maintenance Activities & Costs. Technical memo and spreadsheet characterizing recent canal maintenance activities, locations, and costs. (Task 2).

Appendix C – Canal Classification. Technical memo providing a multivariate classification of Phillippi Creek channel types. Canal types are based on the biophysical characteristics of the channel and its right-of-way, and position in the drainage network (Task 3).

Appendix D – Categorical Improvements. Report describing the kinds of improvements that could be made to the canals, including inert structures (gray infrastructure) and soil bioengineering/stream restoration (green infrastructure) with a matrix of each treatment’s applicability and environmental benefits. (Task 4).

Appendix E – Canal Improvement Costs & Benefits. Report and spreadsheets describing cost estimates for a variety of gray and green canal retrofits for 3 canal types, and their triple bottom line benefits (financial, environmental, and social). (Tasks 5 and 6).

Appendix F – Management System. Memo describing algorithms for a management system that identifies canals subject to the most repair burden and for determining the highest and best treatment alternative for each canal. The treatment algorithm is also expressed as a decision flow chart. (Task 7).

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2.0 ISSUES

History (p. 4)

Maintenance Requirements (p. 7)



2.0 ISSUES

The extensive network of canals, about 100 miles of them, require varying amounts of routine mowing, herbiciding, debris removal, dredging, and erosion repairs. Not all canals are equal regarding frequency and cost of their maintenance activities. Wood determined which canals require the most work and, in general, why.

Even the high-maintenance canals in the system perform their flood management functions as required, but these reaches lack resiliency and do not provide other functions like water quality improvement very well. Wood determined a means to repurpose these assets to increase benefits without compromising the original drainage functions.

Systematic canal construction was initiated in the 1920's, digging deep straight channels to dewater the surrounding land. Unlike the natural drainage system it replaced, this channel form is not self-sustaining and requires significant upkeep.



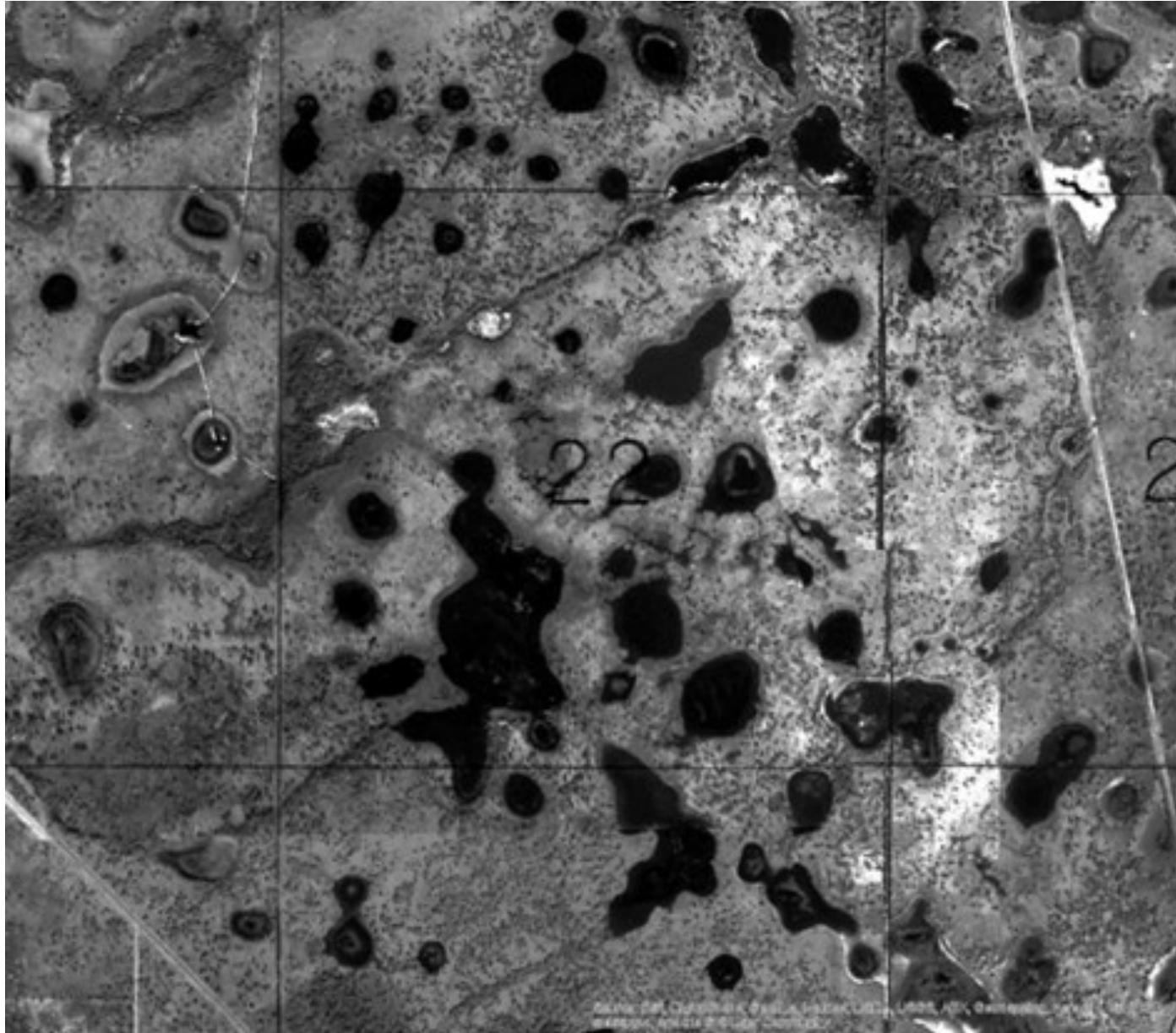
Phillippi Creek canal - east of Sarasota. 1929.

Simpson, G. G. Black & white photonegative, 4 x 5 in. State Archives of Florida, Florida Memory. <<https://www.floridamemory.com/items/show/125094>>



Sarasota County SEU, 2018.

The pre-development landscape of southwest Florida was slowly drained by chains-of-wetlands linked by shallow meandering channels. That system has been almost entirely replaced by canals and subsequent land development in the Phillippi Creek watershed.



1940's—chain-of-wetlands in pine flatwoods



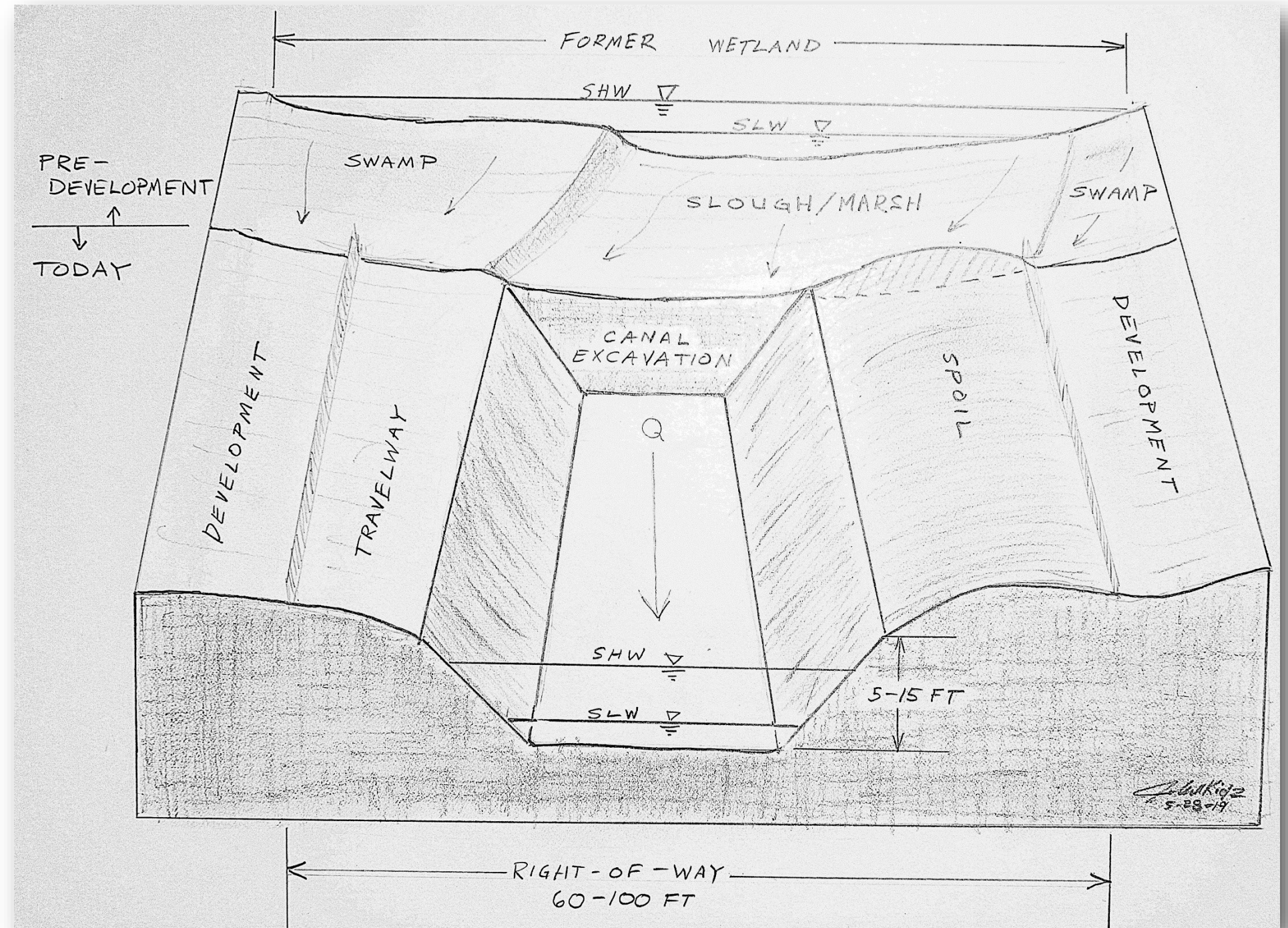
2017—canals and development (same scene as on left)

Phillippi Canals

It is easy to see why the canals are effective drains compared to the natural configuration. Seasonal water fluctuated horizontally under pre-development conditions; flooding extensive marshes, swamps, and their adjacent pine flatwoods with at least a few inches of water during the rainy season. The water table remained close to the land surface during the dry season, so vertical water level fluctuations were relatively minor.

Canal excavation drew the water table down by several feet or more, and conveyed water away more quickly. This created more developable land by compressing the historic horizontal seasonal water fluctuations into a more vertical and rapidly fluctuating pattern contained by the canal. In other words, instead of allowing flow to slowly spread across the land and then gradually recede, the canals direct waters to fluctuate several feet up and down within the channel in response to individual rainfall events. The canals function much like small grass-lined canals.

This landscape transformation from an expansive seasonally-horizontal hydrology to a more compressed and vertically spastic hydrology is what makes the canal networks less resilient against recent trends in storm intensification than natural systems. Their compressed rapid hydrologic response renders the canals more prone to erosion, less capable of pollutant reduction, and less abundant with native fish and wildlife habitats. The severe and repetitive physical stress contributes to their associated high maintenance requirements today.



SHW—seasonal high water. Sustained water levels in nature lasting weeks at a time. These episodes occur as a series of shorter, frequent pulses in urban watersheds. Canals reduced SHW 2 to 8 feet throughout the Phillippi basin.

SLW—seasonal low water. Dry season water table. Canals reduced this 4 to 12 feet in the Phillippi basin.

Swamp—forested freshwater wetland. Generally, these have a couple feet of water during the wet season. Called a strand if flowing.

Marsh—non-forested freshwater wetland. Generally, with two to three feet of water during the wet season. Called a native swale or slough if flowing.

Slough—a gently flowing channel with poorly defined banks, with or without marsh vegetation depending on depth. Bed is organic (peat or muck).



The canals perform their singular drainage function very well, but they are not intrinsically stable. Various forms of bank erosion are common, caused by a combination of high and steep banks vegetated by weakly rooted non-native grass and weeds. The non-native vegetation is typically mowed or herbicided to maintain a low growth form perceived to increase flow efficiency during floods.



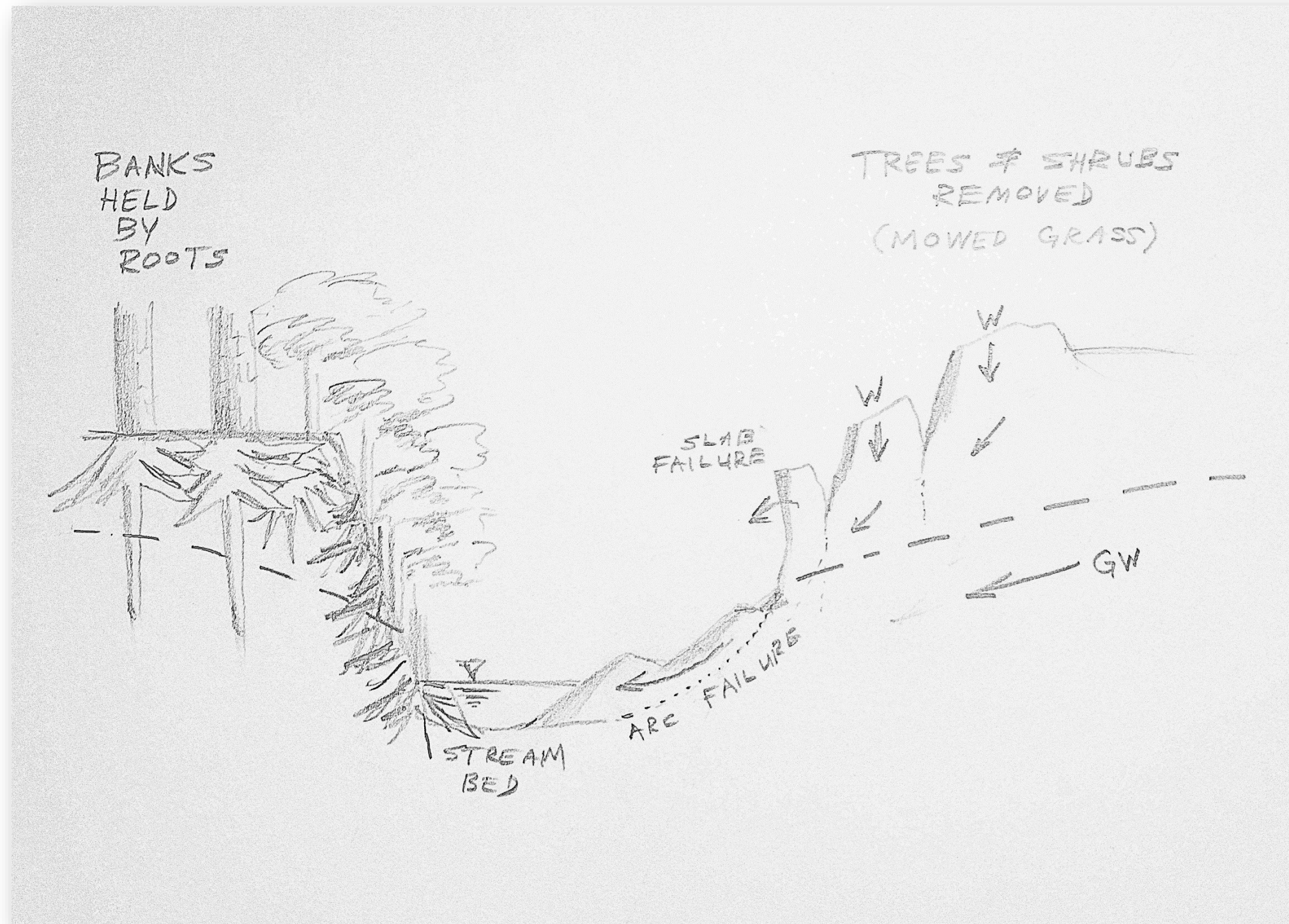
The canal in the image above has banks in excess of 15 feet high at a side steeper than 2:1 (H:V—horizontal:vertical). Shallow rooted grasses simply cannot hold the sandy bank materials together with such severe morphology absent frequent repairs.

Channel banks at least 6 feet high, with side slopes steeper than 2.5:1 (H:V—horizontal to vertical), and mowed grass were rather ubiquitously unstable. Conversely, forested banks of all configurations were much more stable. These patterns were consistently observed even in the common situation where one bank was forested and the opposite bank was being mowed on the same canal.



The canal in the example above is in the early stages of evolving into a more stable two-stage channel, with a small floodplain (bankfull bench) being carved out between the toe scour and scalloped gravity failures on the grassed right bank. If left untreated, erosion will destroy the travelway above it and will deliver many tons of sediment downstream over a period of several decades. In contrast, the left bank is forested and resisting erosion.





The roots of native forested streambanks develop resiliency in balance with natural forces by adding significant shear strength to bank soils and by dissipating energy along the channel margins. In contrast, mowed artificial canals vegetated with turf grass often fail to protect channels from various kinds of erosion including scour from running water, gravity failures in weakly rooted soil mass (weight, W), and groundwater sapping (GW). Because they defy natural form and process, canals often require routine maintenance activities.

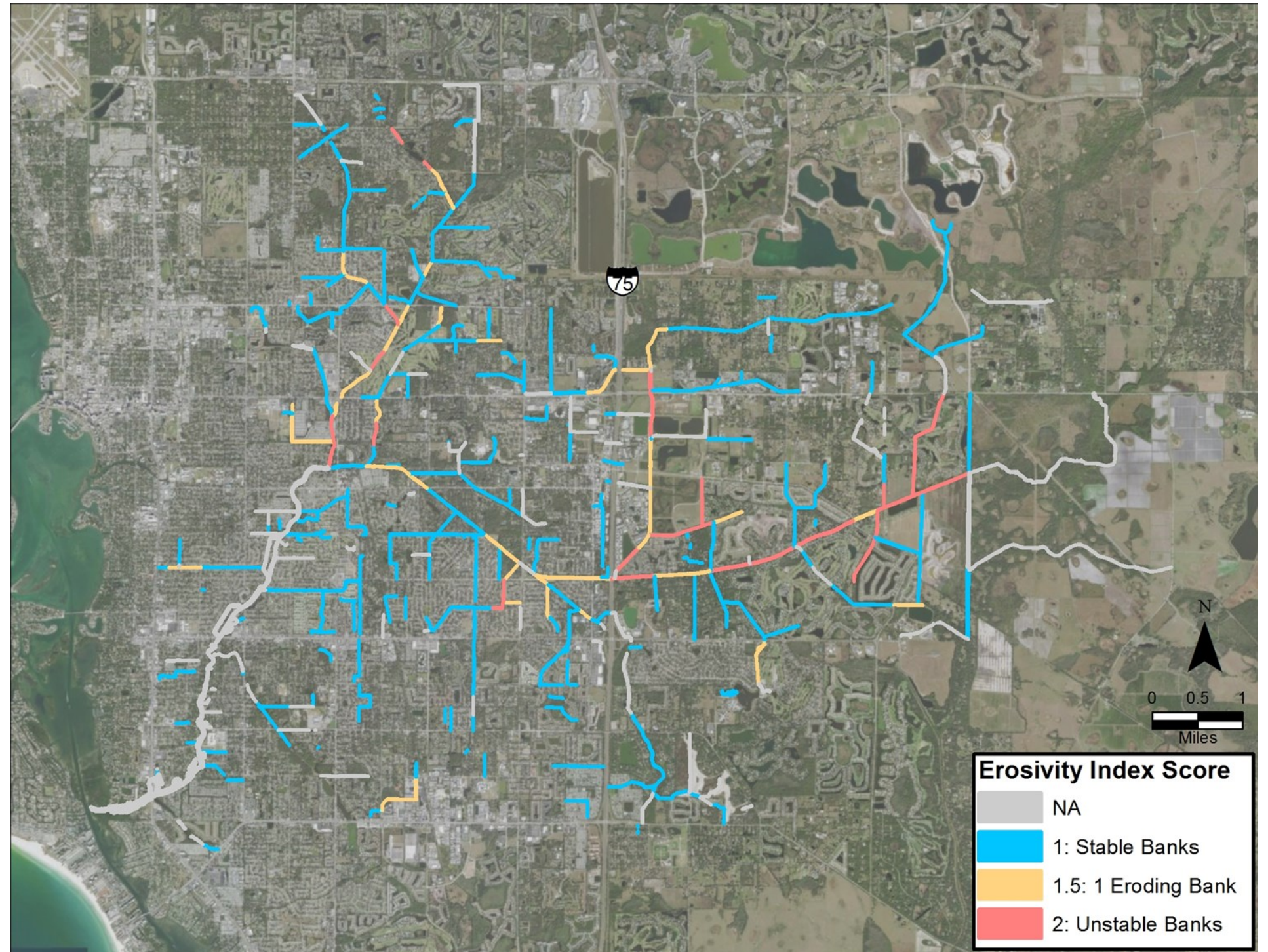


Most of the canals in the Phillippi watershed are comparatively stable, mainly because their banks are forested and/or the canals are small with low banks. Thus the canals most vulnerable to erosion tend to cluster along the larger main drainages.



Uniform water depth over soft sand bed

Excessive sediment transport from eroding banks smothers aquatic habitats and has a downstream effect. This is further compounded because straight canals lack the ability to process those sediments in the beneficial ways that natural meandering streams provide. Meandering channels organize sediments into alluvial habitats such as point bars and natural levees that increase the geomorphic and biological diversity of stream corridors. The canals simply lack the complex flow patterns necessary sustain pools and pockets of vegetation, leaf packs, and woody substrates that improve water quality and that drive much of the fish diversity and abundance found in Florida's natural streams and wetlands.

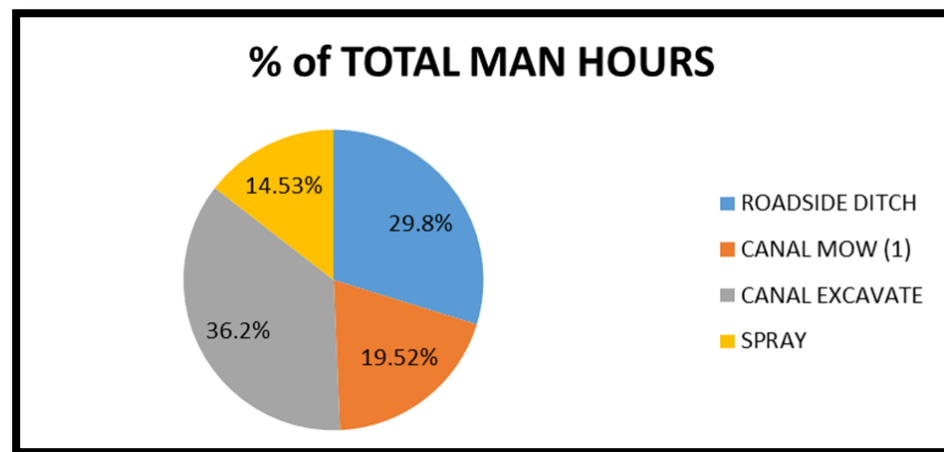


The erosivity index awards 1 point to a canal segment with both banks stable, 1.5 points if one bank is unstable, and 2 points if both banks are unstable. Canals that are orange or mauve are either actively eroding, or are highly vulnerable of eroding. Blue canals are quite stable. Gray canals were not part of this assessment.



Canal maintenance occurs widely throughout the watershed, but with small headwater channels generally requiring the least maintenance. The low maintenance canals are those colored blue in the figure to the right. They characteristically have low banks and many are forested.

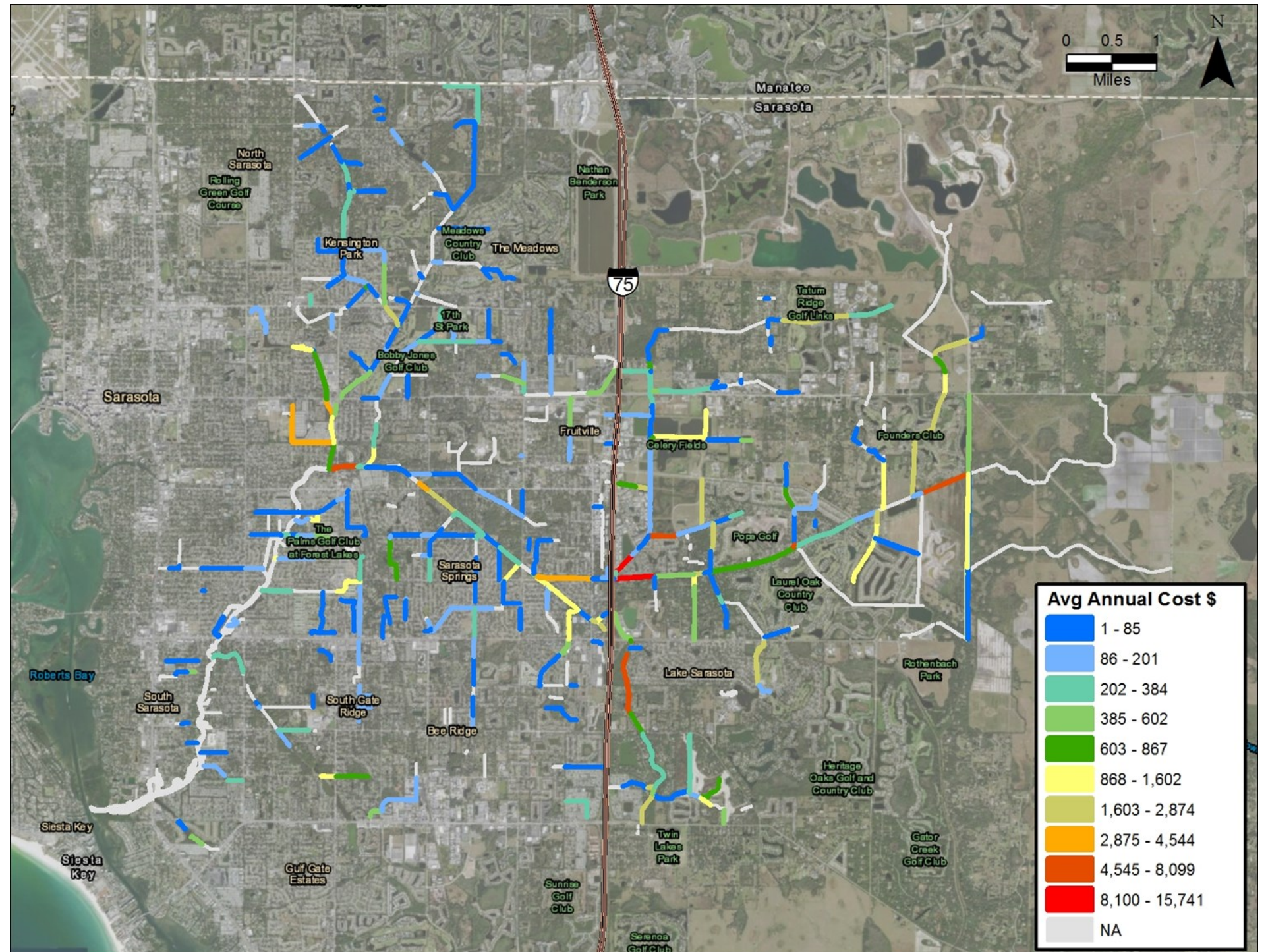
Less than 30% of the canals generated 90% of the maintenance costs from 2008-2015. Just 14 of the canals accounted for half the costs during that time period.



Breakdown of common maintenance activities from 2008-2015. About 2/3rds of the effort was spent on physical patching and clearing of the channel banks and bed, ('roadside ditch' and 'canal excavate' categories). The remaining third of the overall effort was spent on vegetation maintenance ('canal mow' and 'spray' categories).

Based on a detailed cost dataset from 2015, the county spent \$6.6 million that year with 36% on sediment removal and erosion repair using specialized 'walking tractors' that can work from within the canals; 30% on excavation and earthwork conducted with conventional equipment from roadsides and travelways; 20% mowing grass and brush; 14% on herbiciding brush; and 10% on hand-clearing of brush.

This breakdown illustrates that maintenance activities derive from the tremendous effort required to manage sediments and vegetation in the artificial drainage network.



Average annual routine maintenance costs by canal from 2008-2015.* Note that some canals have comparatively high costs.

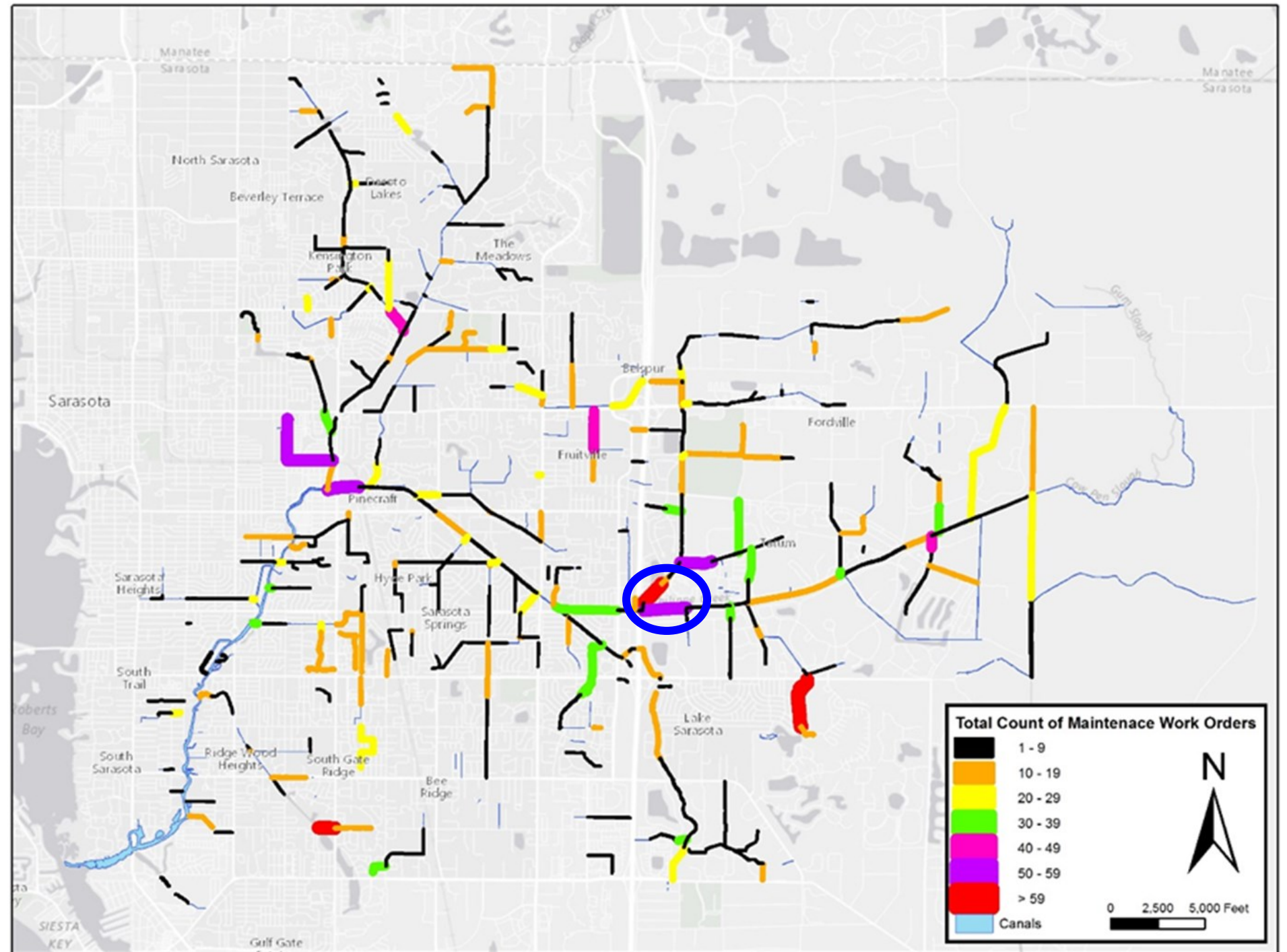
*Total, fully-burdened costs to sustain the canal systems are higher. The data above is a subset of costs intended to reflect routine maintenance activities. For example, these routine costs sum to about \$270,000 for 2015, while total canal maintenance and repair expenses in the same area were \$6.6 million that year.



Certain canals require more maintenance visits than others, but maintenance has occurred extensively throughout the watershed. A select few canals required over 50 separate work orders to maintain. An example of an area with particularly high maintenance requirements occurs at the confluence of canals Main A and C, just east of Interstate Highway I-75 (circled). These two segments collectively required more than 100 work orders over a 7 year period.



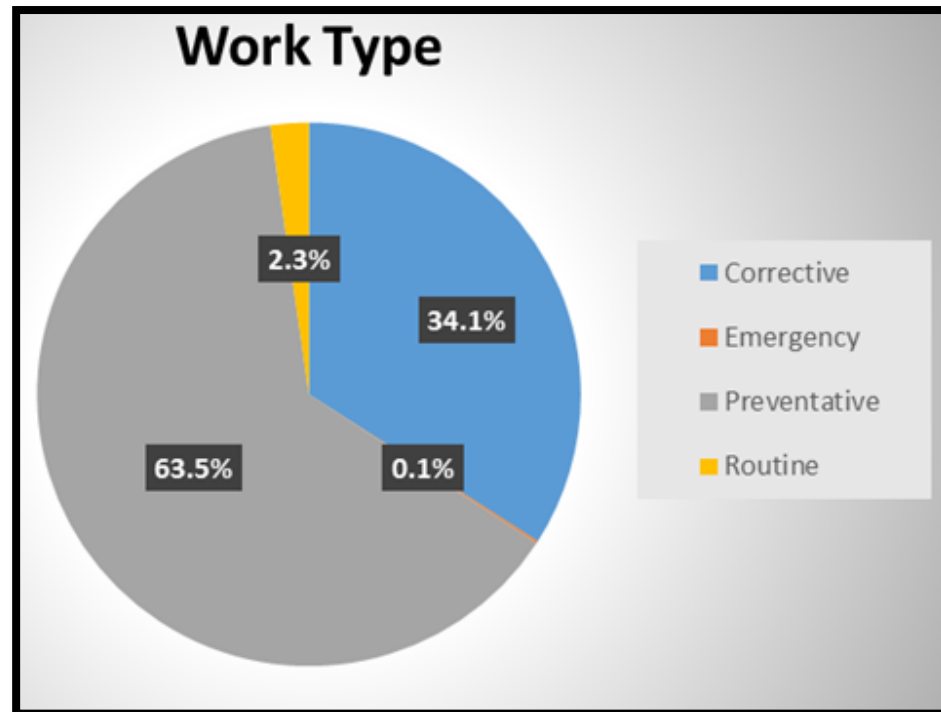
Skilled operators use the County's walking excavators to climb in and out of the canals to remove sediments and debris and mow brush on the banks. These specialized waterway maintenance machines can work on steep slopes and in up to several feet of water.



Routine maintenance orders by canal from 2008-2015.

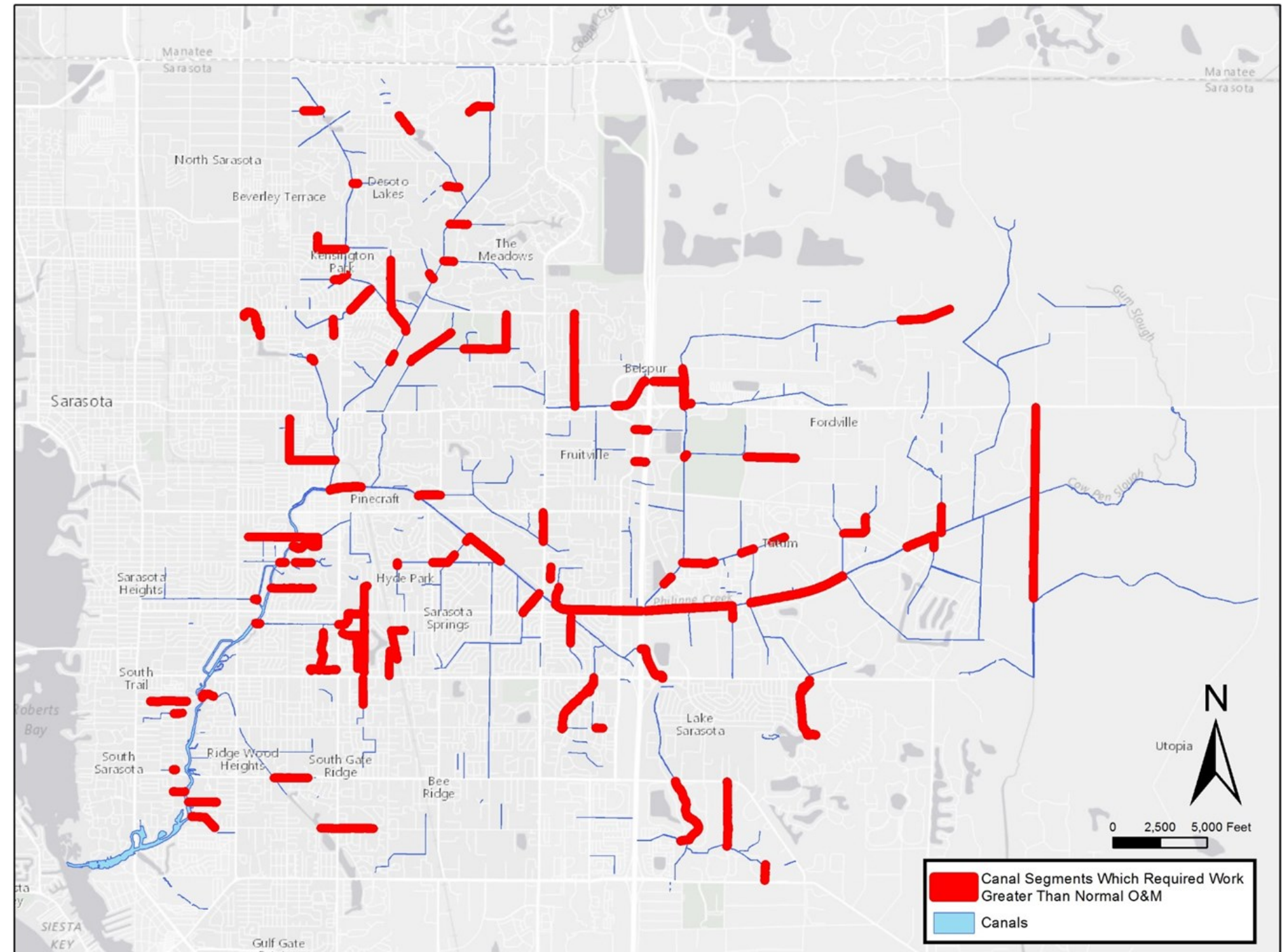


A wide distribution of canals required repairs beyond those deemed to be normal operation and maintenance activities for stormwater drainage systems. This suggests a deteriorating infrastructure warranting a comprehensive retrofit or renewal plan.



Breakdown of maintenance categories from 2008-2015. About 2/3rds of the effort was spent on preventative and routine maintenance, with most of the remainder spent on corrective activities.

- Routine– small works that SEU staff can schedule in advance.
- Preventative– non-emergency work scheduled as-needed to maintain long-term canal performance. Includes most vegetation management and minor erosion repair activities.
- Corrective– repairs made in response to a potentially severe problem likely to adversely affect system performance. Usually involve significant erosion stabilization or debris removal shortly after the problem is observed.
- Emergency– unscheduled work requiring immediate action to protect public from imminent harm.



Canals requiring non-normal work activities from 2008-2015 (in red).



3.0 CANAL TYPES

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Mid-Order Canals (p. 16)

Lowland Canals (p. 17)

Sediment Traps (p. 18)

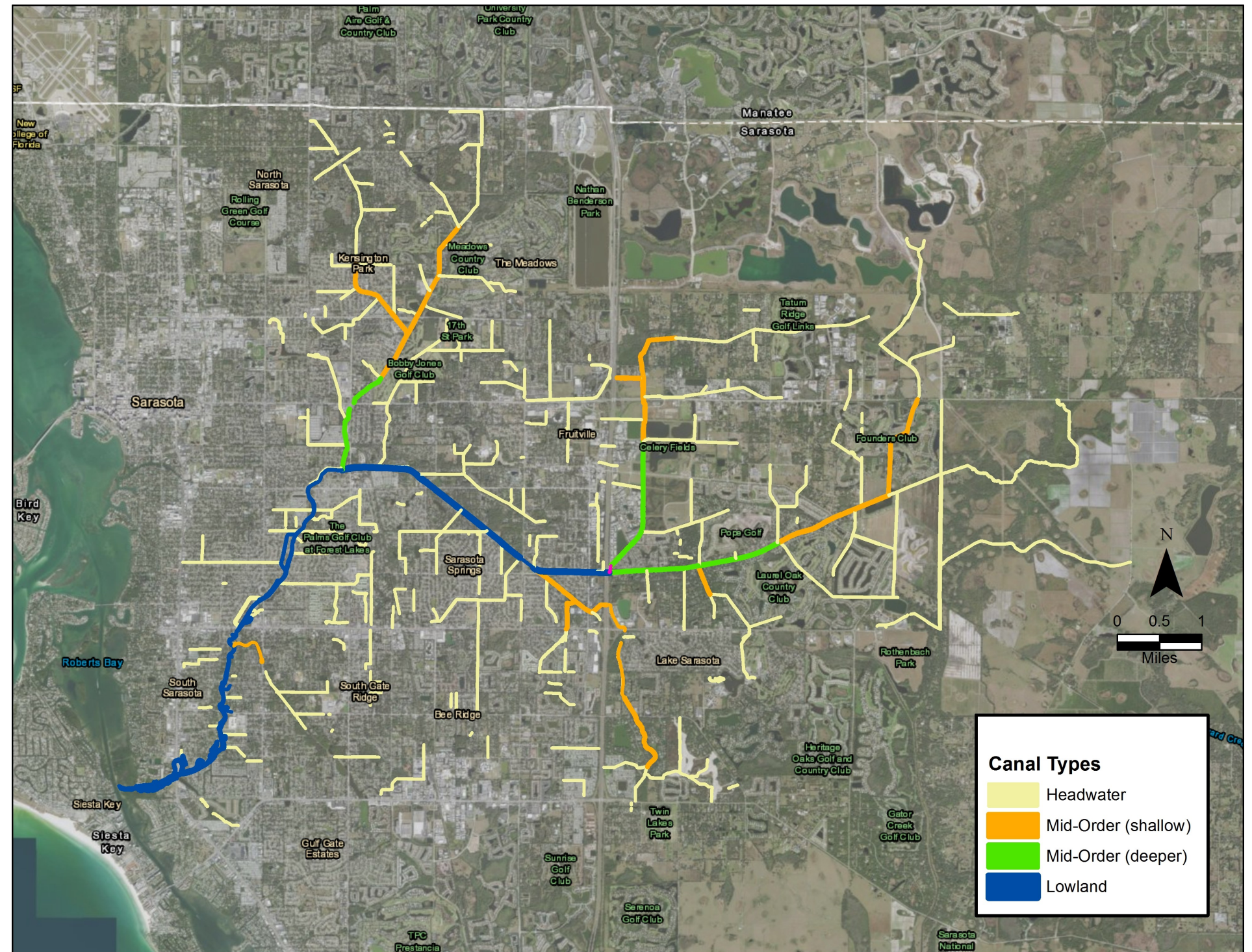


3.0 CANAL TYPES

Three main types of freshwater canals occur in the Phillippi basin, each falling within a range of watershed sizes. These categories were derived using a multivariate analysis of channel shape and dimension; streambank and travelway vegetation; valley slope; right-of-way width; watershed size and soil drainage characteristics; and in-situ water quality data. Those variables are associated with canal stressors and also establish what kinds of restoration outcomes are possible.

The three main canal types occupy headwater, mid-order (middle), and lowland (downstream) positions in the drainage network and are named accordingly. Two types of mid-order canals can be differentiated based on hydrology differences that relate to their recreation potential (shallow and deep). The canal types differ among existing and potential conditions before and after restoration, including:

- Biophysical attributes (size, erosivity, hydrology, fluvial forces, shade, stream metabolism)
- Natural stream types that can be restored
- Wetland and open waterbody sizes that can be restored
- Costs to restore
- Benefits of restoration (water quality, economic stimulus, recreation on and along the water, fisheries, flood reduction)



Mid-Order canals encompass two sub-categories. 'Shallow' systems would only be sporadically passable by kayaks and large fishes, while 'deeper' systems would be passable during most of the wet season and sporadically during the dry season upon stream restoration. Headwater systems are rarely navigable and lowland systems are almost perennially navigable by large fishes and kayaks after restoration.



Headwater Canals

These are small tributaries draining less than 2 square mile watersheds. They usually have undeveloped right-of-way about 30 to 80 feet wide. The existing open channel is often about 6 feet deep or less, and up to 30 feet wide. The canal banks are sometimes vegetated by trees that fully shade the channel. Normal flow depths are just a few inches, but vary greatly with rainfall.

Many of these sites offer excellent restoration potential as meandering headwater streams bordered by forested banks, or as gently flowing forested and non-forested wetlands within chains-of-wetlands.

These systems offer ample opportunities for water quality improvement. Headwater channels provide the highest investment returns for pollutant reduction. Water quality treatment mechanisms rely primarily on flowing water interacting with beneficial bacteria that thrive on carbon rich substrates these systems naturally accumulate once restored as natural channels.

These are 'heterotrophic' streams, meaning that their biological energy is derived from tree leaves and other carbon sources external from the stream. In contrast, 'autotrophic' streams receive their energy from submerged plants and algae that manufacture their own instream carbon. Carbon is nature's energy currency and stream restoration provides this element in useful forms enabling microbial nutrient removal. Understanding the carbon source by stream type facilitates better restoration design. Natural headwater streams are usually heterotrophic because the channel is narrow and is fully shaded by the adjacent trees.

The narrow corridors and shallow depths of headwater canals limit their development as direct resources for large gamefish species, greenway trails, or blueways.¹ However, they provide valuable habitat for small fish species and the young of large species.

Subject to verification by flood studies, local and downstream flood attenuation can be provided by stream restoration in these positions., mainly via increased detention volume.

¹ Blueways are aquatic trails for use by paddle craft like kayaks or canoes.



Mid-Order Canals

Mid-Order canals occupy intermediate drainage positions between headwater and lowland systems, with drainage areas ranging from 2 to 20 square miles. They usually have 50 to 120 feet of available right-of-way, encompassing channels that are frequently 60 feet wide or more and 7 to 12 feet deep. The streambed is sometimes partially shaded. It generally carries a foot or two of water during normal flow conditions.

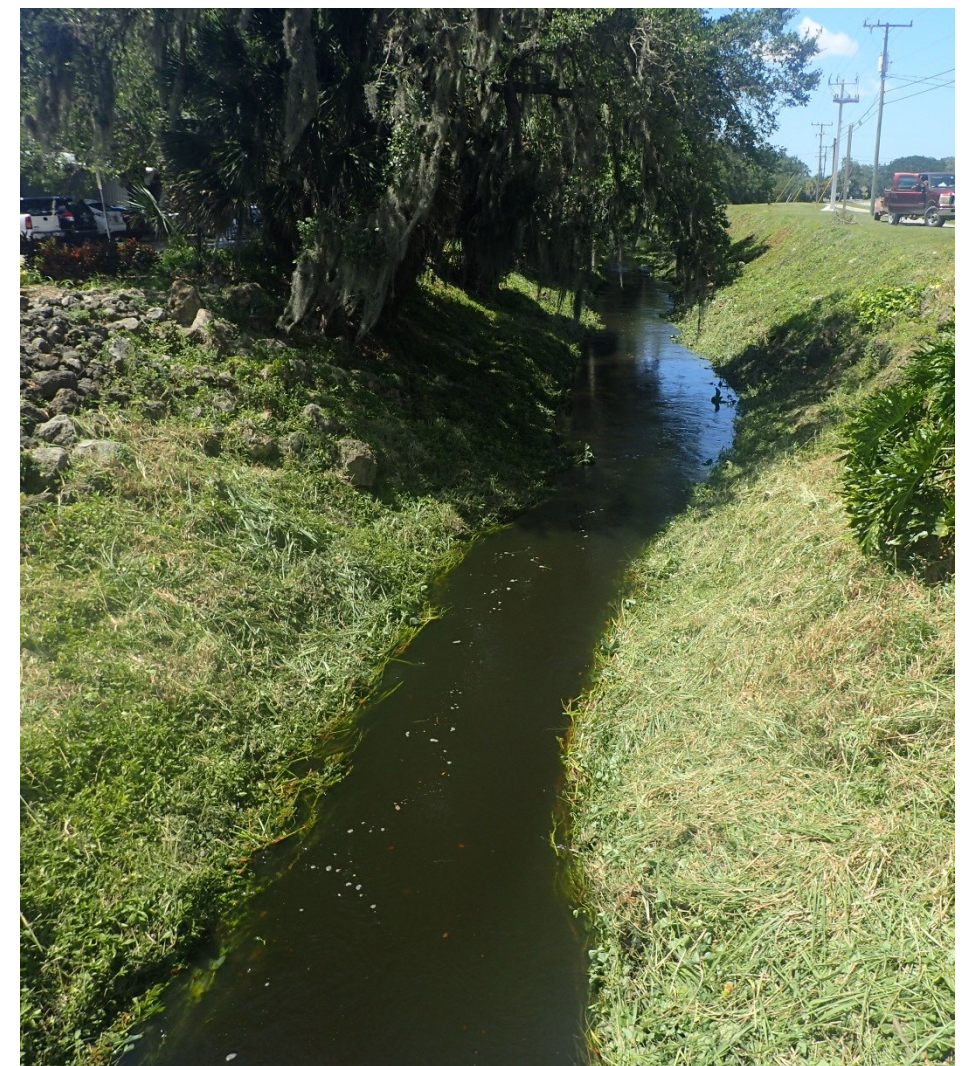
Many of these sites offer excellent restoration potential as meandering streams bordered by forested banks; or as gently flowing forested and non-forested wetlands and ponds within chains-of-wetlands.

These systems offer ample opportunities for water quality improvement mainly from heterotrophic processes in the streams meandering through forests, and autotrophic processes in in-line ponds and marshes (non-forested wetlands).

Mid-Order corridors are often wide enough to include greenway trail development, under shade. The restored channels are generally too small and shallow to be specifically developed into reliable blueways. However, the larger and deeper mid-order systems could be traversed by kayak during parts of the wet season.

Restored Mid-Order streams draining at least 8 square mile watersheds will have deeper pools and higher frequency of dry season conditions allowing safe passage and assembly of large-bodied fishes such as snook and largemouth bass. This habitat expansion is important because Locascio et al. (2018) found these species where analogous habitat patches occur in the canals. Therefore, two sub-categories of mid-order stream occur differing in their seasonal reliability for paddle craft and fish passage. These categories include deeper streams draining 8-20 square miles and shallow systems draining 2-8 square miles.

Subject to verification by flood studies, local and downstream flood attenuation can sometimes be provided by stream restoration in these positions primarily via increased channel capacity and flood detention volume.



Lowland Canals

Lowland canals occupy the downstream parts of the drainage network, draining watersheds of at least 20 square miles. They characteristically have undeveloped right-of-way 90 to 120 feet wide, with open channels greater than 70 feet wide and at least 12 feet deep. In non-tidal areas, the freshwater lowland channel carries about 2 to 4 feet of water during normal flow conditions.

These sites offer excellent restoration potential as either meandering streams bordered by forested banks; or as gently flowing forested and non-forested wetlands and ponds within chains-of-wetlands depending on the available valley slope.

These systems offer ample opportunities for water quality improvement mainly from a combination of autotrophic and heterotrophic processes in the meandering streams and their wetland floodplains, and autotrophic processes in in-line ponds and marshes. They also trap significant amounts of sediment.

Lowland corridors are typically wide enough to include shaded greenway trail development. The restored channels are generally deep and wide enough to specifically develop into reliable blueways, with excellent habitat for virtually year-round game fishing (to the extent allowed by fishing regulations).

Subject to verification by numerical flood studies, local and downstream flood attenuation can sometimes be provided by stream restoration in these positions primarily via increased channel capacity and flood detention volume. Stream restoration can also be part of a multi-layered strategy to increase resiliency against wind-driven tide surge and to dampen associated flood levels in the tidally-influenced portions of lowland streams.



Sediment Management Systems

Sediment management systems are in-line ponds installed within the canal network to prevent much of the excessive sand from being transported to undesirable destinations downstream. These mimic in-line waterbodies in natural chains of wetlands in some ways, especially if they are fringed with wetland vegetation.

Scientists working at the Mote Marine Laboratory found snook and bass in sediment trap ponds and in some of the Phillippi canal segments, especially in areas with evolving vegetated sand bars inducing gentle meanders (Locascio et al. 2018). These meanders are not stream bends per se, rather they are an inner berm that directs the baseflow of the stream. Inner berms improve fish habitat by compressing low flows and increasing their depth and/or velocity. They are essentially a stream within a stream during normal flows.



Mote Marine's Dr. Jim Locascio shows juvenile snook sampled in the Phillippi basin.

Photo Credit: Dr. Nate Brennan/Mote Marine Laboratory.



Sediment management system in the Phillippi canal network. Rocks in foreground are the staging area for cleanout equipment during routine maintenance dredging activities.



4.0 TREATMENTS

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4.0 TREATMENTS

Two approaches to reduce canal maintenance include:

- Stabilization-in-Place (SIP)
- Stream Restoration (aka Natural Channel Design, NCD)

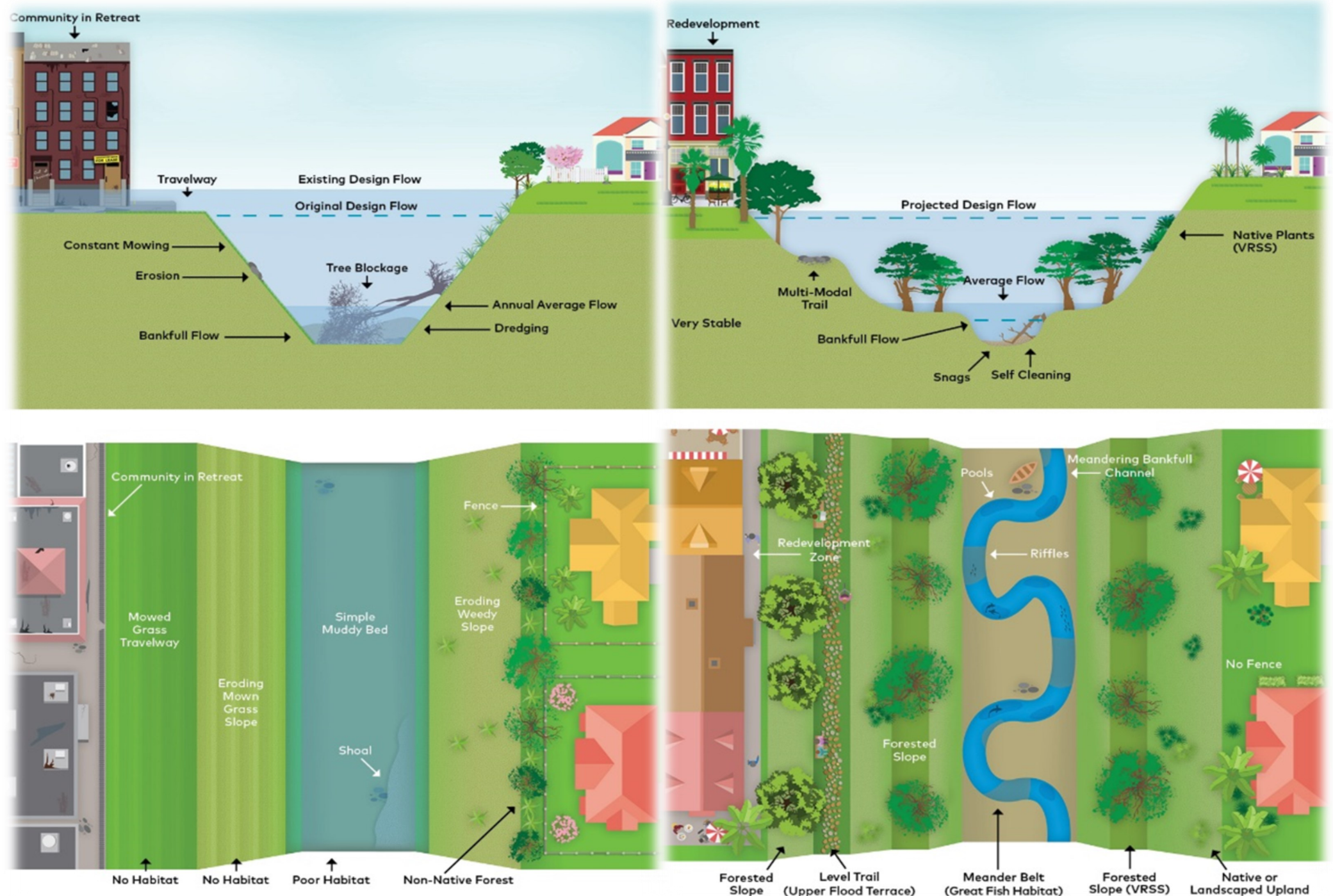
SIP involves retaining the existing straight canal pattern and trapezoidal cross-section shape, with or without modest changes in canal width, depth, or bank slopes. In essence, the drainage feature remains a canal, but receives a new surface treatment resistant to erosion and not requiring mowing.

NCD extensively re-shapes and vegetates the canal right-of-way as a means to harness natural processes and become intrinsically self-organizing and self-sustaining. It installs an analogue to a natural stream corridor complete with meandering channels, forested floodplains, and forested and non-forested in-line wetlands and ponds. These habitats are carefully designed to fit their watershed and valley conditions. They require a certain amount of undeveloped right-of-way to work. Absent that, SIP is required.

Retrofit components can be made from various combinations of inert and living materials. When the treatment's most-essential components are dominated by inert materials that deteriorate over time it is categorized as 'gray infrastructure.' Examples include gabion baskets, concrete retaining walls, and riprap channel lining among others.

Treatments designed to strengthen over time with live vegetation as the fundamental components for project performance are referred to as 'green infrastructure.' Examples include stream restoration and soil bioengineering² structures.

²Soil bioengineering (SBE) integrates inert and live materials to create robust, long-lasting slope stabilization sites. SBE can be used as a form of stabilization-in-place and is often a component of stream restoration.



Straight canal with trapezoidal cross-section. Stabilization-in-place retains the same basic pattern, but alters the material lining the bed and banks of the canal. The system remains a canal designed to perform a singular drainage function. Stabilization-in-place generally only provides bank stabilization. It has limited value where additional objectives are desired.

Stream restoration with a multi-stage channel. The canal is replaced by a two-stage conveyance consisting of a bankfull stream channel meandering through an adjacent vegetated floodplain. The original drainage functions of the canal are retained or improved while also substantially improving fish and wildlife habitat, water quality, & recreation opportunities. These factors improve property value and community resiliency.



4.1 Stabilization-in-Place

Stabilization-in-place is recommended for areas where severe instability occurs and it cannot be addressed using stream restoration. Design is highly site-specific depending on local soil conditions, groundwater table fluctuations, fluvial forces, and the public interest. Selection occurs from among a wide variety of channel lining and slope stabilization technology and must be made by qualified engineers familiar with soil bioengineering, hydraulics, and slope stability practices.

Advantages of some inert materials can include an urban architectural aesthetic, but this comes at a price. For example, segmental-block retaining walls with a textured surface molding cost about \$45 per square foot installed, while the most expensive soil bioengineering bank stabilization method is about \$10 per square foot. Riprap and gabions are less expensive than architectural retaining walls, but are more expensive than most bioengineering structures.

Engineers and architects tend to be better-versed in gray versus green bank armoring approaches, so three common gray infrastructure examples are depicted on this page while a more detailed illustration of the green VRSS technique is provided on the next two pages.

A drawback of inert structures relying on concrete, steel, or plastic is that these materials deteriorate over time and are designed to resist natural forces. Thus, when they ultimately fail they tend to fail utterly, requiring substantial structural and systemic repairs. The effective life of some common inert structures is about 15 years under Florida conditions. Gabions are not forever.



Textured segmental block concrete retaining wall.

Photo credit: <https://www.redi-rock.com/>



Riprap channel lining on Alligator Creek, Starke Florida.



Open cell articulated concrete block, Loxahatchee River Florida.



Gabion baskets along Lake Parker Canal, Polk County Florida.



Vegetation Reinforced Soil Slope (VRSS)

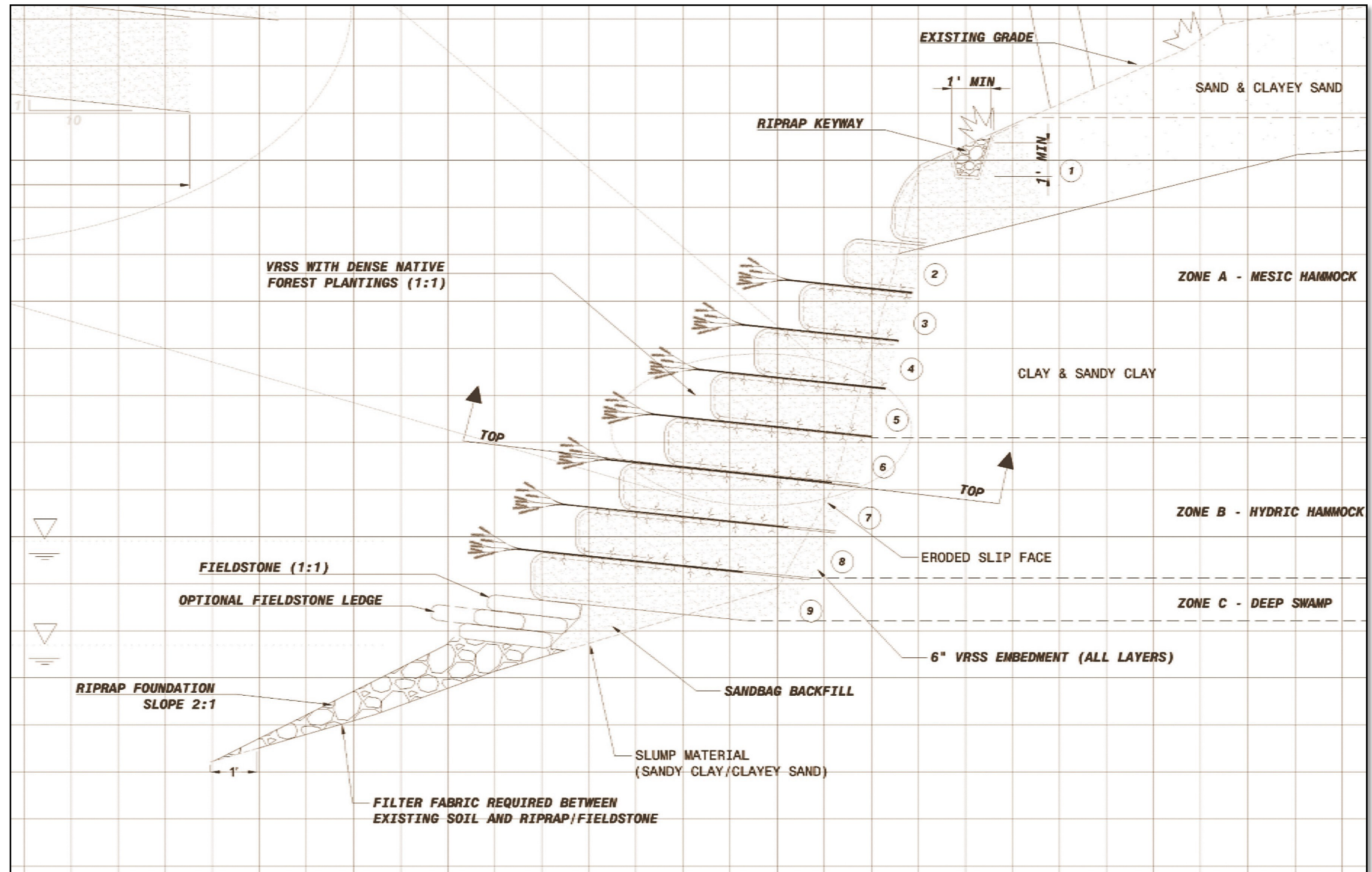
VRSS is a soil bioengineering treatment that can be used to stabilize banks up to 60 feet high and at slopes as steep as 0.5:1 (horizontal to vertical) (Sotir & Fis-cenich 2003). VRSS is highlighted because it enables stabilization-in-place and stream restoration to occur in con-strained right-of-ways that require steep banks.

VRSS consists of a series of vegetated geogrids stacked in one foot layers during construction. The roots of plants in-stalled between the geogrids bind the layers together. Geogrids are not needed for slopes more gradual than 2.5:1.

The geogrids are constructed over an in-ert foundation extending from the chan-nel scour depth to the lower limits of vegetation establishment. The founda-tion often consists of native stone or riprap resistant to stream scour.

Internal bank reinforcement and ground-water curtains may be required depend-ing on groundwater conditions and soil mechanics. Design should be conducted or reviewed by an experienced geotech-nical engineer working with a river me-chanics professional to assure sufficient countermeasures against gravity failure, sapping, and fluvial forces.

The geogrids and area behind them can be designed to include water quality treatment media. This adds value if groundwater seepage is a source of pol-lution to the open water system.



VRSS design schematic for Blue Springs, Orange City Florida. Note that plant materials are adapted to three hydrologic zones specific to this 15 foot high bank and inert materials are installed below the limits of vegetation under water.



VRSS Variants

Either biodegradable or more permanent woven plastic fabrics can be used to install the geogrids. Biodegradable fabrics made of coconut fiber (coir) are typically used in concert with native woody vegetation, while more permanent plastic mats are used with turf and non-woody landscaping plants.

The longest lasting plastic mats, referred to as 'high performance turf reinforcement mats (HPTRM)' are usually rated to last for 20 years but vary by make and model. They resist sunlight deterioration and allow woody and non-woody plant establishment.

Biodegradable coir mats are rated to last up to 3 years. They provide a temporary surrogate for the root masses of woody vegetation as they become established. This enables the project to accept flow immediately upon construction.

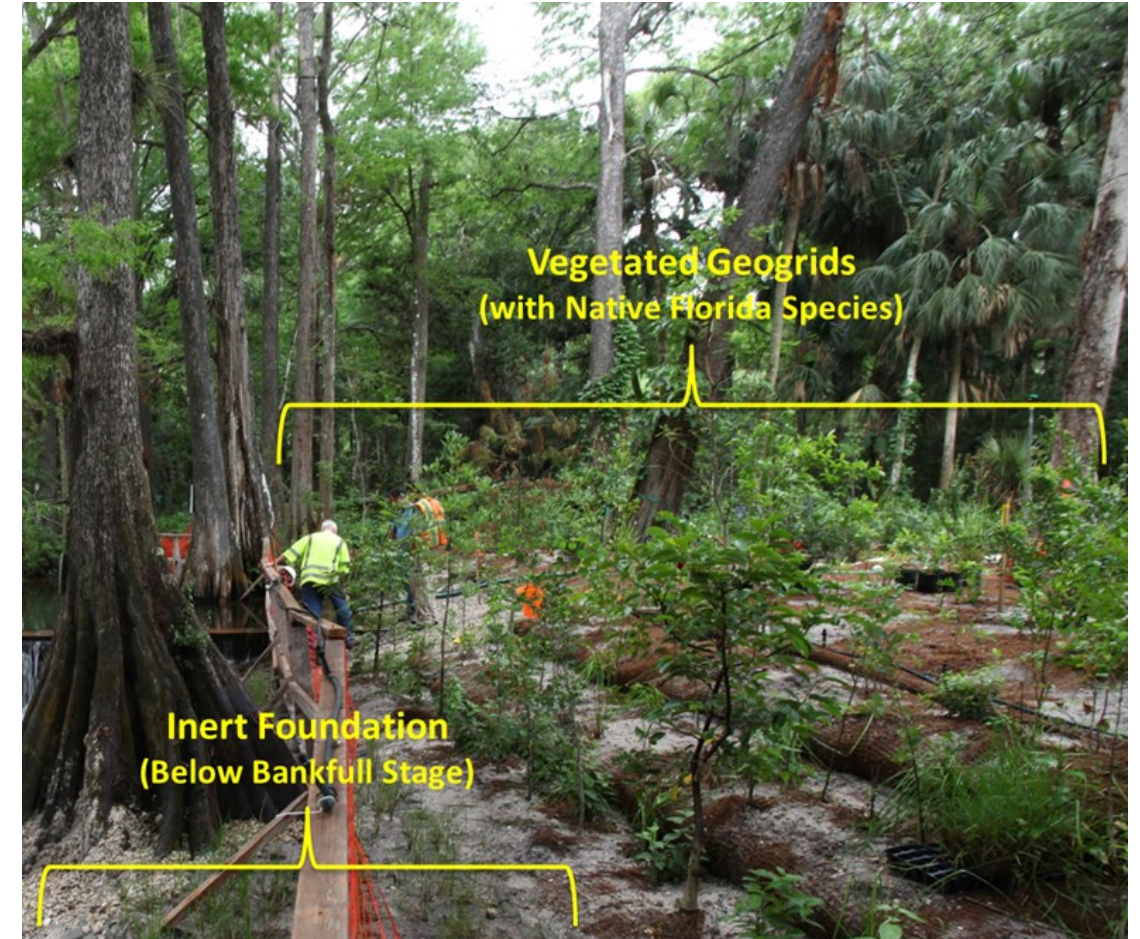
Use of woody plants and coir fabric is preferred because tree and shrub roots provide greater shear strength versus those of non-woody plants. The system strengthens over time. In contrast, plastic turf mats with non-woody species are more expensive to construct, and the integrity of the structure relies on fabric that decays thus requiring replacement every two decades. Reliance on HPTRM and herbaceous vegetation is only recommended in situations where an open aesthetic is essential and the owner is willing to refurbish the bank with new fabric and plants.

In addition to its cost advantage over inert structures, woody VRSS sustainably provides a natural aesthetic with some streamflow energy dissipation, shade, bird and fish habitat, and water quality improvement.



VRSS constructed with non-woody vegetation in concert with an HPTRM geogrid. Approach retains open vistas, but requires routine landscaping maintenance. It also requires geogrid replacement every two decades or so, thus requiring a total rebuild.

Photo credit: Tensar Corporation



VRSS constructed with native woody vegetation in concert with coir geogrid. Approach provides a natural forested bank that does not require routine maintenance or geogrid replacement. The forest becomes self-sustaining and provides canopy for birds, overhanging vegetation for fish habitat, and shade for greenway trails.

This example is from one of Florida's two National Scenic Rivers, the Loxahatchee, near Jupiter. The project was recognized for an innovation award by the Florida Association of Environmental Professionals, and praised by members of the Loxahatchee River Coordination Council for its design befitting the public use and natural aesthetic of the system. It was just a couple of weeks old when Hurricane Irma flooded the project and it withstood that event quite well.

VRSS's are highly modular and can more readily accommodate existing trees than most kinds of inert structures. In this case, VRSS enabled the preservation of several ancient cypress trees in the construction area..



4.2 STREAM RESTORATION

Stream restoration is a broadly used term for a wide array of activities aimed at improving unnatural or impacted stream corridors. Here we use the term exclusively to mean systems designed with biophysical attributes to harness natural forces that quickly become self-sustaining and self-organizing ecosystems. They are designed to be in balance with the flow of water and sediment delivery to the valley. This approach is also referred to as natural channel design (NCD) (NRCS 2007). Good stream restoration answers the question, "Where would you'd rather fish?"



Not stream restoration. Ditch retrofitted with water quality treatment structures referred to as regenerative stormwater conveyance (RSC). RSC mimics step-pool morphology found in mountain streams and the rock steps are impregnated with treatment media to reduce nutrient pollution. While this can be an effective water quality treatment, it relies on mined rocks not rejuvenated from upstream transport. Thus it is not self-sustaining should the rock move, and is more accurately viewed as a variant of riprap installation for stabilization-in-place in Florida.

Photo credit: University of Florida, IFAS



Year 0. Edwards Bottomlands, Starke FL.
(Drainage Area = 25 sq. mi.)



Year 3. Doe Branch 5, Hardee Co. FL.
(Drainage Area = <1 sq. mi.)



Year 12. Maron Run, Polk Co. FL.
(Drainage Area = 3 sq. mi.)



Year 25. Hickey Branch, Hardee Co. FL.
(Drainage Area = 2 sq. mi.)

Stream restoration. Four Florida stream restorations in various states of maturation. Florida rainfall delivers rather extreme seasonal flow variation, leading to fluvial forms with a frequently flooded floodplain encompassing a small meandering low-flow channel. Stability depends on woody plants and continuity of sand transport facilitated by the channel morphology. Kiefer et al. (2015) identified 15 Florida stream types along gradients of watershed size, groundwater inflow, and valley slope. Biophysical integrity relies on understanding how watershed conditions affect those variables.

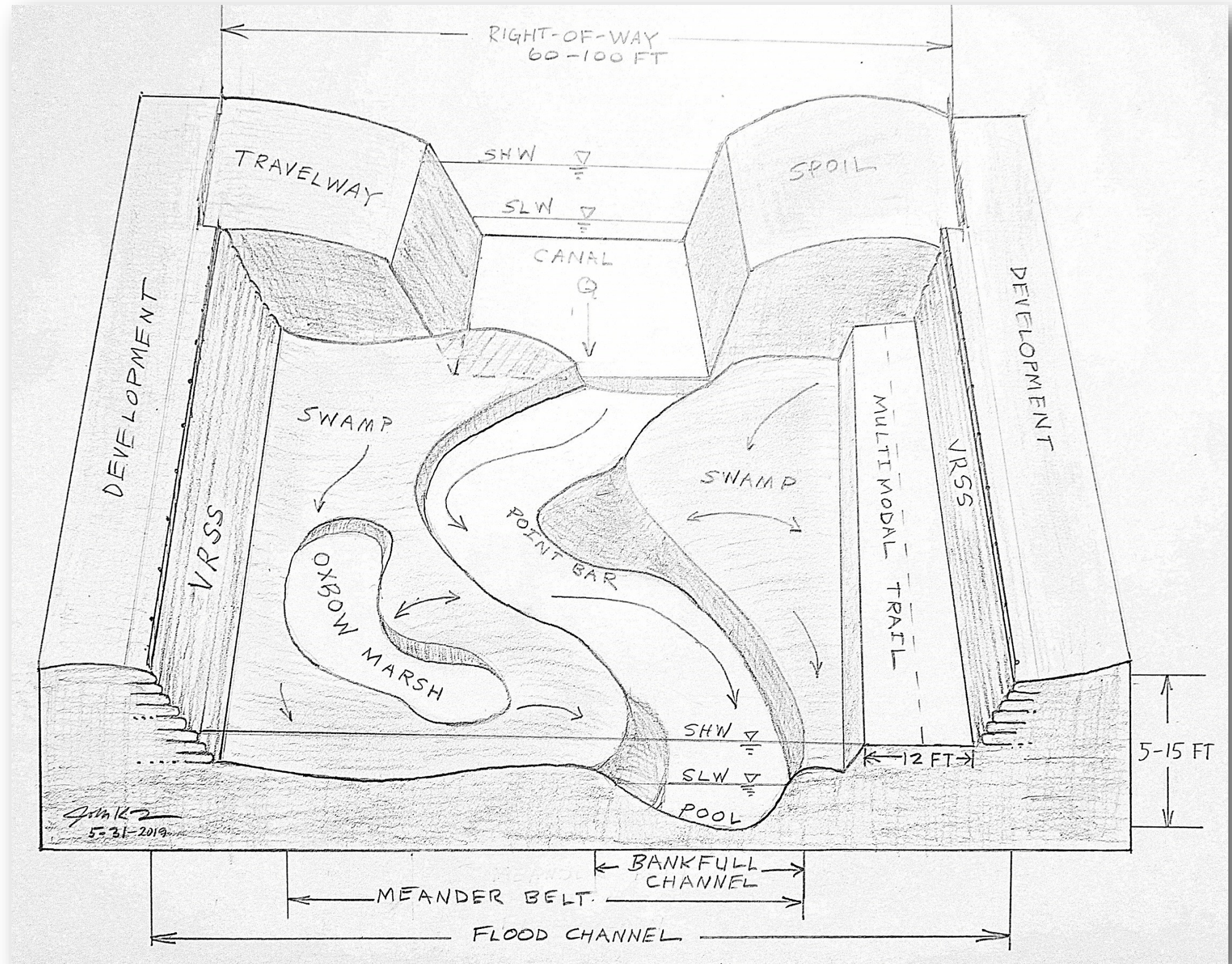
Conversion of Canal to Natural Channel

Canals can be converted to natural stream corridors by excavating the terrestrial portions of the right-of-way to enlarge the floodplain within it, and then installing a meandering bankfull channel within the newly created floodplain. The streambed elevations are often constrained by existing road crossings and limited valley slope and therefore cannot be raised much above that of the existing canal bottom. This constraint means most canal conversions cannot be designed to balance the earthwork excavation and fill onsite and will instead require extensive export of removed soils to provide the necessary two-stage channel without causing offsite flooding.

Several basic geomorphic components must be designed to fit their watershed and valley, and to function in accord with each other. Getting any one of these wrong can destabilize the system. Fortunately, tolerances are fairly wide. The bankfull channel width, depth, bend curvature, and meander belt are all dimensioned based on regional norms in association with watershed size (Kiefer et al. 2015). The floodplain width is based on watershed size and soil drainage characteristics with further adjustments determined by watershed alteration and site location within an urban landscape. The first two variables are required as a starting point to assure physical stability and biological integrity of the stream corridor.

The floodplain width should be enlarged as needed to achieve the required amount of flood protection along the restored drainage feature. Property should also be protected from erosion outside of the meander belt and at transitions between restored and unrestored reaches. Software for computing hydraulics and tractive forces can be used to simultaneously assess flooding and areas requiring special erosion countermeasures.

Maximum benefit of stream restoration can occur when conducted in concert with culvert retrofits at road crossings to provide concurrent equivalency in flow capacity and sediment and debris transport. This prevents bottlenecks at the crossings.



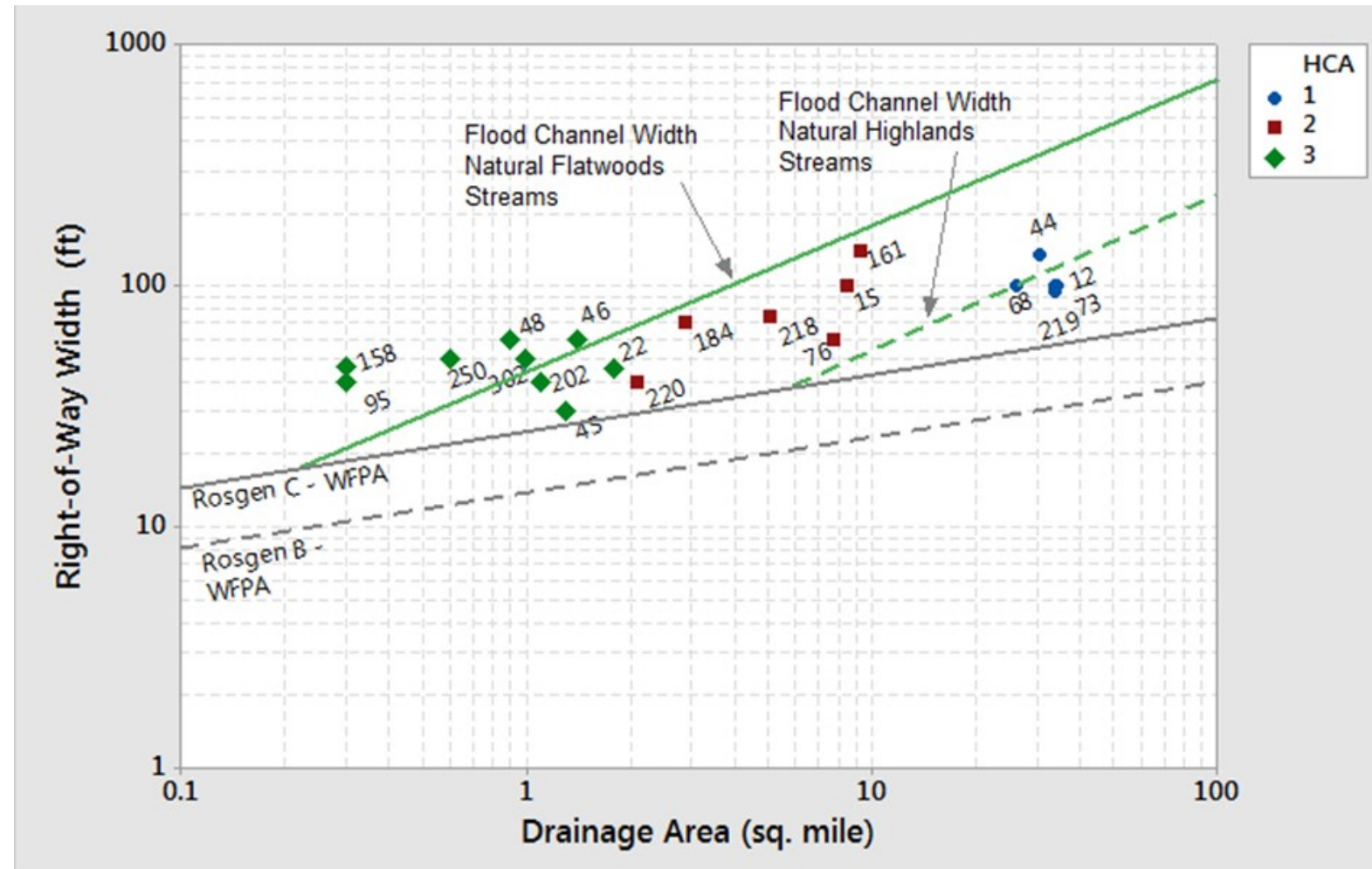
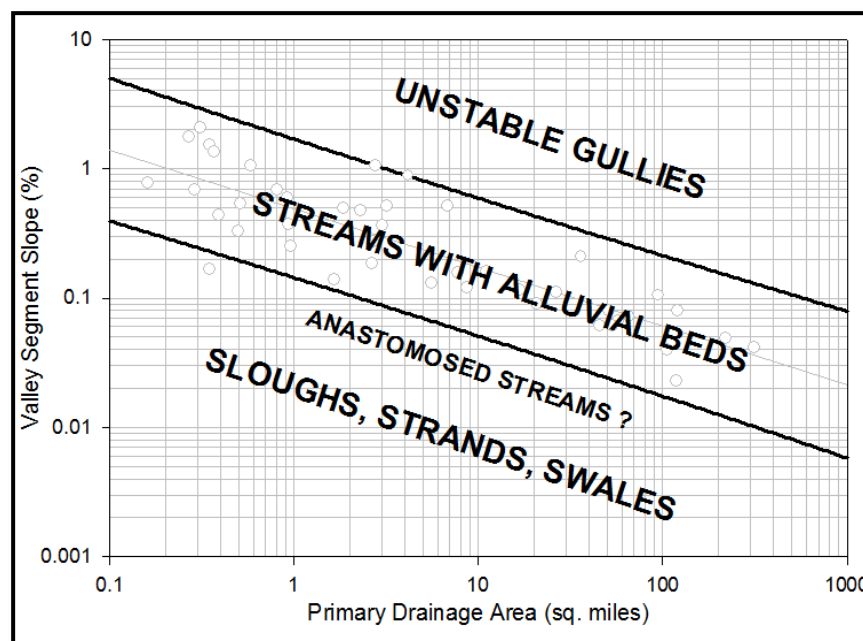
Stream restoration requires room to fit a bankfull channel, its meander belt, and a flood channel. These scale with watershed size, and the flood channel further enlarges with poorly drained soils and impervious surfaces. Water is exchanged through many carbon-rich areas thus sustaining fisheries and improving water quality. Recreation trails with multi-modal access are often co-located with stream restoration.



Is Stream Restoration a Good Fit?

The first question to be addressed for a canal segment is “Does enough undeveloped right-of-way exist to accommodate the floodplain width and meander pattern of the bankfull channel?” If the meander belt width is similar to the floodplain width, then the valley is called ‘well-fit’, and if the floodplain greatly subsumes the belt width then it is referred to ‘unconfined.’ In many urban settings a well-fit condition is the most likely available condition, but the largest available floodplain one can afford to construct is recommended to increase system resiliency and future-proofing against ongoing climate trends of storm intensification. See the graphic to the right for more information.

If right-of-way is sufficient, the second question posed, “Is there sufficient valley slope to carve and maintain an open channel, or is a different kind of flowing waterbody required?” This matters because Florida valleys variably support well-defined meandering channels alternating with other waterbody types within chains-of-wetlands or chains-of-lakes. The positions of different in-line waterbody types depends on stream power which is affected by a combination of watershed size and longitudinal valley slope (see below).



HCA stands for Hierarchical Cluster Analysis. This was the statistical method used to assign canal types, resulting in three main categories:

- Headwater (green diamonds)
- Mid-Order (red squares)
- Lowland (blue circles)

Floodplain width. This graph shows the available right-of-way for 3 size categories of Phillippi canals versus a variety of morphologic criteria for setting minimum floodplain width. Rosgen (1996) sets this using a ratio dependent on bankfull channel depth and varies the ratio by stream type (e.g. type B vs C). Kiefer et al. (2015) determined stable Florida floodplains vary by soil drainage and watershed size. Poorly drained soils historically supporting flatwoods landscapes produce larger floodplains than watersheds with at least 40% well-drained soils found in sandhills and scrubs (highlands). Although the Phillippi watershed was predominantly flatwoods pre-development, flood models of the current system indicate soil drainage is like a highlands landscape today (Sarasota County 2011). The canals draw down the water table and increase the drainage capacity of the soils. Rosgen C criteria appear to provide the best balance of resiliency and efficiency for watersheds up to 6 square miles and Kiefer Highlands criteria provide this for larger systems. Canals 12, 73, and 219 have sufficient right-of-way for Rosgen C, but not enough for Kiefer Highlands. Stream restoration remains a possibility for those sites, but is unlikely to be very resilient against major floods absent special erosion countermeasures. In comparison, most of the headwater canals (HCA 3) have enough room to support flatwoods floodplains, and should be very resilient at that size. Morphologic guidance is merely a starting point and should be carefully vetted by sediment and flood studies on a reach-by-reach basis in all cases.

Stream power. A zone of confidence for peninsular Florida meandering stream channels occurs between unstable gullies and waterbodies lacking an alluvial channel (sloughs, strands, swales). Canal reaches plotting below the lower limits of alluvial streams can be restored as flow-through wetlands or ponds, or retrofit as sediment management basins. Reaches plotting above the alluvial stream zone require grade control measures to be stabilized (Kiefer et al. 2015).



Woody Habitat

Stream restoration requires a variety of habitat features to dissipate energy for long-term stability, and to support biological diversity. Bankfull channel and floodplain morphology, vegetation, and large woody debris play critical roles regarding the biophysical integrity of natural Florida stream corridors. All three of these factors relate to one another and must be designed and installed concurrently. However, forests take years to mature and temporary surrogates for mature trees and the woody debris supply to the bankfull channel are required upon initial construction.

NRCS (2007) (Chapter 11-Rosgen Geomorphic Channel Design) describes several such habitat structures using rock and log vanes to bend water in ways dissipating energy and sustaining fish habitat. Wood's engineers have adapted several Rosgen structures for Florida installations using woody debris instead of rock including treatments called cross vanes (v-log weirs), j-hooks, and toe wood. Wood's engineers also adapted wing deflectors and boulder habitat cluster designs developed for rocky streams using logs and tree stumps instead of rock for Florida stream restoration. Native Florida fish have responded well to these adaptations. The wood is long-lasting (>15 years and counting on our oldest deployment), providing ample time for forest maturation to sustainably stabilize banks and forest sources of woody debris to the channel.

Natural Florida stream morphology and wildlife are adapted to a range of woody debris in the channel. Removal (de-snagging) is seldom necessary for stream restoration sites. Snags, unless they accumulate at culvert openings, hardly ever aggregate at elevations affecting flood levels. In fact, over-zealous de-snagging operations can be counterproductive for flood level reduction because they can so severely destabilize the channel that excess sediments partially clog culverts under road crossings during storm events making flooding worse. For stream channel integrity, 'Wood is Good!'



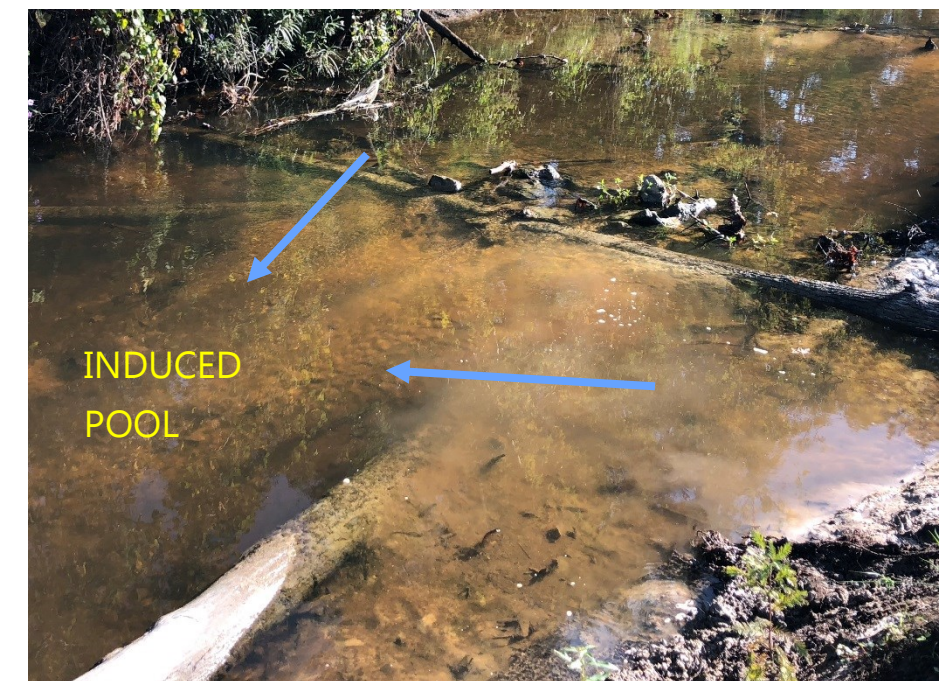
Rosgen Toe Wood. A cantilevered log and stump array that stabilizes bends and sustains deep pools with fish habitat akin to an overhanging bank.



Fish Spawning. Fish nests at a woody 'boulder' cluster. Largemouth bass and bluegill were observed at all woody debris treatments in the restored stream during the first spawning season after project completion. No nests were seen in adjacent un-restored areas of the canal.



Boulder Habitat Cluster. Array of stumps and logs driven into the streambed at prescribed spacings to create refuge for small fish species and turtles.



Rosgen Cross-Vane. Two logs configured as a V pointing upstream focus flow (blue arrows) to the channel interior inducing a pool. This structure creates habitat, improves water quality, and dissipates energy in areas where meanders cannot be established.

Examples all from SRWMD's Edwards Bottomlands Project in Starke, FL, within one year of construction.



In-Line Waterbodies

Some scientific terms are highly useful for describing Florida stream corridor complexity. **Lotic systems** (streams) have comparatively strong flow in well-defined channels that transport sediment (alluvium). Flowing water and gravity organize sediments into sequences of alluvial features like bend pools, point bars, shoals, and natural levees. Stream life is adapted to these features and the forces that create them. Lotic valleys are tilted in a downstream direction and water surfaces follow the slope. In contrast, **lentic systems** are depressions with level pools of water. They are not maintained by the force of flowing waters.

Two main types of in-line waterbodies occur within Florida stream corridors between lotic reaches. **Paralotic** reaches have a slight down-valley slopes but their flow is not strong enough to form alluvial features. These reaches can be fully vegetated by forested and non-forested wetlands, or contain multiple poorly defined and discontinuous open channels (anabranching streams). Paralotic systems are often referred to as sloughs (deeper marshes), swales (shallow marshes/wet prairies), and strands (swamps). Swamps are forested wetlands and marshes are non-forested.

Paralentic reaches are depressions spanning the valley. These can have nearly level pools of water along the length of the depression. Depending on depth, they can be lakes, ponds, marshes, or swamps. Long skinny lakes in river valleys are often called lagoons or billabongs. Paralentic and paralotic systems often have sediment deltas at their stream inlets. These deltas usually succeed to vegetated wetlands.

Presence of herbaceous vegetation in Florida stream corridors depends on long flood periods and fire. Because prescribed fires are not feasible in developed stream corridors, shallow herbaceous wetlands may require weeding to maintain their non-forested status over time. Left to their own devices, they will succeed into forests.

It is entirely feasible to create a variety of paralentic and paralotic waterbodies where valley slopes are insufficient for stream restoration in the Phillippi canal network.



***Paralotic strand restoration.** Mixed cypress and hardwood swamp created in the Hickey Branch restoration project in Hardee County, FL. The left image is at the transition between strand and stream, facing the strand. Strands provide shade, increased water color, and carbon sources that improve water quality. The strand provides forested habitat for migratory birds, including warblers and other species sought by birdwatchers. It also supports a multi-species wading bird nesting colony.*



***Paralentic pond restoration.** This scene is also part of the Hickey Branch project. It was contoured as an in-line depression and vegetated with lily pads. The deeper water supports large fish and a variety of migratory waterfowl. The littoral fringe is used by wading birds and small fish. When designed as open waters fringed by wetland plants these features can promote recreational fisheries for bass and snook in the Phillippi system. They can also be designed as sediment traps.*

Paralentic and paralotic reaches add geo- and biodiversity to the stream corridor that enhance recreation and opportunities for pocket parks.



4.3 APPLICABILITY

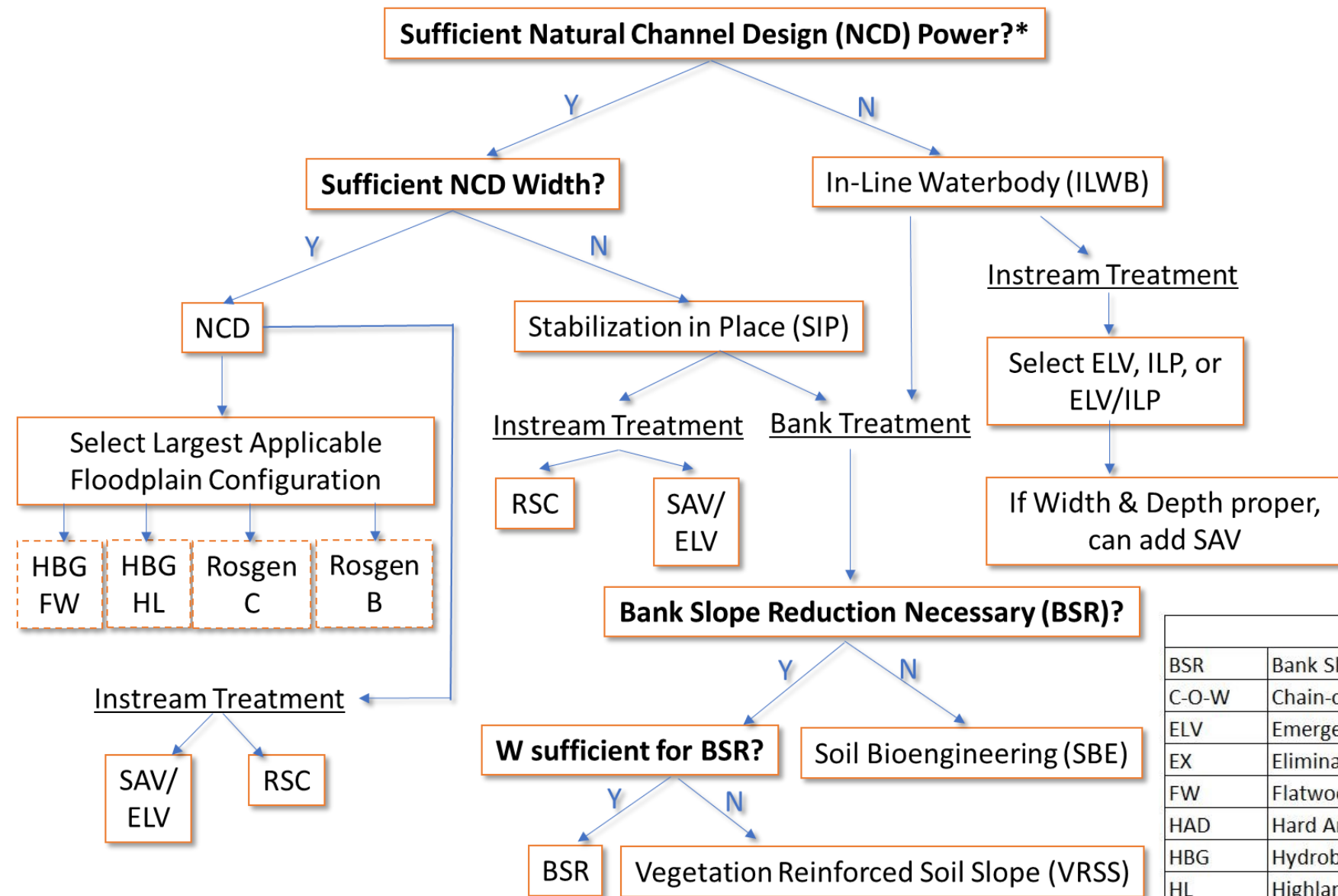
Wood developed a decision tree to assign the most environmentally beneficial retrofit type for any given canal reach. The algorithm is hierarchical. It first examines what kinds of waterbody can be supported, then provides a menu for vegetation, instream habitat features, and water quality enhancements for each waterbody type.

These tiers provide a framework for bank and in-stream treatments that landscape ecologists, biologists, and landscape architects can draw from to create cohesive corridors meeting local and regional objectives for habitat, recreation, and water quality. Some decisions are contingent on numerical thresholds related to corridor morphology and light availability. Canal type is a good way to assess this.

Natural channel design (NCD) is only applicable in areas with sufficient stream power to sustain a bankfull channel and right-of-way for flood channel width. Absent sufficient power, in-line waterbody (ILWB) restoration or stabilization-in-place (SIP) are discretionary options.

If stream power is sufficient, but right-of-way width is too narrow for NCD, SIP can be conducted. Bank treatments depend on slopes and widths and can include simply planting woody vegetation (SBE), reducing bank slopes if available width allows (BSR), or installing VRSS geogrids for steep slopes.

Hard armoring using gray infrastructure is required only in areas where NCD, BSR, SBE, or VRSS cannot be implemented. The benefits of various gray and green approaches are tabulated on the next two pages.



***Stream Power Gradient.** The biophysical attributes of natural channels in Florida classify along a gradient of stream power, increasing in dimension and picking up certain kinds of instream and floodplain habitats as total flow increases and groundwater inflow varies. The available stream power increases with increased watershed size and its associated larger flood pulses and greater dry season flow permanency. Larger watersheds also produce greater sediment loads, which the increased stream power organizes into alluvial habitat surfaces over time. The net result of this is that some habitat attributes cannot be sustained by headwater channels that can be sustained down the drainage network. This chart embodies an algorithm for making informed decisions regarding what kinds of restoration treatments are available in any given canal based on its location in the watershed and also based on the extent of accessible undeveloped property in urban landscape (see page 26).

ACRONYMS	
BSR	Bank Slope Reduction
C-O-W	Chain-of-Wetlands
ELV	Emergent Littoral Vegetation
EX	Elimination
FW	Flatwoods
HAD	Hard Armoring
HBG	Hydrobiogeomorphic Design
HL	Highlands
ILM	In-Line Marsh
ILP	In-Line Pond
ILS	In-Line Swamps
ILWB	In-line Water Body
LWD	Large woody debris
NCD	Natural Channel Design
ROW	Right of Way
RSC	Regenerative Stormwater Conveyance
SAV	Submerged Aquatic Vegetation
SBE	Soil Bio-Engineering Treatments
SIP	Stabilized in Place
VRSS	Vegetated Reinforced Soil Slope



Retrofit Potential

Stream restoration and in-line waterbody creation appear to be feasible for the vast majority of the county-maintained canals in the Phillippi Creek watershed. This determination is based on biophysical criteria related to corridor width and slope using remote sensing data (aerial photos, LiDAR topography) and County tax parcel boundaries.

It is intended as a screening-level assessment. Site-specific feasibility determinations will ultimately depend on more accurate data, including;

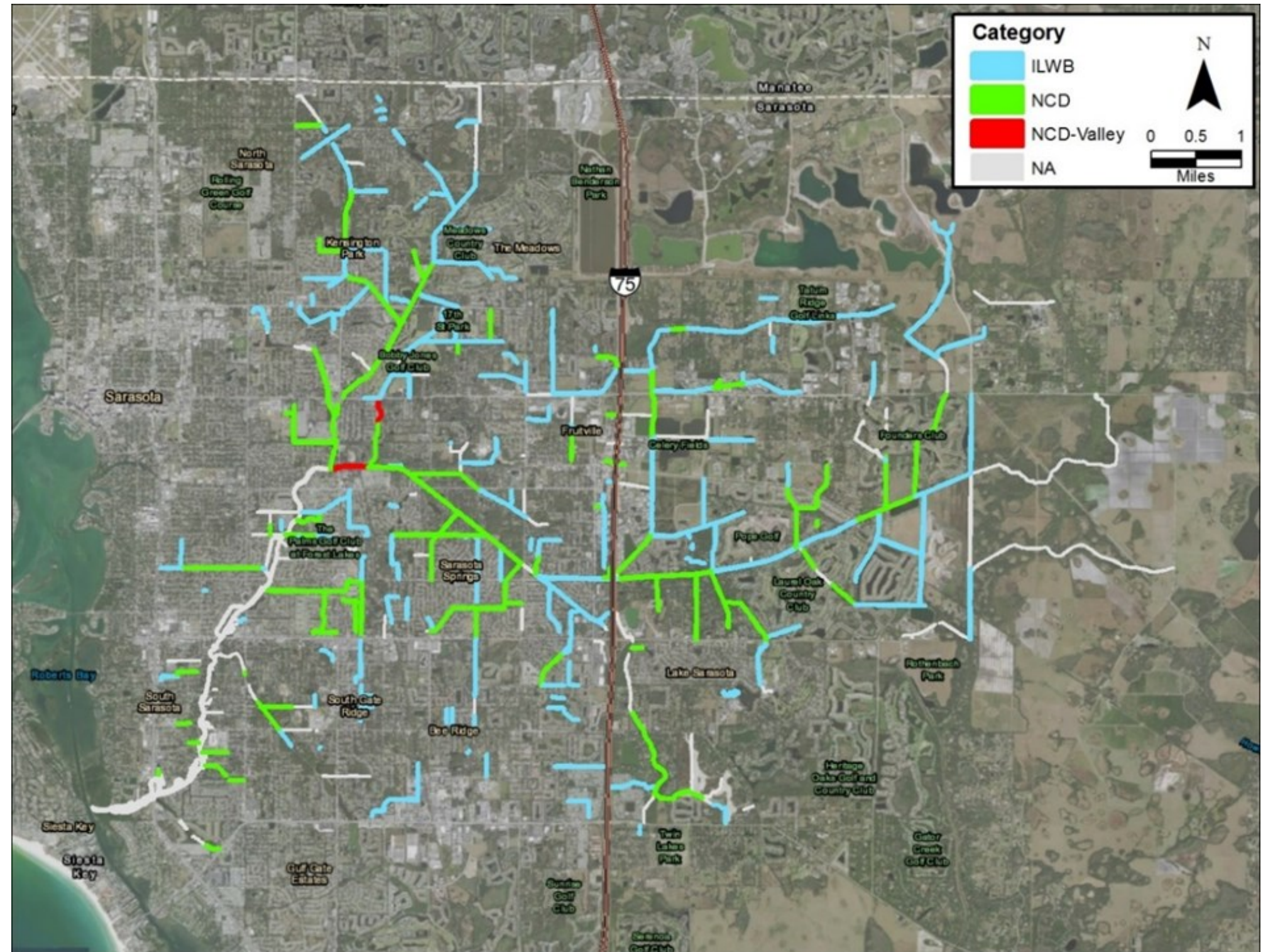
- Streambed elevation surveys
- Property boundary surveys
- Subsurface utility survey and conflict resolution

Not all of the canals are in equal need of restoration, nor do they necessarily have similar costs to implement. Site-specific feasibility also ties to benefits outweighing costs.

This first assessment suggests that options for creating functional analogues for natural chains-of-wetlands are widely available throughout the watershed at locations where the cost and benefits may end up warranting their implementation.

That finding means biophysical variables are seldom going to be the limiting factor for multi-purposing this extensive public asset in ways that retain or improve its drainage functions and improve water quality, increase fish habitat, and provide recreational opportunities on and off the water. This is an important and exciting finding because not all urban stream corridors have such investment potential.

Note: Areas mapped as NA are either tidal with special considerations beyond the scope of this document, or are assets not managed by SEU.



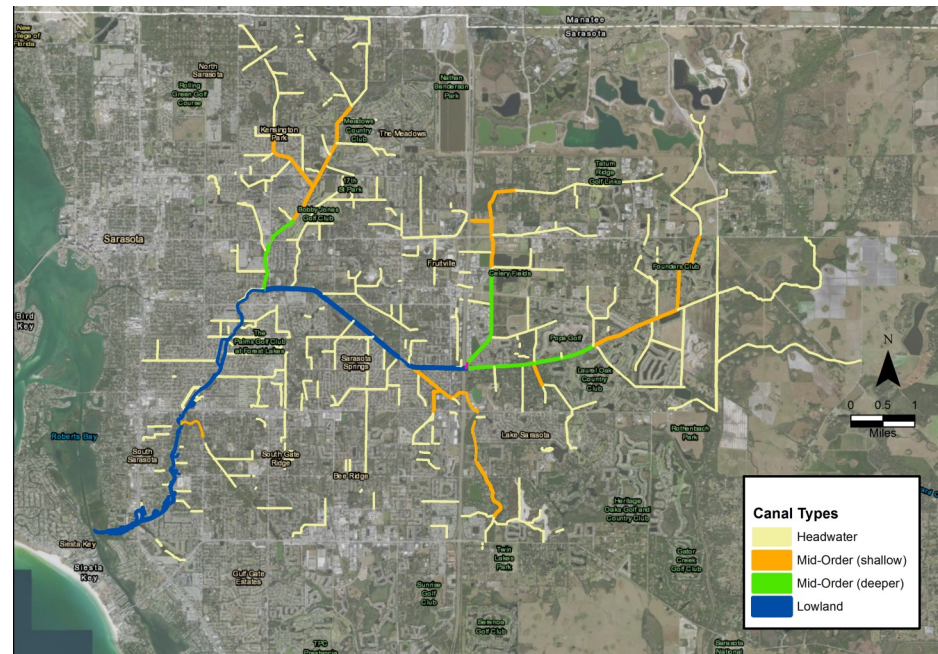
Areas labeled as either ILWB (in-line waterbody) or NCD (natural channel design) have sufficient right-of-way for waterbody restoration. NCD segments can support stream restoration and ILWB cannot. Green segments can support stream restoration and blue segments are restricted to either paralotic and paralentice habitats.

NCD-Valley areas (red) have sufficient valley slope for stream restoration, but insufficient right-of-way and require stabilization-in-place.

Pairing Natural Stream Restoration Type to Canal Type

Headwater Canals

Headwater canals offer excellent restoration potential as fully-shaded meandering headwater streams bordered by small forested floodplains and hillslopes. In-line waterbodies include gently flowing swamps and marshes. Instream treatments should include woody debris deployments. Step-pool structures can be added in some urban Florida headwater streams where unusually steep slopes and hydraulics exist to further enhance water quality treatment and create a 'babbling brook' effect, but most Phillippi channels are meandering through low gradient valleys. In nature, headwater bankfull channels are typically less than 10 feet wide with riffle depths less than 1.5 feet. Floodplains in urban basins should be designed for Rosgen C/E floodprone width or larger. Riparian wetlands can average 5 acres per canal mile. Natural Florida stream analogues might include root-step channels (HL-RSC), baseflow channels (HL-BFC), or flatwoods headwater streams (FW-CV-NC) depending on groundwater versus runoff water sources (Kiefer et al., 2015).



Headwater canals (light yellow) are excellent places to provide small wadable streams that add shade, dampen noise pollution, and improve water quality throughout the watershed.



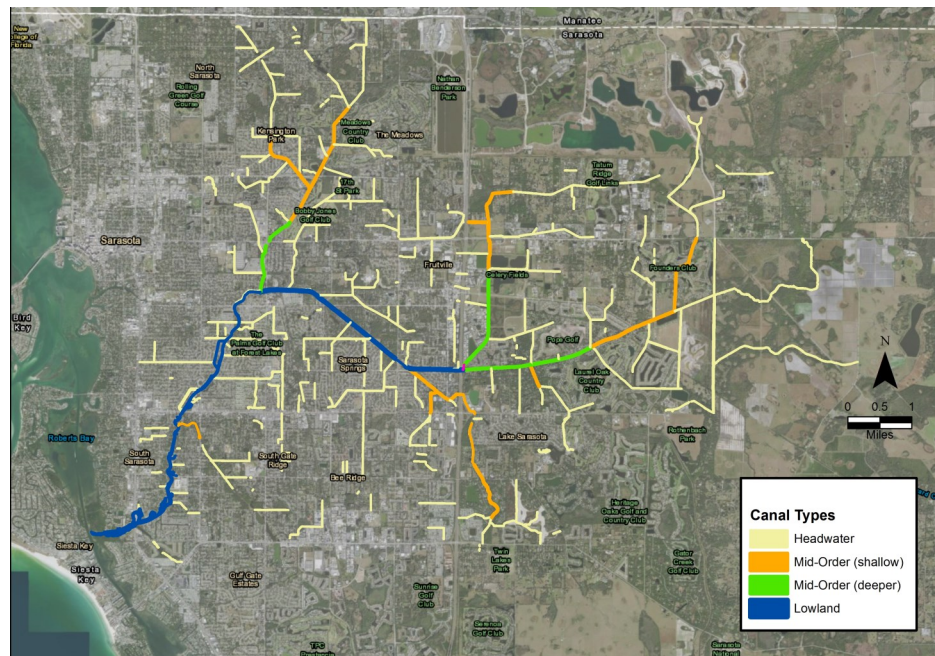
Natural Florida headwater stream corridors support a wide variety of shade forests including hardwoods, pines, and palms and are variably fed by stormwater runoff and groundwater seepage. They are shallow and provide opportunities for wading, scientific study, and peaceful contemplation of nature. A growing body of scientific evidence relates the degree of immersion in nature activity and presence of nearby naturescapes with positive mental and physical health of urban dwellers. These systems are the most common stream types and can be readily restored in urban watersheds.



Shallow Mid-Order Canals

These canals can be restored as shaded meandering streams bordered by forested floodplains and hillslopes. In-line waterbodies include gently flowing swamps, marshes, and ponds. In-stream treatments include woody debris deployments.

Sites draining 2 to 8 square mile watersheds support channel widths 10 to 15 feet with riffle depths about 2 feet. Pools can be up to 4 feet deep. This means large bodied fish can access and use these systems routinely during the wet season, but less reliably during the dry. Floodplains should be designed for the larger of Kiefer Highlands or Rosgen C/E floodprone widths, or larger. Riparian wetland installations can average 6 acres per canal mile. Florida stream analogues could include the same group as for headwater canals plus complex, compact flatwoods streams (FW-AF-CC) (Kiefer et al., 2015). Given the degree of urban watershed modification, an amalgamation of seepage (HL-BFC) and runoff (FW-AF-CC) stream type attributes is recommended for most sites to accommodate the heavily induced baseflow and flashy floodplain runoff.



Shallow mid-order canals (orange) are excellent places to provide small wadable streams that add shade, dampen noise pollution, and improve water quality. They can accommodate some in-line ponds and wet-season fishing.



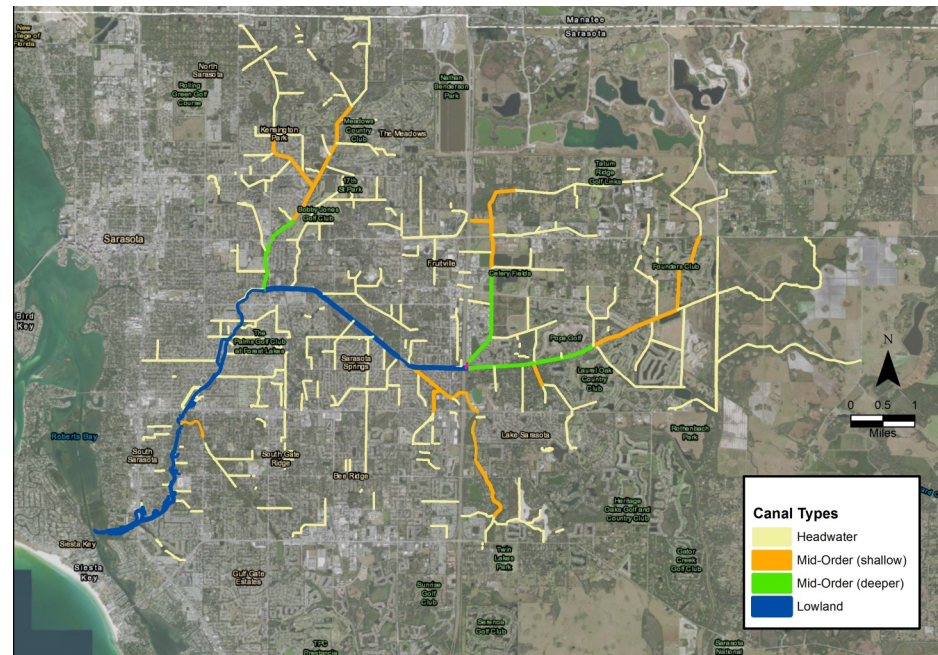
Natural Florida shallow mid-order stream corridors occur downstream of headwater streams and also support a wide variety of shade forests including hardwoods, pines, and palms. They are variably fed by upstream waters, stormwater runoff, and groundwater seepage. They mainly differ from headwater streams by having larger floodplains and slightly deeper channels with bigger bends. They exhibit significant seasonal water levels fluctuations, sometimes going dry. Their peaceful shaded vibe and recreation potential is similar to that of headwater streams.



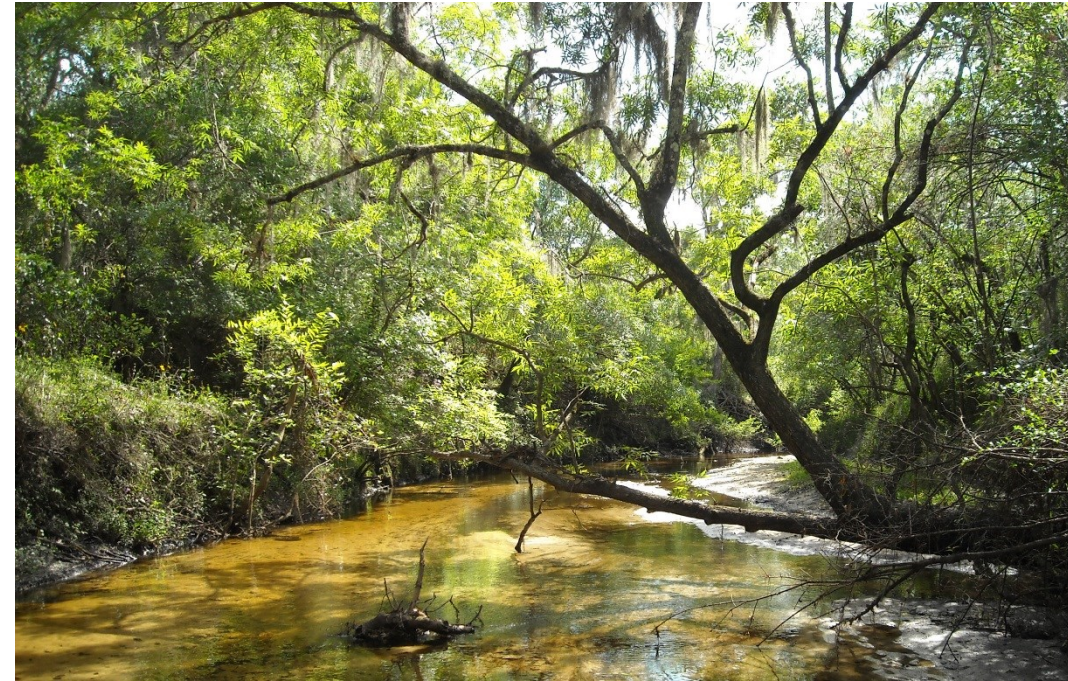
Deeper Mid-Order Canals

These canals can be restored as shaded to partly-shaded meandering streams bordered by forested floodplains and hillslopes. In-line waterbodies include gently flowing swamps, marshes, and ponds. Instream treatments include woody debris deployments and small patches of submerged and emergent herbaceous vegetation.

Sites draining 8 to 20 square mile watersheds support channel widths 15 to 20 feet with riffle depths about 2 to 3 feet. Pools can be up to 6 feet deep. Large-bodied fish access and use these systems routinely during the year, except during severe droughts. Floodplains should be designed for Kiefer Highlands width or larger. Riparian wetlands can average 7 acres per canal mile. Florida stream analogues include those with some alluvial complexity in the floodplain; Kiefer et al. (2015) HL-AFS type for seepage dominated floodplains or FW-AF-CC types for runoff dominated systems.



Deeper mid-order canals (green) are excellent places to provide partially shaded streams and wetlands to improve water quality. They can accommodate in-line ponds with year-round fishing, and some seasonal kayaking. Greenway trails are also possible within the floodprone area.



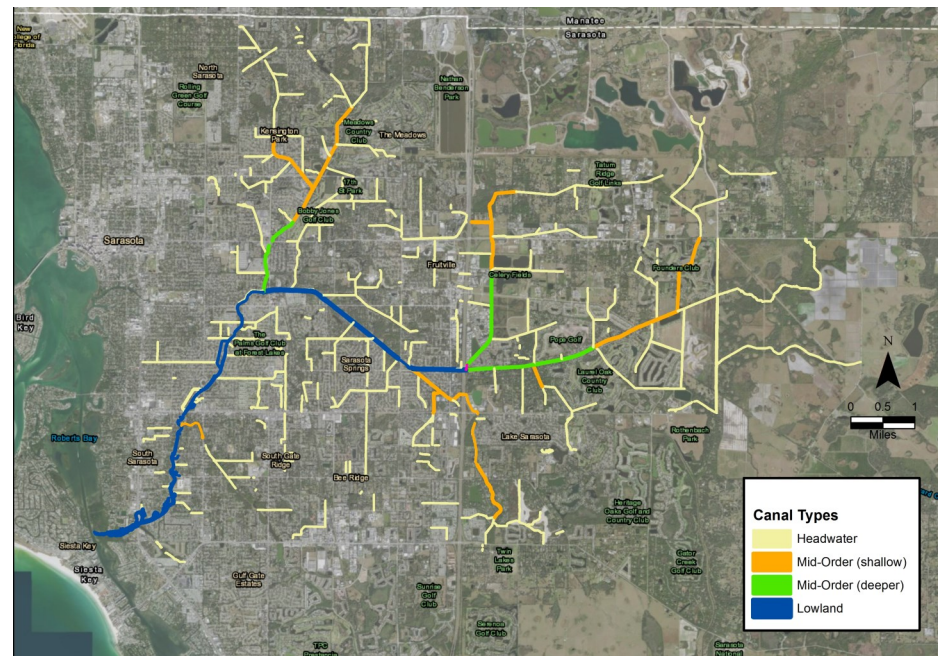
Natural Florida deep mid-order stream corridors occur downstream of shallow mid-order areas and also support a wide variety of forests including hardwoods, palms, and cypress. They are variably fed by upstream waters, stormwater runoff, and groundwater seepage. They mainly differ from smaller mid-order streams by having larger floodplains and bigger channels with longer flow permanency throughout the year. This increases their fishability and wet season traversability by kayak. They may be difficult to wade during parts of the wet season.



Lowland Canals

These can be restored as partly-shaded meandering streams through variably forested wetland floodplains bordered by hammocks. In-line waterbodies include cypress strands and marshes (sometimes with small discontinuous channels); and ponds. In-stream treatments include woody debris and small meadows of submerged vegetation and emergent plants on sand bars.

Sites draining 20 to 35 square mile watersheds support channel widths 20 to 30 feet with riffle depths about 3 feet. Pools are up to 6 feet deep. Large fish can use these streams throughout the year. Floodplains should be designed for Kiefer Highlands width or larger. Riparian wetlands average 8 to 9 acres per canal mile. Applicable Florida stream types include those for seepage dominated floodplains (HL-AFS) and those with relatively wide and flat floodplains in areas with high sediment yields (FW-AF-WF). A hybrid of these two types should be considered in the Phillippi basin. Bottomland plant species tolerant of several feet of flood waters occurring once every couple of years should be selected.



Lowland canals (blue) can support wide meandering streams and wetlands to improve water quality. The perennial channel and floodplain are large enough to facilitate year-round fishing, with blueway and greenway trails. In-line waterbodies can be designed as sediment traps.



Natural Florida lowland stream corridors occur downstream of mid-order areas and also support a wide variety of forests including hardwoods, palms, and cypress, as well as open marshes. They are variably fed by upstream waters, stormwater runoff, and groundwater seepage. They mainly differ from mid-order streams by having larger and more alluvially complex channels and floodplains, with reliably perennial flow. They are kayakable, swimmable, and fishable for most of the year. They are impossible to wade across during wet season flood pulses. The bankfull channels are typically wide enough to preclude complete canopy shading, thus enabling submerged aquatic vegetation (SAV) to occur if water clarity is good. SAV adds biodiversity and new water quality processes to the stream.



Green Infrastructure Applicability, Benefits, and Maintenance

Living treatments strengthen over time, are mostly self-sustaining, provide water quality benefits, and native habitat. Their applicability is restricted to areas where biophysical conditions are suitable.

Treatment	Applicability			Water Quality Benefits		Habitat Benefits			Maintenance
	Canal Type	Morphology	Aesthetic	Sediment	Nutrient	Aquatic	Wetlands	Terrestrial	
Natural channel design (NCD)	All	ROW ≥ FPL W	Natural meandering stream & native vegetated floodplain	Bank stabilization, Grade control, Sediment detention	Treats baseflow & stormflow, Buffer treatment	Large & small fish, Autochthonous & allochthonous food web	Large	Neotropical migrants, wading birds, biodiversity	Contigent - Decreasing
In-line waterbodies (ILWB)	All	ROW ≥ FPL W	Native - shrubby forest, Native - parklike forest, Native - open & grassy, Landscaped vegetation	Bank stabilization, Sediment retention	Treats baseflow & stormflow, Buffer treatment	Large & small fish, Autochthonous & allochthonous food web	Fringing to large	Neotropical migrants, wading birds, biodiversity	Contingent - Decreasing if native, Annual or more frequent if a sediment trap or landscaped
Soil bioengineering afforestation (SBE)	All	All ROW, SS ≥ 2:1, BH unlimited	Landscaped - shrubby, Native - shrubby forest, Native - parklike forest, Integrated Hardscapes	Bank stabilization	Buffer treatment	Allochthonous food web	Fringing	Neotropical migrants, biodiversity	Contigent - Decreasing, Sporadic snag removal may be required absent NCD
Vegetation reinforced soil slope (VRSS)	All	All ROW, SS ≥ 0.5:1, BH < 60 feet	Landscaped - shrubby, Native - shrubby forest, Integrated Hardscapes	Bank stabilization	Buffer treatment	Allochthonous food web	None to Fringing	Neotropical migrants, biodiversity	Contigent - Decreasing, Sporadic snag removal may be required absent NCD
Live stakes & branches	All	All ROW, All traversable SS, BH unlimited	Landscaped - shrubby, Native - dense shrubby forest	Bank stabilization	Buffer treatment	Allochthonous food web	Fringing	Neotropical migrants, biodiversity	Contigent - Decreasing, Sporadic snag removal may be required absent NCD
Regenerative stormwater conveyance (RSC)	Low- & Mid-Order	All ROW, Channel W < 20 feet	Discrete/submerged at high flow. Creates short rapids and small cascades at low flow)	Grade control, Sediment detention	Treats baseflow	Small Fish	None	None	Contigent - may be required after large floods
Aquatic vegetation - submerged aquatic vegetation (SAV), emergent littoral vegetation (ELV)	High-Order (mid-order in patches)	All ROW, Channel W > 20 feet	Native - open & grassy	Sediment detention	Treats baseflow	Large & small fish, Autochthonous food web	Fringing to large	Wading birds, biodiversity	Contigent - Decreasing, Requires upstream stabilization
Coir logs	All	All ROW	Discrete/hidden	Bank stabilization	None	NA	NA	NA	Temporary measure
Rolled erosion control blanket (RECB)	All	All ROW, SS < 2:1, BH unlimited in areas of low NBS	Discrete/hidden	Bank stabilization	None	NA	NA	NA	Temporary measure
High performance turf reinforcement mat (HPTRM)	All	All ROW, SS < 2:1, BH unlimited in areas of low NBS	Landscaped - neat & trim, Native - shrubby forest	Bank stabilization	None	None	None	None	Annual or more frequent, Routine mowing if turf used



Gray Infrastructure Applicability, Benefits, and Maintenance

Inert material treatments deteriorate over time, are not self-sustaining, provide limited to no water quality benefits, and no native habitat. Their applicability is restricted to areas where other treatments are simply not possible based on physical limitations.

Treatment	Applicability			Water Quality Benefits		Habitat Benefits			Maintenance
	Canal Type	Morphology	Aesthetic	Sediment	Nutrient	Aquatic	Wetlands	Terrestrial	
Riprap	All	All ROW, SS > 2:1, BH unlimited	Industrial hardscape - irregular, Toe of VRSS, Rock riffles	Bank stabilization, Grade control	None	None	None	None	Contigent - Increasing, Required after large floods, Herbiciding may be required
Articulated Concrete Block (ACB)	All	All ROW, SS < 2:1, BH unlimited	Industrial hardscape - linear, Landscaped - rough/weedy, Toe of VRSS	Bank stabilization, Grade control	None	None	None	None	Contigent - Increasing, Generally low until corrosion/weathering takes effect, Herbiciding may be required
Gabions	Mid- & High-Order	All ROW, SS vertical to 3:1, BH unlimited	Industrial hardscape - linear, Landscaped - rough/weedy	Bank stabilization	None	None	None	None	Contigent - Increasing, Generally low until corrosion/weathering takes effect
Reno (marine) mattress	All	All ROW, SS < 2:1, BH unlimited	Industrial hardscape - linear, Landscaped - rough/weedy	Bank stabilization, Grade control	None	None	None	None	Contigent - Increasing, Generally low until corrosion/weathering takes effect, Herbiciding may be required
A-jacks	Mid- & High-Order	All ROW, SS < 2:1, BH unlimited	Industrial hardscape - irregular	Bank stabilization, Sediment detention	None	Small Fish	None	None	Contigent - replacement upon concrete breakdown
Reinforced concrete wall	All	All ROW, SS = vertical, BH < 20 feet (typical)	Industrial hardscape - linear	Bank stabilization	None	None	None	None	Contigent - replacement upon concrete breakdown or corrosion

NOTE: A-Jacks are not discussed in this report because they mainly apply to larger rivers than occur in the Phillippi basin. They are large concrete structures with multiple linear projections (shaped like jacks) that can be inter-linked to create robust low-bank shoreline protection with open interstices for fish cover.



4.4 COSTS AND BENEFITS

Several segments of each canal type (headwater, mid-order, and lowland) were randomly selected for benefit/cost assessment. Costs and benefits were monetized at each site for several retrofit types and these were averaged by canal type for comparison.

A triple bottom line approach was taken to assess financial, environmental, and social benefits. Not all possible benefits were monetized, just the potentially major ones directly associated with the proposed activities and with available unit pricing data. Benefits were also selected to prevent overlap, or double-counting. The referent group (beneficiaries) were the residents and visitors of Sarasota County. The referent group is diverse, and some of the economic variables have more direct tangible benefit to County budgets than others. These are highlighted.

All economics are expressed as net present value in 2018 \$US for a 20-year maintenance and operation period with annual cashflows amortized at a 4% annual discount rate. All values are unitized for treatment of a mile of canal length, and are expressed as \$/mile. They can be reasonably extrapolated up or down for project lengths of 0.5 to 10 miles to approximate gross project costs and benefits without changing the assumed economy of scale.

Estimates are based on somewhat hypothetical scenarios applied to a limited amount of case studies, and should only be used for broad planning activities and preliminary cost comparisons. Based on this level of investigation, net prices could be expected to vary by plus 30% to minus 20% of the average treatment costs described (AACE 2012). Site-specific cost estimates should be conducted prior to project budgeting.

Financial Benefits. This line item determines if investment in the retrofit project is justified solely on the basis of the cost savings achieved by not having to operate and maintain the existing canal system. In other words, it answers the question “Is it worth retrofitting the canal solely to reduce or eliminate on-going perennial maintenance?”

Environmental Benefits. These include water quality, wetland habitat, and stream channel habitat.

Water quality is based on total nitrogen reductions. It is a tangible benefit for the County, based on costs of equivalent removal from urban stormwater retrofits. Other water quality benefits could be added to this, but nitrogen was selected because it is readily quantifiable and an increasing pollutant in the region that can adversely affect the Phillippi system and Sarasota Bay. Benefits are equivalent to average costs of stormwater retrofits in Florida (FSA 2017).

Wetland habitat is monetized from market prices of mitigation banks in southwest Florida. It is potentially a tangible benefit as the County could use the created wetlands to mitigate for County impacts. However, it is not likely that water quality and wetland mitigation credits would be allowed by regulatory agencies for the same project. As will be seen, the water quality values are greater. In that case, this benefit should simply be viewed as the intrinsic value of wetlands, monetized based on their market replacement costs.

Stream channel habitat is monetized based on market stream mitigation prices in the Carolinas. These markets were selected because Florida lacks such data. This benefit represents the intrinsic value of natural stream channels, monetized based on their market replacement costs. It is not a tangible benefit to the County budget, but could be a substantial driver of fisheries and tourism values that are otherwise not quantified.

Social Benefits. These include property value increases and property damage reductions from flood avoidance.

Property value grows based on water quality and fisheries improvements. Percent increases were derived from the scientific literature applicable to the proposed improvements (Streiner & Loomis 1995, American Rivers 2016, Nichols & Crompton 2017).

Flood reductions are often a major driver for drainage system improvements, so they were included here. However, these are deemed to be highly site-specific and low to unavailable for the Phillippi watershed.

Recreation and education benefits are substantial and could be monetized, but require cost data for project add-ons not included in the scope of Wood’s assessment which was focused on the biophysical improvements to the canals. So, improvements necessary to fully promote recreation and educational programs including trails, parking lots, launches, and bridge retrofits are not part of this assessment. Instead, we simply acknowledge stream restoration as the first step for unlocking these benefits, without monetization.

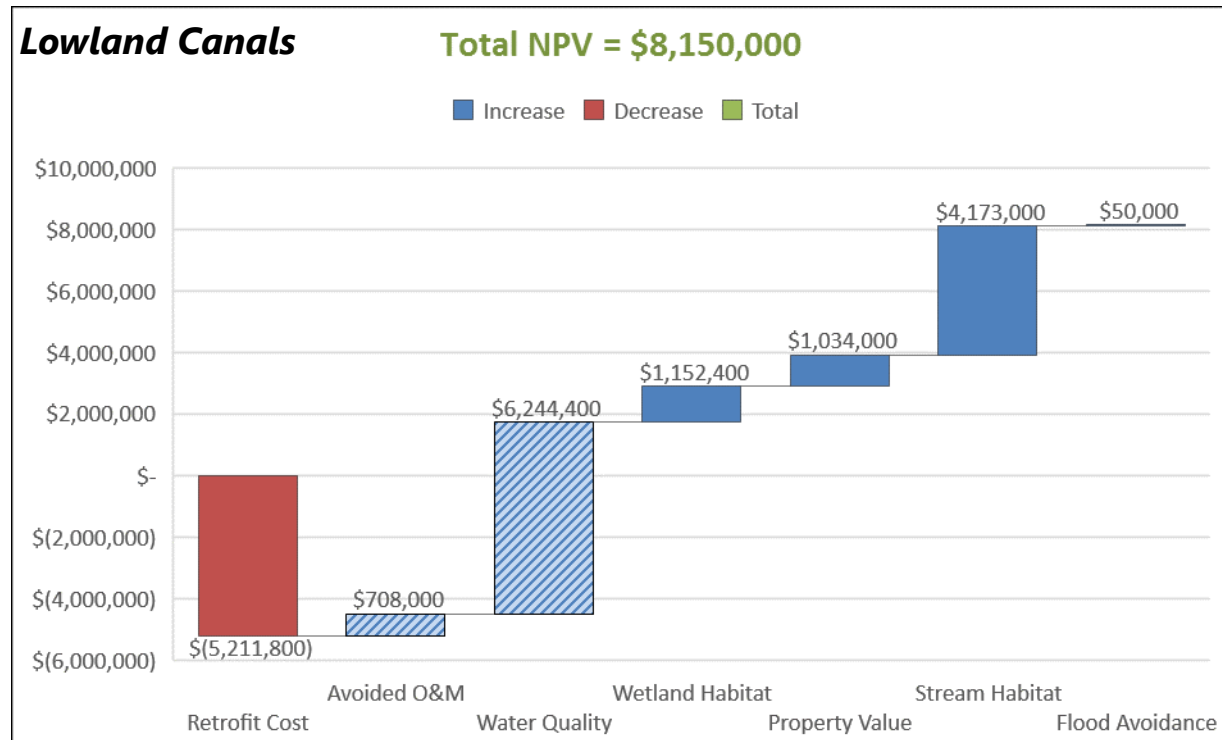
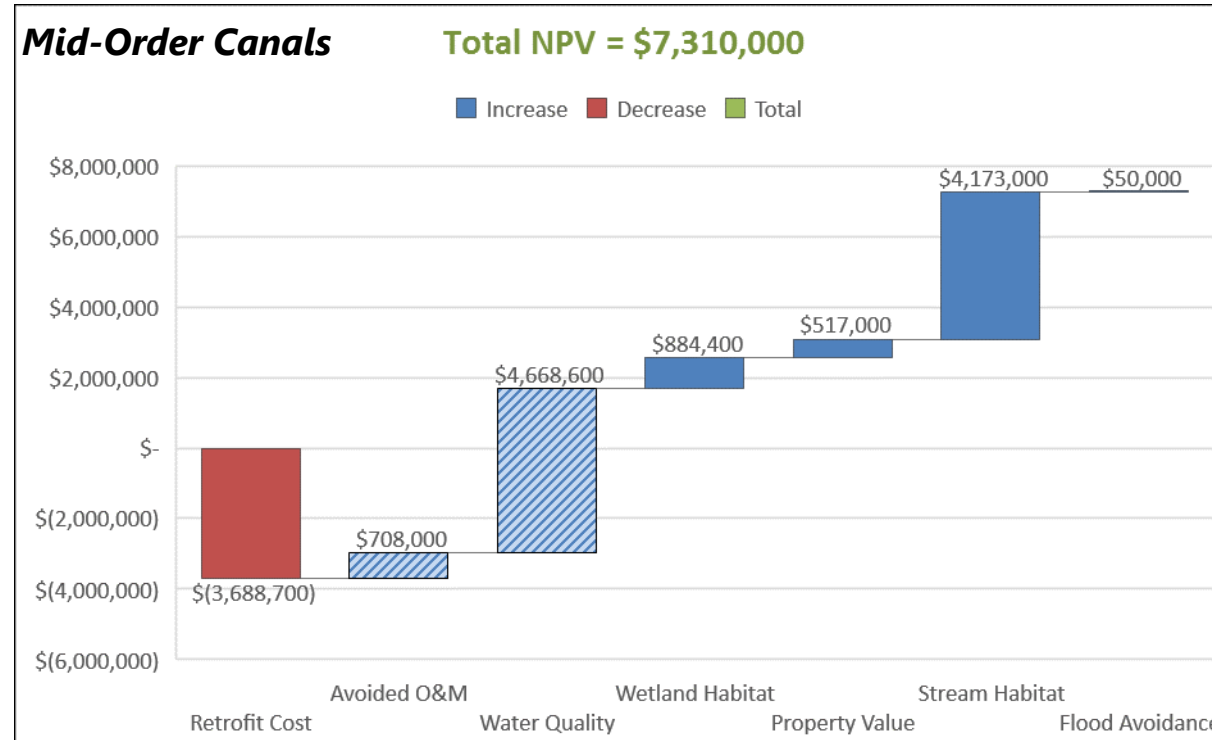
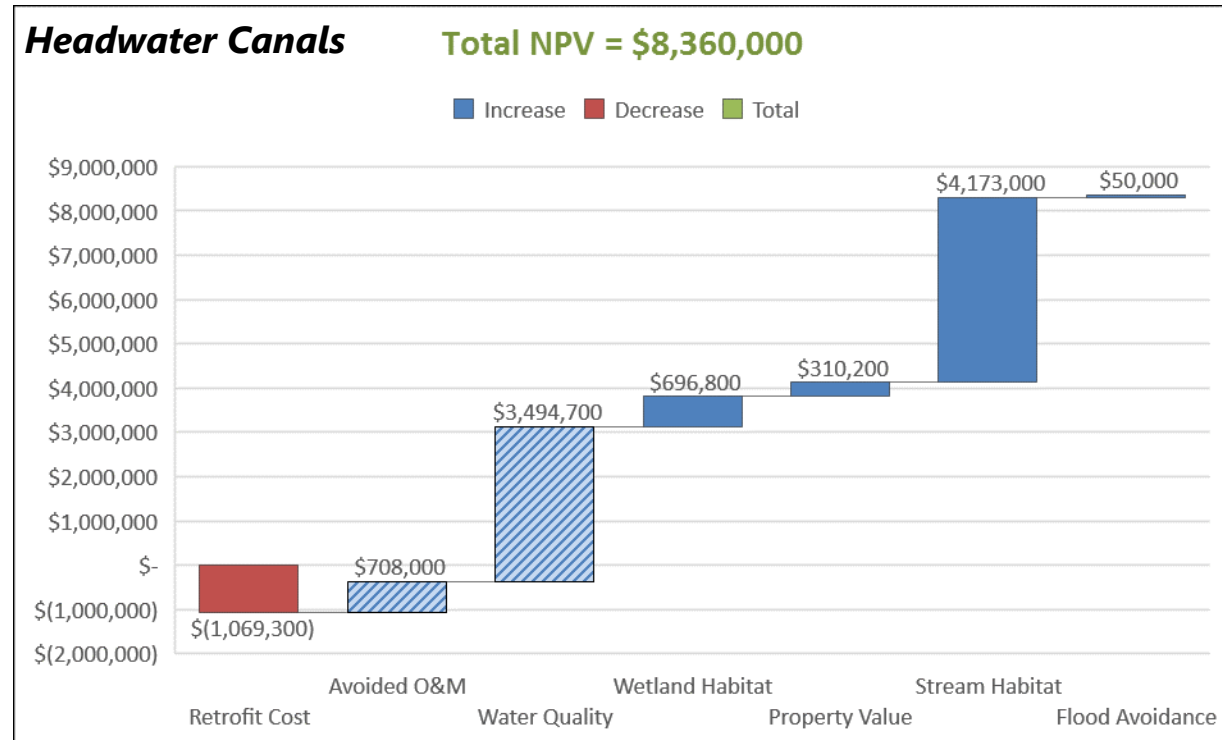
Stream Category	TN Removed (lb TN/yr/mile)			Total
	P1 - Erosion	P2 - Hyporheic	P3 - Floodplain	
Headwater (<2 SM)	51	539	62	652
Mid-Order (2-20 SM)	51	742	79	872
Lowland (>20 SM)	51	1011	103	1165

Nitrogen removal is estimated using an adaptation of Chesapeake Bay TMDL calculation protocols (Schueler & Stack 2014). P1 treatment comes from bank stabilization, P2 from stream channel and streambed processes, and P3 from wetland floodplain processes. Up to 30% load reduction is possible based on the performance of natural streams. Wood’s calculations represent less than half of that and are likely to be conservative (low) estimates of what is achievable.



Stream Restoration—Triple Bottom Line

Stream restoration is clearly a public benefit for all three canal types. It also provides positive return on investment regarding solely the tangible values for the County budget (avoided O&M plus water quality). The greatest returns are associated with water quality and stream habitat.



Variables in the waterfall charts are listed left-to-right in decreasing order of certainty. Light blue bars are tradable values for County government.

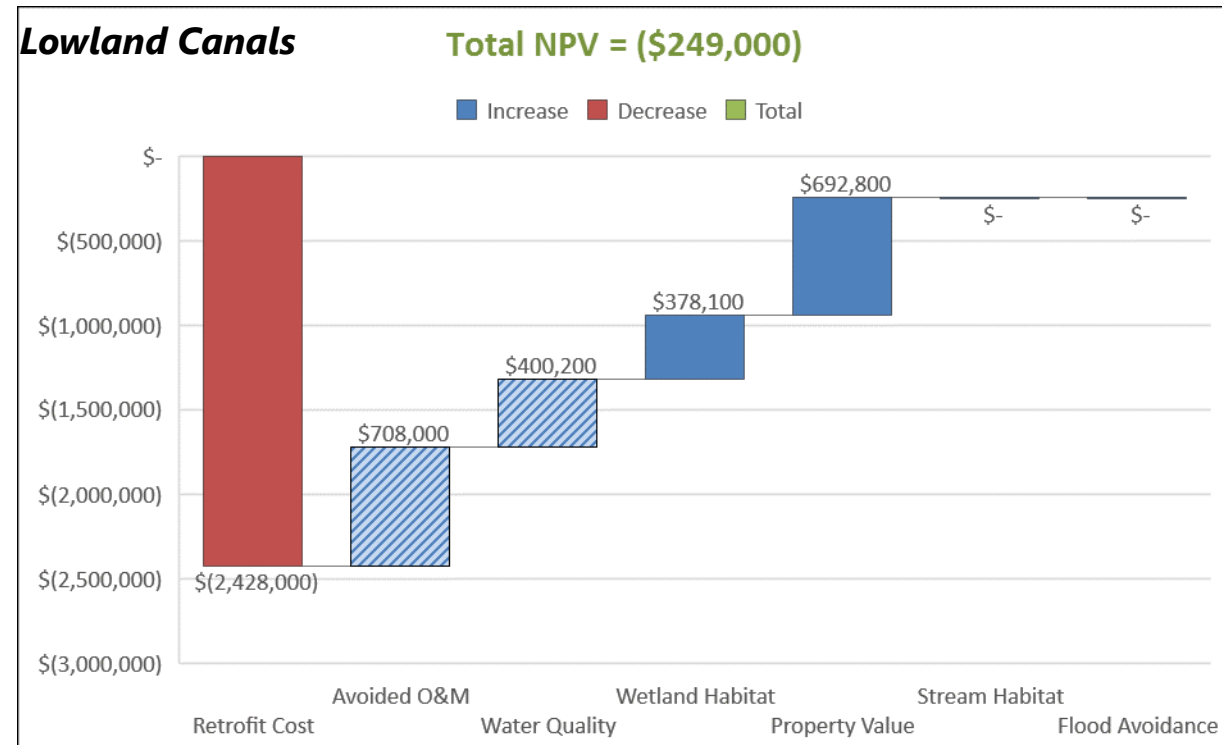
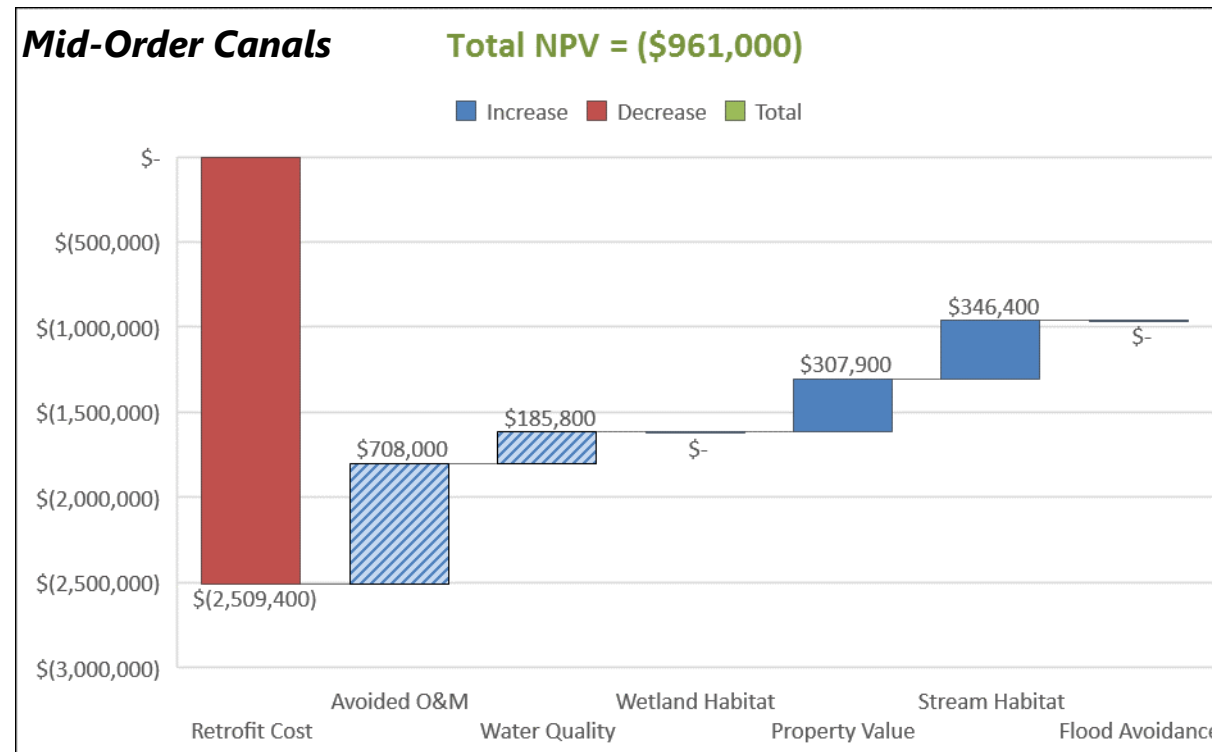
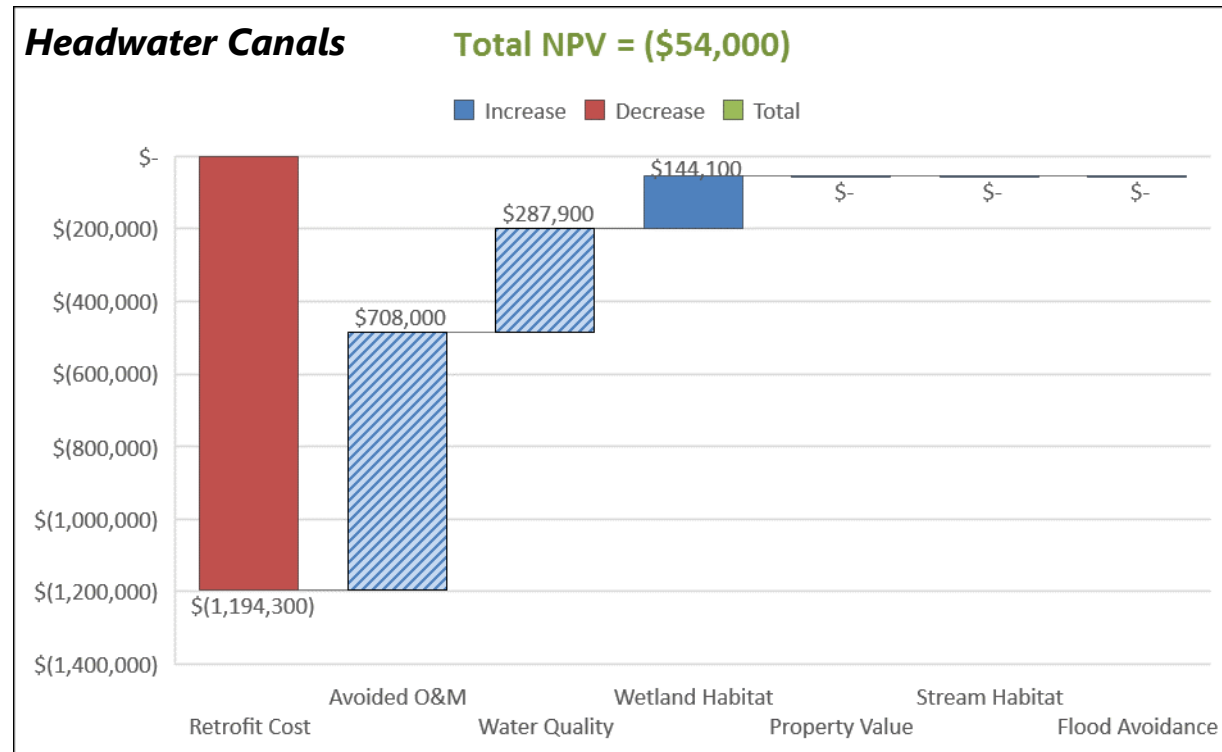
Stream Restoration	Headwater	Mid-Order	Lowland
Financial NPV	\$ (361,000)	\$ (2,981,000)	\$ (4,504,000)
Environmental NPV	\$ 8,365,000	\$ 9,726,000	\$ 11,570,000
Social NPV	\$ 360,000	\$ 567,000	\$ 1,084,000
Triple Bottom Line	\$ 8,364,000	\$ 7,312,000	\$ 8,150,000

The net present value (NPV) of environmental values alone justify public benefit investment in stream restoration for all 3 canal types. Most of the social benefits are derived from increased residential property values.



Vegetation Reinforced Soil Slope (VRSS) —Triple Bottom Line

VRSS is unlikely to provide a positive public investment, except perhaps for some headwater canals where it is close to a break-even proposition.



Variables in the waterfall charts are listed left-to-right in decreasing order of certainty. Light blue bars are tradable values for County government.

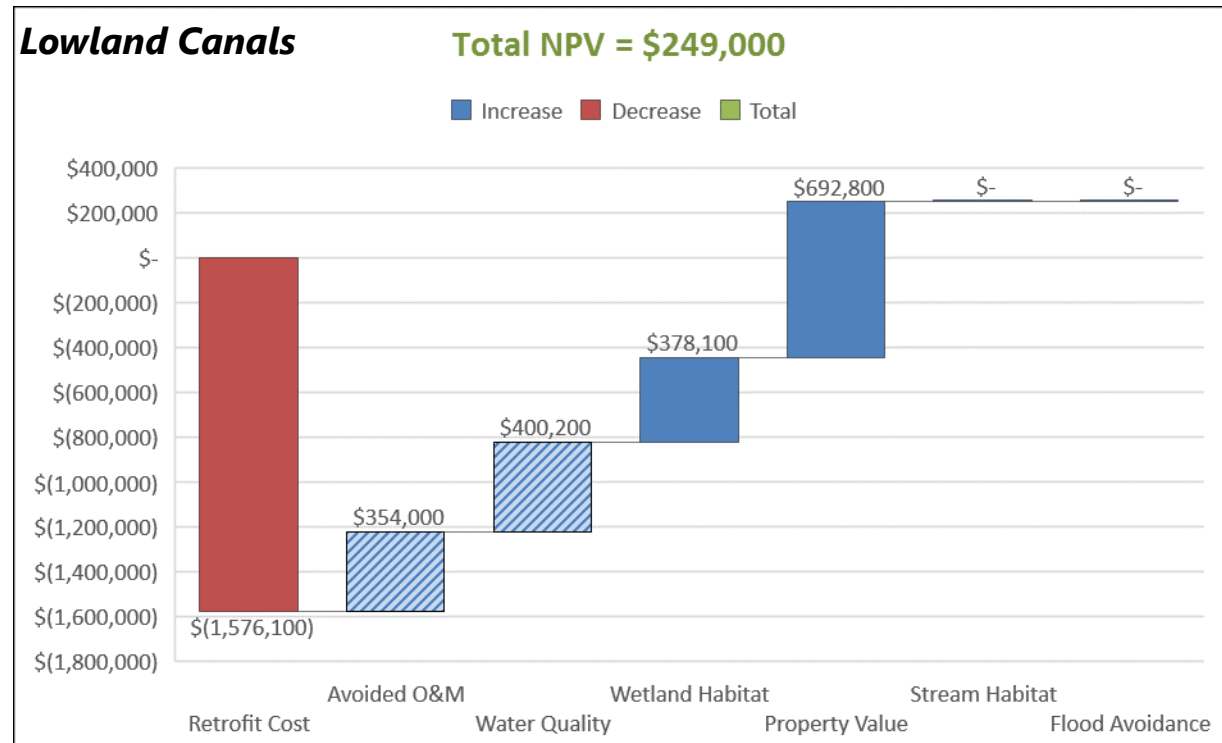
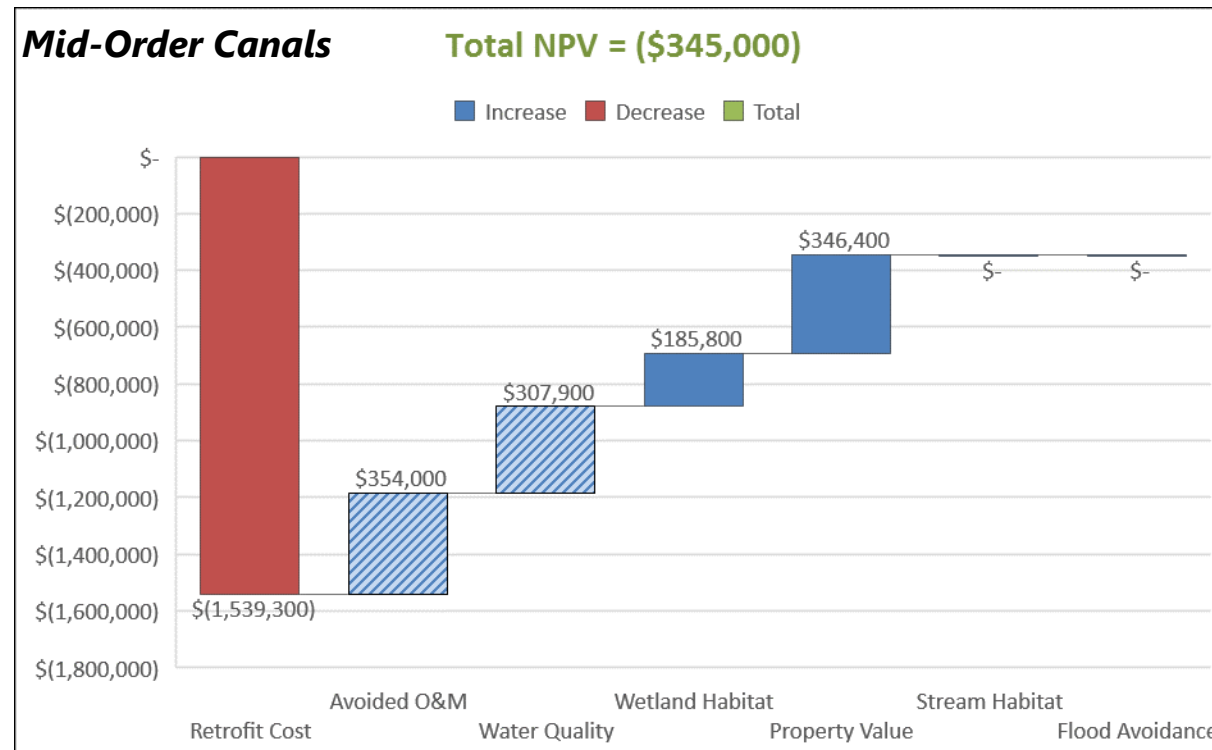
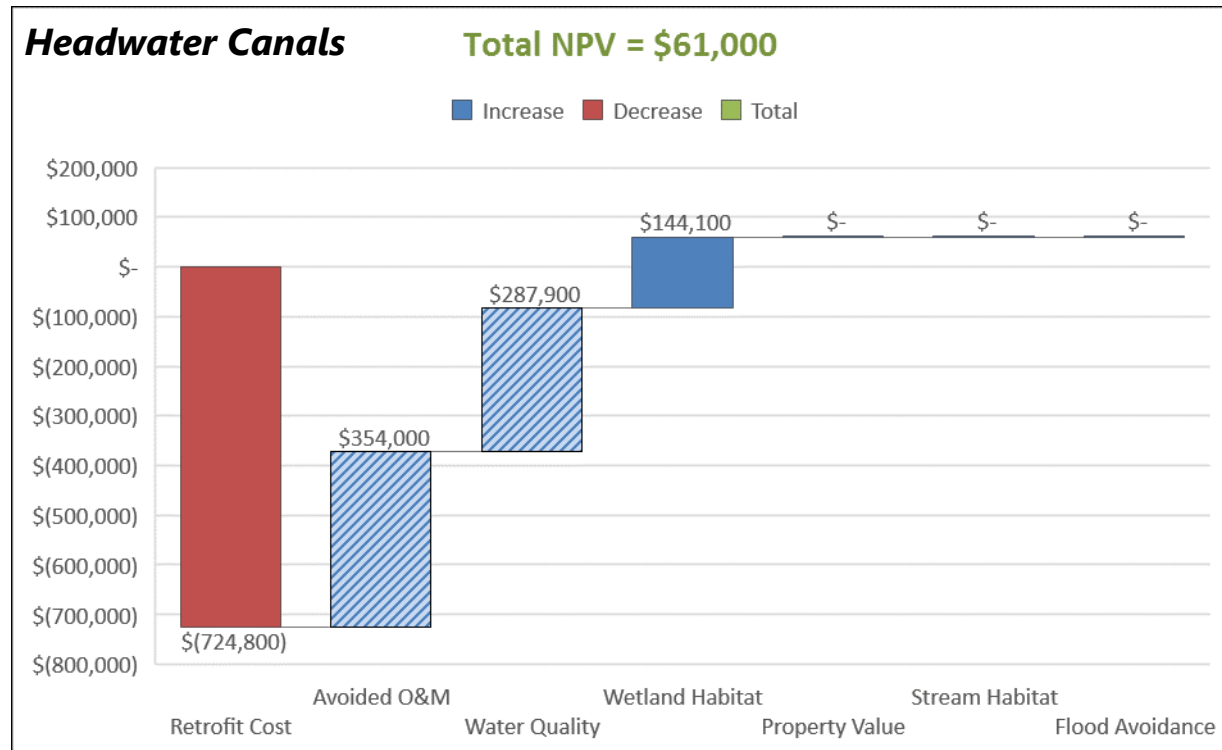
VRSS	Headwater	Mid-Order	Lowland
Financial NPV	\$ (486,000)	\$ (1,801,000)	\$ (1,720,000)
Environmental NPV	\$ 432,000	\$ 494,000	\$ 778,000
Social NPV	\$ -	\$ 346,000	\$ 693,000
Triple Bottom Line	\$ (54,000)	\$ (961,000)	\$ (249,000)

No property value increases were assigned to headwater canals because they lack large open waters and fishability is limited. Environmental and social values increase for mid-order and lowland canals, but remain less than the costs to achieve them.



Turf Over VRSS —Triple Bottom Line

VRSS wetland and water quality benefits accrue mainly in the lower half of the canal bank. A hybrid option of 'turf over VRSS' takes advantage of that by retrofitting VRSS to the lower half of the slope with mowed turf above it. Maintenance costs are reduced but not eliminated. Headwater and lowland canals indicate positive return on investment. Mid-order canals have high costs without achieving the benefits of lowland systems and are less prone to positive return. This approach could apply where stabilization-in-place is needed at communities wishing to pay for an open vista across the channel.



Variables in the waterfall charts are listed left-to-right in decreasing order of certainty. Light blue bars are tradable values for County government.

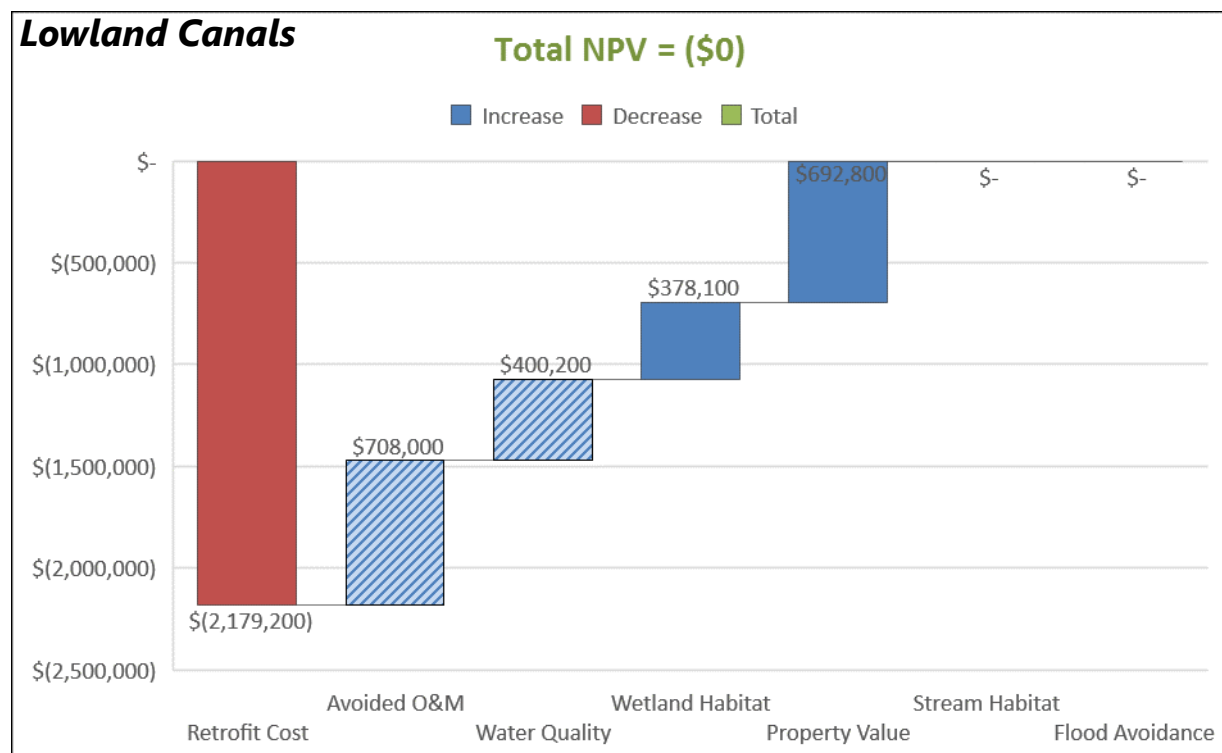
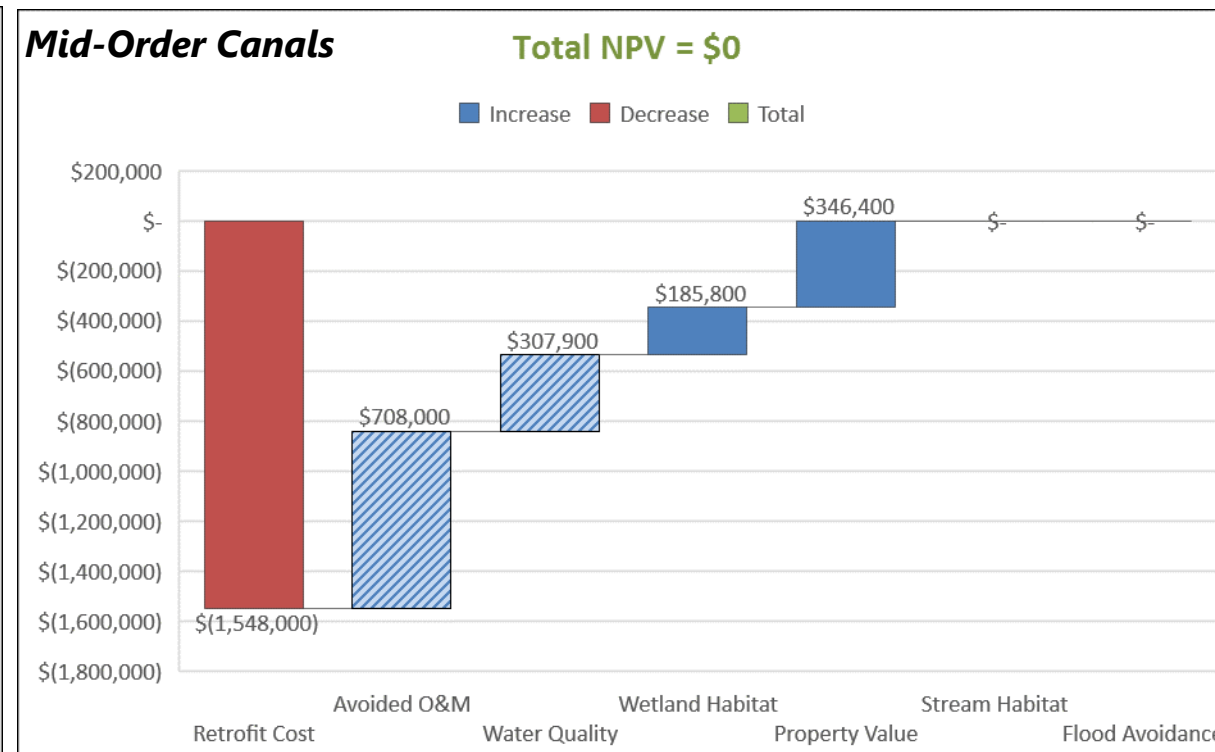
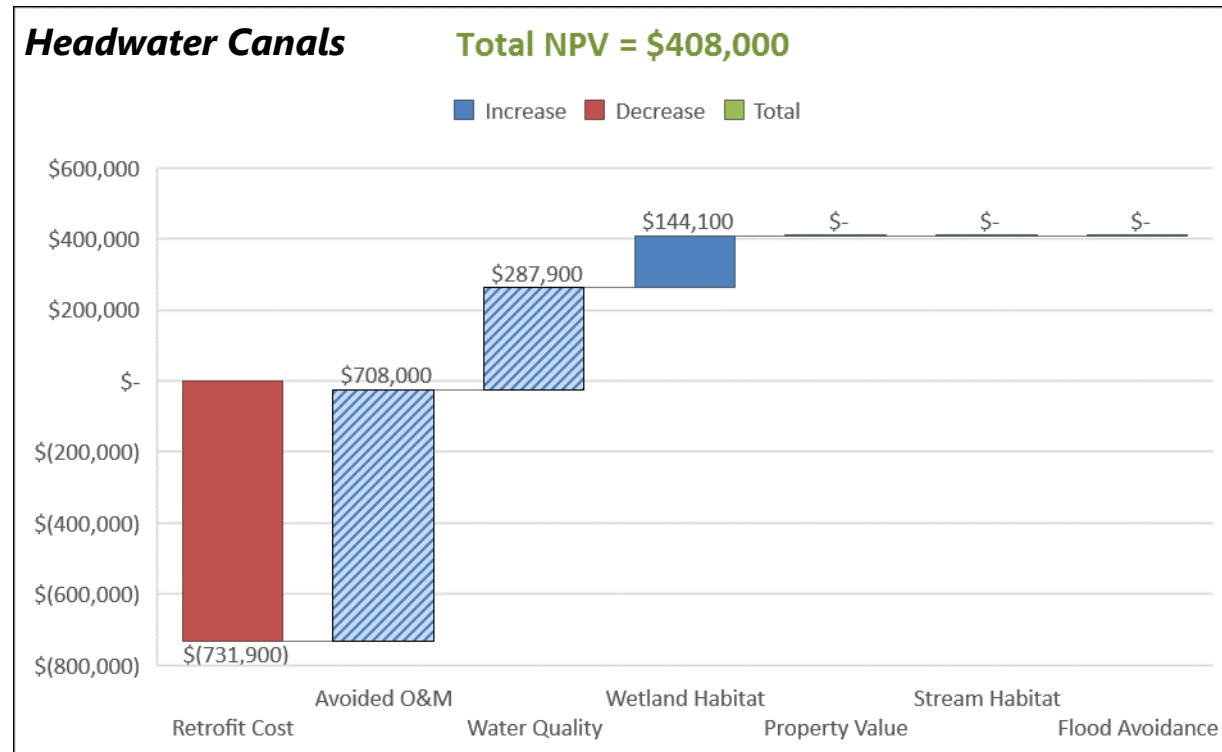
Turf over VRSS	Headwater	Mid-Order	Lowland
Financial NPV	\$ (371,000)	\$ (1,185,000)	\$ (1,222,000)
Environmental NPV	\$ 432,000	\$ 494,000	\$ 778,000
Social NPV	\$ -	\$ 346,000	\$ 693,000
Triple Bottom Line	\$ 61,000	\$ (345,000)	\$ 249,000

No property value increases were assigned to headwater canals because they lack large open waters and fishability is limited. Environmental and social values increase for mid-order and lowland canals.



Forest Over VRSS —Triple Bottom Line

VRSS benefits accrue mainly in the lower half of the canal bank. This hybrid option of 'forest over VRSS' takes advantage of that by retrofitting VRSS to the lower half of the slope with a bank slope reduction forest on the upper half. Maintenance costs are significantly reduced. Headwater canals indicate positive return on investment, with mid-order and lowland canals breaking even. This approach could be taken where stabilization-in-place is desired along communities wishing to have a forest buffer along the canal.



Variables in the waterfall charts are listed left-to-right in decreasing order of certainty. Light blue bars are tradable values for County government.

Forest over VRSS	Headwater	Mid-Order	Lowland
Financial NPV	\$ (23,000)	\$ (840,000)	\$ (1,471,000)
Environmental NPV	\$ 432,000	\$ 494,000	\$ 778,000
Social NPV	\$ -	\$ 346,000	\$ 693,000
Triple Bottom Line	\$ 409,000	\$ -	\$ -

No property value increases were assigned to headwater canals because they lack large open waters and fishability is limited. Environmental and social values increase for mid-order and lowland canals, but the investment is much lower for headwater systems enabling them to achieve greater return on investment for this approach. Instream RSC treatment could be added to further increase nitrogen reduction in headwater canals with sufficient valley slopes..



Gray infrastructure —Triple Bottom Line

Inert structures arrest erosion and provide bank stabilization which prevents sediments containing some nitrogen from mobilizing. They otherwise provide none of the social or environmental benefits explored. Thus only a summary table is provided, avoiding inclusion of a long string of pedantic waterfall charts with lots of zero lifts.

Riprap	Headwater	Mid-Order	Lowland
Financial NPV	\$ (549,000)	\$ (3,355,000)	\$ (3,884,000)
Environmental NPV	\$ 191,000	\$ 191,000	\$ 191,000
Social NPV	\$ -	\$ -	\$ -
Triple Bottom Line	\$ (358,000)	\$ (3,164,000)	\$ (3,693,000)
Gabions	Headwater	Mid-Order	Lowland
Financial NPV	\$ (1,663,000)	\$ (3,355,000)	\$ (3,207,000)
Environmental NPV	\$ 191,000	\$ 191,000	\$ 191,000
Social NPV	\$ -	\$ -	\$ -
Triple Bottom Line	\$ (1,472,000)	\$ (3,164,000)	\$ (3,016,000)
Articulated Block	Headwater	Mid-Order	Lowland
Financial NPV	\$ (725,000)	\$ (3,884,000)	\$ (5,741,000)
Environmental NPV	\$ 191,000	\$ 191,000	\$ 191,000
Social NPV	\$ -	\$ -	\$ -
Triple Bottom Line	\$ (534,000)	\$ (3,693,000)	\$ (5,550,000)

Inert structure retrofits are expensive to install without providing very many new environmental or social benefits. They do not create enough financial value to justify their implementation as a means to replace existing operation and maintenance activities.



Ranked Retrofit Scenarios Under Best and Worst Case Scenarios

Stream restoration in all drainage positions provides the best average returns. Some VRSS treatments provide positive returns under average conditions. These include forest over VRSS (headwater), turf over VRSS (lowland), and turf over VRSS (headwater). Forest over VRSS in mid-order and lowland positions are about break-even propositions. All other retrofits are unlikely to warrant investment under average conditions.

Best case scenarios are likely to generate positive returns for most treatments including stream restoration in all three canal positions; all three VRSS variants in all three drainage positions; and riprap and articulated concrete block at headwater positions. All other inert material retrofits are not justifiable even under best case scenarios. Worst case scenarios are likely to be positive only for stream restoration in headwater and mid-order positions.

In summary, stream restoration is most likely to provide positive return on investment as a means to stabilize canals under a range of cost sensitivities and landscape positions. A more limited set of circumstances result in favorable investments for various forms of VRSS soil bioengineering treatments. Some types of inert structures can be favorable under select circumstances.

Retrofit Scenario	Position	Mean Capital	Capital Range	
			Worst Case	Best Case
Turf over VRSS	HW	\$ (724,800)	\$ (942,240)	\$ (507,360)
Forest over VRSS	HW	\$ (731,900)	\$ (951,470)	\$ (512,330)
Stream Restoration	HW	\$ (1,069,300)	\$ (1,390,090)	\$ (748,510)
VRSS - Whole Bank	HW	\$ (1,194,300)	\$ (1,552,590)	\$ (836,010)
Riprap	HW	\$ (1,256,700)	\$ (1,633,710)	\$ (879,690)
Articulated Block	HW	\$ (1,432,900)	\$ (1,862,770)	\$ (1,003,030)
Gabion	HW	\$ (2,371,300)	\$ (3,082,690)	\$ (1,659,910)
Turf over VRSS	MO	\$ (1,539,300)	\$ (2,001,090)	\$ (1,077,510)
Forest over VRSS	MO	\$ (1,548,000)	\$ (2,012,400)	\$ (1,083,600)
VRSS - Whole Bank	MO	\$ (2,509,400)	\$ (3,262,220)	\$ (1,756,580)
Stream Restoration	MO	\$ (3,688,700)	\$ (4,795,310)	\$ (2,582,090)
Riprap	MO	\$ (4,063,000)	\$ (5,281,900)	\$ (2,844,100)
Gabion	MO	\$ (4,063,200)	\$ (5,282,160)	\$ (2,844,240)
Articulated Block	MO	\$ (4,591,700)	\$ (5,969,210)	\$ (3,214,190)
Turf over VRSS	LL	\$ (1,576,100)	\$ (2,048,930)	\$ (1,103,270)
Forest over VRSS	LL	\$ (2,179,200)	\$ (2,832,960)	\$ (1,525,440)
VRSS - Whole Bank	LL	\$ (2,428,000)	\$ (3,156,400)	\$ (1,699,600)
Gabion	LL	\$ (3,914,500)	\$ (5,088,850)	\$ (2,740,150)
Riprap	LL	\$ (4,591,700)	\$ (5,969,210)	\$ (3,214,190)
Stream Restoration	LL	\$ (5,211,800)	\$ (6,775,340)	\$ (3,648,260)
Articulated Block	LL	\$ (6,448,700)	\$ (8,383,310)	\$ (4,514,090)

Retrofit Scenario	Position	Mean NPV	NPV Range	
			Worst Case	Best Case
Stream Restoration	HW	\$ 8,363,400	\$ 3,146,160	\$ 11,749,000
Stream Restoration	LL	\$ 8,150,000	\$ (636,440)	\$ 13,957,080
Stream Restoration	MO	\$ 7,312,300	\$ 421,690	\$ 11,954,210
Forest over VRSS	HW	\$ 408,100	\$ (381,470)	\$ 969,670
Turf over VRSS	LL	\$ 249,000	\$ (1,482,780)	\$ 1,269,360
Turf over VRSS	HW	\$ 61,200	\$ (549,240)	\$ 514,440
Forest over VRSS	MO	\$ 100	\$ (1,411,550)	\$ 928,930
Forest over VRSS	LL	\$ (100)	\$ (2,089,810)	\$ 1,307,390
VRSS - Whole Bank	HW	\$ (54,300)	\$ (982,590)	\$ 945,990
VRSS - Whole Bank	LL	\$ (248,900)	\$ (2,413,250)	\$ 1,433,230
Turf over VRSS	MO	\$ (345,200)	\$ (1,577,240)	\$ 474,820
Riprap	HW	\$ (357,300)	\$ (1,184,010)	\$ 289,530
Articulated Block	HW	\$ (533,500)	\$ (1,413,070)	\$ 166,190
VRSS - Whole Bank	MO	\$ (961,300)	\$ (2,661,370)	\$ 555,950
Gabion	HW	\$ (1,471,900)	\$ (2,632,990)	\$ (490,690)
Gabion	LL	\$ (3,015,100)	\$ (4,639,150)	\$ (1,570,930)
Riprap	MO	\$ (3,163,600)	\$ (4,832,200)	\$ (1,674,880)
Gabion	MO	\$ (3,163,800)	\$ (4,832,460)	\$ (1,675,020)
Riprap	LL	\$ (3,692,300)	\$ (5,519,510)	\$ (2,044,970)
Articulated Block	MO	\$ (3,692,300)	\$ (5,519,510)	\$ (2,044,970)
Articulated Block	LL	\$ (5,549,300)	\$ (7,933,610)	\$ (3,344,870)

Positive return scenarios are highlighted green. Costs and benefits are in estimate ranges akin to schematic design or conceptual studies with a categorical accuracy range of -20% to +30% for costs. The worst case and best case ranges are derived from those percentages applied to the average costs and benefits calculated for our case studies.

Capital construction costs are generally similar for stream restoration and inert treatments by canal type. VRSS treatments cost less to implement than stream restoration or inert bank linings.



5.0 PRIORITIZATION

Canal Segments (p. 45)

Corridors (p. 46)



5.0 PRIORITIZATION

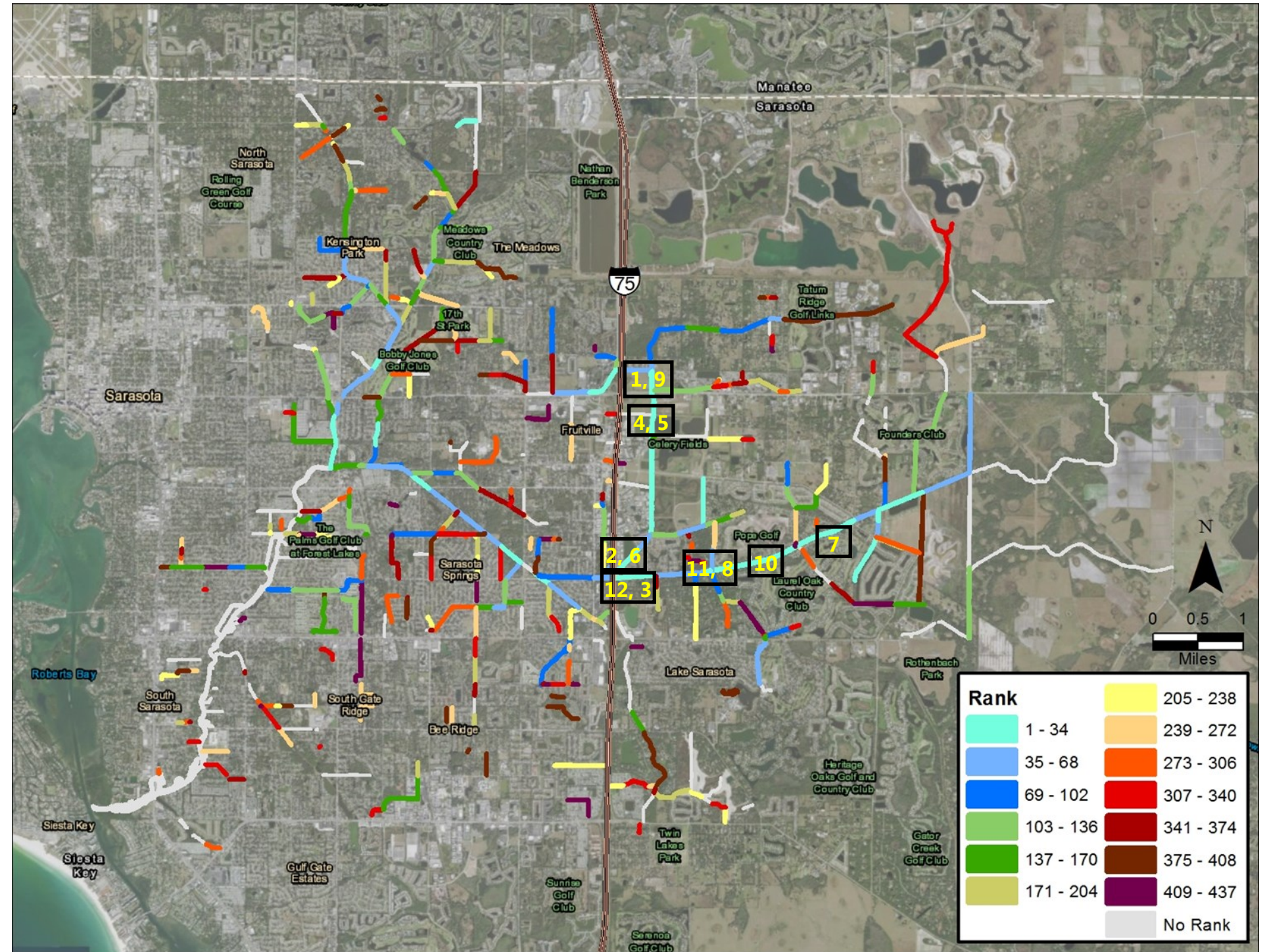
Wood ranked canals based on the product of their erosivity index and an ordination of the County's 2008-2015 maintenance expenditures for each canal. This ranking is useful to explore areas within the drainage network that are least resilient and most in need of retrofit.

Rather than viewing each ranked canal segment as a separate project, concepts of scale and continuity should be considered when developing priority projects. This includes consideration of landscape ecology to identify areas with groups of high priority canals that can be improved in concert to link existing wetland and terrestrial parks, or to create a fish corridor without any large gaps of unsuitable habitat. Areas offering meaningful lengths and usable positions for greenways and blueways could be considered as a means to engage the public regarding the improved assets.

Planners could consider groups of canals that collectively achieve water quality or flood attenuation thresholds of value to co-funding agencies. For example, to create enough nutrient reduction to meet Total Maximum Daily Load (TMDL) or Numeric Nutrient Criteria (NNC) to reduce algal blooms in nearshore areas of Sarasota Bay, or to create enough runoff attenuation to meet FDOT road expansion permit requirements. Assessing such thresholds requires numerical modeling, and knowing where the high priority canals are located is a great means for targeting productive areas.

Label	Canal	Length (ft)
1	6-119.10	705
2	6-119.1	1390
3	4-114.4	75
4	6-119.8	1130
5	6-119.9	755
6	6-119.2	520
7	6-114.7	3770
8	6-114.5	80
9	6-119.11	1240
10	6-114.6	5135
11	6-114.4	360
12	4-114.3	180

Top 12 Worst Canals. These were all tied for worst.



Canals ranked cyan, blue and green are the highest priorities. Cyan represents Tier 1 canals (top 34) and light blue Tier 2 (35-68). These are statistically-derived categorical breaks in the data using ESRI software. The Top 12 worst canals are labeled. They occur between I-75 and the Celery Fields along Main Canal C, and along Main Canal A upstream (east) of Main C. The confluence of Main A with Main C (at labels 2,6 and 12, 3) requires significant repetitive maintenance and directs flow under I-75.



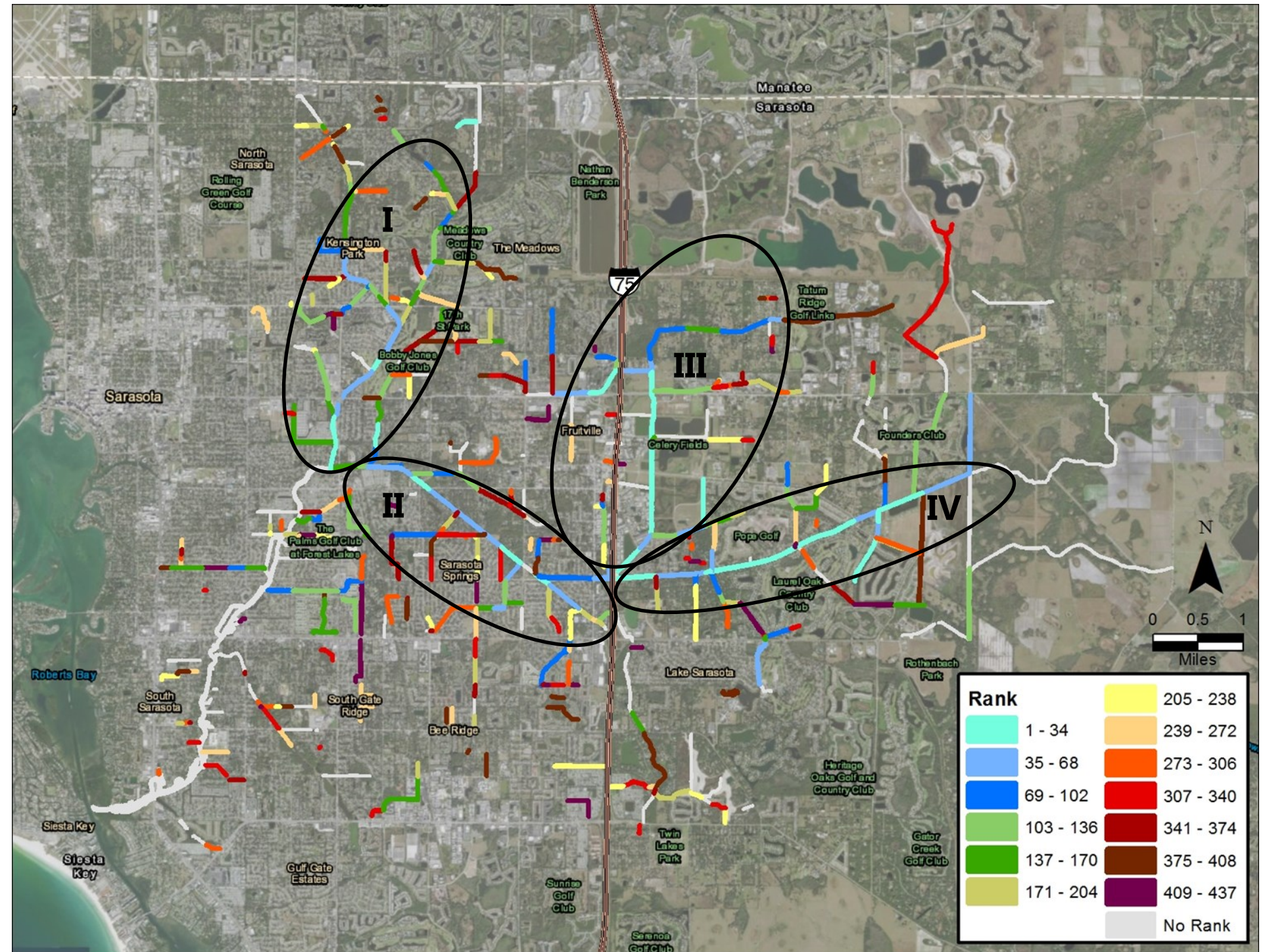
The highest priority canals are those most subject to erosion and also requiring the greatest repetitive maintenance costs, representing areas with combined environmental and economic impacts. Corridors of high priority canals clustered along four main drainages and some of their tributaries. These include, moving from west to east;

- I. Bobby Jones corridor along Canal Main B
- II. Lower Canal Main A corridor west of I-75
- III. Celery Fields corridor along Canal Main C
- IV. Upper Canal Main A corridor east of I-75.

Corridors III and IV have high percentages of Tier 1 priority canals, with most of the top 34 segments being found along the main stems of those two areas.

Corridor III offers some advantages for initial stream restoration projects because of County ownership adjacent to the canal right-of-way where variables outside of the corridor can be controlled by the County. Further, it borders the Celery Fields stormwater management complex, which is a major urban ecosystem enjoyed by County nature lovers. Stream restoration would add some natural geodiversity, gallery forests, and overall biodiversity to this popular nature complex of lakes and wetlands.

Corridors I and II have the most Tier 2 priority canals, representing candidates for the second phase of project prioritization. If the proposed renovations at the Bobby Jones Golf Course provide natural habitat, and if the stream restoration can be integrated into the margins of the course, Corridor I may make most sense for work after Corridors III and IV. Otherwise, Corridor II makes more sense as a logical extension from the upstream work in III and IV. That sequence would create a 10+ mile fish habitat corridor with substantial greenway and blueway potential, linking the watershed's remaining rural headwaters and the Celery Fields to the tidal creek. The tidal portion of Phillippi Creek located downstream (southwest) of Corridors I and II is already enjoyed by kayakers and nature enthusiasts as an important ecological and recreational amenity in the County.



Corridor's I, III and IV occupy upstream components of the drainage network. Stopping their erosion first would benefit downstream areas by preventing excessive sedimentation from smothering aquatic habitat there. Corridor II could be restored ahead of III and IV, but would likely require a sediment management system at its upstream end to protect the restoration.



6.0 END NOTES

Limitations (p. 48)

Portability (p. 48)



6.0 END NOTES

Limitations

This assessment is a screening tool conducted mostly using desktop analysis at a watershed scale. It relied on remote sensing data for important topographic information (LiDAR) and parcel maps for land ownership boundaries. Both of these factors will require verification by more accurate ground survey for project level feasibility assessments.

A major assumption affecting the width suitability of the canal right-of-way is based on the curve numbers used in the County's flood study models, which suggest a moderately well-drained soil condition (NRCS Hydrologic Soil Group C). While this is reasonable on average for the watershed, site-specific conditions may vary and should be validated by more granular modeling efforts, especially in canals receiving local concentrations of drainage from directly connected impervious areas. Areas with poorly drained soils require wider flood channels

Water quality benefits were calculated based on stream restoration protocols developed for the Chesapeake Bay (CB) watershed. Although FDEP has set a co-funding precedent for projects based on these types of calculations, they should be viewed with some caution. Wood took a conservative approach to addressing uncertainties regarding the portability of CB methods to Florida by using the lower end of effectiveness ranges in general. We did not add or enhance modules to account for processes we believe will be amplified in Florida. For example, we did not expand the effectiveness in the floodplain, where we believe the CB method is most likely to underpredict treatment in Florida streams. The CB method also likely neglects treatment increases related to submerged aquatic vegetation, Florida's year-round growing season, and the presence of in-line waterbodies.

Our economic data does not include costs related to potential utility conflict resolutions or highway crossing retrofits, which are sometimes necessary for stream restoration but are highly site-specific. These costs can push projects into the 'worst case' ranges Wood provided, and make projects unaffordable in extreme cases.

Stream restoration is a highly site-specific endeavor, requiring multi-disciplinary experience and expertise to support successful design and construction. Florida has some unique combinations of climate, geology, and biology that affect the physical integrity of our stream corridors.

It is important to match the scope and scale of the solution to the problem, but this can be accomplished in phases if it cannot be addressed all at once. Projects are best sequenced toward the fulfillment of a master plan that works for at least part of the watershed at a time.

Portability

This kind of assessment, using the same resources Wood used or developed for Phillippi, can likely be conducted anywhere with similar canal types and issues in the peninsular Florida hydrophysiographic region. This covers an area nominally from the Santa Fe River to just south of Lake Okeechobee. Wood conducts analogous assessments elsewhere using other hydrophysiographic datasets.

The algorithms and decision tree Wood developed to screen canal corridors for stream restoration sufficiency can be programmed into GIS tools as a means to rapidly screen entire drainage networks at the watershed scale for adequate right-of-way and stream power, in the applicable region only.

The guidance does not cover all aspects of urban stream impacts, and is focused entirely on deeply-cut artificial canals with normally shallow water levels. Southeast Florida canals with perennially deep waters warrant additional consideration.

The Phillippi canals exhibited comparatively little evidence of 'urban stream syndrome' whereby hydromodification at the watershed scale adversely affects channel stability. Wood's recommendations and treatment economics would differ under such circumstances. Urban stream syndrome warrants significant antecedent work to restore watershed functions prior to, or in concert with, stream restoration. For Phillippi, watershed retrofits could certainly be beneficial, but waterbody projects can commence immediately and independently from them.

Likewise, the Phillippi canals seldom exhibited evidence of lost grade control which is another rather ubiquitous affect of urban stress to natural stream corridors. Again, Wood's treatment recommendations and their economics would differ under such conditions.

Further, the Phillippi watershed has moderately well-drained soils and the canals would necessarily have to have larger available right-of-way to support stream restoration if the soils were poorly drained. This is because the stable widths of alluvially active floodplains under poorly drained conditions are larger than those of well-drained watersheds. Importantly, the bankfull channel dimensions are independent of soil drainage and should not be adjusted.

The methods are based on freshwater systems, with minimal to no tidal influence. Analogous concepts can be applied in tidal canals, but the patterns and dimensions differ substantially.

In summary, the approach and techniques recommended for improving canals in the Phillippi watershed are rather portable to similar canal types draining similar watershed conditions in the same hydrophysiographic region, but are not intended to be universal.

In some key respects, the Phillippi canal network occurs in a comparatively favorable landscape for urban stream restoration, representing an excellent opportunity for Sarasota County.



7.0 REFERENCES



7.0 REFERENCES

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8.0 GLOSSARY

Alluvial - surfaces created and sustained by sediment transport under variable flow. The worked sediments are called 'alluvium.'

Autotrophic - channels with clear water open to sunlight that produce their own carbon via photosynthesis. Instream plants improve water quality (see **Heterotrophic** for comparison).

Blueway - aquatic corridor suitable for kayaking and nature observation. A waterway analogue to a hiking trail or greenway.

Chain-of-Wetlands - a valley length consisting of a string of non-alluvial wetland depressions linked by alluvial meandering stream channels. See also, **In-Line Waterbody**.

Fluvial geomorphology - the study of how flowing water shapes land. A core scientific discipline for stream restoration .

Grade control loss - serious streambed erosion problem that usually migrates in an upstream direction over time (called a 'headcut' and the location(s) of active headcutting are small cascades called 'knickpoints'). Also, any alteration in sediment transport that causes a trend in channel elevation over time (either deepening or shallowing). Increased elevation trends are called 'Aggradation' and decreasing trends 'Degradation.'

Gravity failure - bank failure occurring when the weight (mass) of soil cannot be supported based on its internal shear strength. Often occurs in dynamic interaction with stream flow eroding the bank toe; with sudden changes in soil pore pressure during intense rainfall; and in response to rapidly falling water levels. High, steep, and grassed slopes are particularly vulnerable.

Greenway - terrestrial corridor suitable for hiking and nature observation. A land-based analogue to a blueway.

Heterotrophic - shaded channels or those with dark waters that receive carbon from external sources. Beneficial bacteria improve water quality (see **Autotrophic** for comparison).

Hydrobiogeomorphic (HBG) Design - a form of natural channel design (NCD) developed specifically for peninsular Florida streams by Kiefer et al. (2015). It classifies stream types as biophysical systems belonging to their watershed. The concept relies on a small number of key variables regarding catchment hydrogeology, watershed size ,and soil drainage that drive channel and floodplain pattern and dimension. Biological habitat characteristics and water quality regimes vary by stream type in association with the aforementioned physical variables. This system was derived specifically to help planners make better informed decisions regarding place-based stream restoration design in Florida.

Hydrobiogeomorphic (HBG) Stream Types. Stream classification acronyms used in this report are as follows:

- **HL-AFS** - HighLands, Alluvial Floodscape Stream systems
- **HL-BFC** - HighLands, BaseFlow Channel systems
- **HL-RSC** - HighLands, Root-Step Channel systems
- **FW-AF-CC** - FlatWoods, Alluvial Floodplain, Complex Compact corridor systems
- **FW-AF-WF** - FlatWoods, Alluvial Floodplain, Wide Flat corridor systems
- **FW-CV-NC** - FlatWoods, Colluvial Valley, Narrow Channel systems

H:V— ratio of horizontal to vertical slope dimensions. A 2:1 slope is twice as wide (horizontal) as it is high (vertical)

In-Line Waterbody (ILWB) - a non-alluvial pond, lake, or wetland spanning a valley reach located between upstream and downstream meandering alluvial stream channels. Natural ILWBs are formed by geological processes unrelated to ongoing alluvial processes.

Marsh - non-forested wetland.

Net Present Value (NPV) - Current value of an investment based on the sum of its annual costs and benefits expressed in US\$, as adjusted for the time-value of money. A 20-year cash flow with 4% annual discount rate was applied for this project.

Rosgen Natural Channel Design (NCD) - NCD provides stream restoration designs that harness natural processes in regions where sustainable bankfull channel dimension relates to watershed size. Rosgen (1996) developed the original NCD approach, which bases almost all channel and floodplain design variables in the stream corridor on dimensionless ratios of bankfull width or depth. So, things like floodplain width, meander curve radius, pool spacings, etc. all depend on knowing bankfull channel dimensions. HBG design is a variant of this concept to make it more robust for Florida watersheds.

Rosgen NCD Stream Type. Rosgen stream types in this report:

- **C**- channel with bankfull width/depth ratio (w/d) of >12 and an entrenchment ratio (ER) >2.2. These provide the largest minimum floodplain width among Rosgen streams.
- **E** - narrow channel with w/d <12 and ER >2.2
- **B** - channel with w/d >12 and ER 1.4 to 2.2. These provide an intermediate floodplain width in Rosgen's system, but are too narrow for most Florida streams.

Sapping failure - bank failure occurring when part of the streambank soil fluidizes and is carried to the stream due to concentrated groundwater flow through the embankment.

Slough - flowing non-forested wetland lacking alluvial features and processes.

Soil bioengineering - the applied science of using native plants interacting with specific soil, stone, or permeable plastic layers to stabilize banks.

Strand - flowing forested wetland lacking alluvial features and processes.

Swamp - forested wetland.

Travelway - path allowing vehicular access for channel maintenance or emergency vehicles. Is normally dry, but can be occasionally flooded for brief durations. Often co-located above subterranean utilities and along greenway trails.

