LEGACY DISTURBANCES AND RESTORATION POTENTIAL OF COASTAL PLAIN STREAMS

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Abstract. Stream restoration and enhancement provides opportunity to correct or improve previous alterations that have destroyed, diminished, or impaired the character and function of stream systems. The Savannah River Site (SRS) as a National Environmental Research Park operated by the Department of Energy provides an ideal research opportunity for restoration of coastal plain streams. The temporal range of disturbances to SRS streams span the range of pre-SRS legacy impacts through the early infrastructure development in the early 1950's to more recent and current industrial activities. A multiphase program has been established to characterize SRS streams, identify risks of legacy and recent disturbances, and identify disturbed stream reaches improvable by restoration. Phase I involves a broad scale survey of potential stream disturbances and stream basin characterization. Phase II, initiated in 2010, assesses the effects of stream alterations in a subset of Phase I identified streams. Stream hydrology, geomorphology, and habitat availability at the reach, segment and basin level are being assessed. The proposed Phase III project will further evaluate a select subset of stream reaches by measuring additional hydrology, physicochemistry, and geomorphology features. This thorough stream evaluation will guide prescription of restorative actions. Future phases will implement and monitor enhancement and restoration efforts.

INTRODUCTION

Stream restoration refers to activities that are taken to correct or improve previous alterations that have destroyed, diminished, or impaired the character and function of stream systems. Enhancement refers to activities that are initiated to improve an aspect of an impaired stream system where recovery to the natural or reference condition is not feasible or practical. Stream restoration and enhancement projects are commonly performed worldwide and have become an emerging business enterprise. In the United States alone, billions of dollars have been spent on stream and river restorations (Palmer et al. 2005). In highly degraded stream systems, restoration programs and projects within the U.S. are focused primarily upon returning structure to a stream channel cross-section (width/depth, bank full discharge, meanders and pools, hydraulic gradients, and vegetation, etc.)(Rosgen 1997, North Carolina State University 2002, McCandless and Everett 2002). The primary goal is to restore the hydrodynamics and energy gradients to a condition comparable to local natural streams or rivers of similar order, and to stabilize sediment transport (net degradation/aggregation). Given these conditions, restoration success criteria have often in the past been based upon geophysical and floral assessments. In contrast however, restorations efforts aimed at improving biology without adequate attention to the physical aspects frequently fail (Kondolf et al. 1995, Kondolf 2000).

Stream structure refers to the pattern or organization of features within a system, whereas stream functions are the processes and rates of a system (Bunn and Davies 2000). Although the relationship is poorly understood, it is usually assumed that structure and function are closely related. Structural measures have been used to a greater extent than functional measures to characterize the integrity of aquatic systems because the methods for measuring structural attributes are well established and tend to be less complicated. However, functional measures have been advocated for stream assessments (Matthews et al. 1982) and restoration goals (Wohl et al. 2005). In addition, there has been a recent movement to incorporate functional attributes for regulatory purposes (Meyer 1997, Gessner and Chauvet 2002, Davies and Jackson 2006). The combined use of structural and functional measures provides a better assessment of the integrity status of water bodies, and provides better integration across levels of hierarchical organization (Bunn and Davies 2000). A successful restoration will expedite recovery of the stream functional processes as well as the floral and faunal community structures (Kolka et al. 2002).

The Savannah River Site (SRS) is a 801 km^2 (309 square mile) National Environmental Research Park operated by the Department of Energy. The SRS lies on the upper Coastal Plain along the southwest border of South Carolina, USA. Today a broad array of disturbances ranging from pre-Savannah River Site land use to contemporary industrial activities shapes the local landscape. Pre-SRS land use subjected streams to extensive disturbances including cattle grazing, timber harvest, channelization, and intensive agriculture (Cabak and Inkrot 1997, White and Gaines 2000, White 2004). Lasting effects are evidenced by deep erosion gullies along stream valleys and incised or rerouted stream channels. Riparian corridors were fragmented by numerous dams and levees; remnants of many remain. It is becoming increasingly recognized that such legacy impacts can have long lasting effects on U.S. stream systems and at times interact synergistically with more recent disturbances (e.g. McIntosh et al. 1994).

Construction of the original SRS infrastructure was a monumental task. Networks of roads and railroads, power plants, nuclear reactors as well as production and waste handling facilities were completed in only five years (1951-1956). Such intensive construction activity consequently impacted many SRS streams. Subsequent removal of land from agriculture has allowed regeneration of forests now managed by the USDA Forest Service. Present day stormwater runoff and effluent releases from SRS industrial areas and the consequent erosion and sediment deposition continue to alter some streams. Some channels were reconfigured directly (e.g. Beaver Dam Creek) to accept high volume industrial water releases, or indirectly restructured by the discharge of reactor water (e.g. Pen Branch and Fourmile Branch). Both active and abandoned structures may continue to fragment streams, alter hydrology, and provide nick points for beaver impoundment. Characterizing SRS streams will allow us to identify risks of legacy and recent disturbances as well as identify potential contaminant sources including waste sites, outfalls, and contaminated aquifers in relation to surface flow paths and seep zones. A collaborative effort among Savannah River Nuclear Solutions-Area Completion Projects, University of Kentucky, USDA Forest Service, Savannah River National Laboratory, and Savannah River Ecology Laboratory has been undertaken to establish a baseline of wetland impacts to SRS headwater streams and support SRS natural resource stewardship through a three phase program.

OBJECTIVES AND APPROACH

Phase I

A stream characterization project (Phase I) was initiated to assess structure in headwater streams at the Savannah River Site (SRS) and to determine areas where stream remediation may be warranted. This phase involves a broad scale survey of potential stream disturbances and stream basin characterization. We are identifying drainage basins where contiguous high-quality watersheds could be established. A watershed approach is both of critical ecological (Wohl et al. 2005) and regulatory importance (e.g. COE/EPA, (33 CFR Parts 325 and 332; 40 CFR Part 230). The latter establishes requirements of a watershed approach to restoration in association with mitigation. Consequently a stream segment must be evaluated in the context of the relevant drainage basin or sub-basin. Within the basins, stream reaches with disturbances potentially improvable by restoration or enhancement are being identified. Additionally, disturbances are being placed into a temporal context to establish whether disturbances were of pre-SRS or SRS origin. This temporal context assists in determining the regulatory requirements of a disturbance including whether appropriate for compensatory mitigation. Pre-SRS disturbances will also provide valuable insight about a stream's ability to recover without human intervention. Our surveys are identifying streams that represent a broad disturbance gradient ranging from severely altered streams to the best available reference systems. The least disturbed streams are critical to establish an endpoint model system. This also satisfies a requirement of the above cited CFR. Reference condition determination is being conducted in collaboration with Paller et al. (2010). Streams spanning a broad temporal disturbance gradient ranging from likely the early 19th century or earlier (Brooks et al. 2000, White and Gaines 2000, White 2004) to active impacts from industrial areas are being identified.

Phase I efforts require examining aerial photos (1938-2010), LiDAR imagery (2009), existing GIS data, maps (1943 to current), and literature to identify disturbances such as flow impediments, erosion, or channelization. A significant contribution of this study also stems from extensive ground surveys. Study streams were walked from their confluence to near the drainage divide. This included all valleys with perennial or intermittent channels as well as significant ephemeral channels. The ephemeral channels are particularly important to determine where outfalls enter streams since they are often located at the head of ephemeral valleys. Disturbances were noted and waypoints saved. The ground survey located disturbances and stream features that would otherwise have gone undetected. A digital elevation model displaying 1 m gradients created from the 2009 LiDAR imagery is aiding basin characterizations. We are summarizing our data in GIS layers, text descriptions, and detailed tables. Basin characteristics are being measured for each tributary basin (Table 1).

Table 1. Stream features measured in Phase I.

Drainage area	Stream length
Drainage perimeter	Basin relief
Cumulative stream length	Basin relief ratio
Drainage density	Entire stream gradient
Basin length	Cum. Intermittent length
Drainage shape	Main intermittent length

To date, Phase I is focusing on the entire Mill Creek, Meyers Branch and McQueen Branch drainages, 18 Upper Three Runs (UTR) tributaries, six Tinker Creek tributaries and the included main stem, and the Pen Branch drainage above Indian Grave Branch (Figure 1). The Meyers Branch, Mill Creek and Tinker Creek study areas alone include 35 tributary basins, over 100 perennial links, and over 95 km (59 miles) of perennial stream. Additional streams will be surveyed as funding permits.

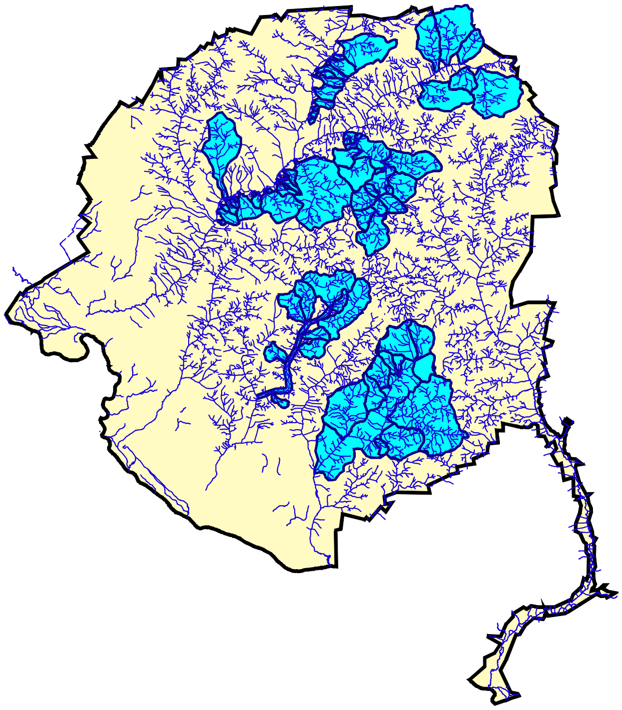

Figure 1. Savannah River Site tributaries (highlighted in blue) presently under investigation.

Establishing present and natural flow patterns is a critical first step in determining the status of a stream system. This is particularly true in relation to waste units and outfalls. Flow patterns, particularly where sheet flow through wetlands is involved, can be complex and not obviously discernible without thorough investigation. Our ground survey has identified tributary and outfall confluences to confirm when stormwater runoff or potentially contaminated water reaches state waters. Channelization and ditching has altered channel form, flow patterns and hydrology of SRS streams. Channelization was particularly prevalent during the early SRS infrastructure development (e.g. Figure 2). However, pre-SRS ditching also commonly drained floodplain wetlands and re-routed streams, particularly along larger streams such as Upper Three Runs. Especially detailed mapping of springs and seeps are being conducted along the east ridge of UTR where aquifer contamination is known. Headwater springs/seeps for all tributaries were identified.

Erosion and incision of SRS streams has long been a prevalent part of the local landscape from pre-SRS land

Figure 2. Meyers Branch 1956. Even though generally consideed an undisturbed stream, the ephemeral headwaters was channelized between 1951 and 1956 to carry stormwater runoff from two industrial areas.

use to more recent industrial activities. Areas of severe entrenchment, instability, or sedimentation are being noted for our study streams. Primary erosion sources include historical land use, present land use, outfalls, roads, railroads, highline cuts, and abandoned borrow pits. Effects of pre-SRS land use is evident by common erosion gullies along stream valleys such as those above the headwaters of Turner Branch. Ephemeral gullies may stabilize over time (e.g. Figure 3A), but effects from excessive runoff and operation of a dam in headwater reaches can cause long lasting impacts on downstream perennial channels (e.g. Figure 3B). The above examples illustrate why knowing the hydrologic status of a stream is critical for determining the need for enhancement. If an ephemeral channel will stabilize on its own, re-working the channel may waste resources and may risk causing more damage than benefit. Stream alteration from stormwater runoff in SRS industrial areas ranges from mild to severe (e.g. Figure 3C). Excessive runoff may alter channel form through incision, bank failure and sedimentation, as well as hydrology by changing channel elevation.

Impoundments behind dams constructed for running mills or water storage have also long been a prevalent part of the local landscape. Mill dams are often difficult to age because many were constructed by the early 19th century (Brooks 1989). Many structures had ceased operation long prior to the 1938 aerial photos. Others were breached

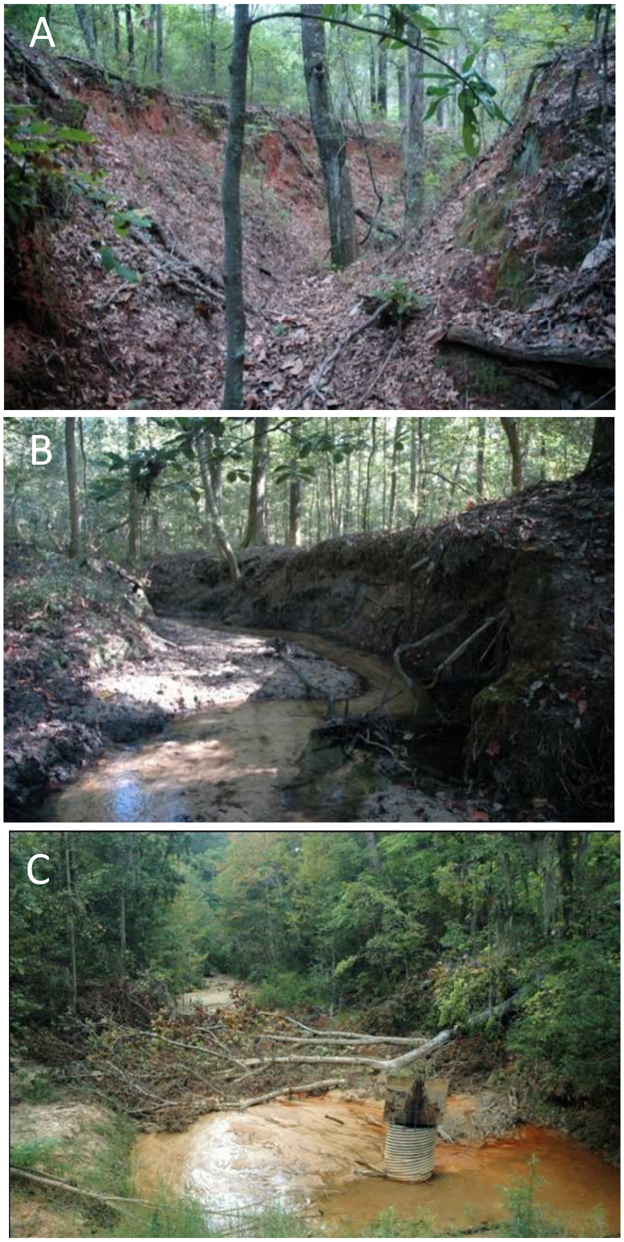

Figure 3. Turner Branch stabilized headwater gullies(A) and unstabe perennial channel (B). Upper Three Runs tributary severely incised by runoff from an SRS industrial area (C).

after SRS construction. Abandoned and active crossings also potentially impact streams depending on their structure and location along the stream gradient. During operation these structures altered the geomorphology of many streams. The remaining abandoned structures may continue to fragment the stream, alter hydrology, and provide nick points for beaver impoundment. Even the less conspicuous abandoned crossings can alter stream hydrology if located below an intermittent stream's head spring. At base flow a small wetland forms above the road forcing the water to go underground and resurface again further downhill. The condition of narrow or wide breach, culvert, bridge, standpipe, spillway, or ford is noted for each obstruction. Over 120 structures representing potential flow impediments were identified in the study areas in Meyers Branch, Mill Creek, and Tinker Creek (Table 2). These included 79 abandoned crossings or dams and 45 active structures. A large majority of the structures were of pre-SRS origin. Work on Upper Three Runs and Pen Branch is in progress.

Table 2. Numbers of structures representing potential flow impediments from pre-SRS and SRS origins in the Mill Creek and Meyers Branch Drainages and the study area of Tinker Creek.

	Pre-SRS	SRS	Unknown	Total
Mill Creek	28	9	0	37
Meyers Branch	48	8	1	57
Tinker Creek	32	3	0	35
Total	**108**	**20**	**1**	**129**

Beavers frequently plug narrow breaches or culverts in small streams. In larger streams, beavers may use the levee as a shield and build large dams behind the levee. Combinations of abandoned and active crossings and dams can result in relatively high densities of flow impediments that put streams such as Mill Creek or long reaches of Pen Branch at risk of impoundment. Although a critical part of the landscape, exploitation of extensive human built structures by beavers may result in substantial loss of natural stream habitat (e.g. Figures 4).

Phase II

Phase II, initiated in 2010, further examines the effects of stream alterations in a subset of streams identified in Phase I. Stream hydrology, geomorphology, and habitat availability at the reach, segment and basin level are being assessed. A total of 48 sites ranging from the least disturbed to severely altered are included. The temporal disturbance gradient ranges from pre-SRS to current. Our protocol draws upon field observations and measurements as well as GIS data. In addition to the Phase I basin characteristics, features such as sinuosity, gradient, valley width, and valley depth are being measured. Water quality parameters will be measured at each site. Some data such as presence/absence of various fish habitats will be generally collected along the entire stream reaches, but much will utilize two sets of transects. Depending upon stream width, study sites will be 150 or 210 m long. Transects for geomorphic data are being set up at 30 m intervals. Channel cross-sections will be surveyed at the 30-m intervals and reassessed periodically to evaluate channel stability.

Data such as canopy coverage, riparian vegetation, stream and channel dimensions, bank stability, bank vegetation coverage, bottom firmness, and water velocities will be collected at each transect. Root masses, aquatic macrophyte coverage, and coarse woody debris will also be quantified across these transects.

Additionally habitat characterization transects are being established. A higher number of transects will be required for this component, so transects are spaced 10 m apart. At each transect, mesohabitat type will be recorded as well as stream width, maximum depth, root masses, bank undercuts, macrophytes, coarse woody debris, dominant substrate, and largest available inorganic substrate. In addition to the above data, bottom sediment will be characterized. Over-story, mid-story and ground cover riparian vegetation layers will be characterized. In each reach, diameter of all over-story trees will be measured and recorded by species in each of three 10 x 10 m plots. The mid-story layer will be characterized by counting and identifying to species all woody stems. For ground layer sampling, two 1.0 m^2 quadrats will be randomly selected in each 10 x 10 m plot. Ground layer richness (total number of species present), diversity (Shannon index), and percent cover (estimated visually and recorded by species) will be estimated in each of the 1.0 m^2 quadrats.

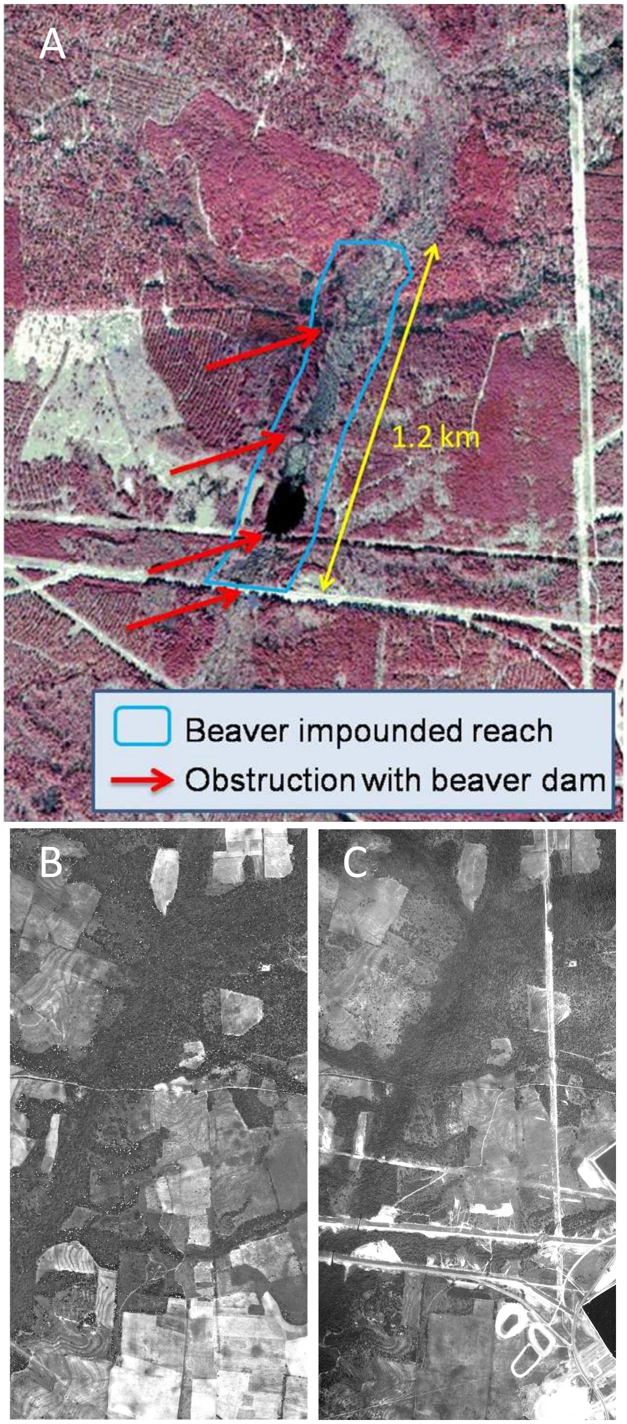

Figure 4. Over 1.2 km of Pen Branch (A, 2001) is flooded from a series of four obstructions. Beavers utilized a pre-SRS abandoned road crossing (B, 1951) and three structures constructed in the early 1950's (C, 1955). The latter three exist today (downstream to upstream) as an active road crossing/utilities crossing, utilities crossing, and an abandoned levee. This is only one of several impounded reaches in Pen Branch.

Phase III

Phases I and II are providing a general characterization of our study reaches. The proposed Phase III project will further evaluate a select subset of stream reaches by measuring additional hydrology, physicochemistry, and geomorphology features of each study reach. A thorough stream evaluation will allow us to prescribe, implement and monitor enhancement and restoration efforts. Additional channel characterization will include standard topographic surveying procedures to determine the rate of incision/filling. Sediment pins will also be installed in banks and active channels to evaluate short-term changes (+ and -) in sediment distribution.

In-channel standing crop of coarse particulate organic matter will be measured seasonally. Litter decay and invertebrate colonization will be determined using sweet gum (*Liquidambar stryraciflua*) leaves and a standard litter bag technique (Boulton and Boon 1991). From a subsample of leaves, total C (organic and inorganic) and N contents will be determined. Macroinvertebrates will be sorted from the leaf bags and identified. Invertebrate biomass will be estimated using published allometric equations (e.g., Edwards 1967, Sample et al. 1993, Benke et al. 1999). Additional macroinvertebrate and fish community surveys are being explored depending upon funding availability.

To evaluate stream discharge patterns, monitoring stations will be established in each reach of the project area. Precipitation data (quantity and timing) will be collected from SRS weather stations. Monitoring stations will simultaneously and continuously record stream temperature and stage height with the latter converted to discharge via stage-discharge rating curve. Water chemistry and suspended sediment samples will be collected at each monitoring station for select storm water events. Water quality parameters such as temperature, pH, dissolved oxygen, electric conductivity, and turbidity will be measured in the field. Automatic water samplers equipped with a flow actuator (programmed to begin sampling in response to a rain event) will be installed to provide samples for laboratory evaluations. Samples will be analyzed for alkalinity, major nutrients, total organic carbon, dissolved organic carbon, and trace elements (Ba, Be, As, Se, Tl, V, Fe, Mn, Pb, Sb, Cu, Zn, Cd, Cr, Ni). Turbidity and total suspended solids (TSS) will used to characterize suspended sediment levels.

Three 30 to 50-cm long sediment cores (as conditions allow) will be collected from each reach. The first core will be used for 210Pb analyses, while the second will be used for elemental and 239+240Pu analyses. The third core will be used for mineralogical and elemental analyses. Cores will be subsampled at 2cm intervals or where evidence of depositional stratification is present. The 210Pb will provide a depth to age profile using the constant rate of supply model that assumes a constant influx of unsupported, atmospheric 210Pb to the site. Measurable 239+240Pu result from nuclear-weapon testing that began in the 1950s, peaked in 1963 and ceased in 1972 and may provide a metric for examining sediment accretion since this time. Mineralogical and elemental characterization by by x-ray diffraction and ICP-OES analysis, respectively, will provide insight into the source of sediments and potential contamination.

PRODUCTS

This program will locate potential ecological impacts and link descriptions to GIS maps. Flow patterns will be established including documentation of where surface or ground water discharges actually enter a stream. Additionally it will provide information useful in refining flow path models such as those associated with SRS permitted outfalls. It will provide critical information to improve reference site or background selection as well as sample placement determination and justification. It will make stream basin characterizations readily available. We will provide improved hydrological information and accurate maps. Provision of locations of numerous historical dams and levees will improve SRS archeological data bases. We will provide detailed assessment of nearly 50 streams with even more detailed evaluation of a subset of these. We will identify locations potentially useful for compensatory mitigation and provide a framework upon which a restoration program and a potential mitigation bank could be built.

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