“CHANNEL STABILITY ASSESSMENT AND ECOLOGICAL RESTORATION DESIGN ON THE BARON FORK RIVER, ADAIR COUNTY, OKLAHOMA (U.S.A)”

MASTER THESIS SUBMITED TO THE ACHIEVEMENT
OF MASTER’S DEGREE IN CIVIL ENGINEERING

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EXECUTIVE SUMMARY

Mining operations in the past had negatively impacted the morphology of the channel of the Baron Fork river, Adair County, Oklahoma. The Oklahoma Department of Wildlife and Conservation (ODWC) is planning to restore it. This Master's thesis aims to orient their final decision, providing an ecological restoration design on the 320-acre land area that they have acquired. This proposal is based on a channel stability assessment that has been carried out as part of this thesis and also, based on the analysis of historical fluvial-geomorphological data that dates back 23 years.

Streambank erosion can damage structures and private property. This study shows that the main area of concern is in the northwest portion of the property where the Baron Fork is impinging on the road. Ecological restoration, natural-design techniques, and in-stream structures could be used to manage river migration over time and maintain bank stability during major storms. The conceptual design presented addresses these recommendations.

The thesis is organized into five chapters: (1) Introduction; (2) Site description; (3) Channel stability assessment; (4) Conceptual design; (5) Budget estimate; (6) Plan for monitoring and determination of success.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND AND OBJECTIVES

In the late 90's Worley's Sand and Gravel Co. was mining gravel with valid permits on the Baron Fork river (OK), upstream of the U.S. 59 crossing, for years, and had been doing so for years. This was thought to be having a negative impact on the river, so in 1998, the Oklahoma Conservation Commission (OCC) conducted a study of the river led by Russell Dutnell. Eight cross-sections were established across the channel with rebar pins at locations downstream, though, and upstream of the mined area. The cross-section was surveyed, as was a longitudinal profile between the cross-sections. An assessment using historical aerial photography was also conducted. The study indicated that the mine was potentially impacting the channel, but the mine continued in operation.

In 2005, the mining permit for the Worley mine was up for renewal and they proposed to extend the area to be mined, and multiple agencies, including OCC and the Oklahoma Scenic Rivers Commission (OSRC), had concerns about the expansion so the Oklahoma Attorney General's office contracted with Riverman Engineering, P.L.C., a sole proprietorship owned by Dutnell, to redo the survey and assessment. This second assessment provided more evidence of the impact that the mining operation was having on the river and also provided evidence that they were already mining in the yet to be permitted area. It should also be noted that the illegally mined material was taken from the top of a point bar. A few months later, following a bankfull flow event; the hole that had been dug was filled almost as if it had never been there.

Following the assessment and subsequent hearings, it was proposed that the mining operation could continue if mining was limited to just the tops of the point bars, which if mined properly would fill back up with every bankfull event. When Worley refused, the permit was denied, and the mining operation was shut down.

Eighteen years later, the Oklahoma Department of Wildlife and Conservation (ODWC) has acquired some land on the Baron Fork river, and they are thinking of doing some restoration on it. The purpose of this project aims to assist them by providing them with useful information and a solution proposal.

The objectives of this project are:

1. To re-survey the site, providing a channel stability assessment.
2. Reanalyze the site, classifying the land in order of restoration priority.
3. Provide a conceptual natural channel design to restore the river.

Apart from this objective, this study also aims to: help the reader better understand the naturally stable character of the river in order to maintain its function and health, the consequences of human actions, and the interrelated process variables which shape the dimension pattern and profile of the river, provide an example on how to predict the most probable stable form, and how to face the challenge of meeting the demands for traditional uses and values of the river without affecting its stability and function.

1.2 Available information

This study has the advantage of having specific survey data of the site from 1998 and from 2005 which is rather unusual when developing a project. In 2021, as part of this project, the site has been re-surveyed and the conclusions are a result of the analysis of the first survey, 23 years ago, the second survey, 16 years ago, and this last survey. The report from 1998 is called “Fluvial Geomorphic assessment of the impact of the Worley Gravel Mining Operation on channel stability and sediment transport in the Baron Fork.” Written by Russell C. Dutnell, P.E., Environmental Engineer, Water Quality Program, Oklahoma Conservation Commission. The second report from 2005, written by the same author, is a second phase of the previous study.

Also, the Oklahoma Department of Wildlife and Conservation has provided useful information regarding their intentions and reasons to restore the site, which has been helpful in determining the best possible solution.

In addition, other available information used can be found in "CHAPTER 6. LITERATURE CITED".

1.3 RELEVANT REGULATIONS

Due to the nature of this project, the Permit Program under the Clean Water Act (CWA) Section 404, and Section 401 Certification should be taken under consideration.

The Clean Water Act (CWA) establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters. The basis of the CWA was enacted in 1948 and was called the Federal Water Pollution Control Act, but the Act was significantly reorganized and expanded in 1972. "Clean Water Act" became the Act's common name with amendments in 1972.[1]

As explained by the Environmental Protection Agency (EPA) :

"Section 404 of the CWA establishes a program to regulate the discharge of dredged or fill material into waters of the United States, including wetlands. Activities in waters of the United States regulated under this program include fill for development, water resource projects (such as dams and levees), infrastructure development (such as highways and airports), and mining projects. Section 404 requires a permit before dredged or fill material may be discharged into waters of the United States, unless the activity is exempt from Section 404 regulation (e.g., certain farming and forestry activities). The basic premise of the program is that no discharge of dredged or fill material may be permitted if: (1) a practicable alternative exists that is less damaging to the aquatic environment or (2) the nation's waters would be significantly degraded. In other words,

[1] "Summary of the Clean Water Act," Overviews and Factsheets, February 22, 2013, https://www.epa.gov/laws-regulations/summary-clean-water-act.

when you apply for a permit, you must first show that steps have been taken to avoid impacts to wetlands, streams, and other aquatic resources; that potential impacts have been minimized, and that compensation will be provided for all remaining unavoidable impacts.

Under Section 401 of the CWA, a federal agency may not issue a permit or license to conduct any activity that may result in any discharge into waters of the United States unless a Section 401 water quality certification is issued, or certification is waived. States and authorized tribes where the discharge would originate are generally responsible for issuing water quality certifications. In cases where a state or tribe does not have authority, EPA is responsible for issuing the certification. 33 USC 1341. Some of the major federal licenses and permits subject to Section 401 include:

-Clean Water Act Section 402 and 404 permits issued by EPA or the Corps.
-Federal Energy Regulatory Commission (FERC) licenses for hydropower facilities and natural gas pipelines.
-Rivers and Harbors Act Section 9 and 10 permits.

The CWA provides that certifying authorities (states, authorized tribes, and EPA) must act on a Section 401 certification request "within a reasonable period of time (which shall not to exceed one year) after receipt" of such a request. A certifying authority may waive certification expressly, or by failing or refusing to act within the established reasonable period of time. In making decisions to grant, grant with conditions, or deny certification requests, certifying authorities consider whether the federally-licensed or permitted activity will comply with applicable water quality standards, effluent limitations, new source performance standards, toxic pollutants restrictions, and other appropriate water quality requirements of state or tribal law.

A federal agency may not issue a license or permit for an activity that may result in a discharge into a water of the United States without a water quality certification or waiver."

1.4 Preliminary concepts

The objective of this section is to help the reader who may not be familiar with the topic, to better understand the project by providing the definitions of a few essential concepts

1.4.1 Natural stream channel stability

"Natural stream channel 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. 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. Channel instability occurs when the scouring process leads to degradation or excessive sediment deposition results in aggradation. When the stream laterally migrates but maintains its bankfull width and width/depth ratio, stability is achieved even though the river is considered to be an "active" and "dynamic" system."[2]

1.4.2 Fluvial geomorphology

Breaking the word fluvial geomorphology down into its Latin and Greek roots we have that, fluvial / L. fluvialis/ of, relating to, or living in streams; geo-/ Gk. geo/ earth: ground: soil; morph-/ Gk. morphe-/ form; -ology / L. -logia / study of. Therefore, taken literally, Fluvial geomorphology means the study of river-related landforms [3]. A more detailed definition would be the study of the physical form, or morphology, of rivers, and the hydrological and sediment transport processes that create them, as they flow over the earth.

Applied fluvial geomorphology utilizes the relationships and principles of fluvial geomorphology to understand, preserve and restore stream systems. The primary principle that must be clear is that the form of a river channel is a result of the hydrological and sediment transport processes occurring within and along the channel.

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[2] D. Rosgen, *Applied River Morphology*.
[3] Klotz, "What Is Fluvial Geomorphology?"

Everything starts with the hydrological cycle, precipitation falls on the landscape and some part immediately evaporates, some other infiltrates and the rest becomes surface runoff. The precipitation represented by surface runoff, about one-third, flows from hillslope or valley bottom to definite channels, usually to small channels that join to form larger ones, which in turn meet to form still larger channels [4]. These channels increase in size as they flow down-gradient toward the ocean. The drainage basin also called catchment area, or watershed is the area from which all precipitation flows to a single stream or set of streams. The morphology of a river is dependent on the size, location, and characteristics of its watershed but also the climate, geology, soil, vegetation, and human impacts contribute to control the shape and function of the stream channel network. The stream channel balances all the influencing factors into a balanced functioning system in its natural, unaltered state.

1.4.3 Sediment load and Lane's stable channel balance

Lane's balance or Lane's relationship is a qualitative conceptual model that can be used as an aid to visually assess stream responses to changes in flow, slope, and sediment. The model is based on the general theory that if the force applied by the flowing water on an alluvial channel boundary is balanced with the strength of the channel boundary and the delivered sediment load, the channel will be stable and neither aggrades nor degrade.
This equilibrium condition is dependent on the sediment load (Q_S), the sediment size (D_{50}), the dominant discharge (Q_W), and the stream slope (S) [5].

This balance can be expressed in the proportional relationship (eq. 1):

$$Q_S \times D_{50} \; \alpha \; Q_W \times S \qquad \text{(eq. 1)}$$

Therefore the stream will remain in equilibrium as long as these four variables are kept in balance.

[4] Leopold, "A View of the River — Luna B. Leopold."
[5] "Stream Restoration Design (National Engineering Handbook 654) | NRCS."

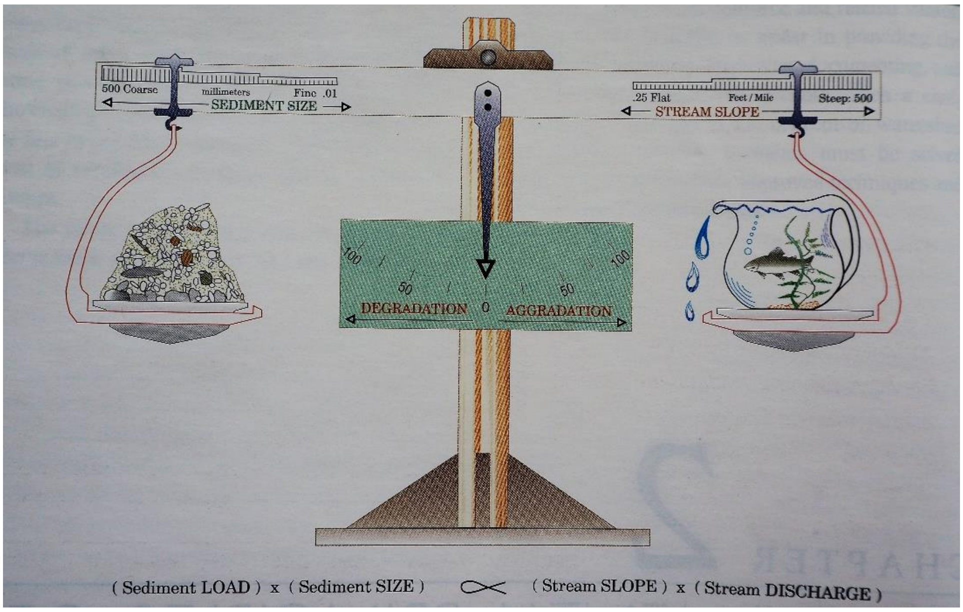


Figure 1 – Schematic of the Lane relationship for qualitative analysis. (After Lane, 1995)

Decreasing the dominant discharge, also known as stream power, results in reduced sediment transport capacity, and aggradation. Increased stream power results in increased sediment transport, and degradation. If the channel reduces its slope going downstream, with no change in discharge, the channel will have less power to transport the amount and size of gravel that it would have in a steeper reach and therefore the material gets deposited on the channel bed causing aggradation and so on. A stable channel does not aggrade or degrade, and so a balance is established between sediment transport and stream power, which in turn drives the morphology of the channel. A natural channel migrates laterally due to erosion on one side, with deposition on the opposing bank keeping a constant channel cross-section on average. Most rivers in cross-section are trapezoidal in straight reaches but asymmetric at curves or bends[6]. The channel of the river might be straight but normally this only happens over short distances. Curves help to erode the concave bank balanced by deposition near the convex bank.

[6] Leopold, "A View of the River — Luna B. Leopold."

1.4.4 Floodplain and riparian ecosystems

Riparian ecosystems encompass a diverse suite of ecosystem types, including riverbanks, floodplains, and wetlands, that are characterized primarily by being ecotones, or transitional zones, between adjacent terrestrial and aquatic realms[7]. They serve as important buffers.

A floodplain is a level area of land near a river channel, constructed by the river in the present climate and overflowed during moderate flow events[8]. When the climate becomes drier and the floodplain is abandoned, this area is called a terrace.

1.4.5 Bankfull stage and discharge

The most frequently occurring discharge in any channel sometimes referred to as the average daily flow, is quite low, and does not come close to filling up the channel. At very high flows, for instance, the one associated with a 100-year return period storm moves large amounts of sediment, but they do not occur very often. The daily average discharge occurs frequently but moves very little sediment. So, it is an intermediate discharge that is both high enough to transport sediment and occurs frequently enough so that over time the most sediment is transported. This discharge is what is referred to as the bankfull discharge. This is the discharge that moves the most sediment and therefore does the most work in shaping the channel.

[7] “Riparian Ecosystem - an Overview | ScienceDirect Topics.”
[8] Leopold, “A View of the River — Luna B. Leopold.”

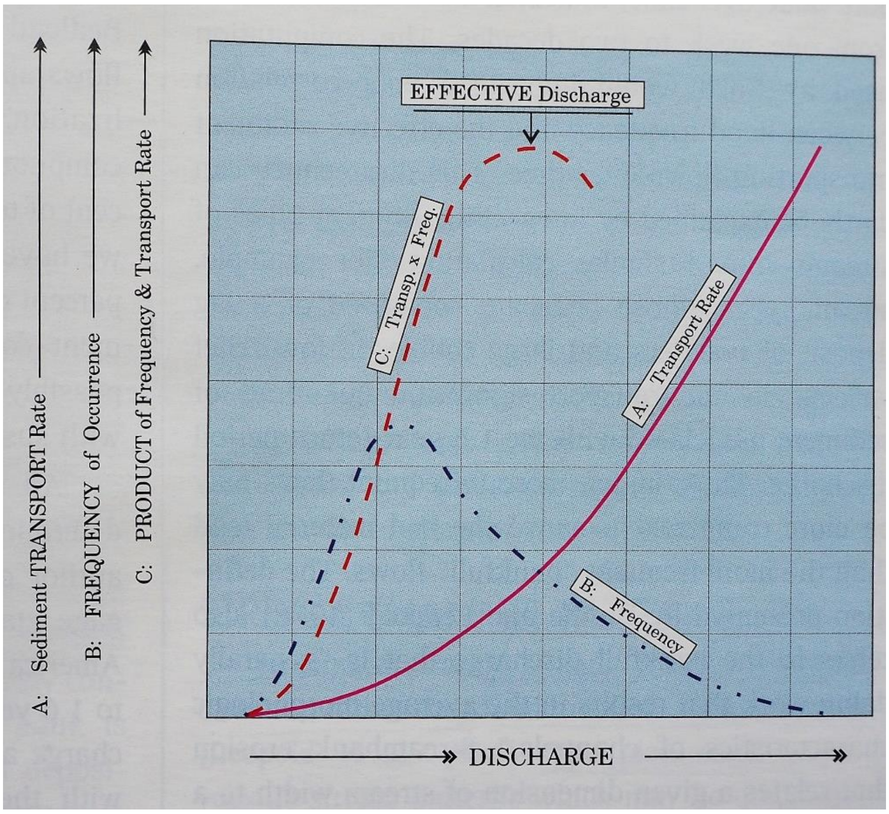


Figure 2 – Relations between discharge, sediment transport rate, frequency of occurrence, and the product of frequency and transport rate. (After Wolman and Miller, 1996)

As defined by Dunne and Leopold in 1978 "The bankfull stage corresponds to the discharge at which channel maintenance is 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." The bankfull discharge has an approximately constant recurrence interval, 1-5 years in the annual flood series.[9]

1.4.6 Stream channel dimensions

1.4.6.1 Width and depth

As wrote by Leopold in 1964, channel widths generally increase downstream as the square root of the discharge. It can be affected by channelization, changes in riparian

[9] "A View of the River — Luna B. Leopold."

vegetation, changes in streamflow regime due to watershed regimes, and changes in sediment regime. A channel can have a stable width even though is migrating laterally. Stream width can remain relatively constant where the role of erosion on one bank is compensated with corresponding sediment deposition along the opposite bank. The mean depth of rivers varies greatly due to the sequence of riffle and pool bed features.

The morphology of the channel is often described in terms of a width/depth ratio related to the bankfull stage cross-section.

1.4.6.2 Pattern

Streams follow a sinuous course. The planimetric view exhibits specific geometric relationships that may be quantitatively defined through measurements of meander wavelength, radius of curvature, amplitude, and belt width.

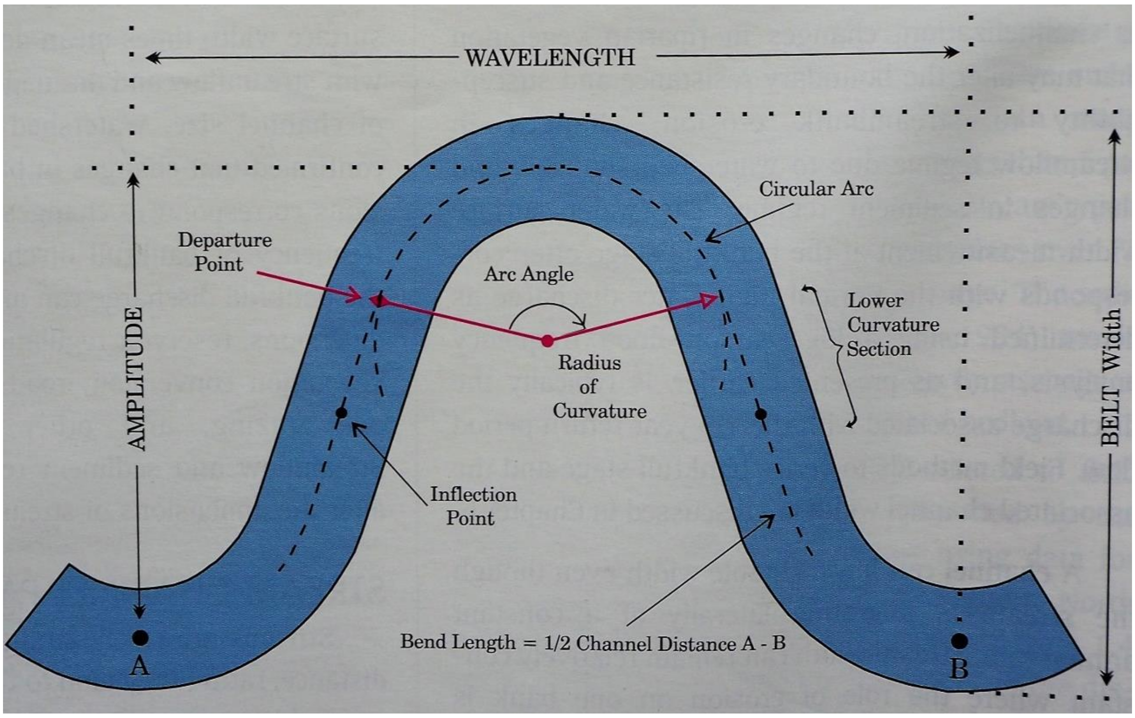


Figure 3 – Schematic Meander Geometry Descriptions (After Williams, 1986)

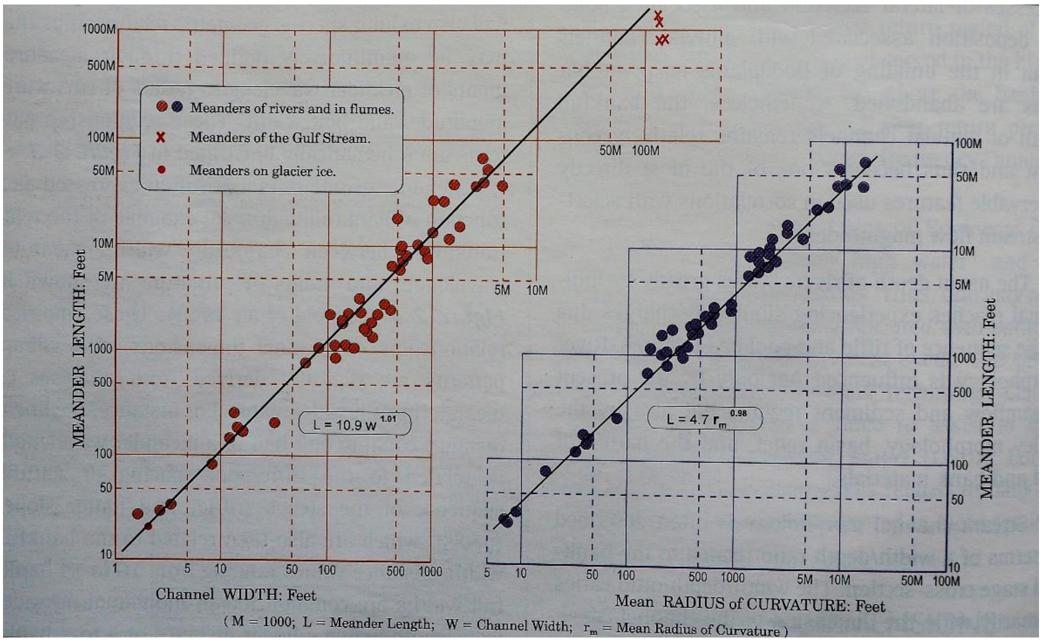


Figure 4 – Relations between meander length and channel width, and meander length and meander radius of curvature (After Leopold, et al. 1964)

Meander geometry is most often expressed as a function of bankfull width. Distance values ranging from 10 to 14 bankfull widths are common for an individual meander wavelength, while a linear distance of 5 to 7 bankfull widths are commonly noted for the spacing of riffle/pool features. [10]

Leopold (1996) developed a sine curve function to describe the symmetrical meander paths of rivers:

$$R_C = \frac{L_m \times K^{-1.5}}{13 \times (K-1)^{0.5}}$$

Where:

R_C: Radius of curvature

L_m: Meander wavelength

K: Sinuosity

[10] Leopold, "A View of the River — Luna B. Leopold."

1.4.6.2 Stream channel profile

Channel gradient decreases in a downstream direction generally. The relation shown by Lane(1995) in figure 1, shows that stream gradient is directly related to bed-material load and grain size and inversely related to streamflow.

1.1.7 Stream channel classification

Classification allows us to infer attributes of individual objects based on the characteristics used to create different categories.

1.1.7.1 Rosgen stream classification system

Stream classification existed before Rosgen's Classification, but the systems used were mainly based on qualitative interpretations of geomorphic features, resulting in inconsistent classification and difficulties in making predictions. Classification systems are more effective if they rely on objective and quantifiable criteria.

Rosgen (1996) lists four specific objectives for stream classification:

- Predict a river's behavior from its appearance
- Develop specific hydraulic and sediment relationships for a given stram type and its state
- Provide a mechanism to extrapolate site-specific data to stream reaches having similar characteristics
- Provide a consistent frame of reference for communicating stream morphology and condition among a variety of disciplines and interested parties.

These objectives can be met through the following hierarchical assessment of channel morphology developed by Rosgen (1996):

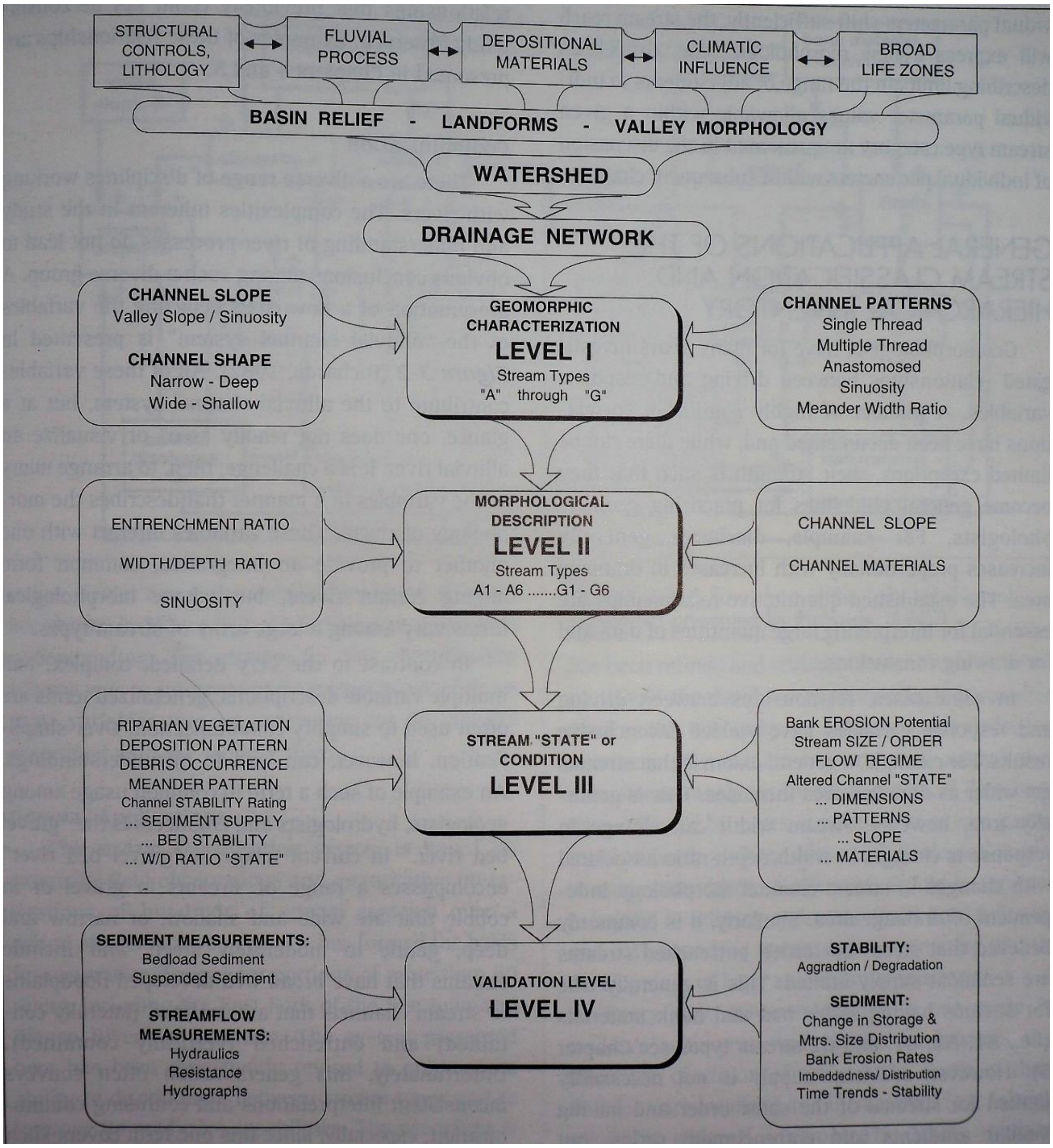


Figure 5 – The hierarchy of river inventory and assessment. Rosgen (1996)

The Rosgen stream classification consists of four levels of detail ranging from broad qualitative descriptions to detailed quantitative assessments. Figure 3.1 shows the hierarchy (Levels I through IV) of the Rosgen classification inventory and assessment. Level I is a geomorphic characterization that categorizes streams as "A," "B," "C," "D," "DA," "E," "F" or "G." Level II is called the morphological description and requires field measurements. Level II assigns a number (1 through 6) to each stream type that describes the dominant bed material based on the d50 of the reachwide pebble count. Level III is an evaluation of the stream condition and its stability; it requires an assessment and prediction of channel erosion, riparian condition, channel modification, and other characteristics. Level IV is the verification of predictions made in Level III and consists of sediment transport, streamflow, and stability measurements.[11]

1.1.7.2 Channel evolution model

Channel Evolution Models (CEMs) provide useful information for understanding morphological responses to disturbance associated with lowering base level, channelization, alterations to the flow, and alterations to sediment regimes. CEMs are very useful tools that can improve river management decision-making.

Often the morphological response of the channel to disturbance is considered in two dimensions, a vertical adjustment which involves aggradation and degradation of the bed, and a lateral adjustment which involves retreat and advance of the banks.

As described by Simon and Thorne in 1996, "Vertical adjustments dominate initial responses driven by erosion and lowering of the bed until the banks become unstable, whereas lateral adjustment dominates as geotechnical bank failures and toe scour result in widening. Eventually, the width of the unstable channel becomes sufficiently large that near-bank flows lose their competence to entrain and remove failed bank material, so that channel width first stabilizes and then decreases as slumped bank material builds bank toe benches and berms at one or both margins. Provided that no further disturbance occurs, the channel recovers a dynamically meta-stable form when its banks and berms stabilize, and the energy slope adjusts to match local sediment transport capacity to the supply of sediment from upstream".

[11] "Stream Restoration Design (National Engineering Handbook 654) | NRCS."

Figure 6 shows the generalized CEM formulation developed by Schumm et al. (1984) which is a five-stage model where the morphological response is characterized by bed degradation followed by bank collapse, widening, and eventual stabilization.

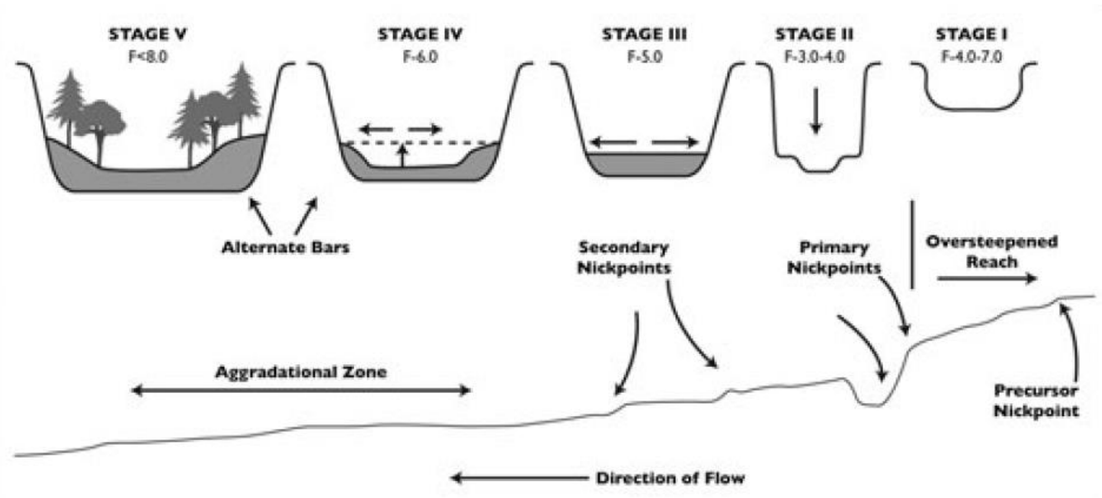


Figure 6 - Schumm et al. (1984) Channel Evolution Model with typical width–depth ratios (F). The size of each arrow indicates the relative importance and direction of the dominant processes of degradation, aggradation, and lateral bank erosion.

Figure 7 shows the six-stage CEM of Simon and Hupp's (1986) which is very similar to the previous one but has some differences. First, the one of Simon and Hupp includes a constructed stage between the pre-modified and degradation stages of Schumm et al. Second, the bed scours continue in Stage IV of Simon and Hupp's model even though the banks are retreating because of geotechnical failure, simultaneously producing channel degradation and widening[12]. The third difference between the CEMs, as pointed out by Gunrell and Petts in 2006, is the greater emphasis placed on the influence of bank and riparian vegetation processes in Simon and Hupp's model; an emphasis subsequently validated by field research that established the effectiveness of vegetation as a 'riparian engineer'.

[12] Cluer and Thorne, "A Stream Evolution Model Integrating Habitat and Ecosystem Benefits."

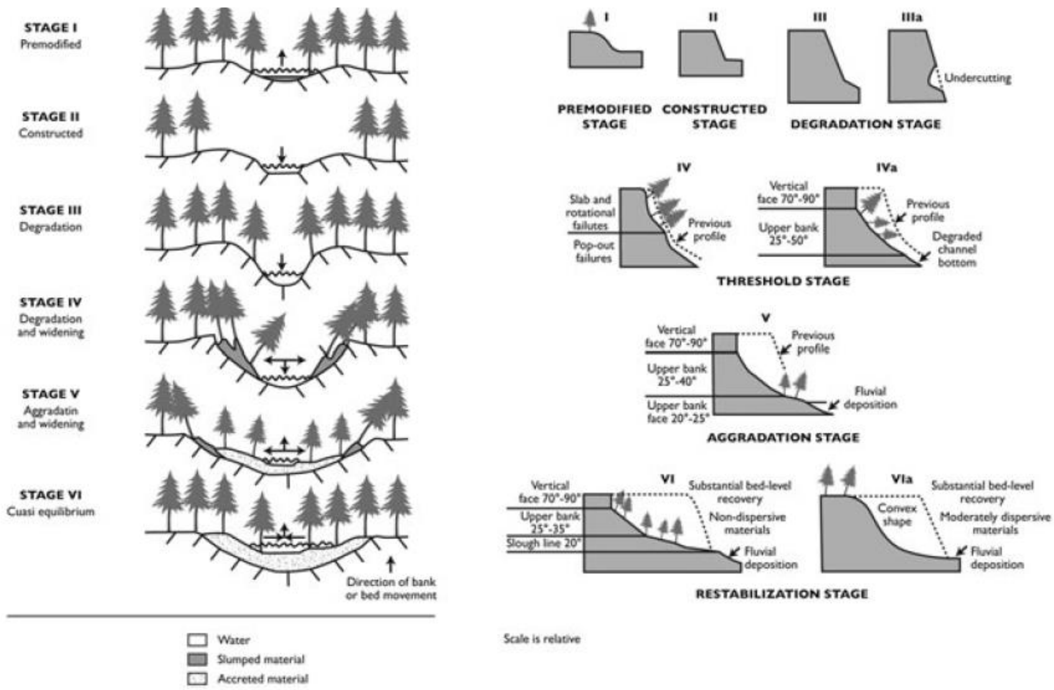


Figure 7 - Simon and Hupp's (1986) Channel Evolution Model.

1.1.8 Bank Erosion Hazard Index (BEHI)

The Bank Erosion Hazard Index (BEHI), created by Dave Rosgen, is a fluvial geomorphic procedure measuring a stream bank's resistance to erosion. It allows researchers to distinguish between streams eroding at a natural pace and those that have the potential to erode at unnaturally high rates[13]. It assigns point values to several aspects of bank condition and provides an overall score that can be used to inventory stream bank condition over large areas, prioritizes eroding banks for remedial actions, etc.

Hazard rating procedures that characterize various streambank conditions into numerical indexes of bank erosion are shown in figures 8 and 9 (Rosgen, 1993a).

[13] "BEHI-Fact-Sheet_PDF.Pdf."

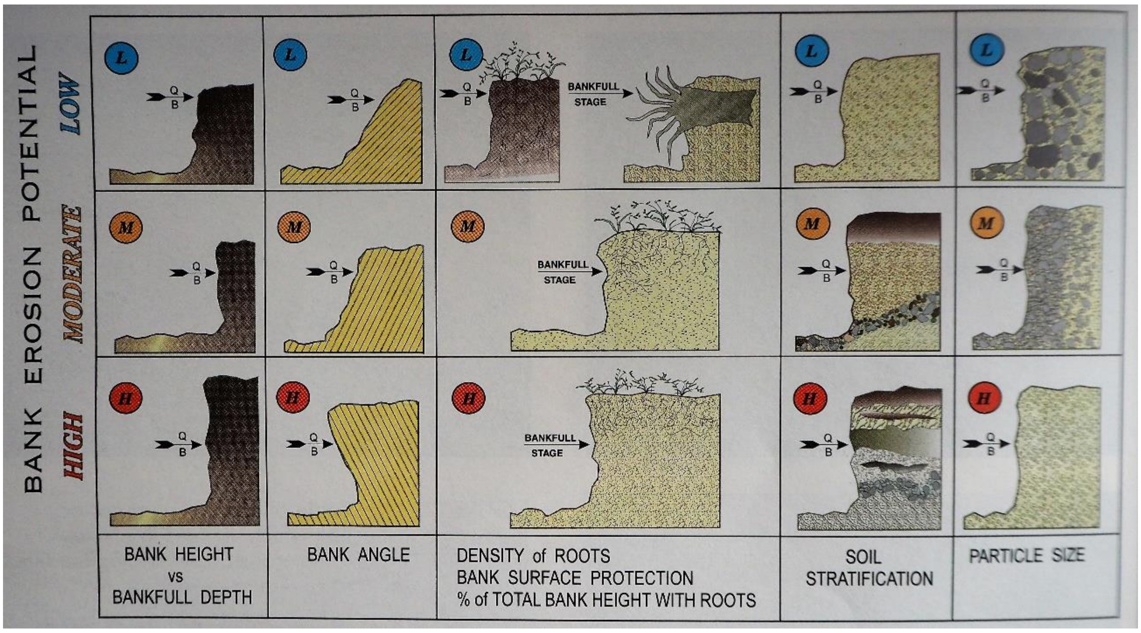


Figure 8 – Streambank erodibility factor (Rosgen 1993a)

	BANK EROSION POTENTIAL											
CRITERIA	VERY LOW		LOW		MODERATE		HIGH		VERY HIGH		EXTREME	
	VALUE	INDEX	VALUE	INDEX	VALUE	INDEX	VALUE	INDEX	VALUE	INDEX	VALUE	INDEX
Bank Ht/Bkf Ht	1.0-1.1	1.0-1.9	1.1-1.19	2.0-3.9	1.2-1.5	4.0-5.9	1.6-2.0	6.0-7.9	2.1-2.8	8.0-9.0	>2.8	10
Root Depth/Bank Ht	1.0-0.9	1.0-1.9	0.89-0.50	2.0-3.9	0.49-0.30	4.0-5.9	0.29-1.15	6.0-7.9	0.14-.05	8.0-9.0	<.05	10
Root Density (%)	80-100	1.0-1.9	55-79	2.0-3.9	30-54	4.0-5.9	15-29	6.0-7.9	5-14	8.0-9.0	<5.0	10
Bank Angle (Degrees)	0-20	1.0-1.9	21-60	2.0-3.9	61-80	4.0-5.9	81-90	6.0-7.9	91-119	8.0-9.0	>119	10
Surface Prot. (%)	80-100	1.0-1.9	55-79	2.0-3.9	30-54	4.0-5.9	15-29	6.0-7.9	10-15	8.0-9.0	<10	10
TOTALS												
		5-9.5		10-19.5		20-29.5		30-39.5		40-45		46-50
Numerical Adjustments												

BANK MATERIALS: BEDROCK: BANK EROSION POTENTIAL ALWAYS VERY LOW
BOULDERS: BANK EROSION POTENTIAL LOW
COBBLE: DECREASE BY ONE CATEGORY UNLESS MIXTURE OF GRAVEL/SAND IS OVER 50%, THEN NO ADJUSTMENT
GRAVEL: ADJUST VALUES UP BY 5-10 POINTS DEPENDING ON COMPOSITION OF SAND
SAND: ADJUST VALUES UP BY 10 POINTS
SILT/CLAY: NO ADJUSTMENT

STRATIFICATION: 5-10 POINTS (UPWARD) DEPENDING ON POSITION OF UNSTABLE LAYERS IN RELATION TO BANKFULL STAGE

Figure 9 – Bank erodibility hazard rating guide (Rosgen 1990)

As described by Rosgen 1996, the ability of streambanks to resist erosion is primarily determined by:

- The ratio of streambank height to bankfull stage.
- The ratio of riparian vegetation rooting depth to streambank height.
- The degree of rooting density.
- The composition of streambank materials.
- Streambank angle (i.e., slope).
- Bank material stratigraphy and presence of soil lenses.
- Bank surface protection is afforded by debris and vegetation.

1.1.9 Near Bank Stress index (NBS)

The Near Bank Stress is another index created by Dave Rosgen to predict the streambank erosion rate. It is an index associated with the energy distribution against the streambanks. It assesses how susceptible a bank may be to erosion due to its morphology, characteristics, and the shear force acting on it. There are seven different methods for estimating NBS at four different levels, the higher the level and the method, the more complex and time-consuming, level VI method 7 would therefore be the most complicated to carry out but not necessarily the most reliable for prediction.

The NBS variables used in the prediction methodology indicate potential disproportionate energy distribution in the near-bank region (the third of the channel cross-section associated with the bank being evaluated), which can accelerate streambank erosion. The user must select one or more of the methods that best represent the on-site conditions[14], and it also depends on available resources.

The 7 methods used to determine an NBS rating are:

- Channel pattern, transverse bar, or split channel/central bar creating NBS or high-velocity gradient
- Ratio of the radius of curvature to bankfull width (Rc/Wbkf)
- Ratio of pool slope to average water surface slope (Sp/S)
- Ratio of pool slope to riffle slope (Sp/Srif)
- Ratio of near-bank maximum depth to bankfull mean depth (dnb/dbkf)
- Ratio of near-bank shear stress to bankfull shear stress (τnb/τbkf)
- Velocity profiles/isovels/velocity gradient

For this study, Level II method 2 will be used to calculate NBS. The reason why is because, as will be seen later in “chapter 3 - channel stability assessment - 3.3 streambank erosion rate analysis”, the sudden change in curvature is what is mostly eroding the banks of study. The high velocity near the bank is ultimately the cause of the shear stress that causes the erosion, but this would require a level IV, method 7 analysis measuring the velocity during bankfull, which is outside the scope of this study.

NBS method 2 Ratio of the radius of curvature to bankfull width (Rc/Wbkf) can be rapidly completed in the field or using aerial photography. This relationship is associated with high to extreme boundary shear stress with Rc/Wbkf values less than 2.0.

[14] Rosgen, Silvey, and Frantila, *River Stability Field Guide*.

CHAPTER 2

SITE DESCRIPTION

2.1 LOCATION

This project is located in Adair County, in the mountainous east-central part of Oklahoma. It is bordered on the east by the state of Arkansas. The Baron Fork of the Illinois River is a tributary of the Illinois River in the U.S. states of Arkansas and Oklahoma. The 320-acre area acquired by the Oklahoma Department of Wildlife and Conservation (ODWC) is located on the Baron Fork, just over a mile upstream of the U.S. Highway 59 bridge crossing, as shown in Figure 1. According to the government survey system, the property is located in Section 36, Township 17 North, Range 25 East of the Indian Meridian.

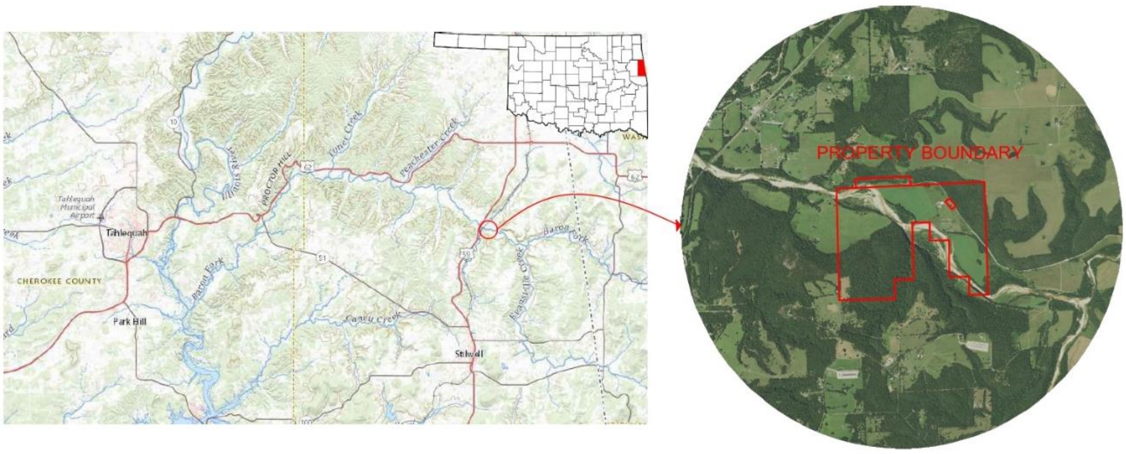


Figure 100- Oklahoma Department Of Wildlife and Conservation property on the Baron Fork in Adair County, Oklahoma

2.2 ECOLOGY AND ECOREGION

The Environmental Protection Agency (EPA) and the Commission for Environmental Cooperation (CEC) have classified the different ecoregions in the United States. The study area is in the 39b ecoregion known as Ozark Highlands, more precisely in the Dissected Springfield Plateau–Elk River Hills, which is a level III ecoregion. Basically, the classification system has four levels, and the higher the level, the narrower is the delineation between areas.

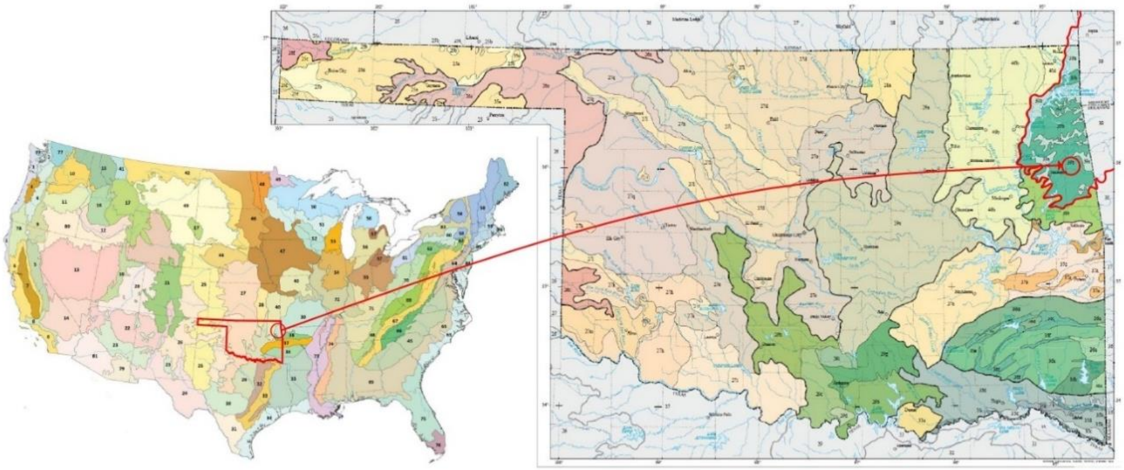


Figure 11-Ecoregions in the United States, zooming Oklahoma and showing that the site location is in the Ozark Highlands ecoregion 39b

As described by the EPA and the CEC, The wooded, rugged, Dissected Springfield Plateau–Elk River Hills ecoregion is composed of narrow ridgetops and intervening, steep V-shaped valleys. Carbonate rocks, along with associated karst features, are characteristic. Springs abound in valleys and contribute cool water to perennial streams. Cherty limestone of the Mississippian Boone Formation is extensive, but older shales, limestone, and dolomite are also exposed in valley bottoms. Ecoregion 39b is more rugged and wooded than either the lithologically similar Ecoregion 39a or the lithologically dissimilar Ecoregion 40b. Upland natural vegetation is oak-hickory and oak-hickory-pine forests and woodlands. Livestock and poultry farming, woodland grazing, logging, recreation, and quarrying are the main land uses. Bank and hillslope erosion has choked many channels and filled many pools with cherty gravel. As a result, braided streams and unstable run habitats have become common. The lower reaches of most streams have aggraded; here, enough gravel has accumulated to promote subsurface flow, except during and immediately after rainfall.

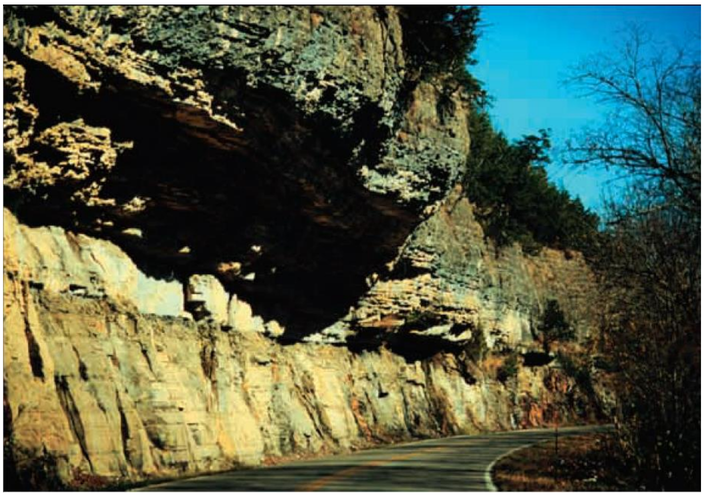


Figure 12-The Ozark Highlands (39) are largely underlain by flat-lying, cherty limestone. Underground drainage, karst features, springs, and perennial streams are common

2.3 CLIMATOLOGY

As described by the United States Department of Agriculture in cooperation with Oklahoma Agricultural Experiment Station, the climate of Adair County is mild and agreeable. The average annual temperature is 59.5° F. The frost-free season of 200 days extends from about April 10 to about October 27. The risk of damaging frost, however, lessens after March 31, and the first killing frost is often delayed until the first week in November. Normally, rainfall is well distributed throughout the year. The average annual precipitation is 43.64 inches; the heaviest rains fall in spring and autumn. Prolonged wet or dry periods are rare. Only 2 wet years and 2 dry years have been recollected. Heavy rains and short periods of drought are more common. Winter is characterized by cloudiness, drizzle, and brief periods of cool temperature broken by periods of moderate temperature. Existing data show an average annual snowfall of 5.7 inches.

2.4 Geology and Soil

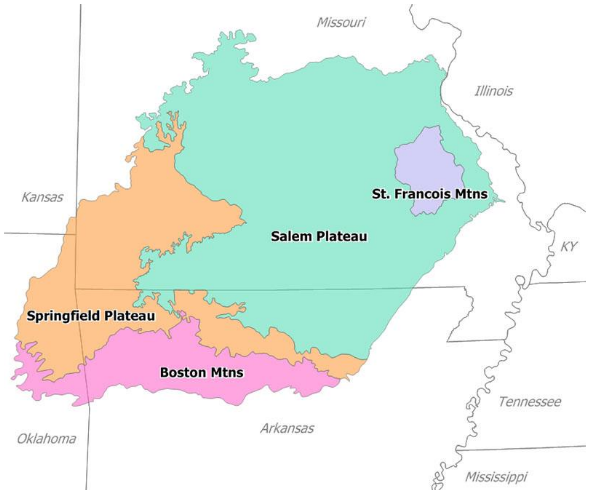


Figure 13 – Ozark Plateau (Wikipedia)

The Ozark Plateau is divided into three physiographic areas: the Salem Plateau, the Springfield Structural Plain, and the Boston Mountains. Only two physiographic areas, however, are represented in Adair County. The southern part is in the Boston Mountains and the northern part of the county is in the Springfield Structural Plain, where the Baron fork river is located. The Springfield Plain is maturely dissected and is underlain by chert and limestone of the Mississippian age. The deep, V-shaped valleys have cut into rocks of Ordovician age, and the isolated outliers that rise above the general upland surface are capped by flat-lying sandstone of the Pennsylvanian age. [15]

[15] "AdairOK1965.Pdf," accessed June 13, 2021, https://www.nrcs.usda.gov/Internet/FSE_MANUSCRIPTS/oklahoma/adairOK1965/adairOK1965.pdf.

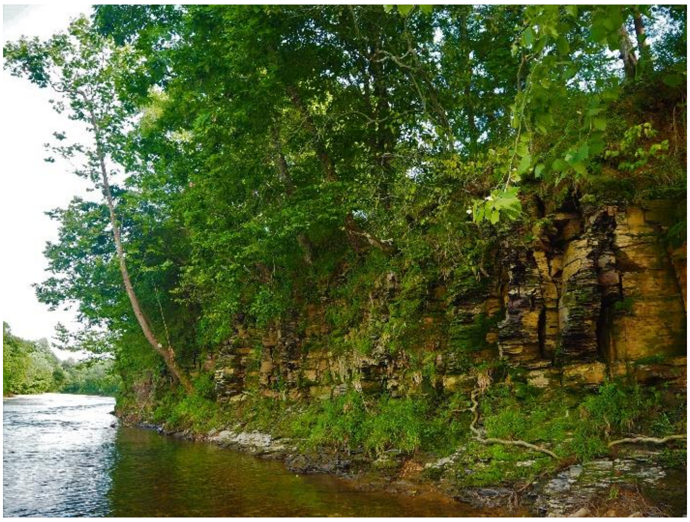


Figure 14 – Chert and Limestone in the Baron Fork

The soil classification for the area of study was found by using the Web Soil Survey (Figure 14) from the United States Department of Agriculture (USDA). The results show that Elsah gravelly silt loam (Ga) covers most of the river's bank, but also Elsah gravelly loam (Hu), Waben gravelly silt loam (EoB), and Clarksville very gravelly silt loam (Bsf) can be found. See “Chapter 8 Appendices; Appendix 8.8 Sketches; soil map”.

Figure 14 – Web soil survey (USDA)

2.5 WILDLIFE AND VEGETATION

Different animals and plants can be found in different habitats. The first part of the chapter is focused on the animals and plants that can be found along the stream, in the forest, and in the caves in the Ozark Highlands. The second part of this chapter focuses more on the specific plants and animals that should be a concern for this project.

2.5.1 Wildlife and vegetation in the Ozark Highlands

Some of the plants and trees that can be found in the upland stream in the Ozark Highlands are American elm (Ulmus americana), Sycamore (Platanus occidentalis), and watercress (Rorippa nasturtium-Aquatica). Regarding the animals, some of them are: Beaver (Castor Canadensis), Baltimore oriole (Icterus Galbula), Green frog (Rana clamitans), Midland water snake (Nerodia Sidepon), Pileated woodpecker (Dryocopus pileatus), Wild turkey (Meleagris gallopavo), Black bear (Ursus americanus), Bobcat (felis rufus), Creek chub (Semotilus atromaculatus), River otter (Lutra canadensis), Raccoon (Procyon lotor), Missouri river cooter (Pseudemys concinna), Western cottonmouth (agkistrodon piscivorus), Green heron (Butorides virescens)

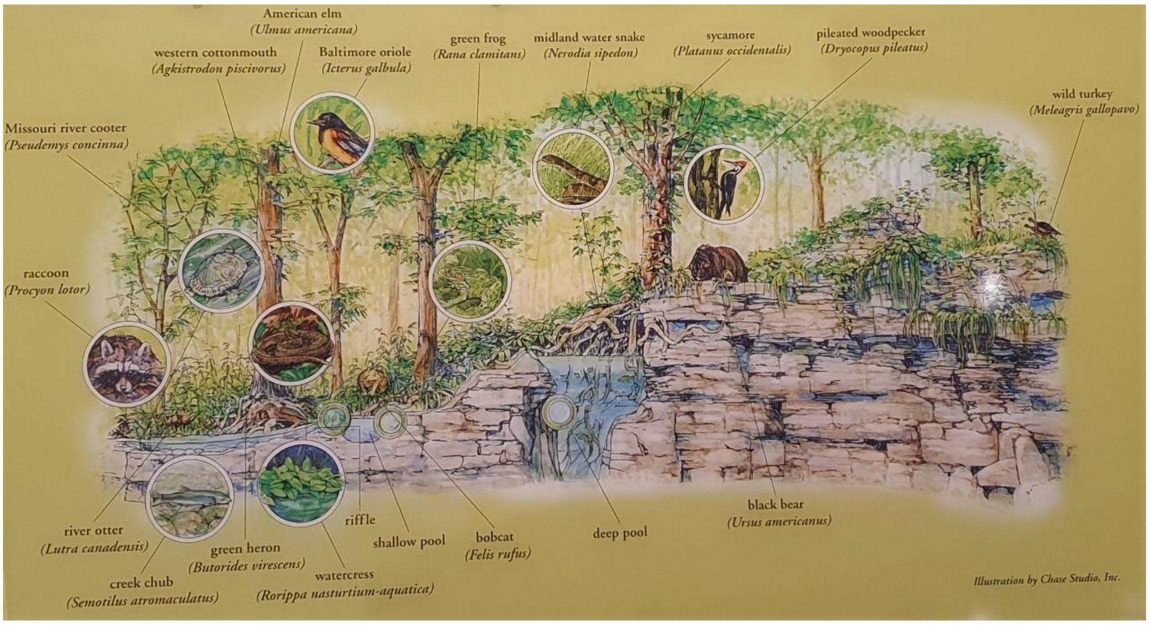


Figure 15 – Upland Stream in the Ozark Highlands, illustration by Chase Studio, Inc.

The streams in the Ozark Highlands vary greatly along their course in-depth, current, and oxygen level. Areas of rapids alternate with deeper, quieter pools. These changing factors create a great variety of stream habitats that support an abundance of life that, like the streams, differs from place to place.

Riffles are areas of fast-moving and turbulent water along a stream's course. It is home to a variety of living things. Some aquatic plants like the waterwillow do not need soft stream bottoms with slow-moving waters to root and are abundant along stream edges. They attach to underwater rocks in the riffle. Minute diatoms and blue-green algae can be very abundant, covering all surfaces in the stream bed. Riffle animals have a variety of traits to be able to survive the effects of the current. For example, the bigeye shiner (Notropis boops) it is a streamlined animal that helps to reduce the dragging force. Sculpins and the mayfly larva are flat-bodied animals that rest close to rock surfaces to avoid being picked up by currents. Some other examples of forms of life that have to adapt their bodies to live in the riffles are the stippled darter (Etheostoma punctulatum), blackfly larvae (Simulidae), riffle beetle (Elmidae), water penny beetle larva (psephenidae), caddisfly larva, and case (helicopsychdae). Some riffle-dwelling invertebrates take advantage of the current to eat the food that it carries them, this is the case of the crayfish, mussels, and some caddisfly larvae (Hydrospsychidae).

Other species like the central stroneroller (campostoma anomalum) live in the bottom of the streams eating algae preventing it from excessive growth and consequently contributing to the health of the stream ecosystem. On the other hand, predators like the largemouth bass (Micreopterys salmoides) eliminate stronerollers allowing algae to recover, which causes increasing silt on the bottom and invertebrate species to decline.
Pools are deep areas of calmer water along a stream. The current slows and drops its load of fine sediments, covering the gravel stream bed with silt. This environment is advantageous for fish but they are a challenge for small aquatic invertebrates that need moving water to survive. Each pool contains a variety of microhabitats that differ in-depth, current, structure, and temperature and may support diverse and abundant fish like the rock bass (Ambloplites), longear sunfish (Lepomis megalotis), smallmouth bass (micropterus dolomieu). On the surface of the pool, we may find fishes like the

Blackspotted topminnows that eat invertebrates that fall onto the water's surface, in the midwater the cardinal shiners that prey in groups on small invertebrates that have been washed out into the pool from the riffles and the bottom feeders like the stippled darter (Etheostoma punctulatum), the northern hogsucker (Hypentelium nigricans) and other bottom dwellers that prey on small invertebrates from the pool bottom. A deep pool is a critical breeding habitat for many fishes that lay their eggs on gravel bars, cracks, and other rocks. Some examples of these fishes are the Redspot Chub, the Crevice Spawning Minnows, and the Longear Sunfish. There are also invertebrates at the bottom of the pools that have adapted to survive.

Beneath the forest is limestone bedrock laced with caverns. In many places erosion has exposed these rocks, sometimes creating entrances to caves. . These caves have formed when groundwater dissolved underground limestone. These are homes for a variety of plants and animals like Cooper's hawk (Accipiter cooperii), western slimy salamander (Plethodon albagula), black rat snake (Elaphe obsoleta). Also, algae and a few green plants like ferns, mosses, and liverworts grow here. The limestone caves are dark, cool, moist and a perfect quiet habitat to a small and diverse community of animals Some individuals spend all of their time in the Twilight zone, while others spend part of their time outside or deeper in the cave. Surface dwellers sometimes visit the cave in search of food or shelter. Some examples of these animals are Big Brown bats (Eptesicus fuscus), Racoons (Procyon lotos), Midland water snakes (Nerodia sipedon pleuralis), Carolina mantleslugs (Philomycus carolinianus), Cave crickets (Ceuthophilus), cave salamanders (Eurycea lucifuga), cave orb-weaver spider (Meta menardi), Pickerel frogs (Rana palustri).

In the forest, we can find animals like Wild turkey (Meleagris gallopavo) Eastern chipmunk (Tamias striatus), Summer tanager (Piranga rubra), Blue jay (Cyanocitta cristata), Five lined shink (Eumeces fasciatus), Northern bobwhite (Colinus virginianus), Gray squirrel (Sciurus carolinensis), White tailed deer (Odocoileus virginianus), Downy woodpecker (Picoides pubescens). Some examples of plants and trees found in the Ozark forest are White oak (Quercus alba), Eastern redbud (Cercis canadensis), Bitternut hickory (Carya cordiformis), Poison ivy (Toxicodendron radicans), Virginia creeper

(Parthenocissus quinquefolia), Violet (Viola), Wild ginger (Asarum canadense), Boxelder (Acer negundo), and Wild geranium (Geranium maculatum).

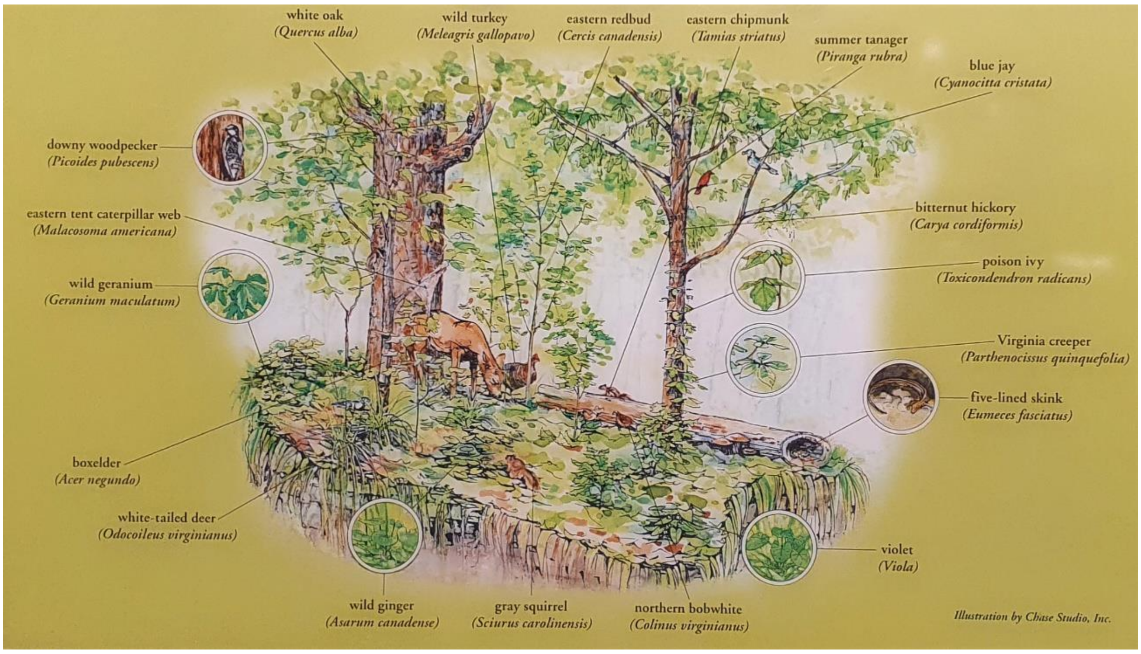


Figure 16 – Oak-Hickory Forest in the Ozark Highlands, Illustration by Chase Studio, Inc.

2.5.2 Threatened and endangered species in the study site

Threatened and endangered species *and their respective habitats* have been identified within the project extents using the Information for Planning and Consultation (IpaC) tool found in the U.S Fish and Wildlife Service's (USFWS) website. The mammals identified as potentially affected by activities in this location are the Gray Bat, the Indiana Bat, the Northern Long-eared Bat, and the Ozark Big-eared Bat.

Figure 17- Gray Bat, Indiana Bat, Northern Long-eared Bat, Ozark Big-eared Bat from left to right (IpaC)

The birds identified as being potentially impacted by construction activities were the Piping Plover and the Red Knot.

Figure 18 - Piping Plover (left), Red Knot (right)

The Clams identified as being potentially impacted by construction activities were the Neosho Mucket and the Rabbitsfoot.

Figure 19 - Neosho Mucket (Left) and the Rabbitsfoot (Right)

There are no potential effects to critical habitats in this location, no migratory birds of conservation concern expected to occur, no refuge lands, and no fish hatcheries. Unfortunately, information regarding wetlands is not available at this time.

2.6 HYDROLOGY

Figure 20, below, is of the Baron Fork River Watershed marked in yellow with an area of 345.860 mi^2.

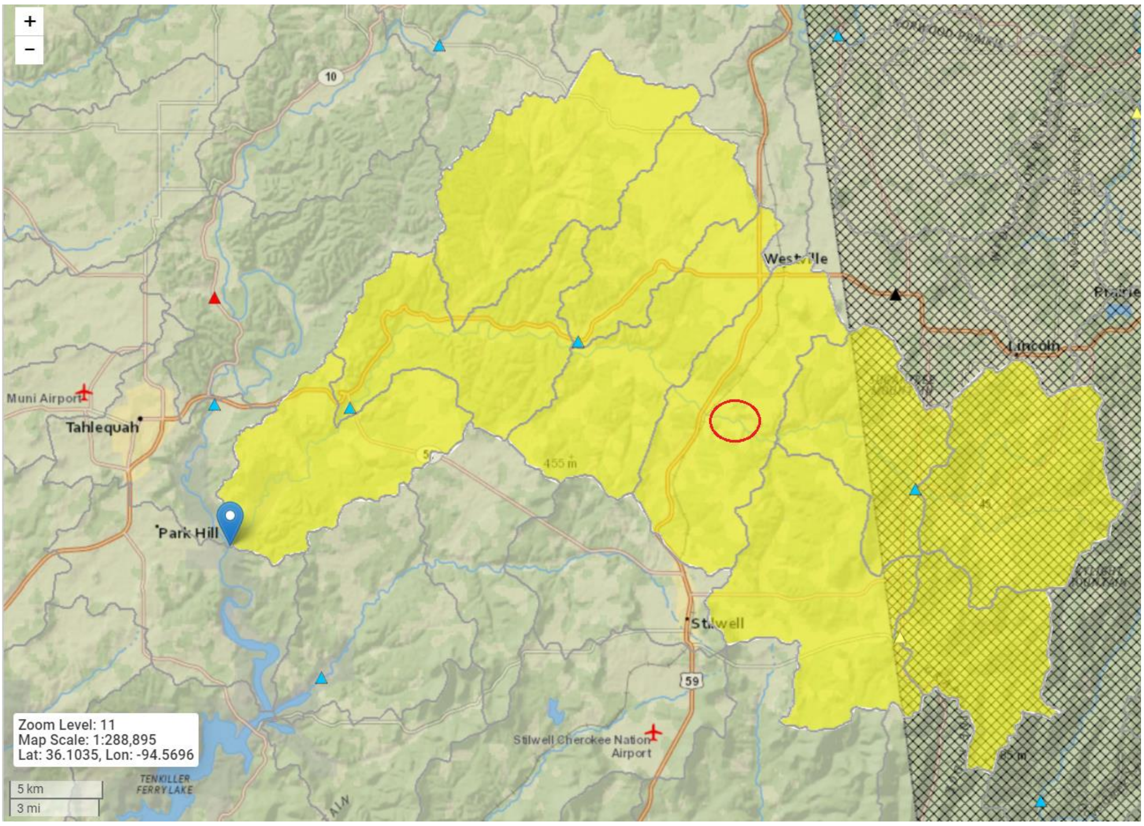


Figure 20 – Baron Fork river global watershed

This area has been calculated by importing the global watershed polygon of the Baron Fork from the USGS StreamStats website to Civil 3D as closed polylines and then checking its geometric properties. The blue location symbol on the left is where the Baron Fork meets the Illinois River, any drop of water that falls in the yellow area and does not infiltrate the soil or evaporate will end up flowing through that point. Blue triangles correspond to gauging stations. There are 3 gauging stations inside the watershed. The one on the left corresponds to station 07197000 Baron Fork at Eldon, OK, the one on the right corresponds to station 07196900 Baron Fork at Dutch Mills, AR, lastly, the one in the middle corresponds to station 07196973 Peacheater Creek at Christie, OK, this station is located in an affluent of the Baron Fork and therefore will not be used for calculation. The red circle between the gauging station 07197000 Baron Fork at Eldon, OK, and 07196900 Baron Fork at Dutch Mills, AR, is where the study area is. The gauging station 07197000, downstream of the site, is approximately 14 miles apart, and the gauging station 07196900, upstream of the site, is approximately 7 miles away following the course of the river.

To estimate the bankfull discharge the Regional Hydraulic Geometry Curves developed in the master thesis "Development of Bankfull Discharge and Channel Geometry Relationships for Natural Channel Design in Oklahoma Using a Fluvial Geomorphic Approach" by Dutnell (2000) have been used. When these Regional Curves were developed, a field survey was carried out, noting field indicators and performing a leveling survey of them, entering the level of the bankfull stage into the discharge rating curve. After determining the Bankfull discharge, its recurrence interval has been obtained doing a flood-frequency analysis using the data of the gaging stations 07197000 Baron Fork at Eldon, OK, and 07196900 Baron Fork at Dutch Mills, AR, obtained from the website of the United States Geological Survey (USGS), Surface Water for Oklahoma, Peak Streamflow. The expected recurrence interval associated with bankfull discharge was in the range of 1.0 to 2.5 years, and the value of 1.5 appears to be a reasonable average[16].

The Regional Hydraulic Geometry Curves are log-log plot curves that compare channel dimensions like top width, mean depth, and cross-sectional area at bankfull discharge versus drainage area. Dunne and Leopold (1978) presented some regional curves that show bankfull dimensions versus drainage area for various hydro-geographic provinces, including the San Francisco Bay region, the Eastern United States, the Upper Green River in Wyoming, and the Upper Salmon River in Idaho. These curves, as explained in the master thesis "Development of Bankfull Discharge and Channel Geometry Relationships for Natural Channel Design in Oklahoma Using a Fluvial Geomorphic Approach" developed by Dutnell (2000), do not apply to Oklahoma because the rainfall patterns,

[16] Leopold, "A View of the River — Luna B. Leopold."

evaporation rates, geology, topography, and land-use patterns in Oklahoma are significantly different than in the San Francisco Bay area, the Eastern United States, Wyoming or Idaho and the morphology of the streams would therefore be expected to reflect these differences. Thus, the Regional Curves used are the ones corresponding to the Ecoregions for Oklahoma derived from Omernik (1987), presented in the above-mentioned thesis. Calculations can be found in “Chapter 8 Appendices; Appendix 8.1 Hydrology calculations”. Here is a summary of the results obtained from the calculations:

Table 1 – Hydrology calculations results

RESULTS SUMMARY		
Bankfull discharge	4600	cfs.
Return interval	1.271	years
Bankfull width	155.658	Ft.
Bankfull area	907.708	sq. Ft.
Bankfull depth	5.831	Ft.
Return Interval	1.271	years

2.7 Surveying methods and equipment

2.7.1 Methodology to obtain the cross-sections and profile

The equipment used to survey the cross-sections and the profile of the site is shown figures 21 and 22:

Figure 211 – Equipment used 1

In figure 21 (left) it can be seen a hammer, wooden sticks and flagging, 1/2” re-bar pins, measuring tape, impermeable bags for the phone, maps with the coordinates of the pins and detailed enough to see natural features that might help locate the pins, a metal detector, 300-foot tape, and a small hand GPS.

In figure 21 (right), the RTK GPS equipment used to obtain the cross-sections and profile can be observed. On the left-hand side is the base, at the right-hand side is the rover and at the bottom, the box used for transportation has on top the computer that controls the equipment, the level for the base, and some extra batteries.

Because this site was previously surveyed in 1998 and 2005m the first task was to find the 1/2” re-bar pins established at each of the cross-sections that were inside the property of the ODWC. These cross-sections are XS5, XS6, XS7, and XS8. To avoid confusion, the label of each cross-section has not been re-named.

Figure 22 – Aerial photograph from 2005 showing location of cross-sections (Dutnell 2005)

To locate the pins a GPS unit, hand-drawn maps, and a metal detector was used. When the 1998 survey was conducted, coordinates of the pins were not available because a GPS unit was not used, and the only tool used to find them again in 2005 was hand-drawn maps. Fortunately, after the survey from 2005, all the GPS coordinates of the pins were obtained as shown in Table 2.

Table 2 – GPS Coordinates for Cross-Section Markers, UTM-WGS84 (Dutnell, 2005)

Cross Section	Left Pin		Right Pin	
	Easting	Northing	Easting	Northing
BF01	15 354031E	3976035N	15 354061E	3976162N
BF02*	15 354893E	3975812N	15 354921E	3975952N
BF03	15 355079E	3975787N	15 355077E	3975835N
BF04**	15 355228E	3975574N	15 355332E	3975866N
BF05+	15 355710E	3975538N	15 355674E	3975769N
BF06	15 356076E	3975382N	15 356229E	3975482N
BF07	15 356517E	3974936N	15 356708E	3975034N
BF08	15 357167E	3974425N	15 357179E	3974540N

* The left pin shown in the Table is actually the center pin. The left pin was not located.
** A center pin was also added at: 15 355308E and 3975779N.
+ The original left pin was not found. The value shown is of a new pin that was set.

However, due to the low precision of the GPS unit, especially under the trees, which would locate the pins within a range precision of 20 feet, the hand-drawn maps were crucial as they contained natural features such as big rocks or tree descriptions which helped a lot to finally find the pins.

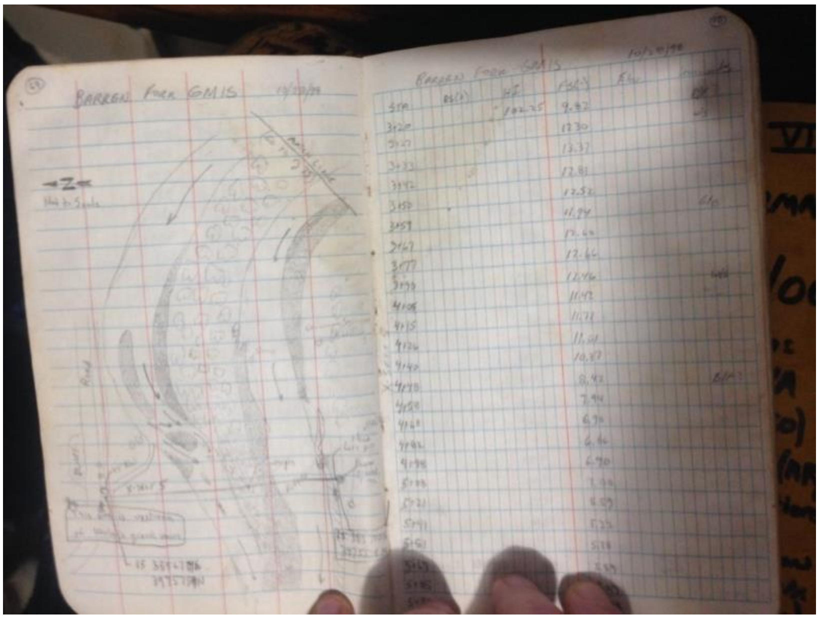


Figure 23 – Example of one of the drawings used to locate the pins from the field notebook (Dutnell 1998)

Figure 24 shows the GPS Oklahoma North State Coordinates of the pins of cross-sections 8, 7, 6 and 5 used for the 2021 survey:

Figure 24 – GPS Coordinates of the 2021 survey used for the cross-sections (Oklahoma North State Coordinates)

From the 8 pins, 2 for each of the 4 cross-sections, only 3 were found. Left pin at cross-section 8, left pin at cross-section 7, and the left pin at cross-section 5. The reasons why the rest were not found were different. The right pin at cross-section 8 was washed out. The right pin at cross-section 7 was not found due to the dense vegetation that had been growing over the past 23 years (all the pins were installed in 1998 and never removed, except for the left pin in cross-section 5 which was washed away and replaced in a new location in 2005) and also it was probably buried a few inches due to the deposition of sediments. In cross-section 6, neither the left pin nor the right one was founded due to the fences that were next to them. The wire interfered with the metal detector making it very hard to find them, even though different techniques were used. Also, the dense vegetation and deposition of sediments did not help. Evidence such as fallen trees where the right pin at cross-section 5 was, indicated that it had been washed away too. Therefore, after looking for the pins, the ones founded were flagged to make it easier to find them again. The good thing is that the 3 pins founded were for different cross-sections, and knowing the width of the cross-sections and the direction where the pin of the other bank was, it was easy to estimate where the other pins should be. Using the best judgment, the pins that were not found were replaced as close as possible to the original ones.

Cross-sections were re-surveyed using RTK GPS during different days of the month of July 2021. Because the position of the satellites depending on the day and the time can affect the precision of the equipment, different control points were established. Their coordinates were obtained every time before starting the surveys, that way, after processing the data in Civil 3D all the points obtained that day could be moved together with the control point from that day to the position where that control point was supposed to be. That way the error from surveying during different days was eliminated.

The cross-sections have been plotted 2 times, the first one would be the actual values obtained directly from the surveys and the second one called "corrected cross-section" drawn in a dashed line is, as the name indicates, a manual correction of the original cross-sections that have been made due to possible errors. Further discussion and explanation of this can be found in "Chapter 3 Channel stability assessment; Section 3.1 Channel change over the past 23 years using historical surveyed data of the site (1998 & 2005)"
Regarding the longitudinal profile, the same equipment was used. The procedure consisted of obtaining every 150 feet approximately, the coordinates of the thalweg, and the water surface at the left and at the right bank of the river. All the pictures and the drawings of the cross-sections and the longitudinal profile can be found in "Chapter 8 Appendices; Appendix 8.4 Sketches; Cross-section 5, 6, 7, 8".

2.7.2 Methodology to obtain current aerial imagery and topography

To obtain current aerial imagery and topography of the site, an ATI AgBot, a drone for precision agriculture applications, provided by the University of Oklahoma was used. The drone is outfitted with the MicaSense RedEdge for capturing valuable multispectral imagery, is fully autonomous, and the installed sensor package was NDVI (Normalized Difference Vegetation Index). It provides very valuable information such as DTM (Digital Terrain Model) used to draw the contour lines, DSM (Digital Surface Model), and also current aerial photography.

Figure 25 - ATI AgBot

To obtain the current topography of the site, the DTM (Digital Terrain Model) file obtained from the flights of the drone over the study area was needed. Before flying, some things needed to be arranged. First of all, make sure to look at the sectional charts and make sure the airspace was not restricted (which was the case). Then the target area had to be defined, the Agbot drone uses mission planning software to autonomously fly the desired area, however, the whole area was too big to fly with a single set of batteries and different polygons had to be drawn as shown in figure 26, each of them corresponding to individual flights and making sure the overlapping was enough to reduce the probability of having blind spots. The size and shape of these polygons depended on the duration of the batteries which ranged between 16 and 20 minutes, the height at which the drone was flying, and the speed. The higher and the faster the drone flies the more it can be surveyed with a single set of batteries, however, the higher and faster the less the image quality. Therefore, a compromise between these factors was needed. The order of magnitude used for each flight was: Surveyed area: 1 000 000 sq. feet; Flying height: 328 feet; Flying speed: 50 feet/second; Flying time: 12-13 minutes.

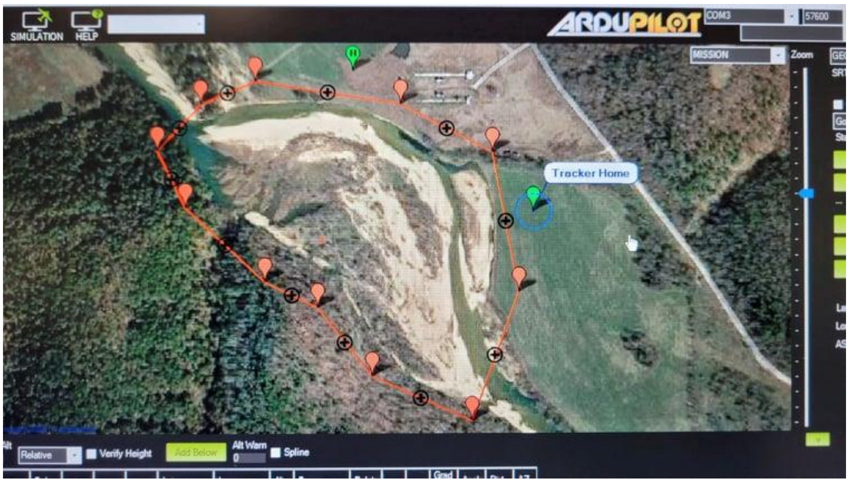


Figure 26 – Drone single flight mission example

Once all the flying missions were completed and the multispectral imagery was obtained, the MicaSende Sensor data was processed to obtain the DSM and DTM, with the software "Pix4Dmapper" following the steps explained on their website[17].

It is important to mention that due to the capacity of the batteries the flying missions were completed in two different days and therefore because the position and the number of the satellites available were different, the coordinates could vary from one day to another. To solve this problem, different control points were established as shown in figure 27.

Figure 27 – Example of one of the control points

[17] https://support.micasense.com/hc/en-us/articles/115000831714-How-to-Process-MicaSense-Sensor-Data-in-Pix4D

Each of the three different flights had in common at least 2 control points to make sure the elevations and rotations matched between them. Once all three were plotted together and corrected using the elevations it looked like figure 28.

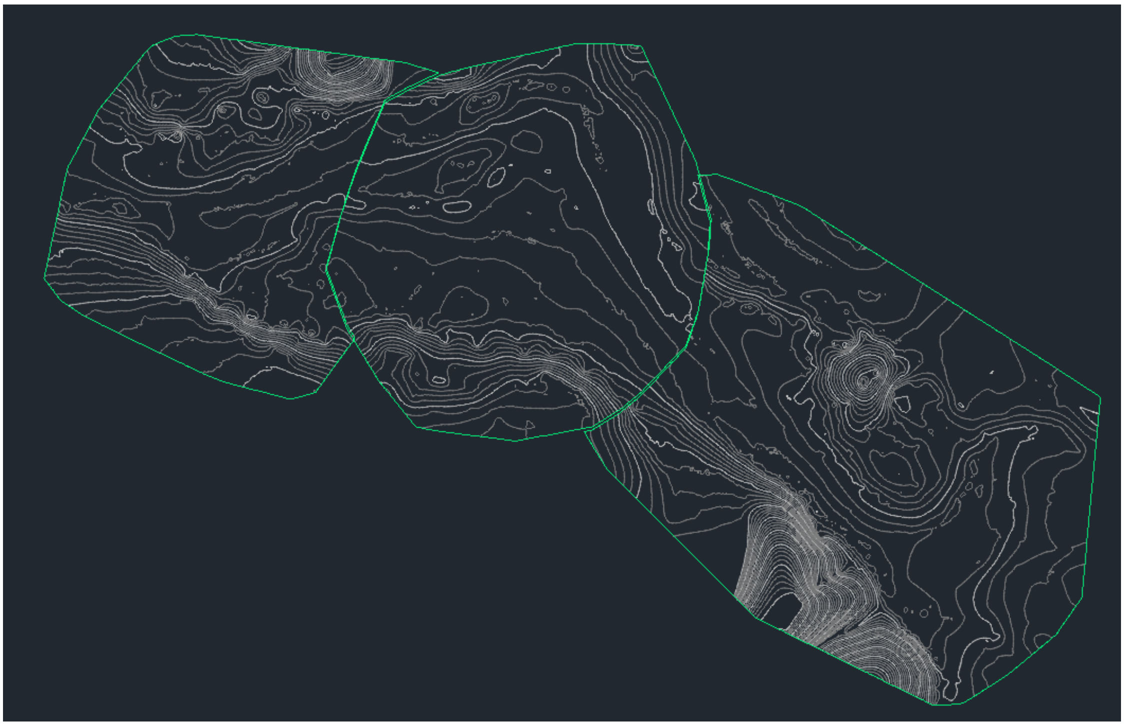


Figure 28 – Contour lines extracted from the DTM of the drone flights

The next step was to create one single surface using the three separate surfaces from figure 28. Even though the AgBot captures the terrain elevation and it can shoot through the bushes, it cannot do it through water, consequently, the coordinates of the bottom of the channel were not well represented by the contour lines extracted from the drone imagery. It was necessary to combine the DTM from the drone imagery with the GPS RTK data. To do that, first, the elevation of the contour lines from the surface created out of the three flights was adjusted by moving its control points to match the elevation and position of the control points measured with the GPS RTK (which were the same control points). Once they matched, a polygon over the surface created out of the three flights was drawn along the river channel to make a boundary, then the existing elevation information was replaced with the new channel surface created out of the point cloud obtained from the

GPS RTK assessment, as shown in figure 29 (top). Finally, a single surface was created combining both datasets as shown in figure 29 (bottom):

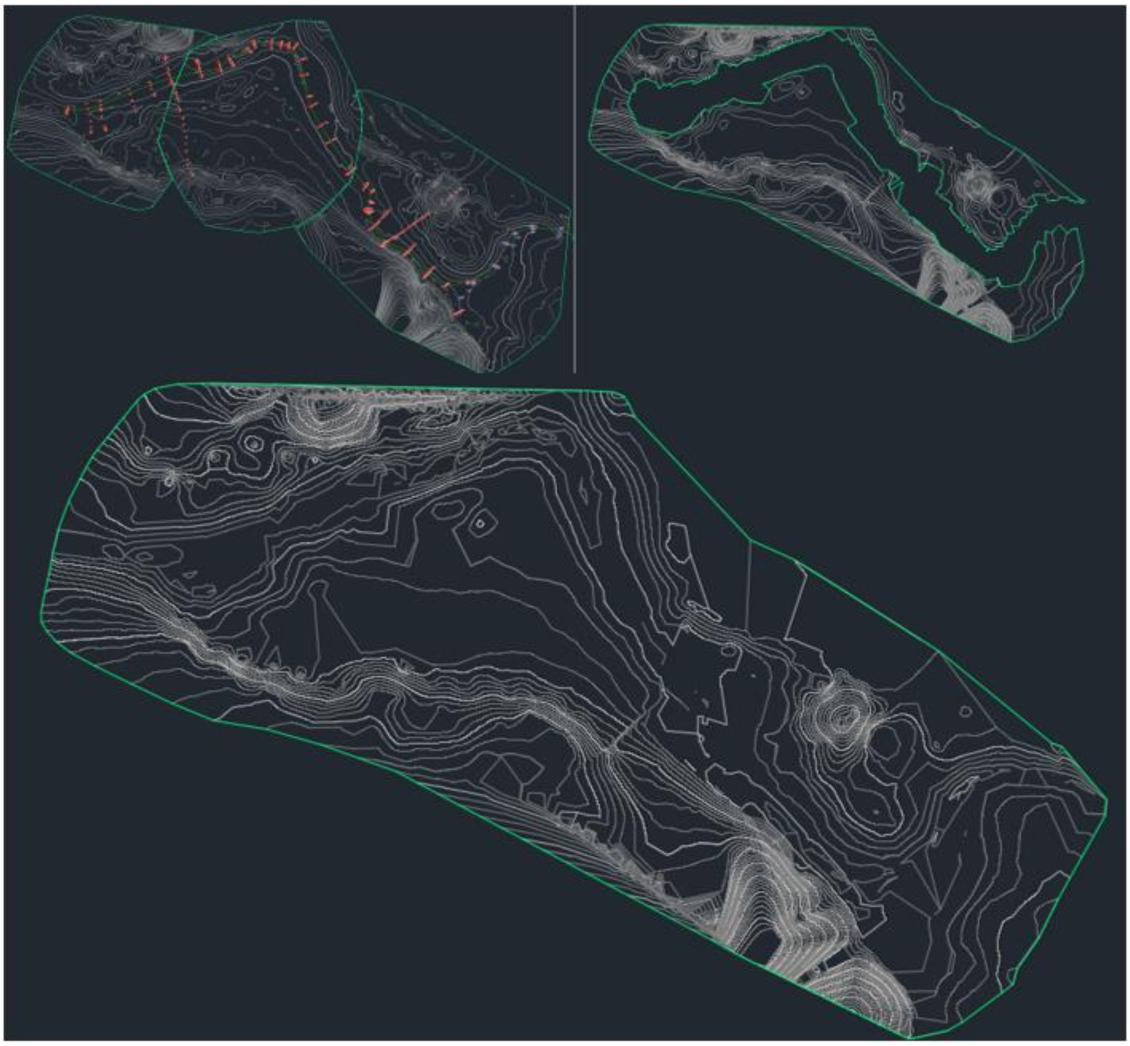


Figure 29 - Contour lines extracted from the DTM of the drone flights with the surveyed GPS RTK points on top (top-left) and polygon contour drawn to replace the drone data with the RTK GPS data (top-right) and Contour lines combining the data from the drone's DTM with the RTK GPS data to represent the topography of the floodplain together with the bottom of the channel (bottom)

2.8 Stream channel classification

Level II stream classification consists of determining the entrenchment ratio, width/depth ratio, sinuosity, bed slope/channel profile, and the dominant bed material.

2.8.1 Entrenchment ratio and width/depth ratio

The geometry of the cross-sections has been obtained using an RTK GPS as explained in the previous section, Chapter 2 Site description; Section 2.7 Methodology to obtain the cross-sections and profile”. Then the bankfull level was established by observing natural features during the survey and comparing it with the processed data to see if it matches with the terrain where it flattens. The width of the flood-prone area has been measured at an elevation twice the maximum bankfull depth. It is relevant to mention that when the cross-sections were measured, the total width of the flood-prone area at an elevation twice the maximum bankfull depth was not surveyed. The way it has been calculated is by using the data from the drone flights which allowed to created contour lines and knowing the elevation of the flood-prone area, it was possible to calculate the intersection with the contour lines and measure the width. This was only possible to do it for cross-section 5 and 6 because 7 and 8 were not flew with the drone and therefore, data from the contour lines were not available. However, looking a the cross-sections it was possible to predict if the values of the width were going to be big enough to have an entrenchment ratio higher than 2.2 or not.

The results and drawings are shown in “Chapter 8 Appendices; Appendix 8.4 Sketches; Cross-section 5, 6, 7, 8 Level II Classification”. As an example, a drawing of cross-section 5 has been provided in figure 30.

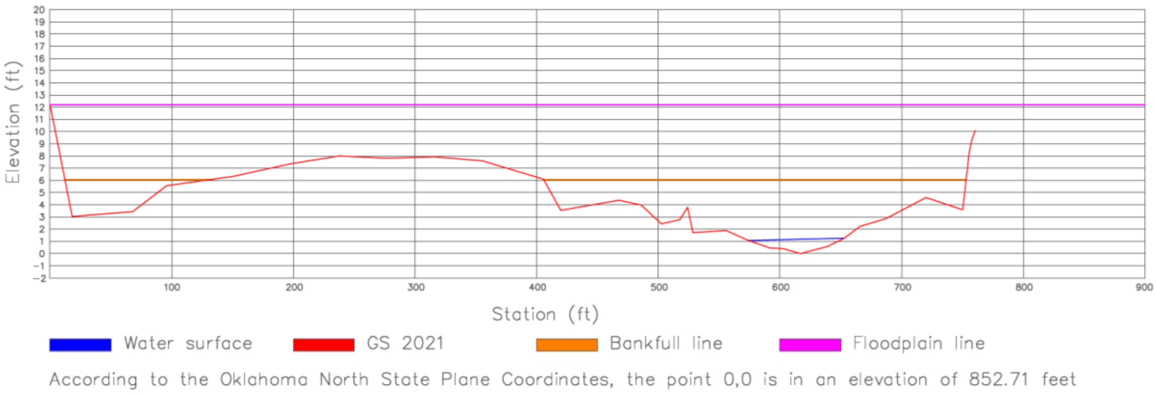


Figure 30 – Cross-section 5 for level II classification

This is the summary of the results of the width depth/ratio and the entrenchment ratio for the 4 cross-sections that were surveyed along the river.

Table 2- Entrenchment and Width/Depth ratio calculation summary

Cross-Section	Bankfull width	Bankfull area	Bankfull depth	Width/Depth ratio	Flood prone width	Entrenchment ratio
XS8	387.428	2003.590	5.172	74.916	> 800 feet (approx,)	>2.2
XS7	220.340	342.490	1.554	141.755	780 (approx.)	>2.2
XS6	326.433	1137.141	3.484	93.707	600.000	1.838
XS5	469.000	1411.926	3.011	155.788	866.810	1.848

In all cases, the Width/Depth ratio is higher than 1.2 and 2 cross-sections have an entrenchment ratio higher than 2.2 and the other 2 cross-sections have an entrenchment ratio close to 2. Further discussion on this can be found in section 2.8.5 Results of the classification.

2.8.2 Sinuosity

The sinuosity is defined as the stream length/valley length or valley slope/channel slope.

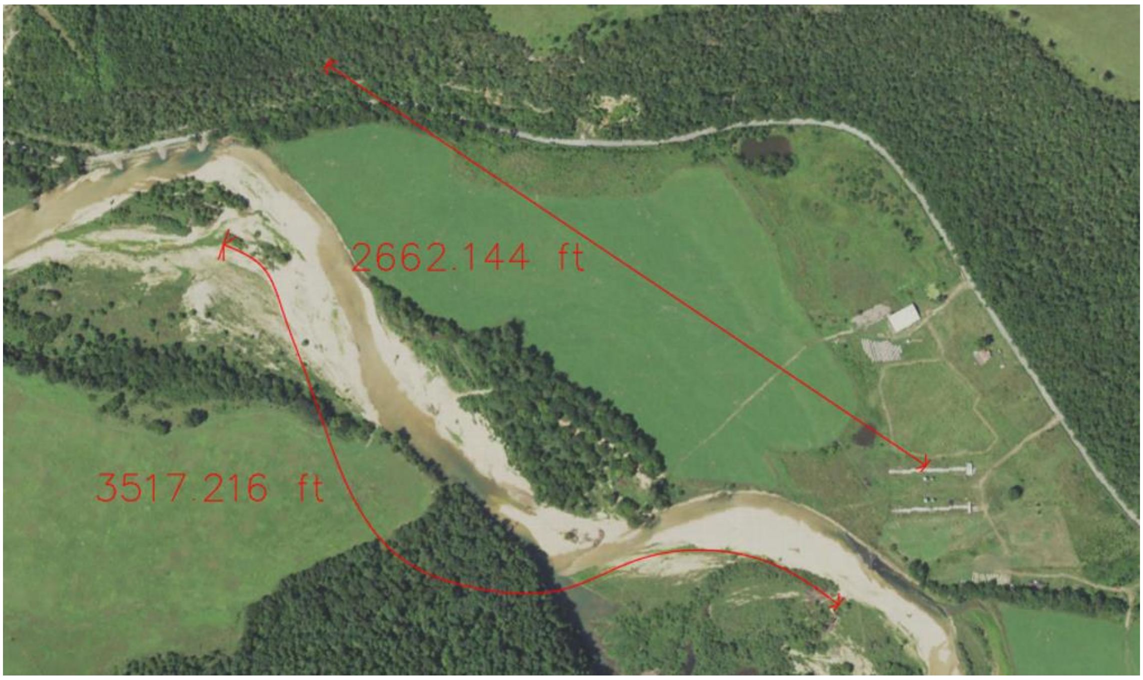


Figure 31 – Length of the stream channel and length of the valley

$$Sinuosity = \frac{Stream\ lenght}{Valley\ length} = \frac{3517.216}{2662.144} = 1.321$$

Therefore the sinuosity is higher than 1.2.

2.8.3 Slope

The slope of the water surface is usually averaged for 20 to 30 channel widths. Using aerial imagery it can be assumed that the mean channel width is approximately 250 meters. Using the data from the longitudinal profile of the water surface that can be found in more detail in "Chapter 8 Appendices; Appendix 8.4 Sketches; Longitudinal profile 1/3, 2/3, 3/3", it can be estimated that the water level drops 13.41 feet in 7500 feet, therefore:

$$30 \times Channel\ width = 30 \times 250 = 7500 \text{ feet}$$

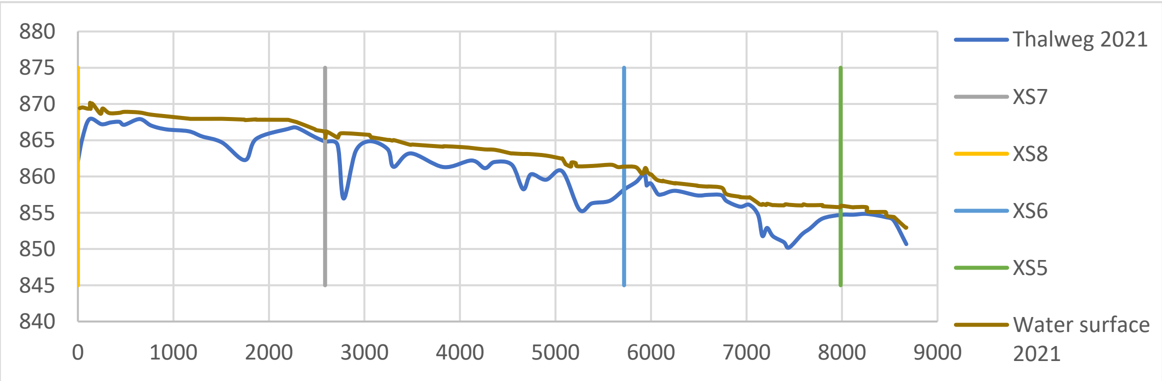


Figure 32 – Thalweg and water surface of the channel

$$Slope = \frac{13.41}{7500} = 0.001788 < 0.02$$

Therefore the slope of the river is lower than 0.02.

2.8.4 Dominant bed material

The dominant bed material in the Baron Fork River is gravel, as the results of the pebble count show and as can be seen in Figure 33, obtained in one of the site visits.

Figure 33 – Site image showing the gravel as the dominant bed material

Channel bed and bank materials influence the cross-sectional form, plan view, and longitudinal profile of rivers; they also determine the extent of sediment transport and provide the means of resistance to hydraulic stress. An assessment of the nature and distribution of channel materials is critical for interpreting the biological function and stability of rivers.[18]

[18] D. Rosgen. Applied River Morphology. Wildland Hydrology Pagosa Springs, Colorado, 1996.

The procedure that has been followed consisted of, first, selecting the portion of the reach to be measured. The portion that has been chosen is where the erosion problems are more severe, where the river is impinging on the road. In particular, 3 peeble counts samplings have been carried out in this area, one upstream another one in the middle, and a last one downstream. Once the site has been selected, the second part is collecting and measuring. Most Standard Operating Procedures (SOP) recommend collecting and measuring a minimum of 100 particles per sample. Starting on the shoreline and averting the gaze the first particle touched by the tip of the index has been picked up. Then the intermediate diameter has been measured as shown in figure 34.

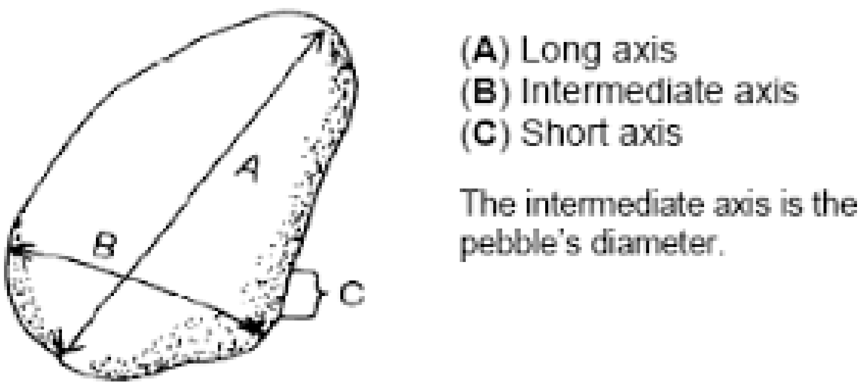


Figure 34 – Peeble count- axis of a peeble

This procedure has been continued across the channel towards the opposite bank, picking up more particles until having 100 measurements per sample.

The results show that the dominant bed material in the Baron Fork channel is gravel. The following illustration is an example of one of the three particle size distributions that have been plotted for this part of the study. The rest of the results are summarized in "Chapter 8 Appendices; Appendix 8.2 Peeble count calculations".

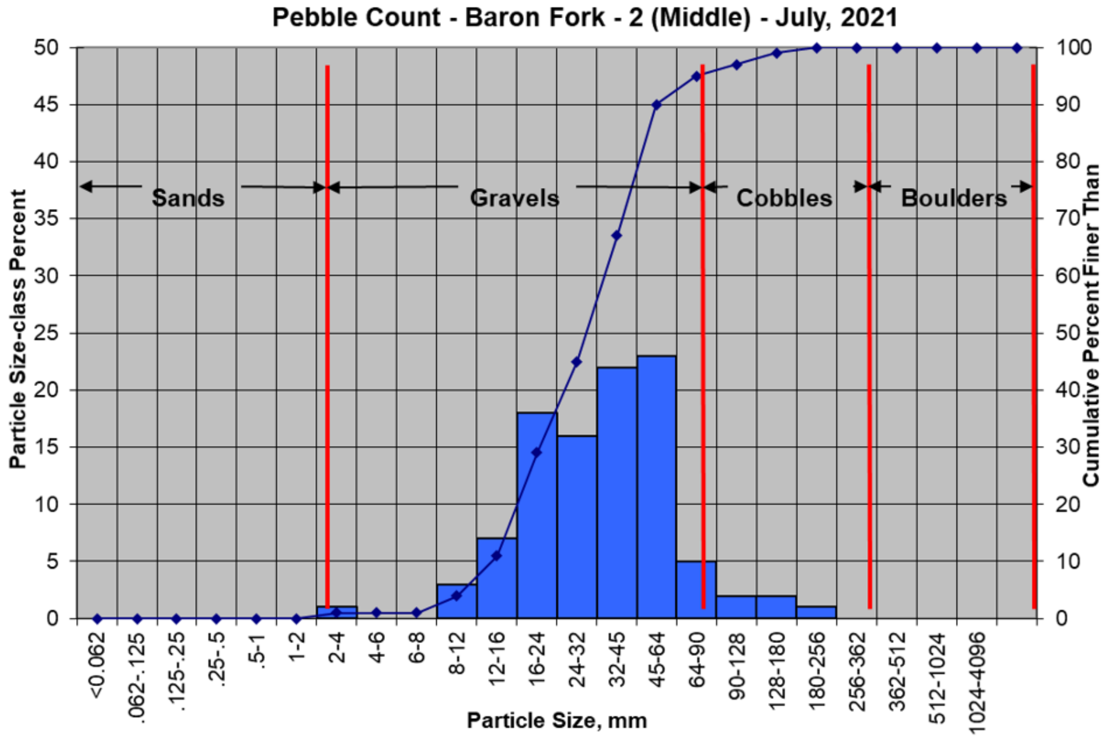


Figure 35 – Particle size distribution obtained from the Pebble count nº 2

2.8.5 Results of the classification

Figure 36 illustrates the different stream types according to Rosgen Classification:

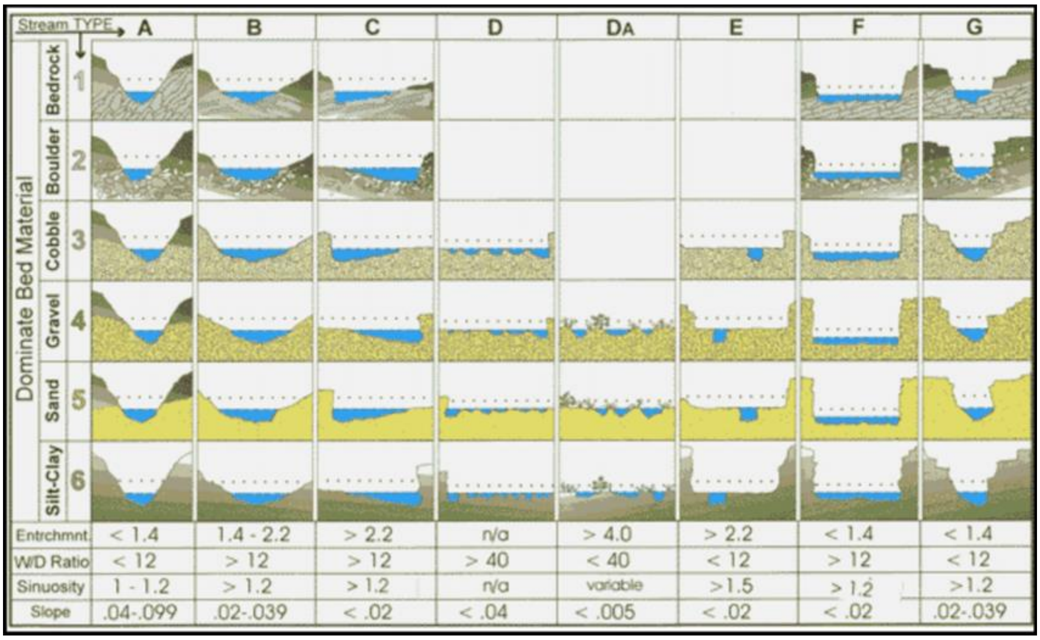


Figure 36 - Primary delineative criteria for the major stream types

According to the above-mentioned results, the Baron Fork river is predominantly a C4 channel based on Rosgen Level II which is characterized by the following parameters:

Table 3 – C4 Stream parameters according to Rosgen Level II Classification

Entrenchment ratio	>2.2
W/D ratio	>12
Sinuosity	>1.2
Slope	<0.02

It is true that at two of the cross-sections the entrenchment ratio was 1.84 and 1.85 which are values lower to two. However, this can be due to the fact that the established bankfull level was not well measured. This error is very common as the bankfull level is measured observing natural features and this can sometimes lead to human mistakes. It has been checked that slightly increasing the bankfull height, the width of the flood-prone area would be enough to give an entrenchment ratio higher than 2.2.

The C4 stream type is a slightly entrenched, meandering, gravel-dominated, riffle/pool channel with a well-developed floodplain. These channels, characterized by point bars and other depositional features, are very susceptible to shifts in lateral and vertical stability caused by flow changes and sediment delivery from the watershed. The stream-banks are generally composed of unconsolidated, heterogeneous, non-cohesive, alluvial materials that are finer than the gravel-dominated bed material. Consequently, the stream is susceptible to accelerated bank erosion.[19] C4 stream channels have slopes less than 2%, a high width/depth ratio, higher than 12, they are more sinuous and have a higher meander width ratio than the C1, C2, and C3stream types. The riffle/pool sequence averages 5 to 7 times the bankfull channel widths in length.

[19] D. Rosgen, *Applied River Morphology* (Wildland Hydrology Pagosa Springs, Colorado, 1996).

CHAPTER 3
CHANNEL STABILITY ASSESSMENT

To assess the stability of the channel, spatial and temporal scales have been evaluated. Spatial scales deal with specific locations and shifts in dimension, pattern, profile, and materials. Temporal scales evaluate changes at the same location over time.

As described in previous chapters, David Rosgen defined river stability as "the river's ability in the present climate to transport the streamflows and sediment of its watershed, over time, in such a manner that the channel maintains its dimension, pattern, and profile without either aggrading or degrading"

Section 3.1.1 of this chapter shows the change in the channel dimension, comparing permanent cross-sections that have been re-surveyed over the past 23 years providing specific results of bed stability (aggradation or degradation), channel enlargement, and lateral accretion. This section also includes an analysis of the longitudinal profile changes over the same period of time, looking at changes in bed features, aggradation, degradation, and slope.

Section 3.1.2 compares the change in pattern, allowing to do a time-trend aerial photography analysis to determine both temporal and spatial scale changes in meander geometry and channel sinuosity.

Section 3.3 Provides a specific analysis of the streambank erosion rates at two specific reaches using aerial imagery and comparing the results to the ones that would have been predicted by the Bank Erosion Hazard Index (BEHI), the Near Bank Stress index (NBS), and the Ozark Stability Erosion Potential Index (OSEPI).

Detailed drawings of this section can be found in "Chapter 8 Appendices; Appendix 8.4 Sketches".

3.1 CHANGES IN CHANNEL DIMENSION, PATTERN, AND PROFILE

3.1.1 Channel change over the past 23 years using historical surveyed data of the site (1998 & 2005)

As part of the fluvial geomorphic assessment of the impact of the Worley gravel mining operation on the channel stability and sediment transport carried out for the first time in 1998 and for the second time in 2005 by Russell Dutnell, eight cross-sections were selected for monitoring and determining the extent of any potential impacts both downstream and upstream from the gravel mine and to assess future downstream and/or upstream migration of the impacts. Of those eight cross-sections, only four (cross-sections 5, 6 7, and 8) have been re-surveyed as part of this study and they are all upstream of the gravel mine. It is important to remember that this project does not aim to re-analyze the impacts of the gravel mine itself but to re-survey the site providing a channel stability assessment on the property acquired by the Oklahoma Department of Wildlife and Conservation (ODWC) to identify the most critical areas that might need some restoration and protection of existing infrastructures. For that reason, only the four cross-sections that are inside the property, cross-sections 5, 6, 7, and 8 have been re-surveyed.

Thanks to the existing historical data, which is not very common to have, and the new surveyed data, comparisons of cross-sections 5, 6, 7, and 8 over the past 23 years are possible allowing observation of aggradation or degradation, channel enlargement, and lateral accretion. Also, the existing historical longitudinal profiles allow comparison of them with the current profile, looking at changes in bed features, aggradation, degradation, and slope.

Figures 37, 38, 39, and 40 compare the cross-sections from 1998, 2005, and 2021. It is important to consider that the water surface level showed in the graphs corresponds to the water level measured during different days of the month of July 2021. The Y-axis has been scaled 10 times the X-axis in order to show vertical variations more clearly. Another thing to consider is that cross-sections 5, 6, and 7 have been plotted two times. The first plot (the one on the top) represents the cross-sections as it was surveyed, plotting directly the obtained values, and the second plot (the ones at the bottom), containing some dashed-lines that indicate that a manual correction of the original cross-sections that were made due to possible field errors.

Cross-section 5

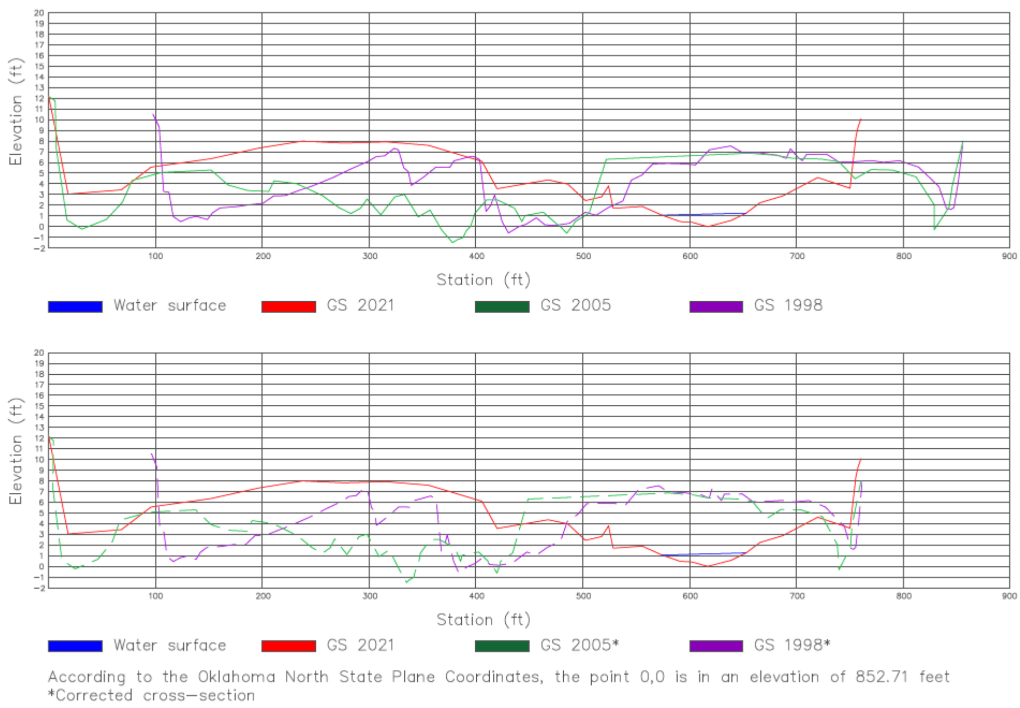


Figure 37 – Cross-section 5 evolution

There was evidence such as fallen trees that the right pin from 1998 at cross-section 5 had been washed away at some time during the period 2005-1998. The left pin from 1998 was washed away at some time during the period 1998-2005 and that is why in 2005 a new pin was located. This left pin from 2005 was found in the 2021 survey and therefore it was possible to start measuring the cross-section from there. Once the data was plotted it can be seen that the width of the cross-section from 2021 is way shorter than the one from 2005 which should not be the case. That is why the plot has been corrected doing some assumptions. Cross-section 5 in 1998 and 2005 was measured with a 300-foot tape. The width of this cross-section is 760 feet. To measure the entire cross-section, the tape had to be removed and set up again at least 3 times due to its short length. This procedure can lead to error due to zig-zagging instead of walking in a straight line. That is why it is assumed that the length of the width measured in 2005 is 856 feet, which is 96 feet longer than the one measured in the 2021 assessment. The procedure to assess this cross-section consisted of flagging the trees where the extremes of the cross-sections were, intending to be able to see both ends all the time, and make sure the measurements were taken in a straight line. However, due to the dense vegetation that had been growing during the past years, it was not possible to see both flaggings at every point of the cross-section. Fortunately, this time 2 people were taking the measurements, and while one was looking at the end of the cross-section the other one was taking the measurements communicating, and following the indications of each other. This way, it is considered that measurements were taken more accurately than in the previous assessments and the 1998 and 2005 cross-sections have been adjusted, distributing the entire error among each of the points, to fit the width that it has been assumed they were supposed to have.

Cross-section 6

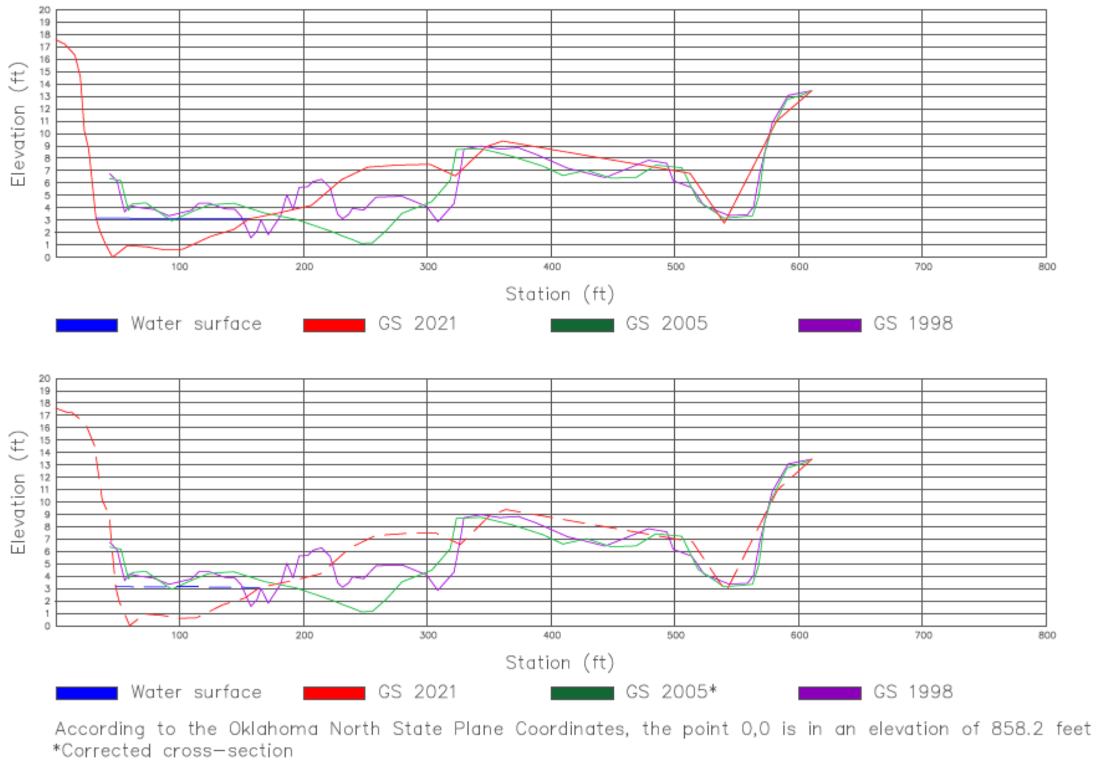


Figure 38 - Cross-section 6 evolution

In cross-section 6, neither the left pin nor the right one was founded due to the fences that were next to them. The wire interfered with the metal detector making it very hard to find them, even though different techniques were used. Also, the dense vegetation and deposition of sediments did not help.

<u>Cross-section 7</u>

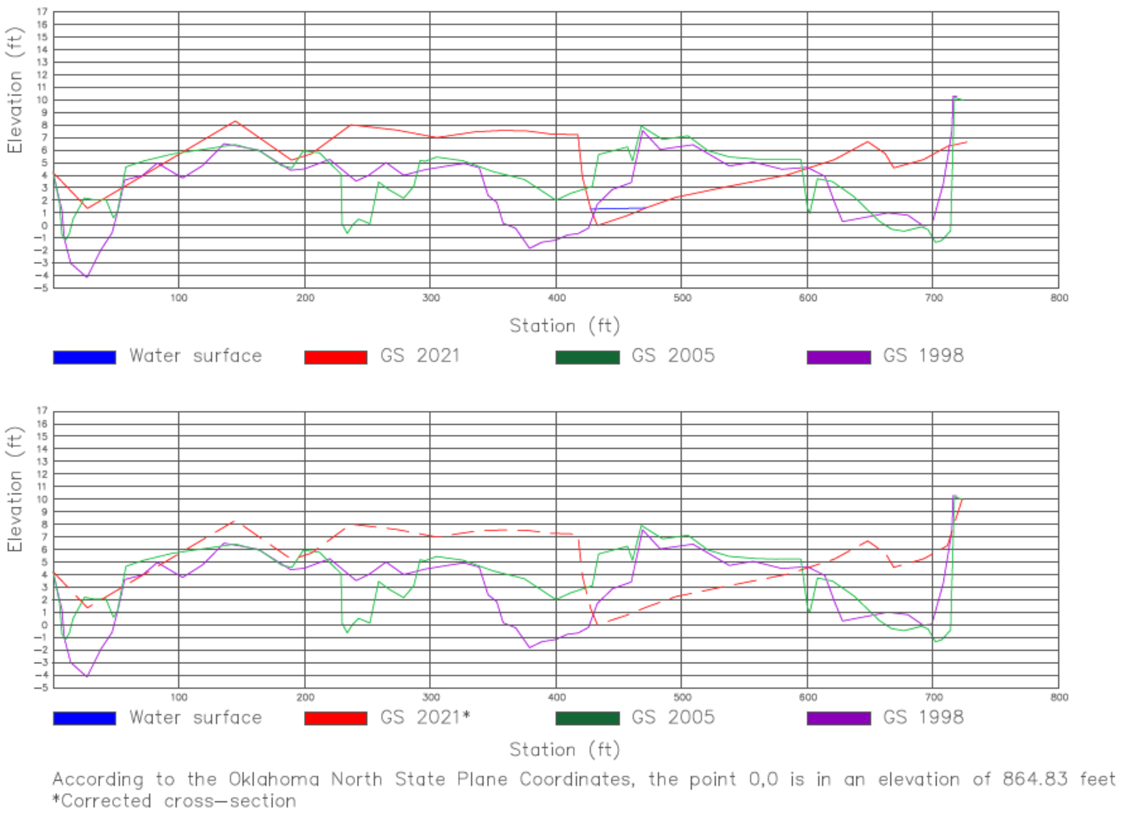


Figure 39 - Cross-section 7 evolution

The right pin at cross-section 7 was not found due to the dense vegetation that had been growing over the past 23 years. It was possible that the pins were buried a few inches due to the deposition of sediments.

Cross-section 8

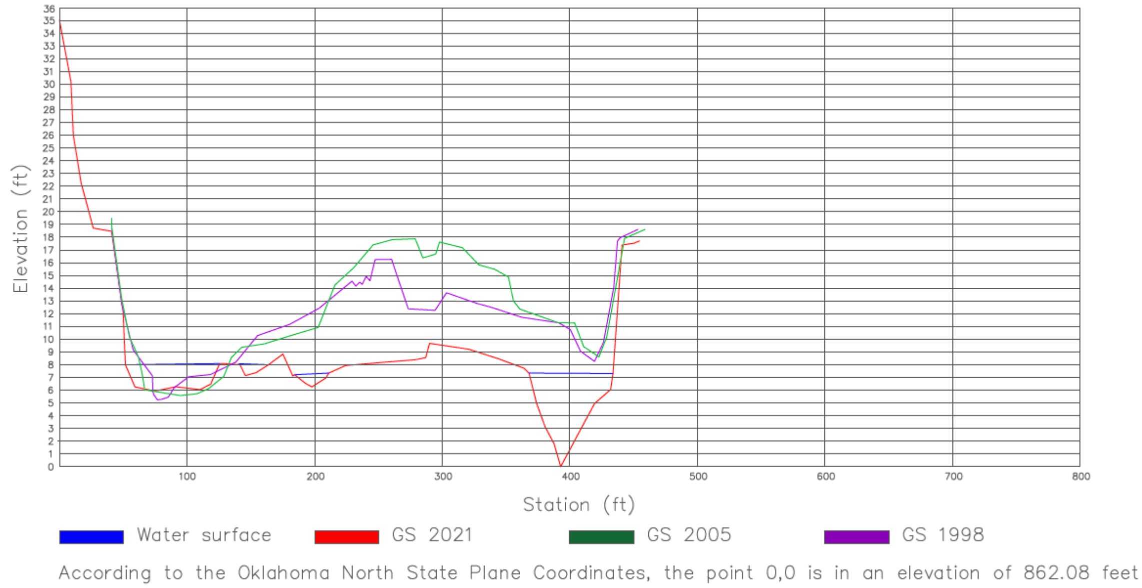


Figure 40 - Cross-section 8 evolution

The right pin at cross-section 8 was not located and appears to have been washed out.

Due to the fact that not all the pins were founded, and some manual calibrations had to be made, these graphs should not be used for a true comparison, except to see how the thalweg and depositional areas have shifted from one place to another.

Figure 41 shows how the longitudinal profile has changed over the years. (See appendix 8 for a more detailed image).

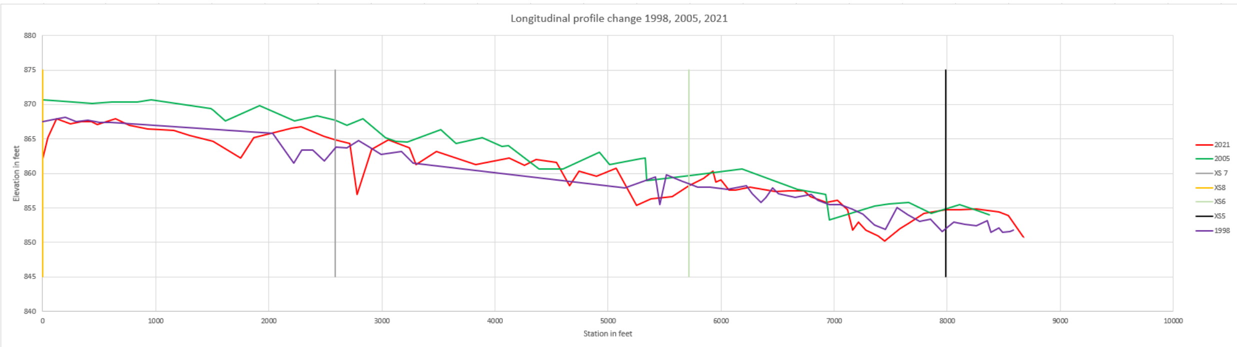


Figure 41 – Longitudinal profile change 1998, 2005 and 2021

The global longitudinal slope does not seem to have changed much, only the position of the pools and slopes. True comparison about if the river is aggrading or degrading cant be done because the equipment used for the surveys was different and the coordinates obtained in 1998 and 2005 were adjusted to be plotted with the ones of 2021. However, the results seem to reinforce the assumptions extracted from the cross-sections. In between cross-sections 5 and 7, even though it is clear that in 1998 the river bed had fewer sediments compared to 2005 it seems that in the long-term it balanced, as the 2021 profile is in between the other 2. However, the reach in between cross-section 8 and a few hundred feet further downstream cross-section 7, seems to be degrading.

3.1.2 Channel change over the past 55 years (1964-2019) using historical aerial photography

Aerial photography is a great tool for assessing geomorphic changes to a river over time. The years covered include 1994, 2003, 2005, 2008, 2010, 2015, 2017, 2019 and 2021. All the aerial images were obtained from the website of OKMaps[20], except the one from 2021. The images for 2021 were not published yet on the OKMaps website. Instead, an ATI AgBot, a drone for precision agriculture applications, provided by the University of Oklahoma was used. The drone description and its utilities are described in "Chapter 2 Site description; Section 2.7.1 Surveying methods and equipment – Methodology to obtain current aerial imagery and topography".

Once all the images were downloaded, a layered system such as Autocad was used to evaluate how the plan form has changed over time and therefore, estimate how is it going to change in the future. Figure 42 shows tracings of the river from all of the available aerial photos, they can be found in more detail in "Chapter 8 Appendices; Appendix 8.4 Sketches; Channel evolution 1/4, 2/4, 3/4, 4/4".

[20] https://okmaps.org/ogi/search.aspx

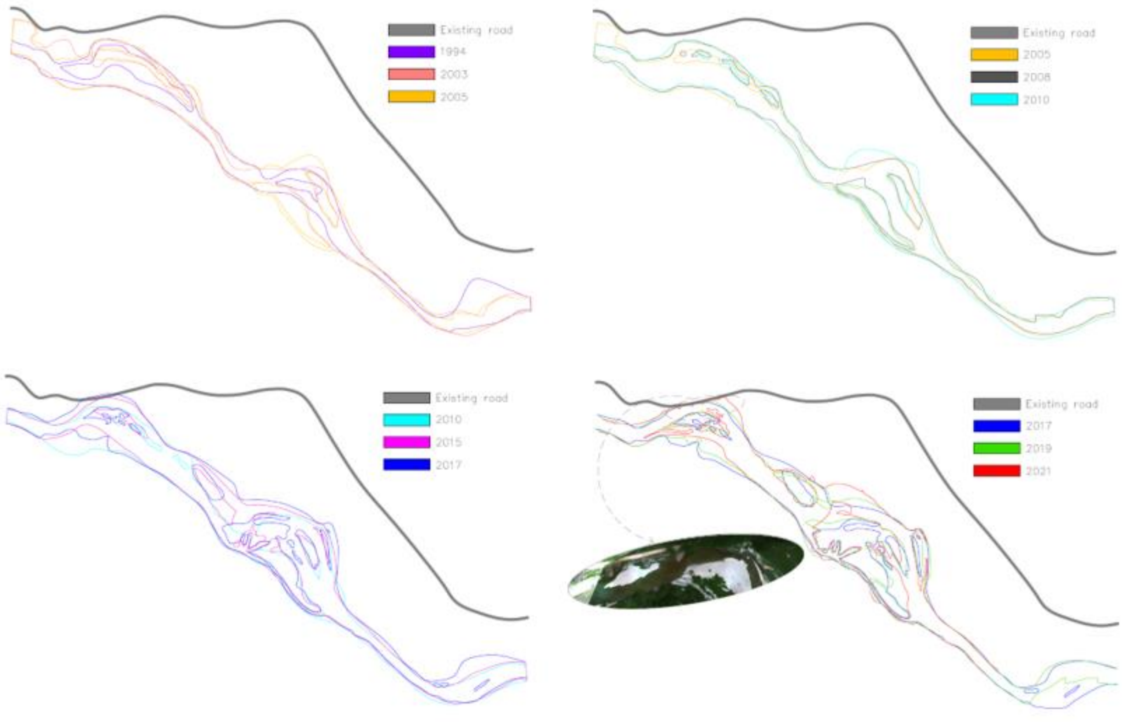


Figure 42 – Tracings of the river from 1994 to 2021

It can be seen how the channel has become more braided over the years but the meander belts have remained in roughly the same relative position, moving out slightly down the valley.

3.1.3 Analysis of the results

The following figure illustrates a combination of the tracings of the river obtained from the aerial imagery of the lower part of reach, from 1994, 2005, and 2021 and the evolution of cross-sections 5, 6, and 7 over the same period.

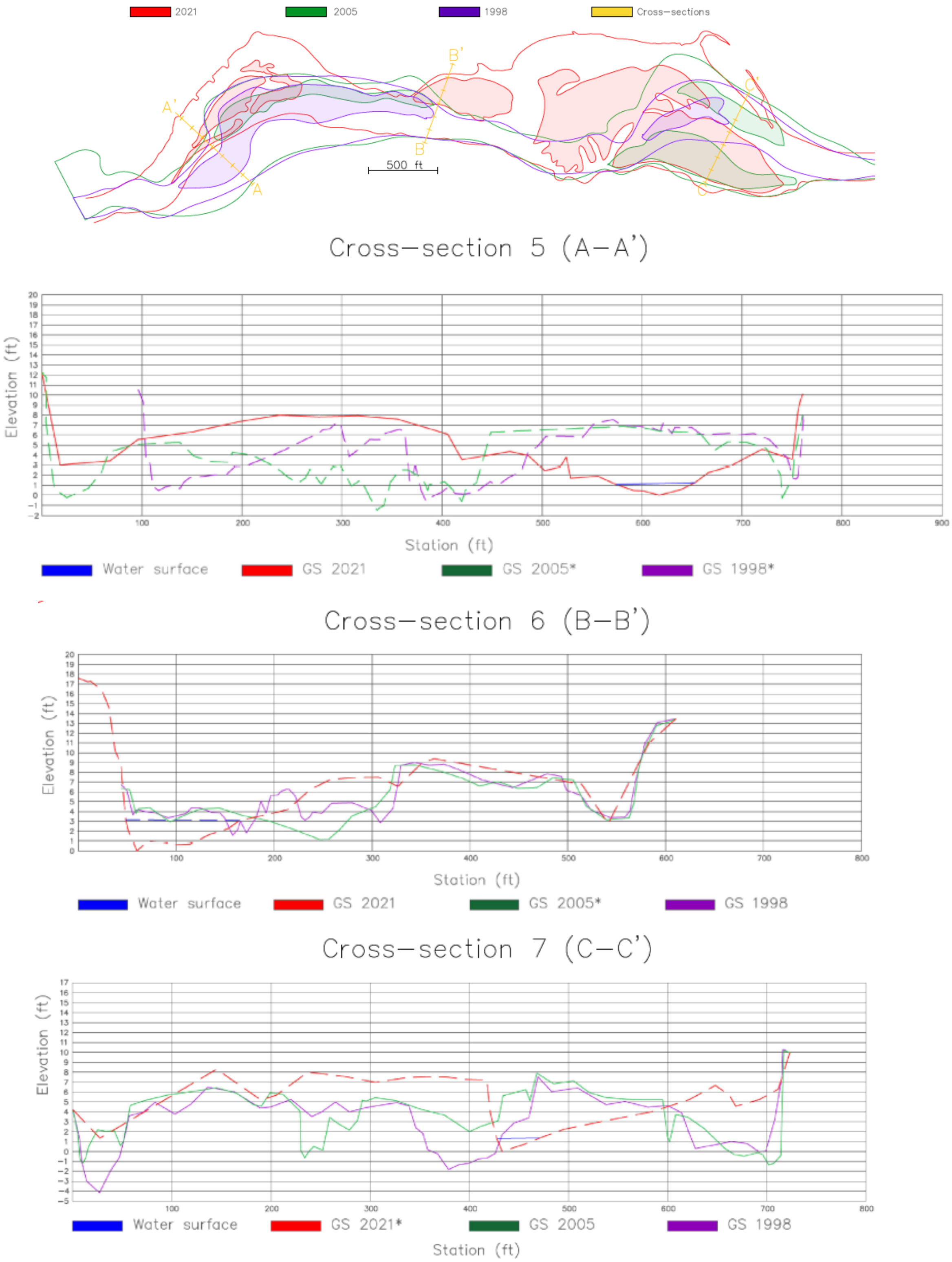


Figure 43 - Aerial imagery of the lower part of reach, from 1994, 2005, and 2021 and the evolution of cross-sections 5, 6, and 7 over the same period.

The inside of the tracing lines represents the exposed gravel. This is the area where the river is still active, and it can give an idea of where the bankfull level was and where it is now. Outside the tracing lines is the floodplain, and the hatched areas inside the river channels represent islands which are terraces of the river where enough water does not normally reach and therefore vegetation was able to establish.

As it can be seen, cross-section 5 has shifted its thalweg to the right bank and its sedimented area has switched to the left side.

In cross-section 6 the thalweg has remained on the left side but moved closer to the bank. It is also noticeable that on the right side, in the period between 2005 and 2021, the river had created a new channel forming an island in between.

In cross-section 7 the thalweg has remained roughly in the same position and in the period between 1998 and 2005 a new channel was formed on the left bank.

It is also interesting to see that in between cross-sections 6 and 7, on the left bank, beavers constructed some dams, as shown in figure 44. These dams were created in 2015 as can be seen in figure 42 -Tracings of the river from 1994 to 2021. These beaver colonies will expand in the future as they rapidly reproduce. It is important to keep track of their activities because even if these dams do not directly affect the road, beaver generations usually move within 0.5 miles to set up new colonies and they could affect it in the future.

Figure 44 – Beaver dams created in 2015 in the left channel of the island between cross-sections 6 and 7

Overall, cross-sections 5, 6, and 7 seem not to be aggrading or degrading even though its dimension has changed, and the thalweg, as well as the depositional area, have shifted from one place to another

The following figure illustrates a combination of the tracings obtained from the aerial imagery of the upper part of reach, from 1994, 2005, and 2019 and the evolution of cross-section 8 over the same period. In this surveyed the drone did not fly as far upstream as cross/section 8 was and that is why the tracings from 2021 are not shown.

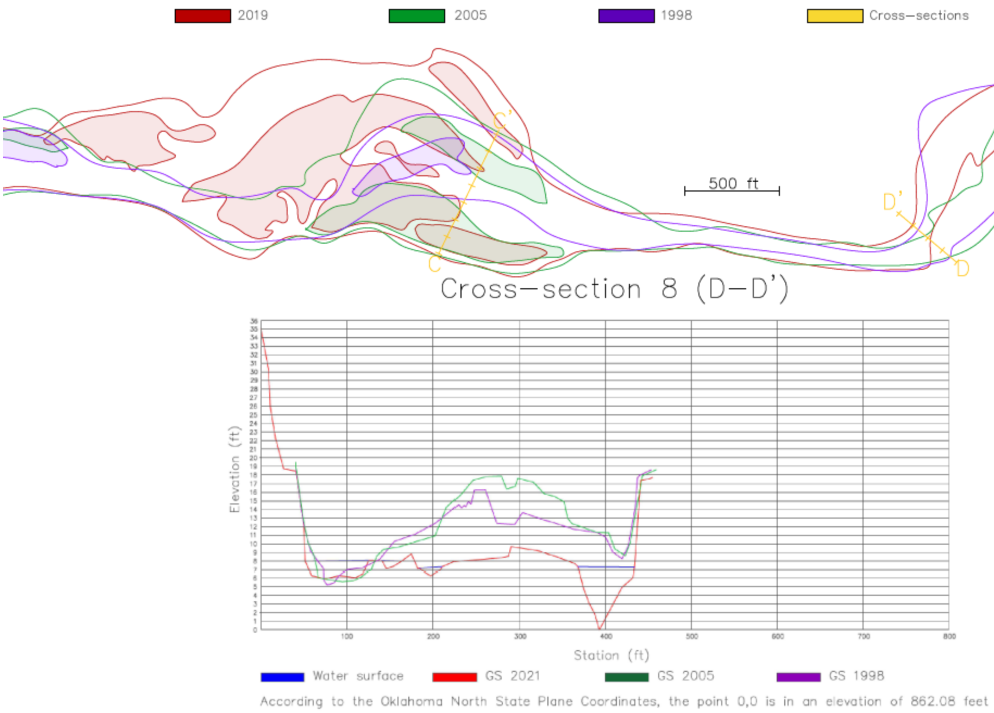


Figure 45 - Aerial imagery of the upper part of reach, from 1994, 2005, and 2021 and the evolution of cross-section 8 over the same period

Cross-section 8 has shifted to the right bank and is clearly degrading. This may be because of the presence of several large trees, as shown in figure XXX, that have become obstructions to the flow at high flows, scouring the bottom of the channel and creating that deep pool.

Figure 45 – Cross-section 8 in red showing the trees blocking the flow of water.

3.3 STREAMBANK EROSION RATE ANALYSIS

The streambank erosion rate is measured from surveyed cross-sections or from aerial imagery changes over the years. Detailed calculations of the streambank erosion rate using aerial imagery can be found in “Chapter 8 Appendices: Appendix 8.3 Streambank erosion rates calculations”.

The first step to calculate the streambank erosion rate is to choose a representative or typical bank condition for prediction. Because the area most susceptible to erosion is the one near the road, 2 reaches have been chosen, one where the river is impinging on the road, “Reach 2”, and the second one in the previous bent, “Reach 1”, that way it will be possible to compare both values. The location of both reaches is shown in figure 46

Figure 46 – Location of the reach 1 and 2

A polyline was drawn where the river was in 2019 and another where was in July 2021, the area of the polygon of the difference between both lines was measured using the command “area” of Civil 3D and the length of the reach has been measured as shown in figures XXXX. Then the area was divided by the reach distance to obtain the retreat over the time between the images and divided by this time (typically every 2 years) to obtain the retreat per year.

The results obtained are shown in Table 47:

Table 4 – Results of the streambank erosion rate measured from the aerial imagery

Reach	Retreat feet/year
1	94.11
2	32.45

Both retreat values are very high, especially the value for Reach 1. There are two contributing factors that could explain the high rate of erosion observed at Reach 1. One factor is that a jeep/truck trail runs down the valley in the forested floodplain, as may be seen in Figure 47 (left). This trail mostly follows an overflow channel flowing through the woods. The second factor was the presence of several large trees on the lower end of a long bare bank. As the upstream bank continued to erode and the channel thalweg pushed north, at some point those large trees with their huge root masses, would have become obstructions to the flow at high flows, directing water into the bank resulting in more force on the bank and increased erosion. The outlet provided by the trail/overflow channel would have encouraged more flow to go that way increasing that erosion further.

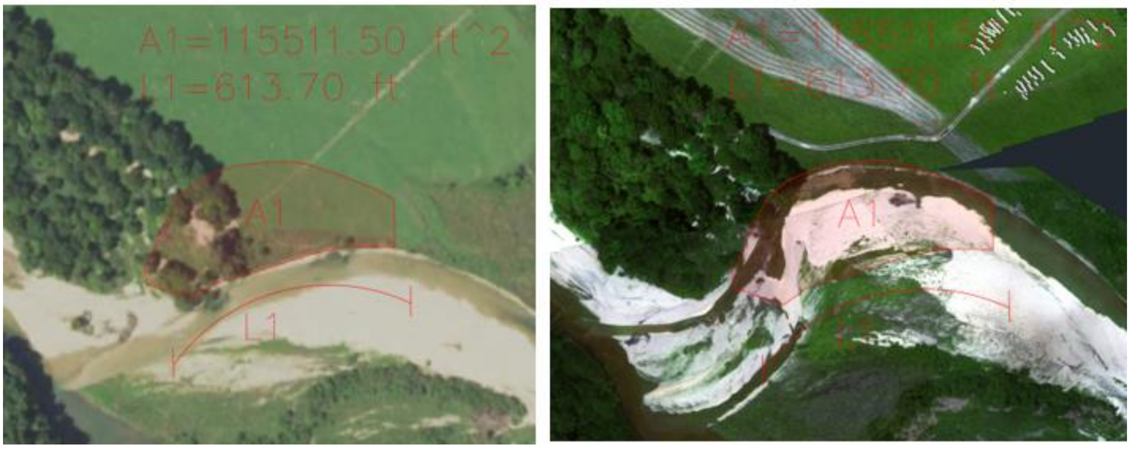


Figure 47 - Reach 1, 2019 aerial imagery (on the left) and 2021 aerial imagery (on the right), showing the erosion in the colored area

Figure 48 – Reach 1, 2021 drone pictures showing the trees that were washed away blocking the flow of water.

What is happening in reach 2 is that the valley begins to pinch in below cross-section 5. This pinch extends from the outcrop downstream of cross-section 5, is most pronounced at cross-section 4, and extends all the way through both bridges downstream. This pinch causes the water to back up creating a depositional zone upstream of cross-section 5. As it can be seen in figure 4, the river has tried to increase its length by meandering more. The "problem" is that the road is in the way, so the County installed the rock barbs, as shown in figure 50 and 51, which seem to have been successful at protecting the road thus far. Unfortunately, as in Reach 1, the bare bank upstream continues to erode and is trying to get around the structures.

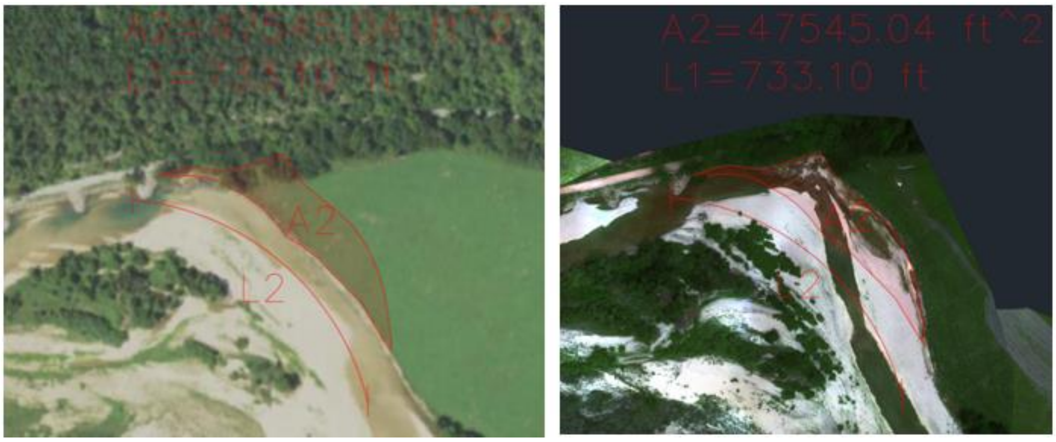


Figure 49 - Reach 2, 2019 aerial imagery (on the left) and 2021 aerial imagery (on the right), showing the erosion in the colored area

Figure 50 - Reach 2 (at the far top right side), 2021 drone picture showing how the river is trying to increase its length by meandering more but the road is in the way.

Figure 121 - Reach 2, 2021 drone pictures showing the erosion and the trees that have been washed away

Figure 52 - Reach 2, 2021 drone pictures showing the existing structures protecting the road

There are different methods used to predict the streambank erosion rate (ft/year). David Rosgen in 1996 proposed the Bank Assessment for Non-point source Consequences of Sediments (BANCS) model. This model uses two bank erosion estimation tools: The Bank Erosion Hazard Index (BEHI) and the Near-Bank Stress. Both methods are explained in “Chapter 1 Introduction; Section 1.4 Preliminary concepts”.

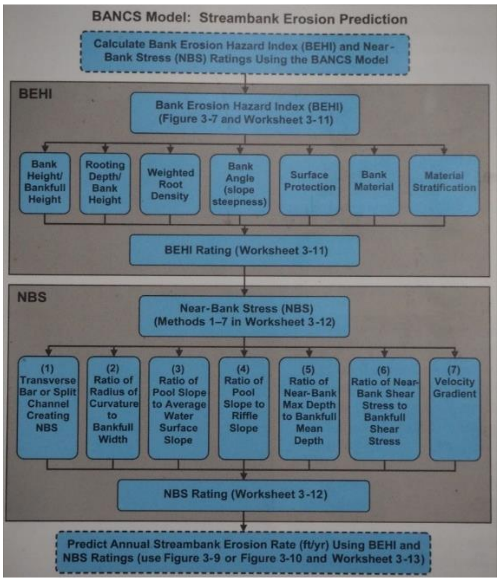


Figure 53 – The BANCS model variables, ratios, and procedures associated with the Bank Erosion Hazard Index (BEHI) and Near-Bank Stress (NBS) to predict annual streambank erosion (Rosgen, 2006b)

This parameters are very important because they can help predict how the river is going to change over the years. It also allows estimating the amount of sediment potentially contributed by streambanks to the annual sediment yield. To do that, the annual erosion rates are estimated and then multiplied by the bank height and by a corresponding bank length of a similar condition, providing an estimate of the volume of sediment per year.

In this chapter, the BEHI is first calculated. The process that has been followed to determined the BEHI at the Baron Fork is described here.

The first step, already explained at the beginning of the section is to select a representative reach of the river. The second step was to measure the bank height (A), the bankfull height (B), to calculate the study bank height ratio (C=A/B), to measure the root depth (D), to calculate the root depth ratio (E=D/A), to measure the root density (F), to calculate the weighed root density (G=F*(D/A)), to measure the bank angle (H) and to measure the surface protection (I). The third and final step was to convert the values to BEHI scores and an adjective rating.

Table 5 – Behi summary reach 1

BEHI BANK 1				
Bank Ht, ft (A)	8.9	C = A/B	2.555	9
BF Ht, ft (B)	3.5	E = D / A	0.112	9
Root Depth, ft (D)	1	G = F x E	0.562	10
Root Densiy, % (F)	5	Bank Angle		4
Bank Angle, Deg (H)	44.0	Surface Protection		10
Surf. Protection, % (I)	0	Material Adjustment	10	10
Bank Material	COMP	Stratification		7.5
(If comp, % sand)	70	**BEHI Score**		**59.5**
Stratification (Low/Med/High)	Med	**BEHI Rating**		**Extreme**

Table 6 - Behi summary reach 1

BEHI REACH 2				
Bank Ht, ft (A)	6.3	C = A/B	2.092	9
BF Ht, ft (B)	3.0	E = D / A	0.476	5
Root Depth, ft (D)	3	G = F x E	23.81	7
Root Densiy, % (F)	50	Bank Angle		3
Bank Angle, Deg (H)	22.0	Surface Protection		10
Surf. Protection, % (I)	0	Material Adjustment	10	10
Bank Material	COMP	Stratification		5
(If comp, % sand)	80	**BEHI Score**		**49**
Stratification (Low/Med/High)	LOW	**BEHI Rating**		**Extreme**

In this second part of the chapter, the procedure used to estimate the NBS is presented. The method that was used to determine the NBS at the banks was Method 2, which is based on the ratio of curvature to bankfull width (Rc/Wbkf). There are different ways to calculate the Radius of curvature, in this case, it has been calculated using the aerial imagery from this year obtained with the drone and drawing a circle based on three chosen points as shown in figure 54 for Reach 1 and figure 55 for Reach 2. The bankfull width was calculated using the surveyed data from cross-section 6 for Reach 1 and the data from cross-section 5 for Reach 2 due to their proximity.

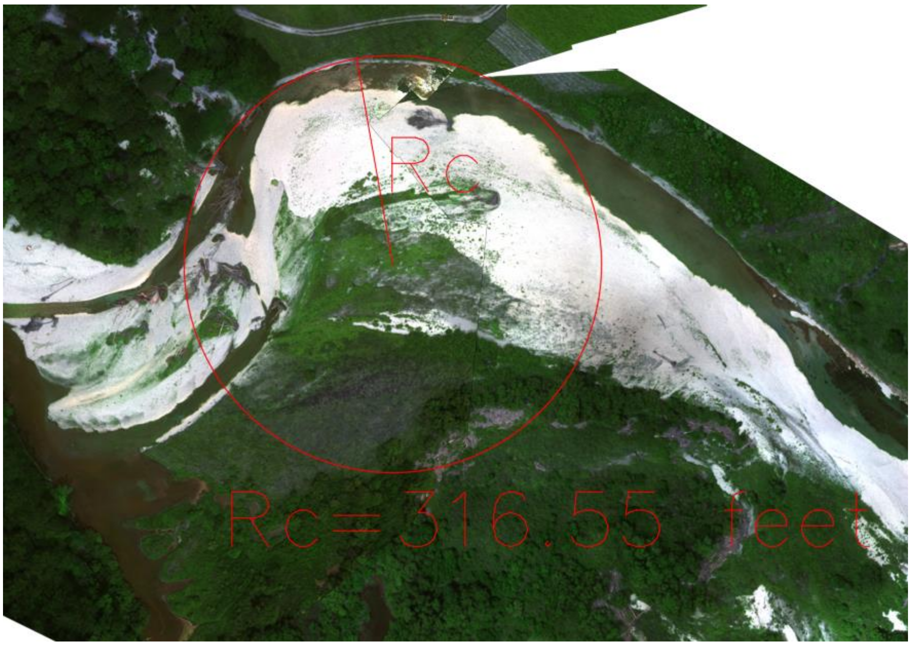


Figure 54 – Calculation of the radius of curvature in reach 1

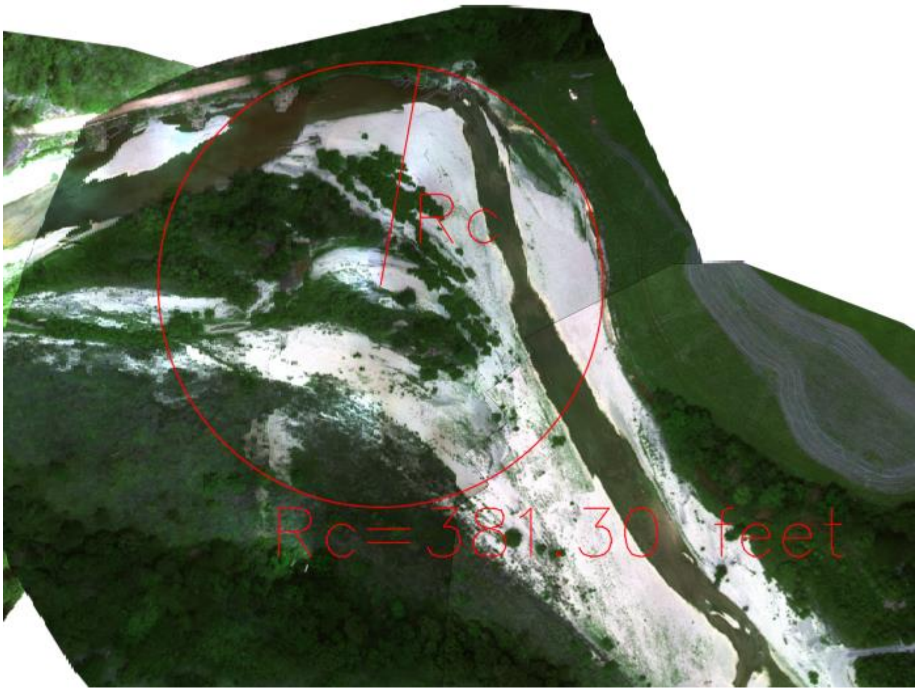


Figure 55 - Calculation of the radius of curvature in reach 2

Once the Radius of curvature is known, using table 7 it is possible to calculate the NBS rating.

Table 7 – Conversion table of Rc/Wbkf values to NBS ratings

NBS ratings based on Rc/Wbkf	
Rc/Wbkf ratio	NBS rating
>3.00	Very low
2.21-3.00	Low
2.01-2.20	Moderate
1.81-2.00	High
1.5-1.8	Very High
<1.5	Extreme

Table 8 – Results of the NBS Method (2) Reach 1

NBS Level II (Reach 1)				
Method (2)	Radius of Curvature Rc (ft)	Bankfull Width Wbkf (ft)	Ratio Rc/Wbkf	Near-Bank Stress (NBS)
	316.6	326.4	0.969724262	**Extreme**

Table 9 – Results of the NBS Method (2) Reach 2

NBS Level II (Reach 2)				
Method (2)	Radius of Curvature Rc (ft)	Bankfull Width Wbkf (ft)	Ratio Rc/Wbkf	Near-Bank Stress (NBS)
	381.3	469.0	0.813006397	**Extreme**

David Rosgen suggests in the calculation of the NBS that the user must select one or more of the methods that best represent the onsite conditions and also that the average of all methods is not recommended, in practice, the resultant highest near-bank stress consequence method is selected. As can be seen by the results, the sudden change in curvature of the river in Reach 1 results in an extreme NBS index. Because this “Extreme” classification is the worst condition possible, additional methods are not required to calculate the NBS index.

Now according to the BANCS model proposed by Rosgen, once the BEHI and NBS ratings are calculated, the following step would be to predict the annual streambank erosion rate (ft/year) using figure 56. These graphs have been calculated doing successive surveys over time.

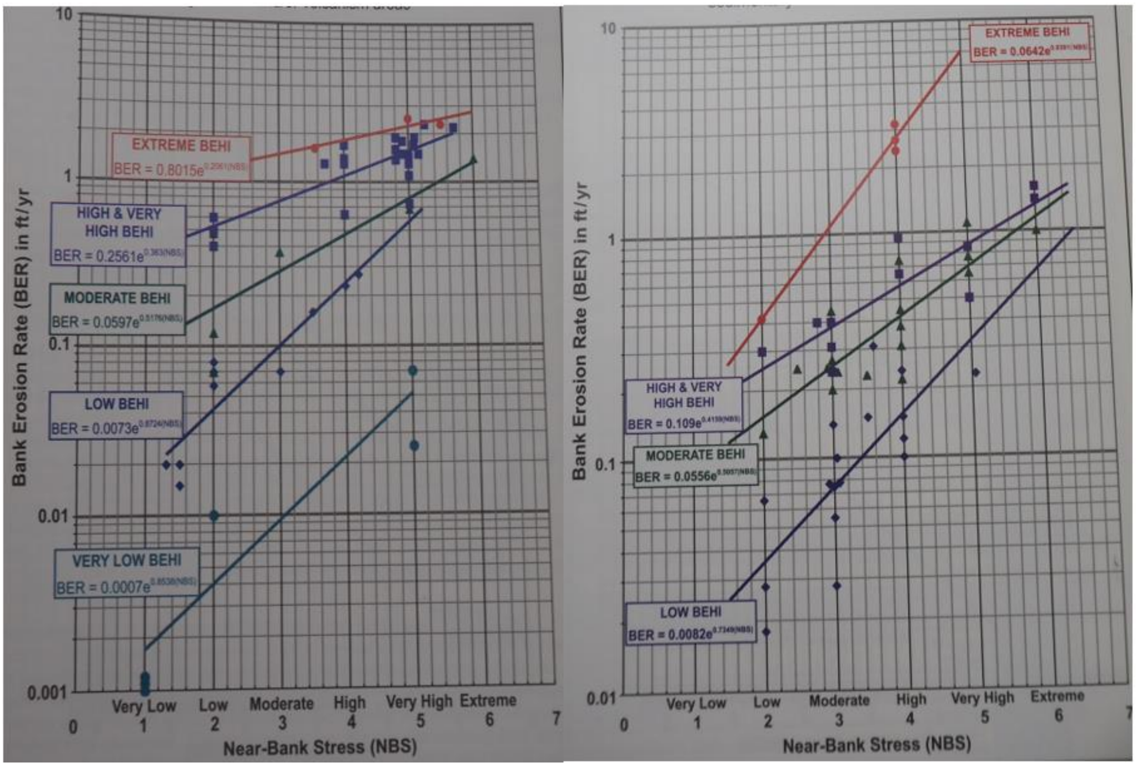


Figure 56 – Prediction of Annual Streambank Erosion Rates using (on the left) Yellowstone National Park 1989 data for streams found in alpine glaciation and/or volcanism areas and (on the right) Colorado USDA Forest Service 19989 data for streams found in sedimentary and/or metamorphic geology and (on the right)

The values for Bank Erosion Rates (BER) in feet/year associated with an extreme BEHI, and an extreme NBS according to the Yellowstone National Park (1989) data of figure 56 is:

$$BER = 0.8015 \times e^{0.2061 \times NBS} = 0.8015 \times e^{0.2061 \times 6} = 2.76\ ft/year$$

The values for Bank Erosion Rates (BER) in feet/year associated with an extreme BEHI, and an extreme NBS according to the Colorado USDA Forest Service 19989 data of figure 56 is:

$$BER = 0.0642 \times e^{0.9391 \times NBS} = 0.0642 \times e^{0.9391 \times 6} = 17.96\ ft/year$$

The problem with this graphs is that this values can not be taken as valid for this project because they were calculated for different stream types located in different ecoregions. That is why the Pfankuch assessment for instance is dependent on the stream type. It would be necessary to develop graphs like this site-specific for the Ozark Ecoregion calibrated with successive years of data in order to be able to estimate the BER from them.

D.M. Heeren, A. R. Mittelstet, G. A. Fox, D. E. Storm, A. T. Al-Madhhachi, T.L. Midgley, A. F. Stringer, K. B. Stunkel, and R. D. Tejral in their paper "Using rapid geomorphic assessment to assess streambank stability in Oklahoma Ozark Streams" has developed another index called Oklahoma Ozark Streambank Erosion Potential Index (OSEPI) which is an alternative to the bank erosion hazard index (BEHI) proposed by Rosgen. The reason why they are not using the BEHI is that they are doing a "rapid geomorphic assessment" to assess the streambank stability and the Rosgen protocol requires combining BEHI with field observations of the erosion rate determined with at least three years of erosion pin data and near-bank shear stress (NBSS) metric for a particular soil and geologic type. So they consider that such a protocol limits applicability for the objective of rapidly identifying unstable reaches within a stream system. And so they developed the OSEPI index by modifying the Channel Stability Index (CSI) (which requires only measuring the bank height, bank face length, river stage at baseflow, degree of constriction, and average diameter of streambed sediment), excluding some of the parameters because they were homogeneous throughout the area. The problem is that their index does not include the shear stress from all the different methods of the NBS. And clearly not taken into account this is affecting their results as you can see in figure 57, the R^2 values are too low.

Table 10- Scores for the channel stability index (CSI) and the Oklahoma Ozark streambank erosion potential index (OSEPI), along with estimated five-year lateral bank retreat between 2003 and 2008 at the 23 studied reaches on Spavinaw and Barren Fork Creeks.

	Reach	Reach Length (m)	Dominant Riparian Land Use on Critical Bank	CSI Score	CSI Category[a]	OSEPI Score	OSEPI Category[b]	Estimated Lateral Bank Erosion (m)
Spavinaw Creek								
Site A	1	100	Pasture	18.0	Moderately unstable	54.0	Unstable	20
	2	100	Forest	16.5	Moderately unstable	39.0	Stable	<1
	3	100	Forest	15.5	Moderately unstable	31.0	Moderately stable	<1
	4	120	Forest	18.5	Moderately unstable	41.5	Stable	3
	5	235	Pasture	19.5	Moderately unstable	51.5	Unstable	9
	6	50	Forest	12.5	Moderately unstable	39.5	Stable	<1
	7	100	Forest	16.0	Moderately unstable	49.0	Unstable	6
	8	50	Pasture	19.0	Moderately unstable	64.0	Moderately unstable	18
Barren Fork Creek								
Site B	1	205	Pasture	19.0	Moderately unstable	61.5	Moderately unstable	19
	2	70	Forest	14.5	Moderately unstable	24.5	Highly stable	17
	3	120	Forest	16.5	Moderately unstable	26.5	Moderately stable	4
Site C	1	85	Forest	13.5	Moderately unstable	17.0	Highly stable	<1
	2	50	Forest	16.0	Moderately unstable	38.5	Stable	<1
	3	50	Forest	17.5	Moderately unstable	61.5	Moderately unstable	<1
	4	20	Forest	19.5	Moderately unstable	59.5	Moderately unstable	<1
	5	85	Forest	15.5	Moderately unstable	43.5	Stable	<1
	6	85	Forest	15.0	Moderately unstable	21.5	Highly stable	<1
Site D	1	75	Pasture	17.0	Moderately unstable	37.0	Stable	<1
	2	70	Pasture	19.0	Moderately unstable	56.5	Moderately unstable	11
	3	25	Pasture	17.0	Moderately unstable	39.0	Stable	6
	4	260	Pasture	12.0	Moderately unstable	12.0	Highly stable	<1
Site E	2	40	Forest	17.0	Moderately unstable	27.0	Moderately stable	<1
	3	50	Forest	19.5	Moderately unstable	68.5	Highly unstable	55

[a] 0-10 = stable, 10-20 = moderately unstable, and >20 = highly unstable.
[b] 0-25 = highly stable, 26-35 = moderately stable, 36-45 = stable, 46-55 = unstable, 56-65 = moderately unstable, and 66-85 = highly unstable.

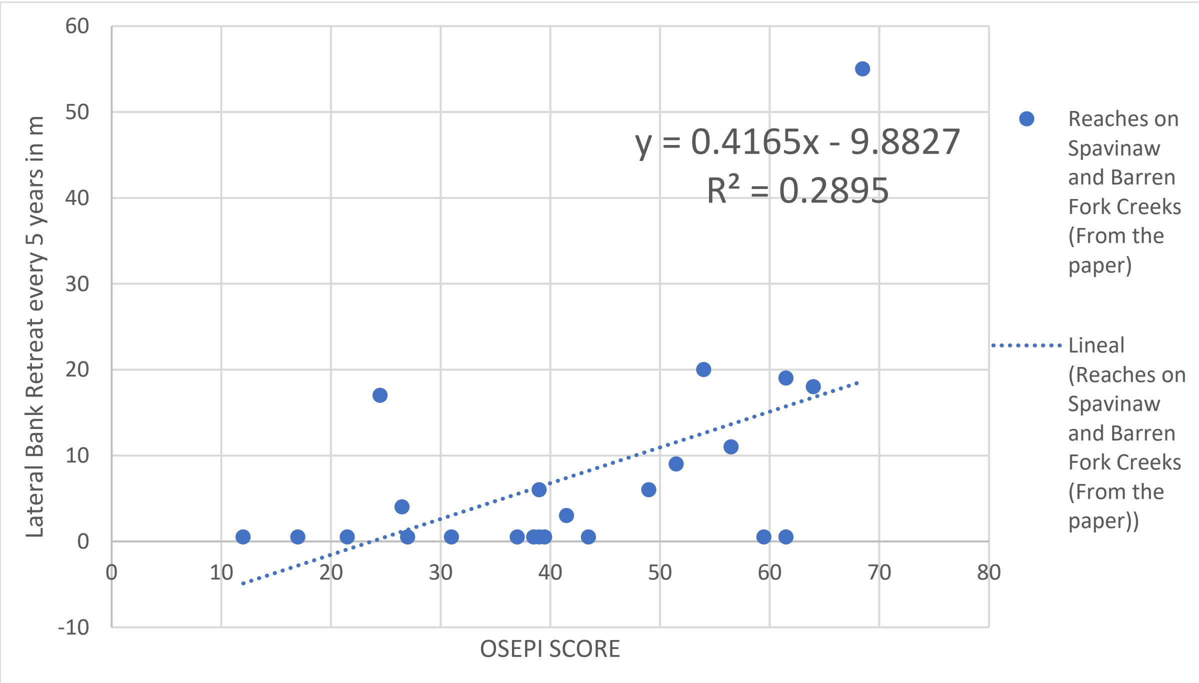


Figure 57 - Correlations between the rapid geomorphic assessments and the estimated lateral streambank retreat from aerial photography from 2003 to 2008: OSEPI = Oklahoma Ozark streambank erosion potential index

A low R^2 value tells that the linear approximation has a poor precission and therefore that the OSEPI index is not accurate. In fact, if the results from the OSEPI calculation obtained in “Chapter 8 Appendices; Appendix 7.3 Streambank erosion rates calculations; section 7.3.4” are plotted in this graph, combined with the lateral bank retreat obtained from the aerial imagery, after transform it to meters and every 5 years, and it can be seen in figure 58 how they are very far from the tendency line and therefore the OSEPI index dows not appear to be an adequate tool for estimating bank erosion at the two reaches assessed in this study.

Table 11 – Results from the OSEPI index and aerial imagery retreat calculations

Reach	OSEPI score	Retreat feet/year	Retreat m/5 year
1	34.00	94.11	143.42
2	44.50	32.45	49.43

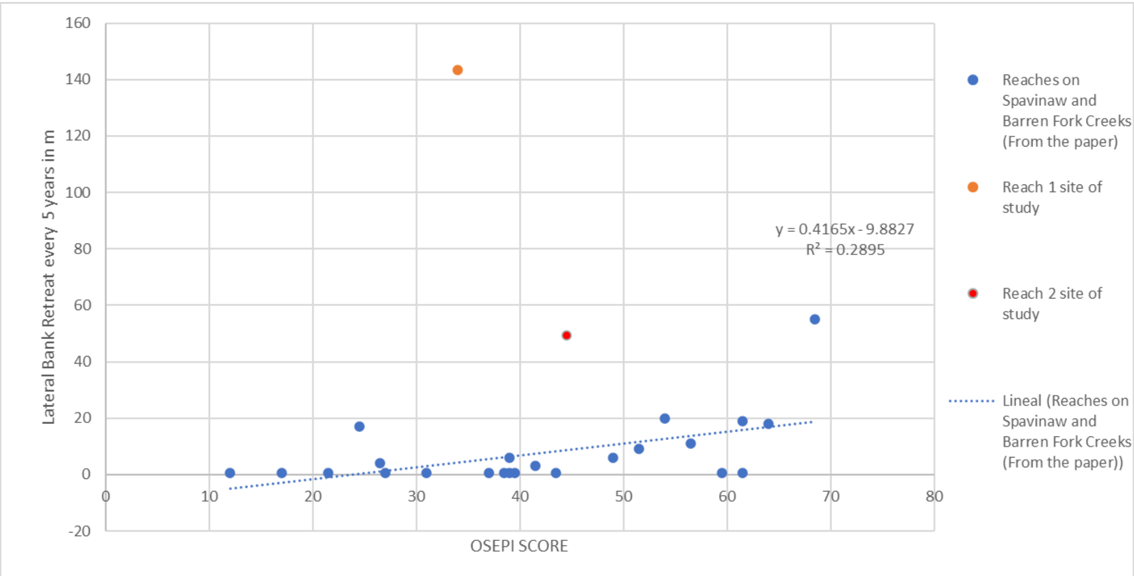


Figure 58 - Correlations between the rapid geomorphic assessments and the estimated lateral streambank retreat from aerial photography from 2003 to 2008: OSEPI = Oklahoma Ozark streambank erosion potential index including the study site reaches.

A possible explanation is that maybe the parameters that they are looking at (bank height, bank angle, percentage of bank height with a bank angle greater than 80º, evidence of cecent mass wasting, unconsolidated material, streambank protection, established riparian woody-vegetative cover, stream curvature) are sufficiently describing what is happening but the ranges and the weigthings are not right.

Another explanation is that they are not including the Near Bank Stress Index in their calculations as does the Rosgen protocol. The R^2 values in the Rosgen's predictions of annual streambank erosion rates of figure 56 are way higher than the ones of the OSEPI. Maybe if calculations of the NBS in the same site were combined with the ones of the OSEPI with the right weightings and ranges, the R^2 would be closer to 1 and the OSEPI index would be usefull to represent the erosion rates in the Ozark Ecoregion rivers of the same type.

3.4 SUMMARY AND RECOMMENDATION REPORT

From section 3.1.1 it can be concluded that due to the fact that some of the pins from the past cross/sections were not founded, an exact comparison can not be done. The thalweg and depositional areas have shifted from one place to another as it is expected, without aggrading or eroding the bed in excess in cross-sections 5, 6, and 7. Cross-section 8 seems to be degrading because of the presence of several large trees, that have become obstructions to the flow at high flows, scouring the bottom of the channel and creating a deep pool. The longitudinal profile analysis seems to reinforce the assumptions extracted from the cross-sections. In between cross-sections 5 and 7, the river bed has balanced its sediments, even though some new pools and riffles have appeared in different positions. In the reach near cross-section 8, the river seems to be downcutting and increasing its slope.

From section 3.1.2 it can be concluded that the channel has become more braided over the years, creating different secondary channels that have formed islands which are terraces where vegetation has been established and allowing beaver colonies to expand. On the other hand, the meander belt has remained roughly in the same position, moving out slightly downstream as they are supposed to do.

From section 3.3, it can be concluded that the retreat values in the areas most susceptible to erosion are extremely high, in between 32 and 94 feet per year. One of these areas is the one next to the road. Here the river is trying to increase its length by meandering more but the road is in the way. The County has installed rock barbs to protect it but, it is evident that the river continues to erode and is trying to get around the structures. In order to maintain functional this road in the future, a solution to this problem has to be found. The cheapest way to fix it would be to simply add another barb (or two) upstream. Eventually, the bend might become so sharp that it will cut through a low spot in the point bar somewhere.

As this project tries to be an ecological restoration design, the solution proposed, even though it will not be the cheapest from an economic point of view, will consist of a more natural solution instead of just armoring the bank with more structures. This solution is based on modifying the current alignment of the river, keeping it away from the existing road by creating a shortcut through the point bar. This new alignment will tend to have the same geometric parameters as the meanders upstream and downstream of it. The design will respect the current hydrology, it will include the necessary pools and riffles, it will also incorporate planting, and in-stream habitat improvement structures that will help protect the banks, as much as to create new habitats.

CHAPTER 4
CONCEPTUAL DESIGN

The new proposed design has the objective of direct the river away from the existing road while minimizing the impacts of changing its natural course. To do that, the new design tries to mimic as much as possible its surroundings, imitating the geometric parameters of the meanders upstream and downstream of the site where the new design is taking place. These geometric parameters are:

1. Radius of curvature
2. Wavelength
3. Amplitude
4. Belt width
5. Bend length
6. The distance between riffles and pools
7. Bed slope
8. Bankfull width
9. Cross-sectional area

The first 5 parameters have been defined in "Chapter 1 Preliminary concepts; Section 1.1.6 Stream channel dimensions", and they apply to the pattern of the river from a plan perspective. Parameters 6 and 7, affect mainly the profile of the river. Theoretically, this distance in between pools and riffles is ½ times the linear wavelength. However, as it can be seen in figure 60, the new design shortcuts the old design, and therefore, perfect adjustment to the theoretical design is not feasible. A similar thing happens with the slopes because the distance from the beginning to the end of the new design is shorter than the existing one, the slopes had to be slightly increased. Therefore, the slope criteria here have been to match the elevation of the existing riffles upstream and downstream of the new design. The bankfull widths and the cross-sectional areas of the surveyed cross-sections have been also used as a reference to draw the new channel cross-sections. Some parameters had to be modified too to meet the requirements of protecting the road while trying to keep a viable budget by maintaining a practicable volume of the excavation from the earthworks. With that said, the new conceptual design tries to provide a solution from an environmental, technical, constructive, and economic point of view.

4.1 DESIGN PARAMETERS

The meander that has been selected as a reference to calculate the parameters for the new design is the meander just upstream of the site as it was in 2019. This is because after this year some of the trees were washed away blocking the flow of water and eroding the river about 94 feet per year as explained in "Chapter 3 Channel stability assessment; Section 3.2 Streambank erosion rate analysis", and this feature is not desirable in the new design.

Figure 59 shows these geometric parameters:

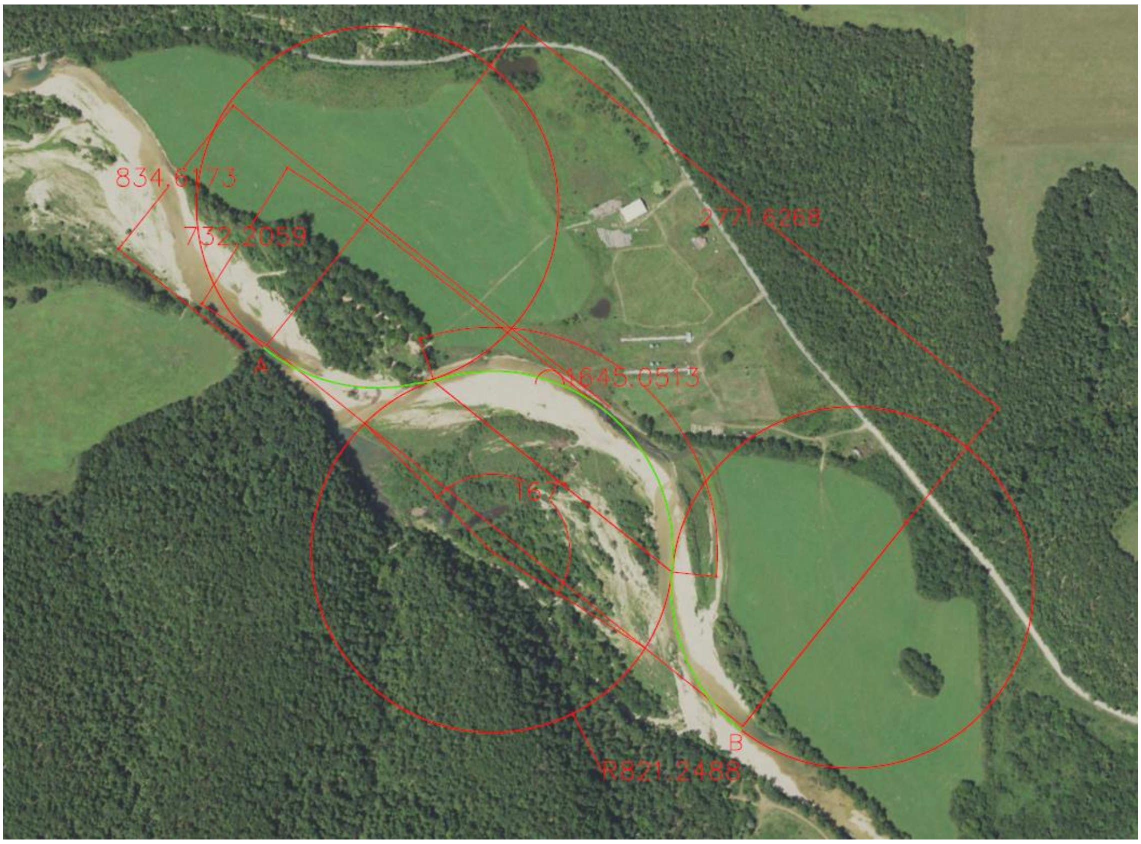


Figure 59 – Reference meander showing the design parameters for the new design

1. Radius of curvature = 821.249 ft

2. Wavelength = 2771.627 ft

3. Amplitude = 732.206 ft

4. Belt width = 834.6173 ft

5. Bend length = 1645.051 ft

    a. Theoretically, this value should be equal to ½ of the channel distance between A-B (showed in figure 59) ≈ 1470 ft

6. The distance between riffles and pools = 1400 ft

    a. Theoretically, this value should be equal to ½ of the meander wavelength ≈ 1385 ft

7. Pool slope = $\frac{856.30-853.9129}{2518} = 9.48 \times 10^{-4}\ m/m$; Where 856.3 is the elevation of the top of the riffle upstream of the new design and 853.9129 is the elevation of the top of the riffle downstream of the new design. The riffle slope has been calculated copying the slopes of the riffles where the river is currently and the new design is supposed to be. More detail of the slopes can be found by looking at the longitudinal profile of the new design in "Chapter 8 Appendices; Appendix 8.4 Sketches; Longitudinal profile 1/3, 2/3 and 3/3".

8. The bankfull height at cross-section 5, which is very close to where the new design finishes, is at an elevation of 861.14 feet. The bankfull height where the new design starts, it's in an elevation of 866 feet, extrapolated from the topography and the aerial images, looking at where the exposed gravel bar ends, and the vegetation starts to be dense. The total length of the new design as it will be seen later is

2524.4 feet. Therefore, an approximate slope for the bankfull level has been estimated and used as the top of each of the new cross-sections.

$$\frac{866 - 861.14}{2524.4} = 1.925 \times 10^{-3}$$

9. The cross-sectional areas at the pools and riffles of the reference meander have been used as a model to draw the new design cross-sections.

4.2 PATTERN SHOWING THE EXISTING AND PROPOSED NEW CHANNEL ALIGNMENTS

Figure 60, shows the proposed pattern for the new design. The pink line defines the alignment itself. The red lines, parallel to the pink one, define the margins of the channel. The green line is the alignment of the current channel. The blue lines perpendicular to the red lines that define the channel corridor represent the cut of the cross-sections which are described later. A few criteria have been taken into account to choose this design. A detailed drawing of the pattern can be found in "Chapter 8 Appendices; Appendix 8.4 Sketches; New design pattern vs current pattern".

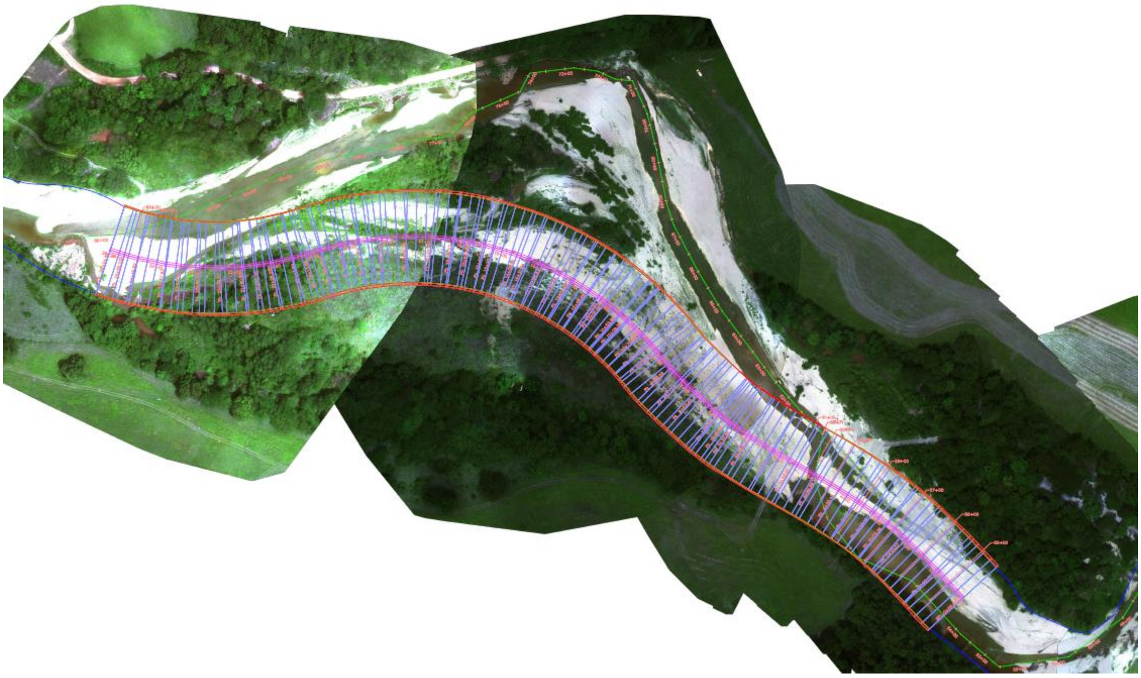


Figure 60 - Pattern showing the existing and proposed channel alignments

The main objective is to protect the existing road, reducing the environmental impacts as much as possible. To do that, the river had to be moved away from the road using an old channel of the river. This old channel is active, which means that even though it does not have water during the year, during high flows it gets flooded as it is below the bankfull level. Proof of that is all the exposed gravel that can be seen from the aerial imagery. The capacity of this channel has been increased using the reference reach from figure 59 and should be enough to carry the bankfull flows. This allows abandoning the current channel by filling it up with the excavation material to increase protection on the road. On the other hand, the volume of the excavation from the earthworks had to be kept practicable, so the lower section of curvature had to be slightly modified, relative to the theoretical parameters extracted from the reference reach, to avoid excessive excavation because otherwise, the upstream part of the new channel would have cut too much the current left bank. Also, this left bank has been there for many years, and cutting it too much would have altered in excess the morphology of the site, which is not something desirable, especially because this design aims to be considered natural engineering.

4.3 PROFILE AND CROSS-SECTIONS OF THE NEW CHANNEL

4.3.1 Calculation procedure

To calculate the elevation profile and the cross-sections the first thing that needed to be done was to plot the contour lines that define the topography of the site. This was done by using the same ATI AgBot drone for precision agriculture applications described in chapter "Chapter 2 Site description; Section 2.7 Surveying methods and equipment; Methodology to obtain current aerial imagery and the topography" which apart from providing current aerial photography, also provided a DTM (Digital Terrain Model) and a DSM (Digital Surface Model). Using Autocad Civil 3D, once the final surface was defined, the new channel alignment was created. Then the thalweg profile was plotted using the new alignment and the surface of the existing terrain. After this step, the standard procedure would be to create an assembly associated with that longitudinal profile which is defining the cross-section that the new channel is going to have and after that defining a corridor that is extending those cross-sections along the alignment with the correct elevations from the profile. Once that is done the corridor is converted into a surface that intersects with the terrain surface, the last step is to create sample lines that delimitate the width and distances of the cross-section between them, and with all that, Autocad Civil 3D plots all the cross-sections intersecting with the terrain every defined distance and allows to calculate volumes of excavations. However, because the channel that is intended to be designed here is a natural design, and the palettes available in Civil 3D include only regular cross-sections, a more traditional procedure had to be done to draw the cross-sections and calculate the cut and fill volumes. This consisted in drawing the desired cross-section with polylines without using the palettes at the key points (pools and riffles) and make the transitions by hand considering the slopes of the thalwegs and the elevation of the bankfull. To calculate the volumes, it was also done by hand, adding the excavation or filling areas for pairs of cross-sections, dividing them by 2, and multiplying them by the distance between them, and then adding the volumes to calculate the net cumulative excavation volume and net cumulative filling volume, then the first one minus the second one to obtain the net volume.

4.3.2 Profile of the new channel showing the riffles and pools

Figure 61 shows the longitudinal profile of the new design. The red line shows the terrain profile following the alignment of the new design, and the blue line shows the desired elevation of the thalweg. The vertical difference between the red line and the blue line gives an idea of the depth of the excavation. Below is the figure it is shown the starting and ending points of the riffles and pools.

From upstream to downstream, the new channel continues the pool of the old channel from station 0+00.00 to station 2+250 with a slope of -0.39%. Then there is a break in the slope to reach the top of the first riffle which is at station 7+88.98. The slope between stations 2+250 and 7+88.98 is 0.87%. The first riffle goes from station 7+88.98 to 1+128.98 with a slope of -1.22%. The second pool after this first riffle goes from station 7+88.98 to station 2+180.52 and the slope in the middle is -0.39%. The second riffle that starts at station 2+180.52 ends at station 2+524.4 with a slope of -1.21%.

A more detailed drawing can be found in "Chapter 8 Appendices; Appendix 8.4 Sketches; New channel profile showing pools and riffles"

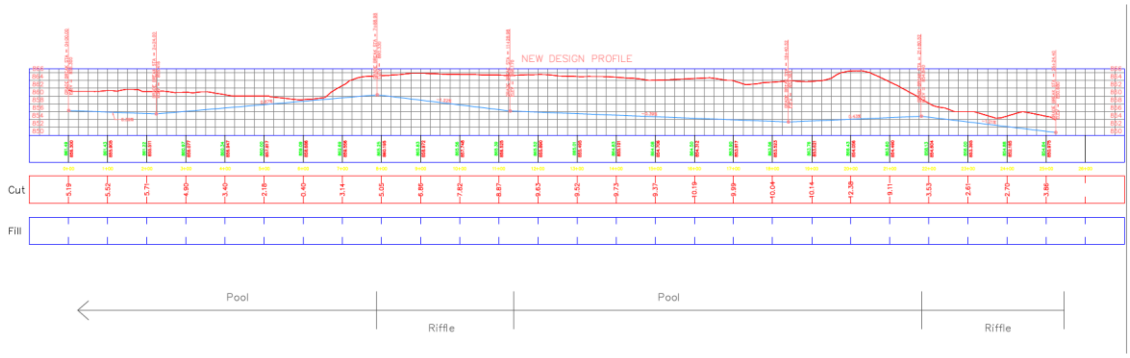


Figure 61 – Profile of the new design showing the existing terrain and location of the pools and riffles

The longitudinal profile has been designed to match the slopes of the pools and riffles trying to mimic what happens in the reference reach. However, as previously mentioned, the new design shortcuts the old design, The current river takes 3050 feet to arrive from the starting point of the new design to the endpoint, whereas the new design takes approximately 2524 feet. These 526 feet difference makes it impossible to have a perfect adjustment to the theoretical slopes and they had to be increased proportionally to match the upstream and downstream riffles elevations.

4.3.3 Cross sections of the new design

The cross-sectional areas at the pools and riffles of the reference meander have been used as a model to draw the new design cross-sections. The cross-sections have been plotted at the beginning and end of each pool and riffle and transitions by hand have been drawn considering the slopes of the thalwegs and the elevation of the bankfull. Figure 62 shows an example of how a pool and a riffle look like in this new design.

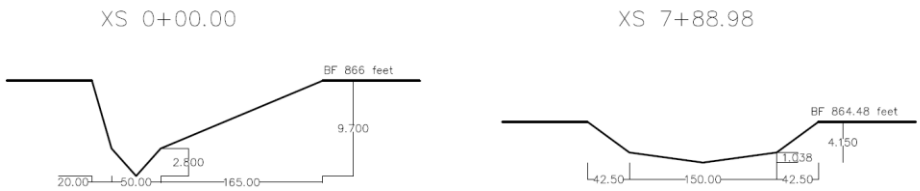
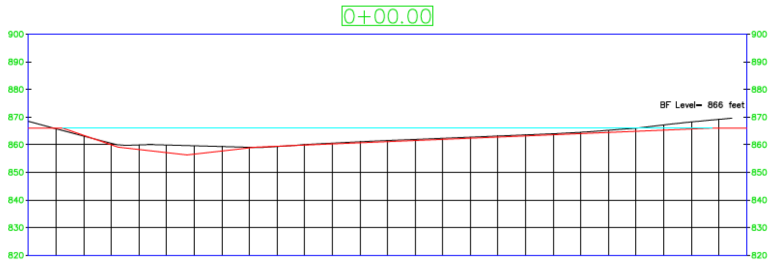


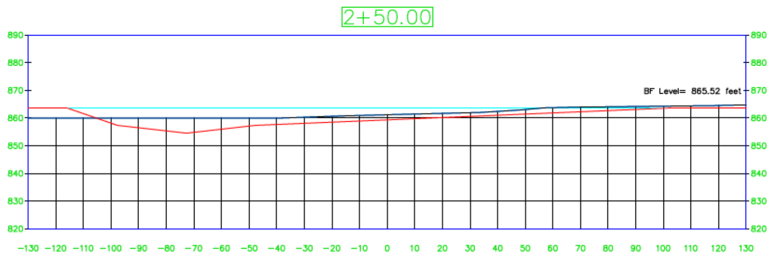
Figure 62 – Pool at XS 0+00.00 and riffle at XS 7+88.98 (Y-axis scaled 10 times X-axis to see bed features)

Once the channel cross-sections were plotted with the terrain cross-sections, the cut area, fill area, cut volume, cumulative cut volume, cumulative fill volume, and the net volume was calculated as explained in in the section 4.1.1 from this chapter "calculation procedure" and as shown in figure 63



Total Volume at Station 0+00.00	
Cut Area	316.640
Fill Area	5.601
Cut Vol	0
Fill Vol	0
Cum Cut Vol	0
Cum Fill Vol	0
Net Vol	0

*Areas in Sq.Ft and Volumes in Cu.Yd



Total Volume at Station 2+50.00	
Cut Area	495.370
Fill Area	70.620
Cut Vol	3759.302
Fill Vol	352.916
Cum Cut Vol	3759.302
Cum Fill Vol	352.916
Net Vol	3406.385

*Areas in Sq.Ft and Volumes in Cu.Yd

Figure 63 - Pool at XS 0+00.00 and 2+50.00 showing the calculations of the volume on the right

The rest of the plots and a summary of the volumes report can be found in "Chapter 8 Appendices; Appendix 8.4 Sketches; New channel cross-section 1/7-7/7"

4.4 FILLING OF THE EXISTING CHANNEL

As part of the design, the old channel is filled to match the bankfull levels as shown in figure 64, that way there is no chance for the river to strike against the road.

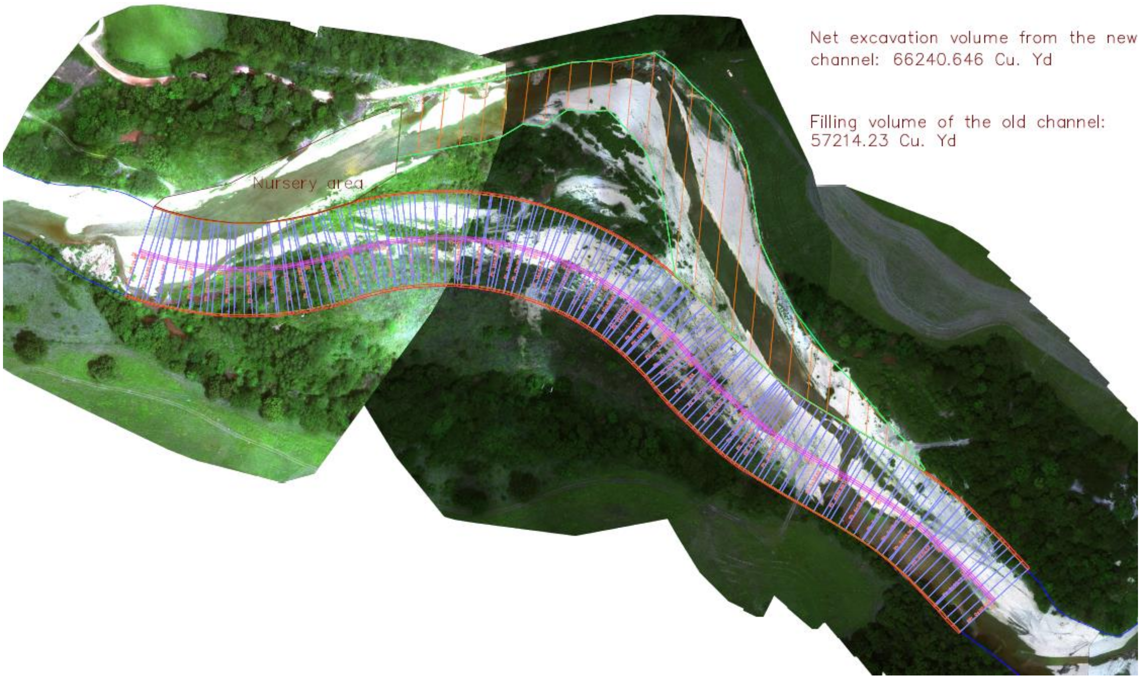


Figure 64 – Fill area of the old channel until bankfull (in green and orange) and nursery area

According to table 12, the final extracted net volume from the excavation of the new channel is 66240.646 Cu. Yd., the volume of filling the old channel is 57214.23 Cu. Yd., and the difference between them is only 9026.416. Trying to equal these volumes has been something intentional, that way the cost of the earthworks could be reduced, however, it was not the first purpose as this was to have a proper design.

Table 12 - Volume report of the excavation of the new channel and filling of the old one

VOLUME REPORT OF THE EXCAVATION OF THE NEW CHANNEL							
Station (feet)	Cut Area (Sq. Ft.)	Cut Volume (Cu.yd)	Fill Area (Sq. Ft)	Fill Volume (Cu. yd)	Cumulative Cut Volume (Cu.yd)	Cumulative Fill Volume (Cu. yd)	Cumulative Net Volume (Cu. yd)
0	316.640	0.000	5.610	0.000	0.000	0.000	0.000
250	495.370	3759.302	70.620	352.916	3759.302	352.916	3406.385
500	38.000	2469.303	518.020	2725.182	6228.605	3078.099	3150.506
788.98	1016.000	5640.456	156.300	3608.607	11869.061	6686.706	5182.355
950	980.000	5951.770	72.800	683.142	17820.831	7369.848	10450.983
1128.98	718.320	5628.982	15.970	294.223	23449.813	7664.071	15785.742
1400	879.790	8020.729	3.920	99.826	31470.541	7763.896	23706.645
1650	1296.700	10076.333	0.000	18.148	41546.874	7782.044	33764.829
1840.52	1211.110	8847.916	76.820	271.032	50394.790	8053.076	42341.714
2000	1792.160	8869.649	81.130	466.479	59264.439	8519.555	50744.884
2180.52	829.140	8762.900	125.890	692.060	68027.339	9211.615	58815.724
2350	542.170	4303.878	83.580	657.425	72331.216	9869.039	62462.177
2524.4	755.120	4189.762	43.770	411.293	76520.978	10280.332	66240.646

VOLUME REPORT OF THE FILLING OF THE OLD CHANNEL			
AREA (Sq. Ft)	Cut (Cu. Yd)	Fill (Cu. Yd)	Net (Cu. Yd.)
290884.23	48.32	57262.55	57214.23

DIFFERENCE (Cu. Yd)	9026.416

As it can be seen, this design also includes a nursery area where juveniles fishes undergo growth and development safe from bigger fishes that cannot get there because the water is too shallow for them.

4.5 DESIGN STRUCTURES AND PLANTING

Structures installed must match the natural, stable, characteristics of the stream. If the inventories and analyses that specify the need for structural improvements do not address the channel morphology and corresponding stable dimension, pattern, and profile, then the effectiveness of these structures is greatly diminished [21].

The primary structures used in natural channel designs include cross vanes, rock vanes, J-hooks, and toe woods. Cross vanes are used for grade control and either rock vanes or J-hooks are used for bank stabilization. In addition, all these structures improve aquatic habitat. The cross vanes, rock vanes, and j-hooks all create pools downstream of the structures and depositional area upstream.

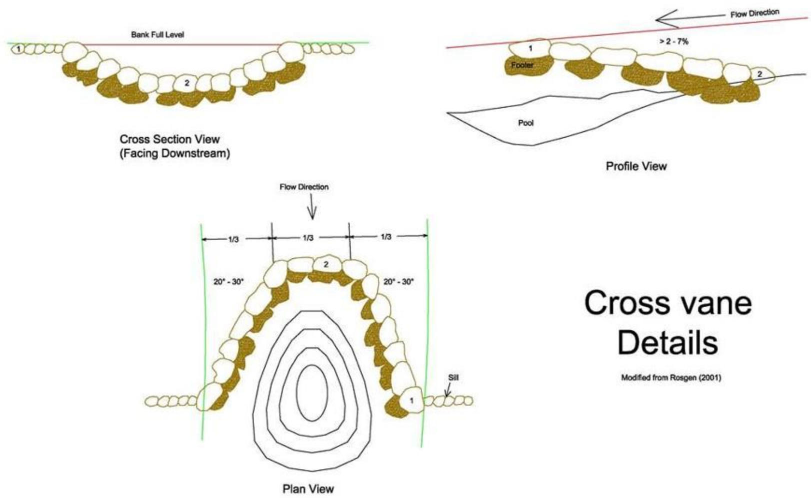


Figure 65 – Cross vane details modified by Russell Dutnell from Rosgen (2001)

Cross vane structures are used for grade control. They are typically constructed with large natural rock (meaning boulders), but they may also be constructed with logs and

[21] D. Rosgen, *Applied River Morphology* (Wildland Hydrology Pagosa Springs, Colorado, 1996).

rock. Cross vanes consist of three sections. Two arms extend from the channel bank at the bankfull level down to the invert of the channel at a point a third of the way across the channel. The arms slope down at a 2-7% slope, and out away from the upstream bank at an angle of 20-30 degrees. Note that the arms also include rock sills that extend into the bank to prevent the structure from being flanked. The ends of the two arms are connected by a central, essentially flat, section with the tops of the rocks installed at the desired channel invert elevation. At high flow the shape of the structure slows the water flowing next to the banks down, and turns it to the middle of the channel, creating a deep plunge pool downstream of the structure. Bedload sediment being transported down the channel is blocked by the central rocks, thus establishing the invert elevation of the bed. Function follows form with these structures; if the structure is flanked or undercut, it will lose its form and it will no longer function as desired. The key to building these structures is to make sure that you have adequate footer rocks. They should be deep enough that high flow will not scour underneath them, often two or three layers deep. Although the schematic diagram in figure 65, does not reflect this.[22]

The next figure represents another type of cross vane that would be more appropriate for wider channels and that is why this is the one that has been chosen for the new design.

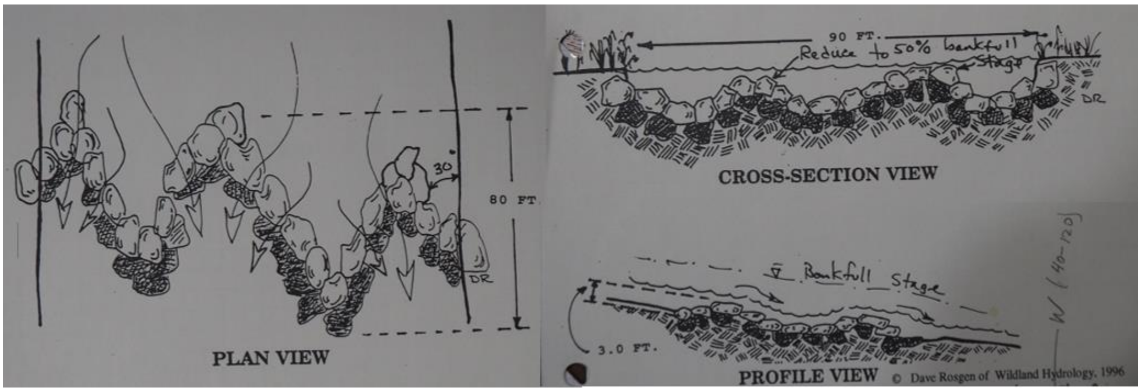


Figure 66 – "W" weir design by Daver Rosgen (1996)

[22] Russell C. Dutnell, "Conceptual Natural Channel Design CEES-5020-999; Graaduate Seminar in Watershed Science and Management; Hydrology and Water Security Program; The University of Oklahoma.," n.d.

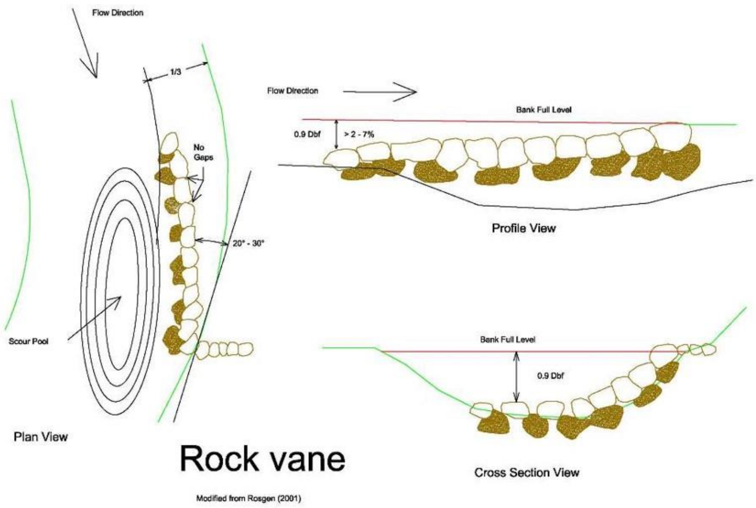


Figure 67 - Rock vane details modified by Russell Dutnell from Rosgen (2001)

Rock vane structures are used for bank stabilization. They are constructed just like a cross vane arm, and as with rock vanes, form follows function so they must be constructed to prevent flanking or undermining. At high flow, the shape of the structure slows the water flowing next to the banks down and turns it to the middle of the channel. This creates a deep plunge pool downstream of the structure, and a depositional zone upstream of the structure, where deposited silt and sand are deposited.[23]

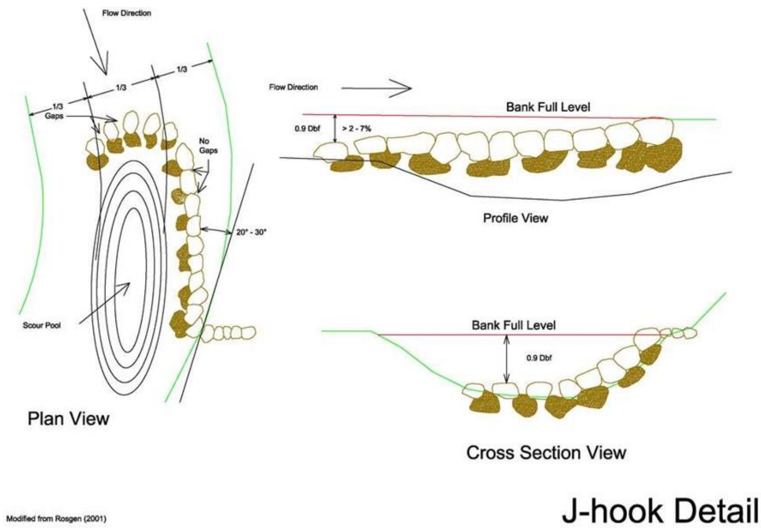


Figure 68 - J-hook detail modified by Russell Dutnell from Rosgen (2001)

[23] Dutnell.

J-Hook structures are used for bank stabilization and are essentially rock vanes with rocks added to the central third of the channel as shown here. The central rocks are added to improve aquatic habitat, as the spacing of the central rocks creates convergence and divergence of the current, resulting in increased micro-ecosystem diversity.

Regarding the proposed planting, as shown in figure 71 the planted area corresponds mainly to the filling area of the existing channel plus the left bank of the new channel where vegetation has not been able to establish yet. The planting covers two different phases. The first phase is planted during low flow months and characterized by a single linear row of fascines and live stakes of Salix nigra, commonly known as black willow. The second phase is planted near the beginning of the higher flow months with the purpose of establishing Arundinaria gigantea, commonly known as river cane

Black willow was chosen as the primary woody vegetation as it is native to the Ozark Highlands. Another reason black willow was chosen was that it is considered a popular woody vegetation choice for riparian buffers as it can grow directly on the banks. A picture of the Black Willow can be seen in figure 69.

Figure 69 – Black willow example (Wholesale Nursery Co)

River cane was chosen as the herbaceous vegetation because is a warm-season species of bamboo that is considered a native rhizomatous grass in riparian zones of the Ozark Highland ecoregion. Figure 70 is an example of what is known as a canebrake, which is a portion of the area densely covered by river canes. River cane provides many ecosystem benefits to riparian zones including erosion prevention from rhizomatous roots, habitat for insects and small creatures, and nutrient uptake (Anderson and Oakes, 2011). River cane is also listed as a culturally significant plant for the people of the Cherokee tribe (Casey and Wynia, 2010). A con of the river cane is that it is hard to get established, so other possibilities should be consider if this does not work.

Figure 70 - River cane after 4 years of establishment (EARF, n.d.)

A few studies have proven that eventually nature will take over and it does not matter to plant or not because within a decade, two sites of the same condition, one with external planting and the other one without it, will end up looking the same. That is why the planting has not been included in the budget estimation, because it would not be necessary.

4.6 FINAL DESIGN

Figure 71 depicts the final conceptual design including all the variables and factors that have been designed in this chapter. A more detailed drawing can be found in "Chapter 8 Appendices; Appendix 8.4 Sketches; Final conceptual design".

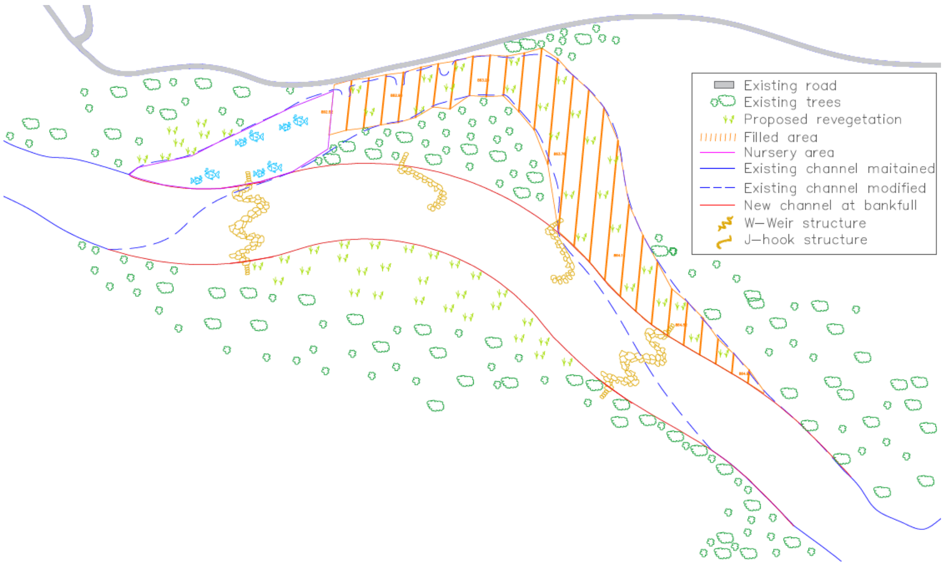


Figure 71- Final conceptual design

4.4 FORCING FUNCTIONS AND ENERGY DIAGRAM

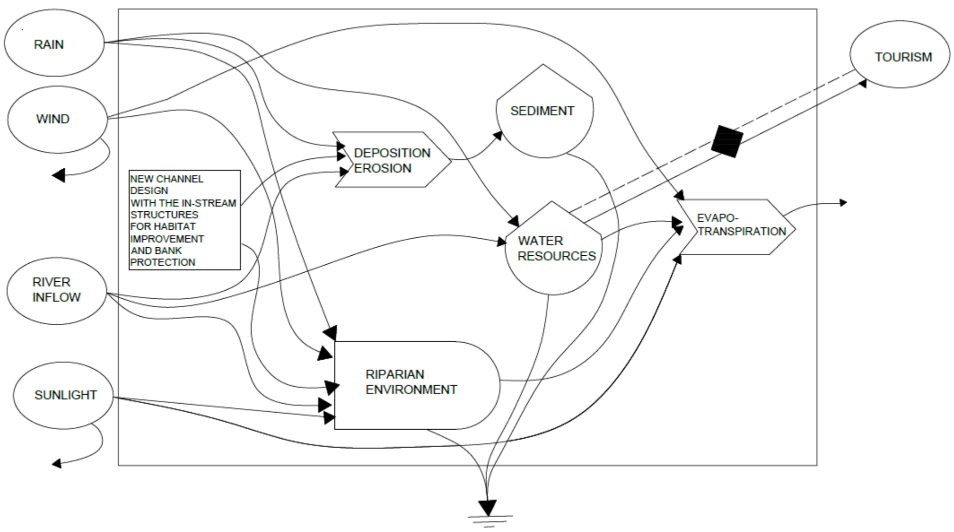


Figure 72 – Energy systems diagram describing the proposed ecological engineering design for the Baron Fork river study site

Figure 72, above, depicts an energy systems diagram that describes the proposed ecological engineering solution, the new channel design with the in-stream structures for habitat improvement, and bank protection for the Baron Fork river study site.

The large box surrounding most of the graphic is the system frame, and it represents the boundaries of the system. Arrows are pathway lines that represent a flow of energy, often associated with a flow of materials. The droplet shapes (Sediment and Water Resources) represent compartments that store energy. Circular or ovular shapes are sources, outside sources of energy called forcing functions. The flag- or dart-like shapes (Deposition, Erosion, and Evapotranspiration, above) are for interactions. These are processes that combine energy or material flows to produce an outflow. The bullet-shaped Riparian Environment represents a producer, a unit that collects and transforms energy. The black diamond represents a transaction: the solid line is for the sale of goods or services, while the dashed line is the exchange of payment (Nairn, 2021). An important transaction that affects the system, as described above, is tourism (which would include fishing and kayaking among other activities) to the site. A successful restoration to the area must consider the entirety of the system and the role that each element depicted in the energy systems diagram plays in the overall balance of the site and the Baron Fork River.

CHAPTER 5

BUDGET ESTIMATE

5.1 Cost analysis

In terms of cost, ecologically engineered restoration techniques have the advantage over traditional “hard-surface” civil engineering techniques because ecologically engineered solutions tend to have lower up-front costs, as well as lower operating and maintenance costs (King et. al 1994).

The main costs for this project will be:

-The costs associated with the earthworks: excavation of the new channel, filling of the existing channel

-The cost of the construction and materials of the “W” weir structures and the J-hook rock vanes

-The machinery

-The operators and labor costs

-Monitoring costs

Table 13 shows an itemized estimate for the cost of the project. The monitoring costs are out of the scope of this project, but they should be taken into account for a real estimation. The cost of the operators and the machinery are included in the unit prices of the boulders and the earthwork. The filling material cost has been neglected as it will be all extracted from the excavation volume as explained in previous chapters. The number of boulders for each vane has been calculated dividing the area of the vanes by 20 square feet, which is the projected area of a typical boulder (4’x5’), then multiplied by 3 because that’s the number of layers selected to make sure at least one entire boulder is buried underground to avoid scouring.

Table 13 – Summary of the cost of the project

Price of 1 boulder of (4'x5'x2')	200 $
Price of 1 Cu.Yd of cut	4.5 $
Number of boulders per rock vane	695 boulders
Number of boulders per cross vane	1725 boulders
Number of rock vanes	2 units
Number cross vanes	2 units
Total number of boulders	4841 boulders
Total cost of the boulders	968200 $
Total volume of excavation	66240.646 Cu.Yd
Total cost of the excavation	298082.907 $
Total cost	1266282.91 $

The total cost of the project will be 12662.91 $.

5.2 Potential funding sources

The most likely source of funding for this project is The Oklahoma Department of Wildlife and Conservation (ODWC), which is an agency of the state of Oklahoma responsible for managing and protecting Oklahoma's wildlife population and their habitats. They are the ones who have acquired the land in the Baron Fork river and are planning to restore it. However, some other potential funding sources could participate covering the expenses of the project and therefore, it is interesting to consider them:

-The Natural Resources Conservation Service (NRCS): NRCS's natural resources conservation programs help people reduce soil erosion, enhance water supplies, improve water quality, increase wildlife habitat, and reduce damages caused by floods and other natural disasters. NRCS provides funding opportunities for agricultural producers and other landowners.

-The Oklahoma Corporation Commission (OCC): the Commission is a regulatory agency for the State of Oklahoma with emphasis on the Fuel, Oil and Gas, Public Utilities, and Transportation Industries

The EPA-Mitigation Bank: The EPA is an agency of the United States federal government whose mission is to protect human and environmental health. Headquartered in Washington, D.C., the EPA is responsible for creating standards and laws promoting the health of individuals and the environment.

The Oklahoma Department of Transportation (ODOT): They ensure Oklahoma has a safe and efficient highway system by building and maintaining interstates, U.S. highways, and state highways.

The Adair County Commission: The Commission is responsible for county administrative tasks, including Maintenance and repair of approximately 700 miles the roadway and bridges,

CHAPTER 6

PLAN FOR MONITORING AND DETERMINATION OF SUCCESS

Watershed and river assessments involve complex process interactions, making accurate predictions precarious. Monitoring specific stream, watershed and biotic processes continually improves our understanding of those processes and their relationships. Well-planned monitoring can also demonstrate any reduced sediment or improved river stability that results from changes in management and/or mitigation practices.[24]

Monitoring is generally recommended to:

- Measure the response of a system from combined process interactions due to imposed change
- Document or observe the response of a specific process and compare it with the predicted response for a prescribed treatment
- Define short-term versus long-term changes
- Document spatial variability or process and system response
- Reduce prediction uncertainty levels
- Provide confidence in specific management practice modifications to mitigation recommendations
- Determine if mitigation is implemented correctly
- Evaluate the effectiveness of stabilization or restoration approaches

[24] Dave Rosgen, *Watershed Assessment of River Stability and Sediment Supply (WARSSS)*, 2006th ed. (Wildland Hydrology Fort Collins, Colorado, n.d.).

- Build a database to extrapolate for similar applications

In this case of study, the reason why monitoring is necessary is because a change of the existing channel has been made to protect the existing infrastructure and to restore its natural meandering shape, and therefore, the response of the system will determine if the project was successful or not. As it has been done in the channel stability assessment, during monitoring, spatial and temporal scales can be evaluated. Spatial scales deal with specific locations and shifts in dimension, pattern, profile, and materials. Temporal scales evaluate changes at the same location over time. The plan of monitoring and determination of success will therefore be based on:

- Yearly visual inspections of the road to make sure the river has not been damaging it.

- Establish permanent control cross-sections and resurvey them one year following their establishment and use the results to analyze the bed stability (aggradation or degradation), channel enlargement, and lateral accretion.

- Obtain yearly drone footage to determine both temporal and spatial scale changes in meander geometry (meander wavelength, radius of curvature, and belt width) as well as to compare deposition and erosion development on the gravel bars. Drone images of the site should be taken during the base flow of the river, to make comparison over time clear.

- A permanent longitudinal profile will be established and resurveyed annually to evaluate changes in bed features, aggradation, degradation, and slope.

- Changes in channel materials will be monitored annually by conducting pebble counts spatially controlled at the permanent riffles. This will allow determining shifts in bed material size distribution over time

- The J-hook rock vanes and the W-weirs should be yearly inspected if possible during low flow periods such as October to make sure they are working as they are supposed to do, to check that the rocks are where they should be and that scouring around the structures has nor occurred.

- Yearly inspections of the planting should also be carried out.

- Apart from the yearly mentioned inspections, after any severe flooding events, the site should be re-inspected, including evaluations of damage to the structures as well as the development of scour pools or excessive bank erosions. If change were to occur, it would be most visible after such an event.

Another output from the monitoring measurements that could be useful, is the possibility to calibrate and validate the models used to predict the streambank erosion rates, hydraulics, sediment competence, and sediment supply.

CHAPTER 7

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CHAPTER 8
APPENDIX

8.1 HYDROLOGY

8.1.1 Calculations

The following figure corresponds to the Ecoregions for Oklahoma derived from Omernik (1987):

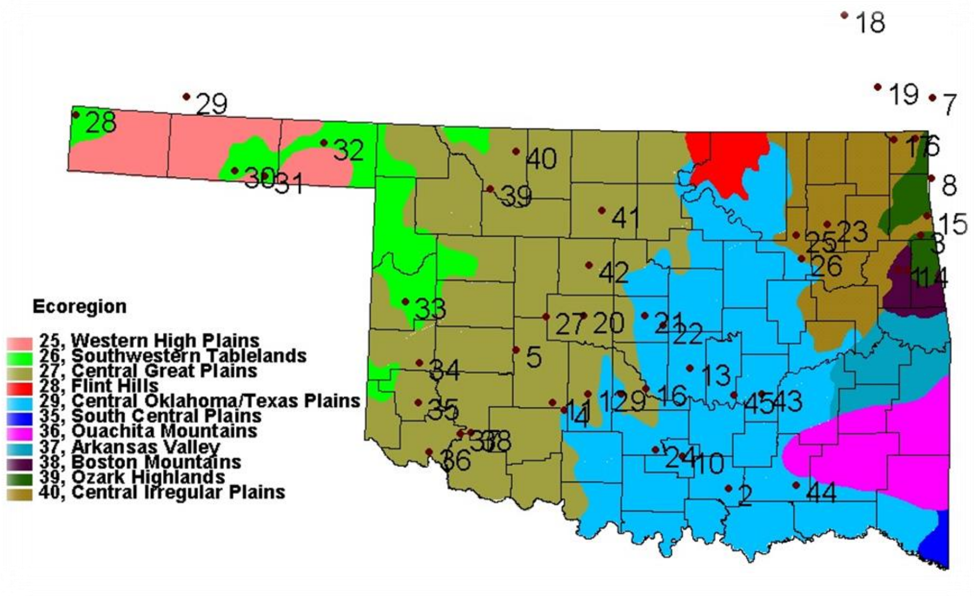


Figure 13 (appendix) – Omernik Ecoregions for Oklahoma

As mentioned in previous chapters the area of study is located in the ecoregion 39, Ozark Highlands. The following figures are log-log plots curves that compare channel dimensions like top width, mean depth, and cross-sectional area at bankfull discharge versus drainage area in the Omernik Ecoregions for Oklahoma. Typically, to estimate the bankfull discharge of the site, the results from the graphs should be obtained for two drainage areas, one upstream the site and another downstream the site, and then interpolated.

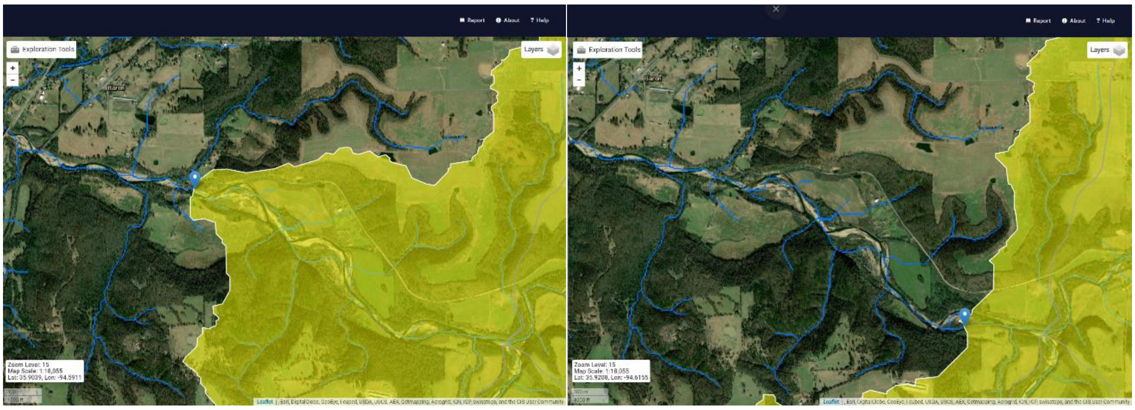


Figure 14 (appendix) – Drainage area 1 downstream the site (left), Drainage area 2 upstream the site (right).

Drainage area 1 is 141.870 mi^2 and drainage area 2 is 140.310 mi^2. These areas have been obtained by importing the global watershed polygon of the Baron Fork from the USGS StreamStats website to Civil 3D as closed polylines, and using the command "Area". Due to the small difference between the areas, and the precision of the graphs, a mean drainage area could be also used to estimate the bankfull discharge.

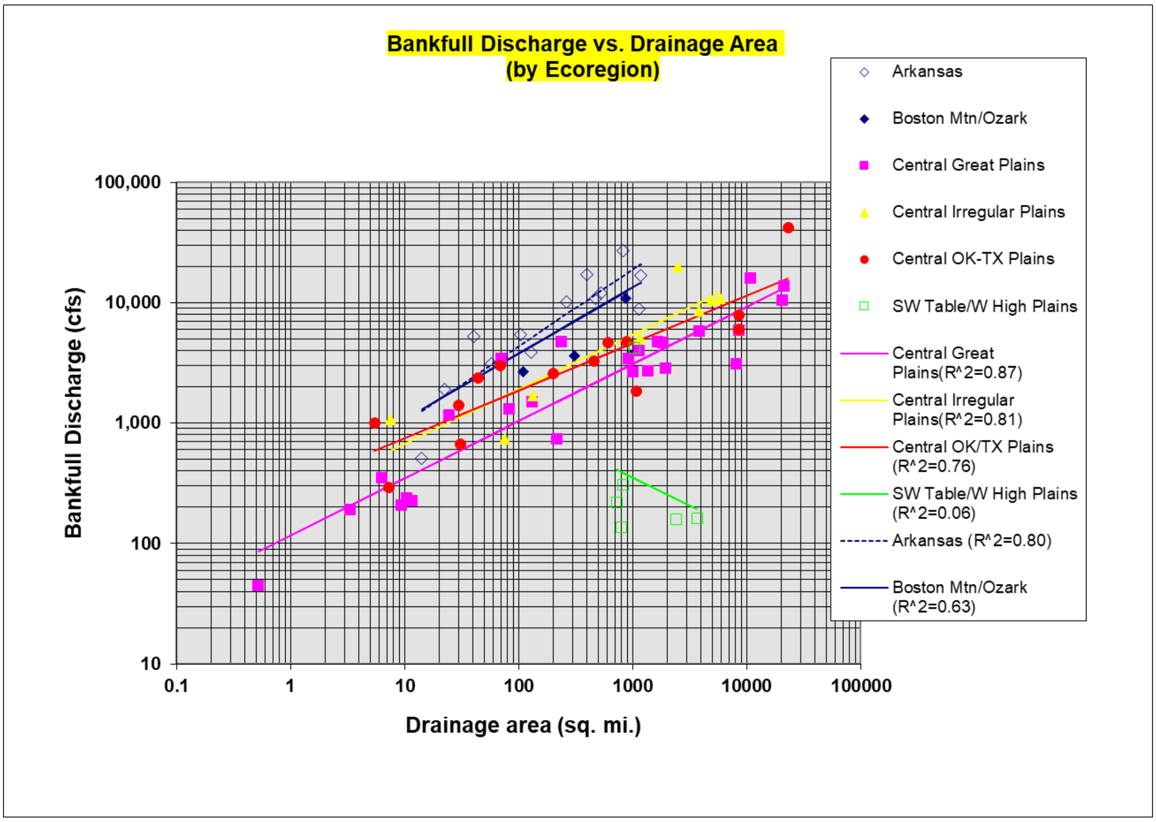


Figure 15 (appendix) – Bankfull Discharge vs Drainage Area by Ecoregion, Dutnell (2000)

The adjusted equation that relates the Bankfull discharge with the drainage area for the Boston Mountains and the Ozark Ecoregions ($R^2 = 0.63$) is:

$$Q_{BF} = 305.33 \times DA^{0{,}548}$$

Where:

Q_{BF}: Is the Bankfull discharge in CFS.
DA: Is the Drainage Area in mi^2

Therefore:

$$Q_{BF_1} = 305.33 \times DA_1{}^{0{,}548}$$
$$Q_{BF_1} = 305.33 \times 141.870^{0{,}548} = 4613.234\ cfs$$

$$Q_{BF_2} = 305.33 \times DA_2{}^{0{,}548}$$
$$Q_{BF_2} = 305.33 \times 140.310^{0{,}548} = 4585.367\ cfs$$

$$Q_{BF} = \frac{Q_{BF_1} + Q_{BF_2}}{2} = \frac{4613.234\ + 4585.367}{2} \approx 4600\ cfs$$

According to the Regional Curves, the bankfull discharge is approximately 4600 CFS.

Now the recurrence interval will be obtained from the flood-frequency curve of the gaging stations 07197000 Baron Fork at Eldon, OK, and 07196900 Baron Fork at Dutch Mills, AR, obtained from the website of the United States Geological Survey (USGS), Surface Water for Oklahoma, Peak Streamflow. Bankfull discharge has an approximately constant recurrence interval, 1.5 years in the annual flood series but can range between 1.0 and 2.5 years. Fortunately, the record of annual discharge at both stations is sufficiently long so that a flow-frequency analysis is possible.

Here is a graph of the Annual Peak Streamflow at the gauging station 07196900 Baron Fork at Dutch Mills, AR, upstream of the site:

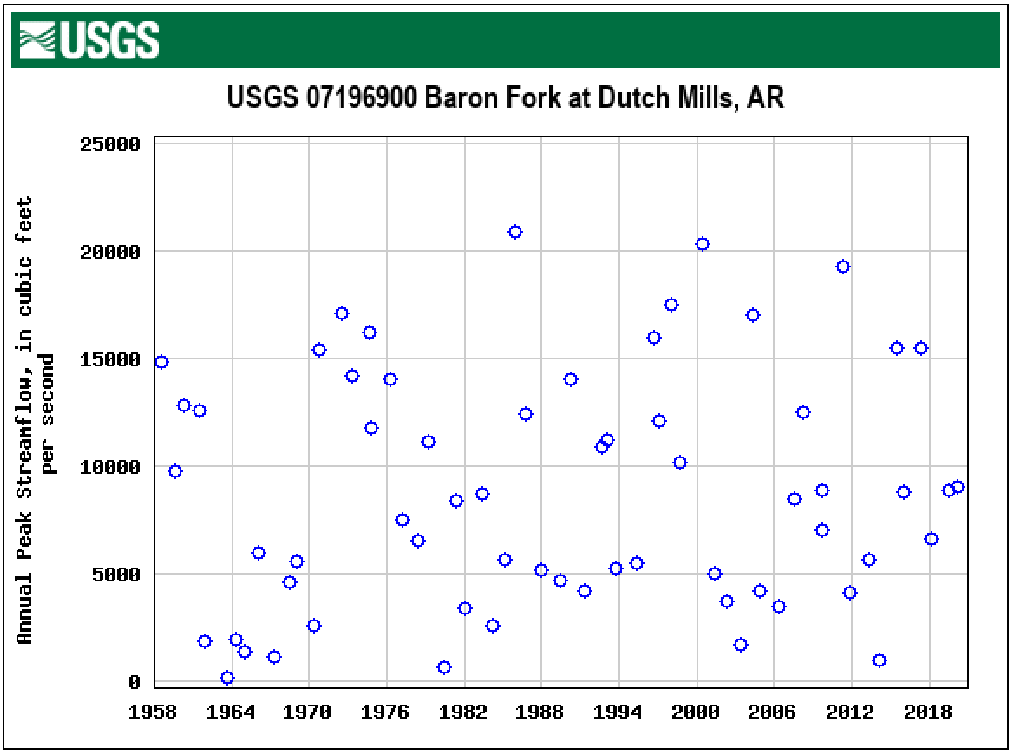


Figure 16 (appendix) – Annual Peak Streamflow USGS 07196900 (Upstream the site)

The first step is to order the annual peak stream flows from higher to lower and rank them from 1 to n, where n is the number of years with available data. The value of 1 will correspond to the highest annual peak streamflow recorded and the value of n to the lowest. Next, the probability associated with that value is calculated by using the following formula:

$$P = \frac{Rank\ Number}{1 + n}$$

Finally, the Return Interval can be calculated by inverting the value of the probability:

$$RI = \frac{1}{P}$$

Table 1 (appendix) – Flow frequency analysis at Dutch Mills

Flow Frequency Analysis: 07196900 Baron Fork at Dutch Mills			
PEAK (cfs/s)	**RANK**	**PROBABILITY**	**RI (Years)**
20900	1	0.016	64.000
20300	2	0.031	32.000
19300	3	0.047	21.333
17500	4	0.063	16.000
17100	5	0.078	12.800
17000	6	0.094	10.667
16200	7	0.109	9.143
16000	8	0.125	8.000
15500	9	0.141	7.111
15500	10	0.156	6.400
15400	11	0.172	5.818
14800	12	0.188	5.333
14200	13	0.203	4.923
14000	14	0.219	4.571
14000	15	0.234	4.267
12800	16	0.250	4.000
12600	17	0.266	3.765
12500	18	0.281	3.556
12400	19	0.297	3.368
12100	20	0.313	3.200
11800	21	0.328	3.048
11200	22	0.344	2.909
11100	23	0.359	2.783
10900	24	0.375	2.667
10200	25	0.391	2.560
9750	26	0.406	2.462
9000	27	0.422	2.370
8910	28	0.438	2.286
8890	29	0.453	2.207
8770	30	0.469	2.133
8680	31	0.484	2.065
8500	32	0.500	2.000
8430	33	0.516	1.939
7480	34	0.531	1.882
6990	35	0.547	1.829
6620	36	0.563	1.778
6550	37	0.578	1.730
5950	38	0.594	1.684
5690	39	0.609	1.641
5640	40	0.625	1.600

Flow Frequency Analysis: 07196900 Baron Fork at Dutch Mills			
PEAK (cfs/s)	**RANK**	**PROBABILITY**	**RI (Years)**
5540	41	0.641	1.561
5470	42	0.656	1.524
5230	43	0.672	1.488
5170	44	0.688	1.455
5000	45	0.703	1.422
4660	46	0.719	1.391
4620	47	0.734	1.362
4210	48	0.750	1.333
4200	49	0.766	1.306
4110	50	0.781	1.280
3750	51	0.797	1.255
3490	52	0.813	1.231
3380	53	0.828	1.208
2630	54	0.844	1.185
2610	55	0.859	1.164
1950	56	0.875	1.143
1850	57	0.891	1.123
1730	58	0.906	1.103
1360	59	0.922	1.085
1140	60	0.938	1.067
1020	61	0.953	1.049
644	62	0.969	1.032
174	63	0.984	1.016

Here is a graph of the Annual Peak Streamflow at the gauging station 07197000 Baron Fork at Eldon, OK downstream the site:

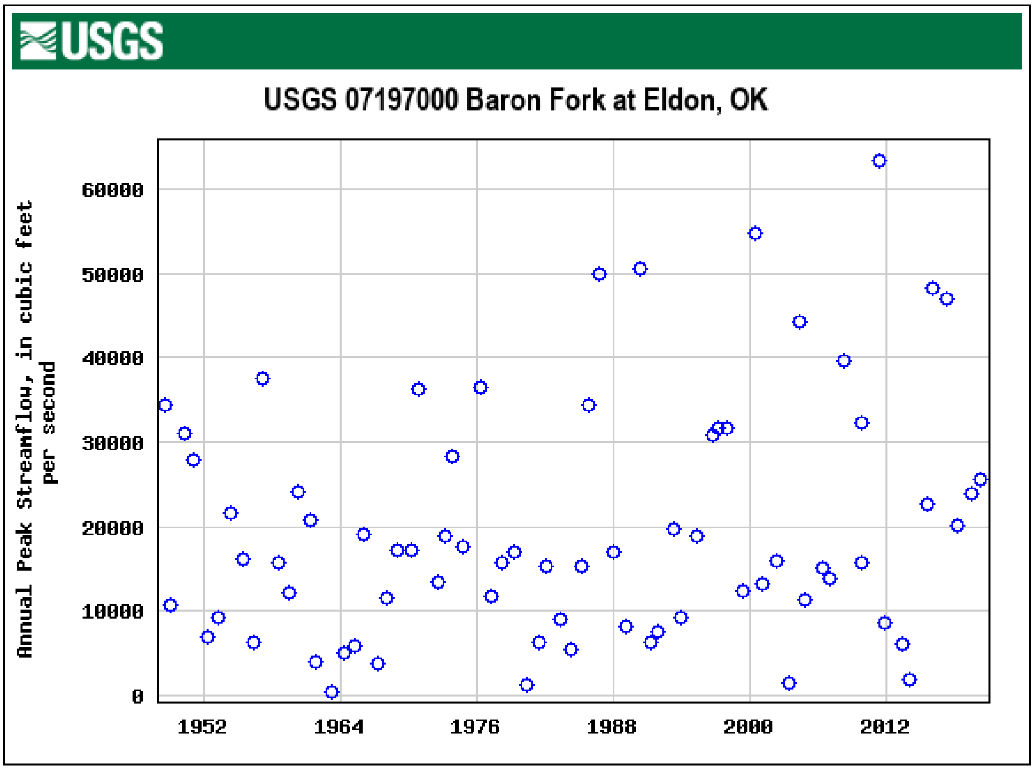


Figure 17 (appendix) - Annual Peak Streamflow USGS 07197000 (Downstream the site)

Following the same procedure as before, the Return Interval has been calculated:

Table 2 (appendix) - Flow frequency analysis at Eldon

Flow Frequency Analysis: 07197000 Baron Fork at Eldon			
PEAK (cfs/s)	**RANK**	**PROBABILITY**	**RI (Years)**
63400	1	0.014	74.000
54700	2	0.027	37.000
50600	3	0.041	24.667
50000	4	0.054	18.500
48300	5	0.068	14.800
46900	6	0.081	12.333
44300	7	0.095	10.571
39600	8	0.108	9.250
37600	9	0.122	8.222
36400	10	0.135	7.400
36200	11	0.149	6.727
34400	12	0.162	6.167
34300	13	0.176	5.692
32200	14	0.189	5.286
31600	15	0.203	4.933

Flow Frequency Analysis: 07197000 Baron Fork at Eldon			
PEAK (cfs/s)	RANK	PROBABILITY	RI (Years)
31600	16	0.216	4.625
31000	17	0.230	4.353
30900	18	0.243	4.111
28200	19	0.257	3.895
27800	20	0.270	3.700
25500	21	0.284	3.524
24000	22	0.297	3.364
23900	23	0.311	3.217
22600	24	0.324	3.083
21600	25	0.338	2.960
20800	26	0.351	2.846
20200	27	0.365	2.741
19700	28	0.378	2.643
19100	29	0.392	2.552
18900	30	0.405	2.467
18800	31	0.419	2.387
17500	32	0.432	2.313
17200	33	0.446	2.242
17200	34	0.459	2.176
16900	35	0.473	2.114
16900	36	0.486	2.056
16200	37	0.500	2.000
15800	38	0.514	1.947
15700	39	0.527	1.897
15700	40	0.541	1.850
15600	41	0.554	1.805
15300	42	0.568	1.762
15300	43	0.581	1.721
15100	44	0.595	1.682
13900	45	0.608	1.644
13300	46	0.622	1.609
13100	47	0.635	1.574
12400	48	0.649	1.542
12200	49	0.662	1.510
11600	50	0.676	1.480
11500	51	0.689	1.451
11300	52	0.703	1.423
10600	53	0.716	1.396
9240	54	0.730	1.370
9240	55	0.743	1.345
8950	56	0.757	1.321
8480	57	0.770	1.298

Flow Frequency Analysis: 07197000 Baron Fork at Eldon			
PEAK (cfs/s)	RANK	PROBABILITY	RI (Years)
8100	58	0.784	1.276
7580	59	0.797	1.254
6840	60	0.811	1.233
6330	61	0.824	1.213
6300	62	0.838	1.194
6260	63	0.851	1.175
5980	64	0.865	1.156
5850	65	0.878	1.138
5430	66	0.892	1.121
5020	67	0.905	1.104
3950	68	0.919	1.088
3640	69	0.932	1.072
1890	70	0.946	1.057
1400	71	0.959	1.042
1300	72	0.973	1.028
365	73	0.986	1.014

As it can be seen the bankfull discharge calculated through the Regional Curves lies between the recurrence interval window of 1 year and 2.5 years mentioned before as it was expected. The precise value has been interpolated according to the distance of the gauging stations to the site:

Table 3 (appendix) - Flow frequency analysis at Dutch Mills (interpolation)

Flow Frequency Analysis: 07196900 Baron Fork at Dutch Mills			
PEAK (cfs/s)	RANK	PROBABILITY	RI (Years)
4620	47	0.734	1.362
4210	48	0.750	1.333

$$\frac{1.362 - 1.333}{4620 - 4210} = \frac{x}{4600 - 4210}$$

$$RI_{Dutch\ Mills} = x + 1.333 = 1.358\ years$$

Table 4 (appendix) - Flow frequency analysis at Eldon (interpolation)

Flow Frequency Analysis: 07197000 Baron Fork at Eldon			
PEAK (cfs/s)	RANK	PROBABILITY	RI (Years)
5020	67	0.905	1.104
3950	68	0.919	1.088

$$\frac{1.104 - 1.088}{5020 - 3950} = \frac{x}{4600 - 3950}$$

$$RI_{Eldon} = x + 1.088 = 1.098\ years$$

Considering that 07196900 Baron Fork at Dutch Mills is 7 miles away from the site and 07197000 Baron Fork at Eldon is 14 miles:

$$\frac{1.358 - 1.098}{14 + 7} = \frac{x}{14}$$

$$RI = x + 1.098 = 1.271\ years$$

Some other useful parameters that can be extracted from the Regional Curves developed by Dutnell (2000) are the Bankfull width, the Bankfull Area, and the Bankfull depth. Drainage area 1 is 141.870 mi^2 and drainage area 2 is 140.310 mi^2. For the calculation of the mentioned parameters an averaged drainage area of 141.090 mi^2 has been used.

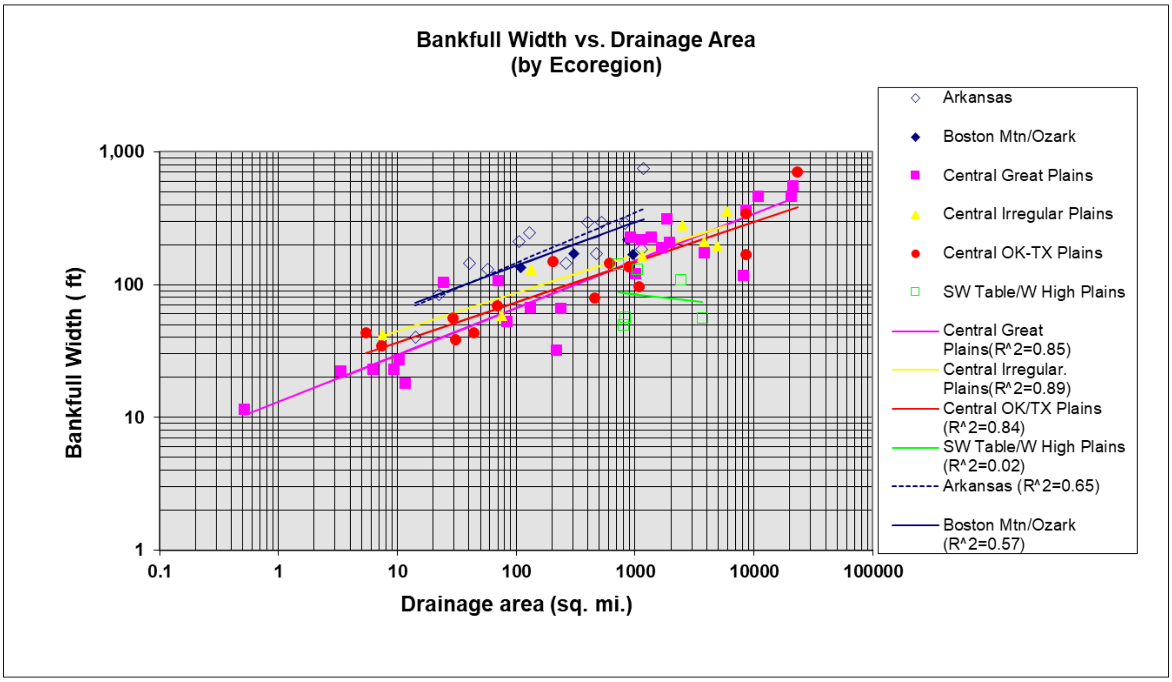


Figure 18 (appendix) - Bankfull width vs Drainage Area by Ecoregion, Dutnell (2000)

The adjusted equation that relates the Bankfull Width with the drainage area for the Boston Mountains and the Ozark Ecoregions (R^2=0.57) is:

$$W_{BF} = 30.70 \times DA^{0.328}$$

Where:

W_{BF}: Is the Bankfull Width in feet.

DA: Is the Drainage Area in mi^2.

Therefore:

$$W_{BF} = 30.70 \times DA^{0.328} = 155.658\,feet$$

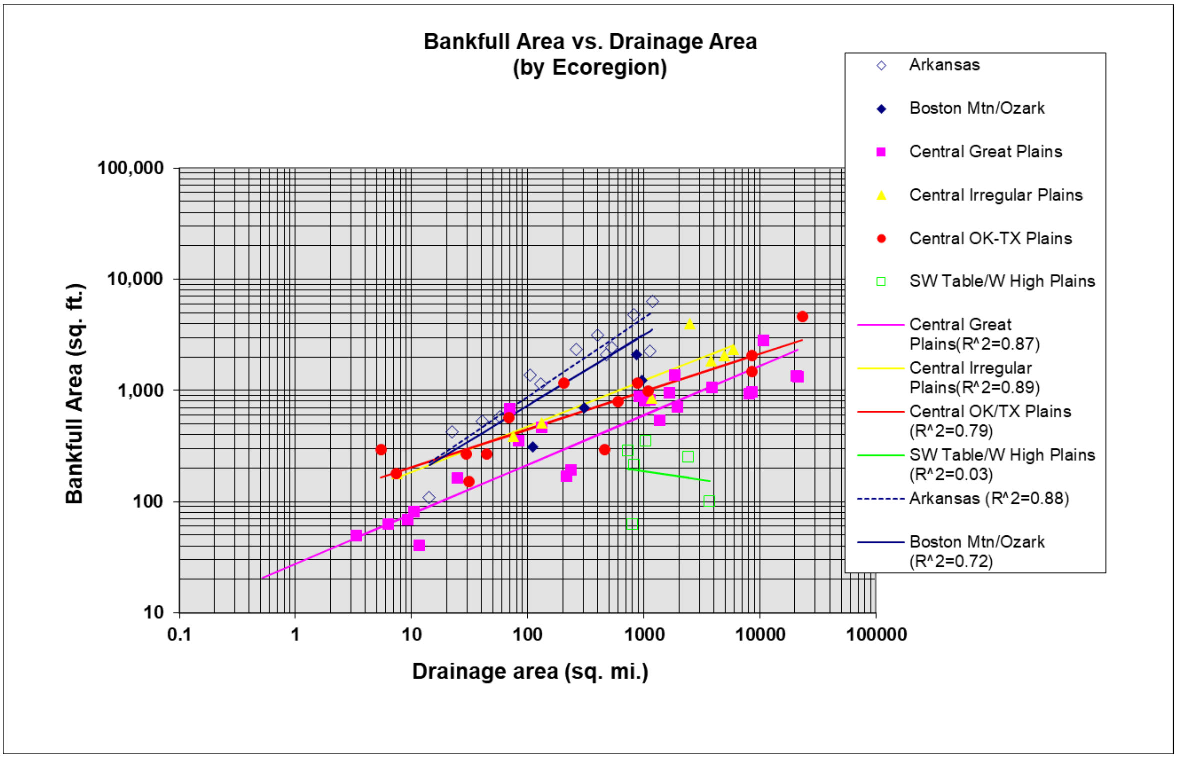


Figure 19 (appendix) - Bankfull Area vs Drainage Area by Ecoregion, Dutnell (2000)

The adjusted equation that relates the Bankfull Area with the drainage area for the Boston Mountains and the Ozark Ecoregions (R^2=0.72) is:

$$A_{BF} = 39.75 \times DA^{0.634}$$

Where:

A_{BF}: Is the bankfull Area in ft^2.
DA: Is the Drainage Area in mi^2.

Therefore:

$$A_{BF} = 39.75 \times DA^{0.634} = 907.708\ ft^2$$

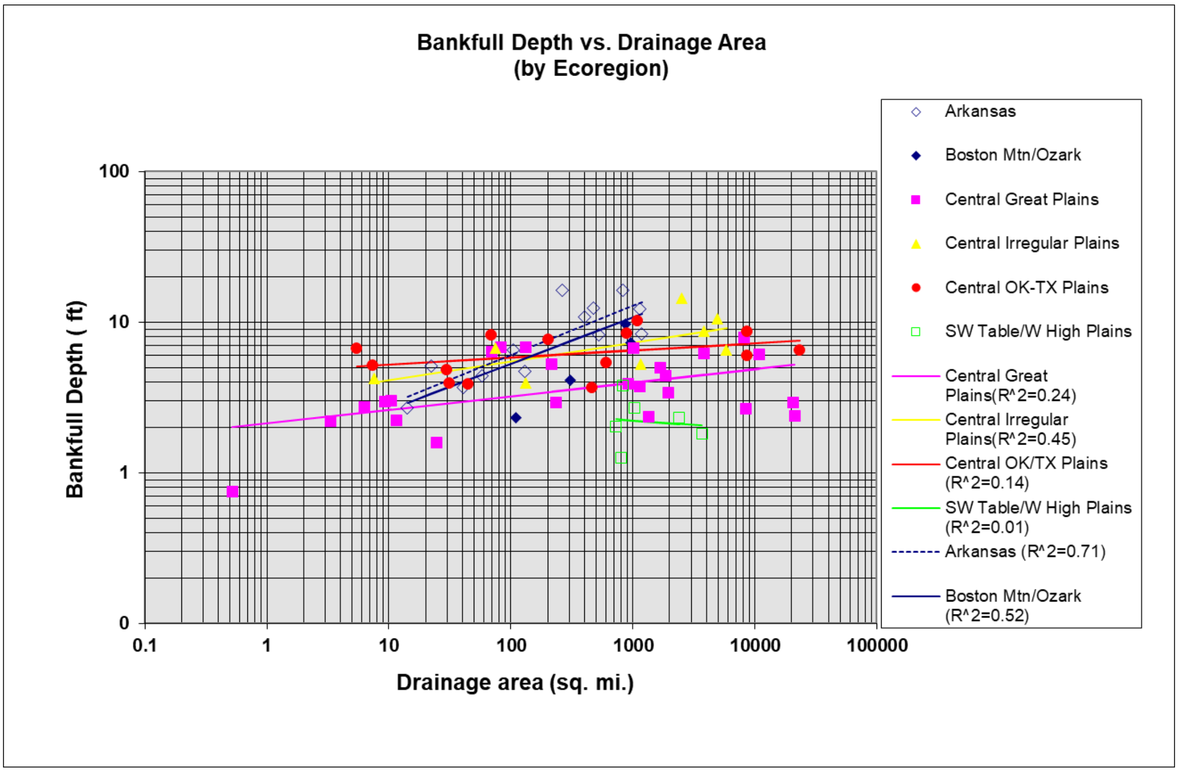


Figure 20 (appendix) - Bankfull Depth vs Drainage Area by Ecoregion, Dutnell (2000

The adjusted equation that relates the Bankfull Depth with the drainage area for the Boston Mountains and the Ozark Ecoregions (R^2=0.52) is:

$$H_{BF} = 1.30 \times DA^{0.307}$$

Where:

H_{BF}: Is the bankfull depth in ft.
DA: Is the Drainage Area in mi^2.

Therefore:

$$H_{BF} = 1.30 \times DA^{0.307} = 5.941\ ft$$

However, it would be more accurate to calculate the Bankfull Depth dividing the bankfull area by the bankfull width:

$$H_{BF} = \frac{A_{BF}}{W_{BF}} = \frac{907.708}{155.658} = 5.831\ ft$$

8.1.2 Stream stats report

Here is the stream stats report for gauging station 07196900 Baron Fork at Dutch Mills, AR:

Region ID: OK
Workspace ID: OK20210623010608271000
Clicked Point (Latitude, Longitude): 35.90417, -94.58074
Time: 2021-06-22 20:06:26 -0500

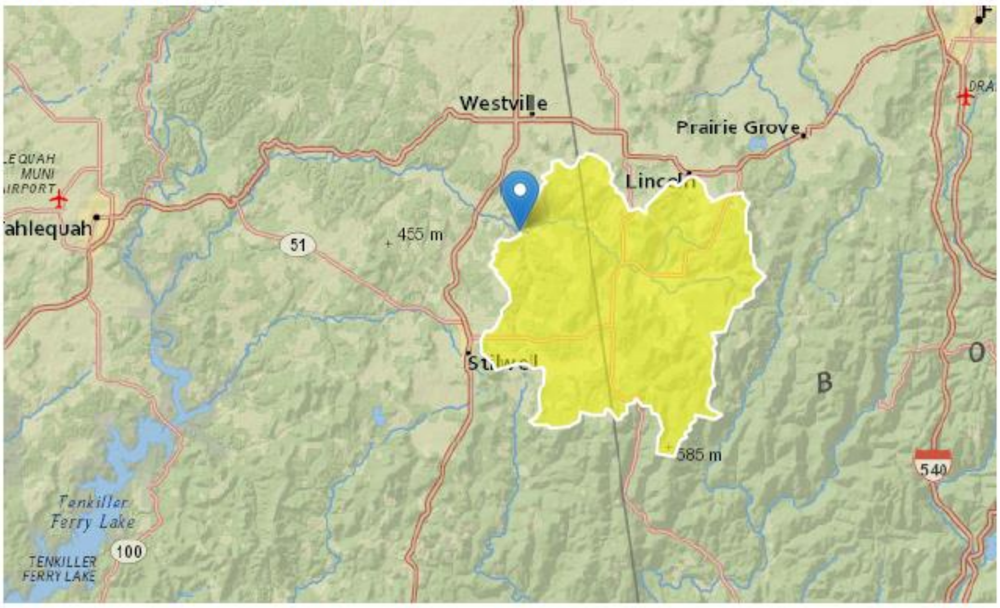


Figure 21(appendix) – Watershed at Dutch Mills

Basin Characteristics

Parameter Code	Parameter Description	Value	Unit
CONTDA	Area that contributes flow to a point on a stream	140.31	square miles
CSL10_85fm	Change in elevation between points 10 and 85 percent of length along main channel to basin divide divided by length between points ft per mi	18.7	feet per mi
DAUNREG	Unregulated drainage area used in OK regulated equations	140.31	square miles

Peak-Flow Statistics Parameters [Peak Region 2 Unregulated 2019 5143]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
CONTDA	Contributing Drainage Area	140.31	square miles	0.1	2510
CSL10_85fm	Stream Slope 10 and 85 Method ft per mi	18.7	feet per mi	1.98	342

Peak-Flow Statistics Parameters [Peak Region 2 NRCS Regulated 2019 5143]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DAUNREG	Unregulated Drainage Area	140.31	square miles	0.1	2510
CSL10_85fm	Stream Slope 10 and 85 Method ft per mi	18.7	feet per mi	1.98	342

Peak-Flow Statistics Flow Report [Peak Region 2 Unregulated 2019 5143]

PIl: Prediction Interval-Lower, Plu: Prediction Interval-Upper, SEp: Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	SEp	Equiv. Yrs.
50-percent AEP flood	8100	ft^3/s	46.9	2
20-percent AEP flood	16000	ft^3/s	36.2	5
10-percent AEP flood	22900	ft^3/s	35	8
4-percent AEP flood	32600	ft^3/s	39.9	9
2-percent AEP flood	43800	ft^3/s	37.1	11
1-percent AEP flood	51600	ft^3/s	39.9	12
0.2-percent AEP flood	84400	ft^3/s	50.7	12

Peak-Flow Statistics Flow Report [Peak Region 2 NRCS Regulated 2019 5143]

PIl: Prediction Interval-Lower, Plu: Prediction Interval-Upper, SEp: Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	SEp	Equiv. Yrs.
Regulated 50-percent AEP flood	8100	ft^3/s	46.9	2
Regulated 20-percent AEP flood	16000	ft^3/s	36.2	5
Regulated 10-percent AEP flood	22900	ft^3/s	35	8
Regulated 4-percent AEP flood	32600	ft^3/s	39.9	9
Regulated 2-percent AEP flood	43800	ft^3/s	37.1	11
Regulated 1-percent AEP flood	51600	ft^3/s	39.9	12

Statistic	Value	Unit	SEp	Equiv. Yrs.
Regulated 0.2-percent AEP flood	84400	ft^3/s	50.7	12

Peak-Flow Statistics Flow Report [Area-Averaged]

PII: Prediction Interval-Lower, Plu: Prediction Interval-Upper, SEp: Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	SEp	Equiv. Yrs.
50-percent AEP flood	8100	ft^3/s	46.9	2
20-percent AEP flood	16000	ft^3/s	36.2	5
10-percent AEP flood	22900	ft^3/s	35	8
4-percent AEP flood	32600	ft^3/s	39.9	9
2-percent AEP flood	43800	ft^3/s	37.1	11
1-percent AEP flood	51600	ft^3/s	39.9	12
0.2-percent AEP flood	84400	ft^3/s	50.7	12
Regulated 50-percent AEP flood	8100	ft^3/s	46.9	2
Regulated 20-percent AEP flood	16000	ft^3/s	36.2	5
Regulated 10-percent AEP flood	22900	ft^3/s	35	8
Regulated 4-percent AEP flood	32600	ft^3/s	39.9	9
Regulated 2-percent AEP flood	43800	ft^3/s	37.1	11
Regulated 1-percent AEP flood	51600	ft^3/s	39.9	12
Regulated 0.2-percent AEP flood	84400	ft^3/s	50.7	12

Peak-Flow Statistics Citations

Lewis, J.M., Hunter, S.L., and Labriola, L.G.,2019, Methods for estimating the magnitude and frequency of peak streamflows for unregulated streams in Oklahoma developed by using streamflow data through 2017: U.S. Geological Survey Scientific Investigations Report 2019–5143, 39 p. (https://doi.org/10.3133/sir20195143)

Application Version: 4.5.3
StreamStats Services Version: 1.2.22
NSS Services Version: 2.1.2

Here is the stream stats report for gauging station 07197000 Baron Fork at Eldon, OK:

Region ID: OK
Workspace ID: OK20210623164907091000
Clicked Point (Latitude, Longitude): 35.91513, -94.60275
Time: 2021-06-23 11:49:26 -0500

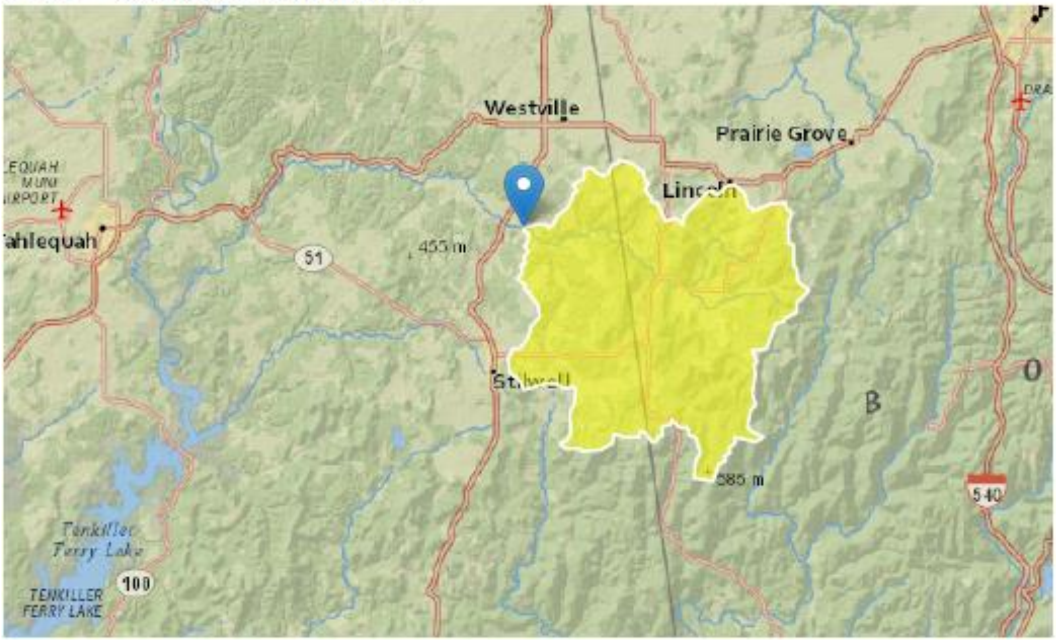


Figure 22 (appendix) – Watershed at Eldon

Basin Characteristics

Parameter Code	Parameter Description	Value	Unit
CONTDA	Area that contributes flow to a point on a stream	141.87	square miles
CSL10_85fm	Change in elevation between points 10 and 85 percent of length along main channel to basin divide divided by length between points ft per mi	17.7	feet per mi
DAUNREG	Unregulated drainage area used in OK regulated equations	141.87	square miles
PRECIPOUT	Mean annual precip at the stream outlet (based on annual PRISM precip data in inches from 1971-2000)	49.38	inches

Peak-Flow Statistics Parameters [Peak Region 2 Unregulated 2019 5143]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
CONTDA	Contributing Drainage Area	141.87	square miles	0.1	2510
CSL10_85fm	Stream Slope 10 and 85 Method ft per mi	17.7	feet per mi	1.98	342

Peak-Flow Statistics Parameters [Peak Region 2 NRCS Regulated 2019 5143]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DAUNREG	Unregulated Drainage Area	141.87	square miles	0.1	2510
CSL10_85fm	Stream Slope 10 and 85 Method ft per mi	17.7	feet per mi	1.98	342

Peak-Flow Statistics Flow Report [Peak Region 2 Unregulated 2019 5143]

PIl: Prediction Interval-Lower, PIu: Prediction Interval-Upper, SEp: Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	SEp	Equiv. Yrs.
50-percent AEP flood	7990	ft^3/s	46.9	2
20-percent AEP flood	15700	ft^3/s	36.2	5
10-percent AEP flood	22500	ft^3/s	35	8
4-percent AEP flood	32000	ft^3/s	39.9	9
2-percent AEP flood	43000	ft^3/s	37.1	11
1-percent AEP flood	50600	ft^3/s	39.9	12
0.2-percent AEP flood	82800	ft^3/s	50.7	12

Peak-Flow Statistics Flow Report [Peak Region 2 NRCS Regulated 2019 5143]

PIl: Prediction Interval-Lower, PIu: Prediction Interval-Upper, SEp: Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	SEp	Equiv. Yrs.
Regulated 50-percent AEP flood	7990	ft^3/s	46.9	2
Regulated 20-percent AEP flood	15700	ft^3/s	36.2	5
Regulated 10-percent AEP flood	22500	ft^3/s	35	8
Regulated 4-percent AEP flood	32000	ft^3/s	39.9	9
Regulated 2-percent AEP flood	43000	ft^3/s	37.1	11
Regulated 1-percent AEP flood	50600	ft^3/s	39.9	12
Regulated 0.2-percent AEP flood	82800	ft^3/s	50.7	12

Peak-Flow Statistics Flow Report [Area-Averaged]

PIl: Prediction Interval-Lower, PIu: Prediction Interval-Upper, SEp: Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	SEp	Equiv. Yrs.
50-percent AEP flood	7990	ft^3/s	46.9	2
20-percent AEP flood	15700	ft^3/s	36.2	5
10-percent AEP flood	22500	ft^3/s	35	8
4-percent AEP flood	32000	ft^3/s	39.9	9
2-percent AEP flood	43000	ft^3/s	37.1	11
1-percent AEP flood	50600	ft^3/s	39.9	12
0.2-percent AEP flood	82800	ft^3/s	50.7	12
Regulated 50-percent AEP flood	7990	ft^3/s	46.9	2
Regulated 20-percent AEP flood	15700	ft^3/s	36.2	5
Regulated 10-percent AEP flood	22500	ft^3/s	35	8
Regulated 4-percent AEP flood	32000	ft^3/s	39.9	9
Regulated 2-percent AEP flood	43000	ft^3/s	37.1	11
Regulated 1-percent AEP flood	50600	ft^3/s	39.9	12
Regulated 0.2-percent AEP flood	82800	ft^3/s	50.7	12

Peak-Flow Statistics Citations

Lewis, J.M., Hunter, S.L., and Labriola, L.G.,2019, Methods for estimating the magnitude and frequency of peak streamflows for unregulated streams in Oklahoma developed by using streamflow data through 2017: U.S. Geological Survey Scientific Investigations Report 2019–5143, 39 p. (https://doi.org/10.3133/sir20195143)

General Flow Statistics Parameters [Duration Region 3 2009 5267]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
CONTDA	Contributing Drainage Area	141.87	square miles	8	2296
PRECIPOUT	Mean Annual Precip at Gage	49.38	inches	38	58

General Flow Statistics Flow Report [Duration Region 3 2009 5267]

PII: Prediction Interval-Lower, Plu: Prediction Interval-Upper, SEp: Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	PII	Plu
Average daily streamflow	163	ft^3/s	122	217

General Flow Statistics Citations

Esralew, R.A., Smith, S.J.,2009, Methods for estimating flow-duration and annual mean-flow statistics for ungaged streams in Oklahoma: U.S. Geological Survey Scientific Investigations Report 2009-5267, 131 p. (http://pubs.usgs.gov/sir/2009/5267/)

8.2 Pebble count

The following tables show the result of the 3 pebble counts that have been carried out. ST stands for silt/clay; SD stands for sand, and BR stands for bedrock.

Table 5 (appendix) – Pebble counts measurements

Sample nº	Size in mm		
	Peeble count 1 (Upstream)	Peeble count 2 (middle)	Peeble count 3 (downstream)
1	40	27	22
2	42	45	19
3	26	25	31
4	st	15	21
5	st	22	60
6	st	53	24
7	st	46	17
8	st	16	11
9	32	19	50
10	25	34	36
11	64	38	19
12	42	16	12
13	40	18	39
14	39	55	35
15	38	24	31
16	65	32	80
17	30	36	30
18	19	40	17
19	25	95	12
20	30	25	45
21	32	16	12
22	13	61	30
23	19	20	62
24	25	34	55
25	35	150	16
26	40	48	5
27	33	48	32
28	24	30	180
29	31	33	22
30	36	30	28
31	17	50	15
32	18	10	35
33	22	52	25
34	25	45	65
35	65	30	35
36	60	35	20
37	36	43	30
38	20	60	20
39	19	33	32
40	24	45	10
41	68	44	28

Sample nº	Size in mm		
	Peeble count 1 (Upstream)	Peeble count 2 (middle)	Peeble count 3 (downstream)
42	16	56	15
43	27	105	50
44	20	190	19
45	15	20	39
46	12	36	34
47	25	24	17
48	14	15	20
49	13	50	22
50	15	20	33
51	30	22	19
52	16	45	4
53	15	22	17
54	29	19	25
55	10	40	38
56	25	20	15
57	17	75	24
58	20	32	62
59	26	29	16
60	30	29	11
61	14	3	9
62	20	14	22
63	11	15	28
64	16	22	35
65	27	43	35
66	17	55	12
67	5	12	5
68	19	72	50
69	32	26	62
70	17	9	40
71	20	14	22
72	10	50	30
73	26	22	39
74	10	75	42
75	18	24	50
76	13	16	59
77	27	15	24
78	30	34	30
79	13	34	80
80	30	85	20
81	26	26	39
82	16	20	40
83	10	32	45
84	35	26	36
85	19	60	22
86	8	35	60
87	11	45	18
88	20	50	16
89	16	160	45
90	27	27	30
91	15	40	85
92	10	22	30

Sample nº	Size in mm		
	Peeble count 1 (Upstream)	Peeble count 2 (middle)	Peeble count 3 (downstream)
93	80	26	32
94	28	50	82
95	30	40	16
96	25	11	5
97	20	85	10
98	68	36	26
99	20	54	24
100	50	46	36

Pebble Count

Site: Baron Fork Reach: 1
Party: R. Dutnell; C. Crespo
Date: July 2021

Table 6 (appendix) - Pebble count 1 results

	Particle	Size, mm	Count	Total	Item %	% Cum
S/C	Silt/Clay	<0.062	5	5	5	5
SAND	Very Fine	.062-.125		5	0	5
	Fine	.125-.25		5	0	5
	Medium	.25-.5		5	0	5
	Coarse	.5-1		5	0	5
	Very Coarse	1-2	0	5	0	5
GRAVEL	Very Fine	2-4	0	5	0	5
	Fine	4-6	1	6	1	6
	Fine	6-8	0	6	0	6
	Medium	8-12	7	13	7	13
	Medium	12-16	11	24	11	24
	Coarse	16-24	26	50	26	50
	Coarse	24-32	25	75	25	75
	Very Coarse	32-45	17	92	17	92
	Very Coarse	45-64	4	96	4	96
COBL	Small	64-90	4	100	4	100
	Small	90-128	0	100	0	100
	Large	128-180	0	100	0	100
	Large	180-256	0	100	0	100
BLDR	Small	256-362	0	100	0	100
	Small	362-512	0	100	0	100
	Medium	512-1024	0	100	0	100
	Large to Very Large	1024-4096	0	100	0	100
BDRK	Bedrock		0	100	0	100
	Totals		100	100		100

D16 =	13	mm
D35 =	19	mm
D50 =	24	mm
D84 =	40	mm
D95 =	60	mm

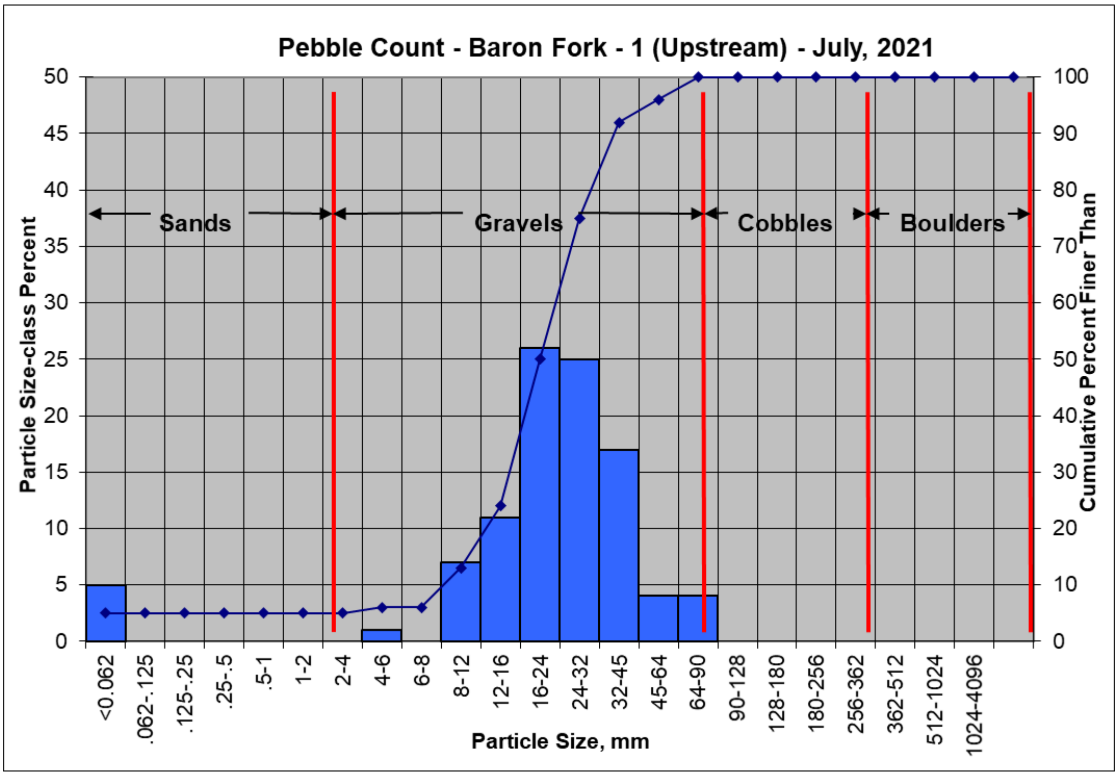


Figure 23 - (appendix) Pebble count 1 results plot

Pebble Count

Site: Baron Fork Reach: 2
Party: R. Dutnell; C. Crespo
Date: July 2021

Table 7 (appendix) - Pebble count 2 results

	Particle	Size, mm	Count	Total	Item %	% Cum
S/C	Silt/Clay	<0.062	0	0	0	0
SAND	Very Fine	.062-.125		0	0	0
	Fine	.125-.25		0	0	0
	Medium	.25-.5		0	0	0
	Coarse	.5-1		0	0	0
	Very Coarse	1-2	0	0	0	0

	Particle	Size, mm	Count	Total	Item %	% Cum
GRAVEL	Very Fine	2-4	1	1	1	1
	Fine	4-6	0	1	0	1
	Fine	6-8	0	1	0	1
	Medium	8-12	3	4	3	4
	Medium	12-16	7	11	7	11
	Coarse	16-24	18	29	18	29
	Coarse	24-32	16	45	16	45
	Very Coarse	32-45	22	67	22	67
	Very Coarse	45-64	23	90	23	90
COBL	Small	64-90	5	95	5	95
	Small	90-128	2	97	2	97
	Large	128-180	2	99	2	99
	Large	180-256	1	100	1	100
BLDR	Small	256-362	0	100	0	100
	Small	362-512	0	100	0	100
	Medium	512-1024	0	100	0	100
	Large to Very Large	1024-4096	0	100	0	100
BDRK	Bedrock		0	100	0	100
	Totals		100	100		100

D16 =	18	mm
D35 =	27	mm
D50 =	36	mm
D84 =	60	mm
D95 =	96	Mm

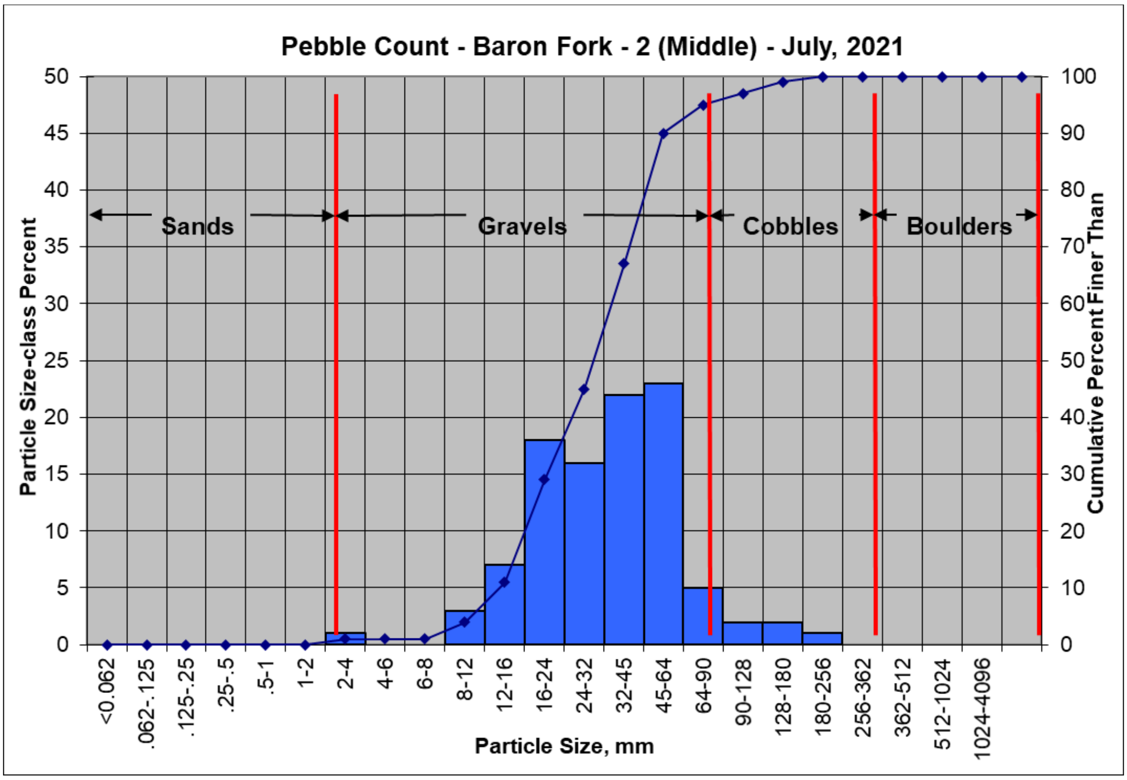


Figure 24 - (appendix) - Pebble count 2 results plot

Baron Fork Reach: 3
R. Dutnell; C. Crespo
July 2021

Table 8 (appendix) - Pebble count 3 results

	Particle	Size, mm	Count	Total	Item %	% Cum
S/C	Silt/Clay	<0.062	0	0	0	0
SAND	Very Fine	.062-.125		0	0	0
	Fine	.125-.25		0	0	0
	Medium	.25-.5		0	0	0
	Coarse	.5-1		0	0	0
	Very Coarse	1-2	0	0	0	0
GRAVEL	Very Fine	2-4	0	0	0	0
	Fine	4-6	3	3	3	3
	Fine	6-8	0	3	0	3
	Medium	8-12	4	7	4	7
	Medium	12-16	8	15	8	15
	Coarse	16-24	27	42	27	42
	Coarse	24-32	17	59	17	59

	Particle	Size, mm	Count	Total	Item %	% Cum
	Very Coarse	32-45	21	80	21	80
	Very Coarse	45-64	16	96	16	96
COBL	Small	64-90	3	99	3	99
	Small	90-128	0	99	0	99
	Large	128-180	0	99	0	99
	Large	180-256	1	100	1	100
BLDR	Small	256-362	0	100	0	100
	Small	362-512	0	100	0	100
	Medium	512-1024	0	100	0	100
	Large to Very Large	1024-4096	0	100	0	100
BDRK	Bedrock		0	100	0	100
	Totals		100	100		100

D16 =	16	mm
D35 =	22	mm
D50 =	28	mm
D84 =	52	mm
D95 =	63	mm

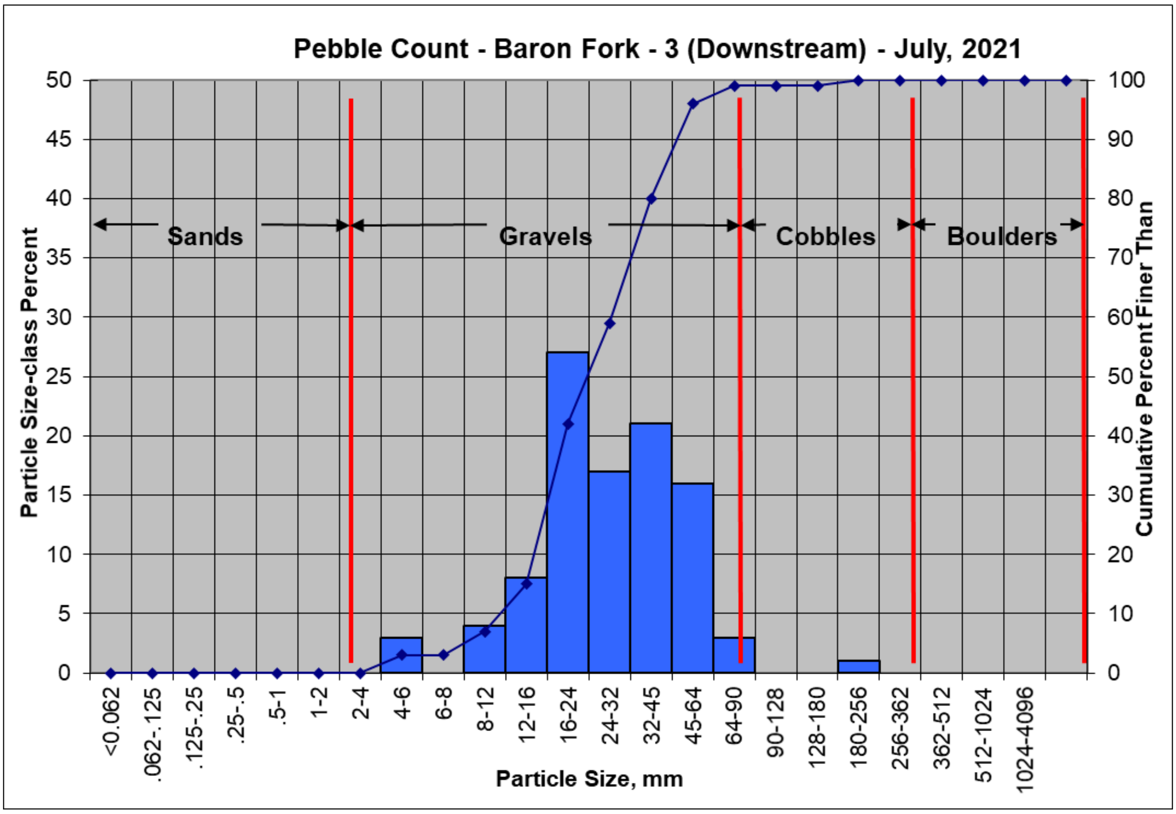


Figure 25 (appendix) - Pebble count 3 results plot

8.3 STREAMBANK EROSION RATES CALCULATIONS

8.3.1 Calculation of the erosion rate using aerial imagery

In the following section, the annual streambank erosion rate has been calculated using aerial imagery. To do that, a polyline has been drawn where the river was in 2019 and another where the river is now in 2021, the area of the polygon of the difference between both lines has been measured using the command "area" of Civil 3D and also the length of the reach has been measured as shown in figures 26 (appendix). Then the area has been divided by the reach distance to obtain the retreat every 2 years and then divided by 2 to obtain the retreat per year.

Figure 26 (appendix) – Reach 1, 2019 aerial imagery, showing the erosion in the following 2 years

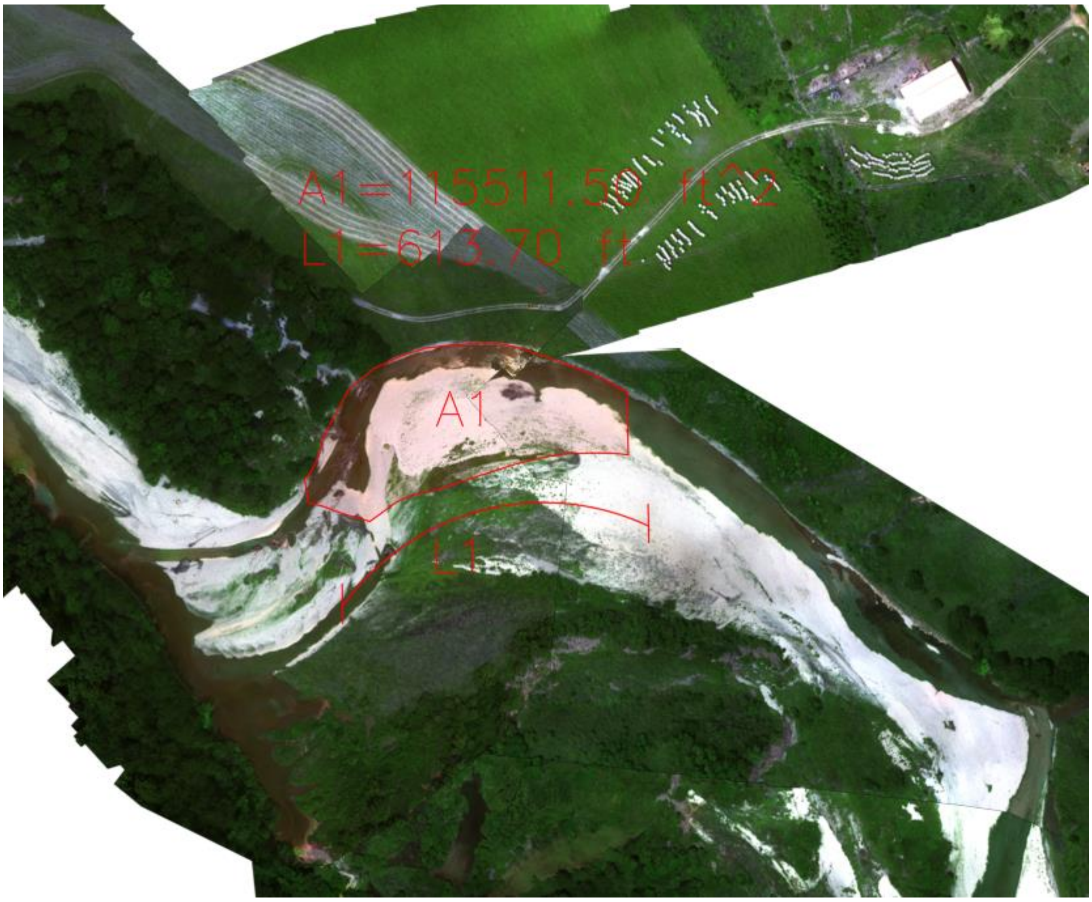


Figure 267 (appendix) – Reach 1, 2021 aerial imagery, showing the erosion in the past 2 years

$$A = 115511.5\ ft^2$$

$$L = 613.70\ ft$$

$$Bank\ Erosion\ Rate\ (BER)\ every\ 2\ years = \frac{A}{L} = \frac{115511.5}{613.70} = 188.22\ ft/2years$$

$$Bank\ Erosion\ Rate\ (BER)\ every\ year = \frac{188.22}{2} = 94.11\ ft/year$$

Figure 28 (appendix)– Reach 2, 2019 aerial imagery, showing the erosion in the following 2 years

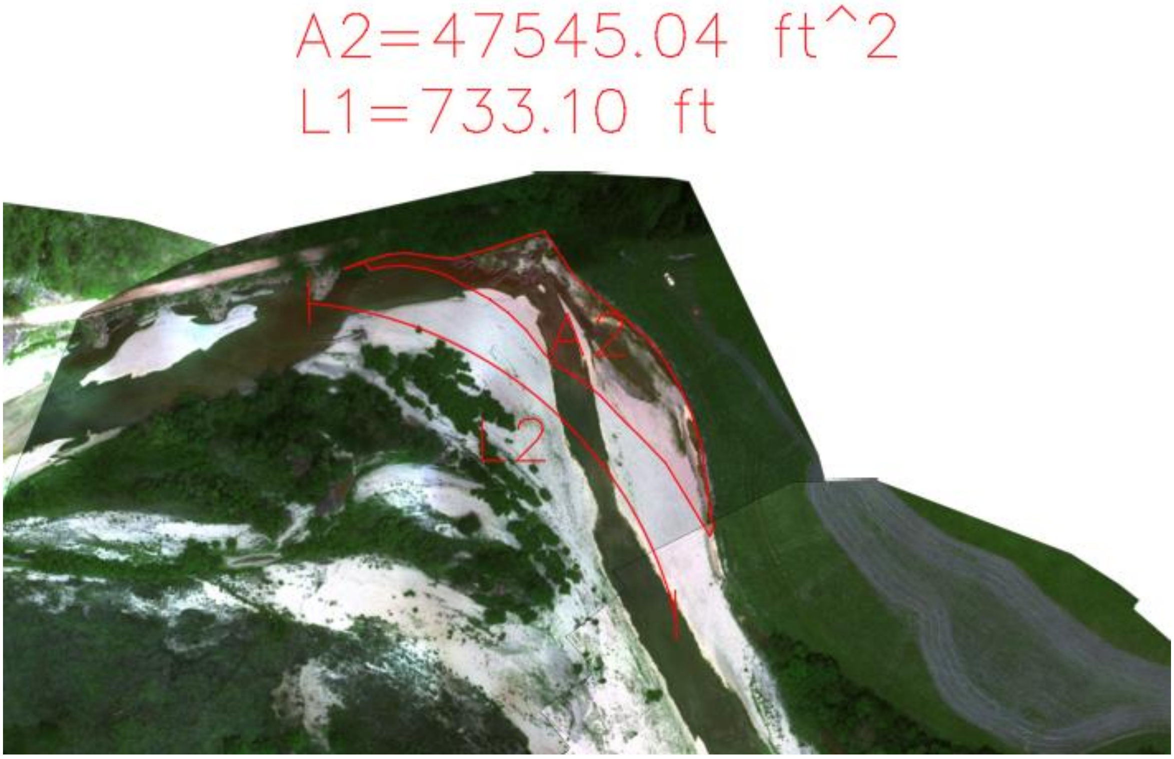


Figure 29 (appendix) – Reach 2, 2021 aerial imagery, showing the erosion in the past 2 years

$$A = 47545.04\ ft^2$$

$$L = 733.10\ ft$$

$$Bank\ Erosion\ Rate\ (BER)\ every\ 2\ years = \frac{A}{L} = \frac{47545.04}{733.10} = 64.85\ ft/2years$$

$$Bank\ Erosion\ Rate\ (BER)\ every\ year = \frac{64.85}{2} = 32.42\ ft/year$$

8.3.2 Ban Erosion Hazard Index (BEHI)

Here is the calculation of the BEHI for the reach 1:

Table 9 (appendix) – BEHI calculation for reach 1

Bank Erosion Hazard Index (BEHI)								
Site No.	1	Site Name:	Baron Fork 1	Bank No.:	1	Date:	08/04/2021	

						BEHI Score
Bank Height/ Bankfull Height (C)						
Bank Height (ft) (A)	8.9	Bankfull Ht (ft) (B)	3.5	(C) = (A)/(B) =	2.554535017	**9**
Root Depth / Bank Height (E)						
Root Depth (ft) (D)	1	Bank Height (ft) (A)	8.9	(E) = (D)/(A) =	0.112359551	**9**
Weighted Root Density (G)						
		Root Density (%) (F)	5	(G) = (F) x (A) =	0.561797753	**10**
Bank Angle (H)						
				Bank Angle (Degrees) (H)	44.0	**4**
Surface Protection (I)						
				Surface Protection (%) (I)	0	**10**

Bank Material Adjustment
Bedrock (Overall very low BEHI)
Boulders (Overall very low BEHI)
Cobble (Subtract 10 pts. If uniform med. to lrg. Cobble)
Gravel or Composite (Add 5-10 pts depending on percentage of bank material composed of sand)
Sand (Add 10 points)
Silt/Clay (No adjustment)

Bank Material Adjustment	**10**
Stratifiaction Adjustment	
Add 5-10 points depending on position of unstable layers in relation to bankfull stage	**7.5**

Very Low	Low	Moderate	High	Very High	Extreme
5-9.5	10-19.5	20-29.5	30-39.5	40-45	46-50

Adjective Rating and Total Score	**59.5**
	Extreme

Here is the calculation of the BEHI for the reach 2:

Table 10 (appendix) - BEHI calculation for reach 2

Bank Erosion Hazard Index (BEHI)							
Site No.	2	Site Name:	Baron Fork 1	Bank No.:	2	Date:	08/04/2021

						BEHI Score
					Bank Height/ Bankfull Height (C)	
Bank Height (ft) (A)	6.3	Bankfull Ht (ft) (B)	3.0	(C) = (A)/(B) =	2.09232813	**9**
					Root Depth / Bank Height (E)	**0**
Root Depth (ft) (D)	3	Bank Height (ft) (A)	6.3	(E) = (D)/(A) =	0.476190476	**5**
					Weighted Root Density (G)	**0**
		Root Density (%) (F)	50	(G) = (F) x (A) =	23.80952381	**7**
					Bank Angle (H)	**0**
				Bank Angle (Degrees) (H)	22.0	**3**
					Surface Protection (I)	**0**
				Surface Protection (%) (I)	0	**10**

Bank Material Adjustment
Bedrock (Overall very low BEHI)
Boulders (Overall very low BEHI)
Cobble (Subtract 10 pts. If uniform med. to lrg. Cobble)
Gravel or Composite (Add 5-10 pts depending on percentage of bank material composed of sand)
Sand (Add 10 points)
Silt/Clay (No adjustment)

Bank Material Adjustment	**10**
Stratifiaction Adjustment	
Add 5-10 points depending on position of unstable layers in relation to bankfull stage	**5**

Very Low	**Low**	**Moderate**	**High**	**Very High**	**Extreme**
5-9.5	**10-19.5**	**20-29.5**	**30-39.5**	**40-45**	**46-50**

Adjective Rating and **Total Score**	**49**
	Extreme

8.3.3 Near Bank Stress

Here is the calculation of the NBS for the reach 1 and 2:

Table 11 (appendix) – Conversion table of Rc/Wbkf values to NBS ratings

NBS ratings based on Rc/Wbkf	
Rc/Wbkf ratio	NBS rating
>3.00	Very low
2.21-3.00	Low
2.01-2.20	Moderate
1.81-2.00	High
1.5-1.8	Very High
<1.5	Extreme

Table 12 (appendix) – Results of the NBS Method (2) for the Reach 1

NBS Level II (Reach 1)				
Method (2)	Radius of Curvature Rc (ft)	Bankfull Width Wbkf (ft)	Ratio Rc/Wbkf	Near-Bank Stress (NBS)
	316.6	326.4	0.969724262	**Extreme**

Table 13 (appendix) – Results of the NBS Method (2) for the Reach 2

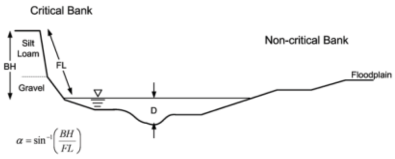
NBS Level II (Reach 2)				
Method (2)	Radius of Curvature Rc (ft)	Bankfull Width Wbkf (ft)	Ratio Rc/Wbkf	Near-Bank Stress (NBS)
	381.3	469.0	0.813006397	**Extreme**

8.3.4 Oklahoma Ozark Streambank Erosion Potential Index (OSEPI)

Here is the calculation of the OSEPI for the reach 1:

Table 14 (appendix) – OSEPI calculation for reach 1

Channel Stability Index							
Site No.	1	Site Name:	Baron Fork 1	Bank No.:	1	Date:	44294



0. Critical Bank		
	Right	Left
Bank Height (ft)	8.9	-
Bank Face Length (ft)	12	-

1. Bank Height (ft)						
	0-5	5-10	10-15	15-20	20+	Value
	0	2.5	5	7.5	10	2.5

2. Bank Angle (º)							
	0-20	21-60	61-80	81-90	91-119	>119	
BH/FL	(0.00-0.34)	(0.35-0.86)	(0.87-0.985)	(0.985-1.00)	(0.87-0.99)	(<0.87)	
	0	2	4	6	8	10	2

3. Percentage of Bank Height with a Bank Angle Greater than 80º						
	0-10%	11-25%	26-50%	51-75%	76-100%	
	0	2.5	5	7.5	10	5

4. Evidence of Recent Mass Wasting (Percentage of Bank)						
	0-10%	11-25%	26-50%	51-75%	76-100%	
	0	2.5	5	7.5	10	2.5

5. Unconsolidated Material (Percentage of Bank)						
	0-10%	11-25%	26-50%	51-75%	76-100%	
	0	2.5	5	7.5	10	0

6. Streambank Protection (Percentage of Streambank Covered by Plant Roots, Vegetation, Downed Logs and Branches, Rocks, etc.)							
	0-10%	11-25%	26-50%	51-70%	70-90%	90-100%	
	15	12.5	10	7.5	2.5	0	15

7. Established riparian woody-vegetative cover							
	0-10%	11-25%	26-50%	51-70%	70-90%	90-100%	
	15	12.5	10	7.5	2.5	0	2

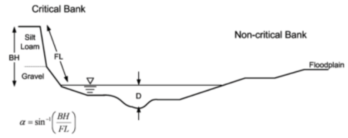
8. Stream Curvature				
	Meander	Shallow Curve	Straight	
	5	2.5	0	5

TOTAL SCORE				34
CURRENT STABILITY				STABLE
0-25	HIGHLY STABLE	46-55	UNSTABLE	
26-35	MODERATELY STABLE	56-65	MODERATELY UNSTABLE	
36-45	STABLE	66-85	HIGHLY UNSTABLE	

Here is the calculation of the OSEPI for the reach 2:

Table 15 (appendix) - OSEPI calculation for reach 2

Channel Stability Index							
Site No.	1	Site Name:	Baron Fork 1	Bank No.:	1	Date:	44294



0. Critical Bank		
	Right	Left
Bank Height (ft)	6.3	-
Bank Face Length (ft)	12.86	-

1. Bank Height (ft)						Value
	0-5	5-10	10-15	15-20	20+	
	0	2.5	5	7.5	10	2.5

2. Bank Angle (º)							
	0-20	21-60	61-80	81-90	91-119	>119	
BH/FL	(0.00-0.34)	(0.35-0.86)	(0.87-0.985)	(0.985-1.00)	(0.87-0.99)	(<0.87)	
	0	2	4	6	8	10	2

3. Percentage of Bank Height with a Bank Angle Greater than 80º						
	0-10%	11-25%	26-50%	51-75%	76-100%	
	0	2.5	5	7.5	10	10

4. Evidence of Recent Mass Wasting (Percentage of Bank)						
	0-10%	11-25%	26-50%	51-75%	76-100%	
	0	2.5	5	7.5	10	5

5. Unconsolidated Material (Percentage of Bank)						
	0-10%	11-25%	26-50%	51-75%	76-100%	
	0	2.5	5	7.5	10	0

6. Streambank Protection (Percentage of Streambank Covered by Plant Roots, Vegetation, Downed Logs and Branches, Rocks, etc.)							
	0-10%	11-25%	26-50%	51-70%	70-90%	90-100%	
	15	12.5	10	7.5	2.5	0	10

7. Established riparian woody-vegetative cover							
	0-10%	11-25%	26-50%	51-70%	70-90%	90-100%	
	15	12.5	10	7.5	2.5	0	10

8. Stream Curvature				
	Meander	Shallow Curve	Straight	
	5	2.5	0	5

TOTAL SCORE			44.5
CURRENT STABILITY			STABLE
0-25	HIGHLY STABLE	46-55	UNSTABLE
26-35	MODERATELY STABLE	56-65	MODERATELY UNSTABLE
36-45	STABLE	66-85	HIGHLY UNSTABLE

8.4 SITE PICTURES

Here are listed all the drone images that were taken during the flight's ordered from downstream to upstream the site:

Figure 27 (appendix) – Drone 1

Figure 28 (appendix) – Drone 2

Figure 29 (appendix) – Drone 3

Figure 30 (appendix) – Drone 4

Figure 31 (appendix) – Drone 5

Figure 32 (appendix) – Drone 6

Figure 33 (appendix) - Drone 7

Figure 34 (appendix) – Drone 8

Figure 35 (appendix) – Drone 9

Figure 36 (appendix) – Drone 10

Figure 37 (appendix) – Drone 11

Figure 38 (appendix) – Drone 12

Figure 39 (appendix) – Drone 13

Figure 40 (appendix)- Drone 14

Figure 41 (appendix) – Drone 15

Figure 42 (appendix) – Drone 16

Figure 43 (appendix) – Drone 17

Figure 44 (appendix) – Drone 18

Figure 45 (appendix) – Drone 19

Figure 46 (appendix) – Drone 20

Figure 47 (appendix) – Drone 21

Figure 48 (appendix) – Drone 22

Figure 49 (appendix) – Drone 23

Figure 50 (appendix) – Drone 24

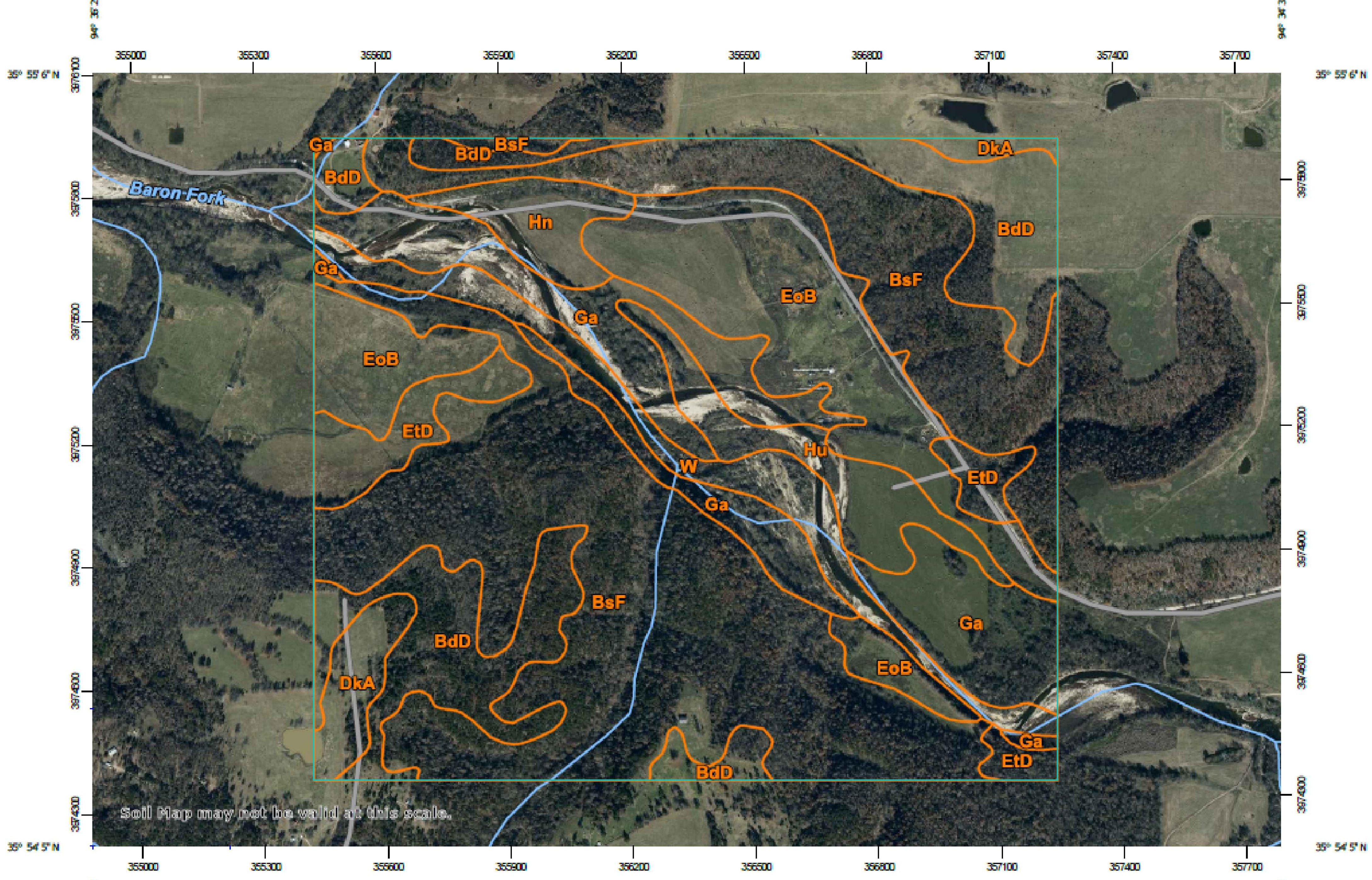
Figure 51 (appendix) – Drone 25

Figure 52 (appendix) – Drone 26

Figure 53 (appendix) – Drone 27

8.5 SKETCHES

Soil Map—Adair County, Oklahoma



Map Scale: 1:13,300 if printed on A landscape (11" x 8.5") sheet.

N

0 150 300 600 900 Meters

0 500 1000 2000 3000 Feet

Map projection: Web Mercator Corner coordinates: WGS84 Edge tics: UTM Zone 15N WGS84

MAP LEGEND

Area of Interest (AOI)
- Area of Interest (AOI)

Soils
- Soil Map Unit Polygons
- Soil Map Unit Lines
- Soil Map Unit Points

Special Point Features
- Blowout
- Borrow Pit
- Clay Spot
- Closed Depression
- Gravel Pit
- Gravelly Spot
- Landfill
- Lava Flow
- Marsh or swamp
- Mine or Quarry
- Miscellaneous Water
- Perennial Water
- Rock Outcrop
- Saline Spot
- Sandy Spot
- Severely Eroded Spot
- Sinkhole
- Slide or Slip
- Sodic Spot
- Spoil Area
- Stony Spot
- Very Stony Spot
- Wet Spot
- Other
- Special Line Features

Water Features
- Streams and Canals

Transportation
- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background
- Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL:
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Adair County, Oklahoma
Survey Area Data: Version 15, May 27, 2020

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Nov 16, 2018—Nov 21, 2018

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Map Unit Legend

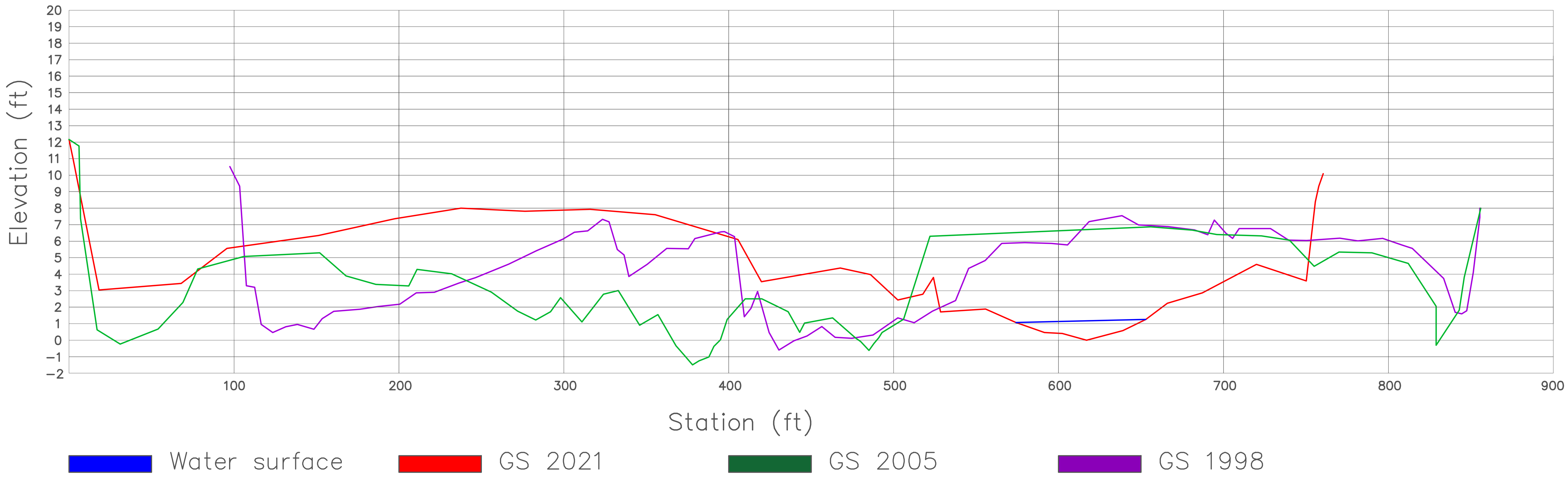
Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
BdD	Clarksville very gravelly silt loam, 1 to 8 percent slopes	91.2	12.9%
BsF	Clarksville very gravelly silt loam, 20 to 50 percent slopes, stony	288.9	40.9%
DkA	Tonti gravelly silt loam, 0 to 3 percent slopes	17.6	2.5%
EoB	Waben gravelly silt loam, 1 to 3 percent slopes	107.1	15.1%
EtD	Waben gravelly silt loam, 3 to 8 percent slopes	28.1	4.0%
Ga	Elsah gravelly silt loam, 0 to 1 percent slopes, frequently flooded	93.3	13.2%
Hn	Razort silt loam, 0 to 1 percent slopes, occasionally flooded	18.2	2.6%
Hu	Elsah gravelly loam, 0 to 1 percent slopes, occasionally flooded	27.8	3.9%
W	Water	34.7	4.9%
Totals for Area of Interest		706.8	100.0%

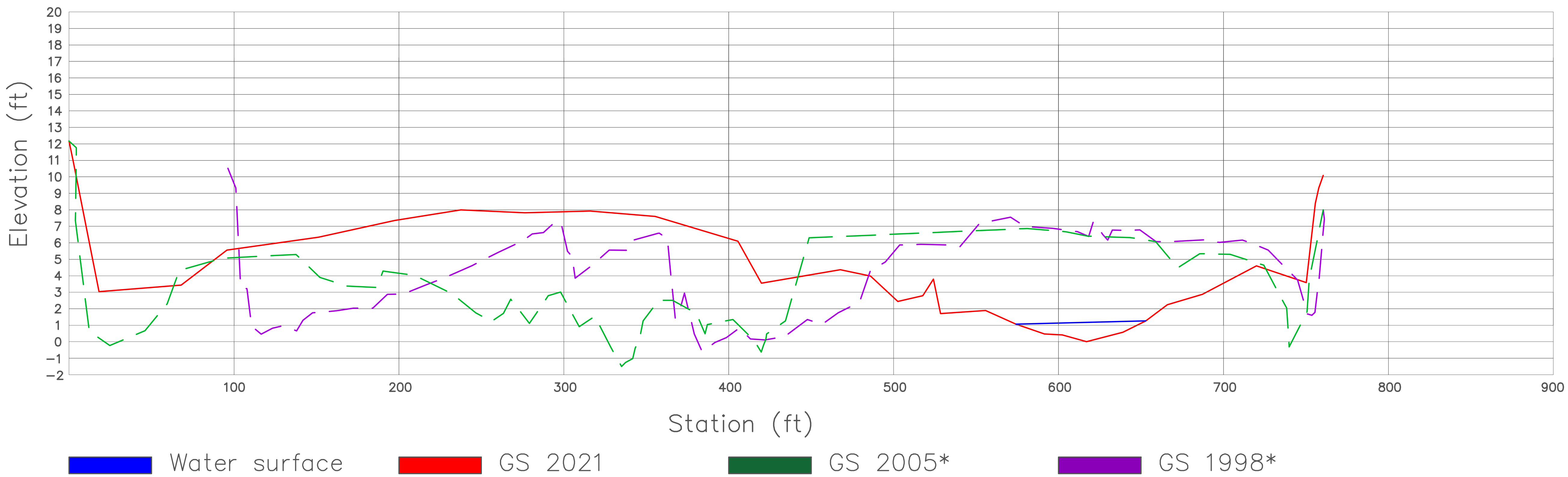
USDA **Natural Resources Conservation Service**

Web Soil Survey
National Cooperative Soil Survey

6/13/2021
Page 1 of 3

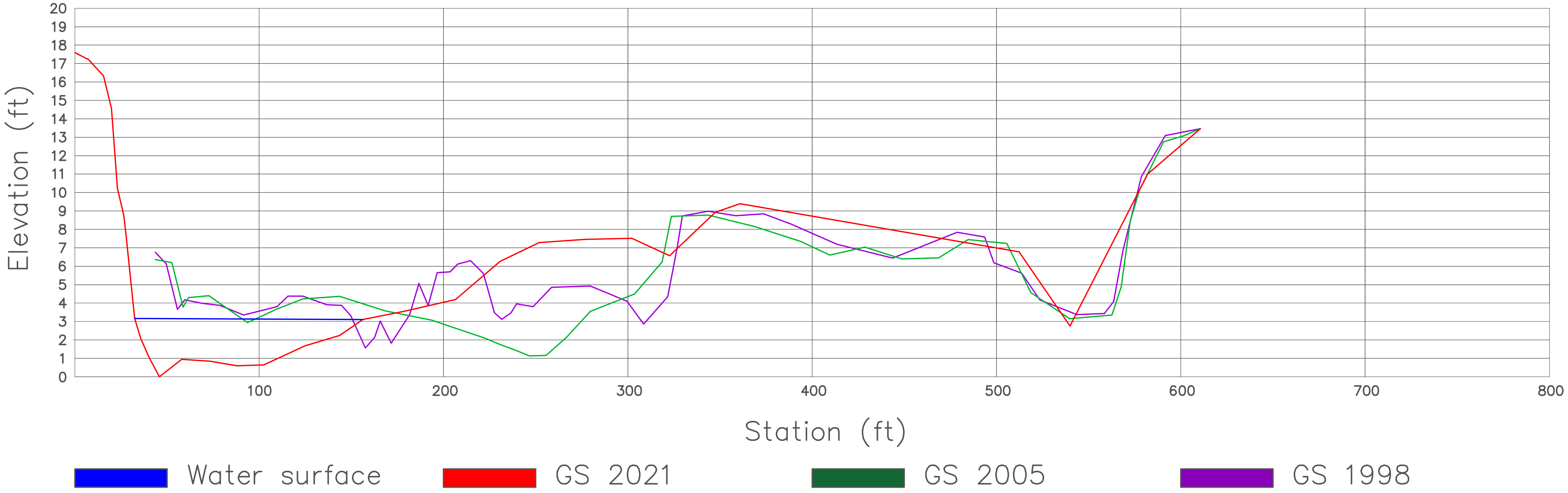
Author:	Scale:	Project:	Title:	Date:
Carles Crespo–Azorín Martínez	0 100ft 150ft	Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	Soli map	July 2021

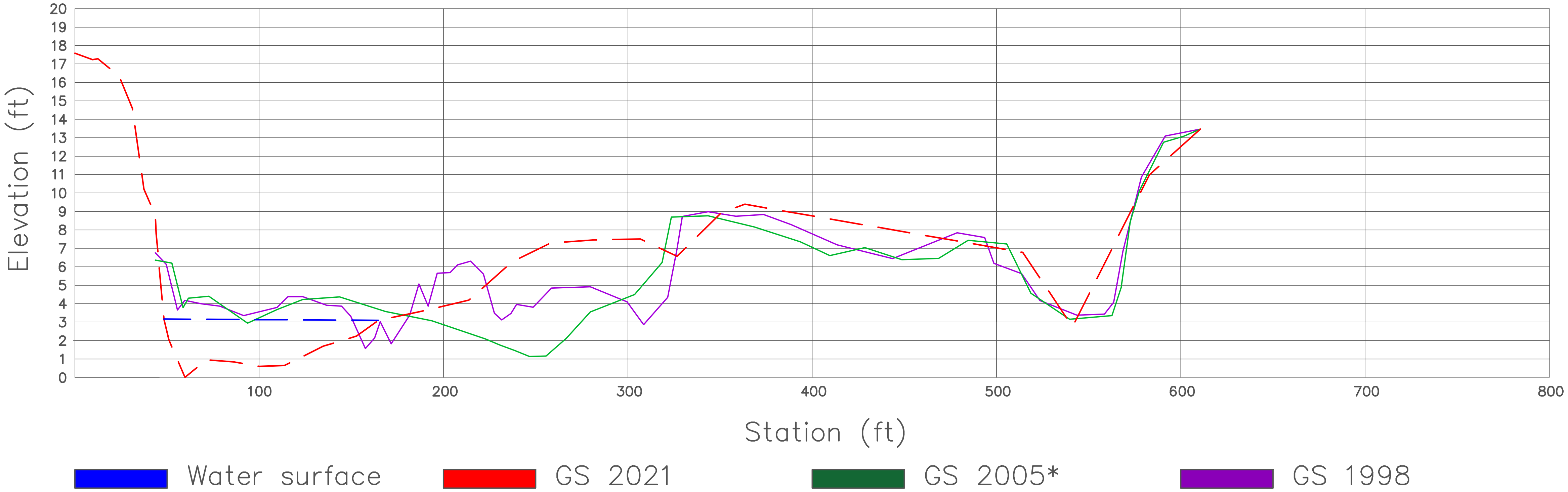




According to the Oklahoma North State Plane Coordinates, the point 0,0 is in an elevation of 854.71 feet
*Corrected cross-section

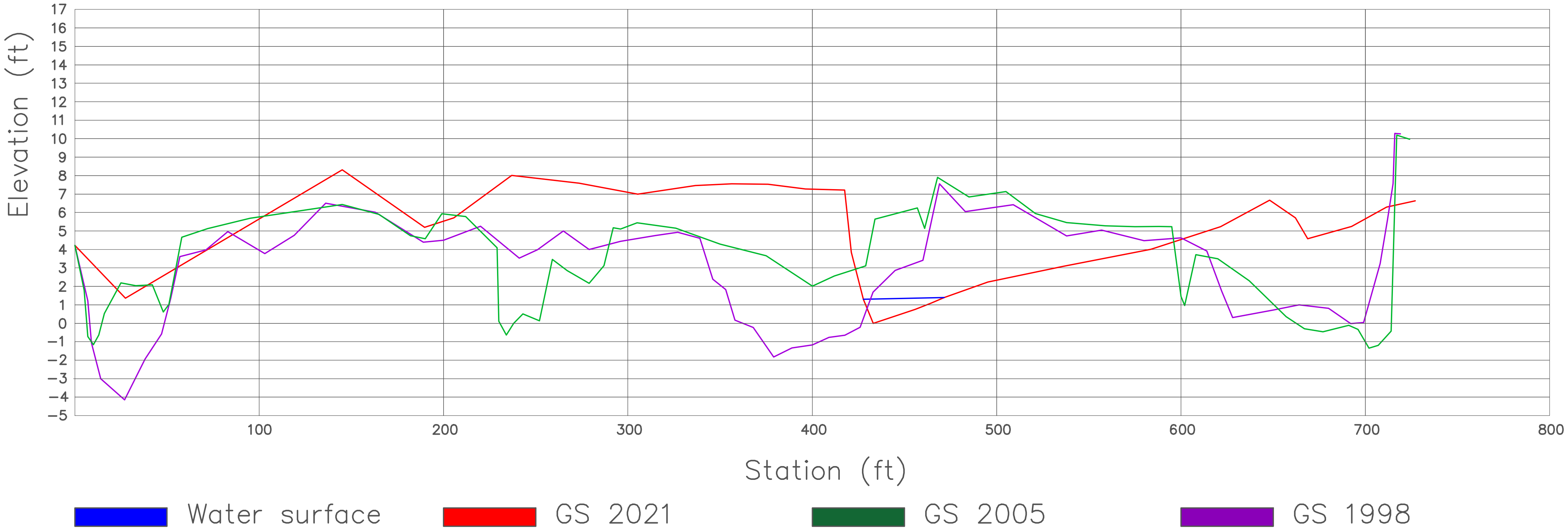
Author:	Scale:	Project:	Title:	Date:
Carles Crespo-Azorín Martínez	H: 1"-70' V: 1"-7'	Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	Cross-section 5	July 2021

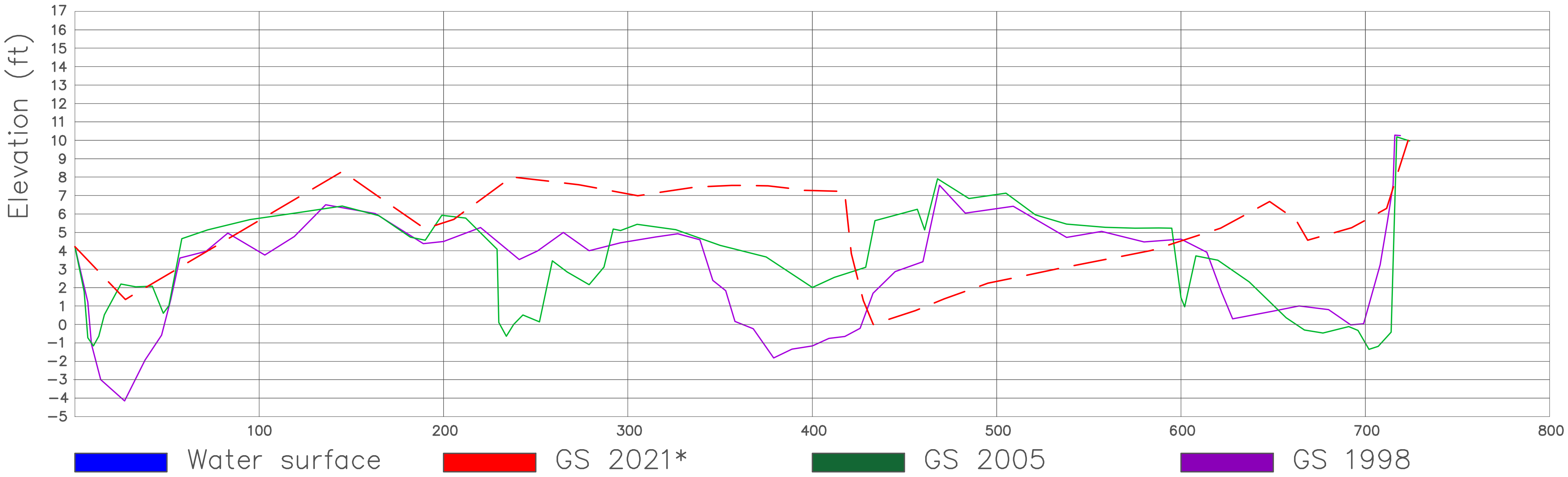




According to the Oklahoma North State Plane Coordinates, the point 0,0 is in an elevation of 858.2 feet
*Corrected cross-section

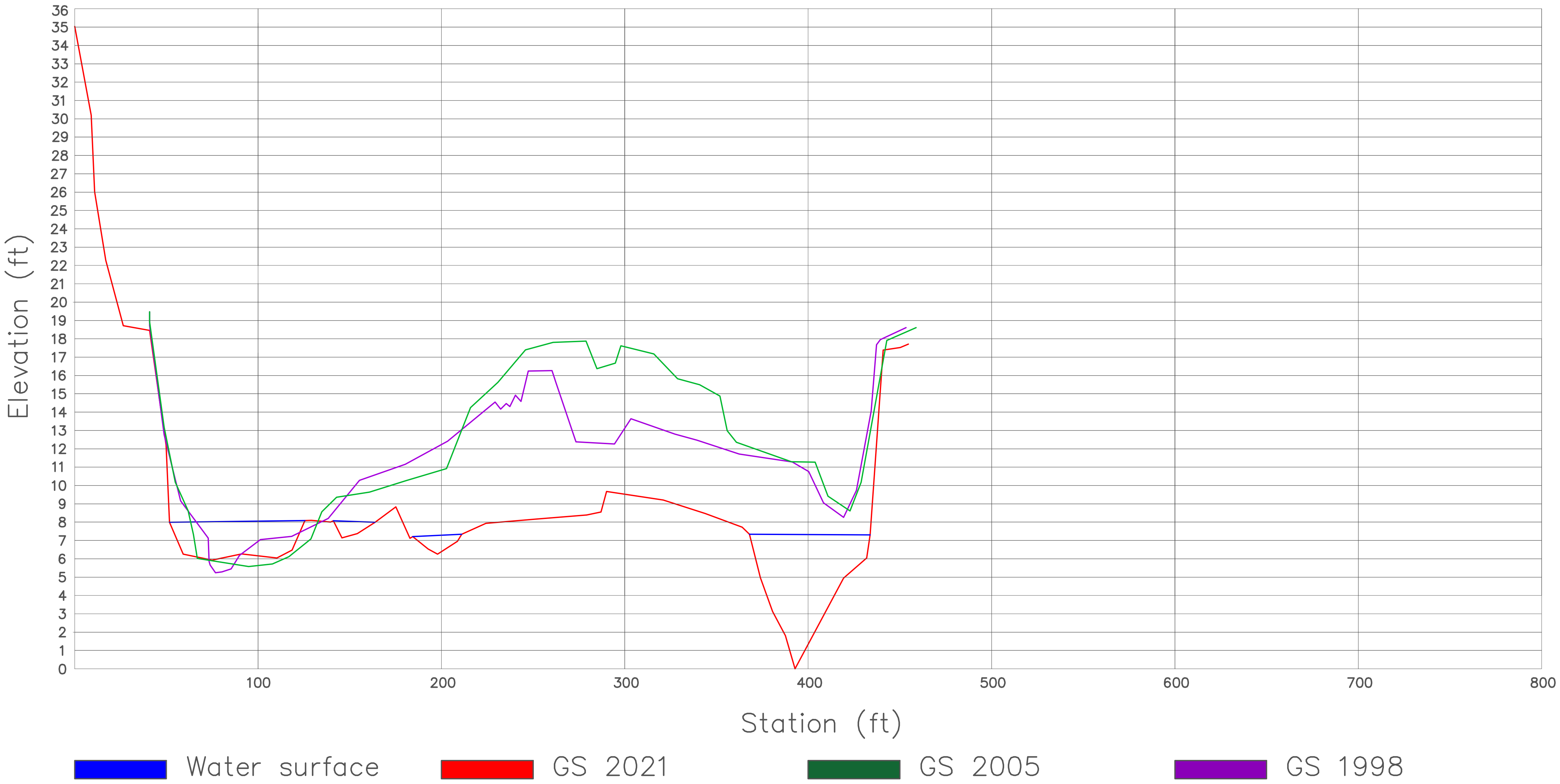
Author:	Scale:	Project:	Title:	Date:
Carles Crespo-Azorín Martínez	H: 1"-70' V: 1"-7'	Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	Cross-section 6	July 2021





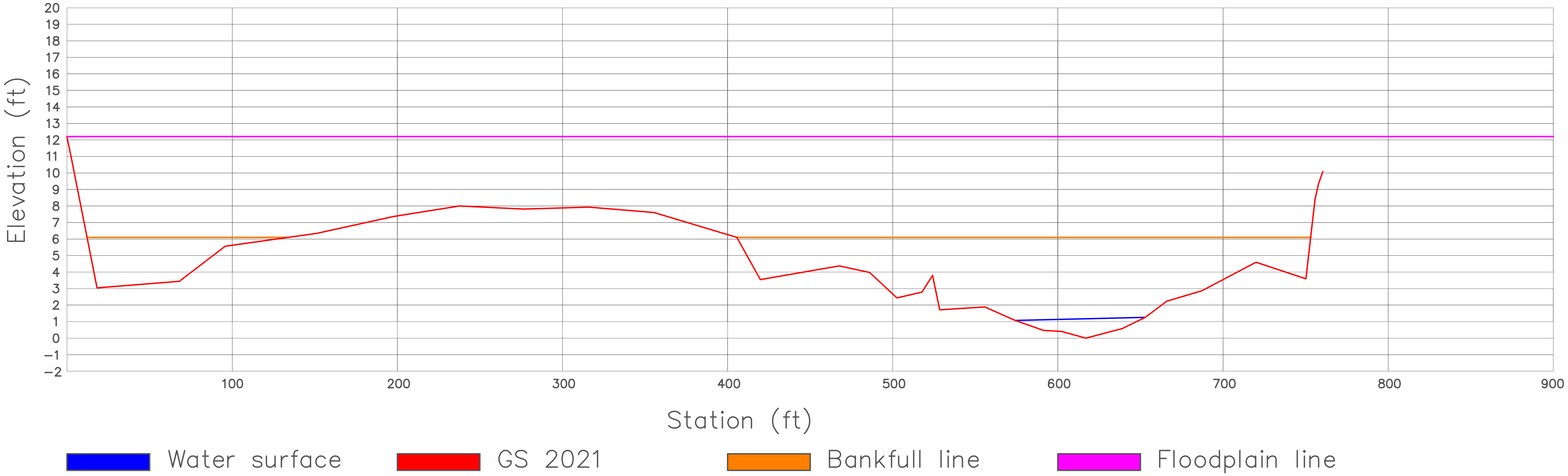
According to the Oklahoma North State Plane Coordinates, the point 0,0 is in an elevation of 864.83 feet
*Corrected cross-section

Author:	Scale:	Project:	Title:	Date:
Carles Crespo-Azorín Martínez	H: 1"-70' V: 1"-7'	Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	Cross-section 7	July 2021

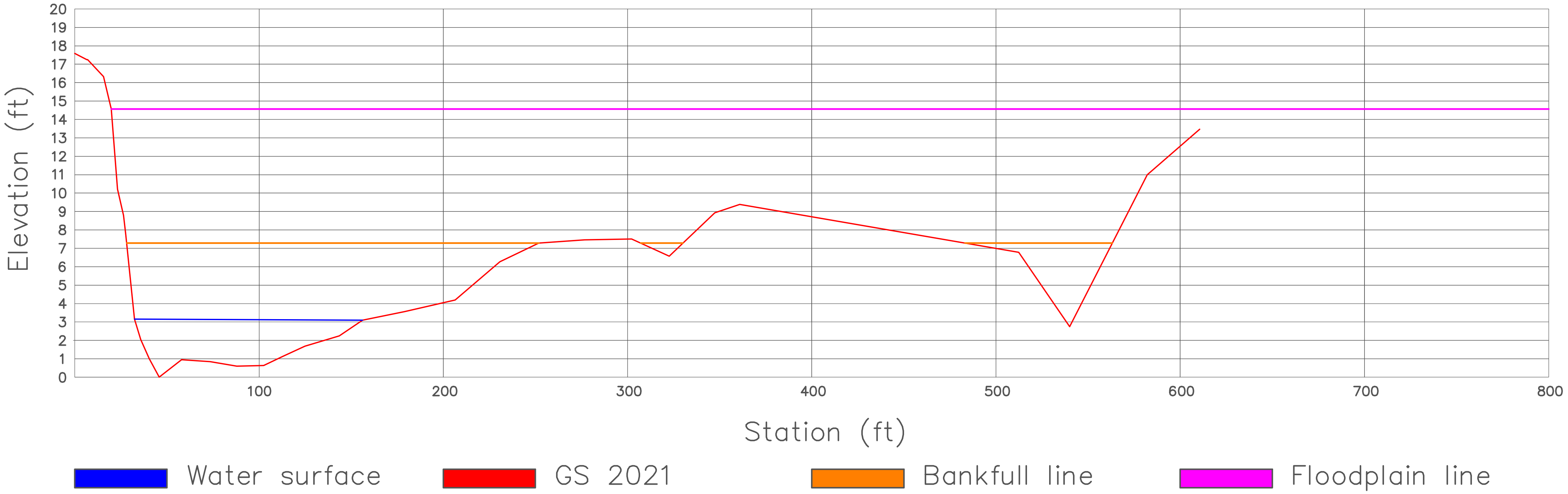


According to the Oklahoma North State Plane Coordinates, the point 0,0 is in an elevation of 862.08 feet

Author:	Scale:	Project:	Title:	Date:
Carles Crespo-Azorín Martínez	H: 1"-70' V: 1"-7'	Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	Cross-section 8	July 2021

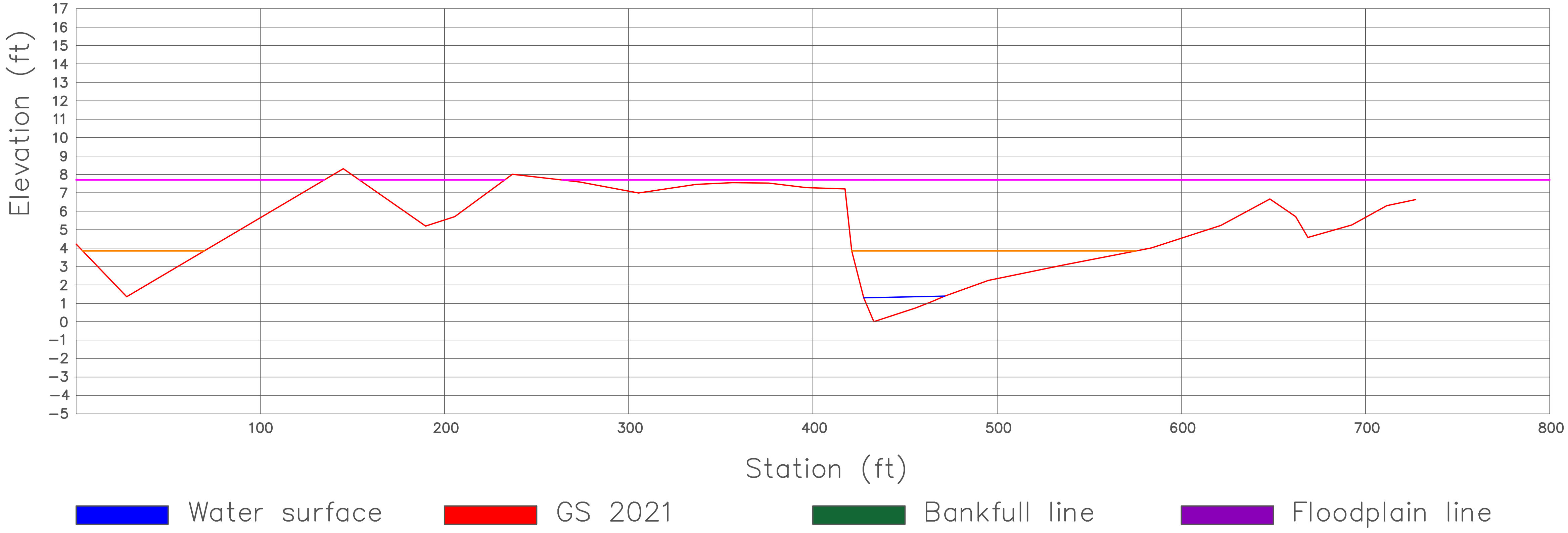


According to the Oklahoma North State Plane Coordinates, the point 0,0 is in an elevation of 854.71 feet



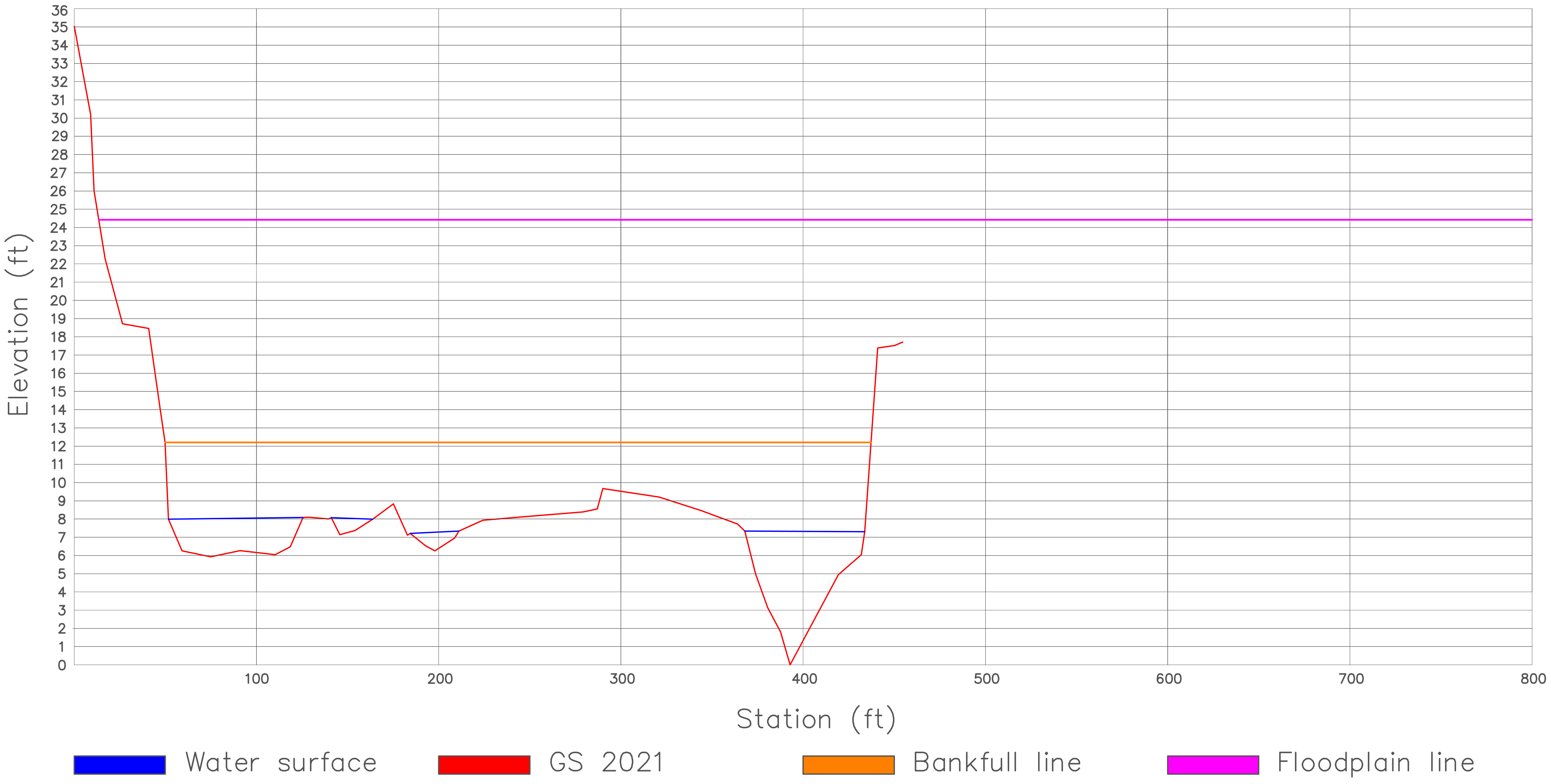
According to the Oklahoma North State Plane Coordinates, the point 0,0 is in an elevation of 858.2 feet

Author:	Scale:	Project:	Title:	Date:
Carles Crespo-Azorín Martínez	H: 1"-70' V: 1"-7'	Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	Cross-section 5 and 6 Level II classification	July 2021



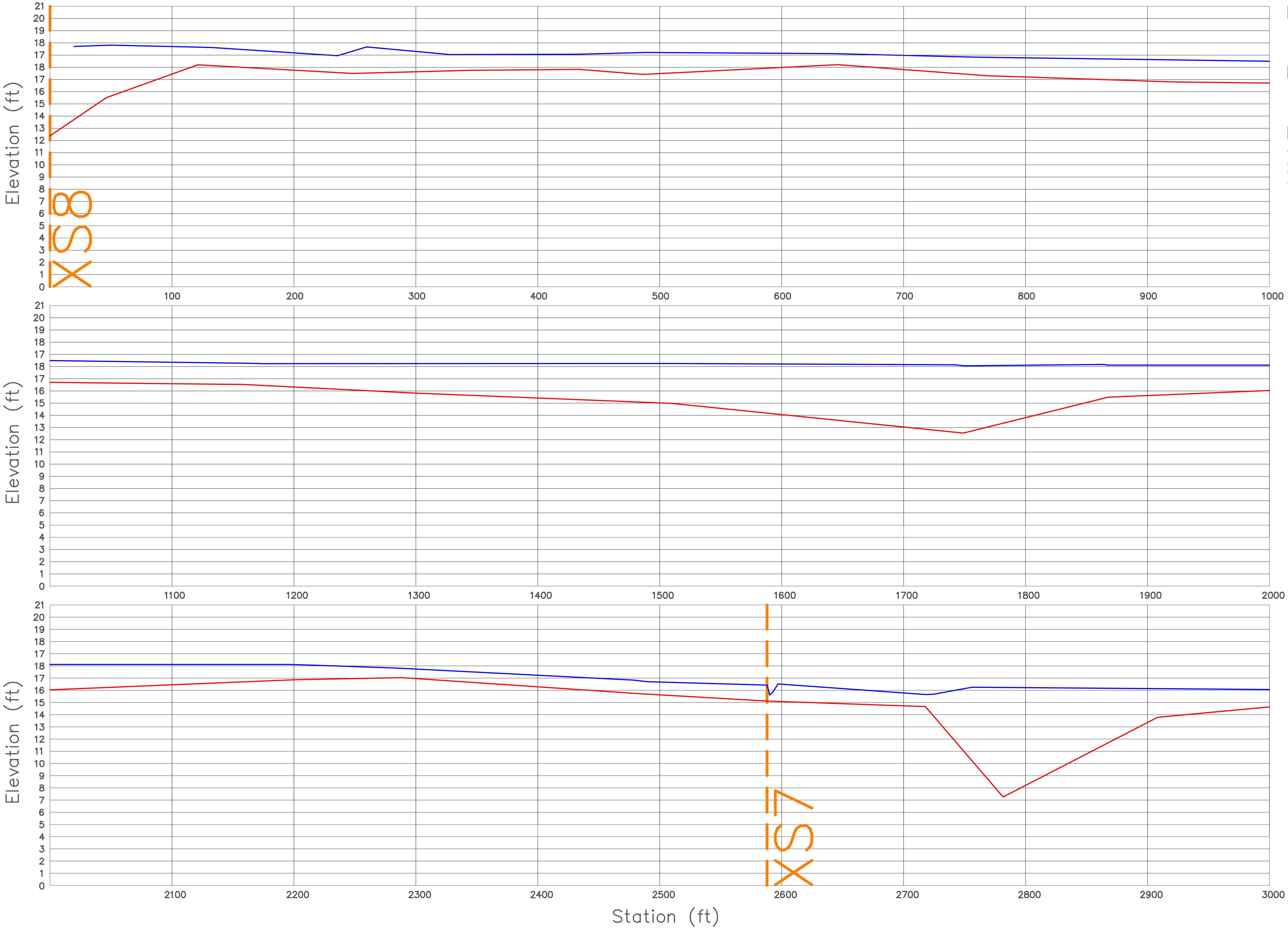
According to the Oklahoma North State Plane Coordinates, the point 0,0 is in an elevation of 864.83 feet

Author:	Scale:	Project:	Title:	Date:
Carles Crespo-Azorín Martínez	H: 1"-70' V: 1"-7'	Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	Cross-section 7 Level II classification	July 2021



According to the Oklahoma North State Plane Coordinates, the point 0,0 is in an elevation of 862.08 feet

Author:	Scale:	Project:	Title:	Date:
Carles Crespo-Azorín Martínez	H: 1"-70' V: 1"-7'	Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	Cross-section 8 Level II classification	July 2021



Water surface 2021

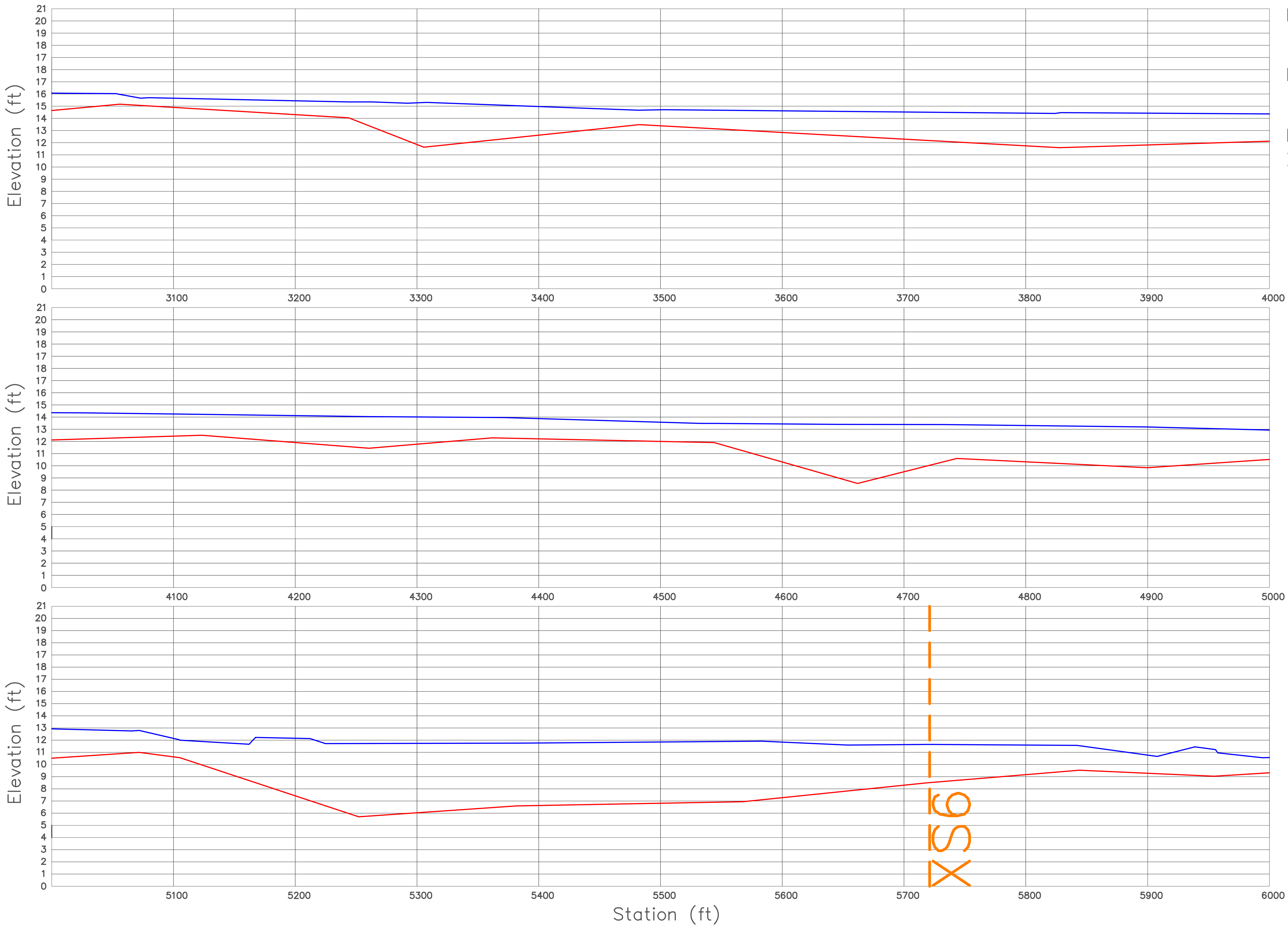
Thalweg 2021

Cross section

XS8 at station 0 feet
XS7 at station 2588.08 feet

According to the Oklahoma North State Plane Coordinates, the point 0,0 is in an elevation of 849.71 feet

Author: Carles Crespo–Azorín Martínez	Scale: H: 1"–80' V: 1"–8'	Project: Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	Title: Longitudinal profile 1/3	Date: July 2021



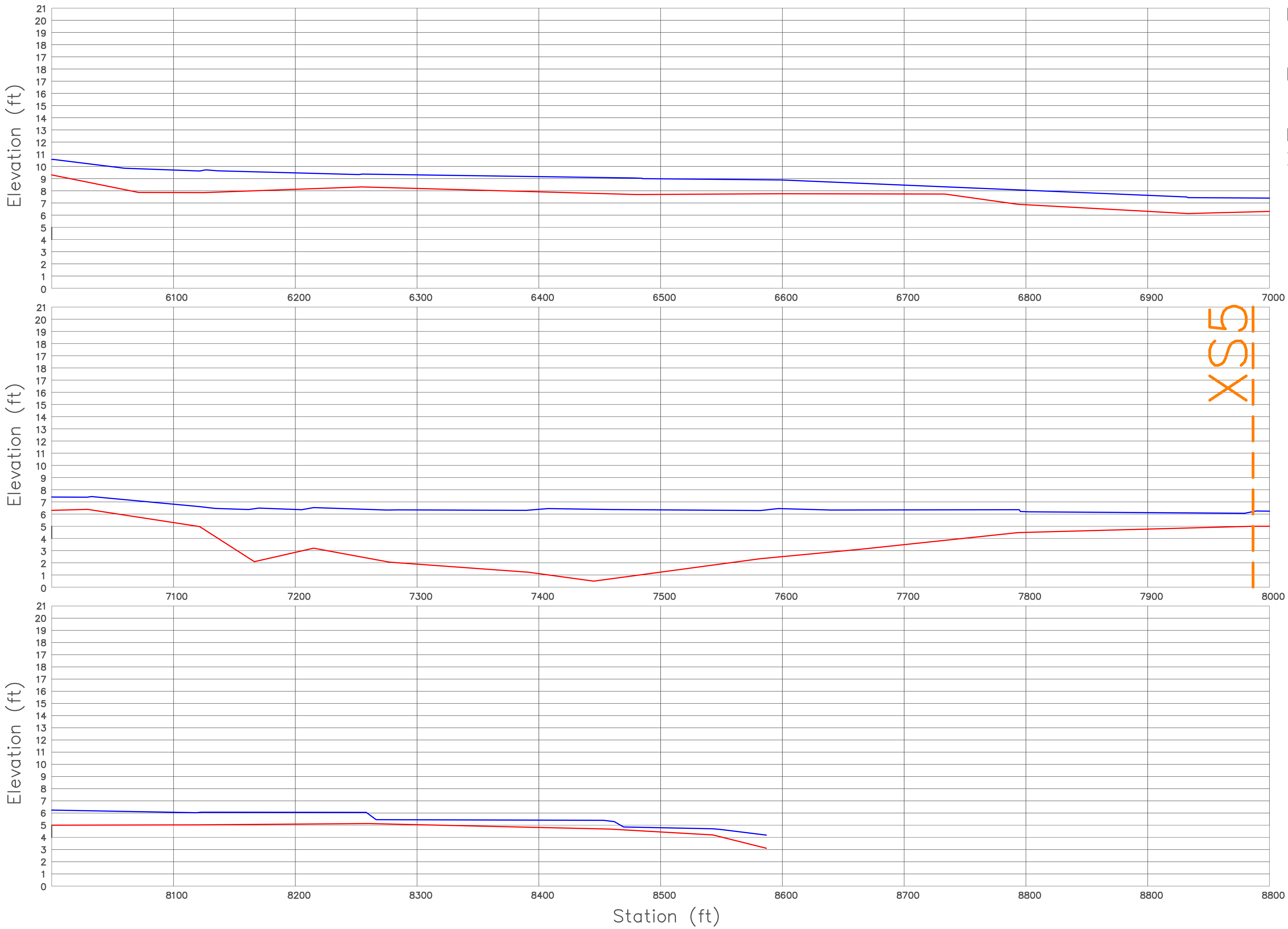
Water surface 2021

Thalweg 2021

Cross section
XS6 at station 5718.51 feet

According to the Oklahoma North State Plane Coordinates, the point 3000,0 is in an elevation of 849.71 feet

	Author: Carles Crespo–Azorín Martínez	Scale: H: 1”–80’ V: 1”–8’	Project: Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	Title: Longitudinal profile 2/3	Date: July 2021



Water surface 2021

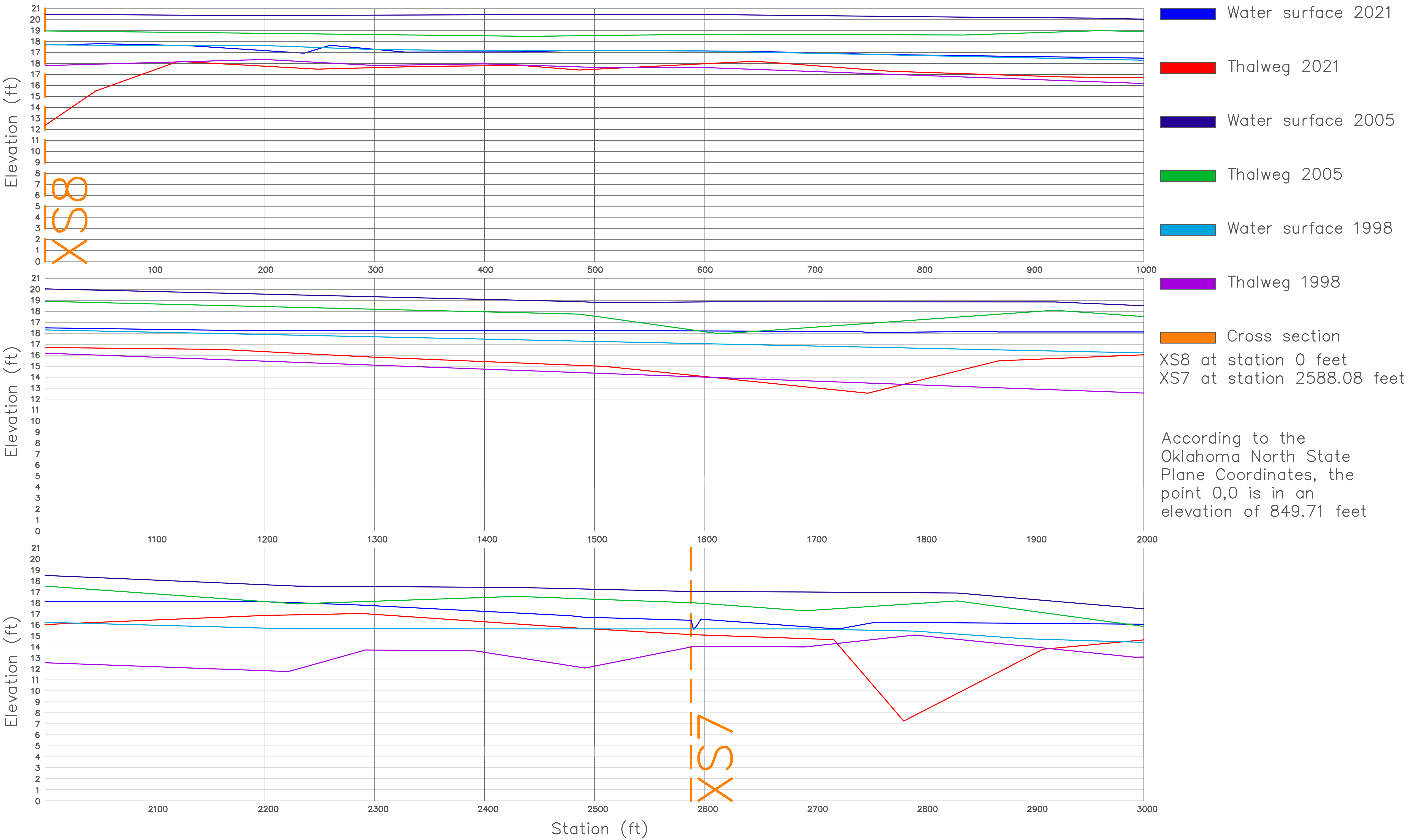
Thalweg 2021

Cross section

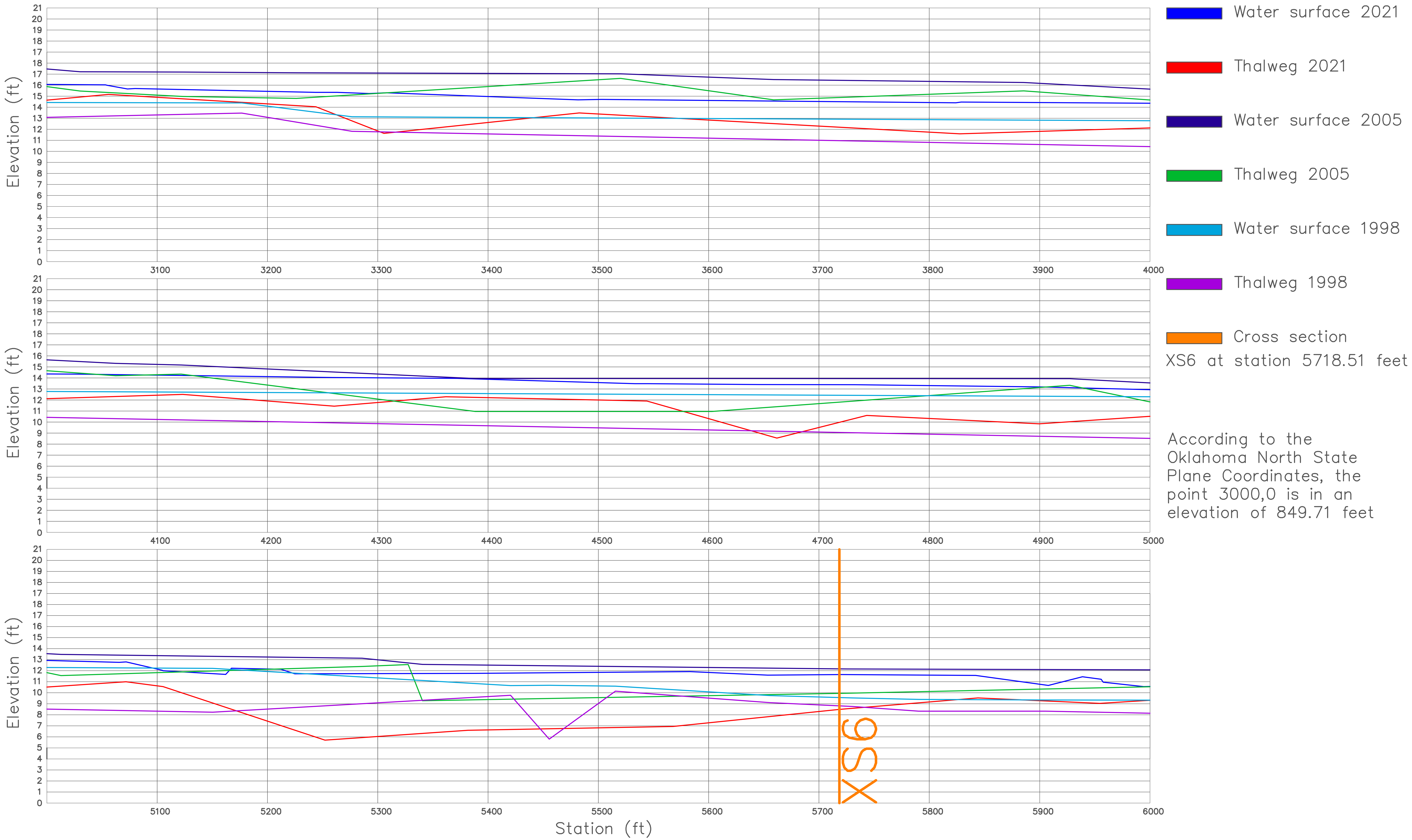
XS5 at station 7985.85 feet

According to the Oklahoma North State Plane Coordinates, the point 6000,0 is in an elevation of 849.71 feet

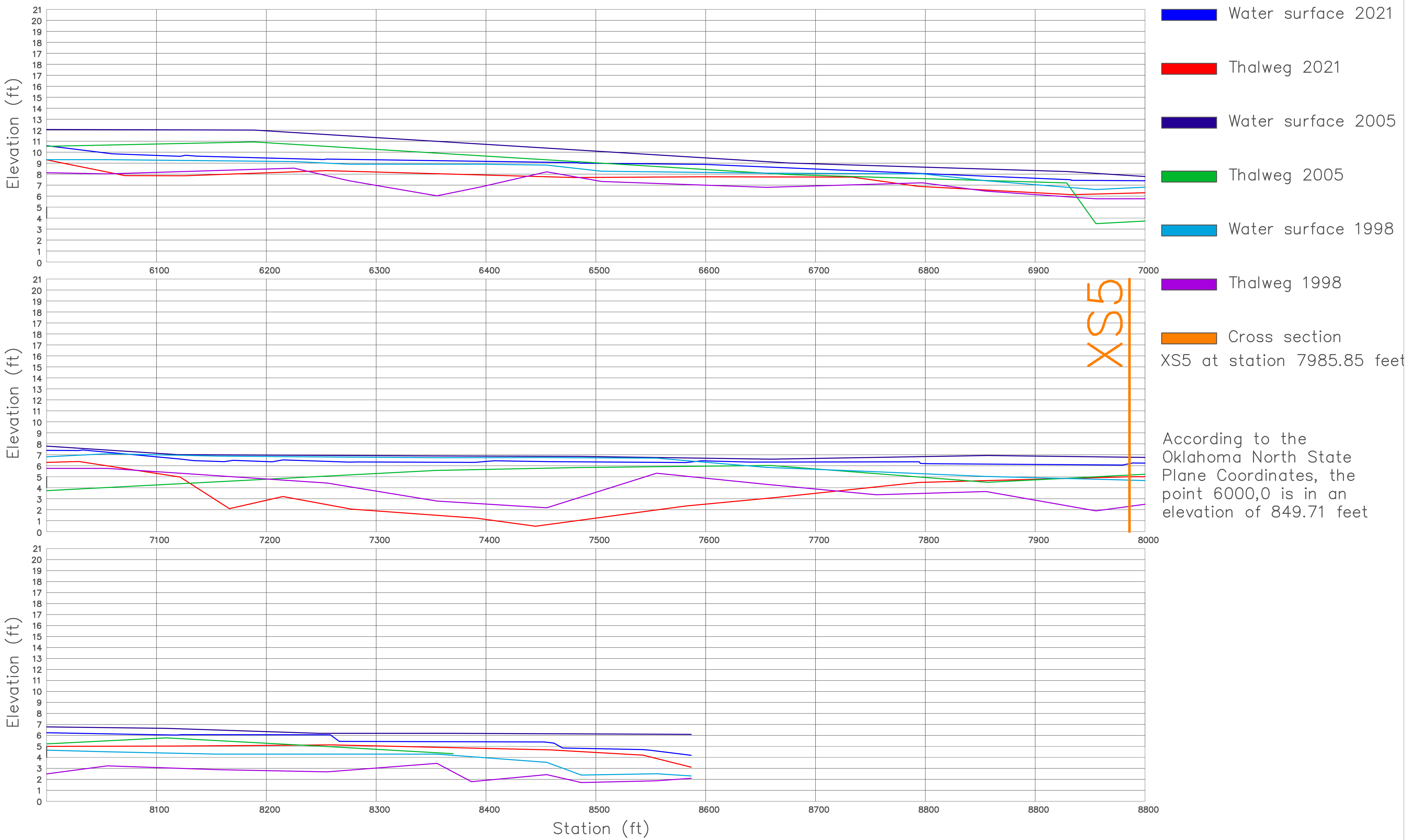
Author:	Scale:	Project:	Title:	Date:
Carles Crespo–Azorín Martínez	H: 1”–80’ V: 1”–8’	Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	Longitudinal profile 3/3	July 2021



Author:	Scale:	Project:	Title:	Date:
Carles Crespo-Azorín Martínez	H: 1”-80’ V: 1”-8’	Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	Longitudinal profile 1/3	July 2021

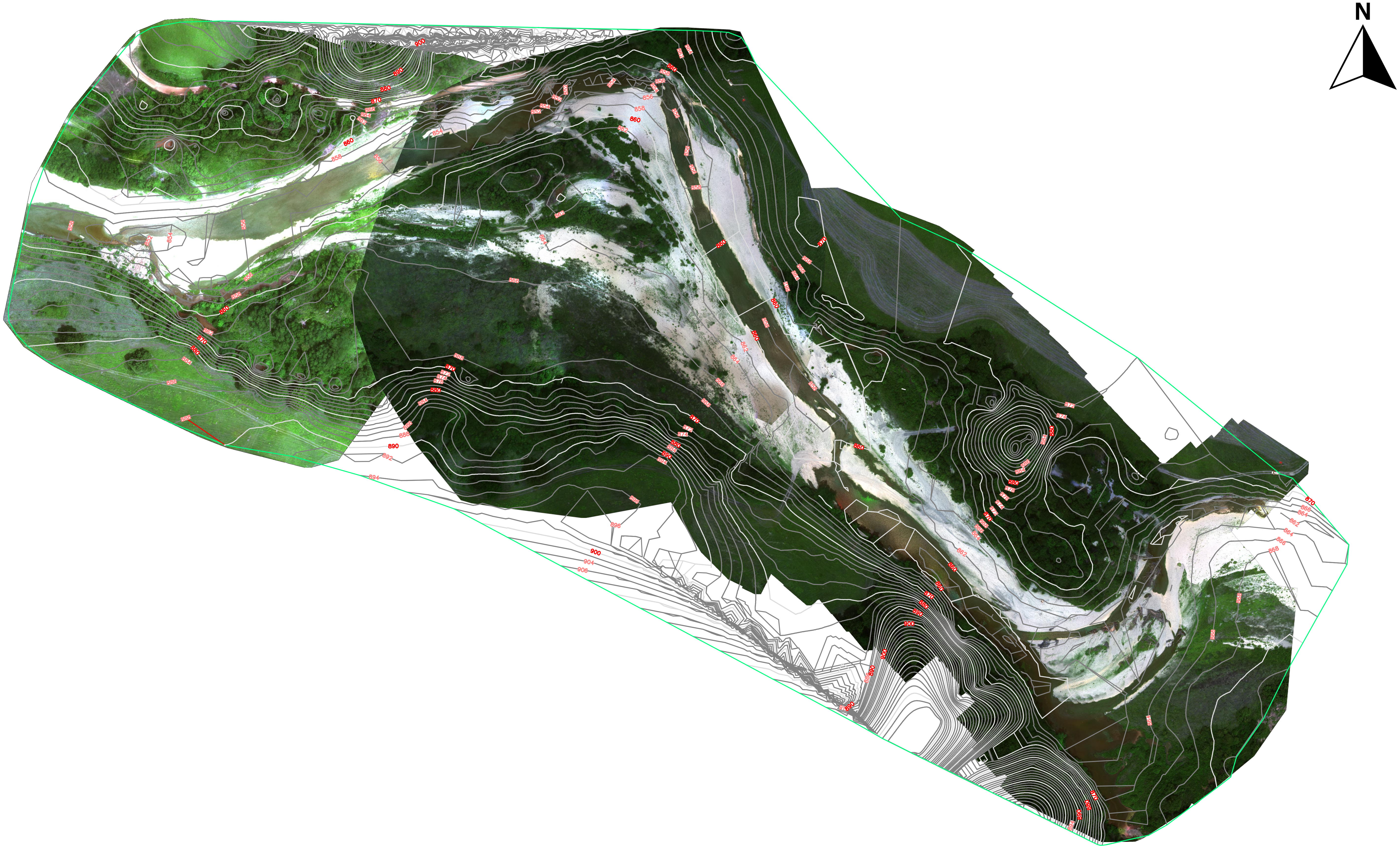


Author:	Scale:	Project:	Title:	Date:
Carles Crespo-Azorín Martínez	H: 1"–80' V: 1"–8'	Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	Longitudinal profile 2/3	July 2021

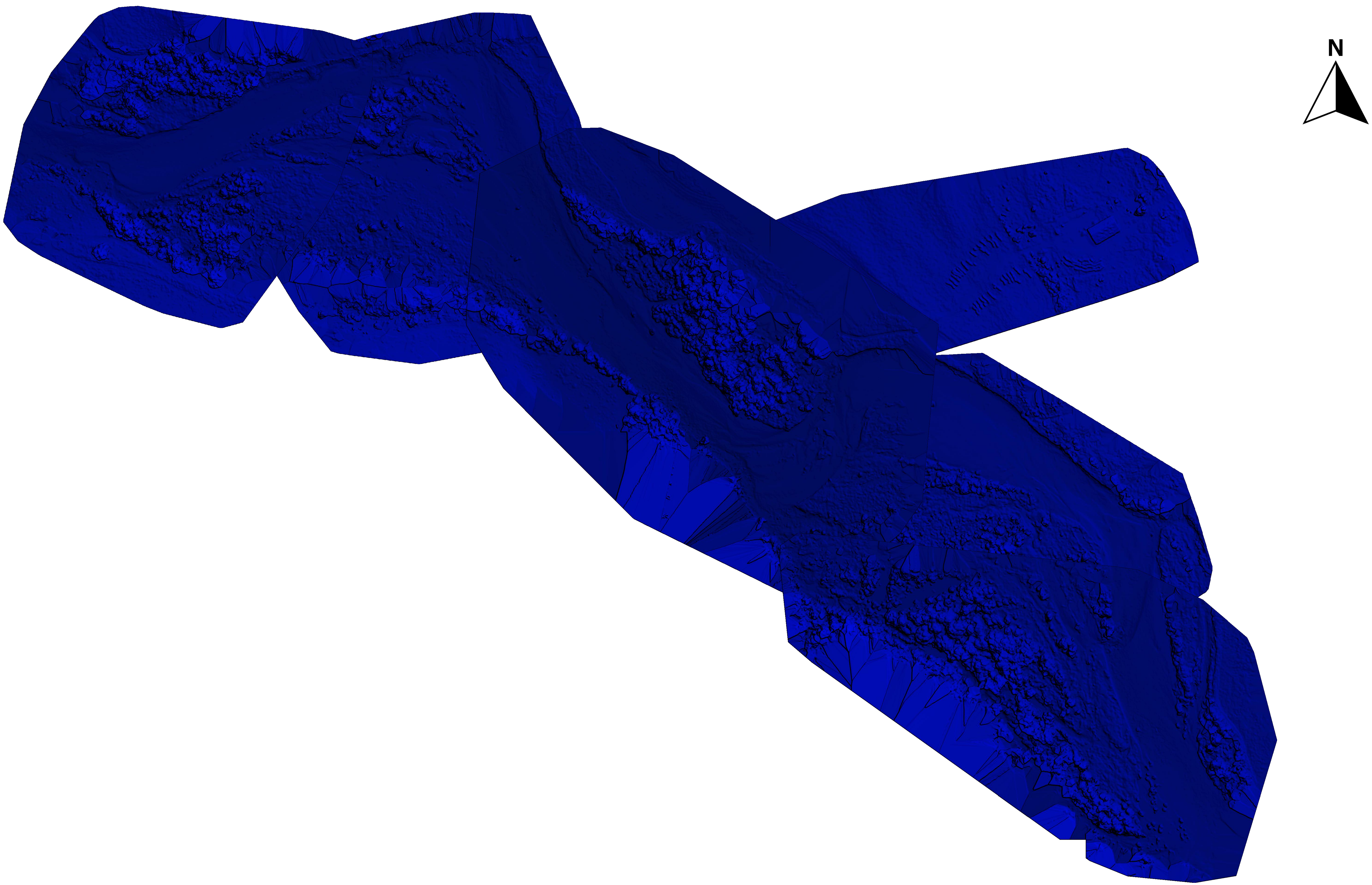


Author:	Scale:	Project:	Title:	Date:
Carles Crespo-Azorín Martínez	H: 1"–80' V: 1"–8'	Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	Longitudinal profile 3/3	July 2021

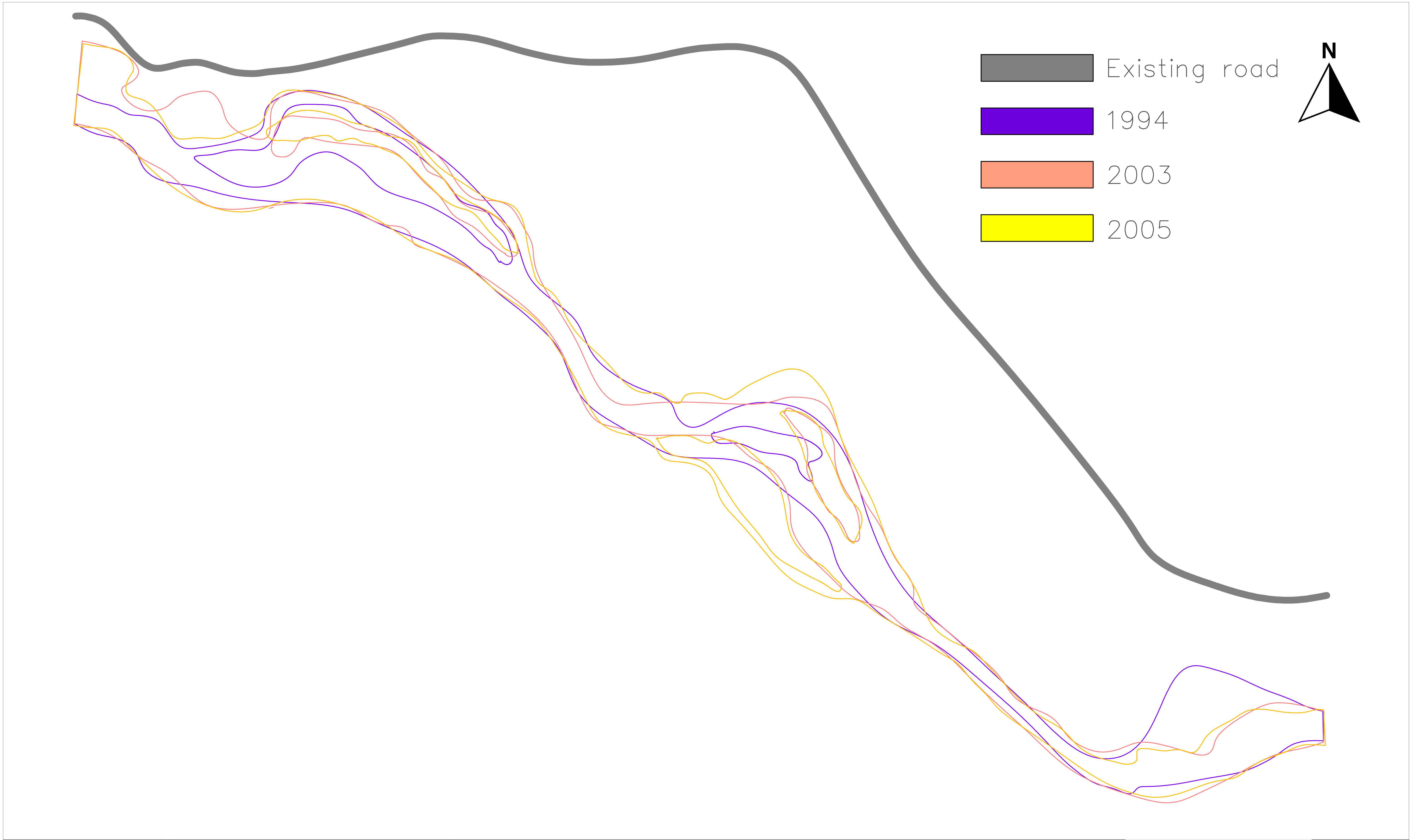
	Author: Carles Crespo-Azorín Martínez	Scale: 0 100ft 150ft	Project: Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	Title: Drone aerial imagery	Date: July 2021



	Author:	Scale:	Project:	Title:	Date:
	Carles Crespo-Azorín Martínez	0 100ft 150ft	Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	Contour lines + Aerial imagery	July 2021

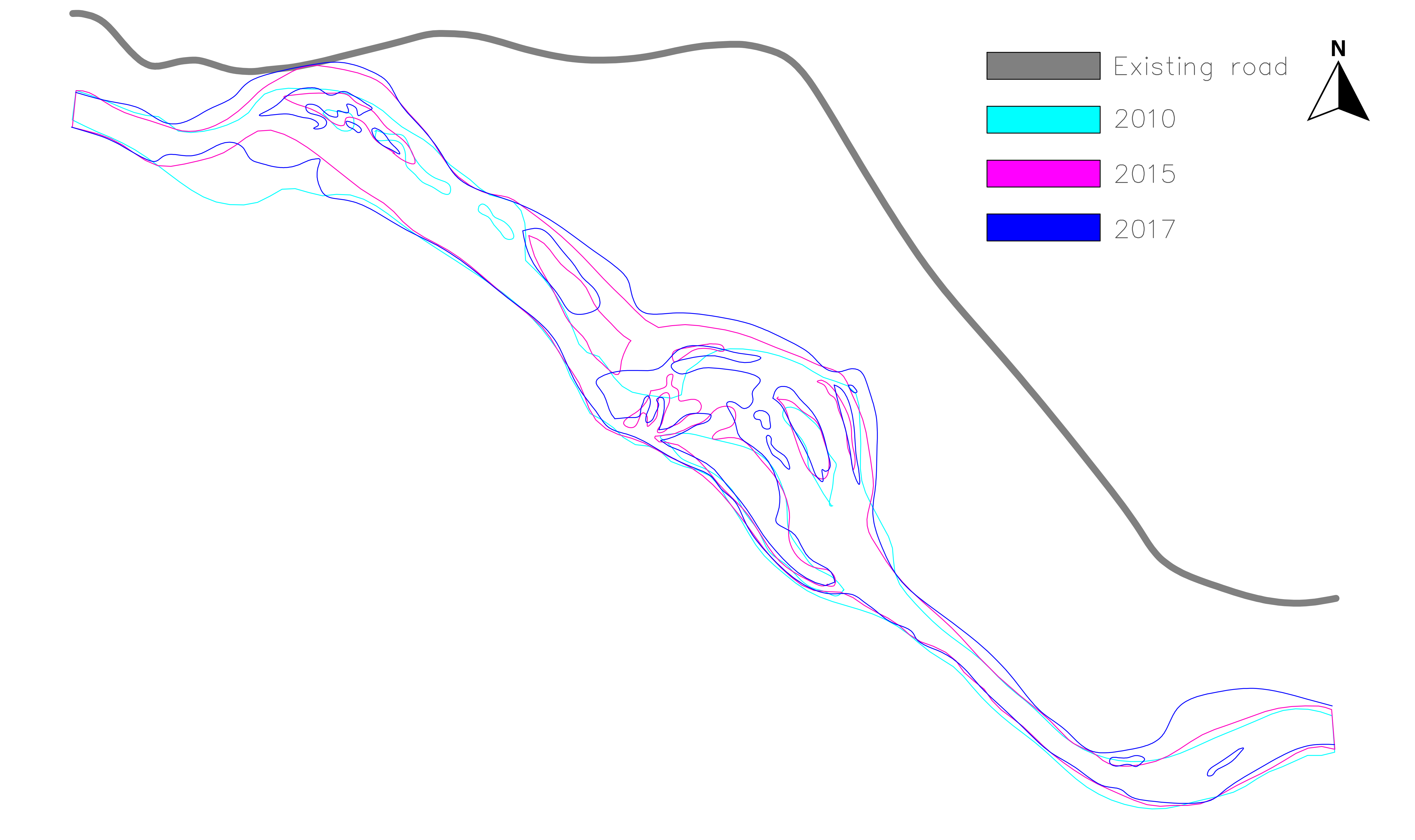


Author: Carles Crespo–Azorín Martínez	Scale: 0 100ft 150ft	Project: Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	Title: Digital Surface Model	Date: July 2021

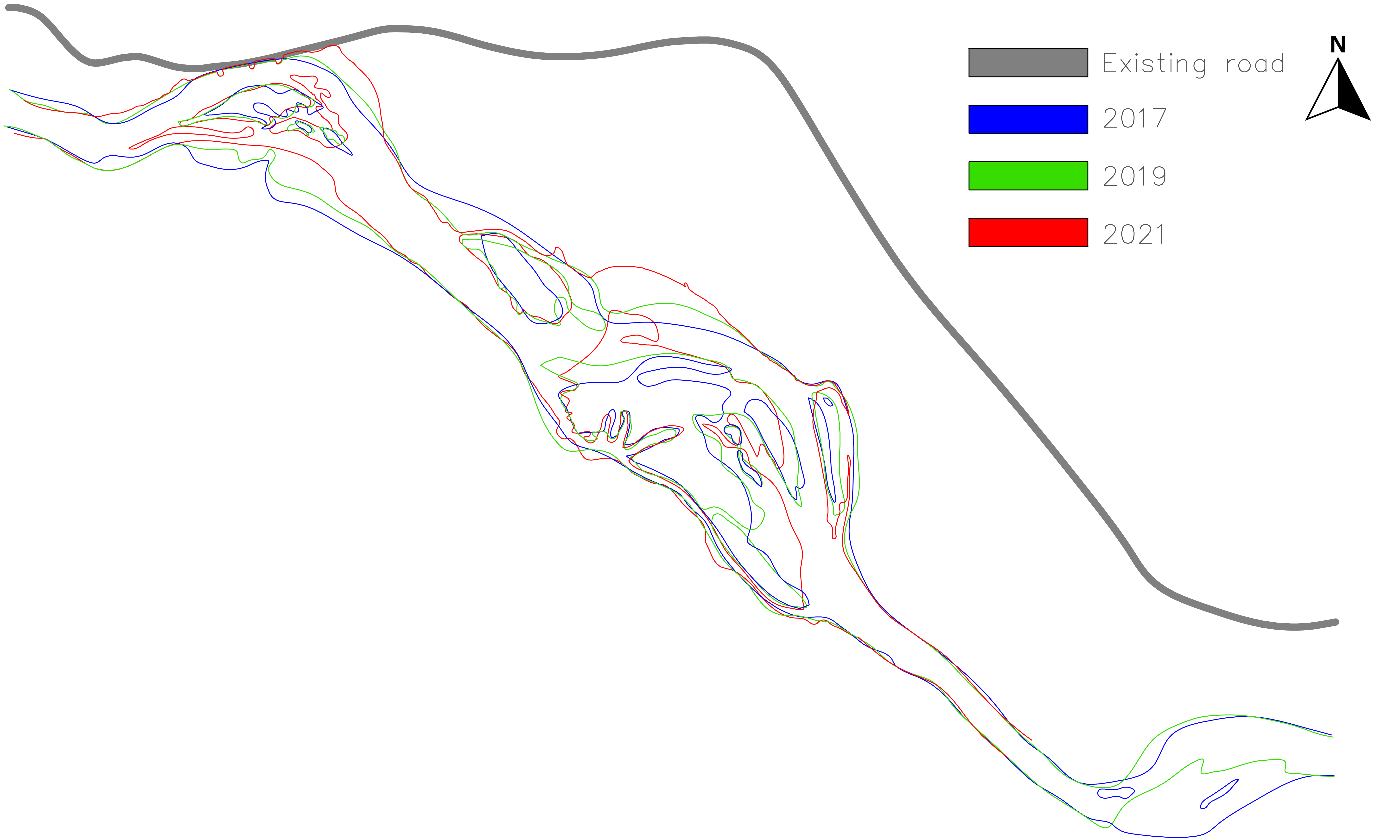


Author:	Scale:	Project:	Title:	Date:
Carles Crespo-Azorín Martínez	1"–500'	Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	Channel evolution 1/4	July 2021

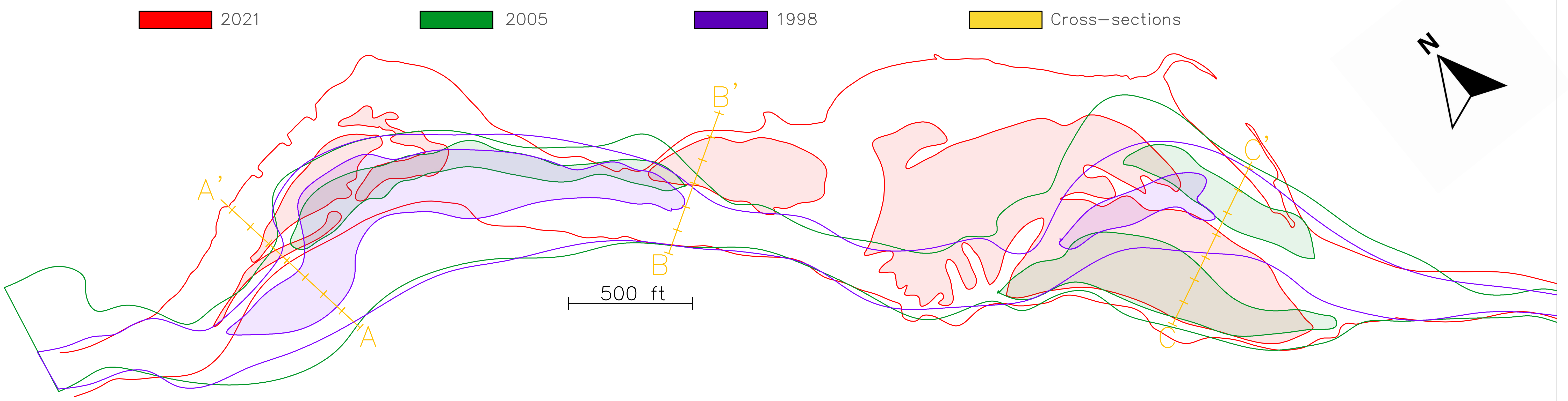
	Author:	Scale:	Project:	Title:	Date:
	Carles Crespo-Azorín Martínez	1"–500'	Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	Channel evolution 2/4	July 2021



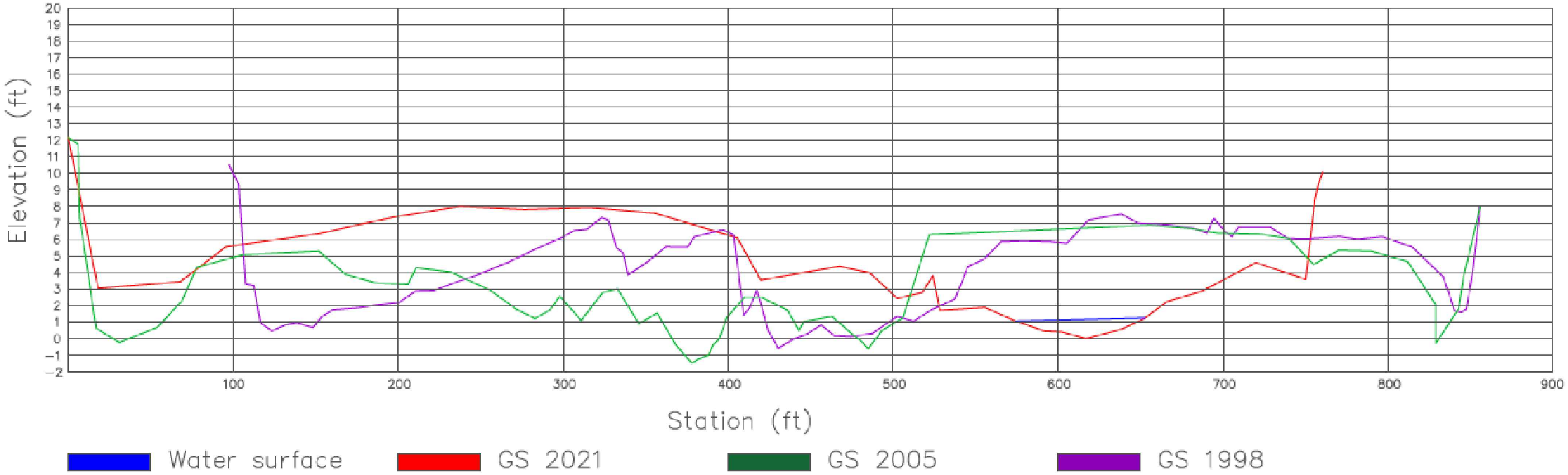
	Author: Carles Crespo-Azorín Martínez	Scale: 1"–500'	Project: Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	Title: Channel evolution 3/4	Date: July 2021



	Author: Carles Crespo–Azorín Martínez	Scale: 1"–500'	Project: Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	Title: Channel evolution 4/4	Date: July 2021

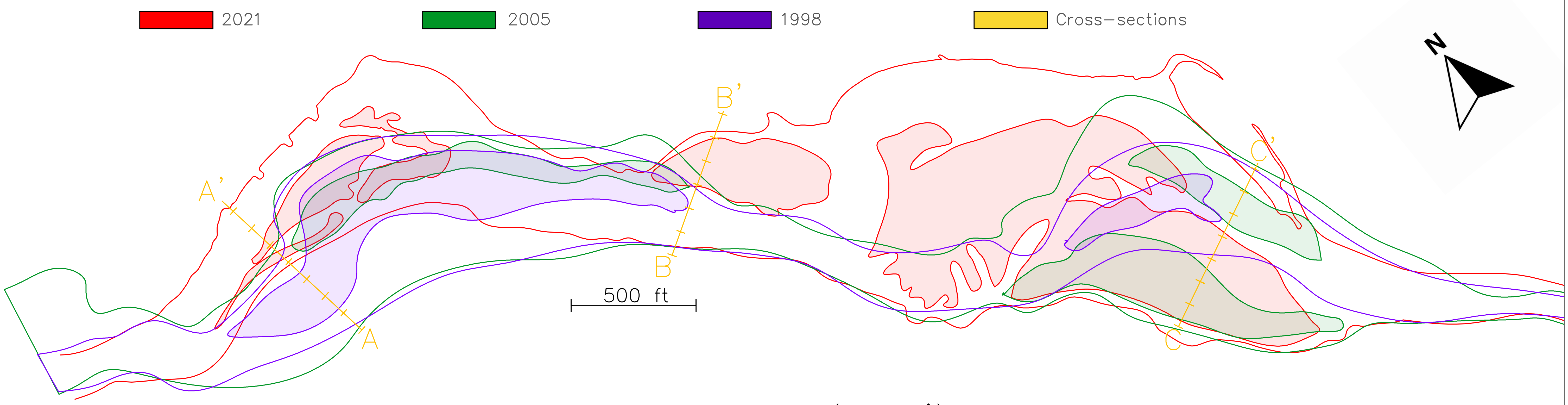


Cross–section 5 (A–A')

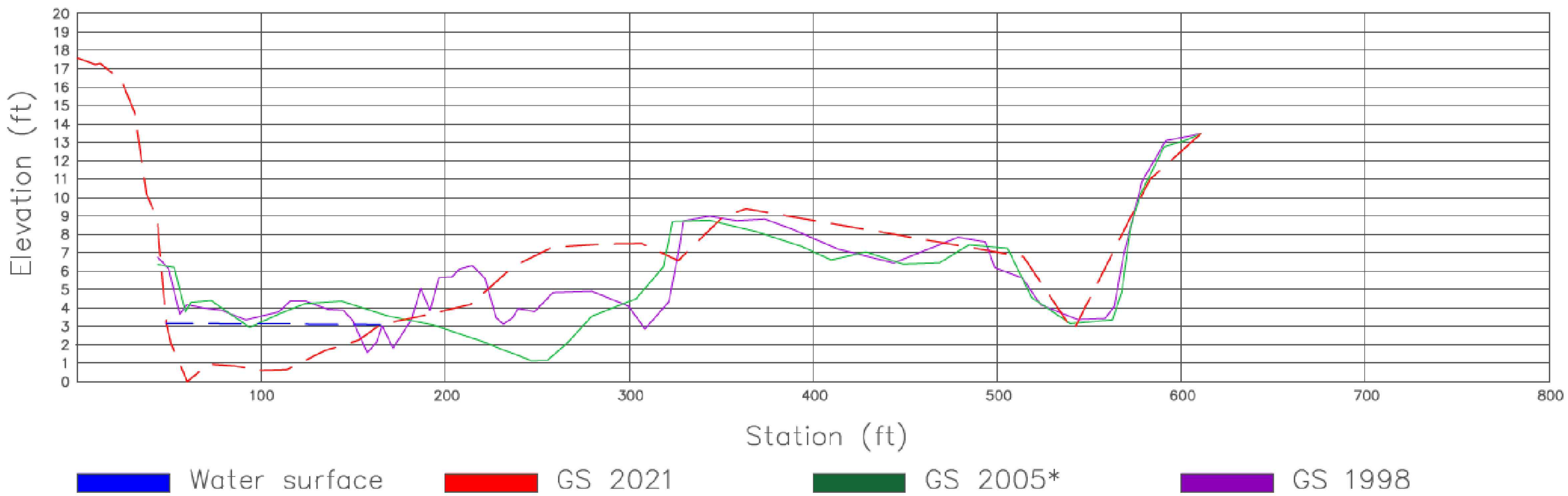


According to the Oklahoma North State Plane Coordinates, the point 0,0 is in an elevation of 854.71 feet
*Corrected cross–section

Author: Carles Crespo–Azorín Martínez	Scale: –	Project: Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	Title: Aerial view + XS 1/4	Date: July 2021

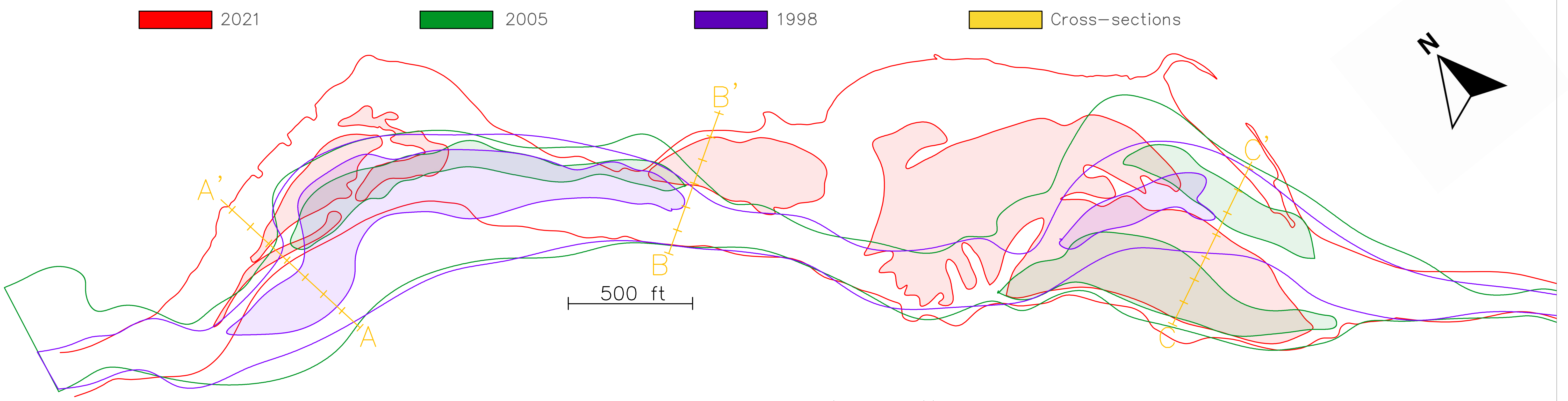


Cross–section 6 (B–B')

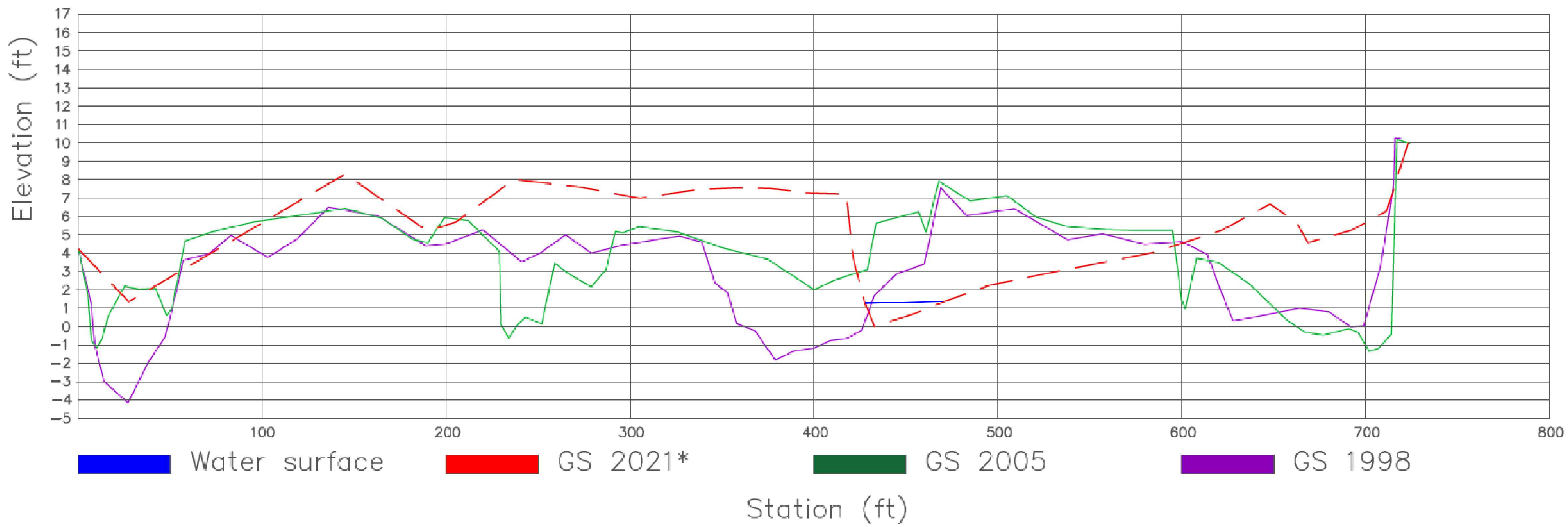


According to the Oklahoma North State Plane Coordinates, the point 0,0 is in an elevation of 858.2 feet
*Corrected cross–section

Author:	Scale:	Project:	Title:	Date:
Carles Crespo–Azorín Martínez	–	Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	Aerial view + XS 2/4	July 2021

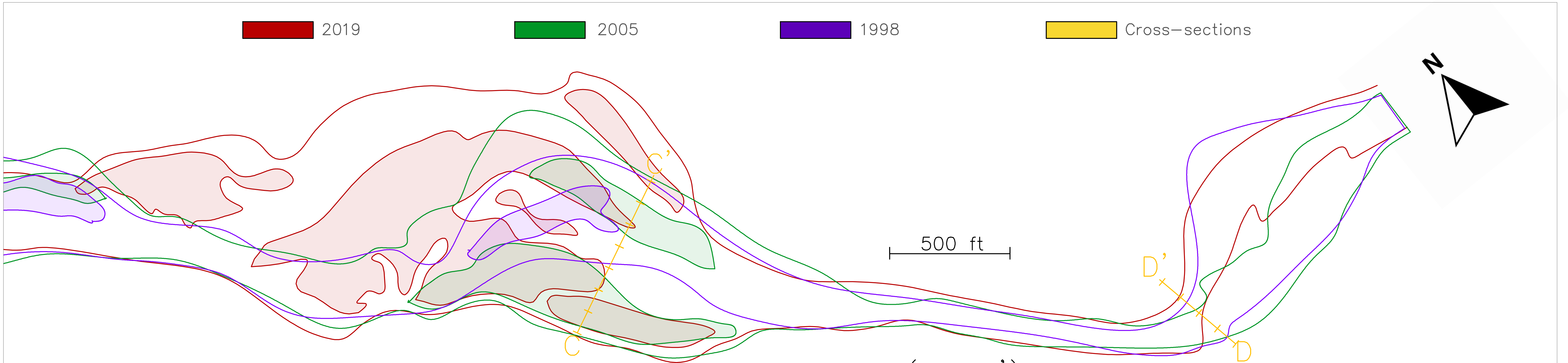


Cross–section 7 (C–C')



According to the Oklahoma North State Plane Coordinates, the point 0,0 is in an elevation of 864.83 feet
*Corrected cross–section

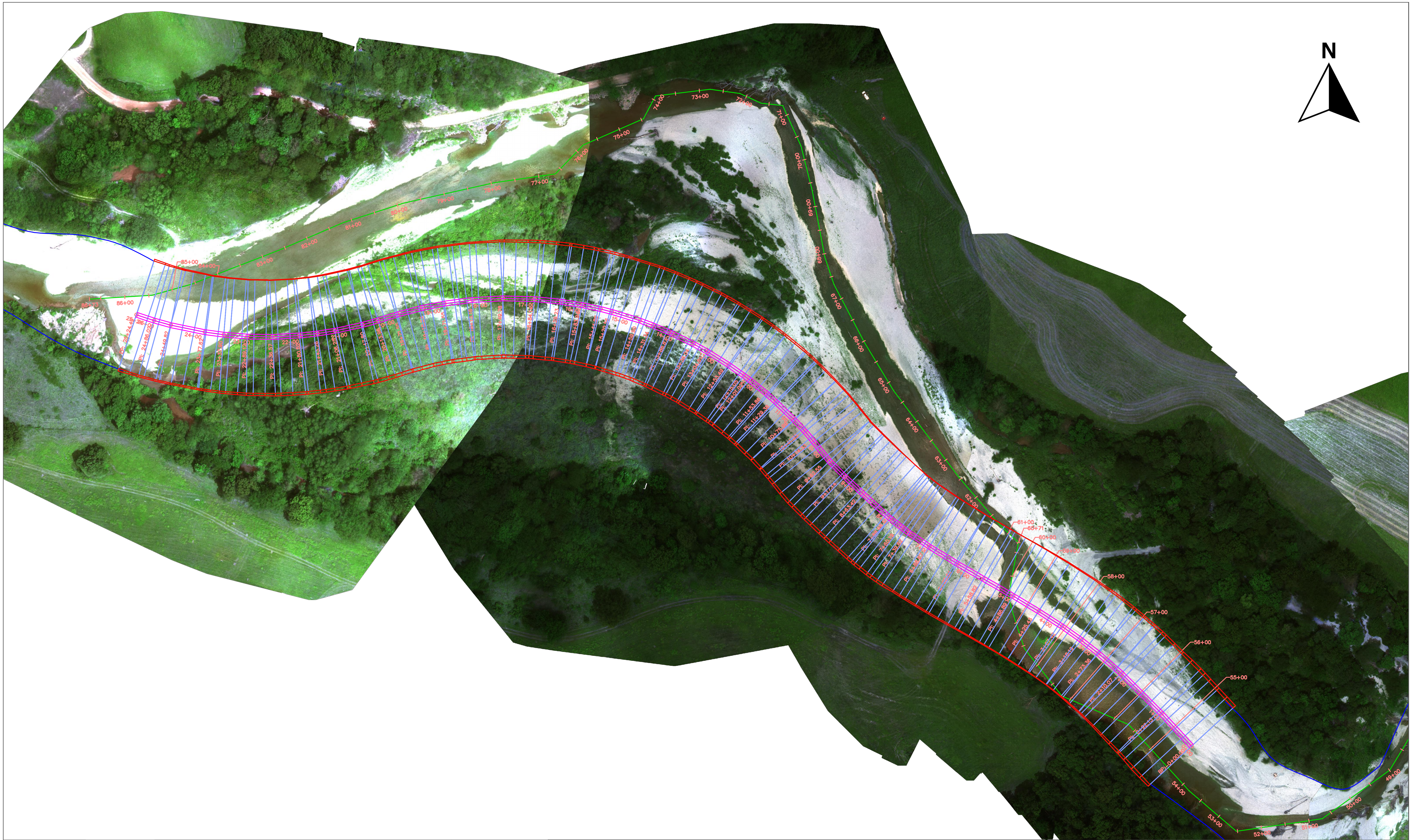
Author:	Scale:	Project:	Title:	Date:
Carles Crespo–Azorín Martínez	–	Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	Aerial view + XS 3/4	July 2021



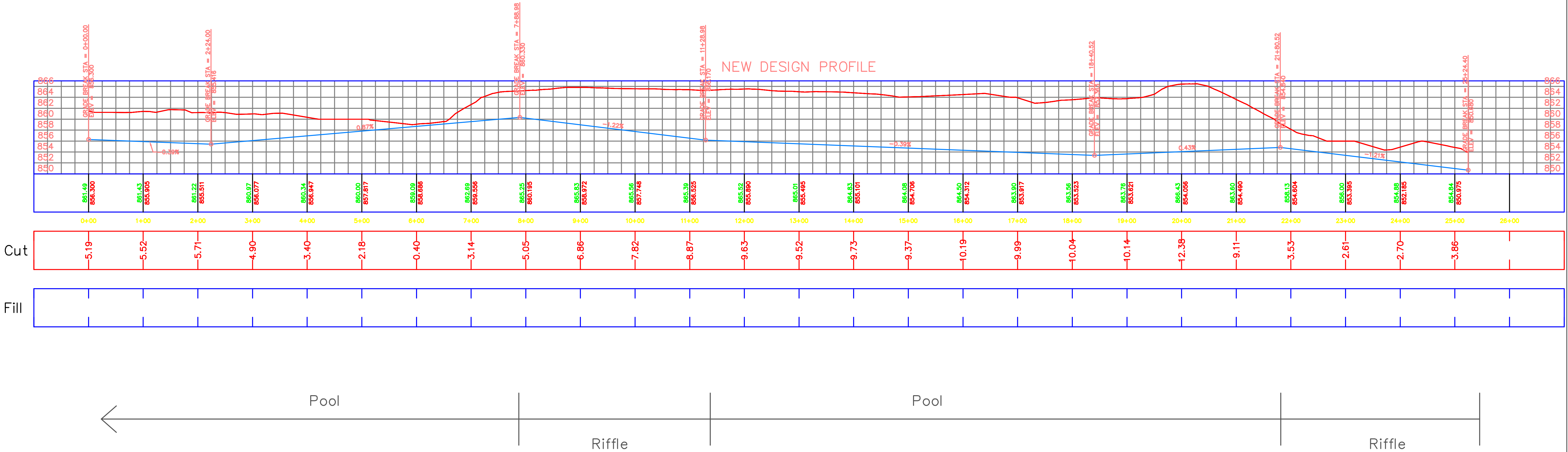
Cross–section 8 (D–D')

According to the Oklahoma North State Plane Coordinates, the point 0,0 is in an elevation of 862.08 feet

Author:	Scale:	Project:	Title:	Date:
Carles Crespo–Azorín Martínez	–	Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	Aerial view + XS 4/4	July 2021



	Author:	Scale:	Project:	Title:	Date:
	Carles Crespo–Azorín Martínez	0 100 ft 150ft	Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	New design pattern vs current pattern	July 2021



Author:
Carles Crespo-Azorín Martínez

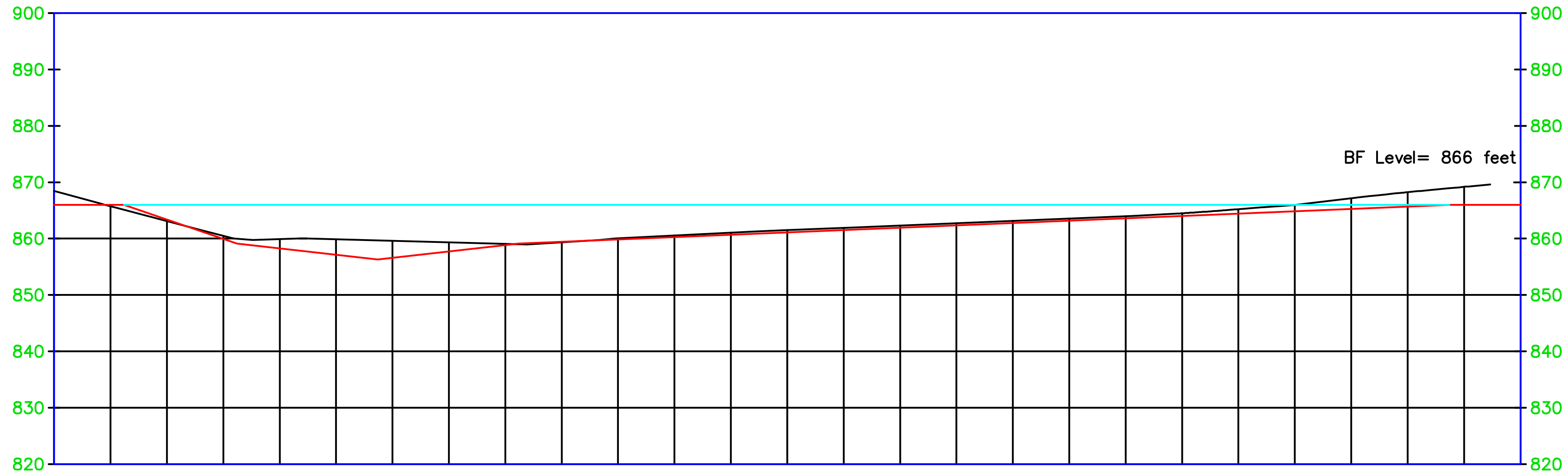
Scale:
0 100ft 150ft

Project:
Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)

Title:
New channel profile
Showing riffles and pools

Date:
July 2021

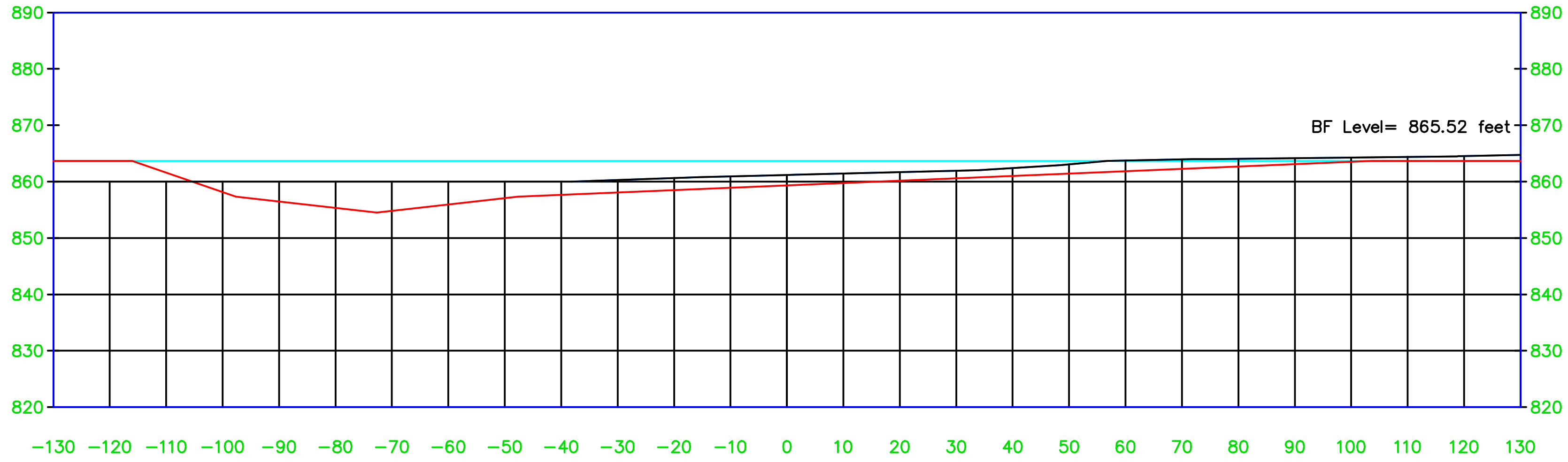
0+00.00



Total Volume at Station 0+00.00	
Cut Area	316.640
Fill Area	5.601
Cut Vol	0
Fill Vol	0
Cum Cut Vol	0
Cum Fill Vol	0
Net Vol	0

*Areas in Sq.Ft and Volumes in Cu.Yd

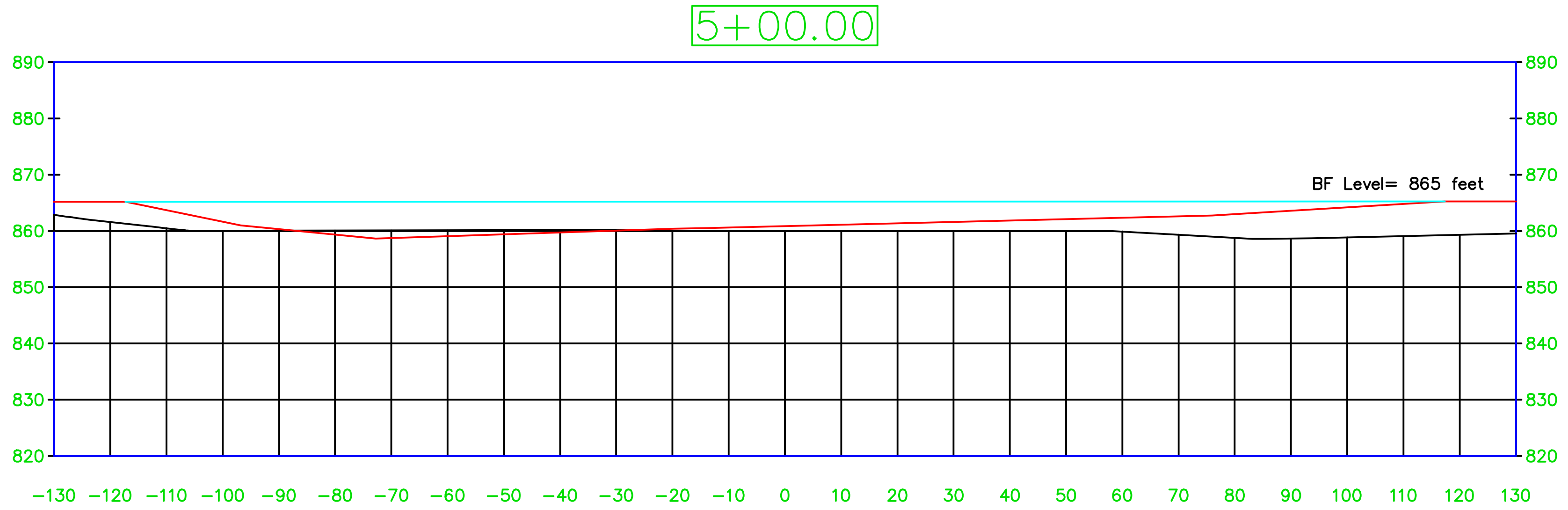
2+50.00



Total Volume at Station 2+50.00	
Cut Area	495.370
Fill Area	70.620
Cut Vol	3759.302
Fill Vol	352.916
Cum Cut Vol	3759.302
Cum Fill Vol	352.916
Net Vol	3406.385

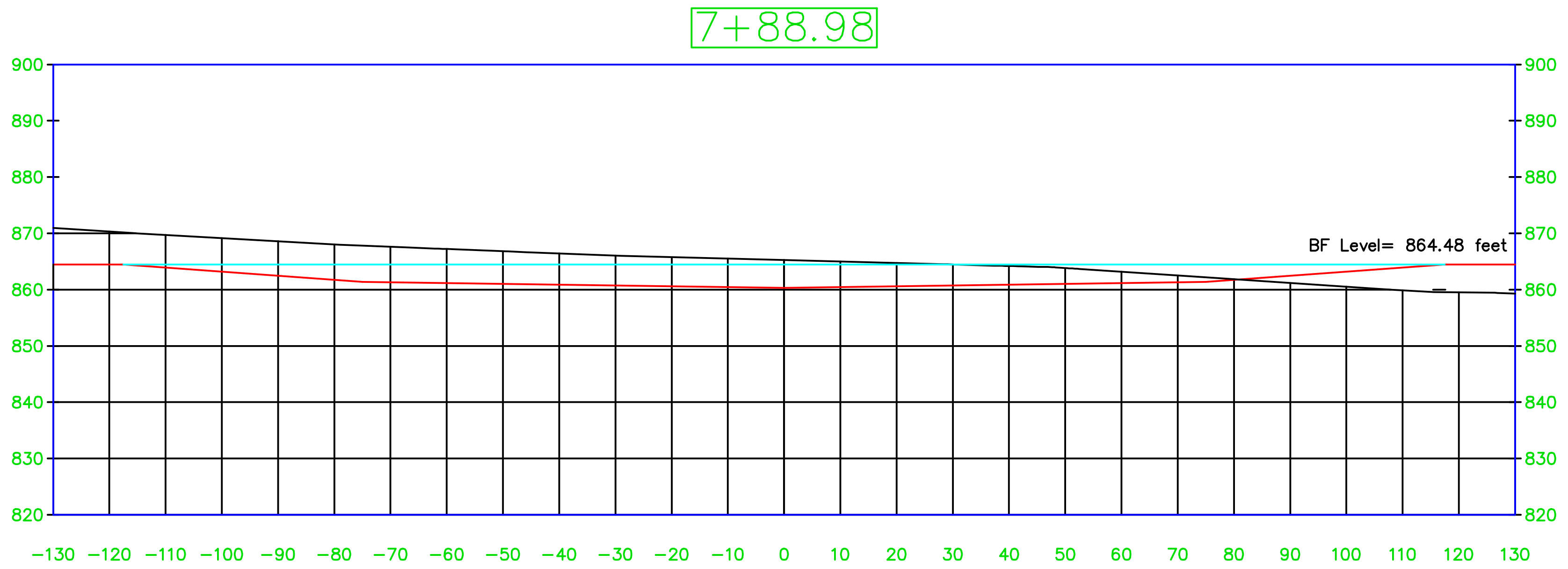
*Areas in Sq.Ft and Volumes in Cu.Yd

Author:	Scale:	Project:	Title:	Date:
Carles Crespo–Azorín Martínez	0 10 ft 20 ft 30ft	Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	New channel Cross section 1/7	July 2021



Total Volume at Station 5+00.00	
Cut Area	38.000
Fill Area	518.020
Cut Vol	2469.303
Fill Vol	2725.182
Cum Cut Vol	6228.605
Cum Fill Vol	3078.099
Net Vol	3150.506

*Areas in Sq.Ft and Volumes in Cu.Yd

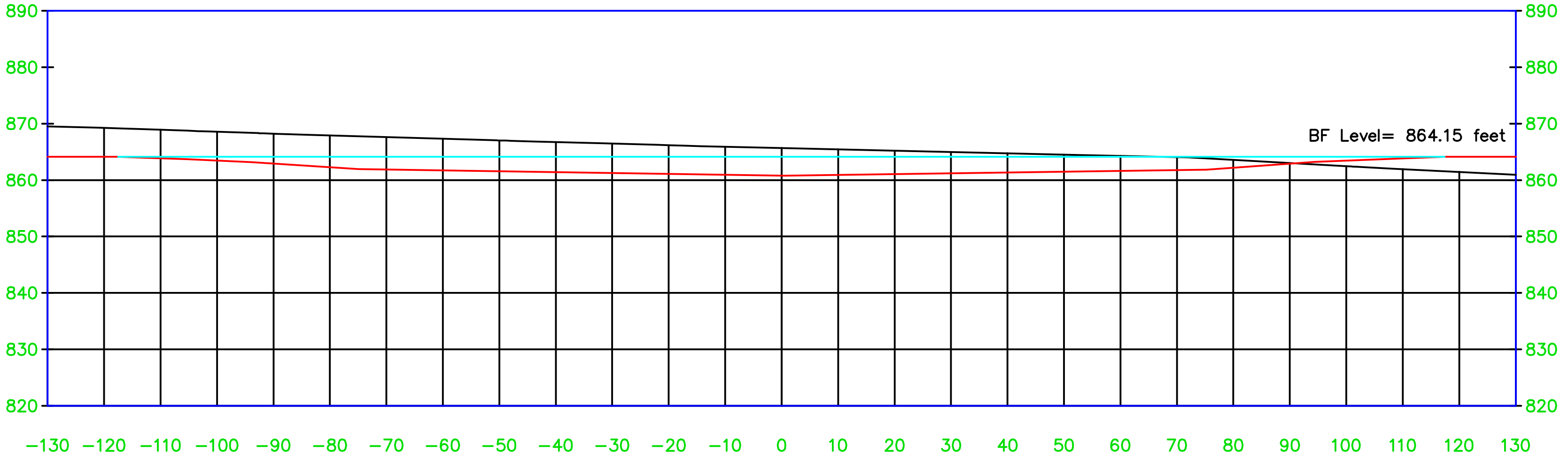


Total Volume at Station 7+88.98	
Cut Area	1016.000
Fill Area	156.300
Cut Vol	5640.456
Fill Vol	3608.607
Cum Cut Vol	11869.061
Cum Fill Vol	6686.706
Net Vol	5182.355

*Areas in Sq.Ft and Volumes in Cu.Yd

Author:	Scale:	Project:	Title:	Date:
Carles Crespo−Azorín Martínez	0 10 ft 20 ft 30ft	Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	New channel Cross section 2/7	July 2021

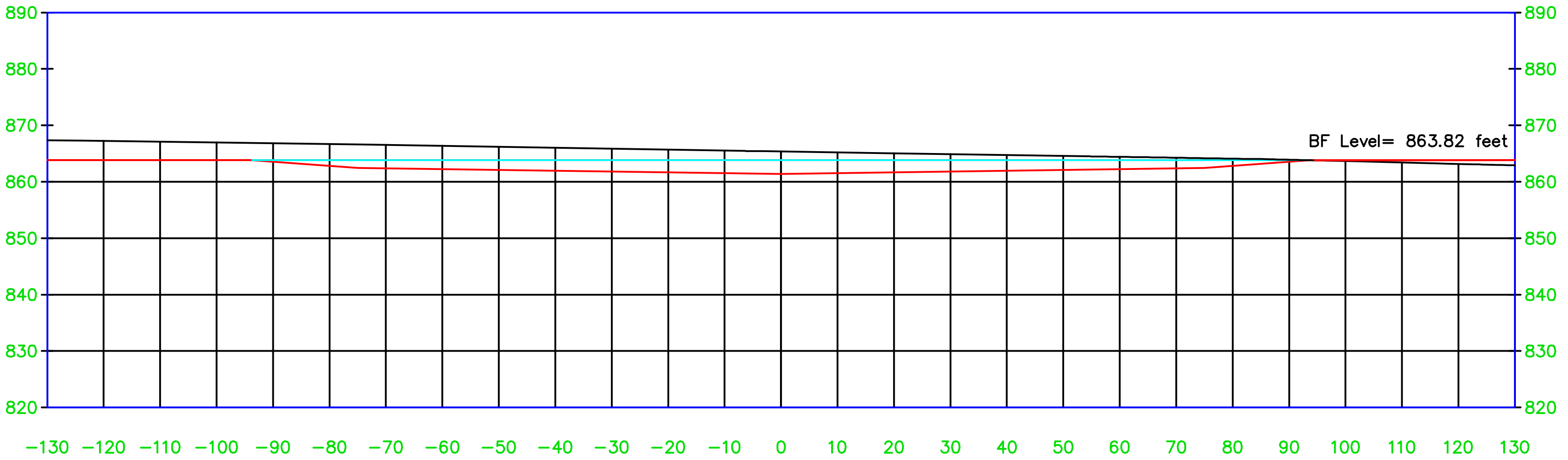
9+50.00



Total Volume at Station 9+50.00	
Cut Area	980.000
Fill Area	78.800
Cut Vol	5951.770
Fill Vol	683.142
Cum Cut Vol	17820.831
Cum Fill Vol	7369.848
Net Vol	10450.983

*Areas in Sq.Ft and Volumes in Cu.Yd

11+28.98

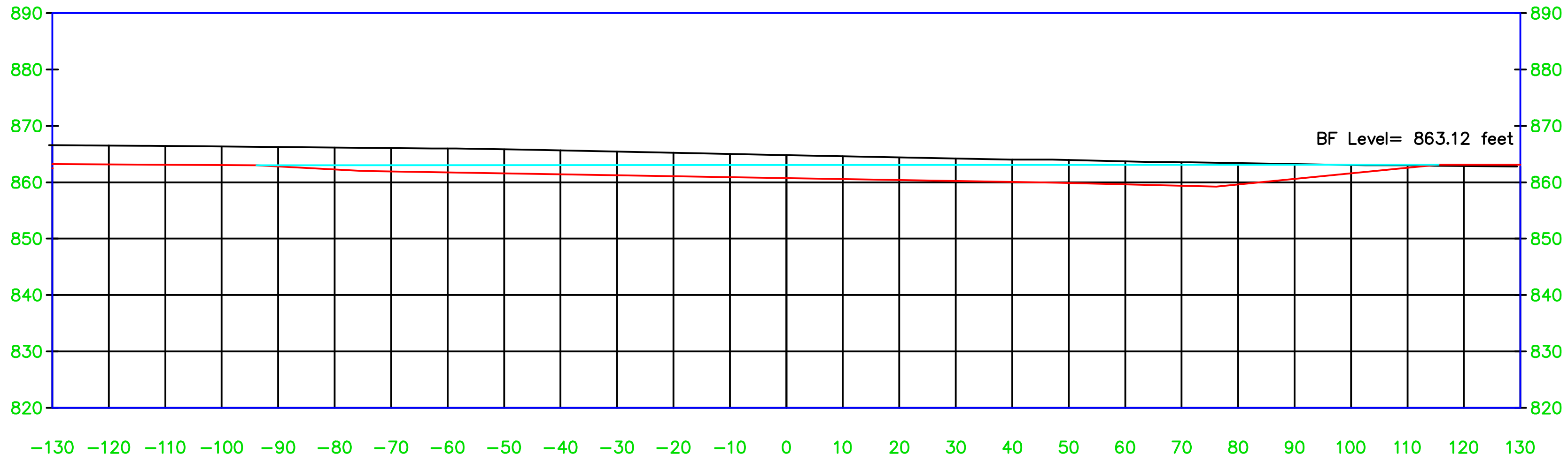


Total Volume at Station 11+28.98	
Cut Area	718.320
Fill Area	15.970
Cut Vol	5628.982
Fill Vol	294.223
Cum Cut Vol	23449.813
Cum Fill Vol	7664.071
Net Vol	15785.742

*Areas in Sq.Ft and Volumes in Cu.Yd

Author:	Scale:	Project:	Title:	Date:
Carles Crespo-Azorín Martínez	0 10 ft 20 ft 30ft	Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	New channel Cross section 3/7	July 2021

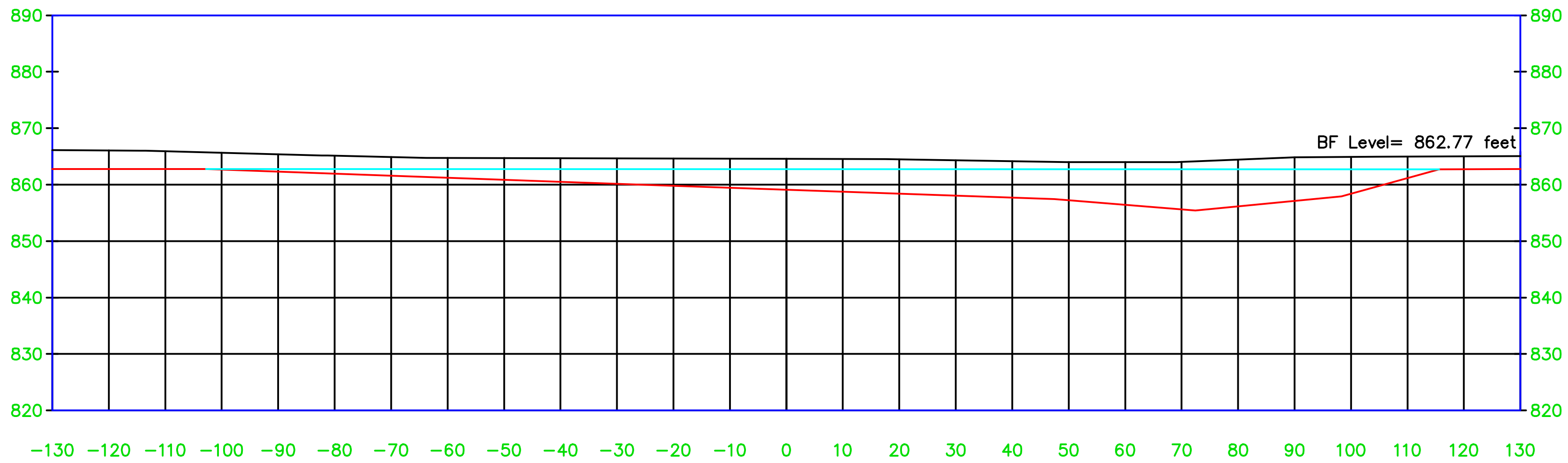
14+00.00



Total Volume at Station 14+00.00	
Cut Area	879.790
Fill Area	3.920
Cut Vol	8020.729
Fill Vol	99.826
Cum Cut Vol	31470.541
Cum Fill Vol	7763.896
Net Vol	23706.65

*Areas in Sq.Ft and Volumes in Cu.Yd

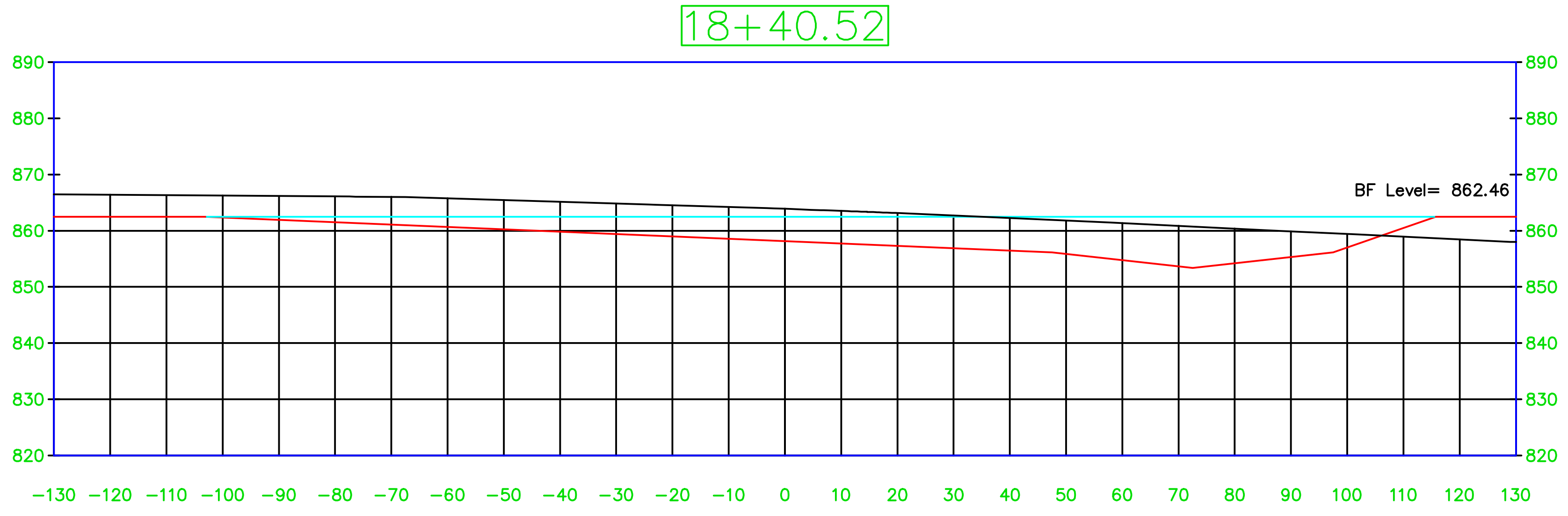
16+50.00



Total Volume at Station 16+50.00	
Cut Area	1296.700
Fill Area	0.000
Cut Vol	10076.333
Fill Vol	18.148
Cum Cut Vol	41546.874
Cum Fill Vol	7782.044
Net Vol	33764.829

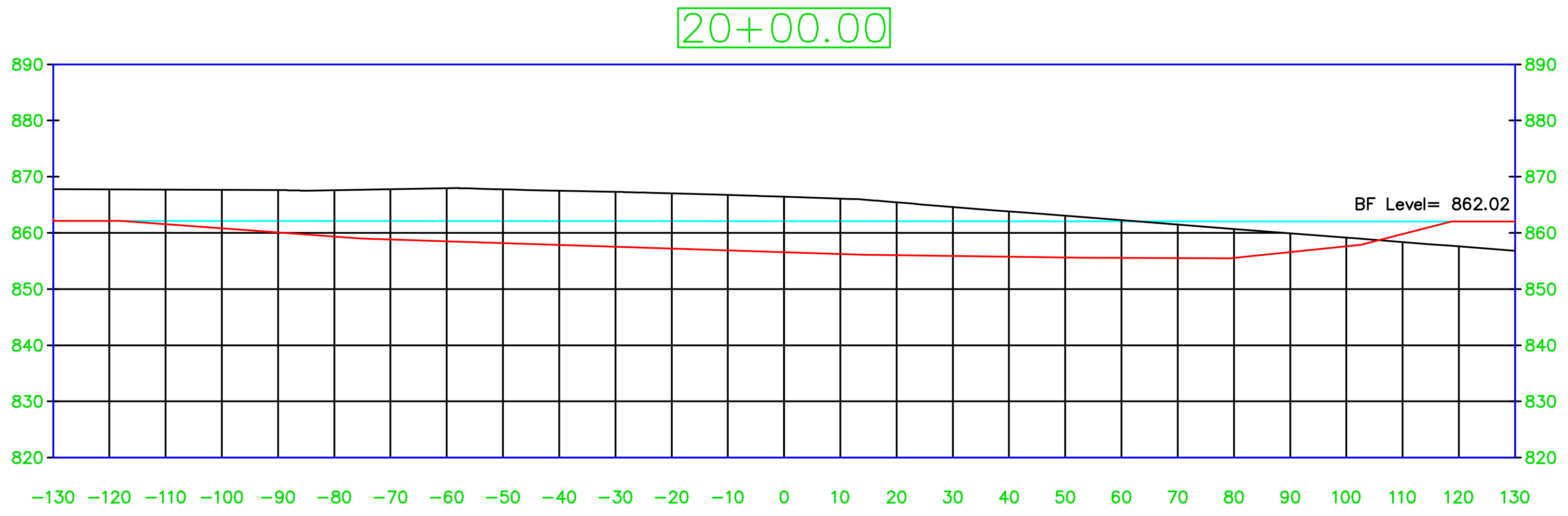
*Areas in Sq.Ft and Volumes in Cu.Yd

Author:	Scale:	Project:	Title:	Date:
Carles Crespo−Azorín Martínez	0 10 ft 20 ft 30ft	Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	New channel Cross section 4/7	July 2021



Total Volume at Station 18+40.52	
Cut Area	1211.110
Fill Area	76.820
Cut Vol	8847.916
Fill Vol	271.032
Cum Cut Vol	50394.790
Cum Fill Vol	8053.076
Net Vol	42341.714

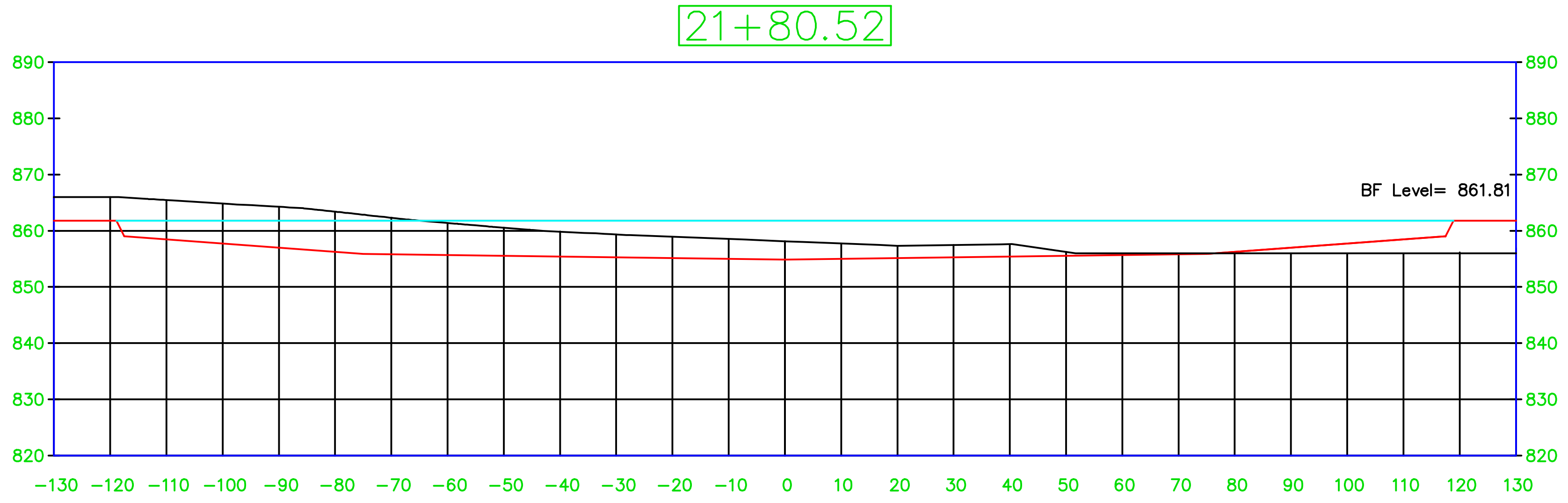
*Areas in Sq.Ft and Volumes in Cu.Yd



Total Volume at Station 20+00.00	
Cut Area	1792.160
Fill Area	81.130
Cut Vol	8869.649
Fill Vol	466.479
Cum Cut Vol	59264.439
Cum Fill Vol	8519.555
Net Vol	50744.884

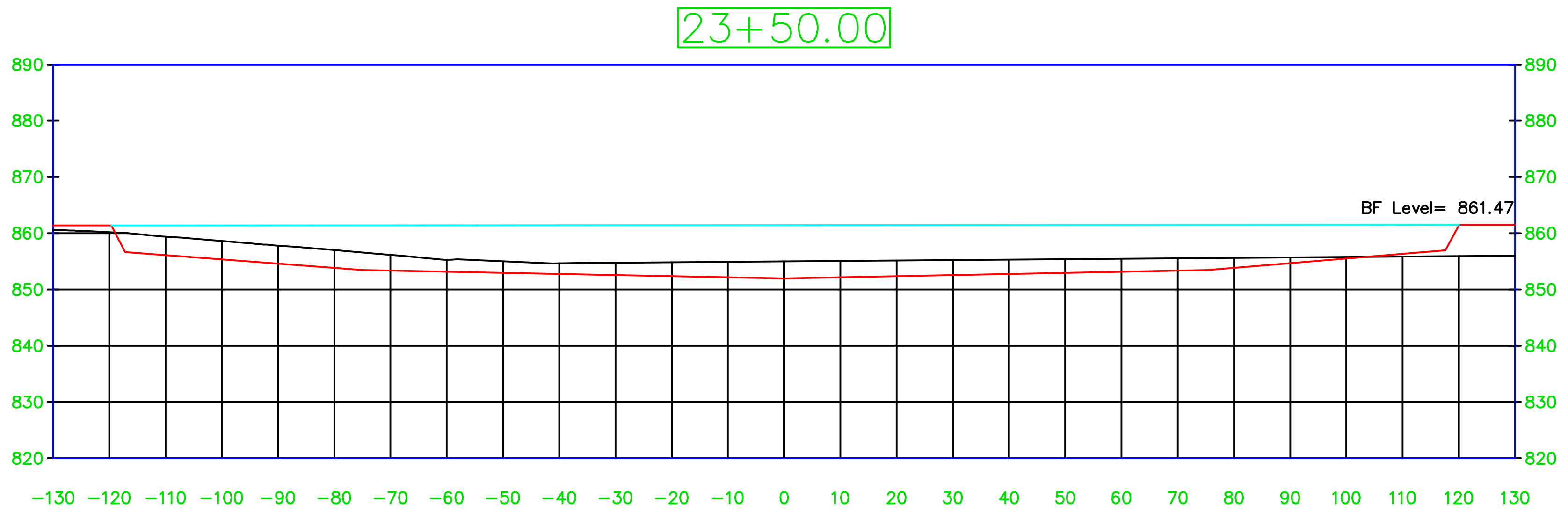
*Areas in Sq.Ft and Volumes in Cu.Yd

Author:	Scale:	Project:	Title:	Date:
Carles Crespo−Azorín Martínez	0 10 ft 20 ft 30ft	Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	New channel Cross section 5/7	July 2021



Total Volume at Station 21+80.52	
Cut Area	829.140
Fill Area	125.890
Cut Vol	8762.900
Fill Vol	692.060
Cum Cut Vol	68027.339
Cum Fill Vol	9211.615
Net Vol	58815.724

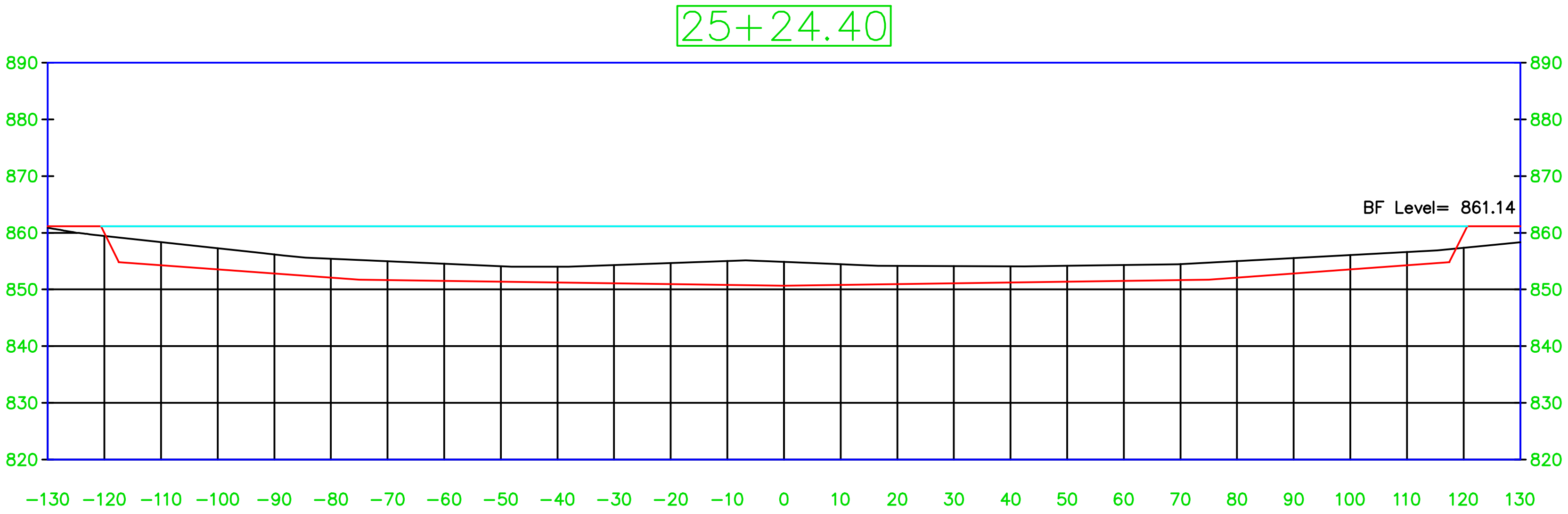
*Areas in Sq.Ft and Volumes in Cu.Yd



Total Volume at Station 23+50.00	
Cut Area	542.170
Fill Area	83.580
Cut Vol	4303.878
Fill Vol	657.425
Cum Cut Vol	72331.216
Cum Fill Vol	9869.039
Net Vol	62462.177

*Areas in Sq.Ft and Volumes in Cu.Yd

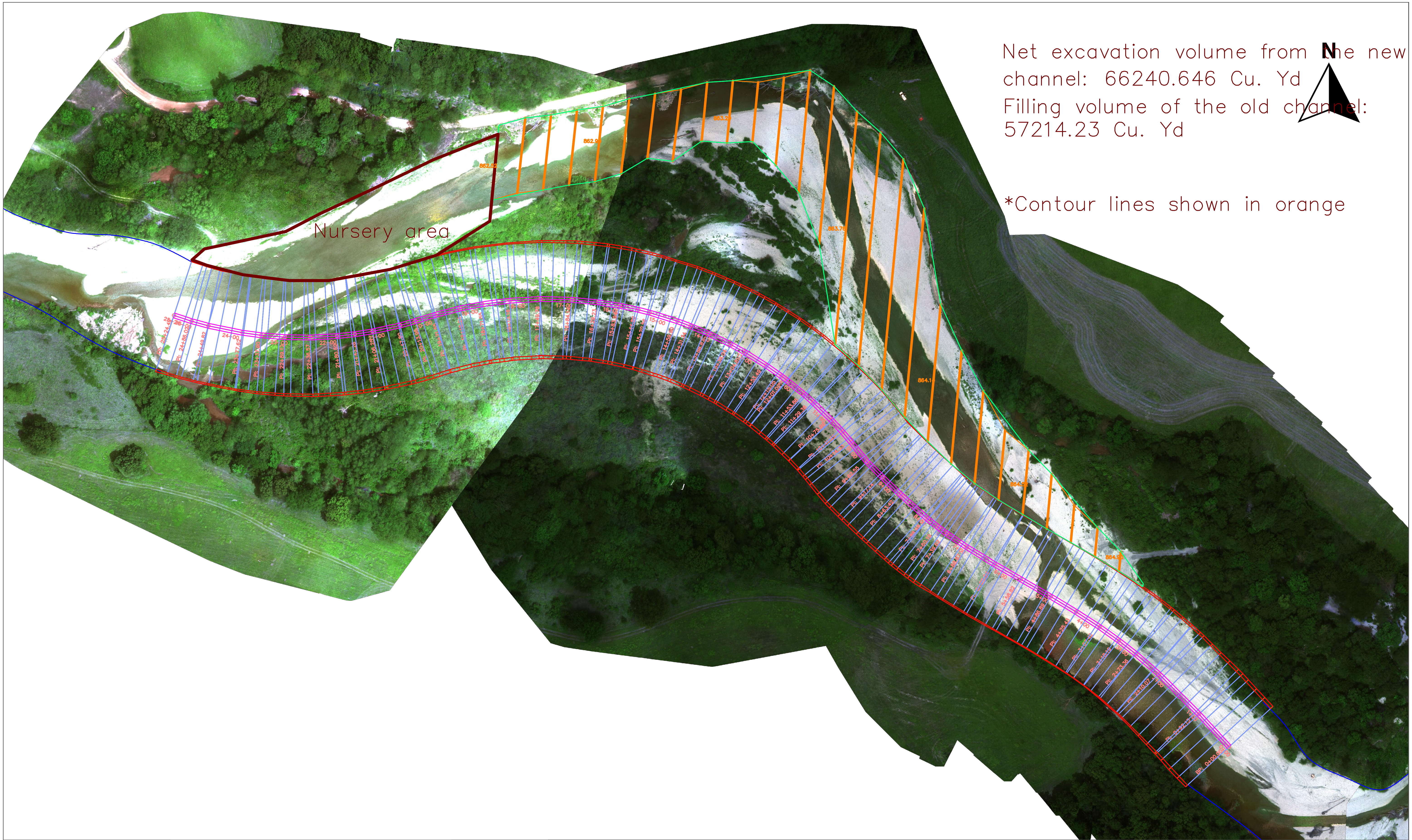
Author:	Scale:	Project:	Title:	Date:
Carles Crespo–Azorín Martínez	0 10 ft 20 ft 30ft	Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	New channel Cross section 6/7	July 2021



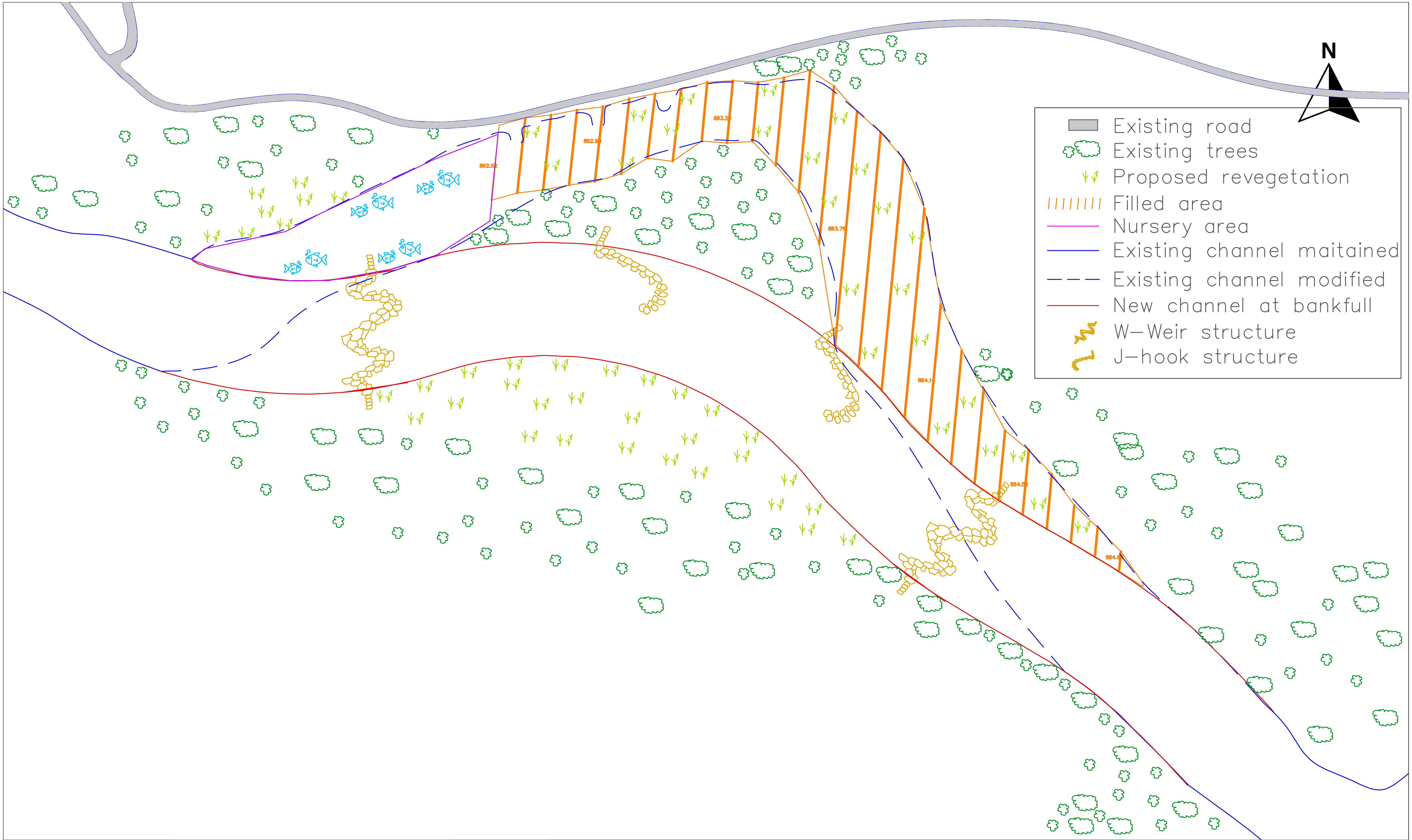
Total Volume at Station 25+24.40	
Cut Area	755.12
Fill Area	43.770
Cut Vol	4189.762
Fill Vol	411.293
Cum Cut Vol	76520.978
Cum Fill Vol	10280.332
Net Vol	66240.646

*Areas in Sq.Ft and Volumes in Cu.Yd

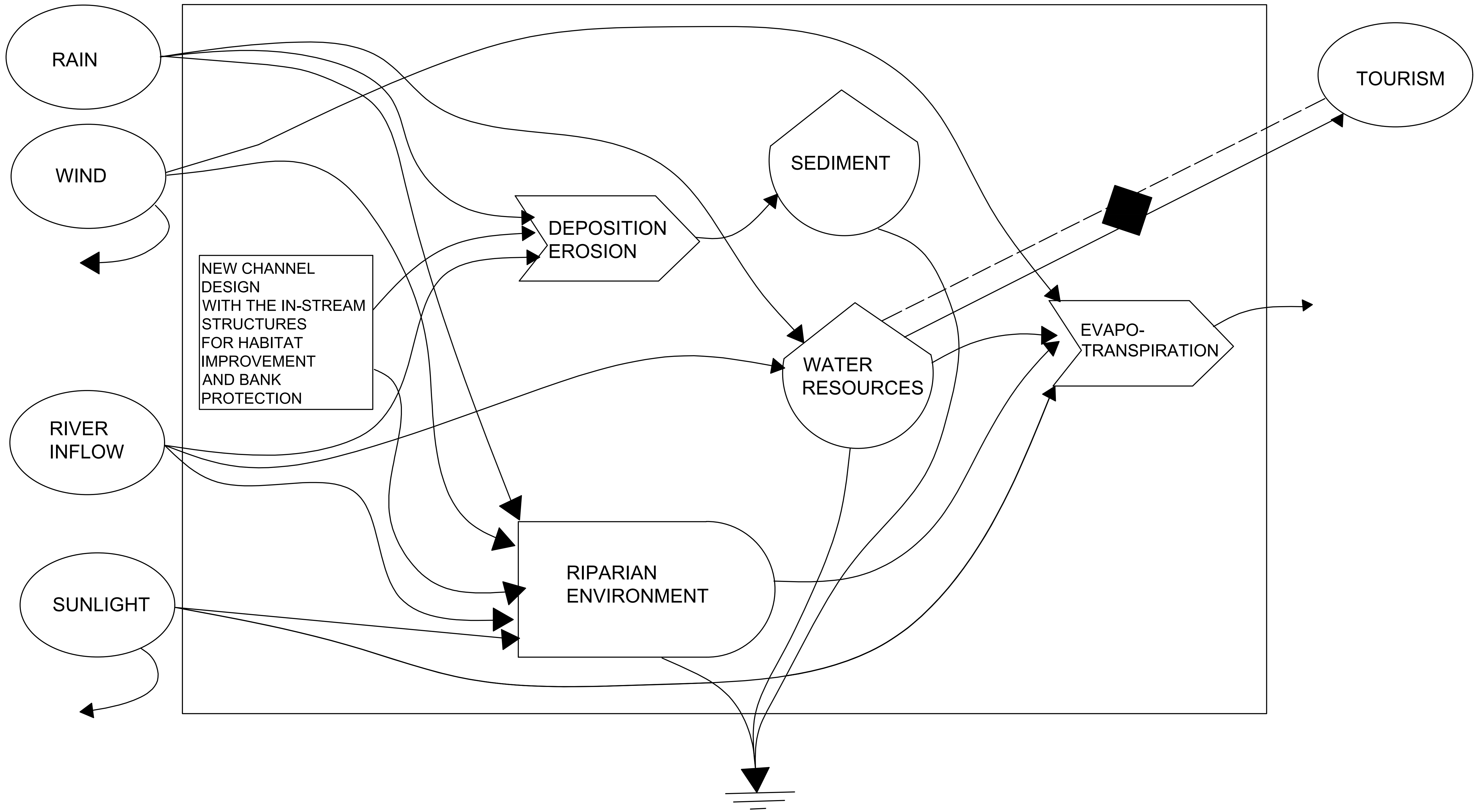
Author: Carles Crespo-Azorín Martínez	Scale: 0 10 ft 20 ft 30ft	Project: Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	Title: New channel Cross section 7/7	Date: July 2021



Author: Carles Crespo–Azorín Martínez	Scale: 0 100 ft 150ft	Project: Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	Title: Old channel fill area and nursery area	Date: July 2021



Author:	Scale:	Project:	Title:	Date:
Carles Crespo–Azorín Martínez	0 100 ft 150ft	Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	Conceptual design	July 2021



Author:	Scale:	Project:	Title:	Date:
Carles Crespo-Azorín Martínez	——	Channel stability assessment and ecological restoration design on the Baron Fork river, Adair County, Oklahoma (USA)	Systems diagram	July 2021