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BANK STABILIZATION THROUGH STREAM RESTORATION

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EXECUTIVE SUMMARY

Over the past century, increasing land use and alteration in watersheds have led to significant streambank destabilization. Like any natural system, streams adjust to perterbation through dynamic responses, attempting to reestablish “stasis”. In general, stream stability comprises a healthy riparian zone with stream channel dimensions/features necessary to accommodate the hydraulic processes characterizing the system. The study of such processes in relation to river behavior (fluvial geomorphology) has led to classification schemes in which streams may be grouped according to certain fluvial characteristics. One such scheme, developed by Dave Rosgen (Wildlands Hydrology), allows stream classification based on eight major fluvial geomorphologic variables. The significance of Rosgen’s techniques is that a stream’s stable reaches may be classified, thus affording natural design objectives for its augmentation.

Unlike most conventional techniques, Rosgen’s methods focus on stream restoration rather than temporal stabilization. To date, many streams have been channelized, concrete lined, or filled with rocks, tires, and other materials in an effort to aid streambank stability. Although these methods have met with some success, none offer the potential for reestablishing the natural, steady state of the system previously occupied through the millennia. Such stability is paramount to the integrity and diversity of stream and riparian communities (Karr, 1981; Barbour et al, 1999).

Many Oklahoma streams list sedimentation as the primary cause for their threatened or impaired beneficial uses (1994 303(d) list). In concert, most of these streams exhibit significant bank erosion, which has lead to remedial activities in high profile or exceptionally problematic reaches. These activities have comprised mostly conventional methods that do not address the natural tendencies of the stream.

In light of this, the Oklahoma Conservation Commission implemented Rosgen’s techniques on three Oklahoma streams with bank stability problems. The primary study objective was to demonstrate the efficacy of the method in arresting bank erosion while simultaneously improving aquatic habitat and water quality. A secondary goal was to inform and educate the public, Conservation Districts, NRCS field personnel, Ag. Extension personnel, and other interested parties regarding the basic principles of fluvial geomorphology and its relation to erosion, aquatic habitat, and water quality. Project sites were selected based on the following criteria: level of impairment, magnitude and extent of bank erosion, feasibility of implementation, willingness of participants, and probability of success. Three locations were chosen for the demonstration projects: Lost Creek at Sante Fe Elementary School in Cleveland County, Chillocco Creek in Kay County, and Spring Creek at Timber Lake in Mayes County.

The Lost Creek project site was a channelized streambed experiencing severe bank erosion and channel downcutting. Bank instability was severe and the continued erosion would soon result in significant property loss. The project site was investigated and classified according to the Rosgen system. Stable reaches downstream also were surveyed and classified to provide design objectives for the project site. The channel was reshaped accordingly including addition of

rootwads and several hundred sandstone boulders for natural revetment and construction of rock vanes and step pools. Two wetland ponds also were constructed for wetland education potential.

Results of the Lost Creek project have been excellent. Despite two flood events immediately following construction, the project reach has stabilized readily as indicated by strong vegetative establishment on the banks and instream. Various wetland and associated plant species not present pre-implementation are now common throughout project reaches. Numerous stream and wetland fauna were also observed in a recent visit. The constructed ponds and associated micro-wetland have successfully established and will serve an educational potential as an “outdoor classroom” for years to come.

The Chilocco Creek project was brief involving remediation of a sharp bend which exhibited severe erosion and threatened continued migration toward an area landmark (> 100 yr rock barn). The project site was surveyed with cross-sections, classified, and altered to improve dimensions, curvature, and outside bank slope in accordance with the Rosgen method. Several root-wads were also installed for revetment and habitat improvement.

Remedial efforts at Chilocco Creek have met with less success. Channel aggradation and point-bar deposition is again forcing water against the outer bank. The result has been toe-slope loss and subsequent sloughing of the outer bank. Similar to the other projects, Chilocco Creek experienced a high flow within a year of project completion which damaged banks before vegetation could become established. A resulting log jam immediately upstream of the project site appears to have altered flow contributing to the point-bar growth and channel adjustment that threaten the project. Poor establishment of tree and grass plantings also continue to compromise bank stability.

The most extensive project occurred near the Timber Lake region of Spring Creek. Following an intensive pre-implementation survey, evaluation, and Rosgen classification, two sites were chosen to implement fluvial geomorphologic techniques to restore streambank stability and improve habitat. At Site 1, only a longitudinal toe-slope with rock revetment was necessary to stabilize the outer bank. However, at Site 2, a complete redesign of the channel and addition of rock vanes, cross vanes, and root-wads were required to restore the area to reference conditions. To accomplish the design, it was necessary to develop a regional curve to afford calculation of the design discharge. This process was intensive and involved geomorphic surveys and Rosgen classification of 10 regional U.S.G.S. gauging sites to produce two regional curves (bankfull discharge vs. drainage area and bankfull area). For comparison, an additional curve (bankfull dishcharge vs. drainage area) was developed using data from 22 sites throughout Oklahoma. Upon determination of the design discharge, a final channel plan was developed.

Although the Spring Creek project area experienced a damaging flood-flow five months post-construction, numerous beneficial impacts have been realized. In general, habitat quality improved and banks stabilized with total area of eroding bank exhibiting a 75 percent decrease from pre-implementation conditions. Streambank and riparian vegetation have increased satisfactorily in response to bank stabilization and cattle exclusion. The fish community at the sites exhibited higher total species, numbers, pool species, and percent intolerant species. Size structure of pool species was better also with presence of young of year indicating reproductive success in response to improved habitat. With the stabilization of Site 2 as a long pool, certain beneficial uses such as fishing and swimming also have been enhanced.

The projects detailed in the following report demonstrate the potential of Rosgen's methods in bank stabilization and restoration of Oklahoma streams. Despite damaging flood flow events not long after completion, both Spring Creek and Lost Creek projects have exhibited satisfactory to excellent stabilization and positive biological responses. All three projects have met educational goals in demonstration and training in fluvial geomorphology and Rosgen's methods. To extend this potential, project funds were used to hold a five day training session with Dave Rosgen and produce an educational flier for distribution to interested parties.

1.0 INTRODUCTION

The history of Oklahoma, like that of many western states, has been influenced greatly by the availability of water. Four thousand years ago, primitive cultures erected mud and wattle dwellings along the streams and irrigated their crops from canals dug from the Cimarron, Beaver and Canadian Rivers (OWRB, 1990). Early exploration and trading by European settlers to Oklahoma centered around the Red, Arkansas, Grand, Canadian and Verdigris Rivers, with commerce on the rivers increasing in the 1820's due to the development of steamboats.

Modification of these river channels for improved navigation began as early as 1831, when army engineers drove a temporary channel on the Red River, then persisted for seven years to remove an ancient, massive pack of fallen timber called the "Great Raft" (OWRB, 1990). In 1893, work began on a 17-mile-long irrigation canal to divert water from the Cimarron River. The canal operated efficiently until the mid-1930s and remnants of the canal still exist in Beaver and Harper Counties. Further west, in Cimarron County, an 8.7 mile-long canal completed in 1916, remains in use to this day (OWRB, 1990). As late as 1940, there were fewer than 5,000 acres of cropland artificially watered in the state. By 1978, a million acres of Oklahoma land were under irrigation (OWRB, 1990). Beginning in the 1910's, reservoirs were constructed for water supply and flood control. Today there are 34 major lakes, 2,303 public and private lakes, 1,964 watershed protection lakes, 585 playa lakes, 62 oxbow lakes (≥ 10 acres), and 220,000 farm ponds (SCS assisted) in the state of Oklahoma, encompassing a total surface area of 1.04 million acres (OWRB, 1990).

The combined result of these changes on the landscape is that nearly every creek and river in Oklahoma has been altered in one way or another. Dams have been constructed to control flood flow and sediment; channels have been straightened, deepened, and widened to increase flood capacity and/or improve navigation; and flood plains and stream side riparian areas have been cleared and developed to increase agricultural production. The result has been a progression from stable (attained through millennia) to unstable stream configurations incapable of transporting sediment loads and flood flows in the basin. As streams restablize, bank erosion results, and more sediment is delivered to the system

Oklahoma's 1994 303(d) list names the waterbodies within the state that have threatened or impaired beneficial uses and the cause(s) of that impairment. A large number of these streams list sedimentation as causative for threatening or depreciating their beneficial uses. The source of the sediment in many of these waterbodies is from bank erosion.

Various methods have been attempted to prevent or minimize the effects of stream bank erosion. People have used concrete, rubber tires, car bodies, silt fences, and even "bio-engineering" generally with less than desirable results. For the most part, these techniques have been implemented with no consideration of the natural, stable state of the system. Rather, they were efforts attempting to "tame" the river.

Dave Rosgen (Wildlands Hydrology) has expanded on the work of Luna Leopold and developed a stream classification system that can be used to classify streams based on eight major variables: channel width, depth, velocity, discharge, channel slope, roughness of channel materials, sediment load, and sediment size. A change in any one of these variables sets up a series of channel adjustments that lead to a change in the others resulting in channel pattern alteration. This is the basic principle of fluvial geomorphology.

Rosgen's method is useful in that a stream's stable configuration can be determined and classified, and the disturbed stream can then be restored to the natural, stable configuration utilizing materials found on-site. A stream restored using these techniques would be stable and efficient at transporting bedload and flood flows. It would also be aesthetically pleasing and increase in-stream habitat for aquatic life.

1.1 FLUVIAL GEOMORPHOLOGY

Fluvial geomorphology is the study of the form or shape of stream channels as they flow over the land. Several researchers have studied extensively creeks and rivers over the years in an attempt to understand and describe their natural tendencies. As a result, numerous classification schemes have been developed. Rosgen (1996), continuing and expanding upon work performed by L.B. Leopold (1964, 1994), M.G. Wolman (1954), and many others, has developed a stream classification system that is based on geomorphic variables including entrenchment ratio, "bankfull" width to "bankfull" depth ratio, sinuosity, slope of the channel, and dominant bed material.

Fundamental to the Rosgen classification system are the concepts of natural stability and "bankfull". "Natural stream stability is achieved by allowing the river to develop a stable dimension, pattern, and profile such that, over time, channel features are maintained and the stream system neither aggrades nor degrades" (Rosgen, 1996). According to Dunne and Leopold (1978), "the bankfull stage corresponds to the discharge at which channel maintenance is the most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics of channels." Bankfull discharge is associated with a momentary maximum flow, which on average has a recurrence interval from 1.0 – 1.8 years as determined using a flood frequency analysis.

Using the Rosgen classification system, the concepts of natural channel stability, and "bankfull," one can determine the stability of a given channel. If the channel is unstable, it can be stabilized by allowing it to do so naturally. However, this is a process of many years, during which potential disturbance(s) would render only a "reset." More importantly to the resource manager, the process may be accomplished by constructing a channel with a stable dimension, pattern, and profile that maintains itself through time and effectively transports the sediment load delivered by the watershed.

1.2 PROJECT OVERVIEW

The Oklahoma Conservation Commission (OCC) implemented this process on segments of Lost Creek (Cleveland County), Spring Creek (Cherokee County), and Chilocco Creek (Kay County), Oklahoma. Although multiple objectives were achieved, the primary objective was to demonstrate that Rosgen's method could be successfully used to arrest bank erosion while simultaneously improving aquatic habitat and the biological community. An additional goal was to inform and educate the public, the Conservation Districts, the National Resources Conservation Service (NRCS) field personnel, Ag. Extension personnel, and other interested parties on the basic principles of fluvial geomorphology and its relatedness to streambank erosion, aquatic habitat, and the biological community.

Because this project was to be used for demonstration and educational purposes, its success was crucial. Good site selection was necessary, as site characteristics (technical, sociological, and political) appeared the most important factors in determining the potential for project success. Sites were selected that best blended these characteristics and exhibited the necessary local support from landowners, Conservation Districts, NRCS field offices, and stream protection groups.

1.2.1 Site Descriptions and Background

1.2.1a Site 1: Lost Creek, Cleveland County

The Lost Creek site is located in the NE¼, NE¼, SE¼ of Section 16, Township 10 North, Range 3 West of the Indian Meridian in Cleveland County, Oklahoma (Figure 3). The Lost Creek watershed is completely contained within Cleveland County and occupies the Central Great Plains ecoregion. It is a small perennial stream that has been channelized and is a concrete ditch for most of its length. It flows out of Moore, OK as a concrete ditch and into Oklahoma City, OK on the Santa Fe Elementary School grounds. The creek (project site) is channelized but not concrete lined through the school grounds. The Lost Creek channel returns to a concrete ditch 259 m (850 ft) subsequent to the school grounds. As a result of the channelization, Lost Creek was experiencing severe bank erosion and “down cutting” of the channel such that a nine-inch sanitary sewer line and several abandoned oil and gas lines that previously crossed under the channel were suspended above the streambed (Figures 1 and 2).

Project site justification was manifold. First, local concerns provided impetus for necessary local support. School officials were upset at the property loss from erosion, and the city engineer’s proposal to line the channel with concrete was very expensive; it would also oppose the desire of some of the teachers who hoped to use the creek as an outdoor classroom to teach students about wetlands and riparian areas. Second, the site location is in an urban setting, thus proliferating the educational potentials of the project. Third, the fix for the stream would be relatively easy. Finally, the chances for success with this system were extremely high

Figure 1. Upstream reach of Lost Creek prior to restoration (facing upstream).

Figure 2. Downstream reach of Lost Creek prior to restoration (facing upstream).

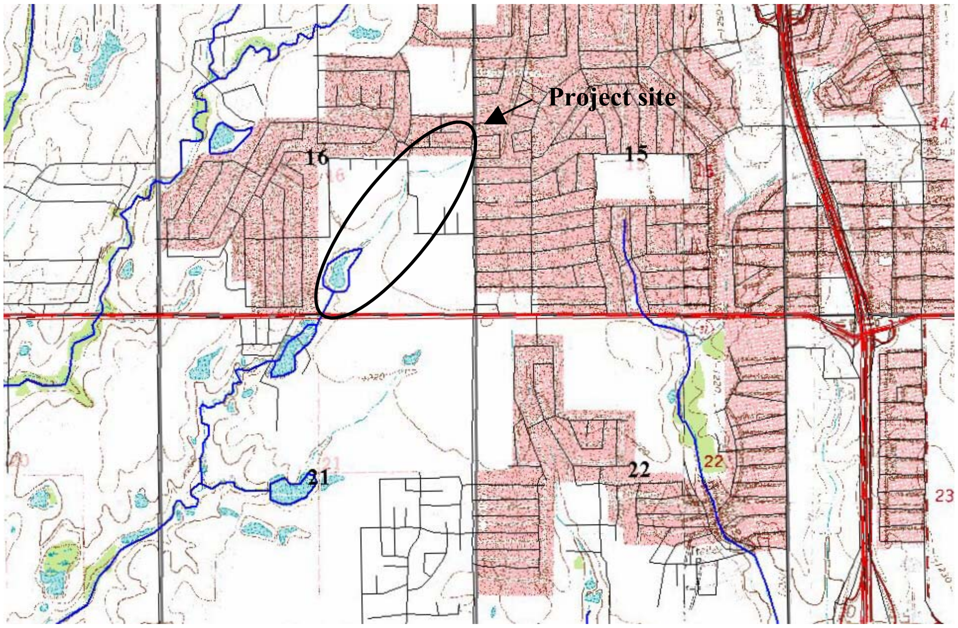

Figure 3. Lost Creek project site (Source: USGS, SE/4 OKC 15' Quad, 1986).

1.2.1b Site 2: Spring Creek, Cherokee County

Spring Creek is a tributary to Fort Gibson Lake in Northeast Oklahoma. Its watershed encompasses approximately 184 square miles traversing Delaware, Cherokee, and Mayes Counties and is almost entirely within the Central Irregular Plains Ecoregion. Spring Creek flows in a west-southwesterly direction for approximately 40 miles before its confluence with the Neosho River at the upper end of Fort Gibson Lake. Timber Lake (misnomer) is the name the locals have given to a reach of Spring Creek located in Section 18, Township 19 North, Range 21 East of the Indian Meridian in Cherokee County, Oklahoma (Figure 4). The project site incorporates two separate bends near this area.

Accelerated bank erosion and deteriorating water quality provided the impetus for inclusion of Spring Creek in the stream restoration project (Figures 5, 6, and 7). Local concern, and thus support, was also strong as a local citizens group (Spring Creek Coalition) was formed to protect Spring Creek from further depreciations in water quality. The landowners also were anxious to see something done and were very willing to offer assistance. Because the problems observed with Spring Creek were not unique to the area, an effective demonstration project would serve to teach other landowners readily employable techniques for their bank stability problems.

1.2.1c Site 3: Chilocco Creek, Kay County

Chilocco Creek, located in Kay County, OK, is direct tributary of the Arkansas River above Kaw Reservoir. The Chilocco Creek watershed encompasses approximately 43 square miles with 28 percent located in Sumner County/Cowley County, KS and the remainder in Kay County, OK. The watershed is mostly within the borders of the Central Great Plains Ecoregion. A 46 m (150 ft) section of Chilocco Creek (SW¼ , Section 22, Township 29 North, Range 3 East of Indian Meridian) (Figure 8) was experiencing accelerated bank erosion due to an old county

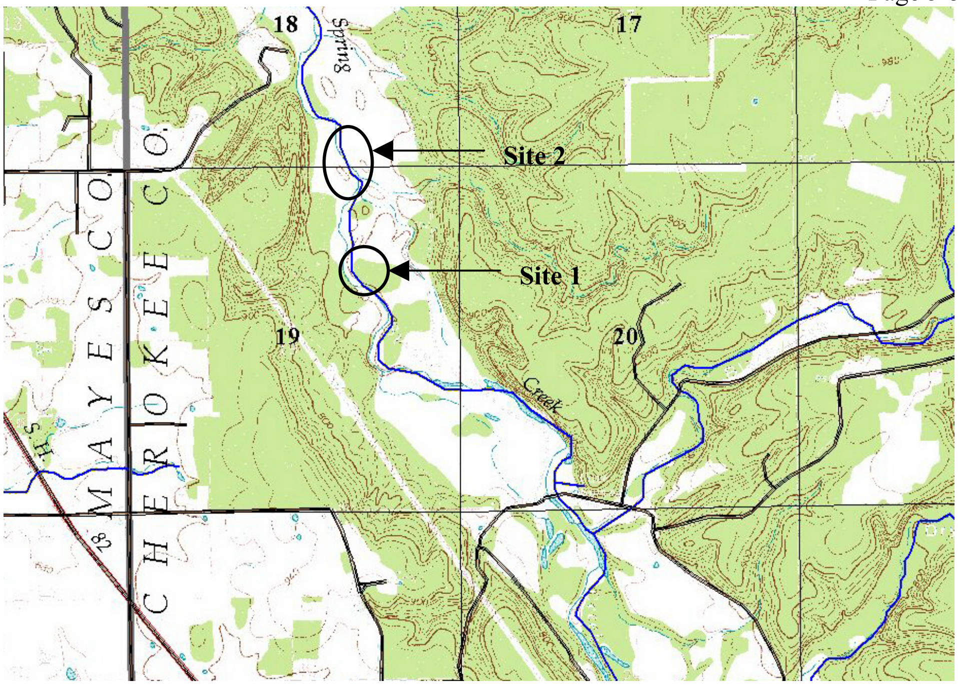

Figure 4. Spring Creek project area (Source: USGS, Peggs 15' Quad, 1972).

Figure 5. Project Site 1, pre-implementation (looking upstream).

Figure 6. Project Site 2a, pre-implementation (looking downstream).

Figure 7. Project Site 2b, pre-implementation (looking downstream).

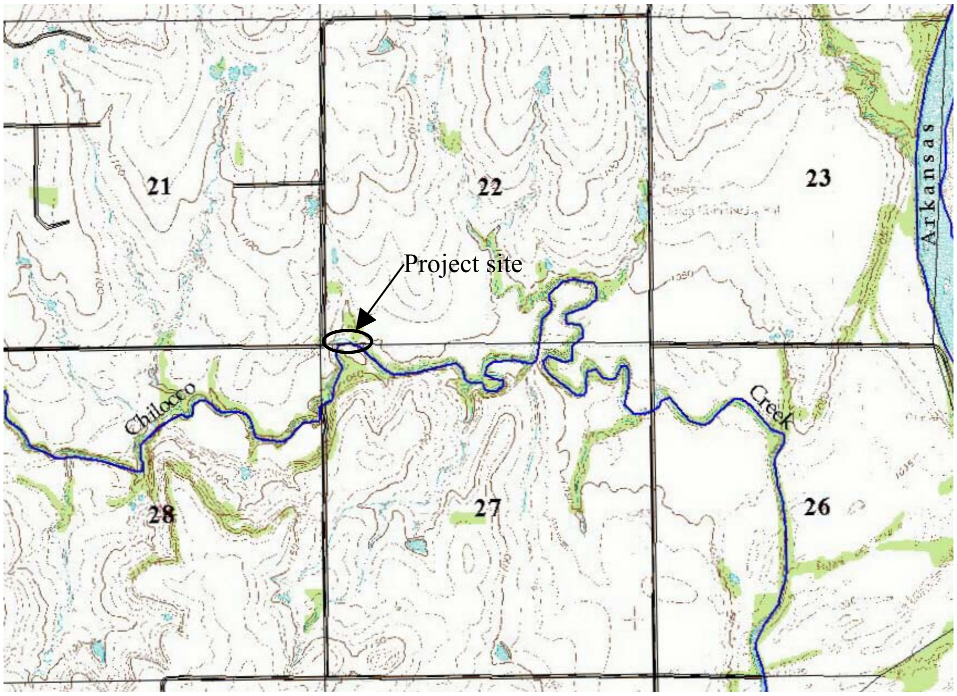

Figure 8. Chilocco Creek project site. (Source: USGS, NW/4 Kaw 15' Quad, 1963).

road bridge that washed out several years previous. The channel made a fairly sharp bend to the east after the bridge but was constricted and had no floodplain. As a result, the outside bank was eroding and threatening an old rock barn built in the late 1800's (Figure 9).

The Chilocco Creek site was chosen for several reasons. First, it was imperative that the lateral migration of the creek at this site be stopped. A remediation plan from the NRCS and Kay County Conservation District proposed planting willows and sod to stabilize the banks. Although an employable stabilization technique, bioengineering in this case likely would have met with failure due to the inappropriate channel dimensions noted in field observations at the site; a prime opportunity for applying principles of fluvial geomorphology. Second, local and District support was strong going into the project. Such a collaborative effort would help to meet the projects educational goals. Third, the necessary remedial measures were simple, and success was highly probable. Finally, the overall scope of the project was focused enough to facilitate cost and time efficiency.

2.0 MATERIALS AND METHODS

2.1 INTRODUCTION

Segments of Lost Creek, Chilocco Creek, and Spring Creek were classified according to Rosgen's classification system (Rosgen and Silvey 1996). Background data showing current impairment was obtained, including magnitude and extent of bank erosion. Stable configurations for relevant stream segments were proposed based on eight fluvial geomorphologic variables. Implementation involved restoring the streams to these proposed configurations. Project success

Figure 9. Chilocco Creek project site (pre-implementation).

was evaluated through pre- and post-implementation habitat and biological monitoring for Spring Creek and habitat monitoring for Lost Creek. No monitoring was conducted for the Chilocco Creek project due to the brevity (both time and length) of the project.

Although TDS, TSS, and turbidity would seem useful indices of bank stabilization success, water chemistry was not monitored during the study. Basal sediment loads upstream of project sites were significant enough that measurable differences in these parameters through site reaches would be miniscule and manifest only during higher flows. High flow data, however, would include significant sediment loading from all other sources in the watershed, effectively obscuring the effects of the restoration project. Additionally, implementation disturbance at project sites would contribute acute loads for a period following construction.

To fulfill the educational component, the OCC conducted a public education seminar with Dave Rosgen. The purpose of the seminar was to inform and educate the public and federal, state, and local government officials about the potential of applying fluvial geomorphologic principals to bank restoration problems. A flier describing the restoration process and the water quality improvements afforded by bank stabilization also was produced and distributed

2.2 FLUVIAL GEOMORPHOLOGIC CALCULATIONS

The techniques employed in this project were developed utilizing the principals of fluvial geomorphology. Design concepts were based upon stream channel restoration techniques developed by Dave Rosgen (1993), who expanded upon the work of L.B. Leopold (1964, 1994), M.G. Wolman (1954), and others. The approach taken in this project used fluvial geomorphology to assess channel characteristics of project sites to determine "stream type" and evaluate differential stability of reaches within the project sites. A fluvial geomorphic approach was also used to design stream channel geometry in certain project reaches.

The fluvial geomorphology of a stream or river is influenced by eight major variables including channel slope, width, depth, discharge, velocity, channel material roughness, sediment load, and sediment size (Leopold, et al. 1964). A change in any one of these variables sets up a series of channel adjustments, which lead to changes in the others resulting in channel pattern alterations (Rosgen, 1996).

Rosgen (1993) has developed a stream classification system based on the eight variables. The classification system organizes the morphologic variables into commonly observed characteristics allowing identification of several "stream types" (Figures 10 and 11). Each of the morphologic variables used in the classification system are addressed below.

2.2.1 Bankfull Discharge

The bankfull discharge is the instantaneous peak discharge that occurs a few days a year and is often related to the 1.5-year recurrence interval. It is perhaps the most important variable in the classification system as other variables are dependent upon it. Determination of the bankfull discharge is critical for proper application of the classification system. Discussions of bankfull discharge and its significance can be found in Leopold et al. (1964), Dunne and Leopold (1978), Andrews (1980), Rosgen (1993), and Leopold (1994).

2.2.2 Width/Depth Ratio

The width/depth ratio is defined as the ratio of the bankfull channel width to the bankfull mean depth. Bankfull channel width and bankfull mean depth are those parameters associated with bankfull discharge.

2.2.3 Entrenchment Ratio

The entrenchment ratio describes the vertical containment of the stream or river and the degree of incision in the valley floor (Kellerhals et al., 1972). It may be defined as the ratio of "flood-prone area" width to bankfull channel width. Flood-prone area is the width of the channel determined at an elevation twice that of bank-full depth (Rosgen, 1996)

2.2.4 Sinuosity

Sinuosity is a parameter describing the meander pattern of a stream or river. It is defined as the ratio of channel length to valley length. It can also be described as the ratio of the valley slope to the channel slope (Rosgen, 1996). Two additional parameters closely related to sinuosity are the meander length and the radius of curvature (Figure 12). Langbein and Leopold (1966) developed the following relationship between these parameters:

$$R_c = \frac{L_m K^{1.5}}{13(K-1)^{0.5}} \qquad \text{(Eq. 1)}$$

where; R_c = Radius of bend curvature
K = Channel sinuosity
L_m = Meander length

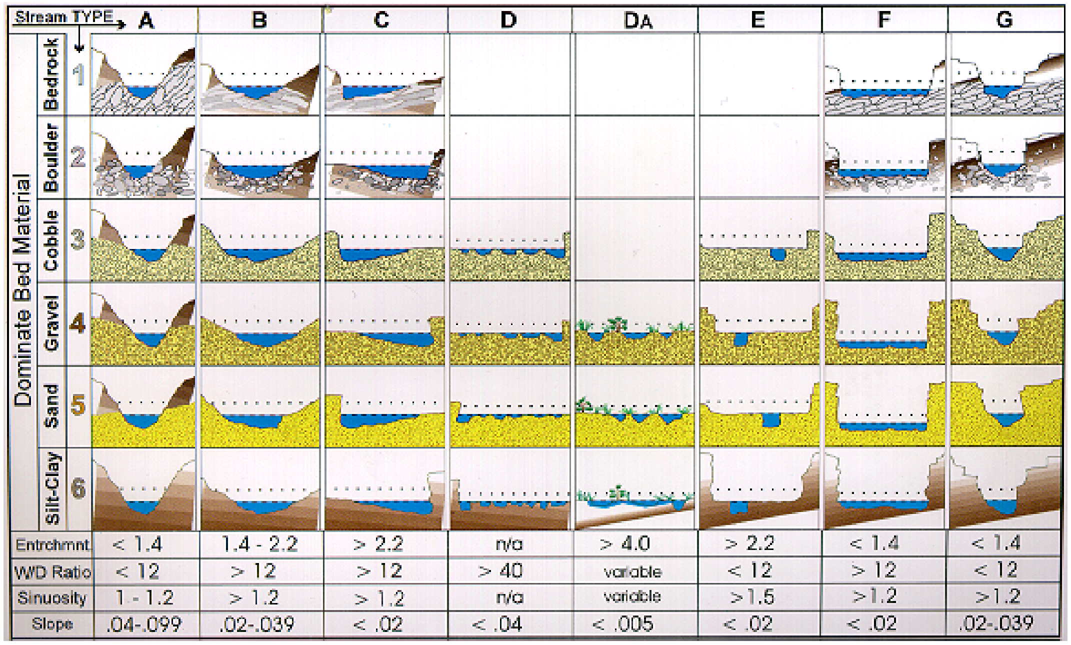

Figure 10. Longitudinal, cross-sectional, and plan view of major stream types (Rosgen, 1993).

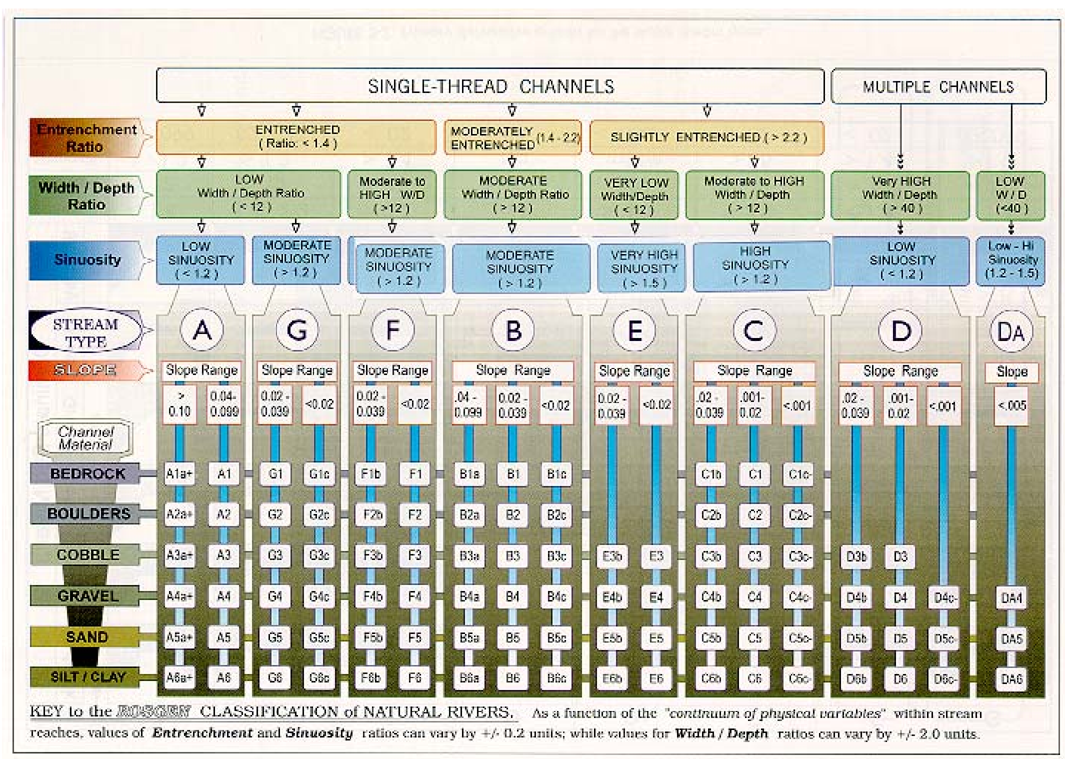

Figure 11. Classification key for natural rivers (Rosgen, 1996).

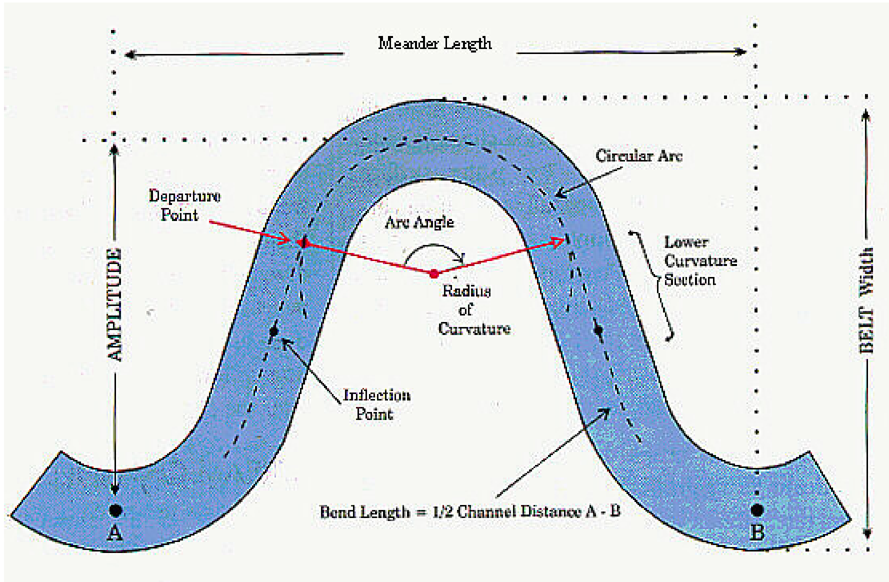

Figure 12. Plan-view of idealized river meander (Rosgen, 1996).

2.2.5 Meander Width Ratio

The meander width ratio is the ratio of the belt width (figure above) to the bankfull channel width. A keystone element of Rosgen's classification system is the link of meander width ratio to stream type. Thus, if the stream type is known, the most probable (i.e., stable) state of channel pattern may be determined and used in stream restoration efforts.

2.2.6 Channel Bed Materials

Channel bed material is crucial in stream hydrology as different materials provide varying resistance to flow and require different energy levels to transport. Differential movement and deposition of material, depending on type, influences significantly channel shape. For disturbed and unstable systems, this influence becomes more prominent. Therefore, channel bed material is a logical component for an effective stream classification system. Field determination of the channel materials is accomplished using the "pebble count" method presented by Wolman (1954).

2.2.7 Slope

The slope of a stream channel is the final parameter used in Rosgen’s stream classification system. Channel slope is crucial to steam hydraulic process as it provides the hydraulic energy to a stream, thus affecting sediment transfer and channel morphology. The slope is typically measured over at least 10 channel widths or one meander wavelength. Stream channel slope was measured accordingly for applicable project reaches.

2.3 IMPLEMENTATION

2.3.1 Lost Creek

A preliminary survey was conducted to determine the existing stream type of Lost Creek. A longitudinal profile and two cross-sections were surveyed using a laser level, a sensor equipped level rod, and a 300’ tape. The cross-sections surveyed were chosen to represent the differential stream types upstream and downstream within the project area.

An extensive survey of the project site was conducted utilizing a total station. Three hundred points were shot over the entire project site. Permanent control sites were established to assist plan layout and construction survey.

A reference reach survey was also conducted two miles downstream of the project site. Two good reference reaches were found exhibiting stable B6c and E6 stream types; these as well as C6 stream types appear to occur frequently in undisturbed streams in the central part of the state. The sites were surveyed with cross-sections and longitudinal profiles, and pool/riffle depths and widths were recorded.

Nether United States Geological Survey (U.S.G.S.) gauging data or a regional curve was available for this project. Therefore, bankfull discharge was determined directly by installing staff gauges and measuring flows at various flow stages. Fortunately, several high flows were measured, including one at bankfull level (as determined from field indicators). This information was combined with runoff rates calculated from a NRCS model to produce an estimated bankfull discharge.

The implementation plan was developed through a series of several activities. The data collected from the existing site survey was entered into AutoCad, and a topographic map of the project site was developed. Locations of important features (e.g., buildings, parking lots, swing sets, pipes) were plotted. The final design channel was elaborated using information from the reference reach surveys and careful examination of the project site. The design channel profile was developed to reflect the stable reference reach profiles at the project site. Cross-sections were generated using AutoCad, and a plan map showing locations and types of structures to be used in the design was prepared. A water quality (401) certification from Oklahoma Department of Environmental Quality (ODEQ) and a 404 permit from the U.S. Army Corps of Engineers (COE) were obtained prior to implementation.

Cut-fill calculations were made utilizing the cross-sections developed from AutoCad. It was determined that an estimated 2840 yd^3 of material would be cut, and 1600 yd^3 of material would be filled. The approximate 1240 yd^3 of excess material was disposed of on school property adjacent to the site.

Although the project site was not identified on FEMA maps as a flood prone area (City of Oklahoma City, personal communication) a flood flow analysis was conducted to assess problem potential. Existing and proposed cross-sections of the project site (as per AutoCad) were entered into HEC-RAS along with appropriate Mannings’ “n” values. A flood flow value of 800 ft^3/s was simulated and results analyzed.

Construction was initiated March 11, 1998 and, following a four day delay due to rain, was completed March 26, 1998. The streambed was reset above the exposed nine-inch sewer line and sloped more gradually than the previous channel to allow mergence with an existing flood plain, abandoned due to the creek channelization. The newly constructed streambed was tied into the existing channel invert via two step-pools. The step-pool channel was created using approximately 300, 0.61 x 0.91 x 1.22 m (2 x 3 x 4 ft) sandstone boulders. Roughly 200 smaller boulders were used to create rock veins and vortex weirs to provide stabilization. Twenty-five root wads (Figure 13) were installed also for natural revetment. In response to desires for continuing education potential, two wetland ponds were constructed in association with the project site. Following construction, willow (*Salix*, sp.) poles, grass seed, and some aquatic vegetation were planted to aid immediate stabilization of all areas. Mosquito fish (*Gambusia affinis*) and tadpoles were also introduced to the stream and ponds.

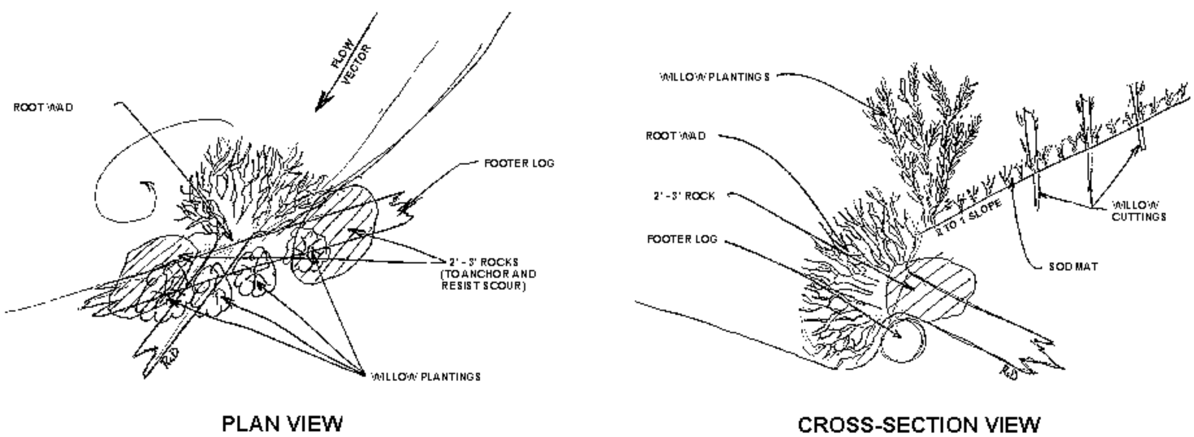

Figure 13. Root wad schematics, plan and cross-section views (drawn by R. Dutnell).

2.3.2 Chilocco Creek

The project site at Chilocco Creek was relatively small and remediation simple. A half-day survey was conducted in which cross-sections were taken in the eroding bend and in bends upstream and downstream of the site. Design drawings were prepared showing the existing and proposed cross-sections, the plan view of the proposed channel (Appendix I), and installation details for the “root wads” (above).

Upon attainment of the necessary COE 404 permit, construction was initiated and completed in one day on April 4, 1997. Activities entailed construction of 46 meters (150 feet) of natural channel and installation of four root wads for natural revetment. Following construction, sod, grass sprigs, and willow (*Salix*, spp.) poles were planted for supplemental stabilization.

2.3.3 Spring Creek

2.3.3a Field Measurements

A pre-implementation survey of Spring Creek was conducted to locate and establish project stations and gather data for cross-sectional profiles. The project area extends from station *25+00* downstream to station *110+90*. Stations were established using 3/8” iron re-bar driven into the ground on both sides of the channel. Cross-sections were established every 91 m (300 ft) for a distance of 3380 m (11,090 ft) extending from a county road bridge upstream of the project area to a low water crossing at the end of the project area. To prepare the implementation plan, a commercial aerial photographer was hired to fly the site and take photographs at 1":100' scale . The existing channel, structures, and significant features were traced onto drafting paper, and the cross-sections drawn by field checking their locations on the aerial photographs.

A longitudinal survey was conducted over the same 3380 m segment to determine the longitudinal slope of Spring Creek. The survey was not tied into a known elevation, thus all elevations are relative. A benchmark located above a pipe cutout at the northeast corner of the low water crossing wing was assigned a reference elevation of 100 feet. All elevations are in reference to this datum.

Bankfull level was estimated from qualitative observations of bankfull indicators (e.g., tops of point bars, changes in vegetation/slope) at most stations. Elevations were recorded for all indicators observed at each station. Bankfull level for the project area proper was determined from the cross-sectional data.

Additional measurements were taken to allow Rosgen classification of Spring Creek and determination of stable channel morphometry. Parameters measured include channel width, depth, slope, and sinuosity. General channel design emulated the stable stream type determined from a Rosgen classification of the reference reach. Final channel dimensions were determined based on design discharge, requisite velocity to maintain shape (back-calculated from basal transient particle size) (Rosgen, 1993; Shields, 1936), and channel meander length and radius of curvature determined from a stable reference reach.

2.3.3b Bankfull Discharge Determination

There was no U.S.G.S. gauging station located on Spring Creek to afford direct determination of bankfull discharge. Therefore, it was necessary to develop a "regional curve" from U.S.G.S. gauges located on other streams in the area. Regional curves relate hydraulic geometric parameters such as bankfull discharge, bankfull area, bankfull depth, and bankfull width to the drainage area for a given hydro-geographic province. Rosgen (1993), Leopold (1994), Dunne (1978), Mueller, et al. (1998) and others have contributed to a significant body of knowledge in this area.

Development of a regional curve employable for Spring Creek was initiated by conducting geomorphic surveys at U.S.G.S. gauging stations in the region. Surveys were conducted at the following gauges: Illinois River, Tahlequah; Flint Creek, near KA; Baron Fork, Eldon; Spavinaw Creek, near Sycamore; Elk River, near Tiff City, MO; Spring River, Quapaw; Spring River, near Waco, MO; Neosho River, near Commerce; Neosho River, Iola, KA; and Neosho River, near Parsons, KA. At each site, cross-sections were established and surveyed, longitudinal profiles were elaborated, and dominant bed material was determined to perform a Rosgen's classification. Elevations of bankfull level and existing water surface level were noted at each cross-section. Stream stage was obtained via Internet for concurrent dates/times of relevant surveys. Bankfull stage was derived by subtracting the current water level from the bankfull level and summing with the relevant stage data.

Rating curves of stage versus discharge were obtained from the U.S.G.S. for each gauge surveyed. The bankfull discharge was determined for each gauge using the bankfull stage previously determined and the appropriate rating curve. The literature indicates that bankfull discharge typically has a return period of one to two years using an annual peak flow analysis. To check this, peak flow summaries were obtained, sorted, ranked and the probability of exceedence was calculated for each annual peak flow. The return period for the calculated bankfull discharge was determined and compared against the one to two year return frequencies as indicated from gauge data.

Two additional curves were used to determine bankfull discharge for the Timber Lake region of Spring Creek. During plan development, the OCC was in the process of developing a regional curve relating bankfull discharge to drainage area for the entire state. The curve used for the project was comprised of data from twenty-two sites. Additionally, a curve relating bankfull discharge to cross-sectional area was also being developed. This concept was adopted, and a curve was elaborated for the Grand Lake Basin and northeast Oklahoma data used in development of the first curve. Spring Creek (Timber Lake) drainage area used in the curves was determined from U.S.G.S topographical maps as per standard procedures.

2.3.3c Project design

To enhance value as a demonstration project, three stream bank stabilization methods were employed. At Site 1 (*0+00* to *18+00*), a longitudinal toe-slope technique was used to stabilize the outer channel margin, reducing bank shear stress and controlling channel grade. A continual rock revetment was constructed and then backfilled at a prescribed slope with cut material from the downstream site. Live willow (*Salix* sp.) bundles were interspersed at regular intervals throughout the rock wall for additional stabilization. No channel modification was made in this area.

At Sites 2a and 2b (*24+00 - 42+00* and *54+00 - 66+00*), channel plan, pattern, and profile were modified and rock structures added. Cross vanes (rock sills) were installed across the upstream ends of associated overflow channels at Site 2a to prevent down cutting and subsequent capture of the channel flow. Rock installations through Site 2b consisted of rock vanes exclusively. Approximately 727 metric tons (800 tons) of 0.61 x 0.91 x 1.22 m (2 x 3 x 4 ft) limestone boulders were used to create the rock formations. Channel pattern and profile were modified for both according to stable stream type dimensions determined from comparison and Rosgen classification of the reference reach.

Cut-fill calculations for Site 2 were made utilizing the cross-sections developed in the field surveys. It was determined that an estimated 11,300 yd^3 of material would be cut and an estimated 5,400 yd^3 of material would be filled. Excess material was used on site as roadbed base material (approximately 2 miles), and the remainder was temporarily stockpiled and made available to the Cherokee County Commissioner at no cost. Some of the material was used for fill at Site 1.

Following construction, applicable tree and grass species (Table 1) were planted to supplement stabilization. Tree planting efforts were collaborative and under guidance of the Oklahoma Forest Service. Tree saplings were dipped in Terre-Sorb® (water adsorbant) and planted according to habitat requirements. The planting regime comprised two rows each black locust *(Robinia pseudocacia*), sycamore *(Platanus occidentalis*), and green ash (*Fraxinus pennsylvanica*) planted near the creek and extending outward by species. Willow (*Salix* sp.) live stakes were attained and driven into the ground near the creek along the project sites as per NRCS recommendations (NRCS, 1994). The remaining species were planted wherever soil predominated. Cold and warm season grass species were mixed and broadcast at a rate of 10 lbs/ac throughout the project site.

"Passive restoration" was used to preserve/increase bank stability throughout and downstream of the project site. This simplistic technique involved fencing of the riparian area to exclude cattle and allow revegetation. Approximately eight thousand feet of fence was used to complete the task.

2.4 MONITORING

Evaluation of project impact was determined mostly through pre- and post-implementation monitoring. For Lost Creek, pre-implementation conditions precluded biological monitoring; the project reach was no more than a bare, clay "ditch" with no water. A post-implementation habitat survey was conducted to document stabilization via established plant species and record habitat increase through establishment of instream ponds and the micro-wetland. Spring Creek monitoring efforts included pre- and post-implementation habitat and biological (fish) monitoring. No pre- or post-implementation monitoring was conducted at the Chilocco Creek site due to the brevity of the project.

Table 1. Quantity and application of tree and grass species planted at Spring Creek project sites.

VEGETATION TYPE/SPECIES	QUANTITY	HABITAT/APPLICATION
TREE		
Black locust (Robinia pseudocacia)	200	Proximal to bank
Sycamore (Platanus occidentalis)	400	Proximal to bank
Green Ash (Fraxinus pennsylvanica)	200	Proximal to bank
Willow (Salix sp.)	200	Proximal to bank
Red Mulberry (Morus rubra)	100	Predominant soil occurrence
Shumard Oak (Quercus shumardii)	100	Predominant soil occurrence
Pecan (Carya illinoensis)	100	Predominant soil occurrence
Black walnut (Juglans nigra)	100	Predominant soil occurrence
GRASS		
K31 Fescue (Festuca sp.)	? % at10 lbs/ac	Throughout project area; cool season
Western wheatgrass (Pascopyrum smithii sp.)	? % at10 lbs/ac	Throughout project area; cool season
Blackwell switchgrass (Panicum sp.)	? % at10 lbs/ac	Throughout project area; warm season
Eastern gamagrass (Tripsacum dactyloides)	? % at10 lbs/ac	Throughout project area; warm season
Yellow bluestem (Bothriochloa ischaemum)	? % at10 lbs/ac	Throughout project area; warm season

Habitat assessments followed modified Environmental Protection Agency (EPA) Rapid Biosassessment Protocols (RBP) (EPA, 1989). Measurements, or scoring for each parameter, occurred every 20 m through project sites. Specific information on exact habitat assessment protocol can be found in OCC Standard Operating Procedures (OCC, 1996).

Fish sampling followed EPA RBP (EPA, 1989) as modified by OCC (OCC, 1996). Fish collections comprised both seining and electroshocking methods and occurred only through project reaches. A Coffelt CPS backpack shocker powered by a 300-ma, 120 volt generator was used for shock collection. Seine samples employed seines of varying size and depth dependent upon the site. All fish not field identified were preserved and sent to a professional taxonomist.

3.0 RESULTS AND DISCUSSION

3.1 LOST CREEK

Data from the preliminary survey was used to determine the existing channel stream type according to the Rosgen system. Analysis of the two cross sections revealed differing stream types between the upper and lower reaches. Upstream (Figure 14), the channel existed as a type B6c. This graded into the downstream reach (Figure 15), which was determined to be a type F6. The sinuosity (Figure 16) reveals the channelization of the streambed through the project area.

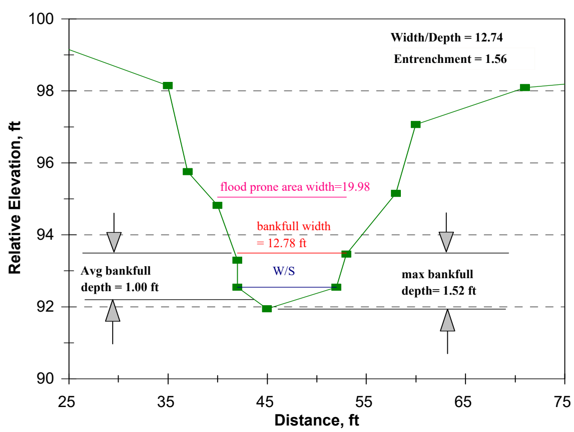

Figure 14. Upstream cross-section.

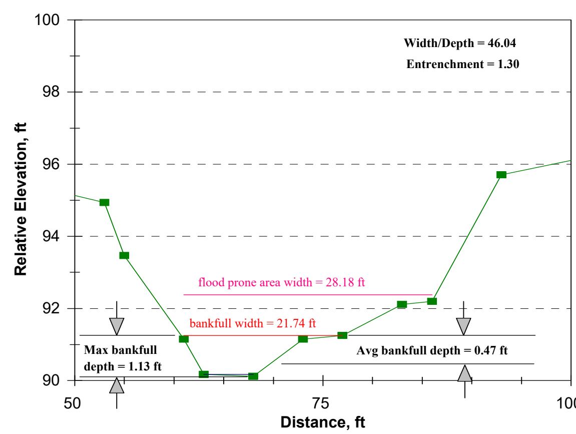

Figure 45. Downstream reach.

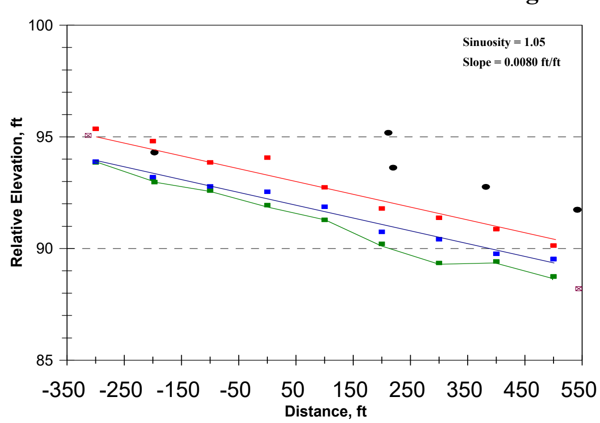

Figure 16. Longitudinal profile and selected metrics of the Lost Creek site.

The design channel (Appendix A1) was planned to approximate the stable stream types of the reference reaches downstream of the project. The resulting design channel begins as a B6c, transitions into a C6, then into an E6, before it steps down to the existing channel in a step pool B2. Both riffles and pools were included in the final design to dissipate energy and provide a natural trend through the project site. The streambed was raised above the nine inch sanitary sewer line allowing it to cross under the channel as previously designed. The final design ties into the old floodplain in the lower reach of the project site. This area constitutes the new wetland "outdoor classroom" and includes a newly constructed pond. The upper reach of the project was joined to the lower reach by a step-pool channel constructed to resemble a series of natural sandstone rock ledges. The ensuing stabilization significantly transformed project reaches (Figures 17 and 18).

Figure 17. Lost Creek pre (top), four months post (mid), and 3.5 years post (bottom) implementation (facing upstream)

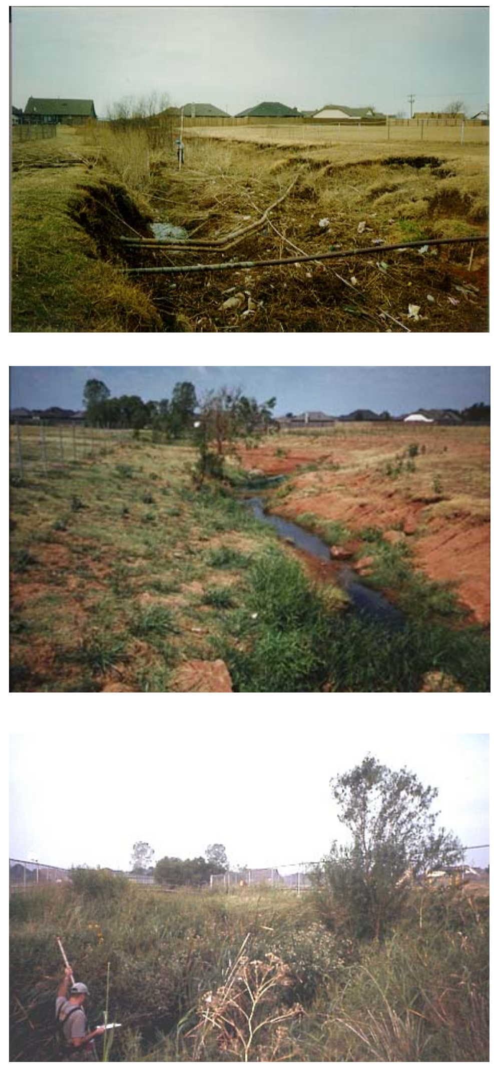

Figure 18. Lost Creek pre (top), four months post (mid), and 3.5 years post (bottom) implementation (facing downstream).

Less than a month after completing construction, the watershed experienced a severe thunderstorm producing significant rainfall. The flow in the channel exceeded the bankfull discharge and flowed out onto the newly constructed floodplain. This compromised the project to some extent. First, major washing of material in and around the bedrock ledges of the downstream step-pool system threatened to undercut the structures. Second, water forces on the new, unvegetated slopes of the downstream floodplain-culvert convergence resulted in significant erosion and deposition of sediment into the culvert.

Due to the nature of the problems, repair efforts were undertaken. To fix the ledges, boulders at each step were first lowered and repositioned to minimize gaps. Gravel was placed around and upstream of the boulders to seal the gaps, minimizing wash-through. The floodplain slope was re-contoured and prepared for sod planting.

Unfortunately, another major storm hit the watershed (4 inches in two hours) before resodding could occur. Once again, the floodplain slope was damaged, and one of the step-pools was slightly impacted. Encouragingly however, the other step-pool functioned properly and was not undercut or bypassed laterally. A second repair effort was therefore made to repair the effected step-pool and the floodplain slope. The step-pool repair again concentrated on repositioning the boulders and sealing them with the gravel. The floodplain slope was re-contoured and immediately planted using approximately 8,000 square feet of sod. The now stabilized step-pools have proven to be effective and attractive (Figure 19).

Although project efforts met with challenge the first year, the implementation area has stabilized readily. Vegetative establishment and succession throughout the area are particularly noteworthy. In general, the site has transformed (photos above) from no more than a bare, clay ditch to a natural, riparian reach with micro-wetland community (Figure 20). A qualitative vegetation assessment on 17 SEP 01 yielded a total observation of 25 plant species (Table 2). Instream cover was dominated by emergent aquatic vegetation (Figure 21) occurring at 45 percent among stations. Canopy coverage was 65 percent among stations indicating good, bank growth and thus stabilization. Percent-eroded bank averaged 14 – 15 percent throughout the project area, a marked decrease from the high, pre-implementation percentage apparent in the photos above.

Figure 19. Step-pool structure, Lost Creek, 17 SEP 01.

Figure 20. Downstream reach flowing into micro-wetland, Lost Creek, 17 SEP 01.

Figure 21. Streambed dominated by emergent aquatic vegetation, Lost Creek, 17 SEP 01.

Table 2. Total plant species observed, Lost Creek implementation project, 17 SEP 01.

COMMON NAME	SPECIES	RELATIVE FREQUENCY A=60-100; VC=30-60; C=5-30; O=1-5; R=<1%
FORBS/GRASSES/WEEDS		
Purple gerardia	Agulinis fasciculata	Occasional
Ragweed 1	Ambrosia spp.	Abundant
Giant ragweed	Ambrosia trifida	Abundant
Bermuda grass	Cynodon	Abundant
Bundleflower	Desmanthus illinoensis	Occasional
Barnyard grass	Echinocloa crusgalli	Common
Sugarcane plumegrass	Saccharum ravennae	Rare
Snow-on-the-mountain	Euphorbia marginata	Common
Annual broomweed	Gutierrezia dracunculoides	Abundant
Wax goldenweed	Haplopappus ciliatus	Abundant
Common sunflower	Helianthus annuus	Very Common
Marsh elder	Iva spp.	Very Common
Water primrose	Jussiaea peploides	Very Common
Lespedeza	Lespedeza spp.	Common
Dotted Gayfeather	Liatris punctata	Occasional
Smartweed	Polygonum spp.	Very Common
Arrowleaf	Sagittaria spp.	Rare
Bristlegrass	Setaria spp.	Very Common
Johnson grass	Sorghum halapense	Abundant
Hedge parsley	Torilis arvensis	Occasional
Cattail	Typha spp.	Abundant
Cocklebur	Xanthium strumarium	Occasional
TREES		
Sycamore	Platanus spp.	Rare
Cottonwood	Populus deltoides	Occasional
Sandbar willow	Salix interior	Occasional
Black willow	Salix niger	Common

Not long after completion and subsequent stocking of the creek and pond, an upstream sewer leak occurred causing acute loss of fish and macroinvertebrates. The absence of water pre-implementation coupled with this occurrence post-implementation precluded any immediate biological assessments. Observations made during the 17 SEP 01 site inspection noted a variety of instream and associated wetland fauna: mosquito fish (*Gambusia affinis*), sunfish (Centrarchidae), crayfish (*Cambarus*, spp.), various dragonfly and damselfly nymphs (Odanata), whirligig beetles (*Dineutus* spp.), various snails (Gastropoda), frogs (Rana spp.), redwing blackbirds (*Agelaius phoeniceus*), and a cottontail rabbit (*Sylvilagus floridanus*). Signs of organic and nutrient enrichment (e.g., blackened water, H_2S production, foam) were still apparent through the first 100 meters. However, downstream water quality appeared to improve markedly (i.e., clear water, no smell, no foam), possibly attributable to the dense instream and marginal macrophyte growth present throughout the project reach.

Results of the HEC-RAS flood flow analysis indicate a potential improvement in storm flow capacity. Given a flood flow value of 800 ft^3/s, model output (Appendix B) indicates a slight lowering of the upstream stage. Though not a marked difference, any improvement means decreased potential of bank degradation during bankfull events and supports the design from a liability perspective

Although bank stabilization was the primary objective, the project also was intended to demonstrate the economy of fluvial geomorphology and create an educational potential for students. The final cost of the project (including repairs) was approximately $76,000, higher than the original estimate of $60,000. Nevertheless, the final cost was still significantly less than the estimated $300,000 to construct a concrete ditch or culvert. Of particular value is the educational potential that has and will be realized for years to come. Teachers at the Santa Fe Elementary School are planning yearly educational projects focusing around Lost Creek. Instructional opportunities exist for water quality, aquatic biology, plant biology, ornithology, wetlands and riparian areas.

3.2 CHILOCCO CREEK

Pre-implementation survey of Chilocco Creek revealed the project area to approximate an F4/F5 according the Rosgen system. Three cross-sections were surveyed and the minor channel alteration designed (Figures 22 – 24). Final work was performed over a 46 meter stretch of the creek and entailed channel adjustment, resloping (2:1) of the outer bank, and installation of four rootwads to aid bank stabilization and adjust shear forces (Appendix A2). Construction was initiated and completed on 4 APR 97. Following construction, sod, grass sprigs, and willow (*Salix* spp.) poles were planted to stabilize the area.

Project construction was completed in one day (4 APR 97) for less than $3,000, with the majority of funding originating from a Section 319 demonstration grant. The general work-plan was cooperative, involving landowners, Kay County Conservation District, local NRCS,

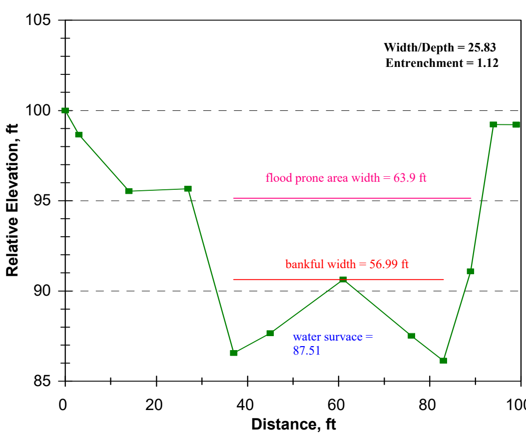

Figure 22. Upstream cross-section and selected metrics, Chilocco Creek project site.

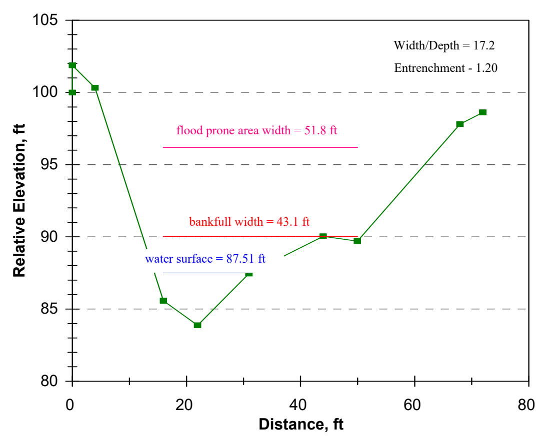

Figure 23. Downstream cross-section and selected metrics, Chilocco Creek project site.

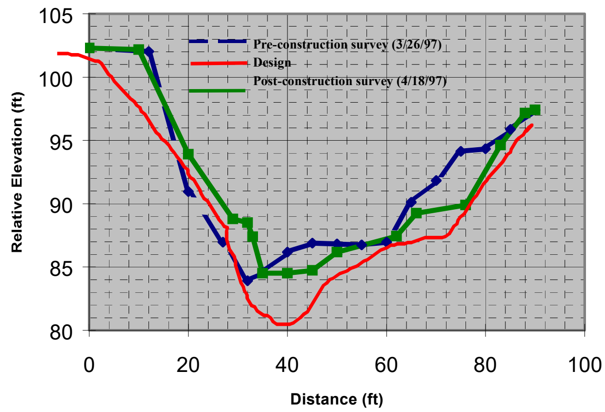

Figure 24. Pre, post, and design x-sections, Chilocco Ck.

and the Oklahoma Conservation Commission. Thus, productive opportunities for corporate education and involvement were realized.

In general, the project has met with limited success. The implementation site exhibited good stabilization and improved in-stream cover, initially (Figure 25). However, a major flood event occurred within a year of completion that washed the toe of the outside bank considerably. To date, some of the project area has sloughed, compromising bank integrity (Figure 26). Also, a sizeable log-jam immediately upstream of the site appears to have altered channel flow and contributed to significant point-bar deposition and aggradation at the upper end of the project.

Although the site has changed, the outer bank still exhibits some stability compared to pre-implementation conditions. (p. 8, Figure 9). A confounding factor in the partial failure of this project appears to be the log-jam (Figure 27) and related point-bar deposition. The resulting formation (Figure 26) is deflecting water flow to the outer bank exacerbating the erosion. Without the log-jam, the project segment may have been able to transport the bed-load and maintain the designed channel dimensions necessary to alleviate shear stress of the outer bank.

Figure 25. Chilocco Creek project site 5 months post-construction (facing downstream).

Figure 26. Chilocco Creek project site 4.5 years post-construction (facing downstream).

Figure 27. Log-jam immediately upsream of project area, Chilocco Creek.

3.3 SPRING CREEK

Pre-implementation evaluation of Spring Creek revealed stable reaches existing as type C4 according to the Rosgen system (Rosgen, 1996). However, from the aerial survey, many reaches (including some in the project area) appear to be predominately type D4, exhibiting a braiding morphology. Type "D" channels are not stable and are indicators of a system in disequilibrium. They often evolve from "C" channels in valleys subject to increased sediment loading and destruction of the riparian area, both of which have been realized in Spring Creek for several years. The combination of increased sediment load and unstable banks results in widening of the channel and an inability to pass the sediment delivered to it. As a result, the channel begins to aggrade and eventually forms multiple channels instead of one. Therefore, the design objective was to restore the relevant project reaches to the naturally stable "C4" stream type.

Before initiating the design phase, it was necessary to develop an applicable regional curve to allow bankfull discharge determination. This was accomplished by conducting geomorphic surveys at regional U.S.G.S. gauging stations (see section 2.3.3b) to determine their bankfull discharge. A regression of the bankfull discharge for respective drainage area (plot in Figure 28) was then conducted to assess relationship. The resulting regression line for the NE Oklahoma and Grand Lake data is given by the equation:

$$Q = 274.12 * DA^{0.447} \qquad \text{(Eq. 2)}$$

Where, Q is the bankfull discharge in cubic feet per second and DA is the drainage area in square miles. The coefficient of determination (r^2) for this data was found to be 0.70.

During the planning of this project, OCC was in the process of developing a regional curve for the entire state of Oklahoma. For comparison, the plot of bankfull discharge versus drainage area for 22 sites around the state was conducted (Figure 29). The regression line for the statewide data is given by the equation:

$$Q = 193.83 * DA^{0.449} \qquad \text{(Eq. 3)}$$

Where, Q and DA are the same as above ($r^2 = 0.74$).

To provide further potential, the OCC also explored the relationship between the bankfull discharge and bankfull cross-sectional area for the Grand Lake and NE Oklahoma data (plot in Figure 30). The regression line for the data is given by the equation:

$$Q = 9.78 * A^{0.91} \qquad \text{(Eq. 4)}$$

Where Q is bankfull discharge and A is bankfull cross-sectional area in square feet ($r^2 = 0.91$).

To design proper channel dimensions, it is essential to determine the appropriate design discharge. Therefore, bankfull discharge was calculated using all curves to provide for comparison and assess variability. A drainage area of 93 square miles was determined from U.S.G.S. maps and input into the relevant equations. Using the Grand Lake Basin/NE OK drainage area curve (Eq. 2) results in a bankfull discharge of 2,079 cfs. It must be noted, however, that the data used to derive the curve do not extend below 100 cfs, a frequent

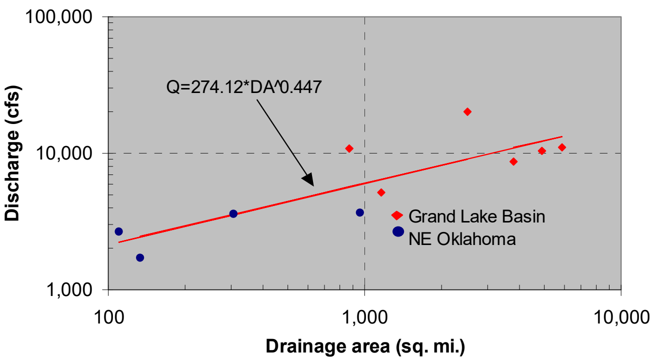

Figure 28. Regional curve showing plot of bankfull discharge vs. drainage area for the Grand Lake Basin and Northeast Oklahoma.

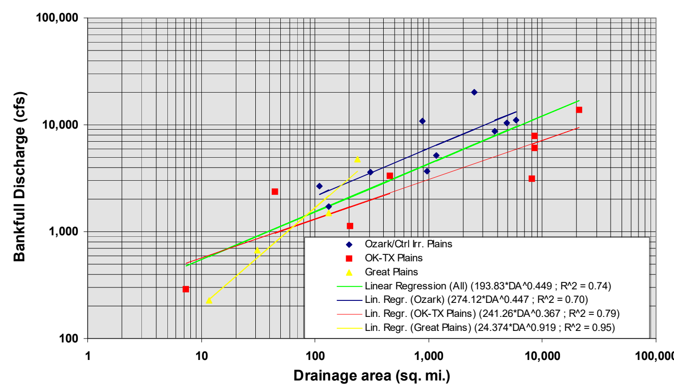

Figure 29. Regional curve showing plot of bankfull discharge vs.drainage area for 22 sites throughout OK.

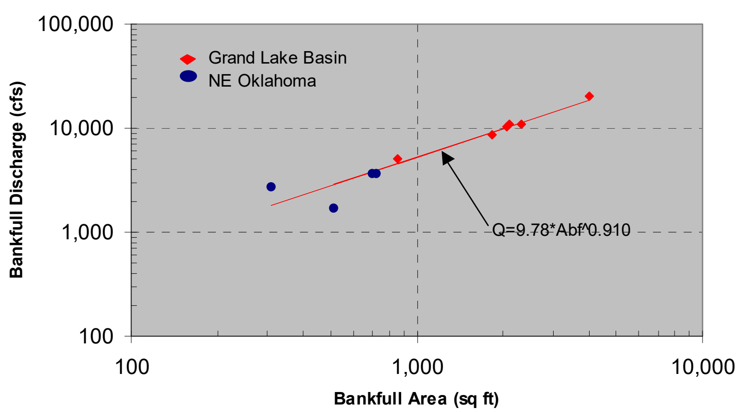

Figure 30. Regional curve of bankfull discharge vs. bankfull area for Grand Lake Basin and NE Oklahoma data.

occurrence with Spring Creek. Bankfull discharge as determined from the statewide curve (Eq. 3) is 1,483 cfs. Using the curve of bankfull discharge vs. bankfull area above (Eq.4) and a cross-sectional area of 324 square feet (determined from survey), bankfull discharge was determined to be 1,886 cfs. Because a slight over-design of the channel capacity is more preferable than underdesign, a final bankfull discharge of 2,000 cfs was assumed in the design process.

With the design discharge determined, it was then necessary to design a channel that would move the water and sediment load, while maintaining a width/depth ratio of greater than 12 (typical of "C" channels). Determining the required water velocity needed to maintain the channel shape requires knowledge of the particle size that the channel needs to move. The Shields criteria (Shields, 1936) may then be used to calculate the velocity or critical shear stress necessary to move this sized particle. Rosgen (1993) has shown that the necessary particle size the channel must move can be found by looking at the downstream third of point bars, mid-way between the thalweg and the bankfull level, and searching for the dominant large particle. In Spring Creek, this particle size was determined to be approximately 40 mm. The width and depth required to move this particle at the design discharge were calculated to be 95 feet and 3.96 feet, respectively. Thus, the design channel was narrower and deeper than the existing channel (114 feet and 2.62 feet, respectively).

As a comparison, "regime equations" (Thorne, et al., 1997) were also used to develop the stream channel dimensions. The regime equations were developed empirically for gravel bed channels with a flow range from 3.9 – 424 cubic meters per second and a D_{50} of 14 – 176 mm. Spring Creek falls within these ranges, thus the results from the regime equations should be consistent with the values reported above. Using the regime equations, bankfull width was determined to be between 25 and 32 meters (82 and 107 feet) depending on the vegetation along the stream. This brackets perfectly the width determined above. The reach averaged channel depth was determined to be 1.51 m (4.97 ft), which is deeper than that calculated from Rosgen's method. However, the bankfull depth represents the mean depth in the riffles and disregards the deeper pools, which would deepen the estimate. Therefore, the two methods appear to be supportive in their results.

The Spring Creek implementation project completed construction in September of 2000. Two major bends in the stream were addressed using rock veins, cross veins, and longitudinal slope techniques (Appendix A3). Specifically, Site 1 efforts entailed rock installations and longitudinal sloping with no channel adjustments. Major channel readjustments were undertaken at Site 2 according to the aforementioned design. Rock veins, cross veins, and root wads were used also in the Site 2 remediation (Figure 31).

Similar to the Lost Creek project, Spring Creek experienced a major flood event before significant revegetation could occur to stabilize loose soils. The flow of this event greatly exceeded bankfull discharge and severely washed certain rock and rootwad installations, depositing material in the redesigned channel. Fill material in the resloped area of Site 1 was especially compromised, causing some sloughing of the bank. Damage to the project area is still apparent (Figure 32). Although remedial efforts were not undertaken, the project still exhibits better bank stability and overall improvement in habitat and recreational quality.

Figure 31. Construction completed, Spring Creek Sites 1 (left, looking upstream) and 2 (middle, looking upstream, and right, looking downstream), SEP 00.

Figure 35. Spring Creek Sites 1 and 2, JUL 2001 (pictures correspond to figure above).

The project site was stabilized with trees and grasses (Section 2.4, Table 1) in accordance with a revegetation plan in early March, 2000. This was a collaborative effort involving OCC staff, students from the Markoma Christian School science class and other volunteers. Vegetative establishment has been moderate to good along project reaches. In a recent site visit, numerous volunteer sycamores (*Platanus* spp.) and other marginal vegetation were noted along the margin of the project area indicating adequate streamside stabilization. Some of this growth is certainly attributable to the fencing of the riparian area, which constitutes a passive but effective stabilization method (Figure 33).

To assess specific project impacts on stream health, pre and post-implementation habitat and biological sampling were conducted. In general, project sites exhibited significant and positive changes from pre-implementation surveys. Physically (Table 3), water depth through the reaches doubled, total area of eroding bank decreased by approximately 75 percent, and total habitat scores improved for both sites. A recent visit (8 AUG 01) to the project site showed the stream channel modifications still holding effectively. Rock vanes had successfully diverted flow to the center of the channel, deepening pools and controlling erosion on the outside of the steam bends. Increase in pool habitat was evidenced by establishment of several coontail (*Ceratophyllum* demersum) beds at Site 2.

Figure 63. Riparian area (through fence) 10 months post-fencing.

Table 3. Pre and post implementation habitat survey results, Spring Creek, Sites 1 and 2.

	SITE 1 PRE-IMP.	SITE 1 POST-IMP.	SITE 2 PRE-IMP.	SITE 2 POST-IMP.
Depth, Left qt. (m)	0.14	0.32	0.22	0.51
Depth, Cntr. (m)	0.27	0.50	0.46	0.85
Depth, Right qt. (m)	0.21	0.71	0.32	0.56
Avg. depth (m)	0.21	0.51	0.33	0.64
Width, Water (m)	7.88	12.47	10.11	11.72
Width, Bank (m)	43.94	28.24	43.28	29.72
% Eroded Bnk., Lft.	8.82	0.00	8.33	0.00
% Eroded Bnk., Rt.	90.29	40.00	65.28	23.89
Total Area Eroded Bank (m^2)	723	198	739	166
Habitat Score	95.1	102.8	96.9	103.8

Some of the greater impacts of the project were exhibited in the fish community (Table 4). Both project sites exhibited more species and markedly higher total numbers (3.5 and 1.5 times for Sites 1 and 2, respectively) of fish in the post-implementation surveys. Total number of pool species (sunfish, chub, sucker) increased by at least 2.4 times their previous abundance in both project reaches, reflecting the deepening and enlargement of pools and overall channel morphology. The size composition of this group indicated multiple year classes, and young of year were found for all three. Thus, it would seem the slower flow regimes and increased habitat resulting from stabilization efforts combined to affect overall reproduction of fish in this area of Spring Creek.

Certain beneficial uses also were restored or preserved in this area of Spring Creek. Bank instability and subsequent gravel input had shallowed many areas, limiting fishing and swimming activities previously enjoyed. Site 2 has stabilized into a long pool sufficiently deep for swimming and fishing. Good number and size of catchable sportfish (e.g., smallmouth bass) were noted in and around the rock vanes at the site during the 8 AUG 01 visit.

Table 4. Pre and post implementation fish survey results, Spring Creek, Sites 1 and 2.

	SITE 1 PRE-IMP.	SITE 1 POST-IMP.	SITE 2 PRE-IMP.	SITE 2 POST-IMP.
Total number	260.0	869.0	407.0	592.0
Total spp	10.0	14.0	15.0	17.0
Total darter and madtom spp	4.0	4.0	4.0	4.0
Total No. Centrarchidae	2.0	33.0	11.0	42.0
Total spp Centrarchidae	1.0	2.0	3.0	4.0
Total No. Suckers	0.0	3.0	4.0	20.0
Total spp Suckers	0.0	2.0	1.0	2.0
Total No. pool spp	24	62	35	84
Total % intolerant spp	76.1	82.6	77.6	88.5
Total % tolerant spp	0.0	0.0	0.7	0.7
Total % omnivores	0.0	0.0	0.0	0.0
Total % insectivores	79.6	74.6	80.6	84.8
Total % top carnivores	0.8	0.6	1.7	1.2

3.4 EDUCATION

A primary goal of this project was to demonstrate the efficacy of the Rosgen method in streambank stabilization and promote its use as an alternative to traditional techniques. To this end, the OCC in cooperation with the Cherokee County Conservation District and Oklahoma Scenic Rivers Commission sponsored an "Applied Fluvial Geomorphology" seminar and shortcourse with Dave Rosgen. The four day course and one day seminar constituted an introduction to fundamentals of river behavior, fluvial geomorphology, sedimentation, hydraulics, and stream bank erosion. Course attendance comprised officials from the NRCS, OCC, and Oklahoma Scenic Rivers Commission.

To create a more lasting and pervading educational potential, the OCC, in cooperation with the U.S. Environmental Protection Agency, Region 6, published an informational brochure (Appendix 3). The brochure titled, "Fluvial Geomorphology: A New Approach to Stream Bank Stabilization and Riparian Restoration," introduces readers to the fundamental concepts applied in the projects above. Additional content addresses riparian area fundamentals and cites two projects exemplifying the use of fluvial geomorphology.

4.0 SUMMARY

Application of fluvial geomorphology and Rosgen's techniques on three Oklahoma streams has met with varied success. Results of the Lost Creek project have been excellent. Despite two flood events immediately following construction, the project reach has stabilized readily as indicated by strong vegetative establishment on the banks, margin, and instream. Various wetland and associated plant species not present pre-implementation are now common throughout project reaches. Numerous stream and wetland fauna were also observed in a recent visit. The constructed pond and associated micro-wetland have successfully established and will serve an educational potential as an "outdoor classroom" for years to come.

Remedial efforts at Chilocco Creek have met with less success. Channel aggradation and point-bar deposition post-construction is again forcing water against the outer bank. The result has been toe-slope loss and subsequent sloughing of the outer bank. Similar to the other projects, Chilocco Creek experienced a high flow within a year of project completion, which damaged banks before vegetative establishment. A resulting log jam immediately upstream of the project site appears to have altered flow contributing to the point-bar growth and channel adjustment that threaten the project. Poor establishment of tree and grass plantings also continue to compromise bank stability.

The most extensive project occurred near the Timber Lake region of Spring Creek. Following an intensive pre-implementation survey, evaluation, and Rosgen classification, two sites were chosen to implement fluvial geomorphologic techniques to restore streambank stability and improve habitat. At Site 1, only a longitudinal toe-slope with rock revetment was necessary to stabilize the outer bank. However, at Site 2, a complete redesign of the channel and addition of rock vanes, cross vanes, and root-wads were necessary to restore the area to reference conditions. To accomplish the design, it was necessary to develop a regional curve to afford calculation of the design discharge. This process was intensive and involved geomorphic surveys and Rosgen classification of 10 regional U.S.G.S. gauging sites to produce two regional curves (bankfull discharge vs. drainage area and bankfull area). For comparison, an additional curve (bankfull discharge vs. drainage area) was developed using data from 22 sites throughout Oklahoma. Upon determination of the design discharge, a final channel plan was developed.

Although the project area experienced a damaging flood-flow five months post-construction, numerous beneficial impacts have been realized. In general, habitat quality improved and banks stabilized with total area of eroding bank exhibiting a 75 percent decrease from pre-implementation conditions. Streambank and riparian vegetation have increased satisfactorily in response to bank stabilization and cattle exclusion. The fish community at the sites exhibited higher total species, numbers, pool species, and percent intolerant species. Size structure of pool species was better also with presence of young of year indicating reproductive success in response to improved habitat. With the stabilization of Site 2 as a long pool, certain beneficial uses such as fishing and swimming have been enhanced.

In overview, these projects have demonstrated that application of fluvial geomorphology and Rosgen's techniques has potential in streambank stabilization in Oklahoma. Although, arguably, traditional methods of have met with adequate success, they falter with regard to ignorance and/or insult of riparian health. Like any natural system, streams, when disturbed, will attempt to return to "steady state." In doing so, channel adjustments are made resulting in streambank destabilization, which persists until channel dimensions satisfy flow and bedload requirements. The methods demonstrated in the projects above are an attempt to identify these requirements and restore them naturally. Use of this method not only restores streambank stability, but also increases habitat, providing and liberating resources for positive responses in the biota.

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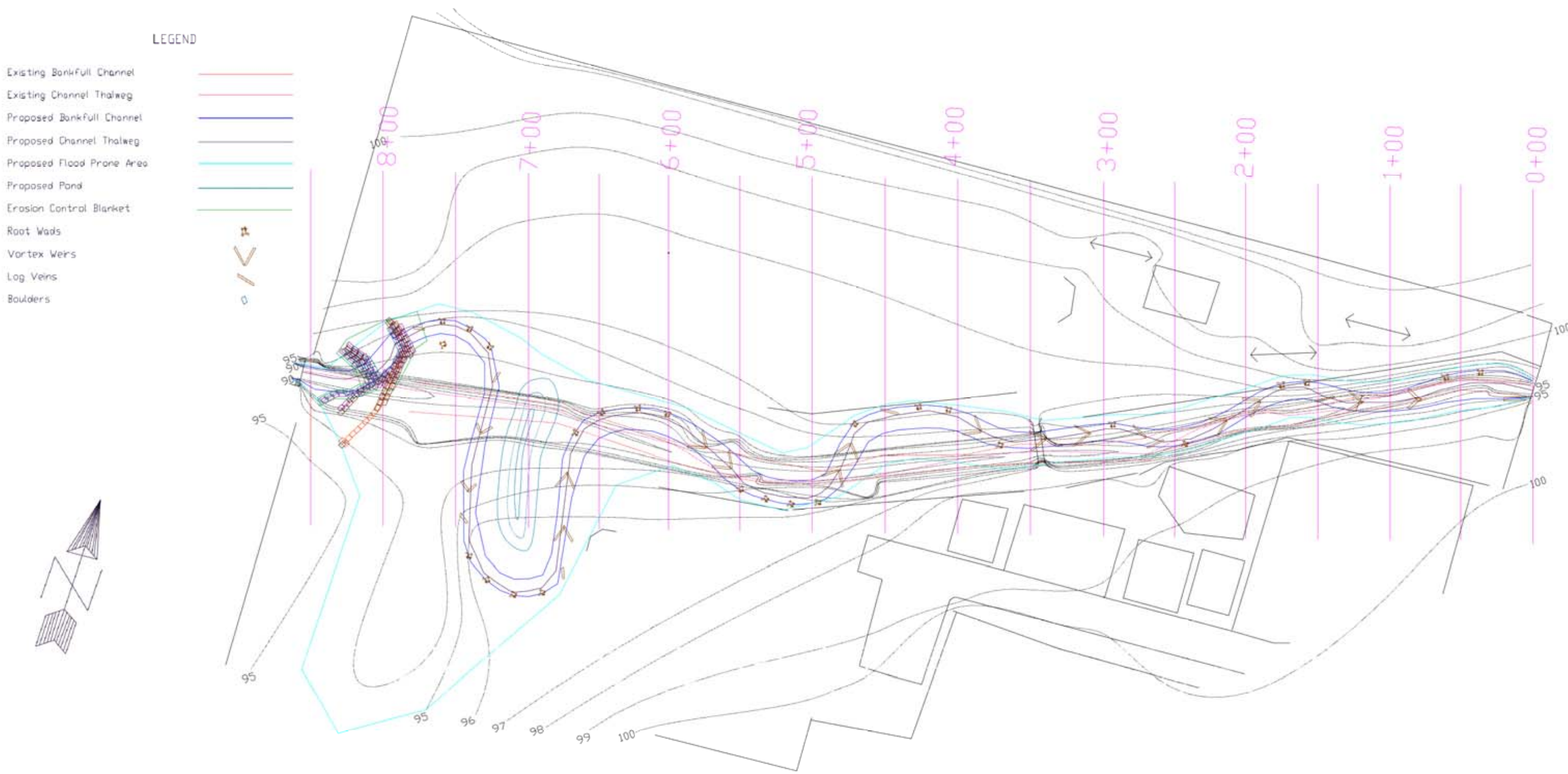
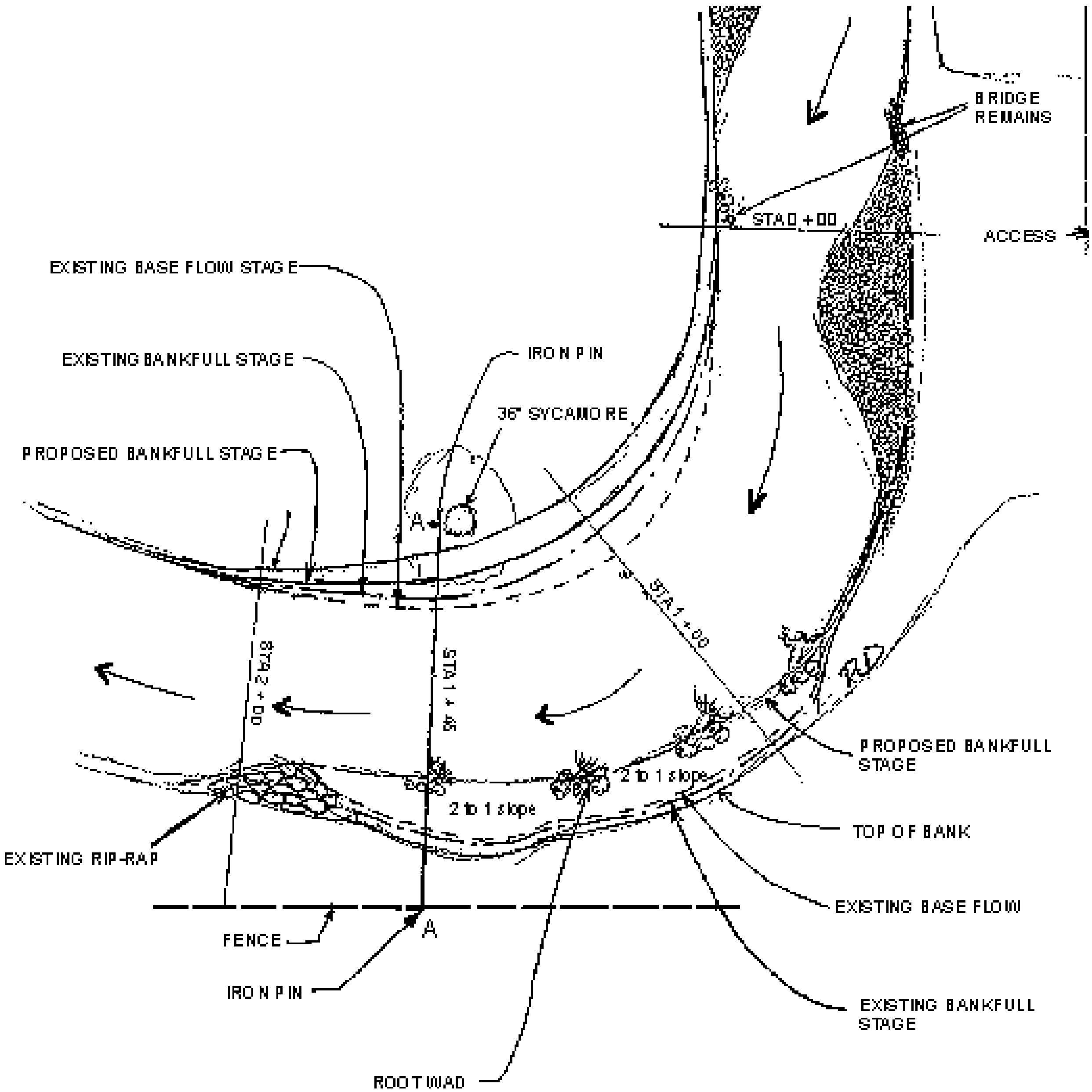
APPENDIX A

Design Drawings for Implementation Projects

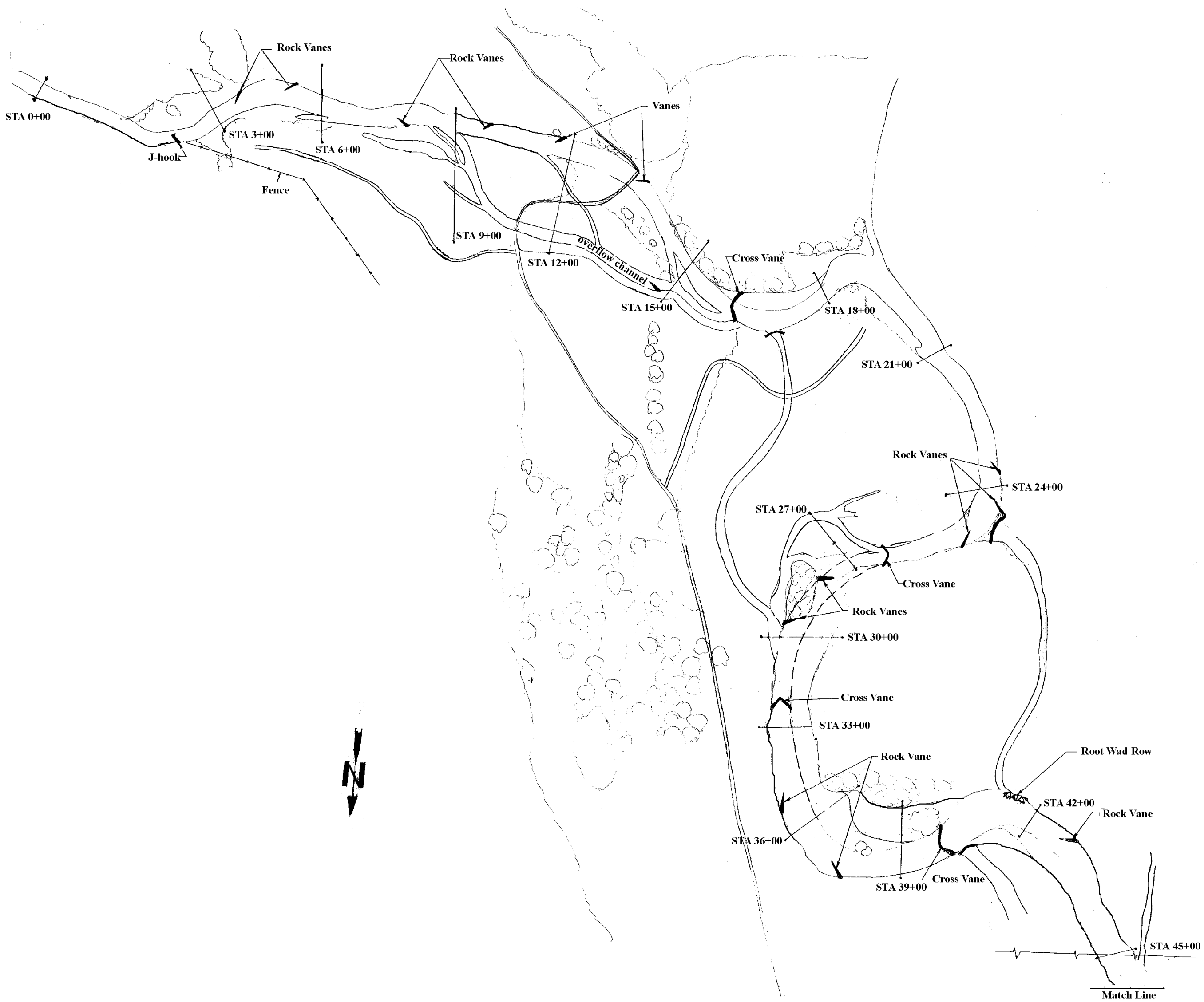
Appendix A-1. Lost Creek Implementation Project Plan.



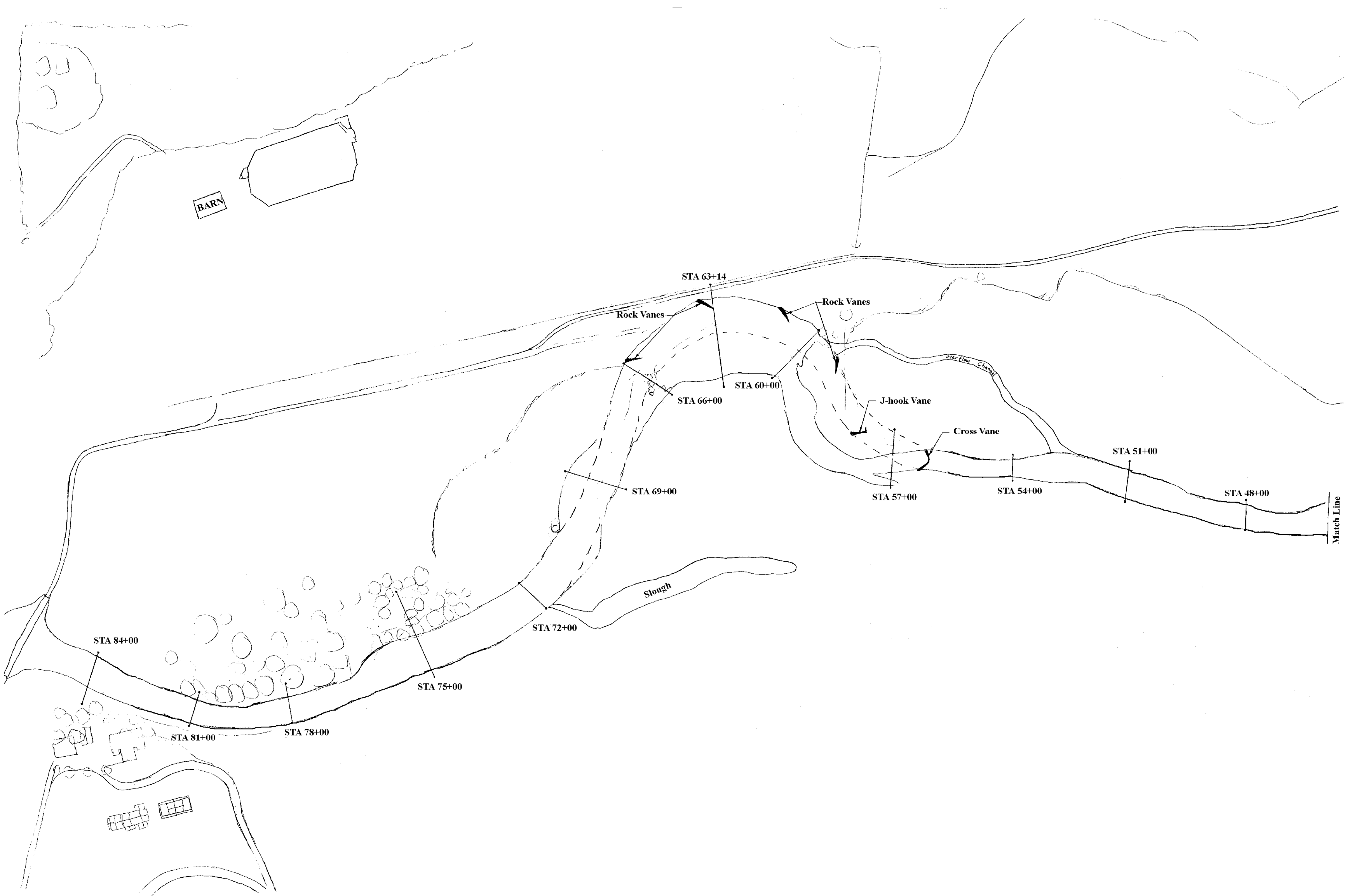
Appendix A-2. Chilocco Creek Implementation Project Plan.



Appendix A-3. Spring Creek Implementation Project Plan, Sheet 1.



Appendix A-3. Spring Creek Implementation Project Plan, Sheet 2.



APPENDIX B

Hec-Ras Flood Analysis Output for Lost Creek

Appendix B. Hec-Ras Flood Analysis Output for Lost Creek.

Reach	River Sta.	Plan	Q total (cfs)	Min Ch El. (ft)	W.S. Elev. (ft)	Crit W.S. (ft)	E.G. El. (ft)	E.G. slope (ft/ft)	Ch Vel. (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froud # Chl
Proj. Area	850	existing	800	93.00	99.46	99.37	100.71	0.021556	9.04	95.49	60.53	0.85
Proj. Area	850	proposed	800	93.00	98.93	98.93	100.98	0.025982	11.64	74.19	24.05	0.94
Proj. Area	800	existing	800	92.46	99.68		99.97	0.004897	4.41	193.16	98.70	0.43
Proj. Area	800	proposed	800	90.69	99.68	95.96	99.93	0.001694	4.33	256.95	98.81	0.28
Proj. Area	750	existing	800	92.20	99.29		99.68	0.006805	4.98	164.98	85.49	0.50
Proj. Area	750	proposed	800	93.14	99.28		99.77	0.005425	6.67	188.06	83.83	0.49
Proj. Area	700	existing	800	91.94	98.86		99.28	0.008994	5.25	152.42	57.07	0.57
Proj. Area	700	proposed	800	90.23	99.19		99.50	0.003198	5.39	236.92	94.59	0.35
Proj. Area	650	existing	800	91.68	98.45		98.89	0.007000	5.32	154.06	63.14	0.51
Proj. Area	650	proposed	800	92.57	98.88		99.29	0.005045	6.45	200.27	80.31	0.47
Proj. Area	600	existing	800	91.30	98.27		98.54	0.005180	4.21	191.89	82.42	0.44
Proj. Area	600	proposed	800	90.84	98.70		99.05	0.004435	5.95	227.90	108.92	0.42
Proj. Area	550	existing	800	90.90	97.81		98.18	0.010186	4.89	163.67	75.40	0.58
Proj. Area	550	proposed	800	91.15	98.34		98.77	0.005952	6.66	216.35	122.24	0.49
Proj. Area	500	existing	800	90.50	97.22		97.75	0.006840	5.83	138.58	47.79	0.51
Proj. Area	500	proposed	800	91.47	97.68		98.36	0.010223	8.18	156.78	77.89	0.63
Proj. Area	450	existing	800	90.00	96.90		97.35	0.008173	5.39	148.40	49.22	0.55
Proj. Area	450	proposed	800	91.58	97.67		97.94	0.003850	5.08	225.17	97.23	0.41
Proj. Area	400	existing	800	89.93	96.49		96.93	0.008745	5.33	150.11	53.01	0.56
Proj. Area	400	proposed	800	90.80	97.79		97.75	0.003524	5.04	248.22	117.99	0.38
Proj. Area	350	existing	800	89.60	95.71		96.35	0.014851	6.43	124.45	49.82	0.72
Proj. Area	350	proposed	800	91.21	96.93		97.38	0.007294	6.52	179.33	85.03	0.55
Proj. Area	300	existing	800	89.40	95.08		95.73	0.010454	6.44	124.29	41.08	0.63
Proj. Area	300	proposed	800	91.34	96.63		97.04	0.005768	5.91	204.81	114.65	0.50
Proj. Area	250	existing	800	89.00	95.01		95.28	0.004650	4.17	192.07	63.68	0.42
Proj. Area	250	proposed	800	91.02	95.46		96.40	0.018789	8.99	128.28	79.13	0.84
Proj. Area	200	existing	800	88.80	94.45		94.98	0.006485	5.89	144.82	55.06	0.51
Proj. Area	200	proposed	800	90.48	95.10		95.56	0.011521	6.82	174.05	95.05	0.65
Proj. Area	150	existing	800	88.50	94.27		94.67	0.004689	5.08	167.84	61.27	0.43
Proj. Area	150	proposed	800	90.28	95.06		95.10	0.001367	2.33	473.61	195.16	0.21
Proj. Area	100	existing	800	88.30	94.19		94.45	0.002721	4.15	214.64	97.63	0.34
Proj. Area	100	proposed	800	89.65	94.83		94.91	0.003384	3.55	401.20	264.16	0.32
Proj. Area	50	existing	800	87.20	94.01		94.29	0.003608	4.45	240.51	220.27	0.38
Proj. Area	50	proposed	800	87.48	94.55		94.69	0.001894	3.82	403.74	279.40	0.29
Proj. Area	0	existing	800	87.00	92.19	92.19	93.77	0.028557	10.10	79.38	26.49	1.00
Proj. Area	0	proposed	800	88.00	92.72	92.72	94.32	0.021832	10.44	85.20	30.67	0.94

APPENDIX C

Fluvial Geomorphology Education Flier

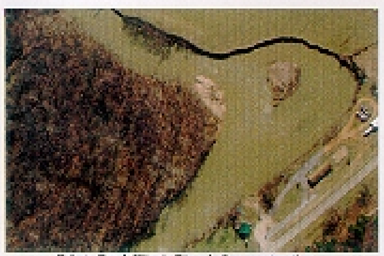
APPENDIX C. Fluvial Geomorphology Educational Flier.

Proven Success

The Oklahoma Conservation Commission (OCC) has recently implemented two demonstration projects in Oklahoma utilizing fluvial geomorphology principles for stream bank stabilization and riparian restoration.

A joint project between OCC and the Kay County Conservation District was implemented on Chilocco Creek in Kay County. The project stabilized 200 feet of stream bank and reestablished riparian vegetation at a total cost of less than $3000.

A second much larger project was implemented on Echota Bend of the Illinois River in Cherokee County, Oklahoma where the bank had eroded over 400 feet in 40 years.



Echota Bend, Illinois River before construction.

By studying the natural tendencies of the Illinois River, the OCC was able to establish a stable configuration for Echota Bend. Vegetation was used to reestablish the riparian area and stabilize the stream banks. The project took 10 days to complete at a cost of approximately $85,000, which represents a substantial savings over the estimated $250,000 cost of rip-rapping the entire bank.

Echota Bend, Illinois River 30 days after construction.

In summary, fluvial geomorphology principles can provide an effective, economic, and aesthetically pleasing alternative to traditional rip-rapping of stream banks for erosion control and stream bank stabilization.

Additional information can be obtained from "Applied River Morphology," D. Rosgen (1996.)

Contacts

For additional information on how fluvial geomorphology may be used to stabilize stream banks and restore riparian areas contact:

Oklahoma Conservation Commission
Water Quality Programs
413 NW 12th St
Oklahoma City, OK, 73103
(405) 979-2200

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FLUVIAL GEOMORPHOLOGY:

A New Approach To Stream Bank Stabilization And Riparian Restoration

Presented by:

Oklahoma Conservation Commission

In Cooperation with:

U.S. Environmental Protection Agency

APPENDIX C. Fluvial Geomorphology Educational Flier, continued.

What is a Riparian Area?

A vegetated ecosystem along a waterbody through which energy, materials, and water pass. Riparian areas characteristically have a high water table and are subject to periodic flooding and influence from the adjacent waterbody. These systems encompass wetlands, uplands, or some combination of these two land forms.

Importance of Riparian Areas

Riparian areas serve several vital functions:

⇒ Erosion Control
⇒ Water Quality
⇒ Wildlife Habitat
⇒ Aquatic Habitat
⇒ Recreation

Erosion Control

Vegetation growing along the banks of a stream holds the soil in place and reduces stream bank erosion. Removing this vegetation causes excessive erosion. Riparian areas are crucial to stream bank stability.

Water Quality

Riparian areas reduce pollutant loading to streams by providing a buffer that allows sediment to settle out rather than reaching the stream. Phosphorous and other pollutants are also filtered out by riparian areas.

Wildlife Habitat

Riparian areas provide excellent habitat for many birds and animals.

Aquatic Habitat

Healthy riparian areas are crucial for aquatic life. Stream side vegetation provides cover and a food source for many aquatic insects and fish.

Recreation

Riparian areas provide scenic shaded areas for relaxing and observing wildlife. They can provide good picnicking and fishing areas.

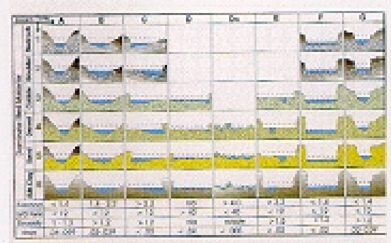
What is Fluvial Geomorphology?

Fluvial Geomorphology is the study of the form and shape of stream channels which are created naturally as a result of the water and sediment that they transport.

Stream Classification

Hydrologists and other scientists studying rivers have used many schemes to attempt to classify rivers. A system proposed by Dave Rosgen of Pagosa Springs, Colorado has gained recent acceptance due to it's widespread applicability and ease of use.

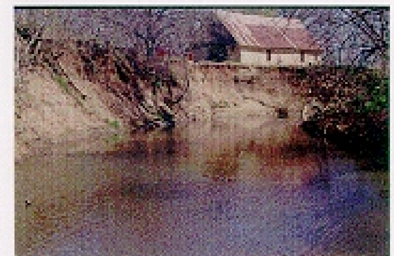
The system requires measurements of channel width, channel depth, slope, entrenchment and sinuosity. The dominant bed material of the channel must also be determined. This information can then be manipulated to determine the stream type of any stream. Some stream types are stable and some are not.



Reprinted from "Applied River Morphology," D. Rosgen (1996).

Stream Bank Stabilization

Many streams in Oklahoma are unstable and experiencing accelerated bank erosion.



Chilocco Creek before construction.

A stable stream is defined as a stream that has a stable dimension, pattern and profile such that, over time, channel features are maintained and the stream system neither aggrades nor degrades. By applying the principles of fluvial geomorphology a natural stable stream channel can be designed and constructed.

Chilocco Creek four months after construction.