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# WATERSHED SCIENCE INSTITUTE
# WATER MANAGEMENT CENTER
# NRCS STATE OFFICE - OKLAHOMA

## Case Summary Report

### Applying Geomorphic Principles to Sands and Low Plasticity Silts in the Sugar Creek Watershed Project

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**CONTENTS:**



Figure 1. Sugar Creek shown 3 miles north of Gracemont illustrates extensive channel widening and readjustment. Remnants of jacks on the left side of island mark the edge of stream at some time in the past.

## INTRODUCTION

The Sugar Creek watershed is located primarily in Caddo County, Oklahoma, approximately 50 miles southwest of Oklahoma City. Settlement began almost overnight as the result of a land allotment in 1901, and the subsequent conversion to agricultural uses set in motion a trend of increasing sediment production.

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Extensive sedimentation and frequent flooding led residents to pursue federal assistance beginning in the 1950's. In the early 1960's, the Soil Conservation Service (now the Natural Resources Conservation Service) began assisting the South Caddo County Soil and Water Conservation District, the North Caddo County Soil Conservation District, and the Sugar Creek Watershed Improvement Association with the implementation of a PL-534 watershed protection project.[4] Planned measures included 43 floodwater retarding dams and 21.3 miles of channel modifications (Sugar Creek Watershed Work Plan, 1959).

The first attempt at straightening and enlarging the natural stream channel began in 1964, but initial attempts proved unsuccessful. In 1966, work resumed using a dragline. Contract drawings show designed bottom widths of 25 to 40 feet, but "as built" records indicate design channel widths and alignments were not attained in many cases due to construction difficulties.

Initially, designers felt so much sediment was moving through the system that extreme operation and maintenance measures would be necessary to keep the constructed channel open. Actually, the response of the channel was exactly the opposite. A process of degradation began almost immediately and has continued ever since. Over the past thirty years, the channel has incised over 23 feet in some locations with depths of 15 to 20 feet very common (see Figure 2). Entrenchment of the mainstem has resulted in a similar evolution of degradation for most of the tributaries.

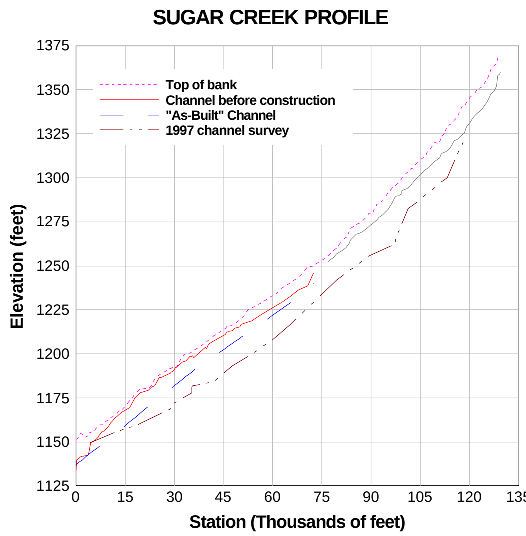


Figure 2. Degradation of Sugar Creek since 1966. Note that the original survey underestimated the actual stream length as the thalweg was not strictly followed. (The thalweg is the line of maximum depth in the stream).

Treatment of individual problem areas began shortly after construction concluded and has been continuous through the present. Most repair work has concentrated on protecting stream banks. However, this has not solved the underlying problem which has been a channel profile, pattern, and dimension inconsistent with the dynamic forces of the natural stream system. Thirty years of structural and vegetative practices to alleviate the problems have not resulted in a properly functioning watershed system.

A decision to perform a geomorphic-based analysis of the entire watershed was reached in December 1995[5]. After

[4] PL 78-534, the Flood Control Act of 1944, authorized eleven watershed projects including the Washita River. The Sugar Creek watershed is one of 64 subwatersheds within the Washita River basin.

[5] Geomorphology can be defined as the study of the form and structure of the earth. In this case, the study focuses on how the stream has been impacted by changes within the watershed and determining a stream configuration appropriate for this setting.

consultation with several sources, it was decided that the analysis would follow a system developed by Dave Rosgen, Principal Hydrologist, Wildland Hydrology Consultants. His classification system[6] and related materials are included in appendix I.

In addition to reviewing the problems with bank stability and ongoing degradation of the tributaries, several additional objectives were identified. First, furnish sponsors with alternatives to reduce escalating operation and maintenance expenditures. Second, provide the Oklahoma Department of Transportation with recommendations on channel gradient controls at new and existing bridge locations. Third, evaluate time and labor requirements for preparing designs consistent with geomorphic based restoration procedures described by Rosgen (Rosgen, 1996). Fourth, develop a regional curve to serve as the design guide for natural restoration measures in the Sugar Creek watershed. Finally, evaluate applicability of this technology in non-armored streams, particularly those based in sands and low strength silts.

This report focuses on the processes, time, and resources necessary to conduct a geomorphic assessment. Additional work is still required for data analyses and design, and an in-depth discussion of those topics is not included in this report.

[6] Several stream classification and channel evolution models are in use across the nation. Selection of the Rosgen system specifically for this project does not constitute an NRCS endorsement of Rosgen's methodology over other procedures.

## BACKGROUND

The Sugar Creek watershed covers a drainage area of 189,076 acres. Sugar Creek originates three miles west of Hinton, Oklahoma, and flows in a south - southeasterly direction for more than 30 miles before entering the Washita River (past the towns of Lookeba, Binger, and Gracemont in that order). Elevations range from a maximum of 1,680 feet to a minimum of 1,150 feet above sea level.

The average annual precipitation is 28 inches with most precipitation occurring in spring and fall. Thunderstorm activity can produce intense precipitation over localized areas resulting in very rapid runoff. Flooding occurred frequently prior to the installation of the flood control structures with 100 floods recorded in the interval from 1923 to 1949. Of this total, 46 covered at least 50 percent of the flood plain with the remainder being of lesser severity. The flood plain ranges from approximately 200 feet in width at the upper reaches to 4,000 feet near the confluence with the Washita River.

The watershed is thought to have been only minimally impacted by human activity prior to 1900. Vegetation consisted of a tallgrass prairie with willows, cottonwoods, and oaks in riparian areas and canyons. The stream was relatively small with intermittent flow.

The area dramatically changed in 1901 when it was opened to settlement. Instead of the customary land run for opening new lands in the Oklahoma territory, a lottery was used for this region (Gibson, 1988). Pioneers rapidly began to convert large areas of prairie to farm land. Removal of native vegetation and the use of land disturbing implements led to extensive upland sediment production and subsequent deposition along the channel and flood plain. Runoff naturally increased with the development of the watershed, and the stream channel began a process of adjustments to accommodate the increased runoff.

Sediment and high flows conveyed through the system were significantly reduced by conservation practices and floodwater retarding structures built primarily in the 1960's. This is illustrated in Figure 3, (USGS, 1983). The curve based on the 1962 data represents a minimally controlled watershed as only two to five structures had been completed at this time. The second curve represents an "as-built" condition as all but one of the 43 structures had been installed by 1974. The latter curve illustrates the reduction of suspended sediment due to floodwater retarding structures and land treatment measures. However, sampling at this stream gauge was discontinued before the channel incision progressed upstream to the gauge location. Therefore, the data recorded did not capture the enormous quantities of sediment resulting from streambed and streambank erosion.

Farming and ranching remain the primary sources of income within the watershed. Principal crops include wheat and alfalfa. Farming extends almost to the edge of the incised channel bank since the flood plain soils are the most productive in the county. Minimal riparian zones exist in scattered locations.

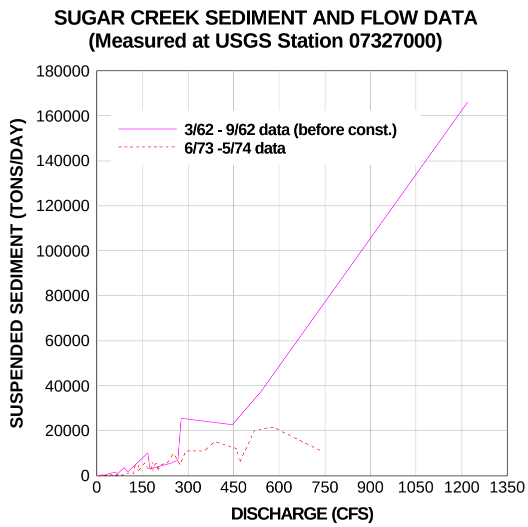


Figure 3. Suspended sediment and flow data for first and last years of gauge use.

## GEOMORPHIC EVOLUTION

The setting for this stream is a very broad alluvial valley with an extensive flood plain and relatively gentle slopes. It is categorized as Valley Type X (Rosgen, 1996).

Aerial photography taken in January, 1937, provides the earliest visual record of the stream. Relatively undisturbed reaches were probably similar to those at the turn of the century. These reaches had numerous meanders and appeared very stable. Such reaches are typical of an E stream type (Rosgen, 1994). An E stream type is a very desirable natural stable form combining a riffle/pool morphology with stable, well vegetated banks (see appendix I for the classification key).

The 1937 photos (see appendix II) also document the extensive changes that had occurred since the first days of settlement. The towns of Lookeba and Binger were well established, and the Rock Island Railroad had already built and deserted a line that ran parallel to Sugar Creek. Much of the area, including hillsides, had been cleared, and extensive gullying is evident. Obviously, the “Dust Bowl” of the early 1930’s significantly accelerated the erosional processes.

Numerous reaches of the channel were also undergoing changes. Channels had been straightened in scattered locations, and still more riparian vegetation had been removed. Sand bars became evident on the lower portion of the stream. The following description of the channel 3.5 miles south of Gracemont was written on the back of a photograph. It reads “Channel changes have been numerous - some humanly induced, others normal cut-offs due to the tortuous course of the stream. Channel averages 30’ X 8’. Bankcutting observed in few instances, but not serious nor extensive. The normal bottom soil appears to be a dark brown sandy loam with a sharp and distinct change to a light reddish sand.”

The relatively undisturbed reaches would still have been classified as E5 and E6 while those altered reaches were possibly moving to C5 and C6 classifications. Such a change from an E to C stream type represented a downward trend in those reaches as the channel became relatively wider and shallower with a higher potential for bank erosion.

E stream types are very sensitive to disturbance. Although established and well vegetated C stream types can be very stable, the changes in this instance resulted from adverse actions within the watershed and the riparian area.

In the early to mid 1940’s, farmers began to install dikes and straighten Sugar Creek in order to farm more of the naturally subirrigated valley (Morton, 1965). This process continued through the early 1960’s, and much of Sugar Creek was effectively separated from its flood plain. In addition, the channel gradient increased as a result of the straightening.

By 1966, a cross-section approximately one half mile upstream of the previously described channel had an average depth of only 3.5 feet, and the top width had increased to almost 100 feet. In effect, this reach had aggraded about 4 feet, and the top width increased over threefold with a resulting C5 or C6 stream classification depending upon the grain size distribution of the bed material.

Meanwhile, the detailed geologic investigation report (Morton, 1965) documented a two foot headcut advancing through the system about ten miles farther upstream. This indicates a movement to a G6c classification for this reach. The G stream type is narrow and entrenched (gully).

In 1966 and 1967, SCS completed channel construction in two phases. The channel was designed to prevent flooding from a 6-hour storm occurring on average once in two years. To achieve the design capacity, the base of the channel was lowered 7 to 9 feet. Perhaps just as important, the channel bottom was now located in fine grained sands rather than the dark brown loam which was considerably more erosion resistant.

The dark brown loam layer is still intact approximately 3 to 6 feet below the valley surface in a number of locations, and it seems to serve as a confining layer. Based upon its moderate organic content and location within the soil profile, this was likely the topsoil layer prior to settlement. Its relative resistance is attributed to a higher clay content and a greater level of consolidation due to the fluctuations of a water table over a prolonged period of time.

In addition to the removal of a relatively erosion resistant layer, construction further straightened and steepened the channel gradient while removing any existing riffle/pool configuration. This began a series of adjustments as lower portions of the system moved rapidly to a G5c stream type.

Since that time, there have been almost continual problems with bank stability, degradation, and sedimentation at various locations. In most of the lower reach, the main channel is incised 15 to 20 feet with oversteepened banks. Flood waters rarely rise to the high terrace, but continue to undercut the toe and cause extensive mass wasting.

Much of the stream has widened in recent years to a F5 classification, although upper reaches would still fall within the G5c category. (The F stream type is deeply entrenched and very wide with high rates of bank erosion).

The value of a geomorphic analysis can be demonstrated when realizing that the stream's adjustments to the various influences were predictable. The E5 and E6 stream types that existed under natural conditions in 1900 responded to the increased sediment loading created by the land use change to intensive agriculture by aggrading and widening to develop a width to depth ratio typical of C5 and C6 stream classifications[7]. The PL-534 watershed measures installed in the 1960's created two major changes in the Sugar Creek channel geomorphology. First, the channel was enlarged (2 to 3 times its original size) and straightened with slopes ranging from 0.0013 to 0.004 foot/foot[8]. This compares to a maximum slope of 0.0019 foot/foot noted in 1965 surveys. Second, the upland sediment sources were dramatically reduced by the floodwater retarding dams which reduced sediment immediately below the dam sites by 95 to 98 percent. The prolonged flow of "clean" water leaving the structures had potential to detach and transport sediment from within the internal channel system.

These two changes in geomorphic factors changed the Sugar Creek system from a highly aggrading system to a rapidly degrading system. The degradation led to oversteepened banks which became subject to mass wasting. Eventually, enough material was removed to develop the width to depth ratio characteristic of an F5 stream classification. In those reaches where entrenchment has reduced the gradient sufficiently, a C channel is beginning to form within the F channel. That occurred because the F channel has eroded its banks laterally until sufficient width is established to develop a new flood plain at some intermediate elevation. Within the new flood plain, a meandering channel with characteristics of a C channel is formed.

Even with man's channel manipulation during the 1960's, the stream channel has responded in predictable evolutionary stages (Rosgen, 1996)[9].

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[7] One of the key tools in classifying streams using Rosgen methodology is the width/depth ratio. This ratio is a strong indicator of condition and trend.

[8] A straightened channel is a manipulated condition that is not classified under the Rosgen system.

[9] The discussion concerning the Evolutionary Stages of Channel Adjustment begins on page 6-7 and is illustrated in Figures 6-5 and 6-6.

An understanding of how a stream is expected to react can be translated to the tributaries as similar patterns are beginning to develop. Currently, tributary degradation is a major concern as active headcuts ranging from five to ten feet advance towards floodwater retarding structures. The areas of primary concern include Kickapoo Creek (sites 22 and 23), Hunt Creek (site 7), and Keechi Creek (sites 4 and 4a). An overfall has advanced to less than half a mile from Site 4.

Sugar Creek has also produced numerous maintenance and replacement problems for county commissioners and the Oklahoma Department of Transportation as they work to maintain bridges and the road structure. Very limited right of ways essentially lock in existing bridge locations, and this also limits any work they might do beyond the immediate bridge area. Measures to protect bridge pilings as the stream downcuts are common, and the widening stream requires longer spans for bridges. Many of the smaller structures have been replaced over the past 25 years with one bridge being replaced three times in the past 15 years.

## DATA AND RESOURCES NEEDED TO UNDERTAKE A GEOMORPHIC ANALYSIS

A geomorphic solution represents a relatively new approach of addressing stream systems for NRCS. Instead of a design based upon regime theory, the geomorphic solution stresses the concept of achieving stream channel stability consistent with the stream's natural tendencies. Traditional designs not utilizing a geomorphic assessment often significantly alter stream characteristics and require extensive maintenance or result in failure.

Rosgen (1996) states that a natural stability is achieved by "allowing the stream to develop a stable dimension, pattern, and profile such that, over time, channel features are maintained and the stream system neither aggrades nor degrades over time. For a stream to be stable it must be able to consistently transport its sediment load, both in size and type, associated with local deposition and scour."

To arrive at such a solution requires a thorough understanding of the stream and contributing factors within the watershed.

### a. Regional Curve

A regional curve is a compilation of field data gathered at USGS gauges that results in the plotting of bankfull depth, top width, and cross sectional area as functions of drainage area. The definition of "bankfull" is as provided by 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." This bankfull discharge has a recurrence interval of approximately 1.5 years (Leopold, 1994).

The elevation of the bankfull discharge described above may be quite different than the lay person's concept of bankfull, which would tend to denote a water elevation associated with a completely filled channel (also the commonly used engineering definition).

For a more detailed description, the reader is referred to Applied River Morphology by Rosgen (1996)[10]. A video demonstrating how to determine the bankfull stage can be obtained from the Forest Service (1995).

A great deal of thought went into the gauge selection process as more than 60 gauges were considered within physiographic settings similar to the Sugar Creek watershed. The first step was to eliminate gauges that did not have at least ten continuous years of data. The next step was to examine the years of record for each remaining gauge. Gauges located in watersheds subjected to extensive land use changes (which impacted the flow regime) during the period of record were rejected[11]. Those gauges where data collection ended at some time in the past were reviewed to determine if the cross section had remained stable in the interim.

Ultimately, the regional curve was based upon data from the field calibration of eight gauges. Each was thoroughly examined in the field for any indications of an unstable cross section that would have caused that gauge to be rejected. The eight gauges selected represent a mixture of continuous and crest stage stations. Drainage areas (uncontrolled) range from 0.52 to 83.0 square miles, and precipitations range from 26 to 35 inches.

The field procedure used was based upon a Rosgen method (1996) with only uncontrolled drainage areas impacting the gauges being used. Drainage areas subject to regulation were not included because the precipitation leading to the bankfull event is not sufficient to cause emergency spillway flow from floodwater retarding structures, and principal spillway flow is minimal in terms of peak runoff.

The regional curve (see Figure 4) is essential in developing a geomorphic solution in highly disturbed systems, particularly in the absence of reference reaches. It becomes the design blueprint for the properly functioning stream by defining important stream characteristics including bankfull area, bankfull width, and mean depth.

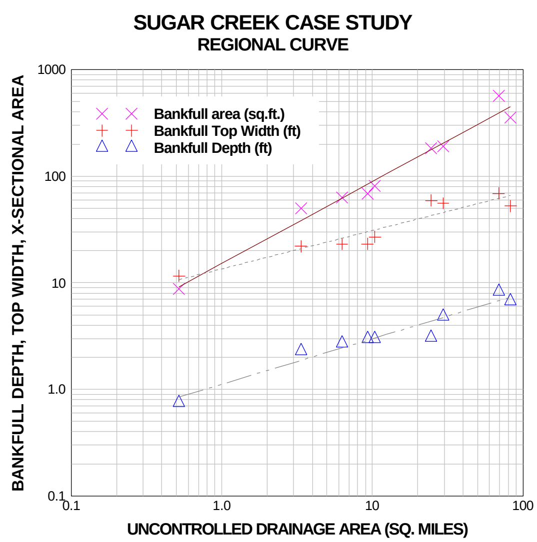


Figure 4. Regional Curve developed for the Sugar Creek study.

### b. Equipment Requirements

Much of the equipment required for the project is the same as needed for ordinary survey projects. Depending upon the size of the project, levels or total station, survey vehicle, stakes, flagging, permanent monuments, and rods are needed.

Materials purchased specifically for this project include 1995 aerial

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[10] See pages 2-2 through 2-4.

[11] Those gauges which had at least ten years of record after the changes ended could have been included. In those cases, only those years reflecting stabilized flow conditions would be included in the data analyses.

photography, two sets of insulated waders, two 300 foot tapes, two 100 foot tapes, hatchet, nails, rope, water resistant 35mm camera, 3/8 inch rebar, and 1/4 inch chains. The combined costs for materials and equipment to date are $1,310.

**c. Time Requirements**

The personnel requirements for such a project are substantial. The original estimate was 281 staff days for surveying, finding sources of data, and preliminary design. While the actual time was not recorded, it appears that the estimate was reasonable. This estimate did not include the extensive survey work completed within the watershed in past years.

One important time saver was the use of a survey grade GPS system. When tied to existing USGS benchmarks, a two and a half day survey resulted in temporary benchmarks located approximately every mile for twenty seven miles of channel. The channel elevations were then obtained by use of laser level.

The two biggest personnel commitments were the development of the regional curve and the channel survey. Calibration of each USGS gauge took approximately four hours of field work with a staff of three. The necessary calculations and documentation added approximately two days for each gauge. Time required for channel surveys depends upon the actual site characteristics and the depth of flow. In the Sugar Creek project, the survey took approximately nine staff days.

**d. Study Reach**

A study reach is used within the framework of the Rosgen system to specifically monitor changes that occur within a typical portion of the stream over time.

Cross section locations are selected, and measurements relating to the physical dimensions of the channel are recorded. Permanent markers are set to facilitate surveys. These same measurements are repeated the following year or after a significant flow to determine the stream's response to the event.

For this project, two such study reaches are in place. One was placed on Kickapoo Creek (a tributary), and extensive measurements have been made since installation. Recent data indicates that a headcut migrated 148 feet upstream in seven months, and the rate of migration has been fairly constant at approximately 20 feet per month. Soil loss has also been constant at 2 cubic yards per foot of headcut advance. The second study reach is on Sugar Creek three miles north of Gracemont. A scour chain and ten feet long rebar bank pins were installed. This study reach had to be reestablished after runoff from a three-inch rainfall caused extensive mass wasting and washed out the ten feet long bank pins.

## Applying Geomorphic Principles to Sands and Low Plasticity Silts

This project represents the application of geomorphic based technology (Rosgen, 1996) to a stream system dominated by very fine grained sands and low plasticity silts in a semi-humid environment. Since NRCS has not used these procedures in a comparable setting, the information and experience gained should provide insights for similar projects.

Sands and low plasticity silts represent an extreme condition. Based upon a soil mechanics report (McElroy, 1965) prepared to assist in early channel design, the soils consist of nearly equal amounts of silt and sand with plasticity indices typically less than four. Material classifications based on the Unified Soil Classification System are SM (silty sand) and ML (sandy silt). In addition, they are very fine grained with nearly 100 percent passing the #60 sieve (0.25 mm).

This is important because a constant source of sediment will move along the channel bed and boundaries. A study of stream flow velocities required to erode particles ranging from 0.001 mm to 1000 mm indicated that coarse silt and fine sand portions (ranging from 0.06 mm to 0.5 mm) are the most erosive (Sundberg, 1956). Furthermore, they can be moved at velocities as low as 0.5 feet per second.

It is interesting to note that Rosgen's classification scheme would differentiate reaches of a stream based on the presence of two different materials (clay/silt or sand). However, the silts and sands in this instance exhibit very little difference in behavior. Clays, on the other hand, could be expected to exhibit a marked difference in structural integrity and performance.

A further refinement of the silt/clay grouping deserves consideration. Low plasticity silts are inherently unstable and easily erodible while most clays are relatively resistant to erosion due to electrical-chemical activity. A change might include grouping low plasticity silts (plasticity index of 4 or less) with sands since they have similar characteristics in terms of resistance to erosion and piping. However, additional review will be necessary to determine if this appears consistent with field observations over an extended range of conditions across the country.

Rosgen is aware of the possibility that some modifications to his classification system might have merit. However, his system has been based on thousands of field observations, and there is insufficient data at this time to establish further material delineations based on channel behavior. Even if additional data indicates a minor change of the classification system may be merited, both the Rosgen Classification System and his method of predicting evolutionary development have proven extremely useful in this watershed. Determination of the correct channel dimension, pattern, and profile is more critical than ever due to the sensitive nature of the soils involved.

## Summary of Findings

This project has substantially advanced understanding and experience in gathering field data and assembling historical records necessary to undertake a comprehensive geomorphic evaluation. This section summarizes the highlights.

### a. Importance of Historical Records

A suprising amount of historical data was available, and all of it proved extremely useful in understanding and documenting the stream's evolution. Most helpful were the 1937 and 1955 aerial photographs, which provide a record of the stream prior to construction. Also critical to the examination of the system and its historical modifications were cross sections and profiles of both Sugar Creek and the Washita River. This information was gathered from a variety of sources including NRCS PL-534 watershed planning data, design drawings, construction drawings, flood insurance studies, and Agricultural Research Service (ARS) studies. The study of these records was not made in an attempt to restore the stream to historical conditions. The stream dimensions associated with those times would not be stable under current hydrologic and watershed conditions. However, using historical data allows one to track changes over time, and more importantly, allowed the examination of the system's reaction to a variety of natural influences and human manipulations.

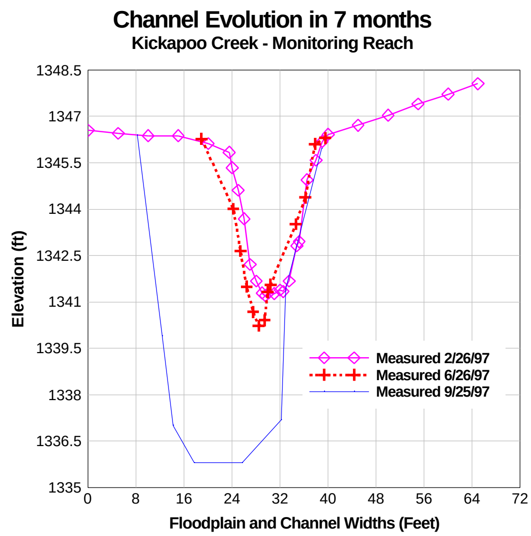


Figure 5. Changes in the Kickapoo Creek (tributary) monitoring station occurring as a head cut advanced through this area.

**b. Necessity of Monitoring**

Determining the physical dimensions and characteristics of the stream is essential to establishing baseline conditions. This baseline is insufficient in and of itself, however. It must be followed by periodic monitoring so that changes can be observed over time (see Figure 5). It is essential that monitoring stations be established in locations representative of "typical" portions of the stream.

**c. Reference Reach**

The term reference reach is used to denote a stable stream with the same general topography, climate, land use, and geomorphologic influences as the disturbed stream system.

Such a reference reach can serve as a template for the dimension, plan, and profile for the specific restoration project. However, locating such a reference reach in the agricultural areas of the Great Plains is not possible in many cases due to extensive channel manipulations and alterations of the past. A field investigation of over 500 square miles of an area most likely to contain a suitable reference reach for the Sugar Creek project proved unsuccessful.

**d. Fundamental Data**

In the absence of a reference reach, the development of a regional curve for defining bankfull channel dimensions is fundamental to a geomorphic-based approach to restoration. The regional curve developed for this project proves very similar to the Eastern United States curve shown on page 7-4 of Applied River Morphology (Rosgen, 1996). The bankfull width is nearly identical, while area and depth values are slightly lower in the smaller drainage areas. The relationship for cross sectional area versus drainage area exhibited a remarkable correlation with an $R^2$ value of 0.986 (see Figure 4).

## e. The Process of Data Collection

Data collection is an intensive process that requires the use of specially trained personnel and access to necessary equipment over a number of months. It is critical to establish a schedule to assure that personnel are available to keep data collection moving forward in a timely manner. Also, equipment needed to complete the data collection must be devoted specifically to the study project
so that valuable time is not lost due to equipment unavailability.

Expertise is extremely critical in the calibration of U.S. Geological Survey (USGS) gauges. As the result of downsizing, USGS has eliminated personnel and abandoned many sites. Many gauge records ended 10 to 15 years ago. In those instances, the investigator must assess whether the cross section has remained stable in the interim and whether a sufficient length of record was obtained during the years of operation. Also, many gauge stations are located on the downstream side of bridges, and it is usually necessary to establish cross sections away from the immediate area to avoid the effects of scour and/or backwater. This move will likely lead to a slight adjustment in drainage area.

Finally, from a safety perspective, it is highly recommended that field work be conducted with at least two team members, preferably outfitted with a cellular phone in case of emergencies. Adverse weather conditions can occur unexpectedly and on Sugar Creek, encounters with quick sand provided intermittent risk to workers.

## f. Base Grade Control

A critical component in a system characterized by non-cohesive soils is base grade control. Control points must be located and understood as a part of the entire system's behavior before meaningful restoration strategies can be contemplated.

The first level of base control for this project is Sugar Creek's confluence with the Washita River. At this location, the Washita River has aggraded approximately 7 feet from 1955 to April 1994 (see Figure 6). This aggradation extended fairly uniformly downstream to the last resurveyed cross section which is located slightly more than ten miles downstream of the Sugar Creek - Washita River confluence (measured along the stream). Indications of aggradation can be visually observed as far downstream as the H. E. Bailey Turnpike bridge which is nearly forty miles downstream of the subject confluence.

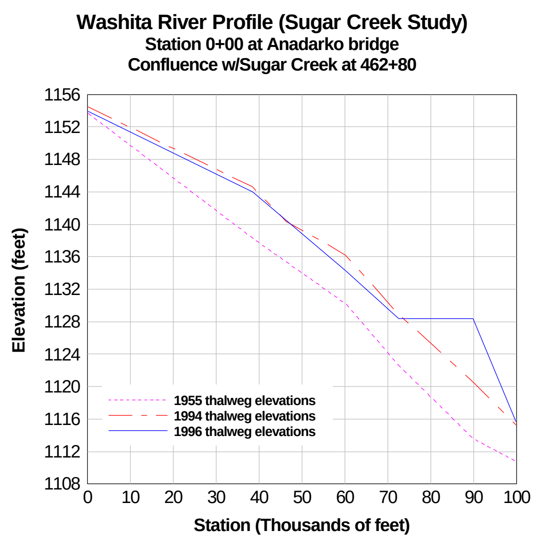


Figure 6. Historical aggradation of the Washita River near Sugar Creek since 1955.

This aggradation illustrates the tremendous amounts of sediment being moved by Sugar Creek as the Washita River above and below the Sugar Creek

sediment plume is a slightly degrading system.
The 1996 survey may represent something of an anomaly as a downstream blockage somewhere in the vicinity of Washita River station 900+00 is indicated. Based on historical trends, it is expected that the river will move this sediment through the system, and the sediment plume will continue to migrate downstream. An average rate of advance has not been estimated at this time.

Even though the future rate of aggradation cannot be accurately predicted, it is expected that the 1994 elevation (1140.4) at the confluence will be maintained or increased somewhat.

The other sources of grade control on Sugar Creek are gabion bridge floors (station 354+19, elevation 1181.0; and station 975+00, elevation 1265.7).

**g. Documenting Trends**

Geomorphic based studies rely in large part on the accumulation and analysis of data to help in establishing trends in stream and river behavior. This is fundamental to considering restoration strategies. A comparison of the 1994 and 1996 data indicates that aggradation of 0.7' occurred at Sugar Creek station 43+80. Such a small amount may not seem meaningful as measurements could vary somewhat on a daily basis. However, this information coupled with the observation that this reach no longer appears to be degrading[12] indicates that the channel is approaching a stable gradient. The slope in this reach was calculated to be 0.0006 ft/ft (between stations 43+80 and 126+75).

[12] Some common indicators of degradation include head cuts, dead or undercut riparian vegetation, and unstable banks.

Trends in changing sinuosity were also noted. In 1937, a minimally impacted reach had a calculated sinuosity of 1.4. The same reach in 1995 showed the effects of extensive straightening with a sinuosity slightly less than 1.1. The objective of restoration for this reach should be to move the sinuosity back toward the more “natural” 1.4. If physical constraints prevent this, an alternative is to develop a stream type which is stable at a lower sinuosity.
A well defined C5 channel is also developing between stations 419+69 and 477+32 in spite of rigid boundaries imposed by the incised channel (see Figure 7). Because a sufficient flood plain does not exist in this area, it is anticipated that larger events would destroy the C5 channel causing the process to begin anew.

Figure 7. A C5 stream type is beginning to develop in this reach.

## Problems Specific to Restoration of Incised Channels

Restoring Sugar Creek to a point where natural stability is achieved presents extreme challenges because it has incised deeply into the landscape.

This incision has caused two fundamental problems that indicate intervention should be considered: 1) the stream is separated from its natural flood plain, and 2) different moisture regimes exist throughout the bank profile. Without a reconnection to the original flood plain, the stream will simply develop a new flood plain within its existing banks through mass wasting of the banks until sufficient widening has occurred. The process will cause extreme land loss for adjacent property owners, and substantial sediment will continue to move downstream impairing water quality and creating recurrent impairment to conveyance of floodwaters. Differing moisture regimes are not problematic in and of themselves, but this situation precludes standard revegetation practices that could help stabilize failing banks. The base of the slope is generally near saturation, but appears too unstable for plants to establish on a long term basis.

Soil moisture decreases with the height of the bank so there is likely insufficient moisture in mid-bank for vegetative establishment. Moisture is actually more plentiful in the upper 4 to 5 feet of the bank because the original soil profile has remained relatively intact. Vegetation could be established in this zone. However, the ability to stabilize the banks in the near term is extremely doubtful since roots would have to extend down 20 to 30 feet to be effective. Given the instability of these banks, even the most vigorous roots could not reach these depths before the plants were severely undercut and lost (see Figure 8). Some type of slope and bank height modification consistent with the designed plan form may be necessary to facilitate vegetation over the entire bank.

Figure 8. Note location of concrete pad for road culvert relative to current stream location and lack of vegetation in the midbank region.

## Future Design and Restoration Plans

The geomorphic characteristics of the Sugar Creek system have been examined in some depth, but additional information is needed before the development of restoration plans *per se* can proceed. This system is so impacted that it became increasingly clear that efforts to stabilize any stream or tributary in the system would be ill-fated without a thorough understanding of the factors impacting the entire watershed. Therefore, additional analyses are planned to project the location and extent of future degradation within Sugar Creek in the absence of any improvements. Factors influencing the analysis include the continuing aggradation of the Washita River, channel geometry from historical aerial photographs, and channel characteristics associated with field assessed “stable reaches”.

Information from those analyses will provide a context within which to assess the relative chance of success as well as costs and benefits of proposed restoration strategies.  A master plan for watershed-based restoration will be developed in concert with local partners, landowners, and other interested citizens.  This document will then serve as a basis for establishing priorities.

A complete design will not be prepared for all of Sugar Creek at the onset. Rather, a tributary or several tributaries will be used as pilot projects to verify the acceptability and effectiveness of various techniques based on geomorphic principles.  If successful, these techniques could be demonstrated under similar conditions on Sugar Creek, albeit on a larger scale.  Ultimately, the principles could be transferred to all future work on Sugar Creek.

Costs of restoration in this system are likely to be substantial, and special efforts to secure funding will be required.  The extent of the costs will not be known until the master plan is complete.

## Implementation Constraints and Concerns

Implementation of any restoration effort in the Sugar Creek Watershed will depend upon the extent to which stakeholders are involved in and committed to the process.  Fortunately, both of the involved conservation districts have always taken a very active role in leading conservation activities. Their involvement will be key in facilitating communication, opening doors to form lasting partnerships, and educating the affected public about the benefits of taking action.  Improved water quality and restoration of a wildlife corridor are examples of benefits that are expected to occur from a restoration project.  However, the topic that most interests landowners is reducing loss of prime farm and pasture lands, and this is the primary reason for developing a restoration plan.

Establishment of a riparian corridor with vegetation covering the entire stream bank will be an essential component of a restoration project. Unfortunately, farming has historically extended almost to the edge of Sugar Creek.  A recent GIS study reviewing approximately ten miles of stream length (Stoodley, 1997) found that riparian vegetation was present for slightly less than ten percent of the studied stream length.  Educating landowners about the value of a properly functioning riparian area and discussing projections of future land loss (if no action is taken) will be important roles for the district.

Physical constraints in this stream system may, however, be more difficult to overcome than cultural concerns (see Figure 9).  The recovery potential of “F5” systems are very poor due to very high sediment supply and streambank erosion potential (Rosgen, 1996).

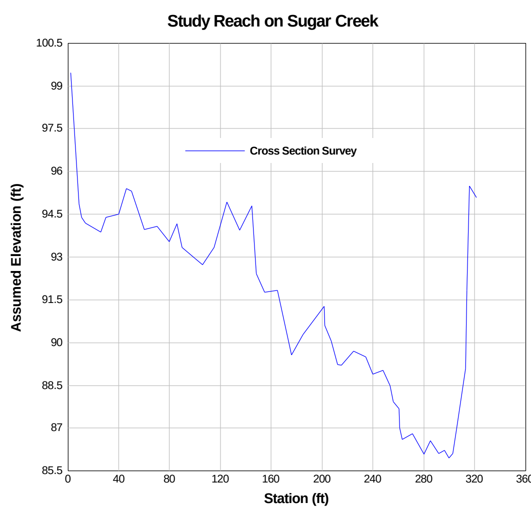


Figure 9. Low flows are typically near elevation 87.  Flows will extend to near elevation 91.5 during bankfull events.  Note the potential for mass wasting of the right bank.

These problems become even more severe in watersheds with flows regulated by dams, such as the Sugar Creek watershed. In highly regulated watersheds, sediment supply is altered by the sediment trapping efficiency of the structures, so the “clear” flows leaving the structures are more likely to detach particles from the banks. While flood peaks are reduced, base flows are normally extended. The extended base flows tend to saturate more of the banks, which in turn makes those areas more susceptible to erosion.

The ability to deal with grade control problems is also of particular concern in such a setting. Traditional “high drop” structures are subject to failure by undercutting and lateral bypass.

Low drop structures may be more applicable in the Sugar Creek watershed. Vortex rock weirs are commonly used in restoration projects in the western United States (Rosgen, 1996). They have several advantages including maintaining sediment transport capacity and redirecting stress away from the banks by breaking up secondary flow currents. Another possibility for selected tributaries is a low head drop (drop height/critical depth less than or equal to one) under development by ARS (Rice, 1997). This structure uses rounded entrance abutments designed to improve performance and reduce scour.

## Summary

Sugar Creek has wound its way through the south central Oklahoma landscape for ages, existing as a small intermittent stream until this century. Since then extreme natural and human-induced changes have been imposed on the system. The stream’s adjustments to the imposed changes have been relatively predictable given its geomorphic setting.

Some of the actions have achieved clear benefits, such as the reduction of annual flooding. Others have been detrimental including increased sediment discharges, land loss, separation of the stream from its natural flood plain, escalating maintenance costs, and loss of riparian functions. To meet multiple objectives, restoration would logically focus on returning Sugar Creek to a more natural functioning state. However, adjacent landowners want to maintain the beneficial flood reduction aspects of the existing system, so reconnecting the stream to its original flood plain is not an acceptable alternative with this sponsoring organization. Restoration plans will have to seek a balance between reducing or eliminating some negative resource conditions while maintaining the system’s ability to withstand floods without inundating adjacent lands. At this time it is not clear whether or how that balance can technologically be achieved using geomorphic principles, but observations of stream systems throughout the area lend credibility to the structure of the tested classification system (Rosgen, 1996) and a natural channel stability model.

It should also be noted that the use of geomorphic principles is not a technical “fad”. Fluvial geomorphology is an established area of scholarly pursuit and its principles and science have been written about for decades. The reliance on geomorphic analyses is relatively new to NRCS engineers, but it is entirely consistent with our agency’s increasing commitment to learn to “read the land” (Geography of Hope, 1996) before we act.

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## How to Get More Detailed Information

Additional project documentation and full size drawings can be accessed at

http://www.wmc.ar.nrcs.usda.gov \projdir\sugar.dir

If you have questions concerning the project, you may contact Ray Riley at the phone number, fax, or address listed:

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